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# ASSESSMENT OF THE ECO-HYDROLOGY OF A GROUNDWATER FED WETLAND IN RELATION TO THE SURROUNDING GRAVEL AQUIFER ON EXAMPLE OF A STUDY FROM IRELAND

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**Abstract.** Fens are wetlands, which accumulate peat and have ground water as their dominant hydrologic input. Groundwater discharge to a fen is the critical factor controlling its ecology and an understanding of hydro-ecological links is critical in the assessment of likely impacts on a wetland, which typically could arise from groundwater abstraction, drainage or agricultural practice. The significance of groundwater to fens was increased with implementation of the EU Water Framework Directive (WFD), under which fens classify as groundwater dependent terrestrial ecosystems (GWDTE) and must be included in River Basin Management plans.

The specific interest of the study was set on the conservation requirements of *Vertigo geyeri* snail and the habitat it lives in. The snail was chosen as being a sensitive indicator of habitat change in spring-fed wetland of Pollardstown. Very detailed investigations revealed that the preferred environment for existence of the snail is a consistently damp atmosphere with relative humidity varying between 80–95%, very small fluctuations in phreatic level of ±10 cm about a stable mean and soil moisture content within the moss substrate at 80–90% saturation levels. In order to meet these requirements an upward vertical hydraulic gradient is required at a rate sufficient to exceed the counterbalance of evapotranspiration at the fen surface.

**Key words**: GWDTE, wetland, *Vertigo geyeri*, bio-indicators, eco-hydrology, hydro-ecology.

## INTRODUCTION

In recent times, with increasing wetland degradation, more emphasis is given to impact definition and assessment of wetlands, and this is specifically driven by the EU Water Framework Directive 2000/60/EC (European Commision..., 2000). Under the WFD, some wetlands are recognised as part of water resources (GWDTE) and protection is given to wetlands in tandem with groundwater or surface body of water that it depends on. As eco-hydrological links at wetland sites are obvious (Ertsen *et al.*, 1995; Lloyd, Tellam, 1995; Wheeler, Shaw, 1995; Wheeler *et al.*, 1995; Toner, Keddy, 1997; Wierda *et al.*, 1997; Keddy, 2000; Pezeshi, 2001; Porporato *et al.*, 2002; McCartney, de la Hera, 2004; Niemi, McDonald, 2004; Reeves, Woessner, 2004; Rodriguez-Iturbe, Porporato, 2004) these need to be firmly defined to offer optimum protection, and this requires systematic assessment guidelines and management protocols (conceptual models of different ecosystems). These guidelines need to address both receptors and stressors but also must define potential distribution pathways for impacts.

This article presents results of a study from Ireland, which was set up to assess the eco-hydrology of a specific site of Pollardstown Fen and its interactions with regional hydrogeology. The site is of international importance. This was one of the most detailed and hence most important studies to be included in the national model for assessing risks to GWDTEs in Ireland. The impetus for the study was construction of a major road in a cutting below water table in the local sand and gravel aquifer, and the concern that dewatering operations might lead to a decline in water levels and hence a reduction in spring flows to the fen, with consequent

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impacts on the fen ecology, including the sensitive *Vertigo geyeri* snail. The mollusc species of *V. geyeri* due to its very small size (<2 mm) has limited movement abilities; therefore, stability of the habitat that it lives in is of high importance for survival of the species. Because of its sensitivity, the snail is considered to be a good indicator to environmental change and was chosen for the study to describe the hydrological controls on the habitat of the fen margin, where it lives (WYG Ltd., 2004).

## STUDY SITE

### ECOLOGICAL SETTINGS

Pollardstown Fen is a wetland located on the northern margin of the Curragh plains (Co. Kildare, Ireland), 40 km west of Dublin (Fig. 1). It is the largest calcareous spring-fed fen in Ireland with multiple nature preservation designations (SAC, SNR, Ramsar Site, EU Biogenic Reserve and other).

Three habitats listed in Annex I of the EU Habitats Directive 92/43/EEC (European Commision..., 2000) occur within the fen area: alkaline fen, calcareous fen with *Cladium mariscus* and petrifying springs with tufa formation. Habitat's Directive Annex II species are also present and these include three *Vertigo* snail species: Geyer's whorl snail *Vertigo geyeri* Lindholm, 1925; Desmoulin's whorl snail *Vertigo moulinsiana* Dupuy, 1849 and the narrow-mouthed whorl snail *Vertigo angustior* Jeffreys, 1830, all of which are rare and declining species in Ireland and Europe (Cameron *et al.*, 2003; Pokryszko, 2003; Moorkens, 2006). The most restricted of these in terms of habitat is *V. geyeri*, and there is an international obligation on Ireland to conserve this species in terms of habitat extent and quality within the studied site. The whorl snail *V. geyeri* is very small in size and individuals have limited movement abilities. The species is hermaphrodite and mainly self fertilizing (Cameron *et al.*, 2003). The species reaches reproduction maturity in less than a year. Large juveniles become adults around midsummer (June/July), and a peak of small juveniles occurs usually in September/October. Cameron *et al.* (2003) reported also that juveniles are present at all times with peaks occurring in late summer and in

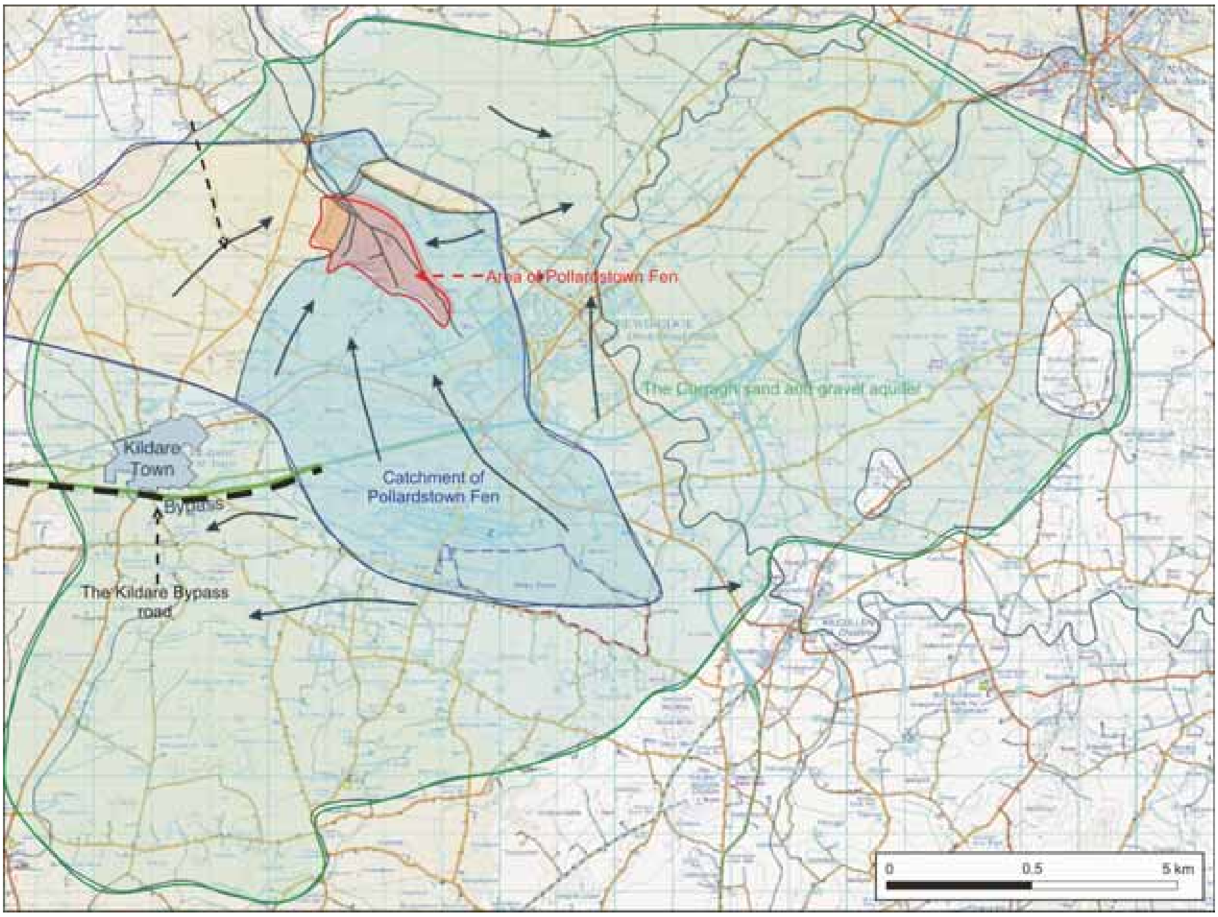


**Fig. 1. Location of Pollardstown Fen in relation to the extent of the Curragh aquifer**

autumn (a two month space from two years of observation), the timing associated with differences in climatic conditions in these years. Individuals may live between one and two years. *V. geyeri* grazes on algae or bacteria on vegetation and decaying humic and plant material. In terms of the preferable conditions, the snail is known from various fen types from rich fen to transition mire (Cameron *et al.*, 2003), the *Schoenus nigricans* tussocks dominated habitat (Killeen, 2003) and the short *Carex*-dominated sward habitat (Cameron *et al.*, 2003). In terms of hydrological conditions, the mollusc shows a preference for calcareous, groundwater-fed seepage areas; often with tufa deposition, a characteristic of extremely rich, calcareous fens (Cameron, 2003; Moorkens, 2007). With respect to topographical settings, the snail is found on gently slopes, which are often present at fen margins along with emerging springs and flushes, Colville (1996), Cameron *et al.* (2003) and Moorkens (2007).

## HYDROGEOLOGICAL SETTINGS

Pollardstown Fen lies in a shallow depression, about 2.2 km$^2$ in area, filled with clay and peat and lies within the northern part of the Curragh aquifer (Fig. 1). Hydrogeology of the Curragh aquifer is significant as it is an important source of baseflow for local rivers and streams, including those in Pollardstown Fen (Milltown Feeder). The glaciofluvial sands and gravels of the Curragh aquifer were deposited in a trough in the underlying Carboniferous limestone bedrock during the Quaternary period. The deposits attain thicknesses of over 60 m in the centre of the trough, but they are typically between 20 and 40m in thickness elsewhere. These deposits display substantial variations laterally, and often include clayey or silty horizons, which influences properties of the aquifer across the groundwater body (Misstear *et al.*, 2008; Kuczyńska *et al.*, 2009). The aquifer is generally unconfined, although confined conditions may arise locally where low permeability layers are present, notably at the fen margin where the snail populations occur (Kuczyńska, 2008). Depths to groundwater vary from a maximum of over 20 m in central parts of the aquifer (where there is a groundwater divide) to zero at locations of groundwater discharge, including the springs and seepages at Pollardstown Fen. A driving head to the fen margin is approximately 4 m. Seasonal fluctuations in groundwater level in the Curragh aquifer are typically between 0.5 and 2.5 m, with the smaller fluctuations occurring closer to the discharge zones.

Inflows to the fen occur via over 40 seepages and springs located mainly around the margins of the fen. The continual inflow of water at the fen creates waterlogged conditions, which lead to peat formation. The peat-marl deposits reach up to 6 m and are usually underlain with clay (Daly, 1981). However, the morphology of the fen margins where the snail lives were found to be characterized by rather shallow and highly variable peat depths, which were not always underlain by clay deposits but could be in direct contact with the gravels. Such conditions allow groundwater to seep through the peat to the fen surface, providing sufficient hydraulic head in the underlying gravel aquifer (Kuczyńska, 2008) to produce the soil wetness and high humidity above the ground surface that appears to be required by the snail.

Water levels in the fen peat at the fen margin are influenced by upward seepage from the underlying gravel aquifer. As there is a significant driving head in regional gravels, the rate of seepage is essentially controlled by the relative elevation of the site and also by the hydraulic resistance offered by the overlying layers of clay and peat – upward seepage rates are possible only where the clay is thin or absent. The simplified conceptual model of the seepage delivery at the fen margin used in this study assumes that there are two layers of different hydraulic conductivities. The upper one is much less permeable and acts as a confining layer for the lower, higher permeability layer (Fig. 2). The upper layer consists of 0.5–1.0 m thick peat and the lower one comprises an extensive glaciofluvial gravel aquifer. This confining layer of peat results in artesian heads in the gravels and causes upward vertical flow whenever the driving head is sufficient.

The upward seepage rate (measured here as specific discharge or Darcy velocity) is controlled by three variables: (a) hydraulic conductivity of the material in the vertical profile through which the water movement occurs; this is the mean vertical permeability of each geological layer within the profile; (b) hydraulic head of water in the confined gravel layer; and (c) evapotranspiration rate at the surface. Saturation of the upper peat is sustained whenever the quantity of water supplied to that layer is delivered at a rate higher than the evapotranspiration rate, i.e. when:

$$AE \leq q_z$$

where:
$AE$ – actual evapotranspiration at the fen surface [m/day],
$q_z$ – upward seepage rate [m/day].

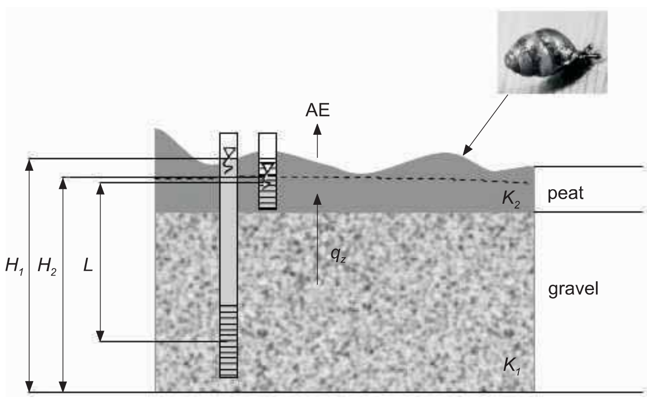


**Fig. 2. Conceptual model of the recharge mechanism through upward seepage at the fen margin**

***$H_1$*** – water level in glaciofluvial gravels under the fen [m]; ***$H_2$*** – water table in peat [m]; ***L*** – distance between screens in deep and shallow piezometres [m]; ***$K_1$*** – permeability of gravel [m/s]; ***$K_2$*** – permeability of peat [m/s]; ***$q_z$*** – vertical seepage velocity [m$^3$/sm$^2$]

# METHODS

## SNAIL MICRO-HABITAT

### Micro-meteorological conditions

Detailed observations of the *Vertigo geyeri* micro-habitat were made within four areas (Sites A, C, D and E located around the fen margin, (Fig. 3). The observations included monitoring of air humidity, air temperature, soil temperature and incoming radiation at the fen surface. In addition, climatic data were recorded on an automatic weather station, which was located on the northern side of the fen (Fig. 3). Data collected at the weather station were used to compare conditions from the fen surface with those recorded at a standard height of 2 m above ground level. All parameters were recorded using automatic data loggers with a one-hourly logging frequency (Kuczyńska, 2008) and were later aggregated at daily, monthly and seasonal time scales. The peat soils were examined for soil moisture (field), surface wetness and soil water content (laboratory). Soil moisture was measured in the field using gypsum blocks (0.02 m in diameter and 0.03 m in depth), which were placed in peat, just below the ground surface, in the direct vicinity of known snail locations. Soil moisture measurements were taken using a soil moisture meter with a range of 1–100%, with 100% indicating full saturation. Surface wetness was measured using small (5 mm diameter) clay balls. The clay balls were used to mimic snails and to measure the "moisture stress" that a snail is likely to experience under dry conditions. The clay balls were placed on the peat surface, between moss leaves and debris which is the micro-habitat where the snails are most commonly found. The experiment involved measurements of the change in weight of the clay balls after exposing them to different surface wetness conditions. The absorption characteristics of clay allowed changing saturation conditions to be measured within the plant cover at ground level using an approach analogous to the moisture content concept given by British Standards Institution (1990). In addition, the soil water content of surface peat samples of a volume of 0.02 $m^3$ (collected from locations where snails had been found) was determined in the laboratory using an oven drying method (Maciak, Liwski, 1996).

### Micro-hydrological conditions

The micro-hydrological regime for *V. geyeri* was established from water level observations adjacent to the known snail locations. The snail can relocate within small areas with respect to water availability. The proximity of the water

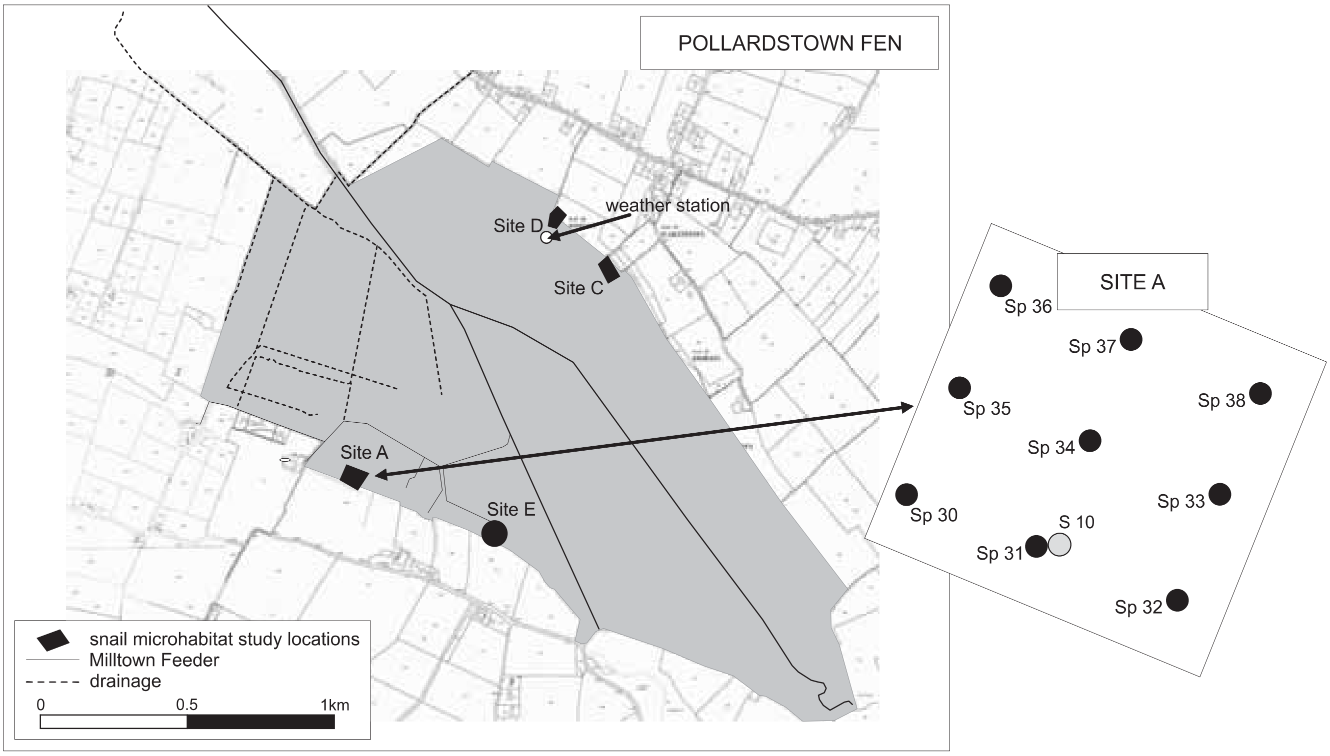


**Fig. 3. Location of *Vertigo* study sites within the Pollardstown Fen**

Within the "Site A" box, black circles present locations of piezometers' nests used for groundwater level monitoring within the site, a grey dot shows a location of water level monitoring in peat used for defining the micro-hydrological for *Vertigo geyeri* table to the ground surface and the spatial distribution of snails with reference to surface water contours were therefore considered to be potentially good indicators of acceptable hydrological conditions. Observations were made using pressure transducers which were installed in 0.05 m diameter perforated plastic pipes pushed into the surface peat layer, 0.5 m below the ground surface; the transducers were set to log water levels every hour. Average daily water level was then compared against the snail presence at the site.

### *Vertigo geyeri* observations

In order to understand the micro-hydrogeological requirements of *V. geyeri*, a method needed to be developed that could establish where individual animals were located at any time within the study area. Therefore, regular observations had to be undertaken in the field without disturbing the habitat. These surveys were undertaken by a specialist ecologist, Dr Evelyn Moorkens (Kuczyńska, Moorkens, 2010). At Sites A, C and D six quadrats measuring 0.5 × 0.5 m were marked with flags in the field (CQ1–CQ6 etc.) and at Site E – two quadrats of EQ1 and EQ2 were selected. During the most active periods for *V. geyeri* (April to October), the quadrats were observed by searching for *V. geyeri* individuals, and noting where they were by placing a nylon grid with 100 cells over the quadrat to establish which 0.05 × 0.05 m area the snails were living in (Fig. 4). The cells were labelled on the horizontal axis from A to J and on the vertical axis from 0 to 9, providing a distinct numbering system for each of the 2,000 cells surveyed each month (AQ1A0–AQ1J9 etc.). When the snails were identified they were returned to the cell where they were found. In all, 100 cells were surveyed in 20 quadrats during 21 different monthly observations (April 2002 to October 2004), providing 42,000 presence or absence observations that could be correlated with micro-hydrological measurements.

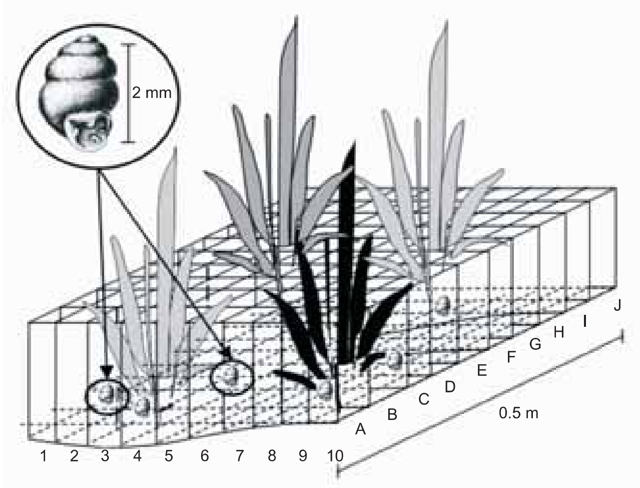


**Fig. 4. Concept of *Vertigo* study locations (quadrats)**

### Relationship between *Vertigo geyeri* observations and the water level in the fen peat

The topography of each *V. geyeri* quadrat was surveyed using GPS equipment with accuracy of 0.02 m on the vertical axis. Measurements were taken using a grid of 0.1 × 0.1 m and were taken from the top of a topographic plane, no matter whether the surface was a ground surface or tussocks. Maps for each *V. geyeri* quadrat were drawn using a specialist drawing software. Daily average water level contours and the locations of snail sightings (for a given day when the snail survey was carried out) were added to the topographical maps (Fig. 5). The proximity of the snail to water in both the vertical and horizontal directions was established using topographic maps and by calculating vertical distances between topographic and observed water level elevations. Since the focus of the study was on the snail habitat, only positive snail counts were analysed for proximity of the water table to the ground surface.

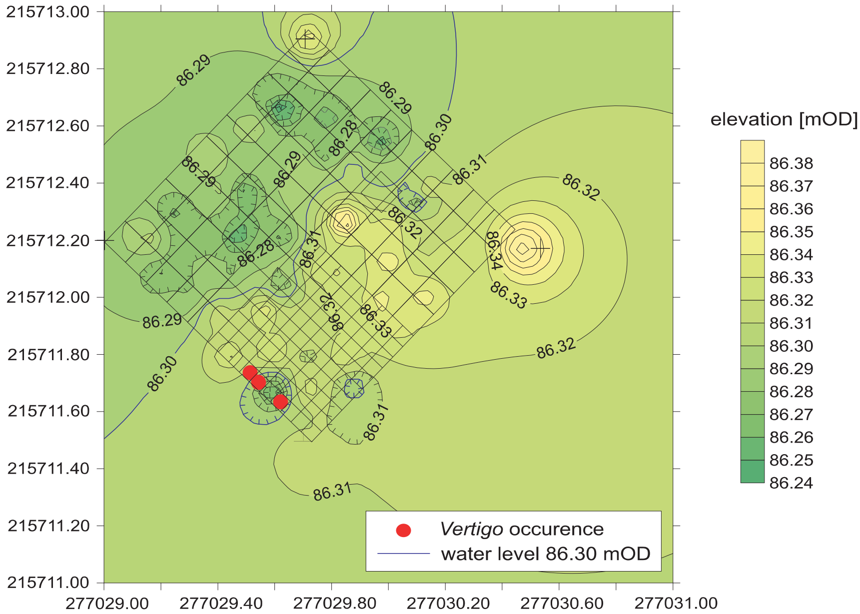


**Fig. 5. Example of a water table contour map showing the occurrence of the *Vertigo geyeri* snail**

Topographic and water level elevations are presented in metres Ordnance Datum, measured above sea level at Poolbeg, Ireland

### RELATIONSHIP BETWEEN THE FEN HYDROLOGY AND HYDROGEOLOGY OF THE SURROUNDING QUATERNARY AQUIFER

The relationship between the hydrology and eco-hydrology of the fen margin and the regional hydrogeology was established from groundwater observations in the Curragh gravel aquifer and in the peat layer at the fen surface. This was studied in detail at one site (Site A), approximately 400 $m^2$ in size, located at the southern fen margin, where groundwater from the regional sand and gravel aquifer seeps into the fen. Nine nests of piezometers were drilled at this site, targeting three depths: shallow (2–5 m) and deep (7–9 m) piezometers in the sand and gravel aquifer underlying the fen, and shallow piezometers in the fen peat (1 m deep; WYG, 2002; Fig. 3). To investigate the delicate water balance between upward seepage rate and evapotranspiration a Darcian approach was applied and results were further verified using soil thermo-dynamic model developed by Van Wirdum (1991, 1998). The upward seepage rate (expressed as specific discharge) $q_z$, was calculated using Darcy's law. Water level data were available on a bi-weekly basis and were collected in piezometers Sp31, screened in gravels beneath the fen, representing water table in the gravel aquifer and S10, screened in peat layer, representing local water table. The hydraulic conductivity of each stratum was established through *in situ* testing (Kuczyńska, 2008), following a review of previous reports on the fen (Daly, 1981; Hayes *et al*., 2001). Potential evapotranspiration (PE) was calculated using a modified Penman-Monteith equation (Allen *et al*., 1998) and was based on climatic data from the fen weather station. Daily actual evapotranspiration (*AE*) was computed by applying suitable crop coefficients determined especially for the fen vegetation (Kuczyńska, 2008). The net upward seepage rate was calculated by deducting actual evapotranspiration from the seepage rate (specific discharge). These net seepage rates were then compared with fluctuations in water levels within the phreatic zone in the peat layer. Vertical seepage rates, $q_z$, were also evaluated using thermo-dynamic profiles. The method is based on a convective heat transport model (Van Wirdum, 1991, 1998) and involves measurements of the temperature at different depths of soil along a vertical axis. The model assumes that the temperature of soil at infinite depth is constant, and that it fluctuates at the soil surface where it is under the influence of ambient conditions. The temperature of soil at some intermediate depth reflects the fluctuations at the surface with decreased amplitude and a phase lag. When the thermal parameters of the soil medium are known, and when they are nearly equal to those of water, the gross velocity of the vertical flow of water can be estimated from the difference between apparent and real thermal diffusivities (Van Wirdum, 1991, 1998).

## RESULTS

### SNAIL MICRO-HABITAT

#### Micro-meteorological conditions

Micro-meteorology was found to be uniform across the whole fen with little difference between data from the fen surface and the weather station. Incoming radiation was about 50% less under the vegetation canopy at the fen surface than that at the weather station. Humidity did not change much across the fen compared to the weather station data, but remained above 80% nearly all year round, with increased values in winter months. Meteorological variability was lowest during the winter period from November until February when diurnal fluctuations were small with respect to all parameters. Humidity ranged between 65–95% and a daily average was above 90%. Average air temperature was below 10°C. Soil temperature was at its lowest in these months, with a minimum occurring in the middle of February; however, the soil temperature never fell below 0°C. As expected, solar radiation was significantly less during winter than summer. In the period from March to October, all parameters increased, both in values and in the extent of their diurnal fluctuations, with maximum values occurring in July. June to August was the hottest period, with daily temperatures reaching >30°C. Increased air temperatures affected the temperature of the soil, which showed similar fluctuations. The summer soil temperature ranged between 7 and 16°C. Humidity is the only parameter measured that decreased during the summer although, despite large daily fluctuations, the average level remained above 80%.

Soil conditions were found to be an important factor in the snail habitat in all parts of the fen investigated. Measurements of soil moisture (field), surface wetness and soil water content (laboratory) showed very high levels of saturation of the soil. The laboratory measurements of soil water content (Tab. 1) ranged between 66 and 81% and the field soil moisture readings using gypsum blocks ranged between 83 and 94% with an average of 89.2%. High soil moisture had a direct effect on surface wetness conditions. The experiment using clay balls showed that fen surface wetness ranged between 52 and 100%; however, 69% of samples showed wetness levels above 80%. The shading provided by vegetation greatly affected the surface wetness level.

Table 1

**Summary of peat soil conditions observed within *Vertigo geyeri* sites on Pollardstown Fen in August 2003**

| | Maximum | Minimum | Average |
|---|---|---|---|
| Soil water content [%] | 81 | 66 | 73.3 |
| Surface wetness [%] | 100 | 52 | 82,0 |
| Soil moisture [%] | 94 | 83 | 89.2 |

### Micro-hydrological conditions

The overall fluctuation in the water level in the peat layer varied from 0.05 to 0.31 m below ground level (b.g.l.) over the summer observation period (May to October 2002–2005). The range of fluctuations is controlled by the minimum water table level that, in turn, depends on the amount of groundwater that is supplied to the fen surface through groundwater seepage. Lower minimum water levels imply a deeper unsaturated zone, which can quickly become fully saturated after intensive rainfall resulting in relatively high water level changes over short periods.

### *Vertigo geyeri* observations

Of the 20 quadrats (0.25 $m^2$) studied, 13 had positive records for *V. geyeri* during the 21 months of the study. Of the 42,000 cell observations made during the study, 89 or 0.2% were positive. However, once present, *V. geyeri* was found to persist either within the same 25 $cm^2$ cell, or in very close proximity over a number of months. An average of 78.2% of snail observations were no more than 5 cm from where they had been recorded previously.

### Relationship between *Vertigo geyeri* observations and the water level in the fen peat

Comparison between the snail occurrence and elevation of the phreatic water table demonstrated that *V. geyeri* appears to accept the range of fluctuations between 0 and 0.2 m b.g.l., with the average water table being c. 0.1 m b.g.l. Where water levels fluctuated on a wider scale than this, the snail was absent. On a horizontal scale, the snails seemed to occur within approximately 0.2 m lateral distance of standing water (Fig. 4).

## RELATIONSHIP BETWEEN THE FEN HYDROLOGY AND HYDROGEOLOGY OF THE SURROUNDING QUATERNARY AQUIFER

The seepage rate, as determined between piezometers Sp31 and S10, is plotted against the actual evapotranspiration rate in Figure 6. Both parameters displayed strong seasonal variations. The fluctuations in seepage rates followed the same general pattern as the fluctuations in water levels in the gravel aquifer (as shown by the hydrograph for borehole Sp31, Fig. 7). The highest seepage rates occurred at the end of a winter period, February–March, when water levels in gravels were at their highest, and the lowest occurred at the end of the summer, or in mid-autumn. There was an overall decreasing trend in the seepage rate over the observation period, which is consistent with the observed decline in water levels in the underlying fen gravels. It is also apparent that evapotranspiration rates tend to exceed seepage rates during the summer months, and this has an effect on the stability of water level in the peat. The negative *net* seepage rates (corresponding to a period of “seepage deficit”) result in a lowering of the phreatic surface. Figure 6 shows a significant fall in seepage rates between 2003 and 2005. The highest seepage rates were recorded during winters of 2001 and 2003, at 0.0048 and 0.004 m/day, respectively. In 2004 and 2005, on the other hand, seepage rates barely exceeded 0.002 m/day. In both 2002 and 2003, seepage rates remained above 0.002 m/day

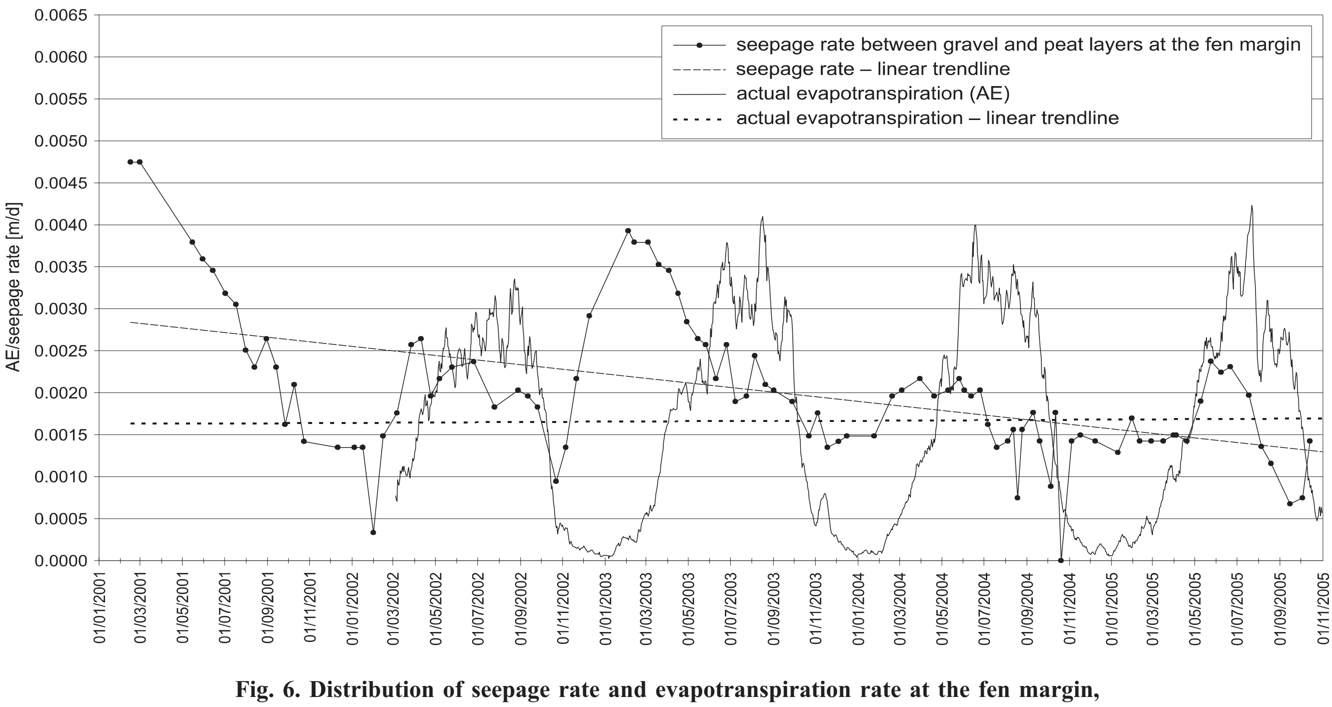


**Fig. 6. Distribution of seepage rate and evapotranspiration rate at the fen margin, Site A, Pollardstown Fen, 2002–2005**

until the middle of September (with short temporal falls below 0.002 m/day in July). In 2004 and 2005, seepage rates of approximately 0.002 m/day continued only until the end of June and July, respectively, and by the end of the summer season (October) they had reduced to 0 and 0.0007 m/day, respectively. Using the thermodynamic approach, the analysis of soil temperature gradients suggested vertical seepage rates of a similar order of magnitude (Kuczyńska, 2008).

The average actual daily evapotranspiration for the summer months May to October 2002–2005 are included in Table 2. In 2003 and 2004, the average summer daily actual evapotranspiration was higher than that in 2002 by 0.0003 m (0.3 mm) which, over the 6-summer-month period, amounted to a difference of about 0.055 m (a 13% increase in summer *AE* compared to 2002). In May to October 2005, total summer actual evapotranspiration was 0.445 m, approximately 7% higher than for the same period in 2002. The *net* seepage rates for the four summer periods are summarised in Table 3. Comparison with water level fluctuations in the peat (see Fig. 7 and Table 3) showed a negative net seepage (i.e. downward flow) occurring during summer months throughout the entire observation period 2002–2005. The overall negative gradient increased throughout the 2002–2005 period, which suggests that the groundwater delivery rate was not sufficient to sustain stable conditions and induced lowering of the phreatic level.

Comparison of the *net* seepage rate with the phreatic level (Fig. 7) shows that a "seepage deficit" leads to instability of the phreatic level whenever the net seepage rate is negative. Some seepage deficit, however, appears to be acceptable to the snail during summer months, provided that re-wetting takes place and the peat is returned to its field capacity during the winter months – as occurred, for example, in the summer of 2002 and the following winter of 2003. Analysis of hydrographs (Fig. 7) suggests that such re-wetting is necessary and requires significant seepage with rates probably not less than 0.004 m/day. The observations suggest, therefore, that both summer and winter seepage rates need to be sustained at certain levels in order to maintain the hydrological conditions required by the *V. geyeri* snail. This in turn suggests that hydraulic head in the underlying fen gravels must be sustained at, or above, a minimum level, in order to provide the required minimum seepage rate for stable peat water table conditions.

Applying Darcy's equation enabled this minimum hydraulic head to be established for this particular study site. The mean permeability in the vertical profile at the fen margin was determined by *in situ* testing as $4.72 \cdot 10^{-7}$m/s (Kuczyńska, 2008). Taking this permeability value, and also taking the average daily actual evapotranspiration in summer at 0.0025 m/day and the minimum water level in peat (at piezometer S10) to be 0.2 m b.g.l., then the minimum hydraulic

Table 2

**Summary of daily summer evapotranspiration and seepage rates in a period between May–October, 2002–2005**

| Parameter | | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| Summer seepage rate | average [m/day] | 0.0019 | 0.0022 | 0.0015 | 0.0016 |
| | total [m] | 0.0154 | 0.0238 | 0.0243 | 0.0162 |
| | maximum [m/day] | 0.0024 | 0.0026 | 0.0022 | 0.0024 |
| | minimum [m/day] | 0.0009 | 0.0015 | 0.0000 | 0.0007 |
| Summer potential evapotranspiration (*PE*) | average [m/day] | 0.0019 | 0.0022 | 0.0022 | 0.0021 |
| | total [m] | 0.3530 | 0.4030 | 0.4100 | 0.3830 |
| | maximum [m/day] | 0.0045 | 0.0053 | 0.0067 | 0.0055 |
| | minimum [m/day] | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Summer actual evapotranspiration (*AE*) | average [m/day] | 0.0023 | 0.0026 | 0.0026 | 0.0024 |
| | total [m] | 0.4170 | 0.4710 | 0.4770 | 0.4450 |
| | maximum [m/day] | 0.0055 | 0.0061 | 0.0074 | 0.0065 |
| | minimum [m/day] | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 3

**Summary of vertical seepage rates and water levels in peat on the fen margin (Site A), May–October, 2002–2005**

| Year | Water level in piezometer S10 (in peat) | | Seepage rate | | Net seepage rate | |
|---|---|---|---|---|---|---|
| | average [mOD] | range [m] | average [m/day] | range [m/day] | average [m/day] | range [m/day] |
| 2002 | 88.40 | 0.16 | 0.0019 | 0.0014 | –0.0005 | 0.0048 |
| 2003 | 88.36 | 0.20 | 0.0022 | 0.0012 | –0.0003 | 0.0051 |
| 2004 | 88.32 | 0.26 | 0.0015 | 0.0022 | –0.0008 | 0.0067 |
| 2005 | 88.26 | 0.14 | 0.0016 | 0.0017 | –0.0011 | 0.0049 |

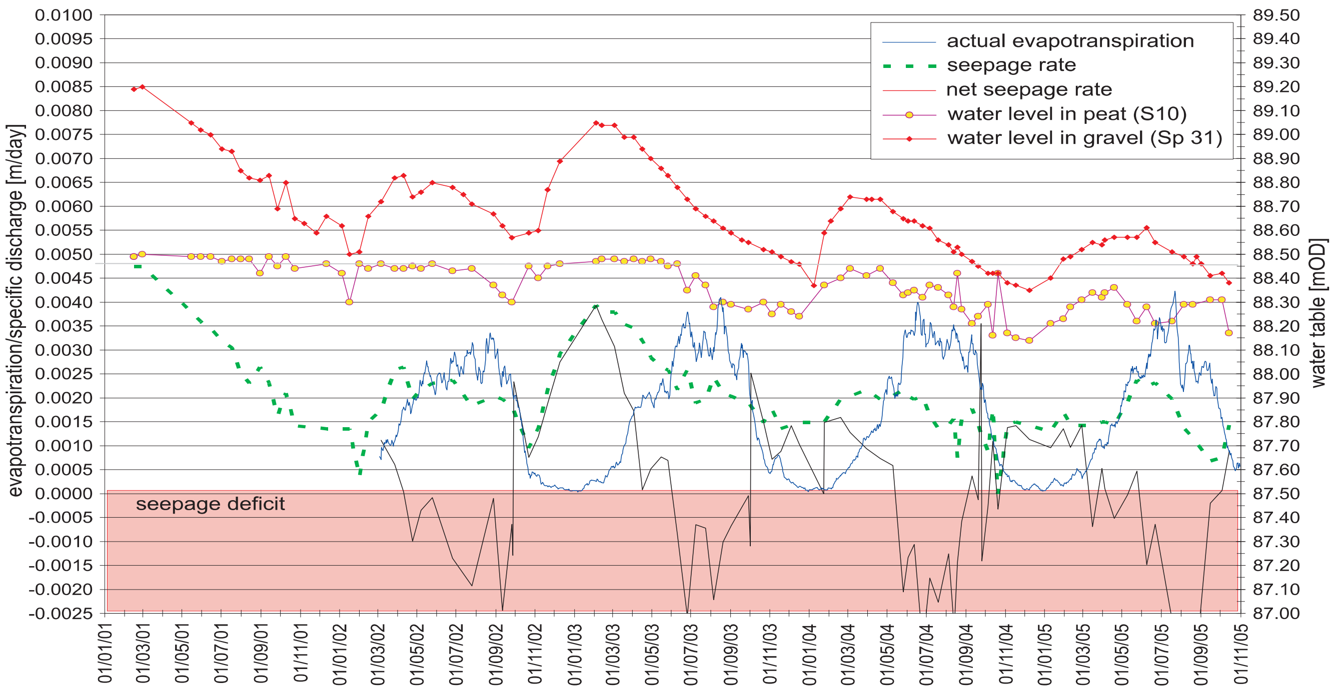


**Fig. 7. Variations in water levels, actual evapotranspiration and seepage rate, Site A, Pollardstown Fen, 2002–2005**

head in the underlying gravel layer is calculated to be 88.67 mOD (at piezometer Sp31). This represents the hydraulic head necessary at that location to drive the upward seepage flow in order to counter balance evaporative losses, keep the soil surface wet and the peat water level at the required stable level.

## DISCUSSION AND CONCLUSIONS

This article described main results of a multidisciplinary study that was undertaken in order to protect rare and sensitive habitat of the chosen indicator specie of mollusc *Vertigo geyeri*, which acted only as an indicator of the specific type of a wetland environment. The article presented a model approach for investigating links between ecology and hydrogeology and related these interactions, which occurred at a local scale, to more broaden frame of regional hydrogeology.

This study investigated the preferred habitat of the *V. geyeri* snail in terms of micro-meteorology and micro-hydrology and then "translated" these conditions into adequate hydrogeological regime conditions.

At a local scale the snail was found to be very conservative in its locations, with habitat being restricted to a micro-scale of centimetres within the quadrats surveyed. As micro-meteorological conditions were found to be relatively uniform across the whole fen area it was concluded that micro-meteorology has less influence on the snail's occurrence than the micro-hydrological regime. Groundwater monitoring programme over four summers suggested that in order to maintain the phreatic level at the required not less than 0.2 m b.g.l., groundwater needs to be delivered to the fen surface at rates that are at least equal to the average summer actual evapotranspiration losses from the surface, that is approximately 0.0025 m/day. Investigation of the links between the micro-hydrology at the fen margin and the regional hydrogeological regime showed that the mechanism of seepage delivery depends mostly on the rate of groundwater discharge and the site geomorphology. At one particular site for which the model was created, it was shown that in order to maintain stable water levels within the fluctuation range acceptable by the snail, the hydraulic head in the underlying gravel aquifer should not fall below 88.67 mOD in piezometer SP 31 during summer months, when the snail is most active. Maintenance of summer water table above such a minimum threshold will restrict the fluctuation of water table in peat and sustain surface wetness at a sufficiently moist level, as required by the fen fauna.

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