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Conceptual flow model and changes with time at Braunton Burrows coastal dunes

Groundwater Management Programme

Commissioned Report CR/07/072N

BRITISH GEOLOGICAL SURVEY

GROUNDWATER MANAGEMENT PROGRAMME

COMMISSIONED REPORT CR/07/072N

Conceptual flow model and changes with time at Braunton Burrows coastal dunes

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Coastal dunes, rainfed aquifer, conceptual model, effective rainfall.

Front cover

Braunton Burrows looking towards Saunton.

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The enthusiasm and encyclopaedic knowledge of Braunton Burrows imparted by Educational Warden John Breeds has been invaluable to the current project. The site visit was both instructive and illuminating and served to highlight a number of issues pertaining to the Burrows today and in the recent past.

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Executive Summary

Braunton Burrows supports a rainfed groundwater system with a water table that is mounded along an axis near and parallel to the eastern boundary of the Burrows, but trends westward towards the north of the system around the Golf Club. Annual water level fluctuations are up to 2 m. The long term recharge and discharge/abstraction estimate for the Burrows is 478.6 mm. Much of this drains to the foreshore at low tide on the west and towards the West Boundary Drain on the landward side in the east. Some groundwater is intercepted by drainage of fields north of Sandy Lane Car Park and at the Golf Course which also has an abstraction borehole in the sands. Deepening of the West Boundary Drain in 1983 affected water levels only in the immediate vicinity of the drain. Effective rainfall has declined by 5% since the mid 1960s. The 24 month moving average for rainfall at Bideford parallels the hydrographs, reflecting a rainfed system independent of significant outside influences. Since 2001 the water level has fallen although there has been considerable recovery during the period February to April 2007. In the long term, groundwater levels may be affected by a number of influences but decline in effective rainfall is the critical influence. Change in land cover is unlikely to be a significant influence on the water table. The historical data set is comprehensive and complements that for the Ainsdale National Nature Reserve on Merseyside. It is recommended that consideration be given to gathering some additional data to cover present uncertainties in order to develop a groundwater flow model for the Braunton aquifer. The model could be used to simulate climate change outcomes, and could enable management options for the dunes and associated wetlands which could be applicable to both Braunton Burrows and other coastal dunes in England and Wales.

1 Introduction and objectives

Braunton Burrows rises to 38 m aOD and has an area some 5 km by 2 km with the long side adjacent to the sea coast. The area comprises a series of north to south oriented dunes and slacks shaped by the prevailing on-shore winds (Figure 1). There is a narrow zone of low fore dunes up to 5 m high adjacent to the beach which are succeeded inland by sand hills up to 15 m high separated by a discontinuous belt of slacks. The succeeding dunes are the highest. Beyond these dunes lies a broad, but poorly defined, belt of lower lying ground with scattered hillocks and many pools, some of which are permanent. Inland again are lesser dunes followed by flat sands with a few scattered small dunes which merge towards cultivated fields on the alluvium. The slacks are mainly dry with ephemeral wet weather pools and these are sensitive to the groundwater elevation (English Nature, 2006). The water table is domed within the sands, being entirely rain fed, with a maximum elevation of 7 or 8 m aOD (above Ordnance datum) in winter beneath the centre of the dome. Monitoring of water levels has been ongoing since 1966 and the resulting data set provides a unique long-term baseline record for a coastal dune area in the UK which will be invaluable in assessing possible effects of climate variability on these sensitive environments.

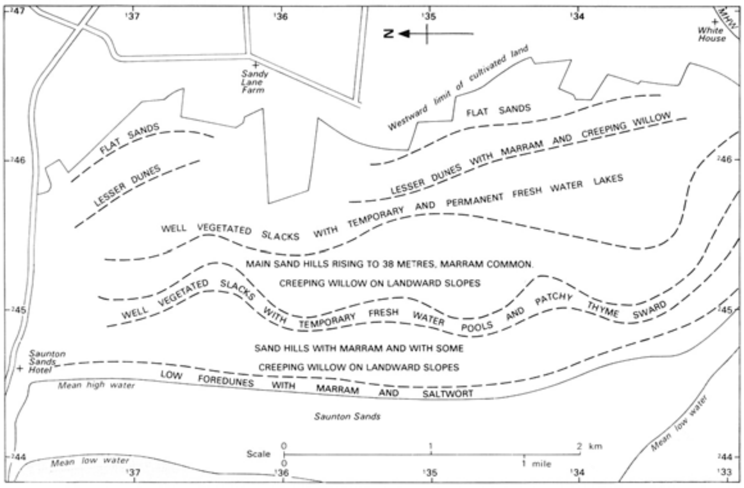

Figure 1 The pattern of dunes on Braunton Burrows (after Edmonds et al., 1979)

A borehole [SS 4525 3424] in the high dune belt, at an elevation of 16 m aOD, penetrated fine-grained sand with silty patches and consolidated layers to 7.3 m; soft blue silty clay to 9.8 m; coarse-, medium- and fine-grained sand and small gravel to 10.3 m; over hard blue rock of Upper Devonian or Lower Carboniferous age. A borehole near Bideford lighthouse at the southern end of the Burrows penetrated blown sand to 8.5 m; sand clay and pebbles (estuarine alluvium) to 14.3 m; over rock. The variation in lithology may represent past soil horizons, channel infill material or deposits from environments other than dunes and slacks.

Concern has been expressed over a number of years that the dune slacks at Braunton Burrows flood less frequently than in the past and that the Burrows are 'drying out'. Burden (1998) highlighted a number of possible influences on the dune hydraulics which could effect a reduction in the groundwater mound within the sand dune area:

- changes in effective precipitation;
- erosion of the fore dune ridge;
- increased evapotranspiration caused by the encroachment of various scrub species;

- drainage at Saunton Golf Club in the north-east of the burrows area;
- land drainage in the adjacent Braunton Marsh.

This brief study aims to identify any temporal changes in water level that have occurred since groundwater monitoring began in 1966 and attempts to correlate them to possible causes. In addition, the data are used in conjunction with other available sources of information to develop a conceptual groundwater flow system and water balance for the Burrows system. The work was undertaken by the British Geological Survey on behalf of Natural England.

The brief for the current phase of work is as follows:

1. create a complete electronic record of the data set;
2. create a visual presentation of the data;
3. undertake an analysis of the water table fluctuations with local weather data;
4. comment on fluctuations and trends.

The following items were additional:

5. GPS record of location of dip wells in relation to dune topography;
6. some predictions for the future of the water table in the light of climate change predictions.

Items 1 to 4 are described in this report and the electronic data set (EXCEL) is appended in a CD with a brief description of the data (WORD). Item 5 was not undertaken as all the currently monitored dip wells had already been located at 1: 5000 scale and leveled to metres aOD. Item 6 is briefly addressed but would best be dealt with, should a second phase of work be undertaken, through the creation and application of a validated groundwater flow model for the dune aquifer.

2 Data analysis

All the available piezometry has been brought together in a single spreadsheet reducing it to metres depth below respective fixed and identified datum points and displaying it with respect to OD. Elevation data were not available for 22 out of the total of 41 shallow boreholes (or dip tubes) that had been monitored from time to time. Without exception, monitoring of all the shallow holes that had not been levelled in was discontinued by 1991, many some years earlier, and much of the data for these sites were erratic. The complete data set is, nevertheless, appended on the attached CD (see Appendix 1). This selection of preferred monitoring points resulted from a conscious decision taken by the warden, John Breeds, to concentrate efforts on three recognisable transects (Figure 2) following the installation of the piezometer series 1N to 6N to create Transect 1. The effect of the West Boundary Drain, and its occasional renovation, on nearby groundwater levels continues to be monitored at the former Broadsands Car Park. Many of the casing tops for the other boreholes have now been lost and cannot now be seen at surface, although their approximate location is known to former site warden John Breeds. Consequently only the data for the 17 holes in Transects 1, 2 and 3 and the two hole(s) at Broadsands Car Park have been thoroughly evaluated.

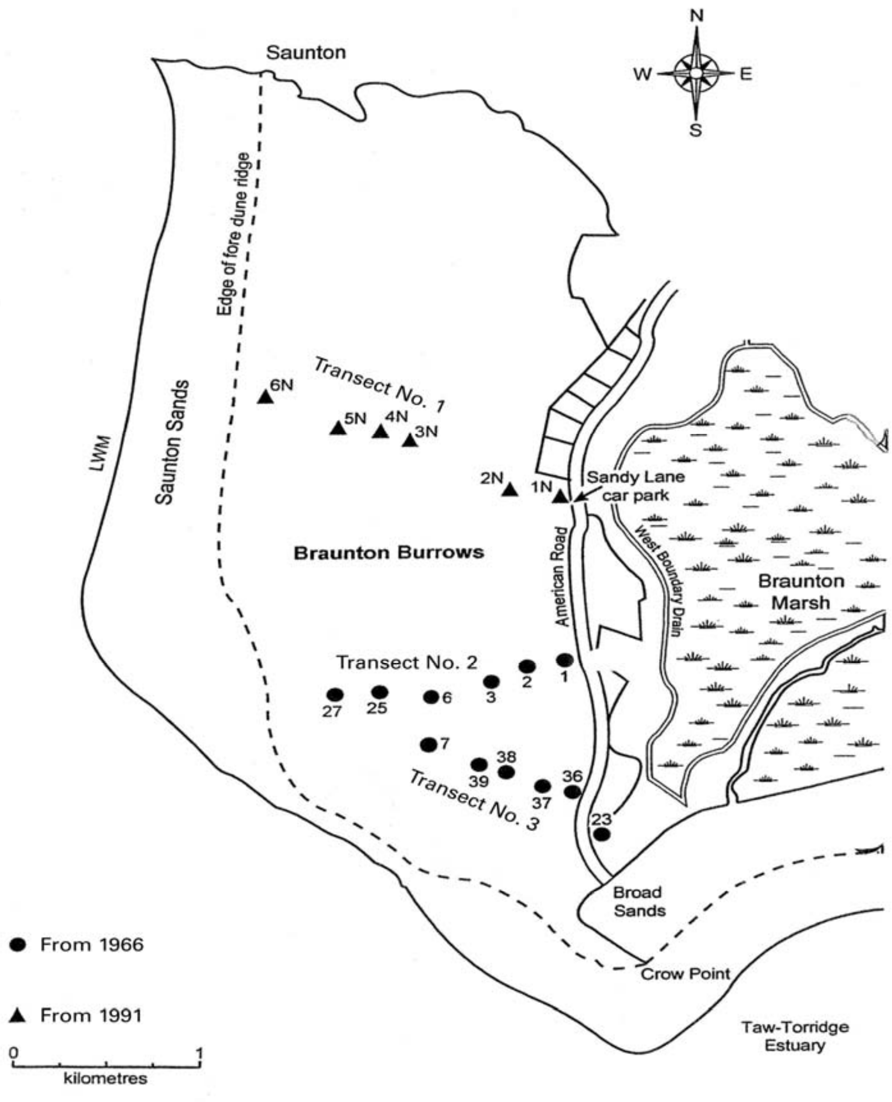

Figure 2 The borehole locations and the transects.

The Environment Agency monthly rainfall data for Bideford have been incorporated for analysis of rainfall trends in the area and the data converted to effective rainfall by subtracting the MORECS monthly actual evaporation data for MORECS grid square 165 (for more information see http://www.metoffice.gov.uk/water/morecs.html). The long term average (LTA) annual effective rainfall is 478.6 mm, and as runoff is negligible except during extreme rainfall events it is assumed that the LTA recharge to the sand is approximately the same value. The annual effective rainfall, however, is extremely variable (Figure 3) and shows a linear trend, or straight line best fit, falling from about 500 mm to 475 mm between 1967 and 2005, i.e. an apparent reduction in effective rainfall/recharge of 5% in just under 40 years.

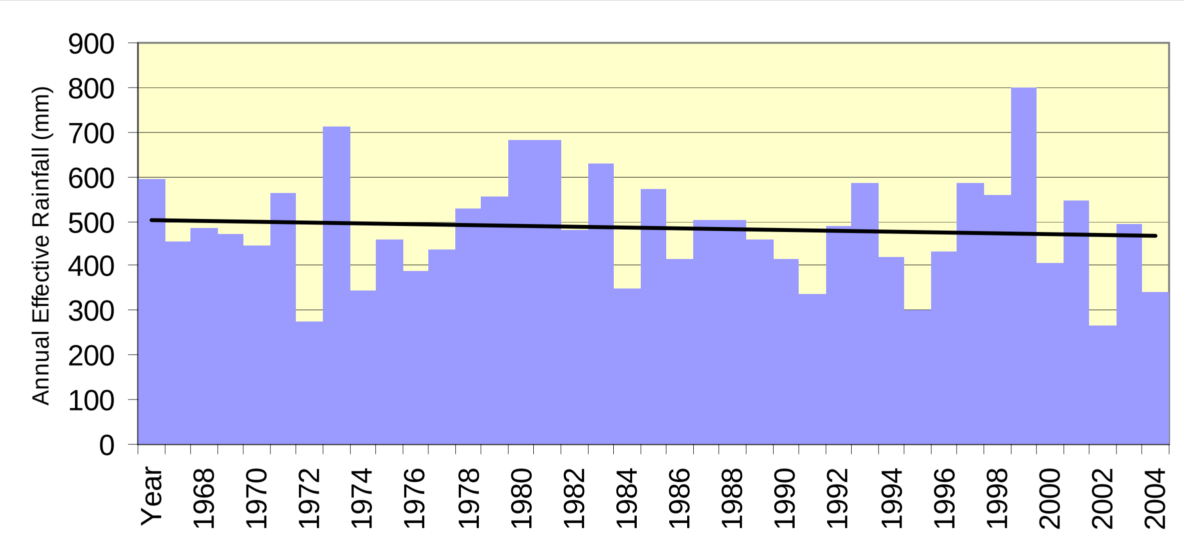

Figure 3 Effective precipitation – Bideford.

The 24 month linear regression line through the monthly rainfall data for Bideford declines from 80 mm/month in June 1966 to 75 mm per month by September 2006 (Figure 4). The mean monthly rainfall over this period was 78.1 mm and the decline of 5 mm/month represents a 6.4% reduction in long term average rainfall in 40 years. Bideford, however, receives more rainfall than Braunton Burrows as shown in Table 1 for the concurrent data series for local rainfall stations. It is assumed that overall Braunton Burrows receives some 94% of the modern Bideford rainfall total in Table 1, i.e 62.8 mm/month. Note also that the mean monthly rainfall for the period January 2002 to September 2006 at Bideford was only 85.5% of the LTA for the forty year period from 1966, again reflecting an overall decline in rainfall during the longer period.

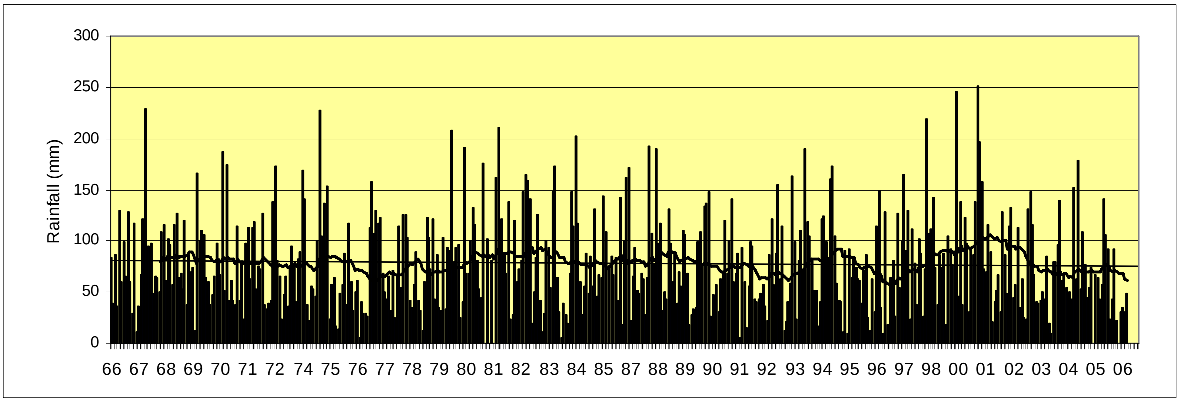

Figure 4 Monthly rainfall Bideford showing linear regression line and 24 month moving average.

Table 1 Comparative rainfall January 2002 to September 2006

	Bideford	Chivenor	Saunton
Mean monthly rainfall	66.8	64.9	60.6
% age of Bideford rainfall	100	97.2	90.7

Figure 5 shows the hydrographs and linear trend lines for typical boreholes in each of transects 1, 2 and 3 plotted against the 24 month moving average for Bideford rainfall. The striking correlation between the moving average rainfall, which is effectively smoothed and damped, with the hydrographs demonstrates that the groundwater levels in the Burrows are rain fed with no significant other non-rainfed external influences on the groundwater levels. Figure 5 also shows an alarming and consistent decline in the overall water table with time. The hydrographs for all the boreholes in each of the Transects 1, 2 and 3 are shown in Figures 6, 7 and 8 respectively. These show that all the boreholes in all these transects react in a similar manner to the rainfall. The exception is borehole 23 at the former Broadsands Car Park in which the same trends were overridden in 1983 by a sharp reduction in the water level of 1 m with a subsequent gradual recovery until 2000 when the level declined, again in response to reduced rainfall in that period (Figure 9). The 1983 drop in the hydrograph corresponds to deepening of the adjacent West Boundary Drain although this decline is local to the drain and is not seen in hydrographs from the three transects within the Burrows. The hydrograph for Borehole 23D (located adjacent to borehole 23) reflects the stage level in the drain itself, and shows brief periods of no flow notably in recent summer periods.

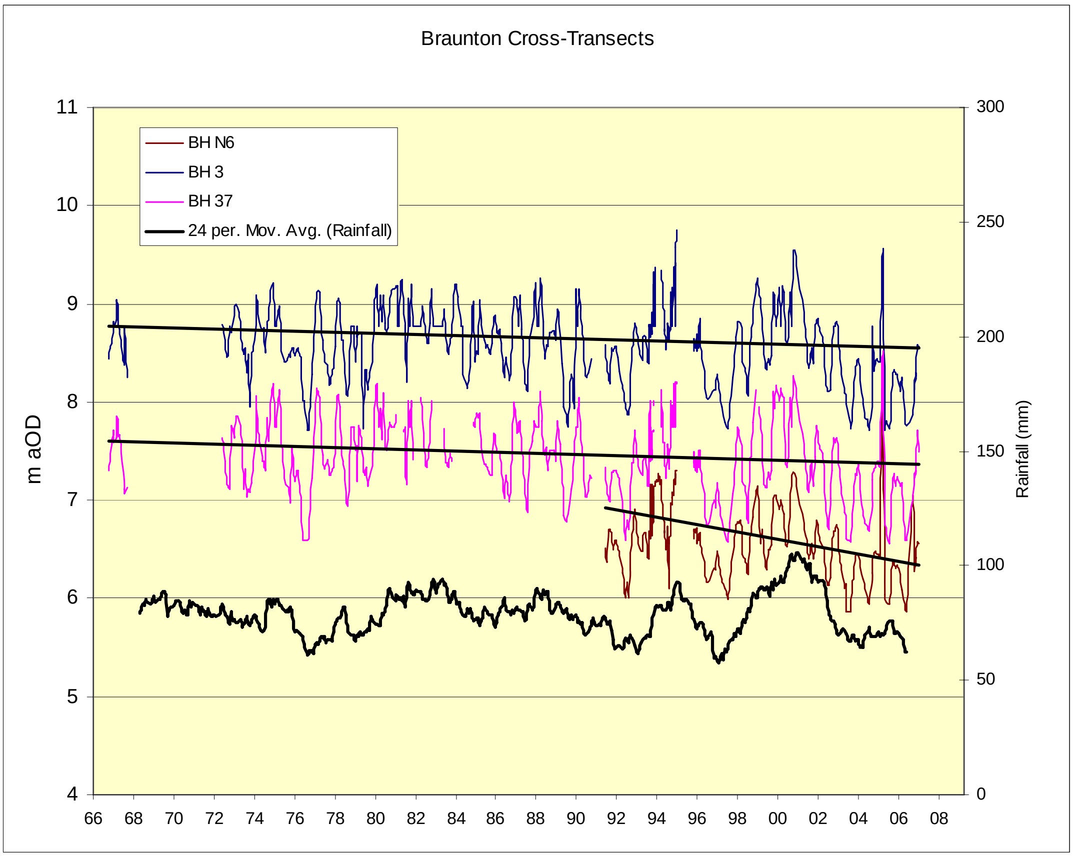

Figure 5 Typical hydrographs from each of the three transects with 24 month moving average for Bideford rainfall and declining linear trend for each hydrograph.

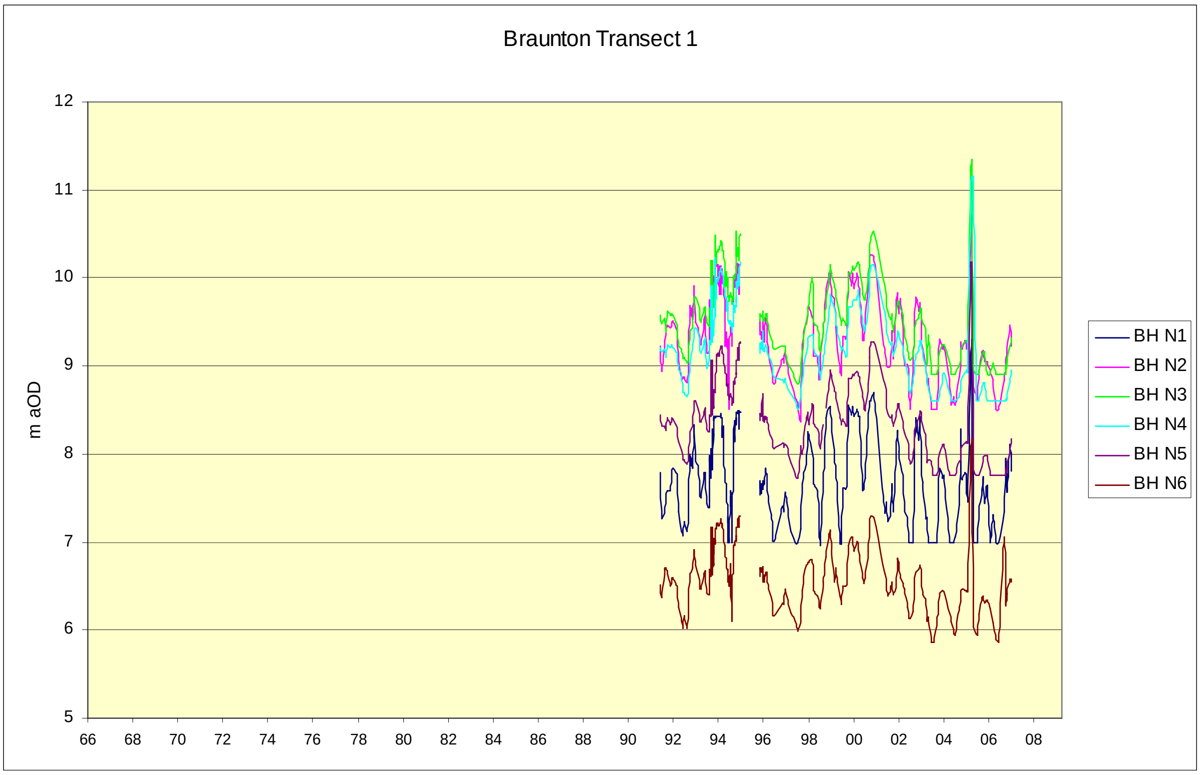

Figure 6 Hydrographs for Transect 1

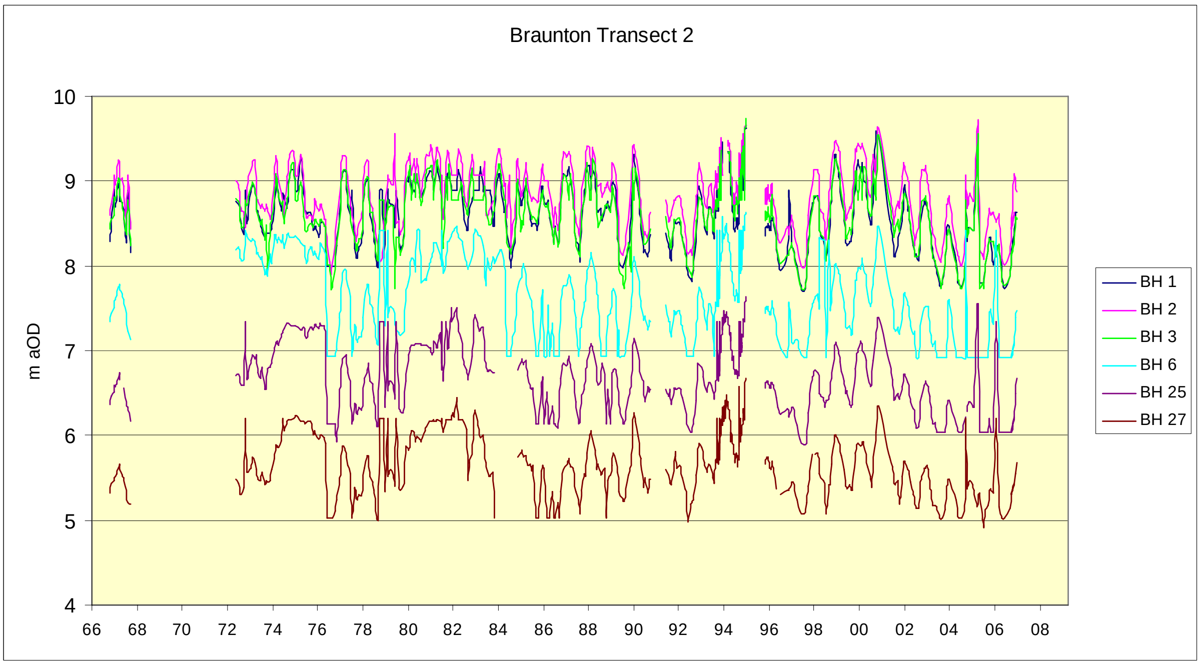

Figure 7 Hydrographs for Transect 2.

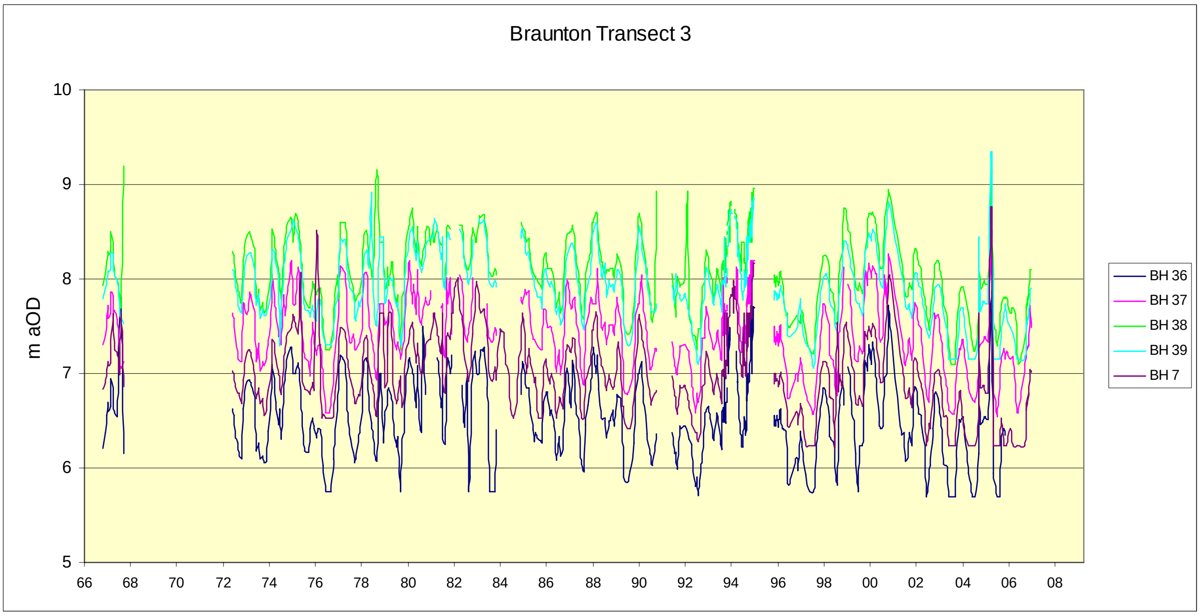

Figure 8 Hydrographs for Transect 3.

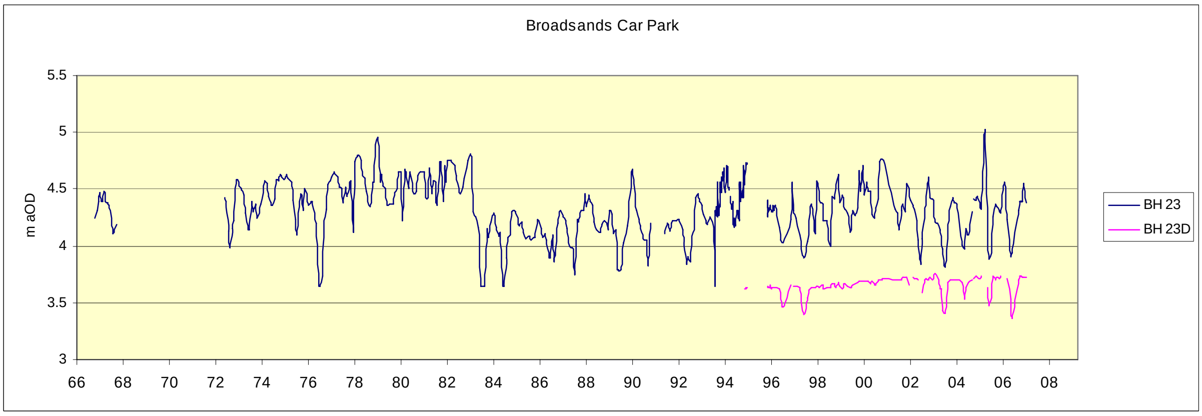

Figure 9 Broadsands Car Park Boreholes 23 and 23d hydrographs.

Finally the data for each of the three transects have been plotted as a cross-section along each transect for the driest period on record and for the wettest period on record (Figures 10, 11 and 12). The selected data are the minimum and maximum water table elevations recorded for each transect for which data are available, and the date on which these events occurred is identified on the cross sections.

The cross sections show that under dry conditions the water table generally lies about 1.5 m below the dune slacks, whereas under wet conditions the water table rises above the dune slacks to create ponding. The cross sections show also how the groundwater is mounded beneath the Burrows, indicative of direct rainfall recharge and seepage discharge around the periphery of the sand aquifer to the foreshore to the west and to the West Boundary Drain (west of the agricultural zone) to the east. To north and south, the groundwater ridge drains towards the Golf Course and the foreshore along the Torridge estuary respectively. As each of the piezometers is located in a slack to minimise auger lengths to the water table, the wet and dry situations indicate an annual range of about 1.5 to 2.0 m, from a flooded slack situation, usually about 0.5 m deep, to a water table some 1.5 to 2.0 m below the slack itself.

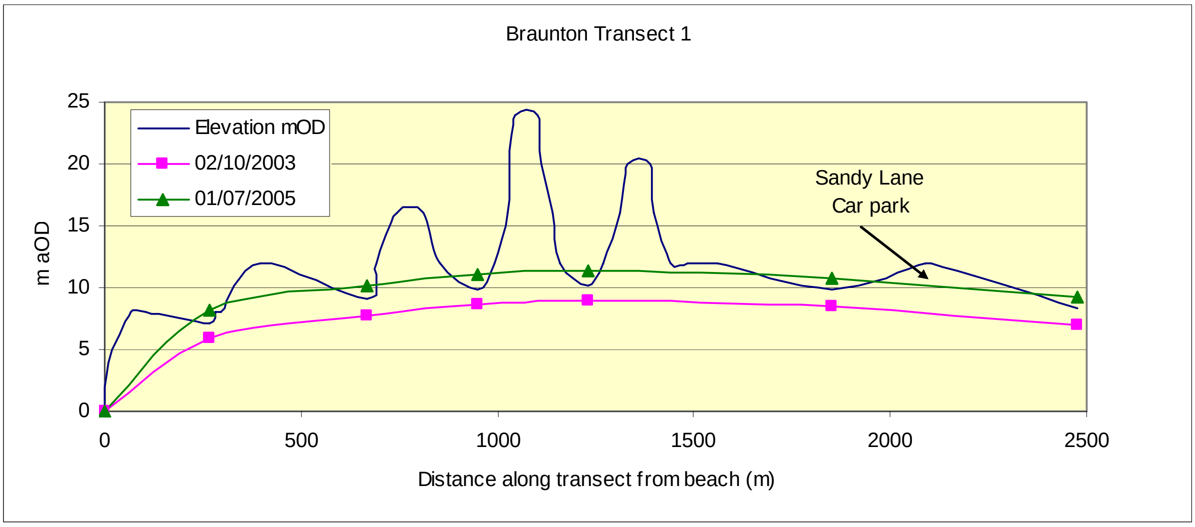

Figure 10 Cross-section Braunton Transect 1.

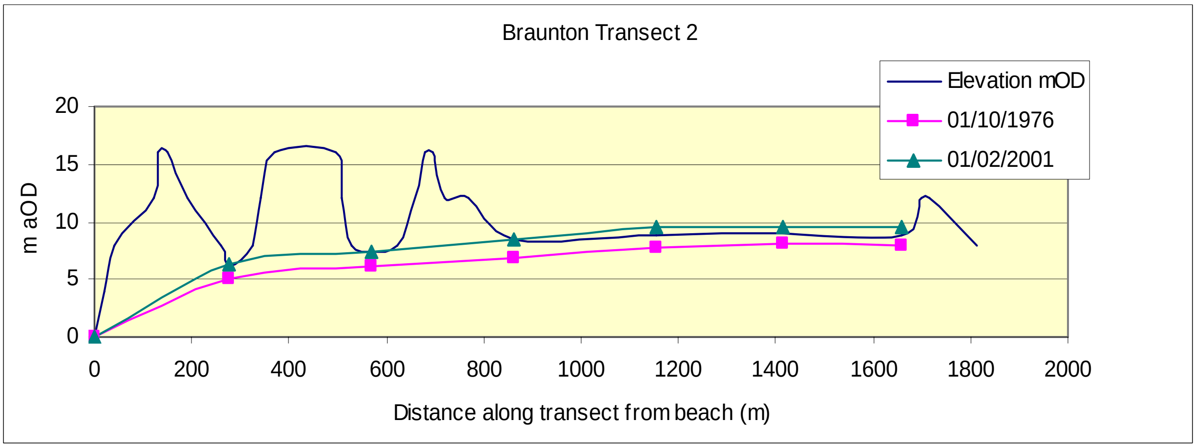

Figure 11 Cross-section Braunton Transect 2.

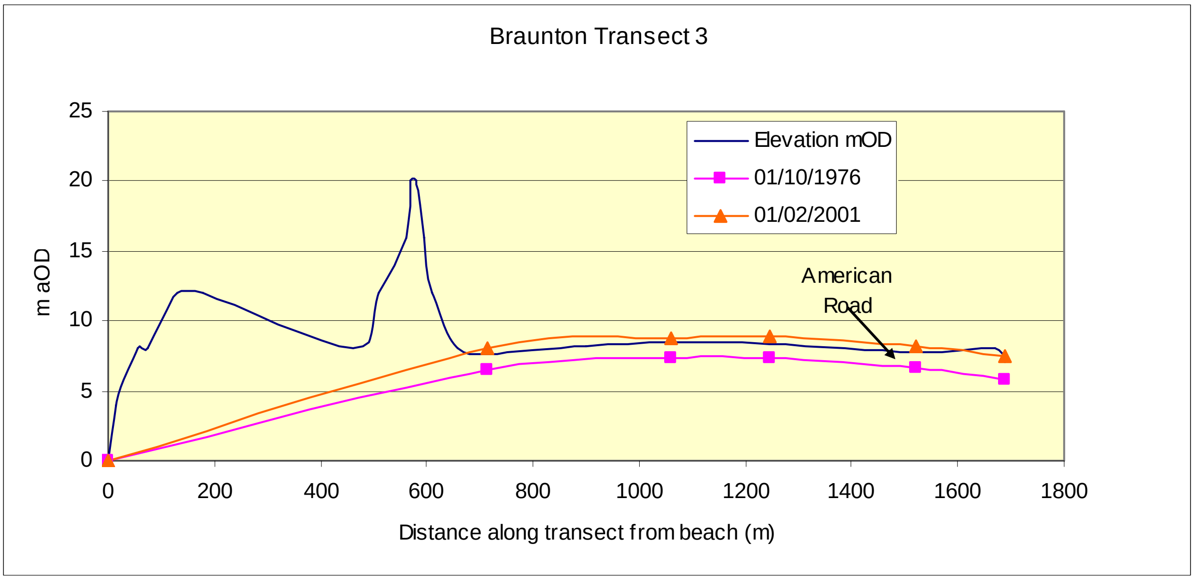

Figure 12 Cross-section Braunton Transect 3.

Taking Borehole 3 in transect 2 as typical of the central area of the Burrows, the average water level recorded for each month over the complete period of monitoring is shown in Figure 14. This shows that the lowest water level centres on the month of August, with slow recovery through September and October continuing to February when recession again sets in.

Comparison of a typical wet year with a typical dry year is shown in Figure 14 again using Borehole 3 as an example. The greatest disparity occurred in the month of July when the difference between these two years amounted 1.25 m, the least difference was in May and June when it was approaching only 0.3 m.

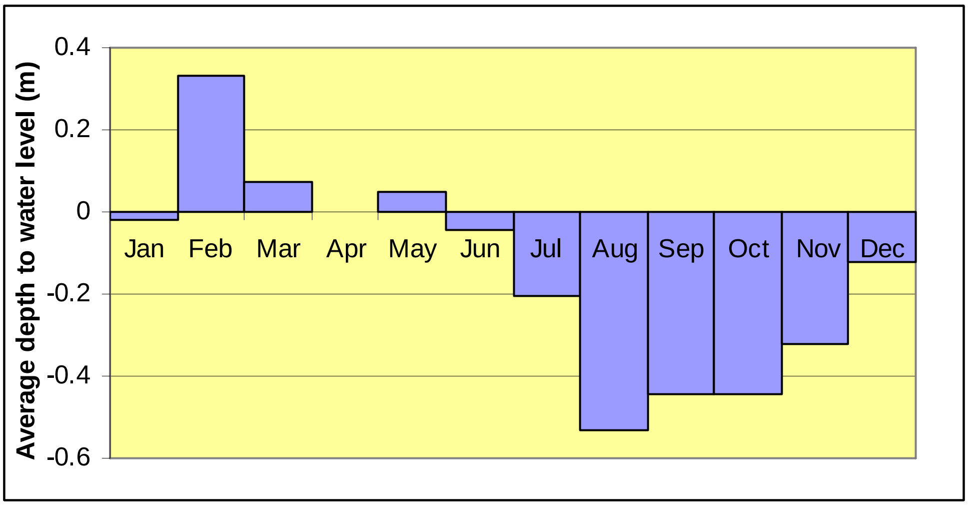

Figure 13 Average water level for each month of the year during the overall monitoring period in Borehole 3, Transect 2 (0 m depth is ground level) Cross-section Braunton Transect 3.

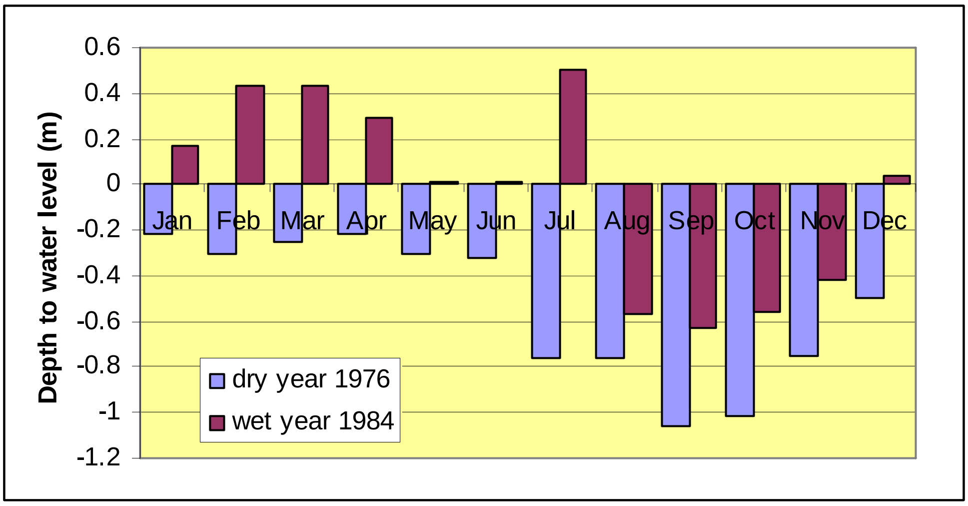

Figure 14 Extremes of water level above and below ground level for the dry year 1976 and wet year 1984 in Borehole 3, transect 2.

3 The Groundwater System

The groundwater levels from the three transects indicate that there is a broad groundwater divide centred along a line about 500 m west of the American Road between Transects 2 and 3 but which swings westwards through Transect 1 towards Saunton in the north (Figure 15). This suggests that under natural drainage conditions the Burrows drain largely towards the west and the coast, discharging as the fresh to brackish water that issues from the foreshore at low tide. Only a small area of the Burrows naturally drains to the east towards Braunton Marsh and the West Boundary Drain as the sands thin towards the alluvium and the permeability of the medium is greatly reduced. The diversion of the groundwater divide to the west towards Saunton reflects land drainage in the fields north of Sandy Lane Car Park and the Golf Course. Local supply boreholes draw from confined water in the Pilton Shale, i.e. are not in hydraulic contact with the sand aquifer (Table 2). The effect of the West Boundary Drain on the dune sands is local because the drain lies within the alluvium throughout its length, and the alluvium is significantly less transmissive than the sand.

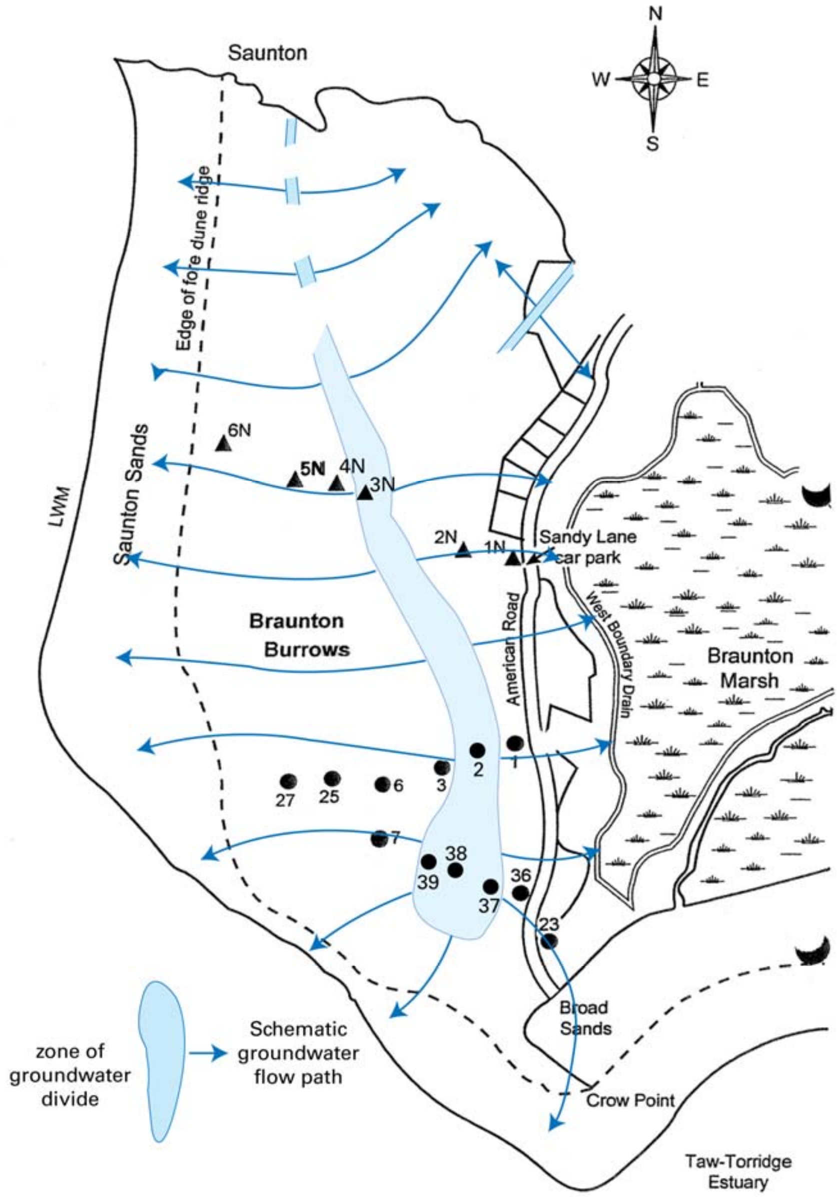

Figure 15 Conceptual groundwater flow model.

The LTA water balance for the Burrows derives from the LTA effective annual rainfall of 478.6 mm. This input is balanced by discharge along the foreshore and drainage to the West Boundary Drain. In addition a small component of the effective rainfall is lost as open water evaporation from perennial ponds and to evapotranspiration to the deeper rooted trees and scrub vegetation that are present in the Burrows area. Collectively these losses are unlikely to be a significant amount of the effective rainfall input.

Measurement of the water level in piezometer 6N at ten minute intervals during a spring tide showed no effect from the sea tide (Burden, 1998). The water level in piezometer 6N, which is only 250 m from the dune front, rarely falls below 6 m aOD. This illustrates how the mounded water table falls to the foreshore to an almost common datum somewhere about mean sea water level. The diurnal rise and fall of the tide only affects the water table nearest the dune front and probably then only for a few tens of metres inland.

In creating cross sections of the water table along the three transects, it is assumed that there is a consistent hydraulic relationship between the high dune areas and beneath the dune slacks. This may not be the case as the hydraulic conductivity of the dune slack floors and the material beneath the floors is lower than that in the high dune areas, and it is likely that the water table beneath the high dunes will not necessarily always be higher than in the slack areas, e.g. during the onset of rain following a long dry period. This hypothesis remains to be tested.

The available time series data do not allow 'joining up' of water level contours throughout the whole of the dune area (c.f. Burden, 1998). However, this could be done efficiently with assistance from geophysical surveying such as ground penetrating radar although additional piezometers through the high dunes would provide useful additional monitoring points.

Table 2 Local water supply boreholes

Number	**NGR**	**Supply**	**Year drilled**	**Depth (m)**	**Depth to bedrock (m)**	**Yield ($l\ s^{-1}$)**	**Specific capacity ($l\ s^{-1}\ m^{-1}$)**
SS43/4	SS46483748	Hotel	1927	24.4	8.2	1.8*	
SS43/5	SS46523745	Hotel	1937	11.4	8.2	1.0*	
SS43/6	SS46483748	Abandoned	1936	125.0	0	0	
SS43/16	SS46503750	Golf Club	1988	62.5	19.2	0.6*	0.03
SS43/9	SS46933554	Airfield	1942	16.6	10.8	1.1	0.12

*Overflowing when drilled

4 Changes with time

The anecdotal evidence for the drying out of the Burrows and the increasingly infrequent flooding of the dune slacks is convincing. The recorded changes in groundwater level within the dunes show an overall decline in level of about 0.5 m since 1966 which reflects a reduction in effective rainfall of about 5% over the same period (see Figure 5). This decline may be exacerbated by land drainage, coastal erosion of the seaward dune face and increases in evapotranspiration but these are likely to be modest influences compared to the overall decline in rainfall. Further anecdotal evidence suggests that the beach level, particularly at the Saunton end, is dropping, and this may accelerate the recession of the dune face.

In 1992 it was estimated that 12% of the 1350 ha dune system had been inundated by scrub vegetation (Burden, 1998), increased in 2007 to about 20% (Breeds, personal communication). However, during the latter half of the 1990s rainfall was temporarily increasing year by year, scrub coverage was increasing as well and yet groundwater levels were rising (Figure 5). From 2000 onwards annual rainfall was declining, scrub cover continued to expand and groundwater levels declined. This suggests that it is effective rainfall that is the controlling influence on groundwater levels with a possible minor input from the increased scrub cover. However, the majority of the scrub is in the high dunes, where roots may be above available moisture in the unsaturated zone, unlike Newborough Warren on Anglesey which was part planted with Pinus nigra var. laricio trees between 1948 and 1965 and which have affected an increased draw on the water budget (Stratford et al., 2006).

A number of ponds have been developed in the dunes to support wildlife. These tend to dry out when the water table falls. They effect a small groundwater sink when flooded but as this is normally in the winter months, overall loss of groundwater by open water evaporation is likely to be small.

Climate variability may continue to develop a reduction in rainfall input and a marginal increase in actual evaporation. This will in turn effect a further reduction in groundwater recharge so that the overall water table beneath the Burrows may likely continue to decline. This may induce further changes in vegetative cover particularly around the dune slacks. However, potential sea level rise will elevate the base level of the system offering a counter to the decline in the water table. These scenarios can best be explored through the development of a groundwater flow model, developed once additional areal data are available for the water table configuration beneath the high dunes and away from the dune slacks.

5 Conclusions and recommendations

The decline in groundwater levels beneath the dune system reflects a real reduction in the LTA annual effective rainfall. Other influences may exacerbate the decline in levels but these, collectively, are small. Projected changes in rainfall and evaporation with time suggest that the situation is unlikely to recover in the long term. A groundwater model should be constructed incorporating the available historical data which would allow predictive runs to be made to determine the groundwater levels with a further reduction in effective rainfall of say 5, 10 and 20%. These would allow prognoses of the regularity of dune slack flooding and the normal depth to water between the dune slacks. This in turn may enable management of the vegetation so that a preferred ecosystem can be maintained. The model would also allow investigation of increased scrub vegetation, land drainage and coastal erosion to be investigated.

Data would need to be acquired using ground penetrating radar to develop the overall water table topography at dry and wet periods. In addition gauging of the West Boundary Drain (at both ends as it leaves the dune area) through a twelve month period would provide valuable data which could determine the dependence on flow from the dune groundwater. These requirements, along with the modelling exercise, could be fulfilled at a cost of several tens of thousand of pounds at current prices. Details of the actual drainage system and the precise groundwater abstraction regime at the Golf Club would also be required.

The Braunton dataset is extremely valuable in showing the base level data for the period 1966 to 1991 and the subsequent response to reduced, then increased and now much reduced input of effective rainfall. It is essential that the monthly monitoring continues so that Braunton can be used to evaluate the effects of climate variability on rain fed coastal dunes in the UK. Consideration should be made of how best to manage the vegetation in the dune slacks in a drier environment than the past. It is noted that a 5% decline in effective rainfall parallels the significant observed drop in groundwater level of up to 0.5 m in 40 years. Should climate vagaries achieve a 20% decline in long term average rainfall, what then, and in this case how should the dunes and slacks best be managed?

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

Burden R J 1998 A hydrological investigation of three Devon sand dune systems: Braunton Burrows, Northam Burrows and Dawlish Warren. Unpublished PhD Thesis, University of Plymouth.

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Appendix 1

The CD attached to this report contains the following files and a copy of this Appendix labelled 'read me':

1. ALL_DATA.xls

There are three tabs in this EXCEL file:

All data is the assembled digitised data with original field codes for all piezometers at Braunton Burrows including those that were abandoned in 1991.

All data mod is the same data with the field codes converted to an appropriate digit or the cell is left blank.

Mod m is the data set converted to m above OD for those boreholes for which a datum has been established. These modified data are located at the bottom of the field data set.

2. Graphs to OD.xls

There are three tabs in this EXCEL file:

Data OD contains the water level data with respect to OD

Sections contains the cross sections

Rainfall contains the rainfall chart

3. BH3 Monthly WL analysis.xls

There is one tab *BH3* in this EXCEL file.

This contains the data and manipulation to achieve report figures 13 and 14.

4. BGS Report CR/07/072N

There is one document in this ADOBE file.