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THE WATER BALANCE OF THE SAND CLAY AREAS, HOLDERNESS PLAIN, KINGSTON UPON HULL, ENGLAND

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ABSTRACT: *Direct confirmation of the external sources was sought, and an indirect attempt to quantify it was made, via the water balance calculations analyses and discussion. Water balance components were calculated for the two sub-catchments at Great Hatfield and South Field as well as for the entire Catchwater Drain catchment. These water balance analyses showed that the predominant low flow contributions to total stream flow during dry weather periods, came from the sandy deposits in the Great Hatfield area, and that these contributions were able to sustain stream flow during dry weather periods, especially in July, August and September. However, the observed low flow contributions greatly exceeded the water balance estimates of low flow over the two dry periods of 1987 and 1988. Also, the observed runoff at the outlet of the Catchwater Drain catchment in dry periods, which analyses of channel flow conditions and measurements of discharge showed came from the sandy areas at Great Hatfield, was much higher than the runoff estimated from the water balance for all the sandy areas combined. In this way both the existence and the scale of the external source of low flow from the sandy areas were confirmed. Furthermore, it seemed reasonable to infer, from the water balance analyses, that the external source occurred at some depth below the Catchwater drain catchment and was probably the underlying Chalk aquifer.*

KEYWORDS: Water Balance, Sand Clay, Holderness Plain, Kingston, Hull, England

INTRODUCTION

Various attempts have been made in the past to check Water balance of the entire Catchwater Drain experimental catchment (c.f. Ward,1972; Pegg, 1974; Tang and Ward, 1982) These Water balance calculations have been largely concerned with demonstrating that over a period of time measured catchment precipitation can be accounted for by the measured outflows of water from the catchment via stream flow and evaporation. All have shown that, in these general terms, the Catchwater Drain catchment is broadly in hydrological balance. However, only very limited attempts have been made by previous workers to address specifically the water balance issues. These were first, that the sand and gravel areas of the catchment contribute a disproportionately large percentage of the stream flow (i.e. base flow) leaving the catchment in dry weather conditions and second, that the total volume of base flow leaving the sand and gravel areas exceeds the amount apparently available from a conventional solution of the water balance equation for these areas, i.e. a solution in which precipitation is accounted for solely by stream flow, evaporation and storage changes.

The first of these issues was addressed Where it was shown that in low flow conditions the sand and gravel areas sustain flow for much longer and at significantly higher discharges than do the clay areas of the catchment. The second of these issues is addressed by means of specific water balance calculations for the Great Hatfield sandy sub-catchment and for the South Field sub-catchment.

Components of the water balance.

The simple water balance equation for a catchment may be stated as:

Inflow = outflow ± change in storage --------------------------(1)

Inflow into the catchment is in the form of precipitation, and outflow is stream flow and evaporation. Changes in storage are frequently subdivided into surface retention, soil water and ground water storage. Given the agricultural land-use and extensive tile drainage of the Catchwater Drain catchment, changes in surface retention and soil water storage are almost inseparable. There are very few ponds and in spite of the impermeable nature of much of the area, the upper layers of the soil are broken up by agriculture. Accordingly, Pegg (1974) suggested that changes in surface retention are probably reflected in changes in soil water content.

The water balance equation for the Catchwater Drain catchment may therefore be stated more fully as:

$P = Q + E \pm \Delta\, GW \pm \Delta\, SM$ ----------------------------(2)

Where P is total precipitation on the catchment, Q is total stream discharge at the outlet of the catchment, E is total evaporation, $\Delta\, SM$ is change in soil water storage, and $\Delta\, GW$ is change in ground water storage.

This equation can be applied to different areas and for different periods of time and to some extent the precision of measurements will be conditioned by both spatial and temporal scales. For example, when long term water budgets are being examined, changes in storage can frequently be ignored completely (c.f. Pegg 1974; Beven and O'Connell, 1983). On the other hand, if short periods are being examined then detailed measurements must be made of as many variables as possible.

This may create a number of difficulties since some variables can be quantified more easily than others, e.g. discharge and precipitation can usually be measured more accurately than evaporation or changes in storage. Although attempts to evaluate catchment-scale actual evaporation are comparatively rare, data on this component for the present work were derived largely from the output of a catchment hydrological model described by Ward (1985). This model uses a simple water balance accounting procedure to calculate inter alia actual evaporation for the slopes and bottom-land areas of the catchment and has been tested both in the catchment and at the Institute of Hydrology.

Quite apart from the problems of interpreting ground water level data. The use of such data to quantify changes in ground water storage is also a much-debated issue (Johansson 1987). Although qualitative analyses from ground water networks have been made there have been few quantitative studies (Olsson, 1980; Sandberg ,1982; Bergstrom and Sandberg, 1983; Soveri, 1985) in which ground water level have been directly transformed into equivalent changes in ground water storage.

Zaltsberg (1987) estimated the ground water contribution to stream flow in a small glacial till watershed in Manitoba using ground water depletion curves. The seasonal and annual ground water balances were calculated using water table fluctuations in two or more observation wells (c.f. also Zaltsberg, 1983) and similar studies have been conducted by many other workers (c.f. Jacobson and Jankowski, 1989; Jacobson, 1988 and Lundin, 1982).

ln the present work ground water storage change was obtained by multiplying the change in water level in the wells in the Great Hatfield sand transect and the South Field clay transect by percentage porosity. In an attempt to estimate the total quantity of ground water present in each type of deposit percentage porosity was assumed to have a value of 0.40 for sand and of 0.50 for clay (Davis and Dewiest, 1966).

The sub-catchment water balances.

Before applying the water balance equation (2) to data from both the sand/gravel and clay sub-catchments, the sub-catchment areas were calculated and also the precise locations of the sandy and gravelly materials were defined. The water balance was calculated for monthly intervals over the two dry periods of 1987 and 1988 for both the great Hatfield and South Field sub-catchments. In addition, the dry weather period water balance was calculated for the Great Hatfield sandy area for the years from 1968 to 1988 and the estimated discharges obtained were compared with measurements of steam flow at the outlet of the Catchwater Drain catchment.

The south field sub-catchment

The water balance data for the clay sub-catchment at south field are set out in table 1 and show relatively close agreement between estimated and measured values of stream flow. Where there are discrepancies between the observed stream flow values and those estimated by using the water balance equation 2, the observed values are always less than the estimated values, especially over the period between July and September, 1988. This may indicate that the heavy soil and subsoil materials in this sub-catchment not only have a lower volume of stored sub-surface water in the summer months, due to rapid lateral flow during the water part of the year which is accentuated by the ploughed layer, tile and mole drainage and clay pan development), but also drain more slowly because of higher soul water retention forces. As a result, their contribution, if any, to low flow was very low during the drier summer period of the year and resulted in the stream channels becoming dry, especially between the beginning of July and mid-October, and in dry water years up to mid-November, as shown by the drainage channel surveys.

The Great Hatfield sub- catchment.

The results obtained for the Great Hatfield sub-catchment are shown in Table 2. From these it may be seen that during the two dry periods in 1987 and 1988, the measured monthly low flow draining from this sub- catchment (0.101 sq. km) was significantly higher than the monthly discharge estimated from the water balance.

These results appear to confirm some of the findings of earlier workers in the Catchwater Drain catchment. For example, Pegg (1974) found in a study of the water balance from 1966 to 1968 that sufficient water was released from the sands and gravels to maintain relatively high levels of base flow, while little water was released from the heavier clays during the summer periods. Again, Oyebande (1972) showed that from 1966 to 1971, more than 70 percent of the total catchment stream flow in September and October came from the sandy areas of Great Hatfield.

The total surface area of all the sand bodies in the vicinity Great Hatfield, including the Great Hatfield sub-catchment itself, is 0.6775 sq. km, i.e. more than six times larger than the sub-

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catchment alone. Table 3 sets out the dry period water balance results for this extended area and shows that the estimated runoff was relatively consistent from year to year, compared with the actual, observed runoff from the entire Catchwater Drain catchment. As proportion of the latter, therefore, it varied considerably, reaching values in excess of 15 percent in seven of the 19 years for which data are available and in excess of 10 per cent in a further six years.

There are perhaps three particularly significant points to emerge from these water balance calculations. First, in total the sandy areas around Great Hatfield contribute an estimated dry weather stream flow which is often three to five times greater than their area (1ess than 4.5% of the total Catchwater Drain catchment) would initially appear to suggest. Secondly, this relatively high contribution is made at a time when the contribution from the clay areas of the Catchwater Drain catchment is either small or non- existent. And thirdly, as the comparisons in Tables 1 and 2 indicate, the low flow contribution from the sandy areas, which is estimated from water balance equation 2, is substantially smaller than the actual low flows leaving these sandy areas during the April- September period each year. This is especially true in the mid- to late summer months when estimated values are usually about 30 per cent of observed values. The actual low flow

Table 1 Dry period monthly water balance components and estimated and observed discharge, South Field sub- catchment, 1987-1988.

Period	(1) P m^3	(2) ΔG m^3	(3) ΔS m^3	(4) E m^3	(5) Q_{est} m^3	(6) Q_{obs} m^3	(7) (5)/(6) %
Jul 1987	10512	-5184	-14112	16992	115	30	380
Aug	16445	-6048	+1152	21053	289	236	123
Sep	11088	-8208	-1238	20304	230	134	172
Apr 1988	10800	-4752	-2880	16934	1498	1432	105
May	6278	+1584	-10656	13622	1728	1670	104
Jun	7488	-864	-7200	14688	864	805	107
Jul	18432	-9648	-1440	29376	144	51	281
Aug	12902	-5322	-1411	19555	80	0.0	—
Sep	8122	-4608	-4320	16963	86	0.0	—

Table 2 Dry period monthly water balance components and estimated and observed discharge, Great Hatfield sub-catchment, 1987-1988.

Period	(1) P m^3	(2) ΔG m^3	(3) ΔS m^3	(4) E m^3	(5) Q_{est} m^3	(6) Q_{obs} m^3	(7) (5)/(6) %
Jul 1987	3616	-2060	-495	5959	212	1030	21
Aug	6050	-2060	+404	7383	323	1124	29
Sep	5979	-1050	-434	7100	343	1188	29
Apr 1988	2828	-4727	-1010	5939	2626	4119	64
May	3737	-121	-3737	4777	2709	5557	49
Jun	3636	-1374	-2525	5151	2384	4988	48
Jul	8787	-2020	-505	10302	1010	1482	68
Aug	5272	-1252	-495	6858	162	550	29
Sep	3656	-929	-1515	5949	152	477	32

contribution from the sandy areas is therefore significantly higher (e.g. often by a factor of at least 10 to 15) than would be the case if all areas of the catchment contributed uniformly to stream flow during the summer of the year.

Topographical analysis, using contours, spot heights and field observation, confirms that there is no higher ground either within or immediately adjacent to the superficial catchment of the Catchwater Drain from which this large excess of base flow could drain. Furthermore, hydrogeological analysis by Bonell (1971), which involved installing numerous observation wells on both sides of the topographical divide of the Catchwater Drain catchment in the vicinity of Great Hatfield, demonstrated that there is no basis for postulating horizontal flow or leakage across the divide, either at the surface or at shallow depths below it.

It may therefore be concluded from the water balance data presented in this study that the predominant low flow contributions to total stream flow during dry weather periods, came from the sandy deposits in the Great Hatfield area, and that these contributions were able to sustain stream flow during dry weather periods, especially in July, August and September. However, the observed low flow contributions greatly exceeded the water balance estimates of low flow over the two dry periods of 1987 and 1988. Also, The observed runoff at the outlet of the Catchment Drain catchment in dry periods, which earlier analyses of channel flow conditions and measurements of discharge showed came from the sandy area at Great Hatfield, was much higher than the runoff estimated from the water balance for all the sandy areas combined. It seems reasonable to infer therefore that the low flow contribution from these sandy areas must have come from a deeper underlying source.

That the Chalk aquifer beneath Holderness is the likely source of this additional base flow has already emerged from the above discussion of a variety of hydrological evidence.

Table 3 Dry period annual water balance components and estimated discharge, Great Hatfield sandy area, and observed discharge, Catchwater Drain catchment, 1968-1988.

Period	(1) P m^3	(2) ΔG m^3	(3) ΔS m^3	(4) E m^3	(5) Q_{est} m^3	(6) Q_{obs} m^3	(7) (5)/(6) %
1968	268966	-173711	+12940	233060	1.97×10^5	8.88×10^5	22
1969	—	—	—	—	—	—	—
1970	195796	-105419	-29675	263548	6.73×10^4	5.43×10^5	12
1971	187666	-89159	-15515	231705	6.06×10^4	3.60×10^5	17
1972	159890	-111110	-29471	227640	7.26×10^4	3.35×10^5	22
1973	255417	-25474	+10976	226963	4.30×10^4	4.21×10^5	10
1974	223575	-56097	+5014	256773	1.79×10^4	2.75×10^5	7
1975	147695	-121137	-21816	200540	9.01×10^4	8.37×10^5	11
1976	166665	-132790	-5014	281840	2.26×10^4	8.38×10^4	27
1977	157180	-102709	-31775	215445	7.62×10^4	5.53×10^5	14
1978	201895	-95257	-26558	235093	8.86×10^4	7.76×10^5	11
1979	—	—	—	—	—	—	—
1980	226285	-13821	-23713	218833	4.50×10^4	5.97×10^5	8
1981	202573	-83468	-49458	203250	1.32×10^5	9.59×10^5	14
1982	209348	-62872	-13550	265580	2.02×10^4	2.78×10^5	7
1983	225608	-28184	-47425	223575	7.76×10^4	1.55×10^5	5
1984	189700	-135500	-14228	271000	6.84×10^4	3.46×10^5	20
1985	246610	-50677	-44038	264225	7.71×10^4	1.23×10^6	6
1986	195798	-62601	-56910	243900	7.08×10^4	1.34×10^6	5
1987	218833	-82113	-47425	241868	1.07×10^5	5.93×10^5	18
1988	169375	-71002	-65650	261447	4.46×10^4	2.93×10^5	15

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