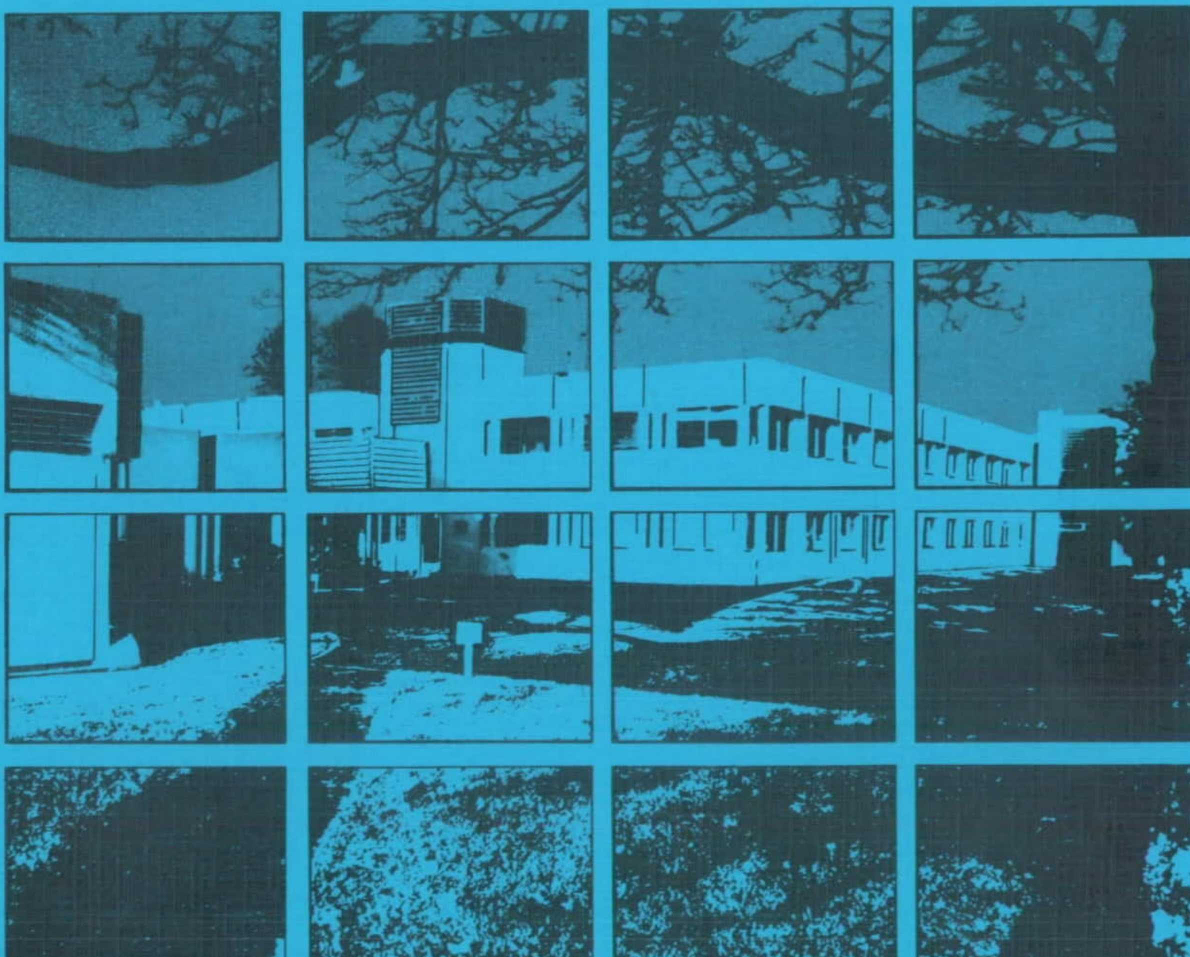
INSTITUTE of HYDROLOGY

The instrumentation of flat low-lying catchments for hydrological research



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The instrumentation of flat low-lying catchments for hydrological research

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Abstract

Much less information is available on the instrumentation of flat low-lying catchments than areas of high relief. It is hoped that this report goes some way to redress the balance. As well as detailing experience acquired in the instrumentation of the Institute's three experimental catchments, this text anticipates additional problems. This report deals with the collection of data; the results of these experiments will be published subsequently.

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Preface

This report contains a detailed account of techniques employed in instrumenting three flat catchments which were the subject of IH commissioned research during the 1980s. Some comments on the extrapolation of the approach to other low-lying catchments are included.

Although not primarily concerned with finance, some equipment costs are included where it is felt that these will be useful. Prices quoted are current at the time of writing (1988).

Research on two of the catchments (Newborough Fen and Boy Grift) was carried out on behalf of the Ministry of Agriculture, Fisheries and Food (MAFF), while that on the third (West Sedgemoor) was commissioned jointly by the Nature Conservancy Council (NCC) and Wessex Water Authority (WWA).

1. Introduction

1.1 LOW-LYING LAND

There are upwards of 9000 km^2 of flat land in England lying below mean sea level. In addition to needing coastal protection, the natural gradient of this land is insufficient to allow runoff to drain under gravity during periods of low tide. The only solution is artificial drainage and the area is served by over 600 pumping stations. The Lincolnshire and East Anglian fens account for the greater part of this area and are served by 368 pumping stations. Other significant areas, with the number of pumping stations given in brackets, are Somerset (15), Humberside (143), Lancashire (14) and Kent and Sussex (60). The pumping stations and their associated drainage channels are usually administered by Regional Water Authorities (RWAs) or Internal Drainage Boards (IDBs). It is usual for the responsibility for a given pumped catchment to be shared between a RWA and an IDB. A few very small pumping stations are owned and operated by farmers or other private individuals.

The majority of the drained land is used for agriculture. The East Anglian fens in particular are regarded as valuable arable land. It follows that the acceptable limits on the water level in the artificially created drains are well defined. Apart from preventing out-of-bank flows during periods of high runoff, there is often a need to ensure minimum water levels during a growing season.

The factors influencing the efficiency with which the drain water levels are controlled are many. The extent and configuration of the drainage network conveying water to a pumping station is a principal consideration. The operating policy employed at the pumping station is as important as the type and condition of the pumps. The way in which the drain system and pumping station interact has to be understood in order to be able to design the system as a single entity.

The information required to achieve this understanding is the subject of this report. As well as describing the approach to the data collection, the report details the practical problems encountered. Some examples of the data are presented to illustrate the way in which drain levels respond to rainfall and, in turn, how pumps respond to drain levels.

1.2 INSTRUMENTED CATCHMENTS

Figure 1.1 shows the location of the three experimental catchments. Newborough Fen was instrumented during 1979-1985 and Boy Grift during 1986-1989. West Sedgemoor was instrumented in 1986 and is ongoing at February 1989.

Figure 1.1 Location map of the instrumented catchments

Figure 1.2 shows Newborough Fen, situated 8 km north of Peterborough, which drains 33.2 km^2 of Cambridgeshire, all of which is flat terrain typically 2 - 3 m AOD (Figure 1.2). The catchment drains to a point on its north-west boundary (grid ref. TF215091) where an automatic electrical pumping station discharges runoff to the River Welland. Drainage has been delegated by the Anglian Water Authority to the North Level Internal Drainage Board (NLIDB) under an agency agreement. Land use is almost exclusively agricultural, main crops being sugar beet and wheat.

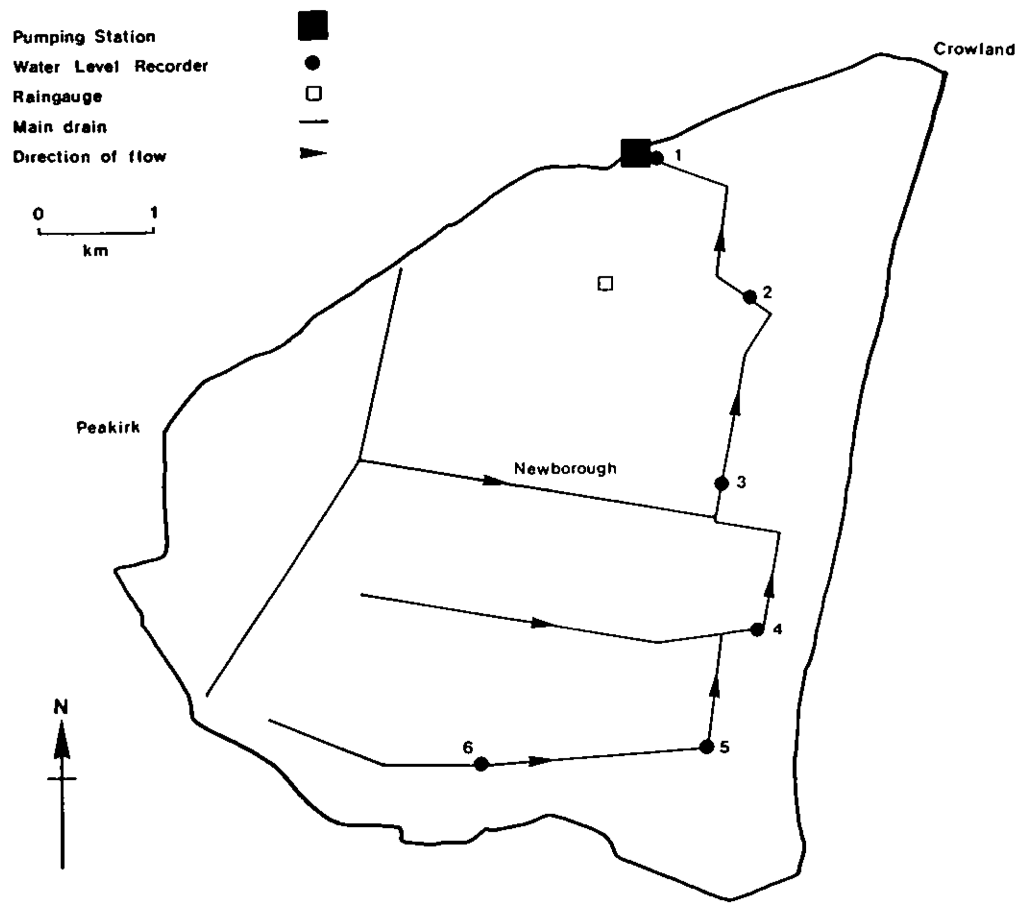

Figure 1.2 Newborough Fen

Figure 1.3 shows Boy Grift, a linear catchment of 21.1 km^2 in Lincolnshire. It rises at Ulceby Cross on the south-east slopes of the Lincolnshire Wolds and drains in a north-easterly direction, passing close to the town of Alford, to an automatic electrical pumping station on the coast 6 km south of Mablethorpe (grid ref. TF533799). Responsibility for catchment drainage is shared between the Anglian Water Authority (AWA) and the Alford Drainage Board (ADB). Ulceby Cross at the south-west end of the catchment is 95 m AOD and approximately a third of the catchment is above 10 m AOD. This upper part of the catchment is partially wooded, contains two seasonally spring-fed lakes and is subject to mixed agricultural use; the remainder is predominantly arable. The lower part of the catchment is 2 - 3 m AOD and is protected by coastal defences. There is a negligible urban component.

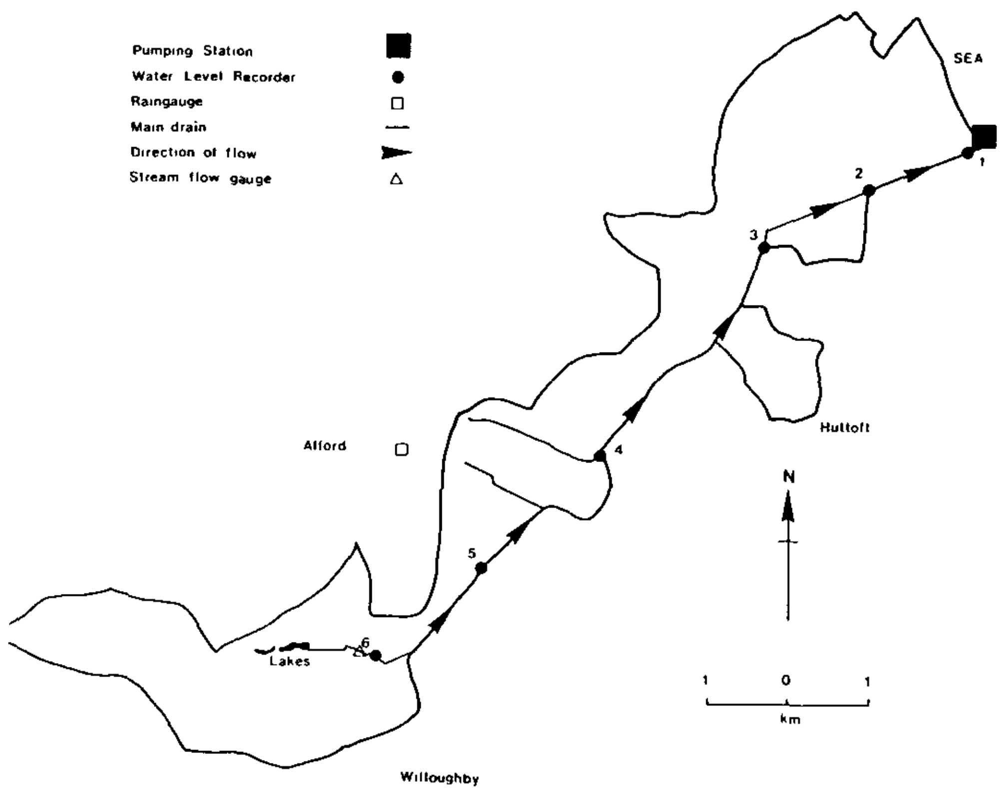

Figure 1.3 Boy Grift

Figure 1.4 shows West Sedgemoor, a rectangular-shaped catchment of 44.5 km^2, 13 km to the east of Taunton in Somerset. The moor itself is a flat area of 13 km^2, about 5 m AOD, which is surrounded on all but its north-east boundary by land rising to a maximum of 80 m AOD. Runoff drains from the surrounding highland onto and through the moor, to a pumping station (grid ref. ST376286) which delivers into the River Parrett. Wessex Water Authority are responsible for drainage and the operation of the pumping station, which is a combined (manual) diesel and (automatic) electric unit on a single site. Land use is predominantly summer grazing, some hay/silage generation and in places withy beds (young willow saplings). The moor has been designated an 'environmentally sensitive area'. Apart from farms and small villages on the edge of the moor, there is no urban development.

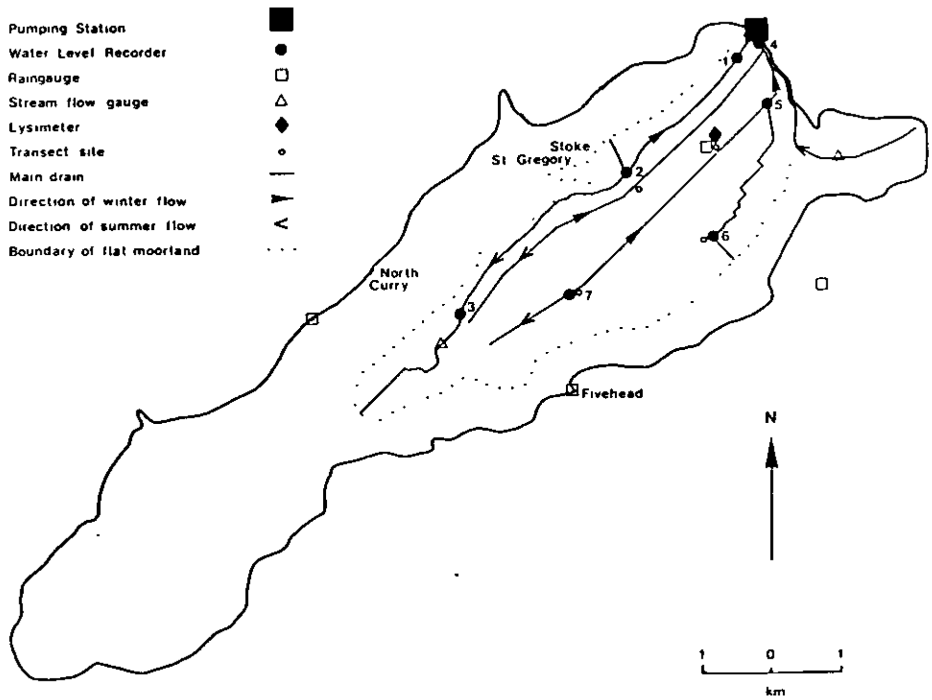

Figure 1.4 West Sedgemoor

1.3 DATA AVAILABILITY

It may be possible to make use of existing data originating from a variety of different sources in addition to that generated by instrumenting the catchment. Land level, water level and rainfall are examples.

Section 2 discusses in more detail the availability of existing data and Section 3 contains suggestions for an initial site investigation; Section 4 covers surveys. Sections 5 - 10 outline how equipment can be implemented to collect the main data types. Sections 11 - 13 give examples of some of the problems most likely to be encountered, and Section 14 illustrates some of the data collected on the three research catchments. Section 15 deals with vandalism.

2. Existing data

2.1 WATER LEVEL DATA

Most flat, lowland catchments will have some existing data, although these may be difficult to locate. Significant bridges usually have staff gauges attached to them; a drainage worker records the water level, certainly at times of flood and perhaps as part of a daily routine. Conventional streamflow gauging stations cannot be constructed in fen areas because of the problems associated with generating measurable head differences in flat terrain.

2.2 RAINFALL DATA

Rainfall data can be used if the gauge is sited either on the catchment or on similar terrain nearby. Raingauges sited very close to the catchment but on higher land will usually record a higher rainfall. The best use that can be made of such a record is in a correlation exercise with a short period raingauge implemented on the site of interest. In West Sedgemoor, the raingauge on the moor was found to return rainfall totals 10% less than those sited nearby but at a higher altitude. Tables 2.1 and 2.2 illustrate the difference between rainfall at West Sedgemoor pumping station and the surrounding land during 1987.

Table 2.1 Monthly rainfall depths (mm), 1987

	J	F	M	A	M	J	J	A	S	O	N	D	Total
West Sedgemoor P.S	**14**	**39**	**35**	**49**	**22**	**52**	**35**	**22**	**33**	**128**	**54**	**29**	**512**
Curry Rivel	12	51	49	46	26	66	30	29	31	143	56	36	575
Fivehead	13	46	42	47	24	61	42	31	31	137	52	35	561
North Curry	11	47	56	60	23	62	29	23	34	142	53	41	581

Table 2.2 Raingauge details

	Altitude (m AOD)	Distance from West Sedgemoor P.S (km)
West Sedgemoor P.S	**8**	**-**
Curry Rivel	55	3.76
Fivehead	67	5.77
North Curry	54	7.63

2.3 LAND LEVEL DATA

Historical land level movement can be detected through the periodic levelling of Ordnance Survey bench marks. Some care needs to be taken in this approach. Bench marks sited on churches or other heavy buildings may sink to a greater extent than the surrounding land, due to the weight of the structure. Triangulation pillars are not sited on lowlands, so the best bench marks to use are those on small bridges or other comparatively light structures.

2.4 PUMPING STATION DATA

Except for the very smallest pumping stations, there are almost always some records available of their operation. The information will usually be of interest to the operating authority, rather than to the hydrologist. Unfortunately the data are not always treated with the respect they deserve, sometimes being thrown away after a time or lost in an office move during a reorganisation of the operating authority. Occasionally they are left to gather dust, oil and water in a cupboard in the pumping station itself or, more confusingly, in a different one.

Data from electrically driven pumps may be recorded in a variety of ways. The cumulative number of hours that a pump has been operated may have been recorded at intervals. Other data types are power consumption (sometimes recorded in such a way that it is possible to tell, in a multi-pump station, how many pumps are operating) and intake-side water level (often used to trigger pump operation). Power data are especially useful when recorded on a chart so that it is possible to identify the exact periods of pump operation, much less so when they appear in the form of quarterly electricity bills.

Diesel pumping stations are nowadays less common. They require manual intervention to start and stop the pumps and supervision while they are running. Operational data recorded may include the on/off water levels in the suction and discharge watercourses, the volume of oil consumed and the less useful 'number of hours since greasing'. However, the periods of operation are usually recorded more accurately than for electrical pumps. A problem with diesel pumps is that they are sometimes fitted with a throttle valve to allow the operator to pump at a rate significantly below the design rate for the pump. A record is not always made of the periods during which this is done.

When calculating the amount of water pumped it will usually be necessary to obtain, from the pump manufacturer, the appropriate pump 'characteristic curve'. First the static head is computed; this is the difference between the water levels in the pump sump and the receiving watercourse. If the pump characteristic curve is given in terms of total rather than static head, then all the energy losses due to the intake point, pipe bends, pipe wall friction etc, should be calculated and added to the static head. If the water level on the discharge side of the pumping station is not recorded, it will have to be estimated. Sometimes the pump discharges at a fixed level above the receiving water level, which simplifies the calculations considerably. This is invariably the case with Archimedean-screw pumping stations and frequently occurs at tidally affected sites. The pump characteristic curve enables the corresponding discharge to be determined at each point where the static head is known, usually as the pumps are switched on and sometimes when they are switched off as well. For each known period of pumping, the volume pumped is computed by multiplying the discharge by the time of pump operation. If a discharge can be calculated from a knowledge of the static head at the end of pumping as well as the start, the average flow can be used in the calculation. Very few, if any, pumping stations are fitted with a monitor which directly records the volume of water pumped.

Figure 2.1 illustrates the characteristic curve applicable to each of the three pumps at the Boy Grift pumping station. It can be seen that the pump is working at maximum efficiency when pumping at the rate of 1.125 cumecs.

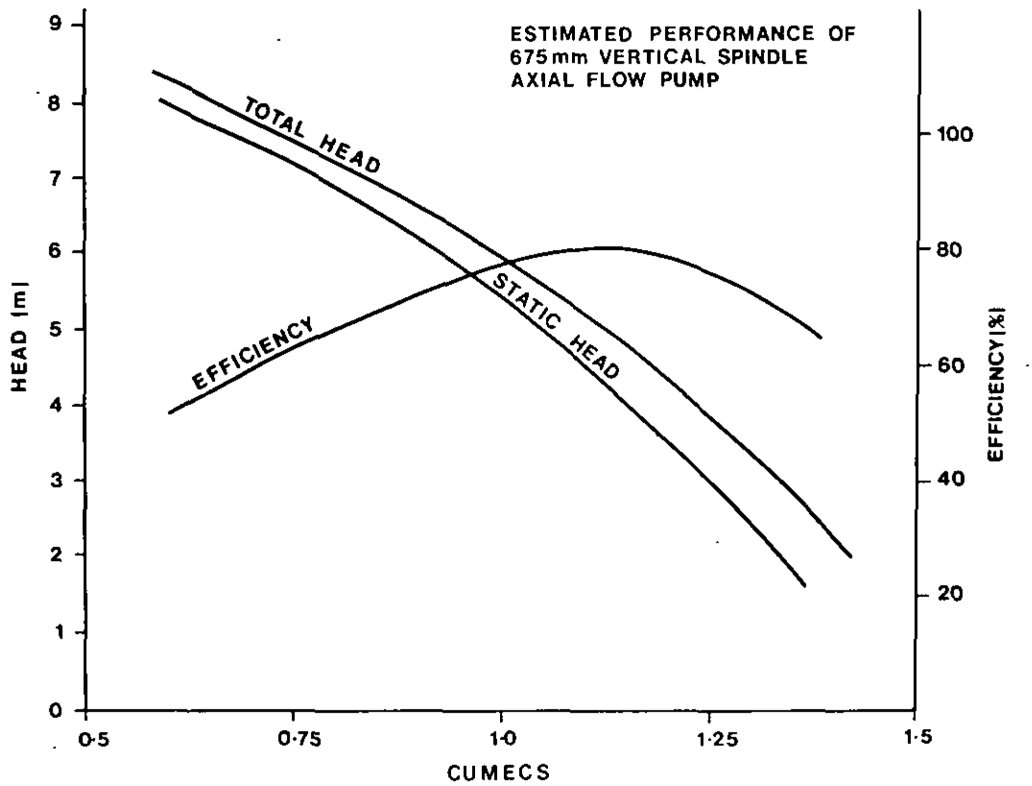

Figure 2.1 Pump characteristic curve, Boy Grift

3. Factors influencing catchment selection

3.1 CATCHMENT BOUNDARY

Unlike highland catchments where the topographic catchment boundary is formed exclusively by the terrain and is easily recognised, low-lying catchment boundaries are often much more difficult to determine. Road or rail embankments which are raised above the surrounding low-lying land are frequently found to be catchment boundaries, as are drain embankments. In the Boy Grift catchment, the boundary is, in places, coincident with one bank of the main drain. West Sedgemoor is surrounded by comparatively high land and its surface area is therefore (unusually) well defined. An accurate assessment of the catchment area is needed for hydrological studies and if there is any doubt as to the boundary, a site inspection will almost invariably be required.

3.2 LEAKAGE

Leakage across a catchment boundary is possible. Many pumping stations are equipped with gravity gates which are usually either close to, or an integral part of, the pumping station and are designed to allow water to pass in the direction of pumping with the pumps switched off. Clearly (when implemented at pumped sites) they can operate only when the water level on the suction side of the pumping station is higher than that on the delivery side; sometimes they are found to be jammed shut. The gravity gates allow water out of a catchment in a manner which is difficult to monitor. If not in good condition, they can allow water to leak back into the catchment when the relative water levels each side of the gate favour it.

Where a catchment boundary has been constructed artificially from earth embankments, leakage both under and through them is possible and may be very difficult to detect. There is less chance of this occurring if the larger drains do not run along the catchment boundary.

Another type of leakage occurs where a catchment contains one or more 'back doors'. These are hydraulic structures or drains which, under certain circumstances, allow water to leave a catchment by an alternative route other than through the usual pumping station. Where these exist, they have usually been implemented to cope with floods which exceed the capacity of a pumping station. Often they are activated by a water level exceeding a critical level. If the volume of water being pumped from the catchment (especially during flood conditions) is of interest, then clearly the amount of water leaving via any 'back door' will need to be estimated as well.

3.3 CULVERTS

If a study involves interpreting water levels within a drain, culverts can present problems. If they ever surcharge (i.e. flood completely at the upstream end) then, clearly, they will distort the longitudinal water surface profile in the vicinity of the culvert. A culvert surcharging has the effect of attenuating a flood hydrograph by an amount which depends upon the extent and duration of surcharging. A culvert which never surcharges is not usually a problem, although the hydraulic drag within it will be different from the rest of the drain. Whether a culvert will surcharge or not depends upon its length, cross-sectional area, roughness, gradient and discharge. Some fairly simple calculations can establish the likelihood of a culvert surcharging. Even if culverts do not surcharge, they may have been constructed with a free overfall at their outlet which might be relevent, depending on the study being undertaken. Time and landowners permitting, it is advisable to walk the entire drainage system. At Newborough, for example, considerable difficulty was experienced in modelling the flow within one reach of the main drain. A subsequent site inspection resulted in the discovery of a further culvert.

3.4 SLUICES

Sluices can generate problems in hydrological studies by diverting flow paths, restricting flow and distorting the water surface profile. So a knowledge of the exact location of all the sluices and the details of their operation is very important. The smaller type are hand-wound but the larger ones may be fitted with electric drives and be controlled automatically, possibly by the water level itself. Hand-wound sluices are not frequently moved. An observer visiting a catchment at least once a month and checking the sluice setting on each visit should derive a good idea of the seasonal variation in settings. Electric drives are usually fitted because the sluice door is very heavy or is moved frequently. If knowledge of the operation of an electrically driven sluice is important and the operator does not keep a record, the only remedy is to install a custom-built sensor. On occasions, sluices can be useful within the context of the study being undertaken as well as to the owner. Within the West Sedgemoor catchment an existing sluice was modified to create a flow measuring station at minimal cost.

Plate 3.1 shows an aperture through the upstream side of one of two concrete wing walls supporting a hand-wound steel sluice which spans a five-metre wide drain. The sluice door, which was kept fully closed, can be seen in the extreme upper left of the plate, while bank weed can be seen in the extreme lower right. The aperture was designed to allow a greater level of control over the flow than could be afforded by the sluice. An aluminium frame supporting a hand-wound movable weir crest has been attached to the inlet end of the aperture. By raising or lowering the weir crest, the water level can be kept at the required level on the upstream side of the sluice. A water level recorder attached to the second wing wall (not shown) continually monitors the water level on the upstream side of the sluice. A record is made of the weir crest level which, when compared with the water level record, allows a computation of the head over the weir. The weir crest was constructed to

Plate 3.1 Sluice converted to flow measurement station

BS3680:Part4A:1965, thereby allowing a direct calculation of flow from a knowledge of the head and weir width.

3.5 MULTI-SITE PUMPING

Some low-lying fen catchments are pumped at more than one site. In effect, the catchment is shared between two or more pumping stations. The only problem this presents is that the amount of work needed to compute the volume of pumped runoff is increased.

Other catchments have part of their runoff pumped twice. This is termed 'double pumping', each time the runoff being pumped up to a level where it can drain under gravity. In such cases, it may be necessary to use only the data originating from the last station to pump the runoff.

3.6 UNDER-DRAINAGE

Much low-lying land is used for agricultural purposes and approximately 20% is under, or 'tile', drained. Tile drainage can affect the hydrograph and if this is important to the study a check with the owner or drainage authority is needed as it may not be possible to locate such drainage from a site survey. Once tile drains are known to be present, it should be possible to identify the location of collector pipes which convey the subsurface flow through the drain banks into the surface drainage system.

3.7 LOOPS AND SYPHONS

Loops in the drain network allow water to travel from one point to another by more than one route. They are not common but can make flow measurement more difficult.

Syphons are hydraulic devices which allow drains to drop below an obstruction, typically a road or higher level drainage channel, and emerge to continue their original path. They do not impede the flow but do tend to collect floating debris and in a flood situation may become blocked. Leakage from one drain to another could also occur at a syphon.

3.8 DRAIN OBSTRUCTIONS

A cattle water is an area where the side of a drain has been cut away to form a shallow slope from an adjacent field down to the drain surface to allow cattle (or sheep) access to drink. Although these are not usually significant, they are frequently enclosed by water gates (e.g. wire fencing across the drain). During periods of high flow, debris can accumulate on the water gate which then forms an obstruction to the flow.

Farmers sometimes obstruct drains and it is not uncommon to discover that sandbags have suddenly materialised, sealing a drain. This appears to be done more often with a view to conserving water in summer than preventing flooding in winter. It can only occur on the smaller drains which are usually of less interest to studies. Farmers also install and operate small pumps to irrigate their land and the effect can be significant on small drains. They need a licence before installing them and the abstraction details can be acquired from the appropriate drainage authority. The licence will of course only indicate the allowed maximum, rather than the actual abstraction.

Plate 3.2 illustrates debris hanging from a small water gate (Autumn 1986) at the intake side of a culvert, close to water level recorder site 6 on the Boy Grift catchment.

Plate 3.2 Water gate on Boy Grift catchment

4. Surveys

4.1 DESIGN AND CONSTRUCTION SURVEYS

There may be design drawings available from the drainage authority. It is not safe to rely on these without a detailed check as design drawings are not always strictly adhered to. Post-construction survey drawings are usually more useful but are seldom available. A drain which was constructed as a regular trapezoidal prism may deteriorate to an approximately elliptical or circular section. Sedimentation, weed cutting, dragline operations and bank slip can all affect the shape and dimensions of the wetted perimeter.

4.2 DRAIN SURVEYS

Artificially cut drains are generally far easier and less time consuming to survey than natural rivers. The majority are straight with regular bank gradients. It is quite usual for a drain's longitudinal bed gradient to be effectively zero for the first few kilometres adjacent to the pumping station. In the case of Boy Grift main drain, the bed level was continually below ordnance datum within 6.5 km of the pumping station and the bed gradient was not significantly greater than zero for a further 1.5 km. A survey may be required to establish the volume of part or all of the drain system. Either the total volume or that volume above a given tail water level may be of interest.

Figure 4.1 shows the position of the five dimensions needed to compute the drain shape above the water level without the need to record angles.

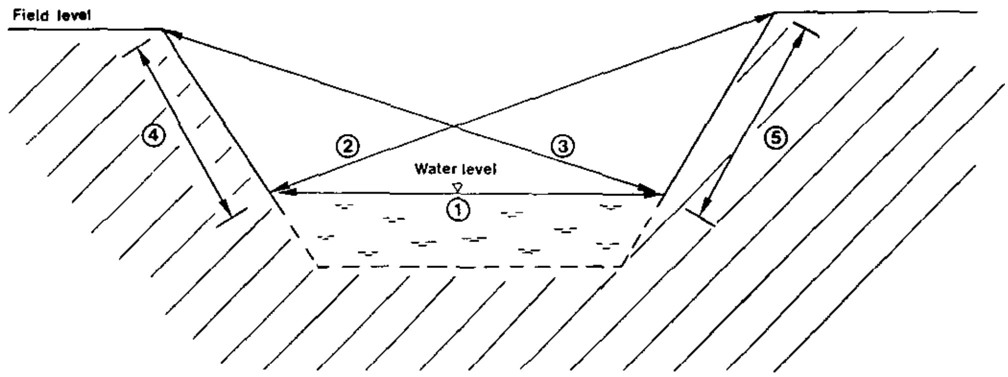

Figure 4.1 Drain cross-sectional survey

Agricultural considerations permitting, a drainage authority may be prepared to adjust the water level in the drains to a level which would assist the survey. During periods of pump inactivity and on days when there is no wind, it is possible to use the water surface to 'transport' a known reference level a considerable distance. This is often useful when surveying in areas devoid of bench marks, providing the survey is of an order of accuracy which justifies it.

4.3 AERIAL SURVEYS

Aerial photographs are always useful at the planning stage of a study and may subsequently assist a specific aspect in greater depth. They are expensive to produce but it is often possible to locate existing photographs and negotiate their use, subject to the scale and date on which they were taken being suitable. Existing aerial photographs were sought and located showing the Boy Grift and West Sedgemoor catchments. They show the overall drainage network, many of the hydraulic structures present on the drain and give an overall impression of land use. They can also be used to identify the route of defunct drain systems and in some cases the (pre-artificial drainage) 'natural' drainage path can be seen.

Aerial photographs can be taken with either conventional or infra-red film. The contrast in reflectivity between a water surface and the surrounding land is far higher when using infra-red film than conventional black and white. A water surface reflects virtually no infra-red light and consequently appears black, while the differing vegetation in the surrounding fields reflect varying amounts of infra-red and usually appear as several shades of red.

There was a need to determine the water surface area of the drains on the West Sedgemoor catchment. Infra-red photographs taken at a scale of 1:10,000 allowed the water surface widths in the drains to be measured with the aid of an optical enlarger, with a maximum error of 0.25 m, typically 12.5%. It was found that the 13 km^2 catchment area of West Sedgemoor included an area of 0.23 km^2 (1.8%) of drain water surface. The definition of the photographs was so good that, with the aid of an optical enlarger, it was possible to confirm the position of the top of a 300mm diameter water level recorder.

5. Water level data

5.1 SUMMARY

Water level measurement is a basic component of any hydrological study of a flat catchment and the design of the network requires several questions to be answered:

* How many sites are needed?

* How are the locations to be chosen?

* What sort of structures are appropriate?

The constraints on the selection of the sites are not only hydraulic in nature but also include the (often major) problem of access.

Figure 5.1 illustrates the behaviour of the water level at the four recorders nearest to the pumping station on the Newborough catchment. Distances (in kilometres) of the water level recorders from the pumping station are given in brackets after the site identifier. Further examples of the graphical presentation of data are included in Section 14.

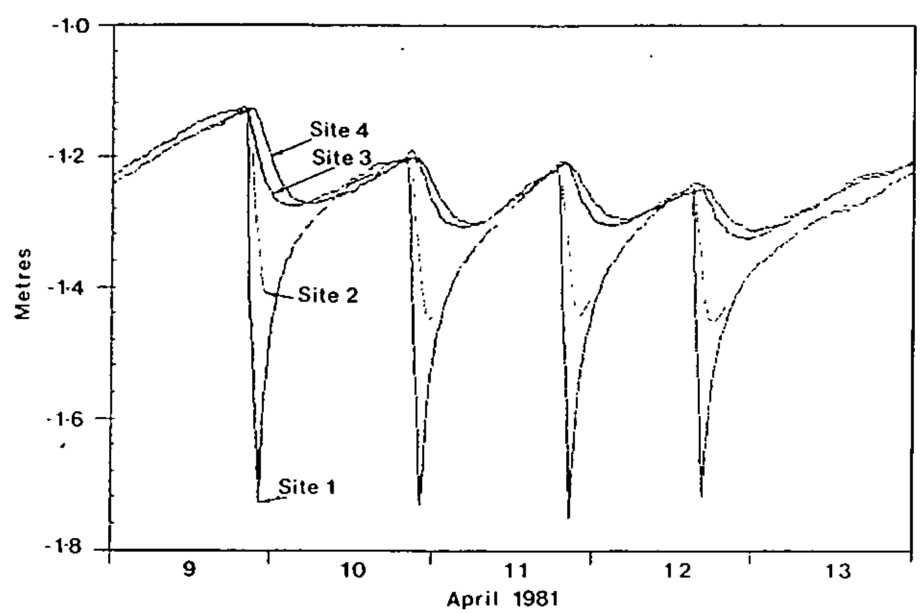

Figure 5.1 Drain water levels, Newborough Fen

While the number and location of the water level recorders are clearly dependent on the objectives of the study being undertaken, it is important to realise that the concept of flood routing has little meaning on flat low-lying catchments. It is invariably the case that recorders show a near simultaneous rise and fall in water level during pumping. Table 5.1 shows the recorder spacing adopted on the three catchments featured in this report but the distances mentioned may not be suitable for all studies.

Table 5.1 Distances between adjacent recorders on the same drain for each catchment

	Maximum (km)	Mean (km)	Minimum (km)
Newborough	2.00	1.80	1.35
Boy Grift	3.40	2.15	1.45
West Sedgemoor	4.15	2.35	0.45

In the following subsections the factors to be taken into account in the positioning of water level recorders at pumping stations and other locations are discussed. The final part of this section illustrates some of the water level recorders which were implemented during the three catchment studies described in this report, outlines the constructional problems encountered and describes how they were overcome.

5.2 WATER LEVEL RECORDERS AT PUMPING STATIONS

In the type of terrain considered in this report, the final removal of drainage water will be via a pumping station. For almost all studies it will be necessary to monitor water levels close to this point, either as an indicator of pump operation, as a means of calculating the static head against which the pump operates or to provide information on drain levels at the lowest and probably most rapidly responding point.

The variation in water level is greatest on the receiving side of a pumping station and a decision to pump is partially influenced by this water level. The exact position of the recorder can be important. All pumps have a weedscreen of some kind; this acts as a fairly coarse filter to prevent the larger floating debris from being sucked into the pump and causing damage. Some weedscreens are mechanically cleaned while others depend on manual intervention. There may be a significant difference in water level across a weedscreen if there is a large amount of debris piled up against it.

Some electrical pumping stations are equipped with water level sensors which, often in association with a clock, switch the pump on and off. If the water level rises to make contact with the higher of the two sensors the pump starts, the water level is then drawn down by the pump until contact with the lower sensor is lost and the pump cuts out. If resources do not extend to the construction of a water level recorder at a pumping station intake, the sensors, while not generating a temporal record of water level, do at least provide information on the vertical constraints imposed upon the water level. It is very common for these sensor levels to be altered on a seasonal basis, to take account of changing agricultural requirements or of the need to provide additional flood storage in the drain channel system in winter. If inferences are to be made, care will need to be taken to keep an accurate record of any change to the sensor level settings.

5.3 DRAIN WATER LEVEL RECORDERS

The location of the water level recording sites should be controlled by the data requirement of the studies being undertaken. In practice there is a marked tendency to site recorders at bridges for reasons of access and construction. The number and distribution of water level recorders depend on the use to be made of the data.

If a recorder is being used to measure the hydraulic 'head' over a structure with a view to using the information to estimate flow, then it clearly needs to be as close to the structure as possible. However, it should not be so close that it affects the flow across the structure, or records the water level at a point where the water is already starting to be drawn down by the structure. (Refer to British Standard BS3680:Part 4:1965). The most economical use of a recorder would be to record both a 'head' and a drain water level. Such situations occur infrequently.

5.4 CONSTRUCTIONAL CONSIDERATIONS

Before any water surface level can be recorded it needs to be screened from floating debris and the direct effect of the wind. The water level recording equipment, usually driven by a float and counterweight, must be supported. A stilling well performs both these functions and usually consists of a vertical perforated PVC cylinder resting on the drain bed with the recording equipment mounted at the top. Probably the easiest method of securing a stilling well is to drive it into the drain bed and then secure it to a convenient bridge. A steel band can then be wrapped around the PVC stilling well and attached to the bridge. Securing bolts for the steel band (either the resin-bonded or self-expanding variety) can usually be attached to reinforced concrete bridges if a metal detector is used to ensure that the drilling takes place clear of the reinforcing. However, it is extremely inadvisable to drill into a concrete bridge which contains pre-stressed steel reinforcing. Drilling into brick arch bridges is also undesirable, especially near the soffit.

The water within the well must of course be kept at the same level as that in the drain, therefore the stilling well has to be extensively perforated. The holes have to be numerous enough to prevent them all becoming blocked, sufficiently small to prevent floating debris entering and obstructing the float, yet large enough to prevent any delay in the internal water level matching the external level during periods of rapid drain level movement. Current IH practice is to drill the stilling well with 10 mm diameter holes at 100 mm intervals around the circumference and at a 100 mm vertical spacing. With a 300 mm diameter pipe, this results in nine columns of holes.

Plate 5.1 illustrates how the water level recorder and logger are supported on two shelves within the top of a stilling well. The relative lengths of the float and counterbalance weight wires depend upon the range of water levels experienced and the length of the stilling well. This length should be such that the water level cannot rise to the level of the recorder and logger. Section 15 (Vandalism) explains the reasoning behind this design.

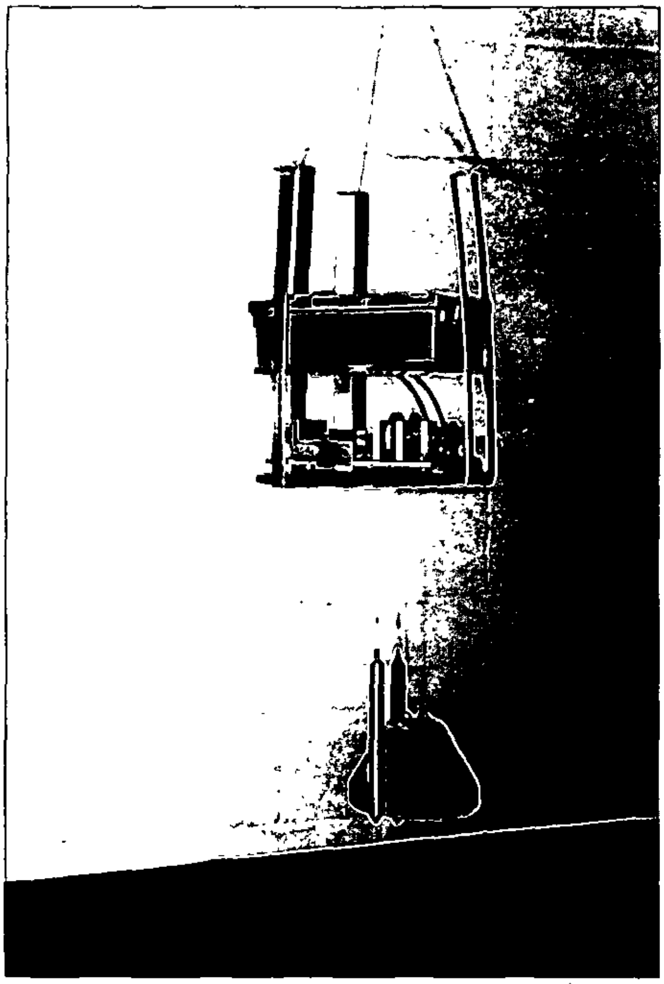

Plate 5.1 Water level recorder assembly and logger

Plate 5.2 shows a stilling well which has been fixed in position by driving it into the drain bed and providing lateral restraint at the top. The bridge did not contain pre-stressed reinforcing and was drilled to provide anchorage for four bolts. The stilling well is gripped between two semi-circular steel bands and has deliberately been positioned clear of the bridge aperture. The top is covered with a cylindrical steel cap which is locked in position by a horizontal steel bolt which passes through both the PVC stilling well and the cap. The bolt is fitted with a flange at one end and can be padlocked in position at the other. The length of the stilling well was chosen to assist access to the equipment inside the top of the well.

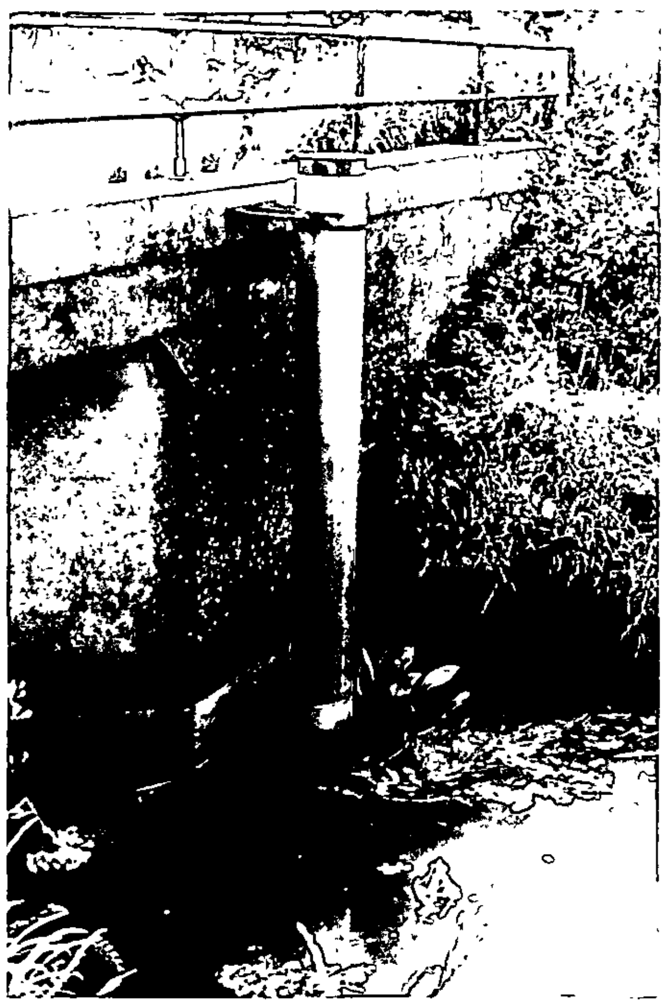

Plate 5.2 Stilling well - reinforced concrete bridge attachment

Silt is deposited at points where the drain velocity falls. This situation arises wherever the channel cross-section suddenly increases (the flow being constant). Hence, stilling wells are generally better situated upstream of bridges rather than downstream especially if there is a marked increase in channel dimensions downstream of the bridge. There has only been one incidence of the inside of a stilling well (shown in Plate 5.5) silting up to an extent that the bed level inside the well was high enough to foul the float. At the site where this happened the stilling well was completely clear of the higher velocity main channel flows. It is probable that the low velocity eddy currents in the immediate locality of the well had allowed silt to settle out inside the stilling well, eventually encasing the float. With hindsight, this could have been prevented by excavating into the drain bed within the stilling well when it was first implemented. This problem is unlikely to occur inside stilling wells which are never subject to very low water depths.

The velocity of flow in drains is low during pumping and practically zero during other periods. The chance of ice forming, while clearly being principally a function of temperature, is also partially dependent on velocity of flow. The lower the velocity of flow, the greater the chance of a stilling well freezing. The water within the well, while protected from the 'wind chill' effect, is almost static which facilitates the freezing. Ice forming on the surface of the drain could cover the holes drilled in the stilling well at that level but is unlikely to cover the holes at lower levels. There have been several incidents of stilling wells freezing. At an isolated site there are no practical solutions to this problem. A stilling well adjacent to a power source (e.g. close to a pumping station) could, in theory, be fitted with a thermostatically controlled heater although the cost might well prove substantial.

Plate 5.3 provides a close-up view of the lateral support afforded to a stilling well, the location of which can be seen in Plate 5.4. The bridge had been constructed of pre-stressed concrete which could not be drilled, so the attachment was made to the railings.

Plate 5.4 shows the position of the stilling well (featured in Plate 5.3) at the edge of the drain. In the event of a flood, there is less chance of it forming an obstruction upon which floating debris could accumulate. However, regard should also be made to the lowest water level likely to be experienced when selecting the exact position.

Plate 5.3 Stilling well - bridge rail attachment

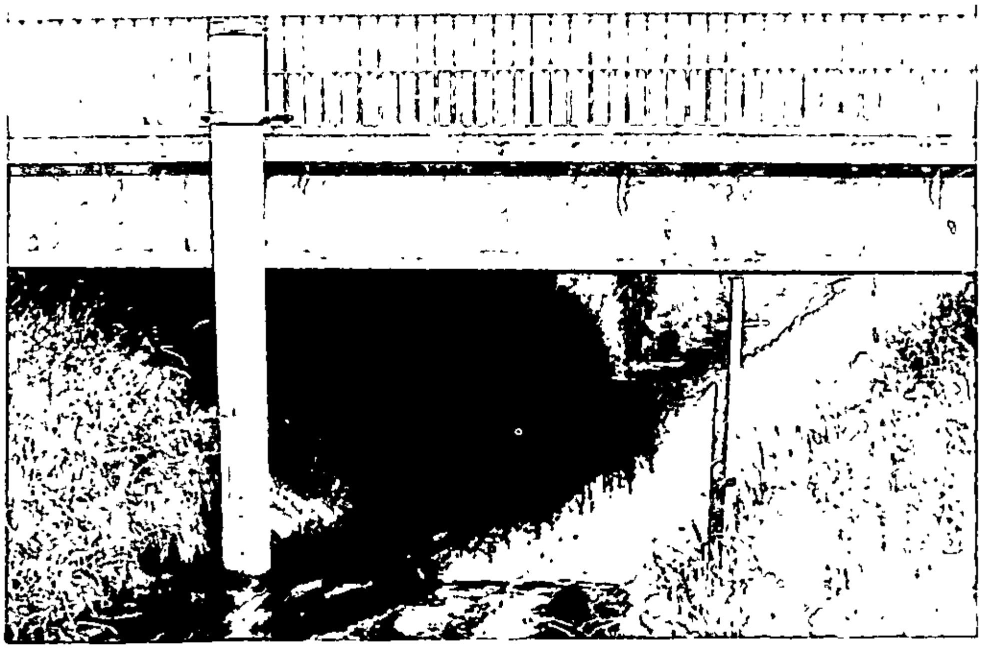

Plate 5.4 Stilling well - channel positioning

Plate 5.5 illustrates a solution to the difficult problem of providing lateral restraint. The brickwork of the bridge was in poor condition and was due for renovation. The vertical pole used to provide lateral restraint is attached to a square plate which is bolted into the concrete underpin. By adopting this solution there was no need to drill into the crumbling brickwork and the stilling well was kept clear of the bridge thus avoiding any chance of having to remove it to allow work on the bridge. As with other stilling wells illustrated, it was positioned clear of the bridge aperture.

Plate 5.5 Stilling well - vertically mounted restraint

If there is not a suitable bridge near enough to the required site it will be necessary to construct 'free standing" support. It has been found from experience that the best way of doing this is by driving four scaffolding poles (surrounding the stilling well) vertically into the drain bank/bed and cross-bracing them with smaller horizontal or diagonal poles. Scaffolding poles can be driven into the bank using a post driver. If necessary a 'walkway' can be built out from the bank to the stilling well.

Plate 5.6 illustrates a site on the upper part of the Boy Grift catchment where the stilling well support had to be fabricated from scaffolding. Note the handrails to the walkway, designed to meet safety requirements.

Plate 5.6 Stilling well - large gantry

Plate 5.7 illustrates a smaller walkway at a West Sedgemoor site. As well as the walkway there is further lateral restraint at a lower level to which the gauge board is also attached.

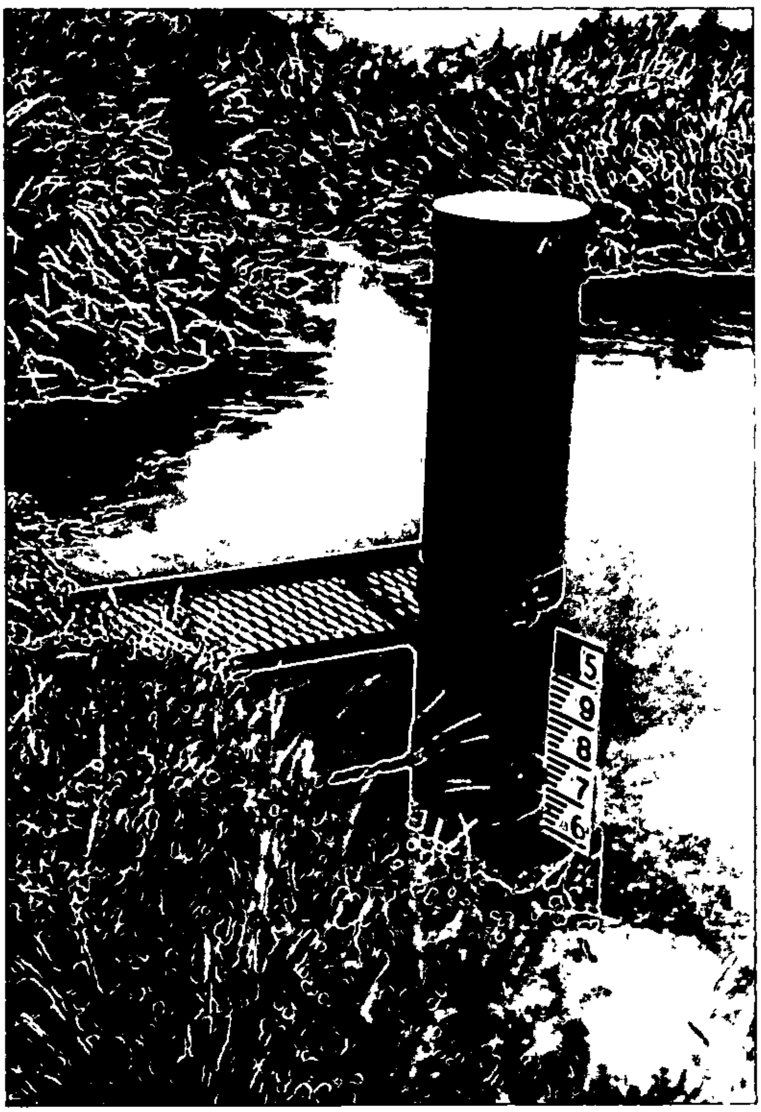

Plate 5.7 Stilling well - small gantry

6. Flow measurement

6.1 DRAIN FLOW MEASUREMENT

On flat low-lying land it is invariably difficult to find a suitable site near enough to the point of interest where, even on a small channel, there is scope for introducing a flow measurement structure. Flumes are sometimes permissible although expensive; the smaller pre-formed glass fibre type are sometimes practicable.

There are rigorous constraints imposed by BS3680:Part4A:1965 on implementing thin plate weirs to ensure that they give accurate results. These structures would otherwise tend to be the natural choice on small drains. A 90 degree triangular weir is capable of recording flows of up to slightly more than 0.1 cumecs quite accurately whilst a rectangular weir can record flows of up to 0.8 cumecs per metre width. They need a substantial 'overfall' which, if not naturally available, necessitates raising the water level on the upstream side which is not often practicable.

An alternative solution to flow measurement on flat land is to use the velocity-area method. Fortunately bridges and culverts abound in areas of flat land where they are used to take the drains under roads, farm tracks, railways and occasionally even under other drains. Inlet and outlet conditions or small-scale bed and cross-sectional changes associated with such structures are often sufficient to impose a unique stage-discharge relationship upstream. For example, there is often a small drop in the drain bed at the end of culverts. If a velocity-area section is set up at the entrance to the culvert, the drop at the end of the culvert acts as a control. The level measuring section should not be in the drawdown zone at the culvert entrance. Once the section has been chosen, a staff gauge should be installed so that the water level can be recorded each time a calibration current meter gauging is taken. This technique has been used successfully on the Boy Grift catchment where a 0.5 m overfall at the end of a 1.5 m diameter, 25 m long culvert under a disused railway embankment was used to provide the control. Wessex Water Authority adopted a similar approach in gauging a drain on the edge of West Sedgemoor. In this case the stream in question was not an artificial 'drain', but a natural channel of low gradient on the fringe of the Moor. The control was a short length of channel of significantly steeper grade rather than a free overfall; as such, it was not as effective during high flows. Subsequently, WWA installed an elm board across the channel to stabilize the channel bed at the control point.

Gauging flows in the larger drains is not easy. The largest drains are those nearest to the pumping station and, as a result of the pumping, the flow within them is almost always unsteady. Trying to establish a velocity-area section in a reach influenced by pumping action is pointless. An electromagnetic gauge is probably the only type which could be usefully employed but would be expensive to install, calibrate and maintain.

6.2 NATURALIZED FLOW MEASUREMENT AT A PUMPING STATION

The volume of water pumped during a given period can be calculated from a knowledge of the 'pump characteristic' curve and the duration of pumping as described in Section 7. It must be appreciated that the result of this calculation does not represent the volume of water that would pass out of the catchment if the pumping station were not present, but is simply a function of the extent and duration of pumping.

If a requirement exists to synthesize 'naturalized' flow at a pumping station, the approach suggested by Reed (1984) can be employed. The dimensions of the larger drains are surveyed and a relationship established between the drain water level and the volume of water in the drains. Information from the drain water level recorders can then be used to compute changes in the volume of water 'stored' in the drains which are then added or subtracted to the volume pumped. In this way a hydrograph can be generated which more accurately represents the natural outflow from the catchment which would occur if the pumping station did not exist. This approach has been usefully employed on the Newborough catchment and could be applied to any pumping station where the larger drains have been surveyed and have been equipped with water level recorders.

7. Instrumenting pump operation

7.1 SUMMARY

Most pumping stations will be found to have some monitoring equipment to record pump operation (see Section 2.4). Clearly, the most economic approach is to make use of the instrumentation which is already installed - if necessary by adaptation. Every case will have a different optimum solution. It may be that a cumulative 'hours run' meter could be read more frequently than it has been in the past or a diesel pump operator may agree to record water levels at additional times. With the exception of Archimedean and some types of variable speed pumps, a record of the hydraulic head against which the pump is operating will be needed. This equates to installing water level recorders close to the weedscreen and immediately downstream of the pumping station. See also Section 12.

7.2 BOY GRIFT PUMPING STATION

At Boy Grift pumping station there was no recording equipment to monitor the three pumps other than 'hours run' meters, which were not read daily. One of the six water level recorders used in this study was implemented adjacent to the pumping station weedscreen which allowed the on and off times of pump operation to be monitored during small pumping events. This indirect technique of detecting pumping through changes in water level is unreliable during larger events involving more than one pump.

East Midlands Electricity agreed to monitor the total amount of power being fed to the pumping station. Before the data could be used, the effect of power consumption by equipment other than the pumps had to be eliminated. By comparing power used during three separate periods when one, two and three pumps were operating, a linear relationship between power consumption and the number of pumps operating was confirmed. This 30-minute interval power data can then be used together with information supplied by the pump manufacturer to compute the amount of water pumped.

Plate 7.1 shows Boy Grift pumping station. The telemetry aerial on the roof is used for transmitting the water level on the tidal (i.e. discharge) side of the pumping station to the AWA offices at Lincoln at 15-minute intervals for use in their tidal warning system.

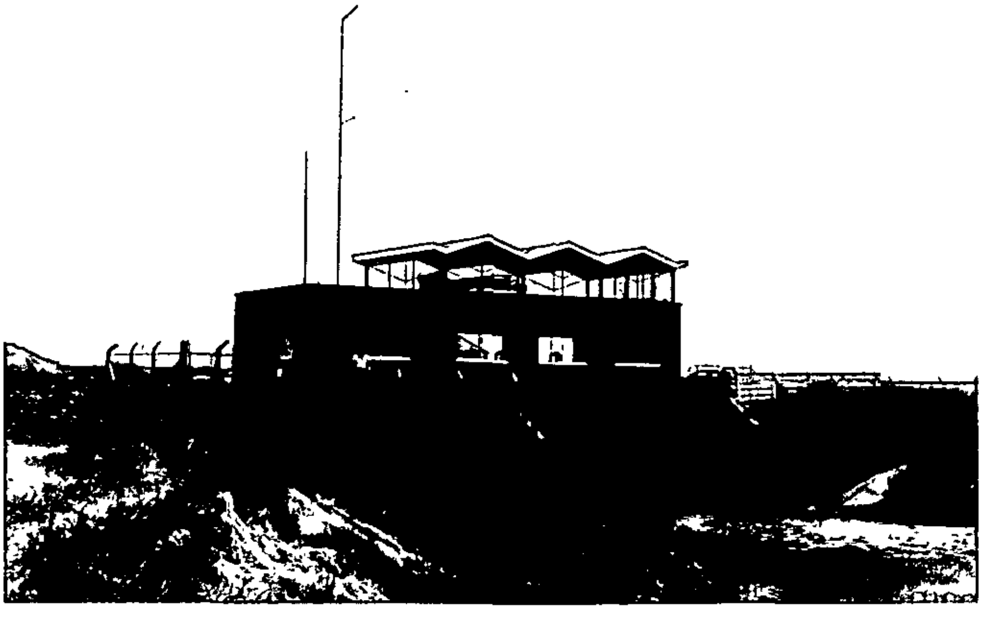

Plate 7.1 Boy Grift pumping station

A further method of instrumenting pump activity was suggested by the IH Instruments section. When a pump is operating, the current flowing through the cable taking power to the motor driving the pump generates a small magnetic field. A magnetic field sensor clip was attached to each of the cables taking power to the three pump motors. The magnetic field induces a very small a.c. voltage in the clip (less than 2 volts) and, by suitably transforming this voltage to d.c., it can be fed to a standard data logger, set to record at a suitable time interval. The resulting data indicate the periods when each of the three pumps is active. As these clips cost only £27 each, the total cost of the equipment (3 clips and the a.c. to d.c. rectifier) was less than £100.

Plate 7.2 shows a magnetic field sensor clip attached to a power cable feeding a pump motor inside Boy Grift pumping station.

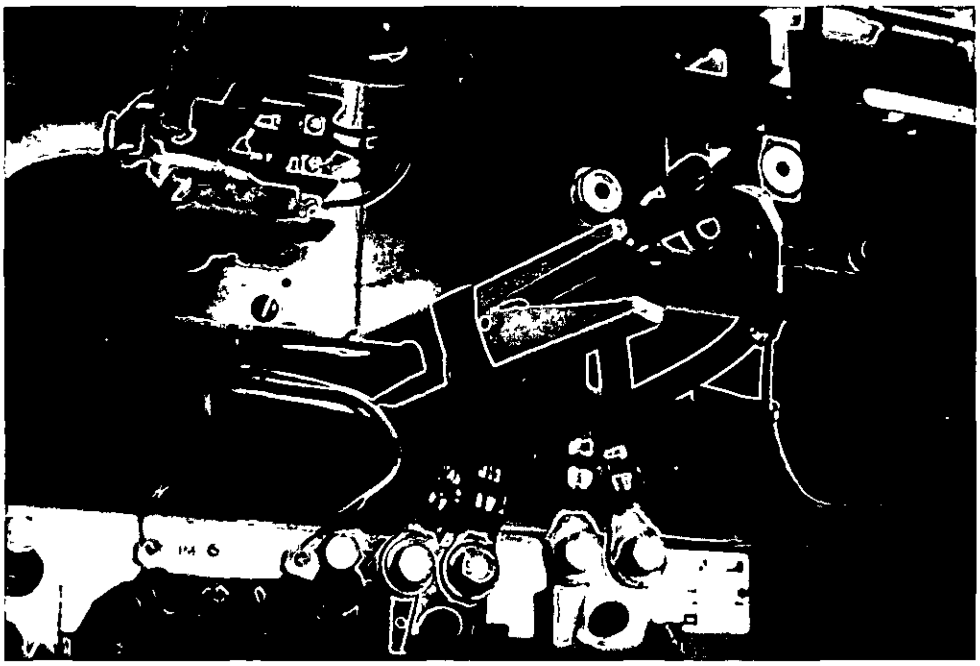

Plate 7.2 Magnetic field sensor clip

Plate 7.3 shows the a.c. to d.c. rectifier and data logger. The inputs from the three sensor clips to the rectifier can be clearly seen.

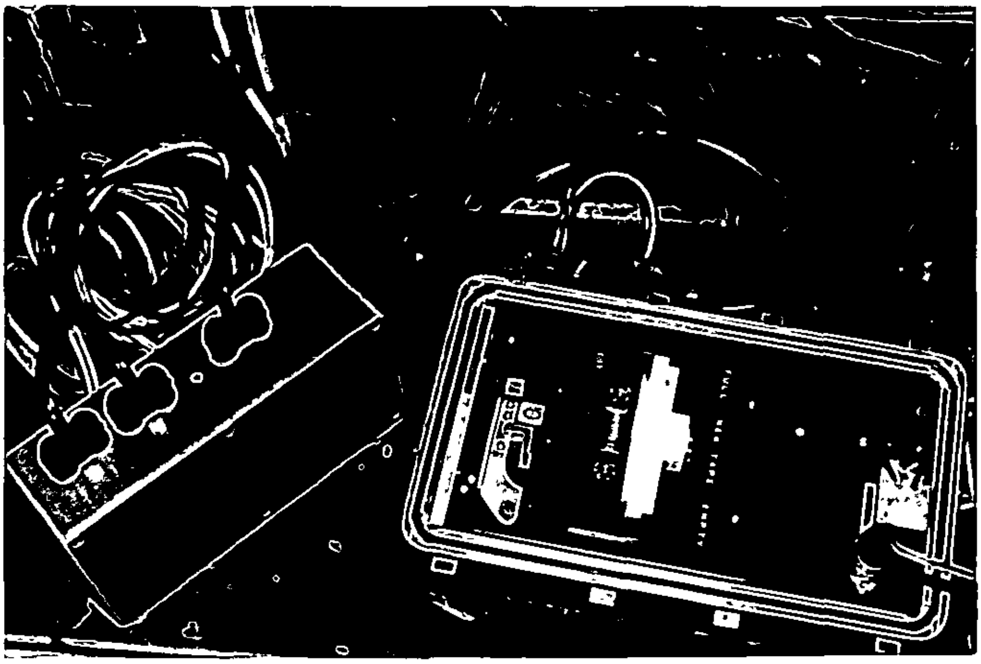

Plate 7.3 Rectifier and data logger

7.3 WEST SEDGEMOOR PUMPING STATION

West Sedgemoor is served by both diesel and electrically driven pumps, housed separately on adjacent sites. Sufficient data (water levels, times and duration of pumping) were recorded by the operator of the diesel pumps to allow computation of the volumes of water pumped by applying these data to the pump 'characteristic curve'.

Plate 7.4 shows the West Sedgemoor diesel pumping station. It contains two 2.2 cumecs pumps.

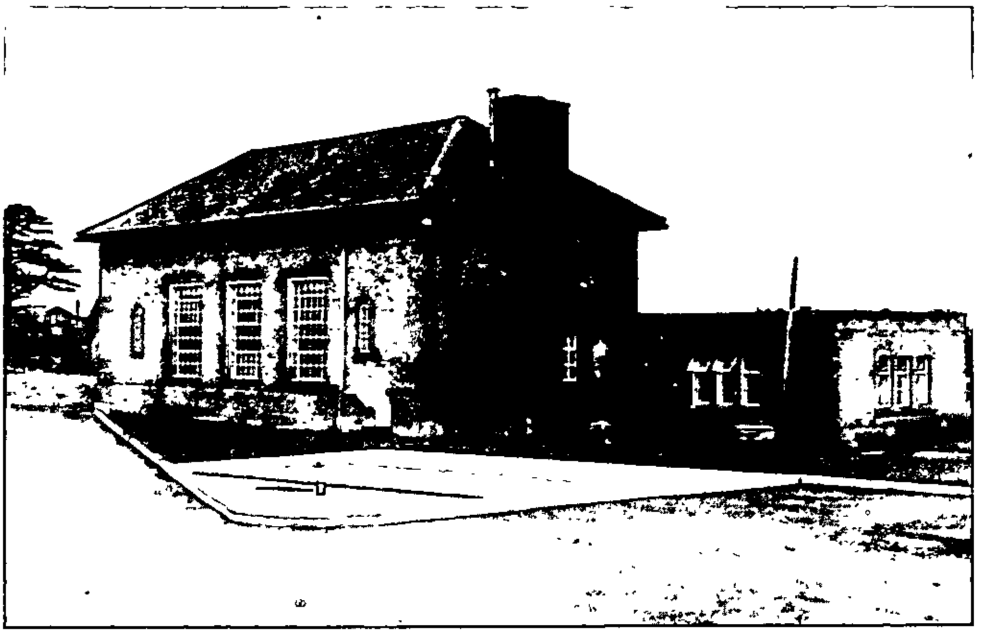

Plate 7.4 West Sedgemoor diesel pumping station

The electric pump is a variable speed unit. Its design parameters at the minimum and maximum operating speeds are included in Table 7.1.

Table 7.1 West Sedgemoor electric pump operating limits

Pump speed (rpm)	Flow rate (cumecs)	Static head (m)	Total head (m)
440	0.6	1.0	1.3
800	1.2	1.8	3.0

For any given static head across the pump, there is a self selecting optimum pump speed at which the operating efficiency of the pump will be a maximum. Should the resulting flow rate prove insufficient, e.g. in a flood situation, the pump speed could be (manually) increased but this would result in reduced efficiency. The maximum available flow rate of 1.2 cumecs constitutes only 21.5% of the total capacity on the site and the electric pump is therefore primarily useful as a 'duty pump' during the drier summer months. The pump was equipped at the time of its construction with a KHRONE magflow meter which gives an instantaneous readout of the pump rate. As the pump was of the variable speed type, there was no unique characteristic curve to which an estimate of the static head could have been applied in order to estimate volumes pumped. It was for this reason that, at the request of the Institute, a cumulative pumped volume meter was installed. Most of the required electronics had already been installed and the additional cost was only £50. Thus the volume pumped between any two meter readings was immediately available. It is unusual for any pumping station to be fitted with instrumentation which allows the volume pumped to be read off directly. Had the effort and expense involved not been so trivial, the increase in accuracy of the resulting data over and above that which could have been generated by making use of the 'hours run' meter would have to be balanced against the increased cost.

Plate 7.5 shows the West Sedgemoor electrical pumping station which commenced operation on 13 January 1987. It contains a variable speed unit capable of pumping between 0.6 and 1.2 cumecs.

Plate 7.5 West Sedgemoor electrical pumping station

7.4 NEWBOROUGH PUMPING STATION

Newborough pumping station was found to be equipped with a paper chart recorder which monitored the current used by the station; 25 mm of travel on the roll representing an hour. In practice, this meant that the time a pump stopped, or started, could be determined to the nearest 5 minutes without the need for the installation of any further recording equipment. As a linear relationship existed between the number of pumps operating and the total (recorded) current used, the number of pumps operating at any given time could be determined. In the absence of information on the discharge water level, the hydraulic 'head' across the pumping station could not be calculated. Thus the recorded periods of operation had to be applied to the pump's design flow rate in order to estimate volumes pumped.

Plate 7.6 shows Newborough pumping station. The pipework associated with the three electric pumps is clearly visible, as is the weedscreen. Unlike Boy Grift or West Sedgemoor, the approach drain opens out into a storage pond (often referred to as a 'bowl') at the pumping station. This helps to avoid very short pump-runs which can occur in non-flood conditions due to the drawdown effect of the pumps on the water level, the rapidly falling water level quickly switching the pumps off. Such high frequency on/off switching of the pump is referred to as 'hunting'. This is inefficient in the use of electricity and has a detrimental effect on the life of the pump.

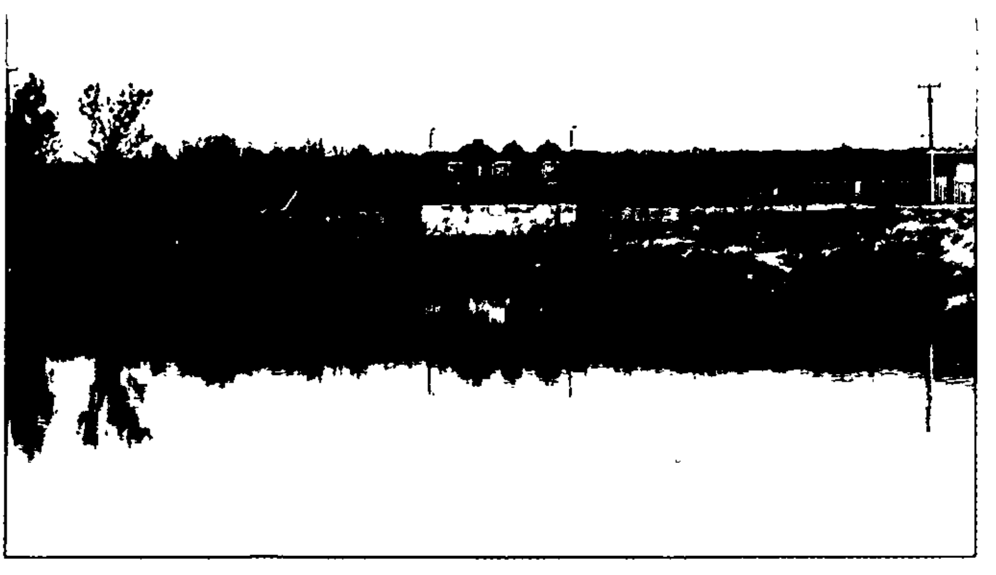

Plate 7.6 Newborough pumping station

8. Pump calibration

8.1 SUMMARY

It is usually fairly easy to secure details of pump operating characteristics from either the relevant drainage authority or the pump manufacturer. However, it is dangerous to assume that a pump will operate at a rate affected only by the hydraulic head across it. After 20 or 30 years of operation, both the pump and driving motor will become worn and the flow rate will diminish accordingly. Some electric pumps are designed in such a way that, as the hydraulic head across them changes, the motor speed varies so that the flow rate does not change much. In these cases, the characteristic curve (which is often valid only for the design motor speed) is of very limited use. The flow rate of pumps can be checked in three different ways.

8.2 ELECTROMAGNETIC SENSORS

The success of this approach depends on there being, within the pump pipework, a sufficiently long straight length of pipe with a constant cross-section capable of inducing uniform flow. An ultrasound signal is transmitted across the pipe diameter, the time taken for it to travel across the known path length and composition being a function of the water speed within the pipe. This derived speed can then be applied to the cross-sectional area of the pipe to arrive at the volumetric rate of flow. At Boy Grift pumping station this approach appeared to work well. The only problem encountered was in finding a point on the pipework where the flow was stable enough to generate a reading. There is always some air entrainment in the pumps and associated pipework and if this reaches too high a level the method will not work. Within the pipework of one of the three pumps, the water velocity was found to be constantly drifting. This is often an indication of pump wear, which can also manifest itself as a surging flow.

8.3 DILUTION GAUGING

This technique is now well established for gauging streams in irregular channels but the fact that it can also be used to gauge pumps is less well known. In the standard equation for dilution gauging:

$$Q.C_0 + q.C_1 = (Q + q).C_2$$

Q	= drain flow rate	C_0	= background tracer concentration
q	= injected tracer flow rate	C_1	= injected tracer concentration
$Q+q$	= pump flow rate	C_2	= downstream tracer concentration

The requirement for mixing, to ensure that the tracer has reached a uniform concentration throughout the drain, is effectively met by the pumps. The tracer can be injected at any point in the drain on the suction side of the pumping station and the (mixed) samples retrieved immediately downstream of the pump outlet pipe. An attempt was made to gauge each of the three pumps at Boy Grift in turn, using sodium iodide (NaI) as a tracer. The tracer was injected from within the basement of the pumping station into the drain immediately adjacent to the pump being gauged.

Plate 8.1 shows the injection of NaI using a Mariotte bottle between the pumping station basement floor and the pump intake casing.

Plate 8.1 Injection of dilution gauging tracer

The samples were taken as close as possible to the discharge point and above the level at which mixing with the downstream water occurred to minimise the scope for contamination.

Plate 8.2 shows downstream sampling. The pump flow rate is approximately 1.25 cumecs.

Plate 8.2 Sampling the tracer concentration

The gauging exercise was unsuccessful because the flow upstream of the pumping station had an abnormally high concentration of iodide ion, which was not appreciated until the samples were analysed in the laboratory. This may have been connected with the fact that Boy Grift pumping station is only 150 metres from the coast. An alternative tracer, lithium chloride (which would have made use of the Li^+ ion), was later considered but rejected because of the cost.

8.4 VOLUMETRIC PUMPING TESTS

If a length of drain immediately downstream of a pumping station can be sealed and its volume surveyed, the time required for a pump to fill it can be recorded. This method can be made easier by carefully choosing the two levels between which the volume is to be measured. The levels should allow surveying of the enclosed volume as accurately as possible. The method will give satisfactory results only if leakage through gates, sluices, penstocks etc. can be either measured or eliminated. The downstream water level and, hence, the hydraulic head across the pump will be continually increasing during the test. The drain volume divided by the time to fill yields an average pump rate. The actual pump rate will not be constant during the test.

This technique was attempted at Boy Grift by making use of a 100 m length of drain between the pumping station and the sea wall. The average pump rates were significantly lower than those given by the electromagnetic sensor test. Observations during the test did not detect any leakage through the tidal doors adjacent to the pumping station but did confirm considerable leakage at the penstock in the sea wall. The magnitude of this leakage was not fully appreciated at the time of the test and no attempt was made to monitor it. With hindsight, the leakage might have been gauged in the outflow tunnel downstream of the penstock. In addition, there may have been some error in surveying the volume of the drain.

9. Field water tables

9.1 SUMMARY

Dipwells may need to be implemented to monitor the groundwater table. These can be designed to generate either discrete or continuous data strings depending on the requirement. While their number and location will depend on the study being undertaken, it should be realised that the field water table in the immediate vicinity of the drains will not accurately reflect what is happening in the rest of the field. At West Sedgemoor the drain water levels were found to affect the field water table over a distance limited to 12 m from the edge of the drain.

9.2 MANUAL GROUNDWATER MONITORING

The wells themselves can be constructed of 100 mm diameter drilled PVC tube and should have a removable cover. While it is unlikely that evaporation will occur at such a pace that it is able to overwhelm the ability of the water level to reach 'steady state', a cover will prevent farm animals from breaking legs and stop the wells from gradually filling up with rubbish. Ideally, the top of the cover should be at field level. (Well tops significantly above ground level are easier to locate but can foul farm equipment). Dipwells installed in West Sedgemoor have been crushed into the peat by vehicle wheels; unless it is practical to fence off the area where the dipwells are sited, there is little that can be done to prevent this. If the water levels within the wells are recorded relative to the top, care should be taken to monitor any vertical movement which, experience confirms, can be in either direction. A 'dipflash' can be used to simplify the manual recording of water levels relative to the top of the well (IH Report 43, Appendix I, 2nd ed., Sept 79).

10. Rainfall data

10.1 SUMMARY

Much has already been written on the correct operation of raingauges (e.g. Observer's handbook, 4th ed., 1982, Met. Office, HMSO). Aspects of raingauge operation specific to areas of low-lying land will be considered in this section.

Rainfall over low-lying areas tends to be lower than over nearby higher land. Where a low-lying area lies within an extensive area of comparable terrain, the existing raingauge network will almost certainly include some gauges near enough to be useful. However, small areas of low-lying land which are surrounded by higher land may well be deficient in raingauges. An attempt to use gauges on surrounding higher land is inadvisable, even if they are not far from the site of interest. On the West Sedgemoor catchment, raingauges sited on land 50 m higher, some 3 km distant from a gauge installed in the centre of the moor, gave readings consistently 10% higher than the gauge on the moor.

The spatial variation in rainfall over a low-lying area is considerably less than for an area of high relief where two gauges close together but on opposite sides of a mountain ridge can often record very different rainfall. A single raingauge was found to be adequate for each of the three catchments described in this report, none of which exceeds 50 km^2 in area.

10.2 RAINFALL DATA INTERVAL

If a gauge is specifically installed as part of an experiment, a decision will be needed on the data interval to be adopted. If hydrological modelling is to be undertaken, an interval as low as 15 minutes may be required. This clearly calls for an automatic gauge. Alternatively, if the rainfall data are needed only for water balance studies, a daily-read gauge will be adequate. Finding a 'reader' though may be more difficult (or expensive) than using an automatic gauge set to a 24-hour interval.

11. Wind effects

11.1 SUMMARY

Wind can distort the surface of any body of water, altering or even reversing the natural water surface gradient. The extent to which any given free water surface is affected depends upon several factors. The most important of these immediately adjacent to the pumping station while Site 4 is several km to the south. When the movement of the depression is such that the wind direction is from the south, the coincidence of the drain alignment with the wind direction leads to the maximum reversal of water levels at Sites 1 and 4. Compare Fig. 11.1 with Fig. 5.1 (which illustrates the typical drain surface levels during a series of pumping events) and contrast the differences in water levels immediately after a 'pump-run'.

12. Tides

12.1 PUMPING AGAINST A TIDAL WATER LEVEL

Some pumping stations discharge to a water course which is subject to tidal influence. The flow rate of most pumps is at least partly a function of the hydraulic head which they are required to pump against. In order to measure the flow rate of a pumping station, a record of the head across it will usually be required. An alternative approach is available where a known relationship exists between power consumption and the volume of water pumped, providing it is possible to record power consumption (Section 7). Some pumping stations discharge into a watercourse equipped with a tide recorder. If there is not a tide recorder at a pumping station, there may be one sufficiently close to be of use. In the absence of a tide recorder, a decision to implement one needs to be justified in terms of the value of the resulting data. Tide recorders were found at Boy Grift and West Sedgemoor pumping stations. Newborough pumping station discharges to the River Welland at a point above the tidal limit.

Archimedean screw pumps are in a separate class from most other pumps regarding discharge levels. These pumps have to discharge at or above the water level of the receiving watercourse. If this is tidal, then the pumping station will be built in such a way that the top of the screw is always above the highest possible water level. This makes the computation of the hydraulic head much simpler as there is no need to monitor the water level in the receiving watercourse.

13. Drain weed

13.1 IMPLICATIONS OF DRAIN WEED

Excessive weed can increase the resistance to flow and accentuate normally modest water level gradients. Weed growth in drains is always seasonal; if a catchment is to be instrumented in winter it is a good idea to survey the

Figure 14.1 illustrates the rainfall and water levels at two recorder sites at Boy Grift during July 1988. The trace representing the water level at Site 1 immediately adjacent to the pumping station shows that the levels, at which the pump cuts in and out, are not well defined. The correlation between the rainfall and pumping activity (reflected by the drain level at Site 1) can be appreciated. The water level at Site 4 (6.4 km from the pumping station) clearly shows that pumping still influences the water level at that point.

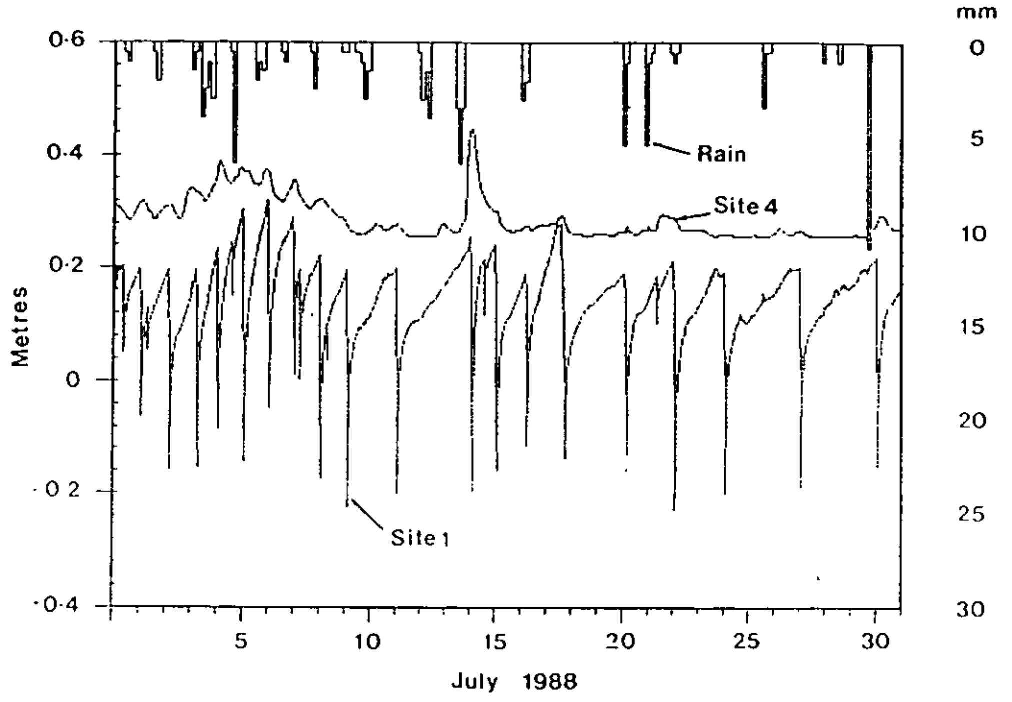

Figure 14.1 Example of monthly graph, Boy Grift Drain

15. Vandalism

15.1 INCIDENTS

Two water level recorders were vandalised at the Newborough site after the equipment had been in place for over three years. The first incident took place during the school Easter holidays, the second during the school summer holidays of the same year, 1983. In the first incident, the top was smashed off a small padlocked plywood box, containing a water level recorder and data logger, attached to the top of a PVC stilling well (Site 6 on Fig. 1.2). Although fragments of the box top were later noticed nearby, no trace was found of the recorder or logger. This site was adjacent to a bridge taking a minor road over the drain being monitored and was clearly visible from the road. The box was easily accessible.

Plate 15.1 shows the water level recorder at Site 5 on the Newborough Fen catchment; the vandalised recorder at Site 6 was very similar. The thin plywood box with an overhanging roof is now recognised as being too weak and is no longer used.

Plate 15.1 Water level recorder, Site 5, Newborough Fen

15.2 VANDAL-PROOF WATER LEVEL RECORDERS

As a result of the vadalism at Newborough, thought was given to the redesign of the water level recorder assembly. The PVC stilling wells are quite strong and would need a considerable sustained effort with a saw to make any impression on them. It was clear that the major problem was the comparative weakness of the enclosure of the recording equipment on the top of the stilling well. The solution was to eliminate the box completely and place the equipment on two shelves inside the top of the stilling well, which was then covered by a steel cap. A bolt passing through both stilling well and steel cap, having a flange on one end and a padlock on the other, was then used to lock the cap in position (see Plates 5.1 - 5.7). All subsequent recorders have been constructed in this fashion and no further vandalism has been experienced.

One other potential mode of vandalism would be to interfere with the lateral restraint of a stilling well. The stilling wells are usually driven into the drain bed but there will inevitably be a requirement to provide restraint near their top as well. This normally consists of steel bands held in position by nuts and bolts. If possible, the fixings should be inaccessible and the stilling well positioned such that, if it were to be released, it would not hit anything important such as gas or electricity conduits which are sometimes attached to the sides of a bridge.

Summary

The report has described experience in instrumenting three low-lying catchments for research purposes. A summary of the resultant data sets is appended.

Acknowledgements

The author would like to acknowledge the considerable assistance afforded by the several organisations and individuals who were involved in the research on the three sites included in this report.

Newborough Fen

The North Level Internal Drainage Board assisted in the initial instrumentation. In particular, Peter Charnley and Stephen Morris are thanked for their assistance with the fieldwork and the subsequent analysis. Survey assistance was also afforded by the Peterborough office of the Anglian Water Authority.

Appendix

DATA SUMMARY

NEWBOROUGH FEN

DAYS WITH DATA FOR 1979

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
DEC	31	31	0	31	0	0	0	13	26
ANNUAL TOTAL	31	31	0	31	0	0	0	13	26

DAYS WITH DATA FOR 1980

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	27	29	0	27	11	31	0	31	31
FEB	29	29	0	29	0	11	10	28	29
MAR	31	31	0	31	4	26	29	26	31
APR	30	30	0	30	25	7	22	8	30
MAY	31	31	0	31	0	31	0	30	31
JUN	18	30	11	30	11	30	0	29	30
JUL	21	31	31	31	10	31	0	21	31
AUG	31	7	31	31	24	9	0	30	31
SEP	30	27	30	30	30	9	0	28	30
OCT	31	31	31	31	31	2	0	31	31
NOV	30	30	30	6	6	24	0	29	30
DEC	31	31	31	29	29	31	0	30	31
ANNUAL TOTAL	340	337	195	336	181	242	61	321	366

DAYS WITH DATA FOR 1981

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	31	31	31	26	31	31	0	30	31
FEB	28	28	28	28	28	28	0	28	28
MAR	31	0	31	0	31	31	0	30	31
APR	30	21	30	21	30	30	0	29	30
MAY	26	31	31	31	31	31	0	31	31
JUN	30	30	30	30	30	30	0	1	30
JUL	31	31	31	31	31	31	0	0	31
AUG	31	31	31	31	31	31	0	0	31
SEP	30	30	30	28	30	30	0	0	30
OCT	31	31	31	31	31	31	0	0	31
NOV	30	30	30	30	2	2	0	0	30
DEC	6	6	11	6	0	0	0	0	31
ANNUAL TOTAL	335	300	345	293	306	306	0	149	365

DAYS WITH DATA FOR 1982

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	29	31	0	31	0	0	0	0	31
FEB	27	28	0	28	0	0	0	0	28
MAR	0	31	31	31	30	30	0	0	31
APR	25	30	30	30	5	5	0	0	30
MAY	23	31	31	31	21	21	0	0	31
JUN	30	30	30	30	30	30	0	0	30
JUL	21	31	31	31	31	31	0	0	31
AUG	20	31	31	31	11	11	0	0	31
SEP	30	30	30	30	0	0	0	0	30
OCT	30	30	30	31	0	0	0	0	31
NOV	30	17	30	30	0	0	0	0	30
DEC	31	0	31	31	0	0	0	0	31
ANNUAL TOTAL	296	320	305	365	128	128	0	0	365

DAYS WITH DATA FOR 1983

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	31	0	31	31	0	0	0	0	31
FEB	28	0	7	28	0	0	0	0	28
MAR	31	24	24	30	0	0	0	0	31
APR	30	13	30	30	0	0	0	0	30
MAY	31	12	31	31	0	0	0	0	31
JUN	26	30	30	30	0	0	0	0	30
JUL	0	31	31	30	0	0	0	0	31
AUG	0	31	31	31	0	0	0	0	31
SEP	0	30	30	30	0	0	0	0	30
OCT	27	31	31	31	3	0	0	0	31
NOV	30	30	30	30	0	0	0	0	30
DEC	31	31	31	31	0	0	0	0	31
ANNUAL TOTAL	265	263	337	363	3	0	0	0	365

DAYS WITH DATA FOR 1984

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	31	31	31	12	0	0	0	0	31
FEB	29	29	29	22	0	0	0	0	29
MAR	31	31	31	31	0	0	0	0	31
APR	30	30	30	29	0	0	0	0	30
MAY	31	31	31	31	0	0	0	0	31
JUN	29	14	30	30	0	0	0	0	30
JUL	31	7	31	30	0	0	0	0	31
AUG	31	19	31	31	0	0	0	0	31
SEP	30	9	30	30	0	0	0	0	30
OCT	12	31	31	31	0	0	0	0	31
NOV	0	6	6	7	0	0	0	0	30
DEC	0	0	0	0	0	0	0	0	31
ANNUAL TOTAL	285	238	311	284	0	0	0	0	366

DAYS WITH DATA FOR 1985

	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8	RAIN
JAN	0	0	0	0	0	0	0	0	31
FEB	0	0	0	0	0	0	0	0	28
MAR	0	0	0	0	0	0	0	0	31
APR	0	0	0	0	0	0	0	0	30
MAY	0	0	0	0	0	0	0	0	31
JUN	0	0	0	0	0	0	0	0	30
JUL	0	0	0	0	0	0	0	0	31
ANNUAL TOTAL	0	0	0	0	0	0	0	0	212

Notes

Notes