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LOCAR/JIF Proposals for Infrastructure and Monitoring on the LOCAR Catchments

A report prepared by the Task Force on behalf of the Technical Expert Group for the LOCAR Thematic Programme Steering Committee

Commissioned Report CR/04/131N

BRITISH GEOLOGICAL SURVEY

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Foreword

This report was produced in 2000 by the LOCAR Task Force to provide a review the existing data and infrastructure in each of the three LOCAR catchments (The Tern, the Pang/ Lambourn and the Frome/Piddle), a review the monitoring and infrastructure requirements to support the LOCAR Thematic Programme and an estimate of the costs involved in delivering those requirements.

This report was not published in the BGS report series in 2000 as it was seen as a working document for the Project Management Consortium (PMC), who were charged with the responsibility for the design and for overseeing the installation of the infrastructure, and for the Infrastructure Management Board to which the PMC reported. However, now that the infrastructure is installed and LOCAR research projects have commenced, it has been realised that there is a need to make the Task Force Report more widely available as it contains much information that is of interest to the researchers. Thus it is now being presented (some four years later) in the BGS internal report series. The Appendices to the Task Force Report are not included, however they are available through the LOCAR Data Centre (http://www.nerc.ac.uk/LOCAR).

It should be noted that, during the installation of the LOCAR infrastructure, a number of changes were made to the overall extent of the infrastructure as well as to the installations at individual sites. These changes were made for a number of reasons including: difficulties with arranging access at some locations, unforeseen ground conditions and budgetary considerations.

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John Tellam, Dick Bradford and Adrian Butler wrote reviews of modelling in the three catchments.

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1.1 BACKGROUND

The LOCAR Thematic Programme will undertake detailed, interdisciplinary programmes of integrated hydro-environmental research relating to the storage-discharge cycle and groundwater-dominated aquatic habitats in the three flagship catchments of the Frome/Piddle, Pang/Lambourn and Tern. In addition to hydrogeological monitoring networks, instrumentation will be established to monitor surface and atmospheric water and ecology of each catchment

The LOCAR research programme will address the following questions:

(i) What are the key hydrological processes controlling surface water-groundwater interactions and the movement of groundwater in lowland catchments?

(ii) What are the key physical, chemical and biological processes operating within the valley floor corridor which affect the surface water and groundwater?

(iii) How do varying flow regimes control in-stream, riparian and wetland habitats?

(iv) How does land use management impact on lowland catchment hydrology, including both water quantity and quality?

(v) How can the hydrological, hydrogeological, geomorphological and ecological interactions resulting from natural or anthropogenic changes be predicted using integrated mathematical models?

LOCAR will provide unique long-term outdoor facilities to support the research required.

The thematic programme has an allocation of £7.75M with the addition of an approved JIF (Joint Infrastructure Fund) bid for £2M for equipment and infrastructure funding for the LOCAR catchments.

The approved JIF-LOCAR funding is earmarked approximately as follows:

Hydrogeological (saturated zone) – £1M

Hydrological – £0.66M

Ecological – £0.34M

Prior to the setting up of the LOCAR/JIF Task Force it was recognised that the JIF funding alone would be insufficient for LOCAR baseline infrastructure and equipment requirements. These were estimated at £5M, indicating a further £3M from LOCAR would be necessary.

At the first meeting of the NERC LOCAR Steering Committee held on 29 July 1999, the requirement for LOCAR Thematic funding to support the JIF money was recognised. Also recognised was the separate, but parallel, responsibilities and financial accountability of the JIF consortium and its contractors to the two funding agencies relating to the experimental design, installation and management of the baseline monitoring equipment. A Technical Expert Working Group (TEG) was established in order to address these responsibilities.

To support the TEG, a Task Force was established to begin the process of experimental design. The Task Force was due to report in December 1999 to the TEG. The Terms of Reference for the Task Force are included in the Appendix to Chapter 1.

The first draft report was discussed at a meeting of the TEG on 20 December 1999. In responding to discussion and feed-back from the TEG, Chapters 3, 4 and 5 were redrafted with amended proposals and recirculated for discussion by the TEG on 28 January 2000. Further adjustments to proposals were made as a result of these discussions. Thus this current document represents the considered proposals of the Technical Expert Group, after three interations with the Task Force.

1.2 THE REPORT

In satisfying the objectives given in the TOR the report provides:

(i) a discussion of the approach to monitoring and a generic strategy (Chapter 2);

(ii) a catchment specific strategy, a review of existing data and infrastructure, monitoring and infrastructure requirements, costing including recurrent costs (Chapters 3, 4 and 5);

(iii) a discussion of important non-science issues, such as catchment management, project management, etc (Chapter 6);

(iv) a summary of costs and proposals (Chapter 7);

A number of Appendices cover the following subjects:

(i) metadata catalogues;

(ii) background reviews of hydrology, geomorphology, hydrogeology and ecology;

(iii) reviews of models of the three catchment areas;

(iv) additional maps.

2 Approach and methodology

2.1 INTRODUCTION

In order to sensibly instrument a catchment for long term research monitoring it seems advisable to adopt a consistent approach or methodology. In the process of developing approaches the following issues have to be taken into account:

- LOCAR aims and central questions;
- individual catchment characteristics;
- requirements for the research programme to be multidisciplinary and integrated;
- budgetary considerations;
- the meaning of 'baseline' monitoring;
- existing monitoring network and facilities and perceived gaps in these systems.

2.2 SURFACE AND NEAR-SURFACE HYDROLOGY AND HYDROCHEMISTRY

For hydrology (including physical hydrology, surface water hydrochemistry and fluvial geomorphology), the Task Force had four main objectives, which are in line with overall objectives of LOCAR:

- to recommend deployment of instrumentation that can reasonably monitor the distribution of fluxes in time and in space within each of the catchments;
- to allow a medium to long term appraisal of the changes with time of these fluxes and storages that can be related to changes in climate, catchment land use and various management practices within the catchments. These changes might include agricultural intensification, soil drainage, flood plain management for conservation, flood risk management, agriculture, increased or decreased water resources exploitation, urbanisation or industrialisation;
- to establish the nature of the processes involved in streamflow generation, especially by surface-groundwater interactions in the riparian zones. This will provide the functionality of subsequent integrated catchment models;
- to provide the basic data that can be used to calibrate and validate integrated hydrological, hydrochemical, hydrogeological, geomorphological and ecological models of the catchments that can be used predictively for catchment management schemes and to assess the impacts of environmental change.

The following sections consider appropriate instrumentation throughout the LOCAR catchments, in the light of modelling concepts and with a particular focus on important interfaces between the atmosphere, surface, subsurface unsaturated and saturated zones.

2.2.1 Conceptual Models of catchment behaviour

The simplest and most common, way of looking at how a catchment responds to atmospheric inputs in the form of liquid and solid precipitation, energy, momentum, and various gaseous, solid and liquid materials, is by use of a tank model. The main compartments or interfaces within most conceptual catchment hydrological models are:

- the atmosphere;

- the boundary layer;
- the vegetation canopy;
- the soil surface;
- the organic layer;
- the root zone;
- the capillary zone above the zero flux plane;
- the drainage interface of the unsaturated zone;
- the unsaturated zone, which itself can be split vertically into layers;
- the saturated zone.

In addition there are lateral flows within the catchment that cross the following domains or boundaries before water and materials appear in the channel.

- throughflow;
- fissure flow in the unsaturated zone;
- groundwater flow;
- re-emergence in the riparian zone;
- bank and bed effluence (and influence);
- channel flow.

The monitoring strategy must therefore be concerned with adequate quantification of these fluxes and stores and in defining their spatial variability. To investigate the ultimate fate of water and materials within a catchment system, attempts must be made to assess the importance of partitioning in each of these layers by estimating fluxes across the interfaces. In groundwater dominated systems, the processes involved in the upper layers of the catchment control movements to the groundwater system, and either directly (by throughflow, near surface, surface or channel runoff) or indirectly (via the groundwater system) to the main river channel.

The interaction between surface and groundwater makes co-location of instrumentation worthwhile at various representative sites within each catchment – so called 'recharge' sites. There should also be a differentiation between 'main-sites' where a large range of relevant properties are measured, at co-located boreholes and hydrogeological instrumentation, and 'subsidiary sites', where only a subset of surface and near surface instrumentation is deployed to improve spatial discrimination and verify the performance of models developed on 'main-site' data. The standard sites may not need to be associated with hydrogeological sites.

2.2.2 Strategies for instrument network deployment

While the catchment water balance does not indicate the internal processes of the catchment, especially those of streamflow generation by surface-groundwater interaction, it nevertheless serves to illustrate the importance of achieving a high degree of accuracy in estimation of certain fluxes in the water balance. This is especially true of catchments where streamflow is a small residual amount relative to the two larger fluxes, rainfall and evaporation. An objective of the proposed instrumental networks is to quantify catchment rainfall, evaporation and river discharge to within 5% on an annual timescale.

Rainfall, flows, soil moisture, groundwater data and water chemistry are available for all catchments. It is important to note that LOCAR needs to cover the evaporation component effectively. Although evaporation exceeds river flow in each of the LOCAR catchments, it is not well covered by existing networks. There is also a need to assess the density of instrumentation networks required for long term monitoring as part of a field measurement network and to identify the need for additional "one-off" and routine surveys to establish catchment characteristics and parameters. Some aspects of network design and installation will inevitably be iterative, based on analysis of data as it stands from existing instruments, and initial data from 'trial' augmentation of the networks. The purpose of LOCAR is to equip the catchments with a basic suite of instrumentation that is sufficient to provide underpinning baseline data for the LOCAR Science Programme.

Estimation of above surface and shallow sub-surface fluxes will be relevant to many parts of the LOCAR research. Individual fluxes will be important for a range of studies being carried out within the catchments (e.g. hydrochemistry and soil erosion). Linking them can provide estimates of recharge to the water table at various points in the catchment. To model this integrated system means that recharge estimates have to be provided for parts of the catchment that are representative of the major environmental units (or domains) in terms of vegetation cover, soils, topography and the spatial variability in the unsaturated zone. A knowledge of the characteristics of the uninstrumented domains is also required, therefore catchment survey and use of GIS becomes extremely important.

The provision of this 'baseline' information is fundamental to the LOCAR Programme. In each of the following sections instrumentation (including numbers, frequency, siting and use of measurements) and other related needs are addressed in a logical top-down sequence, with an emphasis upon the atmosphere/vegetation/soils, unsaturated zone and channel interfaces.

2.2.3 Precipitation Measurement Strategy

The philosophy of rainfall measurement and the degree to which the Environment Agency (EA)/Meteorological Office (MO) networks fulfil the needs of the LOCAR infrastructure is outlined below.

PERIOD RAINFALL

The majority of gauges in all LOCAR catchments are of the daily- or near-daily read Met. Office 5" standard pattern. To obtain accurate, spatially-averaged, catchment rainfall, it is necessary to ensure that the coverage is sufficiently good to develop a realistic rainfall surface and a descriptive rainfall model for each catchment. In upland areas with steep rainfall gradients this is often difficult, with twofold increases with altitude not uncommon, but in the lowlands the gradients are gentler.

Gauges sited in exposed locations should be paired standard and ground level gauges to allow for systematic errors caused by wind. Their capacities will have to be greater than the standard daily gauge, maybe even up to the equivalent of the 'octapent' raingauge (c. 600 mm), if they are not to be read on a daily basis like the rest of the network.

SNOW

Snow is not generally a problem in the West Berkshire Downs, in Dorset or in Shropshire in most years, but it cannot be discounted and may become more of a problem if there is ever a return to colder conditions than experienced over the last decade. Snow can introduce a source of error in precipitation measurement, particularly recording gauges during freezing or windy (drifting) conditions. Its accurate measurement can be critical, as it can be an important source of gentle recharge during thaw. It can also present measurement problems due to the specific conditions set up in vegetation canopies that causes wide variations in evaporation (interception) rates.

In general, provided the sites are reasonably sheltered from the wind and the reservoirs are below ground and able to take advantage of geothermal warming and insulation, the Meteorological.Office standard pattern raingauge records snow reasonably accurately as a period (daily) input. To ensure this, MO regulations regarding daily melting of solid funnel contents must be adhered to. Within-day timing and the spatial distribution of melt however could present difficulties.

HOURLY RAINFALL

The number of gauges in all the LOCAR catchments is insufficient to provide a good approximation of the short-term rainfall or rainfall intensity surface. The current networks in all the LOCAR catchments include at least two recording gauges, either in the catchments or just outside. Ideally at least six gauges would be required in each catchment (or pair) to cover the likely spatial variability in rainfall intensities. This is especially true for convectional storms, and means that, in addition to the two proposed for AWS sites, at least two more recording gauges need to be installed in each catchment.

RADAR SYNOPTIC RAINFALL AND GROUND TRUTH

Further interpolation of the rainfall intensity data from the recording gauge sites might be possible using the Chilbolton radar facility, but is unlikely to be included on cost grounds. However, if used as part of the Scientific Programme, the network of recording gauges can provide adequate ground truth calibration data.

2.2.4 Design of measurement network for the assessment of water storage and fluxes in the soil-vegetation-atmosphere (SVAT) zones

The objective of these measurements is to provide basic information of the water balance and storage in the unsaturated region of the catchments. The fundamental requirement for the networks is to obtain areal average estimates of the components of the water balance, taking into account the spatial distribution of inputs, soils and vegetation. It is therefore highly desirable that the LOCAR network provides spatially distributed estimates of the components. One aim would be to provide estimates on a one kilometre grid. To resolve topography and land cover it will be necessary to map to a finer scale, down to the 20 m grid of the Institute of Terrestrial Ecology land use map and 50 m of the available Digital Terrain Model. It is impractical, and unnecessary, to consider comprehensive measurements over a complete grid across the catchments. A stratified sampling strategy should be adopted which takes into account the expected spatial variability of each component. However, what is important is the eventual availability of information on the parameters used in the model on a raster basis across the catchment.

CLIMATE MEASUREMENTS

The main objective of the climate measurement is to provide the atmospheric forcing to the evaporation estimates. It is recommended that measurements sufficient to drive the basic Penman-Monteith evaporation equation be taken: viz. Net radiation, humidity, air temperature, and wind speed. With the exception of net radiation, these variables are essentially independent of surface type. It is further recommended that net radiation be measured over a grass surface, thus providing standard reference crop potential evaporation. This should also be augmented by net radiation measurements that are specific to land cover type, as part of the flux measurement system. The addition of solar radiation will provide a means of extrapolating the net radiation to other land cover and to slopes. Finally it makes sense to add a recording raingauge to the measurement system as coarse models of evaporation rely on a knowledge of vegetation and canopy wetness, which is itself related to rainfall periodicity and intensity. The measurements should be made (actually, accumulated or averaged) hourly, to resolve the diurnal variation of the driving variables.

SOIL MOISTURE MEASUREMENTS

These measurements will be an important adjunct to the evaporation work, to indicate the level of feedback from soil moisture deficits to stomatal conductance, and also because evaporation represents a major component of the soil water balance from which recharge and streamflow can be estimated (see 2.2.5).

EVAPORATION MEASUREMENTS

(a) Potential evaporation **—** Potential evaporation, using Penman, variations on Penman, and other formulae, can be calculated with standard climate data from manual daily or synoptic (3-hourly) stations, but is better done (and necessarily so in the case of Monteith's hourly calculation) from hourly accumulations or averages from logged automatic stations. These climate data will be critical for extrapolation or interpolation of fluxes to all grid squares or whatever land unit is chosen for the integrated models (vegetation/soils/topographical domains, hillslope units, etc.) on the catchment. While stations outside the catchment can be used in areas of shallow climate gradients, the extra precision derived from internal stations will be worth the investment, and for a variety of environmental studies. As a stop gap prior to AWS data coming on line, and as a means of back-calculating PE for previous years, MORECS estimates can be used as a PE index for each catchment.

(b) Actual evaporation fluxes **—** The provision of continuous measurement of evaporation fluxes through the eddy correlation techniques represents an exciting and challenging prospect in its own right. However in the context of LOCAR it is also a crucial measurement in the attempt to estimate recharge. Eddy correlation has been available as a technique for over 40 years but it is perhaps only recently, with the development of advanced logging systems, that it is practical to consider it as a technique for long-term monitoring.

Evaporation depends strongly on the land cover type (and to a lesser extent the soil type). The deployment strategy must therefore take into account the distribution of vegetation and soils within a catchment. Cost, availability and suitable sites will also limit the deployment of these instruments. It is recommended that HYDRA 3 systems are installed, preferably in each catchment, over the predominant land cover/soil combinations. The full systems could be supplemented by between two and four of the SolHF systems, to be deployed in the minor land cover types if funds allow. This equipment may moved around the catchments.

Each system should also include a net radiometer and soil heat flux plates. It would also be sensible to co-ordinate the flux sites with soil moisture measurement sites.

2.2.5 Soils/unsaturated zone

THE CRITICAL ROLE OF SOIL/UNSATURATED ZONE PROCESSES IN PERMEABLE CATCHMENTS

One of the major unknowns in catchments where the hydrology is dominated by groundwater storage and flow, and therefore one of the factors it is most necessary to quantify, is groundwater recharge. Recharge is controlled not just by rainfall availability but also by the soil-vegetation-atmosphere (SVAT) interactions that determine how much water is finally available to drain below the rooting zone once all other demands have been satisfied. This process is clearly very variable in both space and time. To see the full picture, these fluxes have to be measured or estimated over a number of years to pick up the effects of climate variability, and at a number of locations to take into account the spatial heterogeneity of soils, the unsaturated zone and overlying vegetation and land use.

A considerable body of work has been carried out on SVAT interactions in the UK, with a number of studies concentrating on sites over the Chalk. The processes are now beginning to be understood, and the areas where knowledge is still lacking are being clearly identified. The processes of evaporation and soil moisture/unsaturated zone controls on upward water movements will be critical in the integrated modelling of catchment hydrological behaviour and all other processes dependent on this.

It is also recommended that soil water flux observations be made to facilitate direct comparison with atmospheric flux measurements, either co-located or a little upwind of the atmospheric flux instrumentation. This will give a mutual check on the two sets of measurements as well as allowing the atmospheric measurement to be used for estimation of evaporation when there is no Zero Flux Plane (ZFP). The soil water instrumentation should also be co-located with any hillslope runoff equipment, in view of the potential importance of surface runoff for the soil water balance or rather vice versa, as hillslope intensity threshold (or Hortonian) runoff studies will be part of the Science Programme.

Various computer programs exist (although they will require some adaptation) to calculate the soil water balances from soil water observations. It is recommended that the database should include these procedures as a semi-automatic and routine calculation.

MEASUREMENT OF SOIL WATER CONTENT

Measurements of soil water content and soil water potential (and the changes over time derived from them) will be key information contributing to the understanding of catchment water balances, and for interpreting hydraulic behaviour of soils and understanding the responses of vegetation to fluctuations in soil moisture. Fluctuations in soil water content and soil water potential should be measured in all major representative soil/vegetation combinations in the catchment. Observations have shown that fluctuations in Chalk can be observed down to around 5 m depth, even in a summer with adequate rainfall. The changes observed are probably related to drainage rather than upward movement. To ensure an adequate sampling depth in dry summers, particularly under trees, the profile should extend to 8-9 m. It is also thought appropriate, at one site, to measure down to 30 m depth.

(a) Neutron probes — Current sites in the Pang and the Tern employ, exclusively, neutron access tubes. The Pang sites have been measured for the last three years and could presumably be taken over as part of the LOCAR networks, although the siting philosophy for LOCAR may be more geared to looking at a downslope (catena) cascade of processes than individual randomly located soil types. Downslope processes need not be studied in contiguous soil domains to get a true picture of catchment behaviour. This conclusion is reinforced by the observed dominance in Chalk catchments of vertical rather than the sub-horizontal movements of water that occur in upland situations.

(b) Capacitance or Time Domain Reflectometry (TDR) probes — Monitoring of soil moisture at various depths can be carried out using probes attached to an IH 'Soil Water Station' or Theta probe attached to a data logger. This provides indices of soil moisture content profiles at regular and frequent time intervals that can then be calibrated by less regular neutron probe readings. TDR readings need to be made in the near surface layers, where neutron probes do not work well.

(c) Practical considerations in soil moisture measurement — A major problem for soil moisture sampling by neutron probing and other permanent means in agricultural fields subjected to rotational and seasonal land management is potential damage and disruption to installations. The programme funding should anticipate the need to reinstall some networks, perhaps even on a regular basis, or to rent sample plots and to have resources committed to managing these to emulate the surrounding land use. A proposal to use angled access tubes and potentiometers to counteract these problems is outlined in more detail in Chapter 5 for the Tern catchment.

MEASUREMENT OF SOIL WATER POTENTIAL

(a) Conventional tensiometers — The conventional type of tensiometers, consisting of porous pots linked to mercury manometers, should be avoided on the grounds of unreliability and potential toxic hazard. A new type of tensiometer has been developed, and utilised successfully at the IH site in Black Wood, Hampshire. This is known as the 'puncture tensiometer'. It is cheaper than the mercury unit and counteracts many of these problems. It consists of a conventional porous cup probe, but is connected at the top through a rubber bung via a syringe to a portable tension meter.

(b) Equi-tensiometers — A recent innovation for the measurement of soil matric potential is the 'Equitensiometer'. Their strengths are their robustness, their data logging potential and low maintenance requirements. The technology for installing them to depths of 9 metres is sound. They should perhaps always be installed in combination with conventional porous pot tensiometers for accuracy and precision throughout the full range of matric potentials.

(c) Large scale underground facility or hillslope process facility — Early stage designs have been developed by IH for inovative facilities to observe hydraulic and biochemical processes in experimental facilities, but are beyond the scope of baseline monitoring.

2.2.6 Valley bottoms and riparian zones, especially wetland areas

These generally occur in the critical zone of interaction between surface and groundwater that forms one of the main research thrusts of LOCAR. They also provide much of the conservation interest in catchments, ensure their ecological diversity, and if carefully managed have the potential to form protection zones for the river corridor. The absorption, storage, evaporation and throughflow characteristics of wetlands are different from that of surrounding terrestrial systems and in many situations they have an impact on hydrology and water quality, that is disproportionate to the area of the catchment that they occupy. Wetlands are often attributed many important hydrological functions, including flood reduction, low-flow support, groundwater recharge and water quality improvement through nutrient cycling. However, at present there is very little detailed understanding of wetland functions and the way in which they interact with the rest of catchments. Wetlands are therefore, worthy of scientific interest in relation to both process understanding and environmental management.

Wetlands occur in a variety of hydrological, hydrogeological and topographic settings, so their interactions with river flows are complex. A distinction can be made between:

- "floodplain wetlands" where the effects of routing exogenous flows are the primary influence of the wetland on river flow regime;
- "non-floodplain" wetlands, which tend to occur where either drainage is impeded or there is groundwater discharge at the surface (e.g. springs caused by a break in slope).

Within LOCAR it is important that consideration is given to the wetlands in the catchments being investigated. Of key importance for understanding wetland hydrological functioning are measurements of water fluxes within representative wetlands:

- surface flow to and from the wetlands;

- rainfall;
- evapotranspiration;
- transects of water table and soil moisture across the wetlands and surrounding higher ground.

Many of these measurements (e.g. transects of boreholes and neutron probe access tubes) are the same as those required to gain understanding of the processes occurring within the unsaturated zone. Consideration should be given to locating at least one of these transects across a wetland area. Determination of chemical fluxes can not only provide insight into hydrochemical functioning, but also elucidate many hydrological processes, although this may be covered within the science projects rather than as a baseline requirement.

2.2.7 Water levels in the riparian areas: interaction of surface, soil, unsaturated and saturated zone processes

It will be important to sample the unsaturated zone processes at various representative positions along typical catena within each catchment, as gross differences in distance to water table (depth of unsaturated zone).

This should culminate in a concentration of effort in the valley bottoms, sampling the various types of riparian areas including ephemerally dry valleys, influent and effluent channels below spring lines, groundwater fed wetlands, and surface water fed wetlands of natural or man-made origin (i.e. water meadow systems). Instrumentation should at a minimum constitute nested and shielded piezometers to investigate changes with depth, close-spaced to elucidate the shape and direction of the hydraulic head surface in the near-channel zone, which might even reverse under certain conditions as was witnessed by Von Helmut & Hommes (1988) on the Rhine. In this region, if not necessarily elsewhere, the piezometers and soil moisture instrumentation should be in close proximity, so that from the combined information it ought to be possible to assess from this whether the channel and groundwater are in hydraulic contact at various places along the stream network.

2.2.8 Streamflow Measurement

FLOW GAUGING STRATEGY FOR THE LOCAR TARGET CATCHMENTS

In each of the LOCAR catchments there is a network of flow gauging structures or rated sections from which continuous flow estimates can be derived for various points in the stream network. All of these sites are (or were) run by the Environment Agency and data reside on the EA database (15-min flow) and/or on the National River Flow Archive (daily flow and summary statistics).

Often, only part of the flow range is catered for, e.g. where alleviation of low flows is a problem. Catering for extreme flows normally results in inordinately high construction costs. Frequently, the shape, cross-sectional area or bed slope of the channel are not conducive to the installation of large, conventional structures even if permission were granted. This makes it necessary to consider a variety of different ways of estimating flows. It may be possible to either:

- interpolate flow to other points on the river, where this might be required to isolate catchments or reaches of particular scientific interest;
- install new structures, or establish rated sections, wherever there is a specific need for flow estimates within the overall or individual scientific study;
- improve existing structures to cope with a wider range of flow;

- better calibration of existing structures with an independent technique such as current metering or ultrasonic velocity measurement, and particularly extending the range for out-of-structure or out-of-bank flows.

Great care will have to be taken to get the most out of the investment in new gauge construction, both the short and long term. Design and construction of appropriate and effective structures is a non-trivial operation. The accuracy needs of operational engineers do not always coincide with those of the scientific community. Resistance to the installation of permanent structures in sensitive areas on environmental grounds may also be encountered. It will always be easier, cheaper and less environmentally disruptive to have a strategy that seeks, in the first place, to improve existing structures and, secondly, to fill in the gaps as necessary.

IMPROVEMENT OF EXISTING FLOW STATIONS

In general, structural alterations at existing stations will be difficult to achieve and even more difficult to obtain permission to carry out. Most structures are designed following planning and negotiating by the EA with riparian landowners, conservation and fisheries interests, and with a view to not exacerbating flood risks. Site characteristics often determine channel capacities etc. and the view can be taken that existing structures are as they are for very good reasons, including their original design purpose, e.g. low flow assessment. It may be possible to make some improvements to the operation of some of the gauges to obtain more accurate flow data throughout the flow range. These improvements are listed below (although more detailed location specific considerations can be found in relevant sections):

- crest tapping and/or tail water level monitoring for non-modular flow conditions;
- improved flow station calibrations (dilution gauging and/or current metering).

INCREMENTAL FLOW ESTIMATES

There are numerous ways of obtaining such flow estimates, some relying on a mathematical approach and some requiring additional measurements to be made.

- interpolation — This is probably the easiest and cheapest way of providing flow estimates at any point in the stream. However, it clearly assumes some form of linear flow growth curve between stations, either related to stream length or to contributing (surface) catchment area;
- temporary structures or spot gaugings;
- continuous hydraulic approach.

COPING WITH EPHEMERAL STREAMS

This might in the first instance involve daily observations by catchment technicians, but might eventually be superseded by model predictions based on relationships between these preliminary observations and flows measured at various downstream gauges. Regular, i.e. seasonal, aerial photography might also help with this, particularly where the ephemeral head appears and disappears at numerous locations along the ephemeral reach.

2.2.9 Water quality strategy

WATER QUALITY REQUIREMENTS FOR THE LOCAR CATCHMENTS

Nutrient enrichment involving nitrogen and phosphorus species, resulting in excessive growth of macrophytes and algae and reductions in dissolved oxygen levels, is a growing problem in many UK lowland rivers during the summer. It is the result of changes in the balance between agricultural sources, sewage inputs and river flow.

Nitrate is often the principal form of nitrogen and it is derived from both agricultural and sewage sources. Both drainage of groundwater (historically polluted by agriculture: >25 years), and near surface runoff during the winter periods, provide important diffuse agricultural sources, while sewage point sources can also be highly significant during periods of low flow. Other common forms of nitrogen in river waters come from both agricultural and sewage sources and they include ammonium and nitrite as well as organic nitrogen and particulate matter. Although ammonium and nitrite are typically much lower in concentration than nitrate, they can be extremely harmful to stream ecology due to their high toxicity. Within the river, a complex series of hydrobiochemical processes occurs which attenuate the nitrogen speciation between dissolved and particulate phases.

Phosphorus occurs in three principal forms within rivers, two of them as soluble phases, soluble reactive phosphorus (SRP) and dissolved hydrolysable phosphorus (DHP), the other as particulate phosphorus (PP). SRP represents inorganic monomeric phosphorus (i.e. phosphate), while DHP represents a combination of inorganic polymeric forms and organic phosphorus.

SRP is often the principal form of phosphorus in solution, as it is in phosphate rich fertilisers added to the land, and phosphate from detergent sources, which makes up most of the phosphorus in sewage. In terms of diffuse sources from agriculture, SRP is strongly bound to soils and hence the principal phosphorus flux from the land comes during the winter months when fine sediments are mobilised. In contrast, point source inputs of SRP from sewage show their highest concentrations under low flow conditions.

Over the past fifty years or more, there has been an increasing pattern of climate variability in the UK with a trend towards higher extremes of flow both during the summer low-flow and winter high-flow periods. The impact of these changes is most severe in the lowland areas of the south and east of the UK, which experience the lowest rainfall and highest evaporation rates within the country. The trend towards lower summer baseflow conditions in these lowland rivers reduces their natural capacity for dilution of sewage effluent, which results in elevated nutrient concentrations. In many lowland catchments, increasing population pressure, particularly in the South East of the country, has compounded this effect both by increasing nutrient levels entering the sewage systems and by decreasing flows due to greater water abstraction. Indeed, for phosphorus, the reduction of point sources is a key objective for the protection of surface waters under the Urban Wastewater Treatment Directive and the proposed EC Water Framework Directive.

The overall strategy for water quality sampling is to provide as ‘baseline’ the information required to calculate fluxes of as wide a range of solutes as possible, in as many of the catchments and subcatchments as might be targeted by the LOCAR Science Programme. Sites will generally be at main gauging stations in order that the water-borne flux estimates can be used to aid chemical budgeting within each catchment.

Weekly or monthly sampling will be the needed. Comparing and contrasting information from automatic samplers would be worthwhile, preferably running in flow related mode, but at least running for limited ‘campaign’ periods to pick up more high flow samples (say 70 samples per year from each site). It is known from the outset that there will be problems of data interpretation with composite samples, with the setting up of concentration-flow relationships, and with chemical changes on storage in the field. However, it is felt that a double pronged approach would allow individual scientists to make an informed choice of which data stream to use, depending on the water quality determinand being studied. The major constraints on this strategy are financial. The implications on the LOCAR recurrent budget, of chemical analysis, will be severe.

WATER QUALITY MEASUREMENTS

There is a primary need to measure the nutrient levels (nitrate, nitrite, ammonium, organic-N, particulate-N, SRP, DHP and PP), pH, dissolved carbon dioxide dissolved oxygen, chlorophyll-*a*, suspended sediments and general water quality, as these directly relate to the water quality issues described above. However, there are equally important hydrological research needs within LOCAR to provide chemical tracers for determining quantitatively groundwater source inputs, groundwater variability, water transit routes, within stream water residence times. These tracers also provide markers for agricultural and sewage sources. Within our lowland studies, such markers include:

- dissolved carbon dioxide; this provides a measure of local groundwater sources to stream flow generation;
- boron and chloride; these provide natural chemical dilution gauging information, where point source inputs from sewage works dilute in a chemically conservative manner along the stream channel in response to groundwater and tributary inputs;
- calcium and alkalinity; they provide a chemically conservative measure of the mixing of groundwater sources of high alkalinity with low alkalinity rainfall.

It is proposed that the chemical analysis includes the major ions and trace metals to infill the missing information. This resource will also provide a means for determining quantitatively key underlying mechanisms. For example, calcium, pH and alkalinity determinations will allow determination of the precipitation potential of calcium carbonate within the river. This is important in relation to the nutrients and biological activity within the river as calcium carbonate co-precipitation can remove phosphate from solution: this mechanism has been proposed as a natural within river self cleansing process. There is also a strong case for examining pesticide distributions given the agricultural nature of the catchment.

Continuous measurements will be taken for pH and dissolved oxygen and this will provide an indication of diurnal patterns of behaviour associated with the within river processes of photosynthesis and respiration.

RECOMMENDED ANALYSIS SUITE FOR WEEKLY/MONTHLY SAMPLES

- Nutrients
  nitrate, nitrite, ammonium, organic-N, particulate-N, SRP, DHP, PP
- Groundwater inflows and biological functioning
  PH, dissolved carbon dioxide, dissolved oxygen, alkalinity, chlorophyll-*a*,
- General water quality
  Suspended sediments, major ions, trace metals

CONTINUOUS MONITORS (15 MINUTE DATA)

- Dissolved Oxygen, Conductivity, pH, Temperature.

To this may be added ion selective electrodes for Chlorophyll, ammonia and nitrate, if these are thought important in individual catchments.

2.2.10 Geomorphology/sediment transport

LOCAR SEDIMENT MEASUREMENT STRATEGY – SITES AND MONITORING EQUIPMENT

Regarding the conceptual framework, for each catchment at least 3 turbidity monitoring sites were sought on the main stream to represent upper catchment, middle catchment and lower catchment. This provides opportunity to:

- measure downstream translation;
- observe within reach characteristics;
- cover major discontinuities (such as upland/lowland interface).

In addition, significant tributaries also need to be covered, and other parts of the river network where LOCAR loggers and bulk-samplers are available. The sediment sites should be in line with the river flow monitoring and WQ sites identified in earlier sections. There are many benefits to be gained through integration of site choices for sediment monitoring, with the hydrometric measurements and WQ as the turbidity sensors represent only a minor additional cost at each site. 15min water discharge data at selected sites (reach and network measurements) will be essential data to derive flux estimates. In addition to weekly/monthly sampling routines, flow related manual sampling will be required as most sediment is moving during the higher flow periods. This requirement will depend mainly upon flow triggered automatic bulk samplers and turbidity monitors. However, experience suggests confidence in automatic systems can only be achieved by some parallel manual effort, particularly during high flow events to check and augment these systems.

2.3 HYDROGEOLOGY MONITORING NETWORKS

The purpose of this section is to discuss the rationale behind the design of hydrogeological monitoring networks. More specifically, to provide the background necessary for an assessment of the options for establishing hydrogeological baseline monitoring networks in three lowland permeable catchments that will be developed by the NERC Lowland Catchment Research (LOCAR) Thematic Programme.

Data and observations from the hydrogeological monitoring networks and instrumentation will be principally used to address the five central questions referred to in the Introduction.

The LOCAR Programme has identified a number of specific tasks or topics that may influence the design of the hydrogeological monitoring network and instrumentation. These may be summarised as follows:

- flow and transport in the Chalk and Triassic Sandstone aquifers are poorly understood and the relationships between flow and transport properties at different scales, i.e. pore scale, borehole scale and catchment scale needs elucidating;
- aquifer heterogeneity is a dominant influence on contaminant dispersion and is not yet adequately characterised. The role of fracture flow in the Chalk and sandstones need particular attention;
- the role of drift deposits in influencing recharge and pollution pathways needs investigation;
- chemical interactions need an understanding of pore and fracture scale processes (including heterogeneity and scaling properties), and the role of, and constraints on, microbial degradation, and hence the scope for natural attenuation of pollutants, require investigation;

- the spatial functioning of the surface water system must be mapped onto an understanding of surface water-groundwater interactions;
- interannual variability in groundwater input into streams is likely to have major ecological impacts and may be strongly influenced by groundwater management. These relationships need investigation;
- integrated modelling should include improved representation of the interaction between surface and groundwater in terms of both flow and quality, transfer of pollutants, impact of land use management change, linkage of ecological responses to changes in the hydrological regime, catchment management strategies and climate variability.

2.3.1 Aims of groundwater monitoring networks and design considerations

Significant effort has been invested in the development of techniques to design groundwater monitoring networks, particularly groundwater quality monitoring networks, in the last few years. Loaiciga et al. (1992) have provided a detailed review of groundwater quality monitoring network design. The principals behind monitoring water quality and water resources are identical; consequently, the following section draws on many of the observations in review by Loaiciga et al.

The design of modern groundwater monitoring networks requires consideration of a range of factors that include the following:

- adequate spatial and temporal coverage of sampling sites;
- balancing potentially competing objectives within a monitoring programme;
- the complex nature of geologic, hydrologic, and other environmental factors;
- the significant uncertainty about many parameters used in the design process;
- the range of applicability of the various methods in network design including their relative strengths and weaknesses.

THE NEED FOR SPECIFIC OBJECTIVES

Good design of groundwater monitoring networks requires clearly stated objects. Loaiciga et al. (1992) suggest that monitoring objectives may typically fit one or more of the following categories:

- ***Ambient monitoring***
  To establish an understanding of characteristic regional groundwater trends with time.
- ***Detection monitoring***
  To identify the presence of targeted parameters, such as contaminants, as soon as they exceed background or established levels.
- ***Compliance monitoring***
  A set of specified groundwater-monitoring requirements, usually for chemical constituents, for example near waste disposal facilities.
- ***Research monitoring***
  Characteristically detailed spatial and temporal groundwater sampling designed to meet specific research goals.

For a given objective or set of objectives it is then necessary to choose an appropriate methodology to design the monitoring network. If the monitoring network is designed on the basis of mathematical models it will be necessary to choose objective functions that represent the monitoring objective (Loaiciga et al. 1992). These objective functions may be 'ultimate objectives' or 'surrogate objectives'. Ultimate objectives consider the value of groundwater information in monitoring goals such as environmental protection, resource availability, reduction in remediation costs or minimising exposure risks or health hazards. Surrogate objectives would be the minimisation of statistical parameters (such as the variance of groundwater levels or contaminant concentrations) or of the maximum difference between actual and predicted values.

STATIC OR DYNAMIC MONITORING NETWORKS

In many groundwater-monitoring programmes the dynamic nature of the programme is an important factor in network design. Network design may be an iterative process, where initial sampling programmes are often revised or updated as a result of previously collected data. In addition, the objectives of the monitoring network may also change with time.

MONITORING SCALE

The monitoring scale is determined by the objectives of the monitoring programme, i.e. data used in analysis should be collected at the same scale as the problem under investigation (Domenico and Schwartz 1990). For example, ambient monitoring is commonly undertaken at the regional scale with an annual or semi-annual sampling frequency, research monitoring may be undertaken at the site scale with much higher sampling frequencies.

SYSTEM HETEROGENEITY

Aquifers are highly heterogeneous and data is rarely available at sufficient density to characterise them deterministically. Consequently, design of monitoring networks involves the use of sparse data to estimate an unknown spatial and or temporal pattern in aquifer properties. An understanding of geological processes and the resulting structures can add significantly to models of aquifer properties (e.g. Fogg 1986). Regional geological structure, topography, and surface drainage patterns can all provide information, which affect the hydrogeology.

To map hydraulic gradients it is necessary to obtain water level or head data over a regional scale over time. In strongly anisotropic aquifer systems the potentiometric head map will not indicate true groundwater flow directions unless the hydraulic gradient is coincident with one of the principal axes of hydraulic conductivity. When the aquifer is anisotropic the degree of anisotropy needs to be characterized.

CONCEPTUAL MODEL OF THE AQUIFER/CATCHMENT

Before a monitoring network programme is planned a conceptual model of the aquifer system should be developed. This should encompass the following aspects:

- geological and hydrogeological boundaries;
- physical structure of the aquifer;
- recharge;
- discharge;
- groundwater flow pattern and mechanisms;
- rock-groundwater interactions;
- effects of unsaturated zone processes.

CONSTRAINTS

- time. Is the monitoring programme to be iterative? Will results from initial phases be used to re-assess the monitoring needs or even aims of subsequent phases?
- money;
- access to appropriate sites within each catchment. Access may be limited by the degree of cooperation from local landowners. Some installations in or near rivers and some activities such as groundwater tracing may have undesirable environmental impacts. Approval may be required from the appropriate regulatory agencies;
- availability of staff with appropriate skills during installation and monitoring;
- technical limitations. There may be technical limitations to data acquisition. Capability to remotely monitor hydrogeological variables and/or limitations to measurement resolution and accuracy.

2.3.2 Aims for LOCAR monitoring networks and factors affecting the design of the LOCAR monitoring networks

What are the specific objectives of the LOCAR monitoring network, and what is the most appropriate approach to meeting those objectives? There are four principal aims for the hydrogeological component of the LOCAR monitoring networks. These are:

(i) provide information on appropriate groundwater parameters to enable a consistent (balanced) model of groundwater flow in each catchment to be constructed;

(ii) provide instrumentation to enable investigation of groundwater processes such as:

- 3-D flow and transport processes as a function of time and place within each catchment;
- scale dependence of flow and transport processes;
- aquifer heterogeneity and role in contaminant dispersion;
- flow and transport in fractured aquifers;
- reactive transport from the scale of pores and fractures to the catchment scale;
- surface water-groundwater interactions;
- ecological impacts of groundwater processes and groundwater management;
- the list is not exhaustive.

(iii) Ensure that the hydrogeological monitoring network is fully integrated with other catchment monitoring networks.

(iv) Establish hydrogeological monitoring networks and instrumentation within budget and within timeframe of the LOCAR Programme.

Given the above aims the LOCAR programme is likely to have the following characteristics:

- the network(s) will be based on research monitoring objectives (Loaicga et al 1992);
- the network(s) need to be amenable to quick design and implementation so that they may be used in the main LOCAR research programme;
- there will be limited scope for iterative development of the monitoring network(s) given the time constraints of the LOCAR programme;

- maximum use should be made of the significant background information, both qualitative and quantitative and hydrogeological and non-hydrogeological.

2.3.3 Options for LOCAR hydrogeological monitoring strategies

The aims of the LOCAR programme place restrictions on the options available for the groundwater monitoring network. The aims of LOCAR are principally to investigate processes and, therefore, the network will be based on research monitoring objectives. If there is a need for ambient monitoring this may be assumed, potentially to be met through the use of the existing arrays of boreholes present in each catchment, as described by McKenzie et al (1994) and Chilton and Milne (1994). In this context, where additional boreholes are needed to provide data for water balance models their development may be seen as a response to a research-monitoring objective. Similarly, boreholes located to define recharge characteristics of the aquifers, catchment boundaries, or additional information on the three dimensional flow regime may also be considered as meeting research monitoring objectives.

If the establishment of the hydrogeological component of the LOCAR monitoring network is to meet research monitoring objectives, what are the problems or benefits associated with each of the basic approaches to groundwater monitoring as applied to LOCAR? The following section briefly describes some of the most important strengths and weaknesses of some of the available approaches.

- Hydrogeologic approach:

  The hydrogeological approach is a good, practical, option that can use prior hydrogeological knowledge. It is flexible in response to research monitoring needs, is appropriate to complex hydrogeological systems, and can be developed more quickly than the statistical approaches. A weak point is that it does not necessarily provide the best information to enable a water balance model to be developed, and that it lacks the rigor of a statistical approach. It is probably the most broadly acceptable approach given the institutional constraints.

- Statistical approach - Simulation:

  This approach is computationally demanding and is difficult to apply to a relatively complex hydrogeological system. It is likely to be inappropriate for most of the research monitoring needs.

- Statistical - Variance based (Global):

  This technique is relatively simple, but is inappropriate for research monitoring needs and is not practical given the constraints on land access and the need to co-ordinate groundwater, surface water and ecological monitoring networks.

- Statistical - Variance based (Variance reduction):

  Along with the optimization approach the most appropriate of the statistical techniques. A multi-variate approach would have to be developed if more than one parameter was to be investigated (e.g. piezometric head, hydraulic conductivity, water quality). This approach would be relatively time consuming as it would require full digital data for each catchment. The use of the approach may be inappropriate for research monitoring needs (i.e. where borehole location is not necessarily determined by the need to reduce uncertainty in measurements, but rather to investigate site specific processes).

- Statistical - Variance based (Optimization):

  This approach is similar to the previous approach and similar comments apply.

- Statistical - Probability based:

  The use of the approach is inappropriate for most of the LOCAR research monitoring needs, and it is not practical given the need to co-ordinate groundwater, surface water and ecological monitoring networks.

In summary, the hydrogeologic approach and the statistical variance reduction and optimization approaches appear to be the best approaches for designing the LOCAR groundwater monitoring arrays. However, on balance, the hydrogeologic approach is the most appropriate, particularly given the need to co-ordinate the groundwater monitoring with surface water and ecological monitoring activities. It is also likely to be the most acceptable approach given the complex institutional framework

If the establishment of hydrogeological instrumentation is to be based on research monitoring objectives using the hydrogeological approach, it is important to ensure that the monitoring infrastructure is suitable and addresses the research aims of LOCAR. The following section is an attempt to link LOCAR research aims with the type of groundwater monitoring instrumentation that may be needed.

IMPLICATIONS FOR INSTRUMENTATION

Definition of groundwater catchment boundaries

Instrumentation needs

- piezometers, and possible boreholes, either side of groundwater divides, at various locations around the margins of the groundwater catchments sufficient to define the groundwater divides;
- nested piezometers should be used to characterize sub-vertical head gradients throughout the full thickness of the zone of ‘active’ groundwater circulation either side of the divide;
- boreholes may be needed to characterize the geological controls on interfluve hydrogeology (e.g. geophysical logs, including borehole imaging, flow logs and core analysis);
- monitoring frequency should be consistent with other data sets used to establish the groundwater balance, e.g. rainfall, surface water in unsaturated zone data. It should also be adequate to provide information on recharge events as well as seasonal variations in the groundwater divides (see section below on recharge processes in the interfluve areas);
- information on existing boreholes should be used where possible, however, purpose built piezometer arrays would be preferable;
- piezometer arrays should be positioned to investigate the effects of cover on the position of the groundwater divides?

Linkages to LOCAR research aims

- integrated modeling of the interaction between groundwater and surface water to produce water balance at catchment scale;

- investigation of key hydrogeological processes controlling movement of groundwater in lowland catchments including recharge;
- the role of drift deposits in influencing recharge pathways.

Recharge processes in the interfluve areas

Instrumentation needs

- piezometer arrays at representative (on interfluves, slopes and valley bottoms) locations within the catchments, sufficient to characterize the recharge processes;
- the piezometer arrays should be located (i) at sites that have also been instrumented to study unsaturated zone (matric potential and flow in fractures), and (ii) could use piezometer arrays and/or boreholes that have been developed to define groundwater catchment boundaries (see above);
- the piezometer arrays should provide good vertical head definition through the entire 'active' zone of the aquifer;
- ideally the piezometer array should be associated with a well-characterized borehole to enable geological controls on recharge to be investigated;
- sites may be chosen specifically to target recharge through drift deposits or associated with perched aquifers.

Linkages to LOCAR research aims

- investigation of the key hydrogeological processes controlling the movement of groundwater in lowland catchments;
- investigation of the role of drift deposits in influencing recharge and pollution pathways;
- investigation of the role of fracture flow;
- contributing to a better understanding of surface water-groundwater interactions.

3-D definition of flow across the catchment

Instrumentation needs

- at least three piezometer arrays, penetrating the full thickness of the 'active' aquifer, aligned down the hydraulic gradient to characterize the 3-D head distribution. These arrays should ideally be located across a relatively steep section of the hydraulic gradient;
- cored boreholes should be associated with each piezometric array for geological control on hydrogeology. At on site multiple cored boreholes (vertical and possibly inclined boreholes in fractured sections) should be developed to enable hydraulic and geophysical tests to sample the 2-D and 3-D structure of the aquifer using techniques that cross-borehole tomography, tracer tests;
- the cored boreholes should be analyzed to characterize the matrix and fracture properties of the aquifer to enhance interpretation of the borehole tests;
- the borehole sites may not necessarily need to be co-ordinated with other components of the catchment monitoring network, however, it would be helpful and probably cheaper if the piezometer arrays were located at sites that were also being used for surface water and particularly unsaturated zone monitoring. For example, sites used

for studying recharge could also be used in a piezometer transect looking at the 3-D definition of flow.

Linkages to LOCAR research aims

- investigation of key hydrogeological processes controlling the movement of groundwater in lowland catchments;
- enhance hydrogeological mathematical models of catchments;
- enables investigation of flow and transport, particularly transport properties at different scales, i.e. pore scale, borehole scale and catchment scale;
- investigation of aquifer heterogeneity and the role of fracture flow;
- investigation of chemical interactions and the role of microbial degradation during 3-D flow;
- investigation of interannual variability in groundwater input into streams.

Characterization of fracture flow

Instrumentation needs

- development of boreholes on interfluve, within the catchment, and at groundwater discharge points that enables study of the variation in fracturing with depth and across the catchment. The interfluve boreholes should ideally be associated with unsaturated zone monitoring sites to enable the study of recharge through fractures;
- these boreholes will require detailed fracture logging (borehole imaging and core logging), flow logging and hydraulic testing;
- these sites may not necessarily need to be co-ordinated with other components of the catchment monitoring network, however, they may also be used in other studies such as boreholes developed for the definition of groundwater catchment boundaries, the 3-D definition of flow, aquifer heterogeneity and groundwater – surface water interactions.

Linkages to LOCAR research aims

- investigation of key hydrogeological processes controlling the movement of groundwater in lowland catchments;
- investigation of the role of fracture flow;
- enables investigation of flow and transport, particularly transport properties at different scales, i.e. pore scale, borehole scale and catchment scale;
- investigation of the role of fractures in recharge pathways;
- enhance hydrogeological mathematical models of catchments.

Aquifer heterogeneity and scaling effects

Instrumentation needs

- fully cored boreholes that intersect the maximum possible thickness of the aquifer that enable the full core characterization of the matrix;
- geophysical (borehole imaging) logs, flow logs, and packer tests should be undertaken to characterize the distribution of hydraulically significant fractures;
- boreholes developed for the characterization of fracture flow could also be used for the study of aquifer heterogeneity and scaling effects.

Linkages to LOCAR research aims

- investigation of key hydrogeological processes controlling the movement of groundwater in lowland catchments;
- investigation of the role of fracture flow;
- enables investigation of flow and transport, particularly transport properties at different scales, i.e. pore scale, borehole scale and catchment scale;
- enhance hydrogeological mathematical models of catchments.

Groundwater — surface water interaction near discharge points

Instrumentation needs

- piezometer arrays adjacent to groundwater discharge sites through the full depth of the ‘active’ zone of the aquifer and inclined boreholes beneath rivers should be developed to investigate groundwater – surface water interactions;
- the selected groundwater monitoring sites must be consistent with surface water, unsaturated zone and ecological monitoring sites;
- the piezometer arrays and boreholes should be capable of monitoring seasonal and variations in head distributions, flow characteristics, storage, water chemistry, and microbiology as well as being amenable to use in monitoring very short term events;
- boreholes should provide direct and indirect information on geological controls on the hydrogeology (borehole logging, including borehole imaging, and core analysis);
- instrumentation should have minimum impact on the natural hydrogeological regime;
- there is scope to use piezometer arrays developed to study groundwater – surface water processes to also study 3-D definition of flow across the catchment and fracture flow.

Linkages to LOCAR research aims

- study of the key physical, chemical and biological processes operating within the valley floor corridor that affect surface water and groundwater;
- investigation of how varying flow regimes control in-stream, riparian and wetland habitats;
- study of how land use management impact on lowland catchment hydrology, including both water quantity and quality;

- investigation of how the hydrological, hydrogeological, geomorphological and ecological interactions resulting from natural or anthropogenic changes can be predicted using integrated mathematical models;
- investigation of the spatial functioning of the surface water system;
- investigation of interannual variability in groundwater input into streams and their likely ecological impacts;
- integrated modeling of the interaction between surface and groundwater in terms of both flow and quality, linkage of ecological responses to changes in the hydrological regime, catchment management strategies and climate variability.

Table 2.1 and 2.2 summarize the basic infrastructure needs of the hydrogeological component of the LOCAR monitoring network on a topic by topic basis and highlights potential shared infrastructures between topics.

Table 2.1 Summary of basic infrastructure needs

	Boundaries	**Recharge**	**3-D flow**	**Fracture flow**	**Heterogeneity**	**GW/SW interaction**
Infrastructure Needs	1. Nested piezometers over the full thickness of the 'active' aquifer. 2. Borehole to provide geological control.	1. Nested piezometer arrays over the full thickness of the 'active' aquifer. 2. Coincident with unsaturated zone monitoring arrays.	1. Nested piezometer arrays at a minimum three sites across the catchment. 2. Cored, inclined (?), borehole at each site. 3. Multiple boreholes at least one representative site to enable cross borehole tests.	1. A minimum of three boreholes to investigate trends in fracturing across the catchment.	1. Fully cored borehole near centre of the catchment penetrating the full aquifer	1. Piezometric arrays near discharge point. 2. Inclined borehole for hydrogeological testing and geological control. 3. Sites to be coincident with surface water and ecological monitoring networks.

Table 2.2 Potential for sharing of instrumentation between different topic areas

	Boundaries	Recharge	3-D flow	Fracture flow	Heterogeneity	GW/SW interaction
Boundaries	–	Shared piezometer arrays	Shared piezometer arrays and boreholes	Shared boreholes		
Recharge	–	–	Shared boreholes	Shared boreholes		
3-D flow	–	–	–	Shared boreholes	Shared boreholes	Shared boreholes and piezometer arrays.
Fracture flow	–	–	–	–	Shared boreholes	Shared boreholes
Heterogeneity	–	–	–	–	–	Shared boreholes and piezometer arrays
GW/SW interaction	–	–	–	–	–	–

2.4 ECOLOGICAL MONITORING AND THE ROLE OF MODELS

Of the five questions to be addressed by the LOCAR programme, three are specifically related to biological and ecological interactions. The following sections will consider ecological information and examine strategies for obtaining data which will service the LOCAR objectives.

2.4.1 Role of models

In a natural river system the biotic communities have evolved in response to the prevailing physico-chemical conditions (temperature, light, flow conditions, substratum, oxygen concentration, ionic composition) and biotic interactions such as competition and predation to which a biotic unit can respond. It is important to note that the stimuli are not mutually exclusive and that a biological response is more often than not a result of the various combinations of primary stimuli. Only in extreme cases, for example severe heavy metal pollution or physical disturbance is there one main factor affecting the response.

The reviews of river models in the literature usually concern one aspect for example hydrological processes (Fawthrop, 1994), water quality (Crockett, 1994), sediment transport (Bettess, 1994), or instream flow habitat (Stalnaker, 1994). The Hubbard Brook Project in the USA (Likens, 1984) concentrated observations on the flow of water through a catchment and such studies are central to the understanding of land-water linkages. The Coweeta laboratory was similarly interested in the transport of dissolved and particulate material in relation to logging activities (Webster et al, 1991). In a sense, transport mechanisms are the easiest of the components to examine with a view to modelling but even here, it is recognised that flow paths may be highly variable on all scales. It is this question of scale which complicates the issues when ecological populations etc are placed into the equation.

Primary production is a major driver of the lotic system but this may be swamped by allochthonous material in different parts of the system. Abiotic factors may control the communities in parts of the river whereas biotic influences may be greatest in others. Landuse will also have varying effects on instream characteristics with distance downstream. Thus a model applied to one section of the river will not be suitable for another. So in order to model the catchment we need to examine its components. Figure 2.4.1.1 attempts to divide a river system into areas which have ecological significance and which link to hydrological features. Thus the drainage pattern and hydrological characteristics will be influenced mainly by topography, climate and geology. The divisions into sectors are related to major changes in flow regime, water chemistry and/or channel form and reaches, set and units will be influenced by local factors. Any attempts to model the system would have to be based on a nested series of investigations at different scales.

A possible way ahead is to use modeling techniques to shed light on the processes which determine the specific habitats and their characteristics to be found along a system. So, physical data would be used to model habitat occurrence in time and space together with its variations in characteristics and at the same time a series of studies would examine the ecological characteristics of these habitats and their responses to change. Once the links have been made between habitat and community responses then we will be a step nearer to modeling the ecosystem.

Basic requirements for reach scale ecological models will be information on the following:

- flow regime - hydrograph and spatial variation in patterns of flow at sectors where geological boundaries occur;
- geomorphological characteristics - at reaches representative of sectors (see Figure 2.4.1.1.);
- water chemistry - annual cycles in nutrient and major ion chemistry (the data on this is already good for a small number of sites);
- sediment characteristics (deposition and transport) in representative reaches in each sector of the rivers;
- surface/groundwater interactions (areas of loss, upwelling, effect of landuse). The identification of areas where discharge may be affected by local geology resulting in an unexpected lowering of discharge or areas of upwelling is of fundamental importance to salmonids (affecting redd production) and may also have local effects on riparian and instream vegetation;
- insolation (light penetration/primary production links).

2.4.2 Strategy

The amount of background ecological information will vary between study areas. This disproportionate spread of knowledge suggests that ecological studies should in the first instance, match the data available and secondly take account of the particular attributes and issues associated with each catchment area. These points are considered in detail in the catchment review chapters but it is worth considering the overall strategy required to provide base-line information which will characterise the catchments and service future research projects.

Ecological characterisation requires knowledge of the biota and their temporal and spatial dynamics. This could be a very costly procedure if all elements of the biota from bacteria through to mammals were studied. In practice, characterisation usually focuses on macroinvertebrates and macrophytes for which there exists a body of information on their distribution and the factors which control it. Additional information on riparian and instream habitat provides the essential link between hydrological and geomorphological and biotic change. Where possible surveys should cover as much of the river length as possible to provide the information necessary to select representative sectors for reduced intensity repeat surveys. These in turn will provide the necessary background information on ecological stability. This knowledge is essential to show how geomorphological and hydrological variability impacts on ecological habitat and will provide the data needed to interpret the results of research projects in the catchment areas.

The issues within each major study area will largely determine the intensity and coverage of ecological characterisation. In some catchments baseline work will be necessary along the whole system, particularly where the relationship between headwater and downstream hydrology and geology are a focus of interest. In other areas more intensive work in sub-catchments may be more appropriate and in some cases ecological input may be downgraded as a result of lack of baseline data. Each catchment will be considered to assess the distribution of survey effort (see catchment review chapters).

In summary, the ecological survey strategy has as its primary aims the following:

- knowledge of the composition and distribution of biota associated with the instream and riparian environment;
- information on the stability of these communities over time;
- detailed data on the occurrence, composition and temporal fluctuations in instream and riparian habitat;
- that these data should if possible have as wide a coverage as possible along the systems and at the very least cover representative reaches in all major sectors of the studied rivers and characteristic tributaries.

2.4.3 Linkages to LOCAR research aims

The ecological strategy outlined above will provide baseline information for research projects which address the LOCAR questions relating to biological processes and their relation to the flow regime and natural and anthropogenic changes. The information on habitat will provide the link between knowledge of the biotic communities and hydrological, hydrogeological and geomorphological interactions.

3 The Frome/Piddle Catchment

3.1 INTRODUCTION

The relative paucity of ecological data in the two lowland catchments first proposed by the LOCAR working group led to the consideration of the Frome catchment. The presence of the Rivers Laboratory of the Institute of Freshwater Ecology within the catchment and the fact that the Frome is the last natural Chalk salmon stream in the UK, and the consequent focus of a considerable amount of ecological research over the last 20 years, resulted in its inclusion as a catchment within the LOCAR programme.

The Frome catchment suffers from a scarcity of groundwater monitoring whereas the Piddle catchment to the north, which is similarly underlain by Chalk and Tertiary deposits, has had considerable attention paid to it in recent years. These studies have been carried out as a result of its designation by the Environment Agency as a river requiring Alleviation of Low Flows (ALF) (NRA, 1995, Environment Agency, 1999). The Piddle discharges into the Poole Harbour estuary very close to the Frome and appears to provide a good scientific parallel to the Frome in its behaviour. It was, therefore, included with the Frome for the LOCAR programme. In contrast to the Pang/Lambourn Chalk catchments, it is large and demonstrates greater diversity of geology and geomorphology. It incorporates a subcatchment (South Winterbourne) both similar to the Pang/Lambourn and others of very different physiography, geology and soil cover. Maps 3.1 and 3.2 show the physiography and geology of the catchment and Map 3.3 shows the distribution of annual rainfall across the catchment. These maps also show the surface water and groundwater catchments.

The Frome/Piddle river system is generally noted as being of high amenity value due to its visual, sporting (angling), faunal and floral attractions. This historical situation has been largely due to the maintenance of its rural character, and the lack of industrial development. The naturally high water quality is maintained in a system highly buffered from acidifying influences. There is also a lack of pollution in the sea entry to the catchment through Poole Harbour, which allows migratory fish to enter. The flood plain areas are managed to maintain suitable water levels in riparian meadows and wetland areas. The rivers have therefore remained clean enough to support thriving populations of brown trout and salmon, yet have the habitat characteristics in their lowland reaches to also sustain a healthy population of coarse fish. However, in recent years a number of changes have conspired to move the status of the rivers towards a trophic threshold that, if exceeded, could significantly change the ecology in future.

Generally, the Frome offers opportunities to study many complex and interesting sediment dynamics questions. Sediment transport pathways are likely to show great variety with regard to links between the catchment slopes and channel and, given the scale of the catchment, there are many opportunities for within-channel storage of sediments. The variety in channel form and histories of human intervention (and current abstraction and compensation waters management issues) present interesting linkages between geomorphology, sediment routing and surface/groundwater interaction.

Particular characteristics of the Frome/Piddle are set out below in summary form. These have influenced the infrastructure development and monitoring strategies for the whole three-catchment programme and the particular design of the Frome/Piddle.

3.1.1 Dominant catchment characteristics

- Complex geology. Flow contributions may be received from Jurassic limestones, Upper Greensand, Chalk, sands of the Palaeogene deposits, superficial sands or gravels and clay with flints.
- The solid geology is affected by extensive faulting which is likely to provide controls or constraints on groundwater flow and influences on surface contributions or outflows.
- The interfluve between the Frome and Piddle shows many karst features on the Palaeogene and superficial deposits indicating extensive karst development in the underlying Chalk aquifer.
- Extensive superficial sands and gravels provide the likelihood of large groundwater storage, particularly in the lower catchment.
- Both the Frome and Piddle could be subdivided into hydrological domains, i.e. chalk stream (South Winterbourne), headwater streams with perched water in Upper Chalk, flood plain areas on gravels, subcatchments with considerable clay cover.
- The Frome is a braided river in parts of the middle and lower reaches.
- The upper Frome and Piddle offer steep slopes through the less permeable middle and Lower Chalk with hills capped with upper chalk.
- There appears to be considerable sediment transport even in the upper reaches of the Frome and Piddle systems.
- Geomorphological/ecological interest can be found in the middle to lower reaches of the Frome.
- Wetlands can be found on the Frome floodplain (e.g. East Stoke)
- Considerable data on the ecology and water chemistry of the Frome and Piddle exists, generally focussed on specific sites and tributaries.
- The Frome and tributaries are predominately well gauged but have a poor groundwater monitoring network.
- The Piddle is well gauged with an extensive observation borehole network.
- Land and facilities at East Stoke occupied by the IFE provide an excellent and secure environment for integrated experimentation across all disciplines in unconsolidated flood plain deposit environment.
- The Piddle offers opportunities for new collaborative studies with the Environment Agency, where the consequences of low flows and their alleviation require investigation.
- The extensive access to the River Frome and its side channels with associated fishing rights provide ideal opportunities for setting up boreholes and other long term environmental observations.

3.1.2 Strategy

Broadly the emphasis of infrastructure development in the Frome/Piddle should lie in ecology and geomorphology, whilst adequate hydrological and hydrogeological infrastructure and monitoring should be available to support integrated studies including modelling.

Some specific elements of the strategy are listed below.

1. Concentrate on ecological studies integrated with hydrology/hydrogeology/ geomorphology.
2. Concentrate sediment monitoring on total catchment and comparative subcatchment studies.
3. Minimise monitoring of surface water/groundwater interaction processes except in the floodplain region.
4. Expand Frome groundwater network to provide baseline monitoring.
5. Upgrade stream gauging to include water quality and sediment sampling.
6. Better define geology.
7. Build on good Piddle groundwater monitoring network.
8. Develop a flood plain/wetland monitoring facility on IFE Rivers Laboratory land.
9. Install minimum soil moisture monitoring to cover major land use types.
10. Water quality monitoring at gauging sites.
11. Set up experimental facilities at East Stoke and/or build on Rivers Laboratory infrastructure and land.
12. Install gauging stations at Maiden Newton on the upper Frome and on Bovington stream.
13. Install two Automatic Weather Stations as minimum baseline requirement.

3.2 EXISTING INFRASTRUCTURE AND DATA

3.2.1 Hydrology

CATCHMENT WATER BUDGETS

From the assessment of the raingauge networks and flow gauging structures (see later sections), it is possible to construct a water budget for each of the main and sub-catchments (Table 3.1). These use the annual average rainfall (spatially-averaged) for the current network of gauges in and around the catchments, and annual average flow from the estimates of average daily flow given by the EA and held on the NRFA.

At the scale of the main Frome and Piddle catchments, annual streamflow represents roughly half the annual rainfall. However, the subcatchment budgets indicate variable and often low annual streamflow values, which suggests losses other than by evaporation (groundwater flows, abstractions).

In the Frome/Piddle, evaporation is clearly an important flux. The IOH Flow Regimes and Environmental Management map indicate a PE of around 525 mm. The main aim of the hydrometeorological studies in LOCAR is to estimate groundwater recharge as the difference between rainfall and evaporation, so the accurate and precise estimation of these two fluxes (to within 5%) is critical. Accurate streamflow estimates are also vital for the study of surface groundwater interactions, and ecological habitat assessment.

Table 3.1 Approximate annual losses (evaporation plus net groundwater losses) from provisional water balances for the Frome and Piddle catchments and their tributaries

Catchment	Outlet	Area (km^2)	Average annual rainfall - P (mm)	Average daily flow (m^3s^{-1})	Average annual flow - Q (mm)	Losses P-Q (mm)
Frome	East Stoke	414.4	932	6.435	489	442
	Dorchester	206.0	943	2.993	458	484
Hooke	Hooke	9.7	962	0.177	575	386
Winterbourne	Steepleton	19.9	963	0.09	142	820
Sydling Water	Sydling St. Nicholas	12.4	954	0.181	460	493
Piddle	Baggs Mill	183.1	888	2.360	406	481
	Briantspuddle	111.6	888	1.640	463	424
	Little Puddle	34.8	888	0.184	166	721
	South House	21.4	888	0.164	241	646
Devils Brook	Dewlish at Woodsdown	20.3	888	0.112	174	714

RAINFALL

The network of period raingauges in the Frome-Piddle catchment system provides a good spatial coverage. Unfortunately, many of them, and especially the network of recording gauges, have only been installed recently, with only three dating back to the 1960s. It is difficult to assess long term average rainfall with such short records, and as yet the EA have not attempted to estimate a 1961-90 average annual rainfall (AAR) for gauges installed after 1992. This will become possible as the length of overlap with older gauges increases.

The details of the raingauge networks are given in Table 3.2. and are shown on Map 3.4. There are no obvious anomalies in any of the period gauge totals as deviations from a west to east, or high to low altitude, gradient. However, photographs that have been studied of the raingauge sites in the Frome (Aston, 1999) indicate that some are poorly located and suffer from either excess or inadequate shelter.

There are no recording gauges near the centre of the catchments, the only event recorder in the catchment being at the Frome's source at the western end at Evershot. However data from five recording gauges are available within or just outside the catchments (Table 3.2), all installed in 1995.

CLIMATE

There is currently no known official meteorological station in the Frome/Piddle. Other than one period raingauge, there are no meteorological instruments at East Stoke. MORECS data is available, which must be based on data from a climate network station, but not necessarily one within the Frome or Piddle catchments.

Table 3.2 Raingauge network in the Frome-Piddle system

Name	Catch-ment	Met. Office No.	East	North	Altitude (m)	AAR[1] 61-90 (mm)	Start Date	Frequency	Recording?
Toller Porcorum	Frome	348342	3558	0975	134	989	1993	Daily	No
Sydling St. Nicholas	Frome	348558	3632	0995	109		1997	Daily	No
Charminster, Hill View	Frome	348809	3675	0927	77	918	1982	Daily	No
Kingston Maurward	Frome	348916	3719	0910	73	916	1963	Daily	No
Winterbourne Abbas	Winter-bourne, Frome	348972	3618	0906	105	1010	1993	Daily	No
East Burton	Frome	349598	3834	0870	18	881	1986	Daily	No
East Stoke, IFE Lab.	Frome	349695	3869	0867	9	879	1968	Daily	No
Piddletrenthide, Hillside farm	Piddle	347351	3707	0999	132		1994	Daily	No
Lower Ansty, Ivy Cottage	Piddle	347553	3769	1029	123	946	1982	Daily	No
Bere Regis	Piddle	347911	3847	0948	43		1994	Daily	No
Trigon	Piddle	347973	3887	0889	18	830	1961	Daily	No
Powerstock	Asker, Brit	351523	3531	0971	87	921	1990	Monthly	No
Beaminster, North Street	Brit	351187	3483	1016	65	977	1992	Daily	No
Church Knowle	Poole Harbour	350029	3942	0809	60		1994	Daily	No
Beaminster	Brit		3480	1010			1995	Daily/ Event	Yes
Evershot	Frome		3578	1043			1995	Daily/ Event	Yes
Friar Waddon	Coastal		3653	0858	65		1995	Daily/ Event	Yes
Nuffield Road	Poole Harbour		4016	0934	7		1995	Daily/ Event	Yes
Powerstock	Asker, Brit		3517	0960			1995	Daily/ Event	Yes

EVAPORATION

The only evaporation data available for the Frome/Piddle system is that derived for MORECS squares 180 & 181 to enable calculation of effective rainfall (Aston, 1999).

[1] AAR – Average annual rainfall

SOIL MOISTURE

As far as is known, there is no monitoring of soil moisture and soil moisture studies have not been carried out in the Frome or Piddle.

FLOW GAUGING

The main flow gauging problem is concerned with the ability of the current stations to give accurate and precise measurements throughout the flow range. Such estimates are important, not just for hydrological purposes, e.g. water balances, rainfall-runoff modelling, but also to provide flux estimates for chemicals, sediments and biological drift. Most of the gauges installed in recent years have been for low flow assessment, and as such will flow out-of-bank on numerous occasions. Minimisation of afflux upstream of weirs to prevent backing up and local flooding has meant that weir crest heights have been kept low, exacerbating the problem of non-modularity at higher flows. For the most part there is no contingency for monitoring non-modular conditions either by use of crest tapping, which is notoriously problematical, or by downstream tapping, which is difficult and expensive to carry out in retrospect. For the latter, an extra stilling well system is usually required if high precision is the aim, in order that potentiometric or shaft encoder water level recorders can be used instead of pressure transducers.

One of the difficulties of gauging in the Frome is that historical management of the river in its flood plain area below Dorchester has led to artificial braided channels. Historically, water has been diverted for mills and to maintain levels in water meadow systems, often by encouraging out-of-bank flow. In many cases these systems are disused but the channels remain, and flow gauging techniques have been adopted that can cope with this divergent parallel channel system. However, these structures do not always meet British and International Standards.

Of the newer gauges in the area, mainly in the Devils Brook (Piddle), most have been constructed for the purposes of gauging low (compensation) flows in response to groundwater level reductions around water supply boreholes. This is not an ideal situation on which to base hydrometry for a scientific programme like LOCAR.

FROME GAUGES

In the Frome the main sets of gauges are at East Stoke (2 combined), Dorchester (3 combined), with a number of gauges on the main tributaries (Table 3.3). These have been assessed according to EA records, NWA station assessment and the NWA 'Aide Memoir' gauging station checklist.

Other minor structures on the Frome consist of smaller structures on headwater feeder streams on the Hooke at Hooke, on the Sydling Water at Sydling St. Nicholas, and on major tributaries lower down, the Wool at Wool, and the South Winterbourne at Steepleton. The majority of these have been running since the late 60s or early 70s, and even the latest of these at Hooke, installed in 1989, has ten years of record.

PIDDLE GAUGES

Details of the structures on the Piddle and their hydraulic performance are shown in Table 3.4. The main structure is at Baggs Mill, with subsidiary structures ranged at intervals up the Piddle and 3 further structures on the Devil's Brook. This tributary of the Piddle has come under considerable scrutiny in recent years, with impressive new structures built in 1995 and 1997. The main issues on the Devil's Brook have been low flow problems associated with groundwater abstraction, and, unusually for a Chalk stream, a history of destructive flash flooding (hence its name) mainly caused by runoff from the steep scarp slopes to the east of the channel.

Table 3.3 Flow gauging stations in the Frome and its tributaries (flow in m^3s^{-1}) (see Table 3.4 for explanatory notes)

River	Station	Area (km^2)	East	North	Record	Q95	Sensitivity %	QADF	Q10	Q1	Max. Design Flow	Comments on hydraulic performance (telemetry unless stated)
Frome	East Stoke (combined)	414.4	3866	0868	1961-pres	1.874 (2.179)	5.7	5.341 (6.42)	10.261 (12.1)		(25.86)	Compound Flume/weir. Non-B.S. flume and rectangular long base flanking crests. Full range modular. Needs check rating. Peak flows outside structure.
	East Stoke		3873	0867	1965-pres	0.136		1.094	2.335			Crump weir. Flow to be added to East Stoke main channel. Bypassed at high flows.
Frome	Loudsmill (combined)	206.0	3708	0903	1969-pres	0.607 (0.858)	15.1	2.293 (3.06)	4.755 (6.078)		Modular to (14.6)	Two crump weirs at Loudsmill, one on mill race and the other a spillway at right angles to channel. Poor compromise head measure-ment position. Recent recom-mendations by NWA led to second tapping for mill race. Asymmetric flows over spillway. Bypassing at high flows.
	Stinsford		3701	0907	1971-pres	0.184		0.7	1.269			Modular to 4.6 m^3s^{-1}. Weed growth can cause drowning. Added to Loudsmill for Dorchester
Hooke	Hooke	9.7	3539	0999	1989-pres	0.079		0.177	0.311			Flat-V. Upland catchment
S. Winter-bourne	Steepleton	19.9	3629	0897	1974-pres	0.008	60	0.09	0.236	0.6		Flat-V. Compensation inputs upstream. Very poor sensitivity.
Wool Stream	Wool	5.1	3848	0869	1975-pres							Flat-V. No telemetry
Sydling Water	Sydling St. Nicholas	12.4	3632	0997	1969-pres	0.062	25	0.181	0.361	0.6	1.0	Crump weir. Full range modular. Poor sensitivity at low flows.

Table 3.4 Flow gauging stations in the Piddle and on the Devil's Brook tributary (flow in m^3s^{-1})

River	Station	Area (km^2)	East	North	Record	Q95	Sensitivity %	QADF	Q10	Max. Rec. Flow	Max. Design Flow	Comments on hydraulic performance (telemetry unless stated)
Piddle	Baggs Mill	183.1	3914	0876	1963-pres	0.766		2.360	4.697	11.9	8.1	Critical depth flume with hump in bed. Full range modular. Needs check rating. Bypassed above 8.1 m^3s^{-1} but flow estimated through railway arches.
Piddle	Briantspuddle	111.6	3822	0934	1992-pres	0.135		1.640	4.184			Flat-V. Weed growth causes non-modularity.
Piddle	Little Puddle	34.8	3719	0965	1992-pres	0.009		0.184	0.367			Flat-V. Weed growth causes non-modularity
Piddle	South House	21.4	3707	0991	1992-pres	0.013		0.164	0.377			Flat-V. Weed growth causes non-modularity, and restriction through culvert downstream
Devils Brook	Dewlish P.S.		3779	0996	1995-pres			0.085				Flat-V mainly for low flows. Upland catchment quite flashy
Devils Brook	Dewlish Village		3778	0985	1997-pres							Flat-V mainly for low flows. Upland catchment quite flashy
Devils Brook	Dewlish Woodsdown	20.3	3775	1002	1972-pres	0.022		0.112	0.257			Crump weir

Notes on Tables 3.3 and 3.4

Q95 - flow exceeded 95% of time, Q10 - flow exceeded 10% of time, Q1 - flow exceeded 1% of time
QADF – Average daily flow (m^3s-1)
Sensitivity – percentage increase in flow for 10 mm stage rise

With the exception of Baggs Mill that uses an old mill structure, the gauging stations are all high quality Flat-V weirs, which are relatively sensitive at low flows, or Crump weirs. However, in many cases there will be problems of non-modularity at higher flows, either due to downstream channel constrictions or weed growth.

3.2.2 Surface water quality

WATER QUALITY DATA AVAILABILITY

Most of the data available on water quality of the Frome/Piddle system has been collected as part of a long-term programme by the IFE at East Stoke, including regular sampling at selected sites and occasional *ad hoc* surveys of up to 30 sites around the catchments. The data was collected to support studies of nutrient supply in the catchment and their ecological impacts.

3.2.3 Geomorphology and sediment transport

AVAILABLE SEDIMENT DATA

Time series data for turbidity, which may be useful to indicate river suspended sediment responses, are available for a limited number of locations within both the Frome and Piddle. There are periods of turbidity monitoring on the Frome at the East Stoke gauging station and some spot measurements of suspended sediment concentrations have also been made. Exeter University (Walling and Amos, 1999) have carried out a study of sediment dynamics in the Upper Piddle. One year of measurements of suspended sediment loads and concentrations using turbidity monitors were carried out at two sites. They noted that turbidities rarely dipped below 10 mg/l and that after the delivery of fines to the channel, trapping suggested channel storage and slow downstream migration of sediment slugs. This work also gives data on particle size, organic carbon and nitrogen.

The Environment Agency carries out routine suspended solids monitoring on both the Frome and Piddle. These records are of insufficient frequency to represent particulate fluxes and rarely include times of peak sediment concentrations. More intensive WQ monitoring is carried out in connection with particular pollution events although this often does not include measurement and archiving of suspended solids data.

No evidence of any turbidity archives for treatment works has come to light. Information was also sought on effluent discharges from sewage treatment works, fish farms, cress beds, etc. but these enquiries are not yet completed.

A limited amount of bed sediment data is available for the Frome and Piddle. However, routine repeated regular cross-sectional or longitudinal topographic channel surveys are not available. Carling carried out a broad survey of bed sediment properties including some sites in the Frome and Piddle. An extensive survey of channel cross sections was carried in 1992 for the Environment Agency by Seaman Smith.

As in the other LOCAR study catchments, digital terrain, soils and land-cover data will be useful. There are no specific Environment Agency fluvial audit reports on the geomorphology or reports on the riparian zone driven by geomorphological or channel enhancement requirements e.g. driven by landscape architects. Some basic geomorphological observations of channel form and rough measures of bed sediments are available from the Environment Agency River Habitat Survey (at 16 sites on the Frome). River corridor surveys focussed on the ecology are also available for 1994, 1995 and 1996.

3.2.4 Hydrogeology

GEOLOGY

A detailed discussion of the geological setting is given in the Appendix and is illustrated in Map 3.2. Geological Map sheet 328, Dorchester (BGS 1998) covering the lower end of the combined Frome/Piddle catchment area has recently been surveyed and published incorporating the new Chalk stratigraphic nomenclature (see Appendix). Major structural features and geomorphologic features such as solution hollows have been identified. However, the western part of the catchments and the 5km buffer zones cover extensive areas of structurally complex geology that fall on the Bridport (327) and Yeovil (312) sheets, neither of which are due for resurvey.

GROUNDWATER LEVEL MONITORING NETWORK

The Environment Agency's existing groundwater level monitoring network is shown in Map 3.5. The network consists of 23 boreholes in the Piddle catchment (8 of which are logged every 15 minutes, the remainder being manually dipped) and 7 sites in the Frome catchment all of which are currently manually dipped.

GROUNDWATER QUALITY MONITORING NETWORK

The Environment Agency's existing groundwater quality monitoring network is shown in Map 3.4. There are five sites within the Piddle catchment and seven within the Frome. Each site has been sampled between 40 and 70 times since 1996. Determinands from analyses include inorganic major, minor and trace constituents including nitrogen species plus additional measurements of organic carbon, temperature, conductivity and dissolved oxygen.

GROUNDWATER MODELS

There is only a very limited number of modelling studies available on the Frome and Piddle catchments and these are described in detail in the review report by Butler in the Appendix. Groundwater flow and storage changes across the Frome catchment were modelled by Aston (1999) as part of an MSc thesis. A detailed modelling study of the Piddle was undertaken by Halcrow on behalf of the Environment Agency (Halcrow, 1995).

A more detailed review of the hydrogeological data available for the Frome/Piddle catchment area is given in Appendix.

3.2.5 Ecology

INFRASTRUCTURE

In the case of ecology, infrastructure has a somewhat different meaning than in the other disciplines. Background ecological data could be considered as an infrastructure component and the Frome and Piddle catchments have a wealth of information on biotic communities although this is not usually catchment wide. Additional infrastructure elements include the fish counter at East Stoke. This is a long established facility for continuous monitoring of the migration of adult salmon that has records extending back 30 years.

DATA

Catchment wide information

English Nature has a phase 1 survey (1982-3) of Dorset at a scale of 1:25000 but it is 'broad brush' and there have been many changes since completion. There have also been a number of more detailed surveys. Dorset Wildlife Trust has had a SNCI project in operation since 1989 and this has accumulated over 1300 sites. The quality of each site has been assessed against a set of guidelines specifying the important habitats and species in the county and national context. The South West Biodiversity Audit (Cordrey 1996) summarises both species and habitat information and sets out the significance in a national and regional context. In Dorset the County Red Data Book (Mahon & Pearman 1992) describes the rare species. More recently, a summary of the important habitats of Dorset and their key species has been prepared (DERC 1997). There is also a provisional atlas of habitats (Stewart 1995) available at DERC.

Habitat information

The whole area was mapped to phase 1 standard at a scale of 1:25000, circa 1982 (originals and target notes at Slepe Fm. Copy of map in EA). More recent phase 1 surveys are restricted to the SSSls and SNCls, kept with targets notes at Slepe Farm and DWT respectively. River corridor surveys have been completed for both rivers (Exton, 1988, 1993).

The vegetation of East Stoke Fen and Tadnoll (Edwards 1995, 7), Bindon Meadows (Pearman, 1997) and Nunnery Mead (Greenshields, 1997) have been surveyed in detail. Surveys of the Frome from Dorchester to Wareham were commissioned by English Nature in preparation for SSSI notification (Walls 1994 and EN files). All the SNCls marked have detailed maps to phase 1 standard or better, a commentary and species lists (usually a partial list of plants and notes of notable fauna). There is a survey of the Piddle valley by Horsefall (1979) highlighting the most diverse fields. There have been many changes and the valley is being resurveyed from aerial photographs by DERC (pers.comm. March 1998). The only NVC survey that has been completed is Wallace & Prosser (1998) covering the RSPB land at Wareham Meadows and the Moors. The RSPB has collected general information and has a management plan in draft (Clowes). NVC communities are identified in some SNCI reports and these are noted in the Appendix. The grassland inventories for Dorset are incomplete with the exception of the chalk grasslands. DERC is currently preparing reports on neutral (Edwards 1998) and acid grasslands and will start accumulating data on limestone grasslands in the summer of 1998. The few sites within the study which are mentioned in the drafts of these reports are also SNCls. The Dorset Lowland Heathland Directory has no sites in the floodplain, but there are a number of adjacent sites above the flood level. The Ancient Woodland Inventory (Spencer 1988) has only one site, West Field Coppice. References to catchment and habitat surveys are presented in the Appendix.

In addition to these surveys there have been several studies concerned with predicting instream habitat in relation to discharge by the Environment Agency and IFE/IoH. Although this work has been primarily concerned with fish habitat other studies have examined the relation between macrophyte growth/discharge and instream habitat (see the Appendix).

Microbiology/Algae/Macrophytes

The amount of microbiological and algal data is relatively low with emphasis on short term studies. However there are some important data on algal production and the ecology and production of protozoa in chalk streams. There is a large quantity of information on macrophytes. This includes studies on ecology, production biology and 'ecophysiology' of submerged, marginal and riparian aquatic plants illustrated primarily by Chalkstream Water Crowfoot, *Ranunculus calcareus*, but with comparative studies and species interaction with native Water Cress, *Nasturtium aquaticum*, and other submerged and emergent higher-plant species and bryophytes. This body of work has provided a better understanding of the cycles of macrophyte growth and plant management in chalk stream rivers and comprises one of the most extensive sets of data on macrophyte ecology in the country.

Macroinvertebrates

There are more studies on this group (75 papers, 27 reports and 33 theses and dissertations) than in any other category. Most of the work concerns short-term investigations (two-three years) on the general biology and ecology of selected organisms and groups of organisms in both main rivers and in tributaries. Whole catchment studies are rare but there have been a number of surveys along the length of the main river Frome and some of its tributaries. In recent years, studies have examined habitat occurrence and distribution and associated faunal communities in the main river Frome. In the lower Frome there are data on the development of faunal communities over a year that could link with future floodplain/main river interaction studies.

In addition to these more detailed studies there are data on routine monitoring of sites within the Frome and Piddle catchments held by the Environment Agency. A study of the Piddle was written up for Wessex Water (Green 1986). Taken as a whole the invertebrate data provide a comprehensive picture of the faunal communities of the area with information on life-history, production and distribution all of which is necessary to a complete understanding of the Frome/Piddle ecosystem.

Fish

Fish studies have examined growth and production in the Frome/Piddle system and over the last thirty years a sound knowledge of fish populations and dynamics has been obtained. This work has included commercially important species such as salmon and eels. Over the years, experience of fish counting devices and their validation by photographic and video techniques has been gained and there now exists over twenty-five years of information on salmon counts in the lower Frome. Fish and habitat interactions have been examined in the Frome and Piddle system in relation to discharge, substratum and bankside characteristics.

The Environment Agency have carried out a number of studies, mostly on salmonids, and these include freeze coring of spawning sediments (work done by IFE staff), redd counts through the catchment, and parr surveys using single longitudinal transects and visual counting. The parr surveys have been stopped because of lack of funding. IFE have now carried out four years of smolt counting at East Stoke, the data are at present of limited value because observations were made only in April and May and because the equipment is being developed. However, knowledge of smolt movements is crucial to the understanding of salmonid population fluctuations and will at the same time provide an indicator of conditions throughout the whole catchment.

3.3 BASELINE REQUIREMENTS

3.3.1 Hydrological baseline requirements

RAINFALL

It is proposed to install a further 3 period (weekly) raingauges in the catchment, to coincide with recharge sites at Evershot, East Stoke and near Maiden Newton.

Two further recording raingauges will be installed with AWSs within the catchments, one at the extreme eastern end at Evershot, and one associated at East Stoke. A further recording gauge at the new gauging station site at Maiden Newton should provide useful data at the upland/lowland interface.

CLIMATE

It is proposed that 2 AWSs are installed as described in the previous section, to cover the maximum range of conditions in terms of west to east gradients and altitudinal effects.

EVAPORATION, SOIL MOISTURE AND RECHARGE

It is proposed that 3 soil moisture sites are set up in the Frome /Piddle to provide calibration data for evaporation, soil moisture and recharge models developed in the more intensively monitored Pang and Lambourn or elsewhere in chalk catchmnets. The 3 sites will be spread between the 3 main geological zones, and each will cover the three land uses arable, grassland and riparian vegetation. The locations of the sites are shown in the accompanying map of LOCAR instrumentation (Map 3.6).

FLOW GAUGING

The network of EA gauges is comprehensive in its geographical spread, covering all the major tributaries and also nested on the main limb of the Piddle and Frome. However, gaps exist. These will be filled by two new structures. A structure is proposed for the Frome near the upper limit of ‘main river’ in the region of Maiden Newton, to measure flows from the Hooke, the upper Frome and the Wraxall Brook to assess fluxes of waterbourne materials from the upland to the lowland portion of the catchment. A second structure is proposed for Bovington Stream to assess the effects of tank movements on sediment fluxes.

In addition, improvements are recommended for the existing flow structures on the Frome as follows:

- Extra measurements of downstream water levels should be made at structure sites where none currently exist to take into account non-modularity at moderate to high flows.
- Independent calibrations should be carried out on structures that do not conform to any known standard.
- A more intensive channel maintenance programme should be introduced where siltation and weed growth are a problem (the two may happen together).
- New structures should be installed, or another permanent, continuous flow gauging technique used, at the upland/lowland interface on the Frome near Maiden Newton and on the Bovington Stream.

WATER QUALITY

The collection and analysis of water samples from the main outfall site at East Stoke on the Frome will continue. At Baggs Mill on the Piddle a comprehensive programme should be introduced for the first time. Continuous monitoring should also be introduced, as outlined in the water quality strategy, and as is already in place in the Pang/Lambourn (see Chapter 4). This is proposed at 11 sites as shown on Map 3.6. The practical considerations of instrumentation siting will have to be addressed, from the points of view of the logistics of sampling and data collection, security, representativeness of sampling, minimum interference with existing installations, access and visual aspects. The existing huts at the main flow gauging stations are currently too small for much extra instrumentation to be installed, and separate enclosures will have to be used and budgeted for.

Water quality recommendations

- Regular (weekly) sampling at the outfalls of the Frome and Piddle, with a comprehensive analysis suite of determinands as above.

- Certain variables should be monitored continuously, including temperature, pH, DO, conductivity, chlorophyll-a and nitrate.

GEOMORPHOLOGY AND SEDIMENT

There are 13 gauging stations in the Piddle and Frome System (with a supplementary station at Aston Pancras). Ideally the opportunity to gain turbidity from each station would be of value to observe within-catchment suspended sediment dynamics across a range of land uses and practices, geological formations, low flow management and channel change conditions. The base network on the main Piddle and Frome should be at 11 sites identified for continuous monitoring of both sediment and water quality (see Map 3.6), plus 4 extra reach sites for turbidity. These should include downstream stations at Baggs Mill on the Piddle and East Stoke on the Frome.

3.3.2 Hydrogeological baseline requirements

INTRODUCTION

The baseline data requirements required to characterise the catchments for the LOCAR thematic programme can be classified into two groups; one off data sets and time series monitoring. Evidently the one off data sets are those which are not expected to change frequently with time and will include: Geology, digital terrain model, river bed levels, borehole datum levels and locations, Ordnance Survey coverage and aquifer parameters. Time series monitoring requirements will include groundwater levels and groundwater quality.

ONE OFF DATA SETS

A good understanding of the geology of the catchment area is fundamental to the hydrogeological conceptual model. Recent developments in the understanding of the lithostratigraphy of the Chalk aquifer highlight the relationship between the stratigraphy and certain topographic features. Whilst the new stratigraphy has been applied to the recently re-surveyed area included on the Dorchester 1:50,000 geological map (sheet 328), it has not yet been applied to the western part of the catchments and the 5km buffer zones which are covered the Bridport (327) and Yeovil (312) sheets, neither of which are due for resurvey. It is important that the new stratigraphy is applied to these areas because of the recognisable relationship between the stratigraphy and certain topographic features. Additionally, some members of the newly defined members of the succession have distinctive geophysical log signatures. Identification of these stratigraphic horizons (particularly those which act as preferential flow horizons) is essentially to understanding the groundwater flow within the catchment areas. Thus it is recommended that revision mapping of the geology of the western part of the Frome/Piddle catchments should form a fundamental part of the JIF/LOCAR baseline knowledge for future research initiatives.

The distribution of marls and hardgrounds throughout the catchments will affect the nature of fracturing. Many small faults exploit weaker horizons such as marls and so fracture porosity would be enhanced at the intersection of faults and marls. In addition, both faulting and jointing intensity may be greater in hardgrounds than in normal soft chalk. So the intersections of faults with hardgrounds may also lead to an increase in fracture porosity.

Geological survey of the catchments is essential to provide aquifer/rock characterisation through:

- location and characterisation of the distribution of marls and hardgrounds.

- determination of the distribution of fracturing in the catchments over a range of scales:
  - at the catchment scale by mapping the size and displacement on the largest fault zones;
  - at the outcrop scale by obtaining data on joint distributions and bedding fracture frequency;
  - and at the borehole scale through the correlation of fracture data with geophysical and hydrogeological observations.

TIME SERIES MONITORING

Ambient monitoring should potentially be met through the existing networks. However, as can be seen from section 3.2.4, the groundwater level monitoring network is particularly deficient in the Frome catchment. Additionally, with regard to groundwater quality measurements, it is recognised by the Environment Agency that their network measurements are not generally carried out to a research standard. Thus monthly groundwater sampling and analysis (at research standard) from a minimum of twenty boreholes throughout the catchment area is required in order to provide baseline data on groundwater quality.

Validation and strengthening of the hydrogeological component of the conceptual model of the Frome/Piddle catchment will be aided by the installation of a number of boreholes, each one designed to achieve a number of objectives. The number of boreholes (of differing designs for different collective objectives) is constrained by a number of factors, some of which can not be evaluated within the TOR of the Task Force (e.g. access). However, it is possible to provide the following recommendations, while recognising that such constraints might limit their application:

- as many as possible of all new boreholes and piezometers should be multi-objective;
- all pilot holes and boreholes to be geophysically logged including detailed fracture logging (borehole imaging and core logging), flow logging;
- a minimum of five new boreholes are required to augment the existing groundwater monitoring network in the Frome catchment. They will be cored at narrow diameter (cores being logged, pore waters sampled and analysed, and remaining core to be stored), and then reamed to required finished diameter. All of these boreholes will be equipped with 3 nested piezometers;
- a number of existing boreholes need to be equipped with data loggers to provide additional enhancement of the existing groundwater monitoring network;
- a minimum of three boreholes are required to investigate surface water/groundwater interaction within the Frome valley corridor. Again these should be cored and logged and each equipped with 3 nested piezometers;
- investigation of surface water/groundwater interaction at a floodplain wetland site is afforded by access to land at the IFE River Laboratory at East Stoke. This facility will require an initial “central” borehole to prove the local geological conditions and an inclined borehole below the river corridor. A series of shallow piezometers will characterise the flow regime in the river gravels.

3.3.3 Ecological baseline requirements

PRELIMINARY

- For each area a set of large scale digitised maps will be required – this is an essential precursor to any survey work.
- A GIS including blue line, digital terrain model, high resolution land-use data, field boundaries, deep and drift geology, small area statistics, soil, occurrence of designated areas (e.g. SSSI's). This would form the central core of information on each catchment. It should be able to be serviced, accessed and run from the relevant research sites, so for example the system for the Frome would be run from CEH-Dorset.
- For each area, an attempt should be made to produce a catalogue of landowners (including tenants) and any perceived problems with access. Meetings may be required to explain the objectives of LOCAR. These points were raised at the meeting with the Environment Agency and although they have much of the information, it was understood that they are unable to make this available. However there may have been some change and discussions with the Environment Agency HQ in Bristol concerning their current policy is advised.
- The ability to measure discharge throughout the catchment including headwaters would seem to be a necessary precursor to any subsequent research. This should, at the very least, show where major changes in discharge occur in relation to surface/groundwater interactions etc. The infrastructure in each catchment should accommodate this need.

ONE OFF DATASETS

- Basic land-use survey – it is recognised that details will change over the period of study but the essential characteristics of the catchment will remain the same.
- Geomorphological surveys - these would provide the baseline against which developments over the LOCAR study period can be measured. The survey should include substratum analyses to provide information on bed particle size and siltation. Ideally the geomorphological survey would be done in association with River Habitat Surveys (RHSs) including mammal and bird records and macrophyte distribution mapping etc and these latter modules should be repeated throughout the study period (time-series) to account for natural variability.
- Instream sub-surface inflows – identification of areas of upwelling. This dataset will provide basic information for a number of research issues including salmonid spawning, water quality and siltation studies.
- These activities are included in the ecological one-off survey. The need for a survey of Micro-organics in river water each year for 4 years at £2000 per year was considered as a desirable requirement for baseline data. The characterisation of the catchments in terms of their pesticide and herbicide loading is an important background attribute and knowledge of loadings and their temporal and spatial distribution would provide a key background descriptor of the environment. However, it was excluded following discussions with the Technical Expert Working Group due to budget restrictions.

TIME SERIES MONITORING

Chemical monitoring of main river and tributaries for major ions, nutrients, micro-organics and metals. Catchment wide studies require a wide network of sites and this information is central to subsequent research.

River Habitat Surveys with macrophyte mapping and geomorphological add-ons (see Newson et al. 1998 "The geomorphological basis for classifying rivers" Aquatic Conservation 8: 415-430, and the Environment Agency's River Habitat Survey Methodology for the general approach). These should be repeated at least twice after the initial survey during the LOCAR study period.

Faunal communities in representative river sectors – This would be carried out in association with RHS etc (see above) at a reduced number of sites. The information will elucidate the interactions between habitat availability, biotic communities and physical variables such as discharge and geomorphological determinands.

Fine sediment dynamics. Measures of sources, storage and mobilisation should be made on a weekly basis at key sites. Supplementary information should be obtained from sediment traps, surface material run-off and field observations of sediment sources (see Walling & Amos 1999, "Source, storage and mobilisation of fine sediment in a chalk stream system", Hydrological Processes 13, 323-340). Supplementary continuous measurements of turbidity should be gathered at strategic points to monitor sediment inputs (as in LOIS). These data will not only add to the fine sediment project but will provide essential information for studies of fish movements that are related to turbidity. These activities are included in the hydrological proposals.

3.4 PROPOSALS

3.4.1 Hydrological

CLIMATE, INCLUDING RAINFALL AND EVAPORATION

This will require the following:

- Addition of 3 period raingauges to the EA/MO networks (£4.5K).
- Installation of 2 AWS in each catchment for climate and potential evaporation, plus one extra recording raingauge near the proposed Maiden Newton gauging station (£22.5K).

The detailed costs of purchase and installation for this will be **£27K**.

SOILS AND UNSATURATED ZONE HYDROLOGY, AND RECHARGE ESTIMATION

Three recharge sites will be set up, identical to the layout detailed for the Pang and Lambourn hydrological flagship catchments (Chapter 4). The following storages and processes to be quantified at 3 sites:

- soil water content using 3 neutron probe access tubes, 5 Theta TDR probes for continuous monitoring and 3 suction samplers for soil moisture chemistry (£40K);
- soil tensions near surface using 12 puncture tensiometers. Soil tensions through the unsaturated zone using 10 equitensiometers and borehole jacking tensiometers (£40K);
- shallow groundwater logging using dipwells and piezometers (£5K);

- direct measurement of evaporation by HYDRA has not been included on cost grounds, but will have to be used as a campaign instrument if actual evaporation is required for recharge estimation.

The total cost will be **£85K**.

CHANNEL FLOWS

Integrated and incremental flows will be estimated using the following techniques:

- improvements to existing EA stations, including tail water monitoring;
- installation of 2 new stations at Maiden Newton and Bovington (£150K+£30K);
- establishment of rated section on Bere stream using velocity area and dilution methods for calibration. (£3K).

The total cost will be **£183K**.

WATER QUALITY AND SEDIMENT

Much of the water quality work and suspended sediment sampling relies on recurrent expenditure for manual and storm sampling, sampler operations, maintenance of continuous monitors and laboratory sample manipulation and analysis. However, the following will need to be purchased and installed:

- continuous water quality monitors at 11 sites, including spares for routine exchange (WISER system). These would measure temperature, conductivity, pH, chlorophyll-a, dissolved oxygen, and possibly also nitrate (£114.4K);
- turbidity measurements from 15 separate sensors will be required (£42K).

The cost will be **£156K.**

Portable laser diffraction equipment will be needed to analyse the origin and distribution of instream sediments and to monitor fluctuations in turbidity. This equipment is on the JIF bid.

Estimated total cost £55,000.

RECURRENT COSTS

Using a unit cost of £50 per sample analysis, recurrent cost for chemical sample analyses are estimated as follows.

River water and rain water chemistry at 11 sites on a weekly basis for the first year and monthly basis for the following three years, **£57,000**.

3.4.2 Hydrogeological

Evidently the total costs will depend on the number of each type of installation discussed above. As a basis for further discussion several installations for the Frome/Piddle catchment areas are proposed and costs for these facilities estimated.

GEOLOGY

The structural complexity of the geology of this area has important implications for the hydrogeology. Thus a good understanding of the geology is essential if the hydrogeology is to be understood. Such an understanding will be achieved by geological survey, the use of geophysics and drilling.

Map sheet 328, Dorchester covering the lower end of the combined Frome/Piddle catchment has recently been surveyed incorporating the new Chalk stratigraphy. Major structural features and geomorphological features such as solution hollows have been identified. However, the western part of the catchments and the 5km buffer zones cover extensive areas of structurally complex geology that falls on the Bridport (327) and Yeovil (312) sheets, neither of which are due for resurvey. The cost for surveying this remaining is estimated at £32,230 and would result in the following deliverables:

- geological draft maps at 10K and fully digital at 50K;
- addition of the new Chalk stratigraphy;
- technical report incorporating biostratigraphy and structural geology.

Geophysics will be used to locally identify faults to assist with siting of new boreholes and to confirm structural control of streams as indicated on the Dorchester geological sheet.

Estimated total cost £35,000.

Two new boreholes will be drilled in the upper to middle reaches of the Frome catchment to prove the geological succession through to the Gault, providing information to assist with application of the new Chalk stratigraphic nomenclature. These boreholes are costed below as part of the augmentation of the existing monitoring network

GROUNDWATER MONITORING NETWORK

As can be seen from Map 3.5 the current groundwater level monitoring network in the Frome catchment is very limited. It will therefore be necessary to augment this network. It is proposed to drill a number of additional boreholes throughout the catchment to permit characterisation of piezometric surfaces. These will be of varying depths depending on their location in the catchment and some are included in facilities discussed in the following sections. Five boreholes are not included in the additional facilities and are costed here. They will be cored, logged and pore waters sampled throughout their depth. A depth of 100 m for each of these boreholes is assumed – the two most westerly of the new boreholes will prove depth to the Gault and will be completed with piezometers to enable chemical sampling and heads to be monitored in the Greensand, Lower, Middle and Upper Chalk. The remaining three holes will not reach the Gault but will be completed with piezometers to allow monitoring of heads in and chemical samples to be collected from the Lower, Middle and Upper Chalk and/or the Eocene beds where appropriate. Some of these boreholes will be co-located with sites selected for soil moisture measurement.

Estimated total cost £125,000.

ADDITIONAL DATA LOGGERS

A sum of money is required for equipping existing boreholes with data loggers as part of the augmentation of the existing observation network.

Estimated total cost £20,000.

SURFACE WATER/GROUNDWATER INTERACTION

This aspect will be investigated by a series of three boreholes along the river Frome valley corridor. One of approximately 30 m depth will be sited above the proposed new river flow gauge at Maiden Newton (SY60 98), one of approximately 50 m depth in the reach between Maiden Newton and Dorchester, and one of an estimated 80 m depth between Dorchester and Pallington (SY 790 190).

Estimated total cost £59,000.

FLOODPLAIN WETLAND-SURFACE WATER-GROUNDWATER INTERACTION

This facility will be based at the IFE River Laboratory at East Stoke on the floodplain of the river Frome. An array of 9 shallow holes with two piezometers per hole will be located in the alluvium and Tertiary beds between the Frome and Mill Stream. A 50 m borehole (into the Tertiary Beds) will be drilled initially to prove the local geological conditions. Surface geophysics will be used in conjunction with the information gained from the borehole to design an array of 9 shallow holes equipped with two piezometers per hole (approximately 15 m depth each) in the flood plain between the two rivers. An additional three holes (up to 50 m depth) will be located at varying distances from the initial borehole to provide additional observation holes for aquifer tests. A single inclined borehole (drilled length 25 m) will be drilled below the river. Figure 3.4.2.1 shows the proposed layout.

Estimated total cost £93,000.

GEOPHYSICAL SURVEY

Localised geophysical survey to assist with location of the boreholes required for the above facilities.

Estimated total cost £14,000.

RECURRENT COSTS

Groundwater chemical analyses from 20 sites on a monthly basis for 4 years @ £50 per sample.

Estimated total cost £48,000.

3.4.3 Ecological

2X High sensitivity temperature probes. These will be part of a central facility available to all catchments in order to identify, survey and monitor the incidence of upwelling areas along the length of the rivers.

Estimated total cost £2,000.

Pressure transducers. The increase in volume due to the growth of macrophytes displaces water during the summer and bankfull levels are frequently observed in rivers where the weeds remain uncut. It is important to know how these changes effect estimates of discharge with more conventional techniques and most importantly the dynamics of the floodplain environment.

Estimated total cost £3,000.

Smolt counter. The measurement of losses at different stages of salmon development is extremely time consuming. Aggregated loss rates can be measured at two points in time, adult salmon returns from the sea (see continuous monitoring) and smolt runs to sea. At these times all the adults and smolts pass one point in the river, simplifying measurement. This new smolt counter will enable long term monitoring of smolt numbers to be undertaken at an economic cost and will provide data which can be used to produce a stock recruitment model for the river. A basic requirement if looking to identify relationships between flow and salmon movements.

Estimated total cost £80,000.

Fish tracking system. Very little is known about habitat utilisation by the common UK fish species. This information is vital in order to plan effective conservation management strategies. Of particular interest are ranges and spawning requirements. The system will be used to monitor the daily and seasonal movement of coarse fish in the River Frome (in response to flow and other environmental and biological variables (included in central equipment pool).

Estimated total cost £38,000.

ONE OFF SURVEYS

Ecological characterisation of catchment. The catchments offer a diverse range of geology with its concomitant effect on flow regime and instream and riparian habitat. It is important that a base-line descriptive data set is collected which will provide the background necessary for subsequent studies in these catchments. The data need to describe the broad range of environmental conditions to be found along the main rivers and their tributaries. The River Habitat Survey methodology provides a convenient and tested technique for describing river habitat and this, in conjunction with habitat patch (mesohabitat) mapping will present a detailed account of the lotic environment. Supplemental surveys will provide information on algal communities on hard surfaces and faunal communities of individual mesohabitats.

Estimated total cost £ 52,000.

Redd count @ £8,000. Salmonids lay their eggs in selected areas of gravel, these are called redds and are frequently situated in areas where upwelling provides a clean and well-oxygenated environment. The distribution of redd counts will provide data which will link with studies of upwelling and their relation with contour and hydrogeology.

Estimated total cost £ 8,000.

Fish population electro-fishing. There are few background data on the composition and distribution of fish populations which cover the length of the river in a systematic manner and the proposed survey will provide this information.

Fish population data analysis. Routine surveys do not include information on age structure. Data analysis will provide quantitative estimates of fish populations and length/weight relationships will be analysed in conjunction with scale reading to determine the age-structure of the fish populations. Such data are an integral part of any study which attempts to relate catchment characteristics with instream fish communities.

Estimated total cost £ 24,000.

ANNUAL SURVEYS

Ecological characterisation 2 years @ £17,000 per year. These annual surveys will take place on a reduced set of sites and will provide information on the dynamics of habitat change and associated biotic communities. Such data will provide the necessary background to studies that will examine the processes of change in relation to a wide range of environmental variables. Process-based research will be able to draw on the information obtained in these routine repeated surveys.

Estimated total cost £ 34,000.

Adult salmon counting 4 years @ £ 14,000 per year. This gives basic data of salmon numbers and movement to the spawning grounds.

Estimated total cost £56,000.

Smolt counter. The measurement of losses at different stages of salmon development is extremely time consuming. Aggregated loss rates can be measured at two points in time, adult salmon returns from the sea (see continuous monitoring) and smolt runs to sea. At these times all the adults and smolts pass one point in the river, simplifying measurement.

Use of the smolt counter will enable long term monitoring of smolt numbers to be undertaken at an economic cost and will provide data which can be used to produce a stock recruitment model for the river. The figure quoted represents running costs and staff time for use of the counter and basic analysis of results.

Estimated total cost £40,000.

3.4.4 Summary Total Costs

Table 3.5 Frome/Piddle Infrastructure. Capital items/one off surveys

		Cost	Sub Total
One off Surveys	Geology	£35,000	
	Geophysics	£14,000	
	Ecology	£52,000	
	Redd count	£8,000	
	Fish population - electro fishing - data analysis	£24,000	
	Identification of water gain/loss/stream/temp profiles	£6,000	**£139,000**
Hydrology	2 Automatic weather stations	£21,000	
	Additional rain gauges (4)	£6,000	
	3 soil moisture sites	£85,000	
	Maiden Newton flow gauge	£150,000	
	Bovington stream flow gauge	£30,000	
	Establishment of rated sections on Bere stream	£3,000	
	11 Automatic water chemistry monitoring systems	£114,000	
	15 turbidity systems	£42,000	
	Routine spares water quality and turbidity	£10,000	
	Portable laser diffraction equipment	£55,000	**£516,000**
Hydrogeology	Groundwater monitoring network	£125,000	
	Loggers for installation in existing boreholes	£ 20,000	
	Surface water/groundwater monitoring	£ 59,000	
	Wetland monitoring experimental site	£ 93,000	**£297,000**
Ecology	2 x high sensitivity temperature probes	£2,000	
	Pressure transducers	£3,000	
	Smolt counter	£80,000	**£85,000**
Site acquisition	11 sites @2,500 per site		**£27,500**
Field and laboratory equipment	Sampling equipment for labs	£ 7,500	
	Pump for shallow water sampling	£1,900	
	Mobile pump for chemical sampling	£3,200	
	Bladder pump and control unit	£2,000	
	Double packer for 85mm- 185mm boreholes	£2,000	
	Data logger interrogation unit	£250	
	3 water level dippers	£1,000	**£17,850**
Grand Total Infrastructure Capital/one off surveys			**£1082,850**

Table 3.6 Frome/Piddle Recurrent Costs

		Cost	Total
	Surface water chemical analysis	£57,000	
	Groundwater chemical analysis	£48,000	
	Ecological characterisation surveys (2 off)	£34,000	
	Adult salmon counting	£56,000	
	Smolt counter	£40,000	
	Land rental – nominal sum	£10,000	
Grand Total recurrent costs			**£245,000**

4 The Pang/Lambourn Catchment

4.1 INTRODUCTION

The rivers Pang and Lambourn occupy adjacent catchments within the Thames basin. Both are fed by the Chalk aquifer of the West Berkshire Downs and exhibit the characteristics of Chalk groundwater dominated river systems, with slow, damped responses to rainfall and 'bourne' behaviour of headwater reaches when the water table is low. However, despite their proximity and shared groundwater source, the Pang and Lambourn catchments are different in character. This is a result of both dissimilar historical development and hydrogeology. Maps 4.1 and 4.2 show the physiography and geology of the catchment and Map 4.3 shows the distribution of annual rainfall across the catchment. These maps also indicate the surface water and groundwater catchment areas.

In the upper reaches of the Pang catchment, the river is noted particularly for visual amenity, enhancing the beauty of several villages along its course. Further downstream the river is a designated EC salmonid fishery, though this is largely maintained by stocking. The Pang has a recent history of groundwater abstraction (for public supply) which has caused the depletion of low flows in the summer months, such that in 1989 the river was designated as in the top ten requiring alleviation of low flows (ALF). As a result subsequent investigations, including installation of two high quality gauging stations, abstraction was reduced resulting in a rise in groundwater levels and renewed flow in the upper reaches.

The Pang catchment is intensively farmed with recent increases in pig farming and Christmas tree growing, bringing water quality issues. Sediment washed from arable land has been a problem and the local authority closed the water cress beds near Standford Dingley, where a major spring appears (Blue Pool), due to bacterial contamination. Current studies are aimed at identifying whether the source is human (e.g. broken sewer) or animal (e.g. from pig farm slurry) waste. A water quality survey (Neal, 1999) has identified three distinct hydro-chemical zones (upper, middle and lower reaches) driven mainly by carbon dioxide content. Nutrients, major ions and trace metals were also recorded.

The River Lambourn remains a more natural stream than the Pang, with 71% of its channel classified as "retaining geomorphological diversity, gravel bed and a range of signs of past modification" (Geodata Institute, in prep). In contrast to the Pang, flow accretes as a series of inputs along the line of dry valleys entering at right angles. The catchment is less intensively farmed and there is also little groundwater abstraction. Although the West Berkshire Groundwater Scheme has potentially an impact on streamflow, this is seldom used except in severe droughts (1975, 1976 and 1990) and the ecological status of the river has been largely maintained. The widespread occurrence of *Ranunculus* (water crow's foot), populations of fish (such as trout, bullheads and grayling) and diverse invertebrates (250 species at one sampling site, Berrie *et al*, 1973) led to the Lambourn becoming one of the 27 rivers designated as a Site of Special Scientific Interest (SSSI). A wide range of ecological studies has been undertaken on the Lambourn. The reach at Bagnor has received one of the most intensive and long term ecological studies of any river in the UK with over 30 scientific papers written (Wright & Symes, 1999). Plant distributions were mapped every month between 1971 and 1979 and intensive sampling programmes for fish, invertebrates and plants undertaken every June and December, allowing their response to flow to be analysed. The programme was re-established in 1997. In addition, modelling of instream physical habitat for trout, invertebrates and macrophytes was undertaken at Hunt's Green (Johnson *et al,* 1993).

4.1.1 Dominant catchment characteristics

Both the Pang and Lambourn have been found to exhibit features that influence the direction and type of infrastructure and monitoring required to address the LOCAR questions. These features are outlined below:

PANG

- The Pang is a largely Chalk catchment lying predominantly on Upper Chalk even in the headwaters.
- The only notable tributaries are found in the lower catchment.
- The lower catchment is characterised by a wide flood plain associated with the Thames and a palaeo-river course (possibly the Kennet).
- A major summer inflow is provided by karst fed springs at the Blue Pool in the middle catchment, however, the karst behaviour in the catchment is not understood.
- Bourne behaviour is seen over several kilometres upstream of Frilsham.
- Tertiary deposits influence recharge in the middle reaches.
- Superficial deposits of clay with flints influence recharge on hill tops.
- The groundwater flow regime is obviously influenced by the Thames base level and the definition of the groundwater catchment is unclear.
- Influence of upward movement of Upper Greensand water is unclear.
- Many hydrological/hydrogeological and modelling studies have been carried out with limited success but pointing to clear gaps in knowledge.
- Nitrate is a water quality issue in the Pang.
- The Pang has limited ecological data but is of interest in terms of potential rehabilitation of a degraded system.
- The Pang has some surface water quality data to build upon.
- A good flow gauging network is present.
- With some gaps a good groundwater monitoring network is present.
- History of groundwater abstraction in the Pang which has now ceased allowing water level recovery.
- Recent land use changes (pig farming, Christmas trees) have introduced new possible recharge/pollution issues.

LAMBOURN

- The Lambourn provides a classical Chalk stream that consists of a single linear channel with considerable variation in length dependent on ‘bourne’ activity (i.e. from summer to winter).
- Dry valleys, which only occasionally contain flowing streams, intersect the surrounding chalk hills approximately at right angles to the main river.
- The perennial stream is characterised by valley bottom (river corridor) wetlands with side springs/seepages.

- Considerable historic groundwater data is available from the Environment Agency.
- The Lambourn is of ecological interest and the river is an SSSI.
- The one major tributary of the Lambourn, the Winterbourne, is a simple chalk subcatchment that offers the opportunity for exploring scaling issues.
- Three stream gauges on the Lambourn (two out of use) can be upgraded to provide a well gauged catchment.
- The Winterbourne subcatchment is gauged.
- The groundwater catchment appears to be reasonably well defined from existing level networks.
- There are suitable sites for the monitoring of a wetland area on the Lambourn and surface water/groundwater interaction on the Pang.

4.1.2 Strategy

It is clear that the major advantages of the Pang/Lambourn are its wealth of hydrological/hydrogeological data. The catchments provide the opportunity to take low flow catchment hydrology/hydrogeology much further than hitherto if emphasis on detailed monitoring in hydrology (particularly recharge and water quality) is made. Thus broadly in the Pang/Lambourn less focus will be given to geomorphological and ecological monitoring than in the Frome/Piddle, and rather more on the hydrogeology and hydrology, in particular the interface scientific issues of recharge and groundwater/surface water interaction.

Some specific aspects are listed below:

(i) Concentrate detailed monitoring sites for Chalk stream (bourne) behaviour on Pang.

(ii) Develop detailed monitoring of unsaturated zone on a variety of sites covering major land use and geologies.

(iii) Develop wetland monitoring site on Lambourn at the perennial head (spring).

(iv) Use Winterbourne catchment for scale studies.

(v) Better define geology.

(vi) Better define Pang groundwater catchment.

(vii) Develop surface water/groundwater interaction monitoring site on Pang.

(viii) Build on existing water quality network.

(ix) Monitoring the hydrology/hydrogeology of the Blue Pool.

(x) Develop facility for accurate calculation/evaluation of groundwater recharge including measurement of evaporation.

(xi) Develop a site for detailed study of reactive and non-reactive transport in saturated and unsaturated chalk.

(xii) Flow gauge the Bourne (tributary of the Pang)

4.2 EXISTING INFRASTRUCTURE AND DATA

4.2.1 Hydrology

The Pang and Lambourn catchments have been intensively scrutinised over recent decades to assess the water resources and ecological implications of groundwater pumping from the chalk aquifer. They have been the subjects of intensive campaigns of monitoring for rainfall and streamflow, initiated at the design phase of various flow augmentation and water resources schemes, and the effects have subsequently been monitored by the Environment Agency. This infrastructure, along with instrumentation for scientific studies that have addressed the issues raised, means that the catchments can lay reasonable claim to having amongst the most spatially intensive and highest quality hydrological networks on Chalk in the UK.

LONG TERM WATER BALANCE ANALYSIS

The long term Pang and Lambourn water balances are given in Table 4.1, using summary rainfall and streamflow data provided by the EA through the National Water Archive.

Characterising the hydrology of the Pang and Lambourn, or any permeable catchment, by analysing water balances is not an exact science because of the uncertainties surrounding unmeasured movement of groundwater, and the non-coincidence of the surface and groundwater boundaries. However, the accurate and precise measurement of the component fluxes of the catchments is important if the internal processes within the catchment are to be better understood. In this area of the West Berkshire Downs where the mean annual rainfall (1968-1997) for the pang is 692 mm and for the Lambourn is 731 mm, the mean annual flow in the Pang (112 mm) is only half that of the Lambourn (228 mm) (Table 4.1). Most of the difference between rainfall and flow in the Pang is due to evaporation at around 525 mm per annum, but is also due to heavy and time-variable exports of abstracted groundwater, and groundwater flows across the boundary and under the main gauging station at Pangbourne.

Table 4.1 Long term water budgets for the Pang and Lambourn catchments using the common data period 1968-1997

Catchment	Area (km^2)	Mean annual rainfall – P (mm)	Mean annual flow – Q (mm)	Estimated mean annual losses P – Q (mm)[1]	Penman PE (mm)[2]
Pang to Pangbourne	170.9	692	112	580	525
Lambourn to Shaw	234.1	732	228	505	525

[1] Evaporation plus net outward groundwater flow plus non-returned abstractions (mm) minus imports.

[2] Mean annual Penman potential evaporation from the Flow Regimes and Environmental Management Map (Institute of Hydrology).

RAINFALL

The period gauge networks total 16 sites in and around the Pang and 18 in and around the Lambourn. The majority are read daily, with two accumulated over weekends and two read monthly. Unfortunately, 6 of the sites in the Pang and 8 of the sites in the Lambourn have been discontinued, with a total of 6 gauges abandoned in the 1990s. To compensate, 4 gauges in and around the Pang, and 2 in the Lambourn were installed in the 1990s. The most serious loss is the gauge at Compton, which was the only gauge in the higher altitude northern end of the Pang. This has been replaced very recently by a recording gauge at Knollend with a check gauge.

Annual rainfall distribution (Map 4.3) around the Pang/Lambourn varies from 647 mm to 706 mm.

In spite of the closure and establishment of individual gauges in the Pang and Lambourn a very similar network structure has remained, and there are enough period raingauges to describe accurately the rainfall surfaces across the West Berkshire Downs. From this it will be possible to interpolate rainfall at specific process sites and to obtain a good estimate of mean catchment rainfall. However, extra gauges in the higher altitude parts of both Pang and Lambourn would improve the accuracy of estimates. Their locations should coincide with long-term process monitoring studies where access is good, regular visits will take place and data can be used directly for scientific study at the site.

Many of these network gauges are read by volunteer observers for the EA and Meteorological Office, for purposes other than catchment research needs, and the quality of data and appropriateness of siting will have to be checked to ensure conformity to full Meteorological Office standards. There are no obvious rainfall anomalies in the Pang or Lambourn, however, which is a good indication of overall quality.

It can be concluded that with some augmentation from LOCAR, the current period (daily) raingauge network will give comprehensive coverage. Current gauges in and around the Pang/Lambourn are shown in Tables 4.2 and 4.3 and in Map 4.4. Gaps exist in the daily-read network in the northern, higher altitude part of the Pang and in the middle section of the Lambourn, north of the river.

Table 4.2 Details of raingauges in and around the Pang catchment

Gauge	East	North	SAAR	ALT	BEGINS	DBYR	ENDS	Daily?	sub-D	NAME
265414	4558	1743	688	104	1884	1961	curr	5or6d		Yattendon Court
265632	4643	1767	668	41	1972	1972	1992	5or6d		Pangbourne S.Wks
264845	4601	1818	655	45	1986	?	curr	daily	event	Cleeve Lock Auto.Sta.
265647	4625	1720	662	53	1860	1903	1979	daily		Englefield
264898	4598	1806	694	48	1956	1961	curr	daily		Goring
265462	4599	1731	647	67	1958	1962	1995	daily		Bradfield P.Sta.
265637	4645	1718	669	45	1972	1972	1990	daily		Theale S.Wks
265605	4593	1763	679	125	1967	1972	curr	daily		Upper Basildon
265135	4514	1801	675	105	1975	1976	1994	daily		Compton P.Sta.
264893	4596	1808	678	41	1990	1990	curr	daily		Goring Lock
264844	4601	1818	655	45	1993	1993	curr	daily		Cleeve Lock
265379	4551	1709	691	68	1994	1994	curr	daily		Bucklebury
264872	4642	1816	706	162	1995	1995	curr	daily		Woodcote
265628	4635	1763	655	43	1963	1963	curr	irreg.		Pangbourne P.Sta
269949	4613	1697	666	46	1974	?	1984	?	lapsed	Englefield
265415	4558	1743	688	104	1996	?	curr	?	event	Yattenden Court Auto.Sta.
	4456	1829		144	1999	1999	curr	?	event	Knollend

Table 4.3 Details of raingauges in and around the Lambourn catchment

Gauge	DCNN	East	North	SAAR	ALT	BEGINS	DBYR	ENDS	Daily?	sub-D	NAME
268851		4469	1739	699	104	1980	?	curr	Daily	event	Chieveley S.Wks Auto.(RADAR) Sta.
268196	5504	4313	1802	743	142	1997	?	curr	Daily		Upper Lambourn
268103		4305	1817	735	150	1984	?	curr	Daily	event	Lambourn, Maddle Farm Auto.Sta.
268991		4487	1739	698	118	1930	1931	curr	Daily		Priors Court
266949		4260	1756	770	146	1909	1931	curr	Daily		Aldbourne
268812		4461	1770	744	145	1931	1961	curr	Daily		Peasemore House
268637		4385	1737	705	119	1963	1963	curr	Daily		East Shefford
268184		4296	1802	759	145	1963	1963	1995	Daily		Fognam Down P.Sta. No.1
268398	5505	4355	1817	720	192	1967	1967	1996	Daily		Lambourn
267755		4350	1682	741	91	1969	1969	1977	Daily		Hungerford, Dunn Mill
268698		4425	1713	703	98	1968	1969	1979	Daily		Boxford
266969		4263	1755	759	130	1969	1969	1985	Daily		Aldbourne, Half Moon Cottage
268744		4453	1801	726	167	1976	1977	1989	Daily		Catmore Farm
267090		4301	1731	793	183	1977	1978	1989	Daily		Eastridge House
267088		4300	1736	776	140	1989	1989	curr	daily		Ramsbury, Witcha House
268850		4469	1739	699	104	1995	?	curr	mnth		Chieveley S.Wks
268102		4305	1817	735	150	1995	?	curr	mnth		Lambourn, Maddle Farm
268056		4477	1674	720	70	1954	1961	1970	?		Newbury S.Wks

Key to Tables 4.1 & 4.2

GAUGE	Met. Office raingauge number. This does have significance in a hydrological referencing sense.
SAAR	Standard annual average rainfall 1961-90.
ALT	Altitude of site in metres.
BEGINS	Start of the raingauge record.
DBYR	Data base year. Start of the digital record. Note that digital data before 1961 will require special dispensation from the Meteorological Office (and payment).
ENDS	End date as a year or "current".
DAILY?	Recording frequency. This request has been for daily gauges only. "5or6d" indicates that either Sunday or Saturday and Sunday are not recorded. The result is an accumulation on Monday.
sub-D	Whether a sub-daily recorder is, or has been, in operation at the site.
NAME	Meteorological Office name for the site.

There are currently 4 recording raingauges in the Pang and Lambourn providing event or hourly data, at Cleeve Lock and Yattendon in the Pang area, and at Chievely Sewage Works and Maddle Farm in the Lambourn area. Although a new recording gauge has recently been installed at Knollend (GR 4456 1829) towards the north-western extremity of the Pang.

CLIMATE

There are currently no climate sites within the Pang or Lambourn contributing to the Meteorological Office official network. The nearest are the Institute of Hydrology (Crowmarsh) and RAF Benson meteorological sites 10 km away north west from the north eastern boundary of the Pang catchment.

EVAPORATION

The Pang has been targeted as a prime catchment for land use studies where the spatial variability of the evaporation process will largely dictate recharge to the aquifer. Currently there are no direct measurements of evaporation made, and catchment evaporation cannot be estimated accurately from the surface water balance at the annual level (Table 4.1). MORECS provides regional (40 km x 40 km) monthly evaporation data, and transpiration estimates for various agricultural crops may be calculated from soil water balances at the soil moisture sites.

SOIL TYPE AND MOISTURE

There are 11 different soil associations within the Pang catchment (Figure 4.2.2.1 and Table 4.4) on the Soil Survey's 1:250,000 map (Soil Survey of England and Wales, 1983). The dominant soil types can be grouped as chalk soils, clay with flints, and soils developed on tertiary deposits (Reading Beds). The northern part of the catchment is dominated by calcareous fine silty soils of the Coombe 1 and Andover 1 series (chalk soils occupy 36.9% of the catchment) on the slopes and valley bottoms of the chalk downland, and Hornbeam 2 clay soils developed on the plateau drift (clay with flints occupy 23.5%). In the south, Frilsham loamy soils developed on drift over chalk, Wickham 4 clay loam (Reading beds soils occupy 20.5%) and Southampton plateau gravels/river terrace drift dominate, with the Thames floodplain alluvium and Hurst river terrace gravel deposits near the catchment outlet. The minor soils altogether occupy 19% of the catchment.

Until recently, IH has run 13 neutron probe access sites in the Pang, most of which have been read on a regular basis over the last three years. As a result, much is already known of the spatial distribution of soil moisture in the Pang. However, these sites, biased towards the Andover series where currently 3 sites (9 tubes) are situated, are confined to a narrow band of altitude and gentle slopes (Table 4.4).

The Pang sites can provide data to give an initial appraisal of soil moisture conditions that can inform future site selection. Some tubes recently removed because of agricultural operations will be reinstalled and made deeper under LOCAR, as these sites form part of the new recharge site strategy outlined in Section 4.3.

FLOW GAUGING

The existing river flow gauges on the Pang and Lambourn have all been visited and assessed with regard to their historical records and their performance. Use has been made of both the National River Flow Archive (NRFA) records and specialised knowledge from EA staff. The NRFA 'Aide Memoir' has been used as a basic check list for all facets of gauging station operation.

The current gauges were installed for operational water resources purposes, mainly to monitor the effects of heavy groundwater abstractions in the Pang and Lambourn as part of the West Berkshire Groundwater Scheme. They provide high quality flow measurement and are well sited to meet the objectives of LOCAR.

Table 4.4 Details of existing soil moisture sites in the Pang catchment from the Soil Survey of England and Wales classification (1983)

Site	Tube Nos.	Soil type	Description	Grid Ref.	Altitude (m)	Slope (deg.)
10	1	Andover 1 (343h)	Shallow, well-drained, calcareous, fine silty soils on chalk	45106 18167	149	0
	2			45136 18182	149	0
	3			45167 18197	115	3.8
20	4	Andover 1 (343h)	Shallow, well-drained, calcareous, fine silty soils on chalk	45136 17970	120	2.8
	5			45167 17939	120	0
	6			45197 17924	120	5.7
30	7	Wickham 3&4 (711g,h)	Fine/coarse, seasonally-waterlogged loam over Tertiary/Mesozoic clay	45212 17258	50	5.7
	8					
	9					
40	10	Andover 1 (343h)	Shallow, well-drained, calcareous, fine silty soils on chalk	45167 18470	120	0
	11			45136 18545	120	0
50	12	Hornbeam 2 (582c)	Deep, fine loam over clay soils on plateau drift	45515 17697	143	0
	13					

Each site has been assessed with respect to:

- the likelihood of design flows being exceeded;
- the onset of non-modularity where this information is available, and provisions for corrections to be applied;
- low-flow performance and sensitivity;
- its ability to give accurate and precise estimates of 15 minute flows on a continuous basis.

PANG

There are currently three flow stations fully operating on the Pang (details are given in Table 4.5) of which the gauges at Frilsham and Bucklebury were installed for the Alleviation of Low Flows (ALF) scheme in 1992. There were also incremental flow surveys undertaken at 11 sites in the Pang in the 1970s and early 1980s for the purpose of identifying the locations of major inputs.

In addition, a flood warning station (unsuitable for accurate full range flow measurement) is due to be installed at Tidmarsh, and a discontinued, temporary weir was installed at Hampstead Norreys where the Pang is frequently dry. The weirs are constructed on permeable foundations and have some leakage underneath.

The main structures are all of high quality construction, of Crump or Flat-V designs, incorporating pre-cast crests in concrete weir blocks and sidewalls. Structurally, they conform to British Standard design ratings under most conditions.

LAMBOURN

There are two fully operational structures on the Lambourn (Lambourn at Shaw and the Winterbourne at Bagnor) plus two further structures originally used for the 'Lambourn Ground Water Recharge Pilot Scheme' (at East Shefford and Welford) but discontinued in the early 1980s (details are given in Table 4.6). East Shefford has temporarily been reopened for use by Birmingham University. Welford could again operate as a full gauging structure but to conform to full British Standard design specifications would need some expensive modifications, particularly to the position of head measurement.

FLOW INCREMENTATION

Longitudinal flow surveys have been carried out in the 1970s and early 1980s for the purpose of identifying the locations of major inputs to the Pang (Map 4.4). All surveys highlight the importance of springs in the vicinity of Blue Pool in almost doubling flows in the Pang. On the Lambourn, flow incrementation surveys have been undertaken by Birmingham University, which highlight the intermittent nature of inputs along dry valleys (mini-scarps) at right angles to the channel. The Shefford and Welford structures would provide temporal information on flow incrementation in the Lambourn.

4.2.2 Surface water quality

THE PANG

A survey of the surface water quality of the Pang has been undertaken, and the conclusions to the study are presented within a recent paper by Neal *et al.* (1999). The water quality functioning of the Pang varies along its length, and the study has recognised three hydrochemical units within the channel that will require baseline water quality measurements to be made within LOCAR

- The Upper Pang, from its source to half way along its length at Rotten Row.
- Downstream from the Blue Pool springs to the confluence of the Bourne.
- The Pang downstream of the confluence with the Bourne.

Regular sampling has been undertaken at four sites in the Pang. At Tidmarsh (SU 4636 1748) weekly sampling is undertaken, augmented by continuous pH, conductivity and dissolved oxygen measurements. Monthly sampling is also taken at two upstream points on the Pang at Rotten Row and Bradfield (SU 4584 1717 and SU 4603 1728) and the Blue Pool (SU 4583 1717).

THE LAMBOURN

There has to date been no detailed survey undertaken of the Lambourn. If the Lambourn to Shaw catchment is considered, it should be noted that this will include nutrient enrichment from sewage near its downstream confluence with the Kennet at Newbury. This is already the case in the Winterbourne, where discharges from Chievely STW have an impact on the water quality of this otherwise pristine stream.

4.2.3 Geomorphology and sediment transport

AVAILABLE SEDIMENT DATA

There is no routine manual monitoring of river sediment loads for either the Pang or Lambourn by the Environment Agency. Similarly, data from regular bulk sampling for suspended solids analysis (or from field or laboratory based turbidity measurements) is lacking. The exception to this rule is the random sampling of effluent discharges and spatial investigations of pollution incidents, which unfortunately tend not to be archived. No continuous records of river turbidity have been noted either from Environment Agency or Thames Water PLC.

Table 4.5 Details of flow structures in the Pang (see Table 4.6 for explanatory notes)

Name	Area (km^2)	Record Period	Q95 ($m^3 s^{-1}$)	Sensitivity Index %	Mean flow ($m^3 s^{-1}$)	Q10 ($m^3 s^{-1}$)	Max. Rec. Flow ($m^3 s^{-1}$)	Max Design Flow ($m^3 s^{-1}$)	Hydraulic Performance
Pangbourne Crump **GR 4634 1766**	170.9	1969-present	0.184	17.4	0.59	1.08	6.5	16.0	Full range. Occasionally drowned by Thames backing up and at extreme high flows by downstream culvert. Tailwater levels system inoperative, but due to be replaced in 2000. Some doubt over interaction with Sulham Brook. Maybe affected by Pangbourne P.S. Flood Estimation Handbook noted anomalous peaks. Otherwise max. flow well within capacity. Telemetry.
Tidmarsh **Level/Tele-metry**		2000-							Double channel. Proposed installation on both for flood warning by telemetry. Stable sections that could be rated but will be prone to hysteresis.
Bucklebury Flat-V **GR 4556 1711**	109	1991-present	0.000	N/A as Q95=0	0.20	0.551	2.0	6.475	Full range. Susceptible to drowning May-June due to weed growth but this is controllable. D/S tapping for non-modular flow and level corrections made by EA. Telemetry. Adequate capacity to pass maximum flow recorded . Rarely by-passed. Drys up in most years.
Frilsham Flat-V **GR 4537 1730**	89.8	1991-present	0.000	N/A as Q95=0	0.16	0.424	1.1	2.278	Drowning/non-modularity more often a problem than at Bucklebury, due to weed growth. Non-modularity corrections done by EA. Drys up in most years (Q95 = 0). Low capacity constrained by channel depth. Telemetry.

Table 4.6 Details of flow structures in the Lambourn and Winterbourne

Name	Area (km^2)	Record Period	Q95 ($m^3 s^{-1}$)	Sensitivity Index %	Mean flow ($m^3 s^{-1}$)	Q10 ($m^3 s^{-1}$)	Max. Rec. Flow ($m^3 s^{-1}$)	Max Design Flow ($m^3 s^{-1}$)	Hydraulic Performance
Shaw **GR 4470 1682**	234.1	1962-present	0.743	13.8	1.68	2.778	5.4	17.0	10.67m wide Crump structure with high, low-flow sensitivity index. Rarely drowned but D/S recorder available for non-modular flow due to weed growth. Spillage at high flows to Donnington Lake causes temporary storage. Telemetry.
Welford **GR 4411 1731**	176.0	1962-83	0.409	14.6	1.02	1.678	3.1	3.86	Inoperative. Double Crump and rectangular long base weir set in 3 arches of road bridge. Crests at angle to channel will give asymmetric flow. Head measurement too far upstream for BS requirements
East Shefford **GR 4390 1745**	154.0	1962-83	0.097	7	0.77	1.612	2.5	11.5 - 20	Recently re-opened by Birmingham University. 3-bay Compound Crump with excellent approach conditions. Good sensitivity at low flows.
Winterbourne at Bagnor **GR 4453 1694**	49.2	1962-present	0.050	36.7	0.16	0.296	0.7	0.9	Full range Crump; note width reduced from 5.5m to 3m in 1968 to increase low flow sensitivity. Affected (rarely) by WBGS discharge upstream and sewage effluent from Chievely. Telemetry.

Notes on Tables 4.5 and 4.6

Q95 - flow exceeded 95% of time, Q10 - flow exceeded 10% of time, Sensitivity Index – percentage increase in flow for 10 mm stage rise

The most recent measurements of suspended sediment concentrations on the Pang have been spot samples taken by the Institute of Hydrology during 1998/99 at five sites (weekly to two monthly intervals) showing the following ranges (Table 4.7).

Table 4.7 Suspended sediment concentrations (in mg l^{-1}) – Pang 1998 (modified from Neal *et al*., in press)

Site	Mean	Min	Max
Upper Pang	4.88	0.10	14.00
Blue Pool	1.56	0.01	5.60
Bradfield	6.51	0.10	23.70
Tidmarsh	7.47	0.60	48.20

This indicates a range in suspended sediment concentrations from 0.01 mgl^{-1} up to 48 mgl^{-1}. With the exception of the special conditions at Blue Pool, there is a general increase in concentration downstream. This is similar to most British rivers, although the overall concentrations are rather low. This may reflect the fact that this is only one year's routine data and is unlikely to have included higher concentrations from higher magnitude flow events.

With regard to bed topography, routine Environment Agency cross sectional surveys are available for both the Pang and Lambourn. Bed sediments are mainly gravels, sometimes with a top layer or matrix of fines (which may vary through the year) and some cobble sized materials. No intensive or repeated bed sediment surveys are available for either the Pang or Lambourn.

There has been no emphasis upon the links between particulate matter and chemistry in the routine monitoring

4.2.4 Hydrogeology

GEOLOGY

The geological setting is illustrated in Map 4.2. Some 40% of the total topographic catchment area and surrounding 5 km wide "buffer" zone has been covered by recent geological survey work of the British Geological Survey (as yet unpublished). The remaining 60% occur equally on the Newbury sheet which is due for resurvey in 2002/03, and the Abingdon sheet that is not part of BGS' current 15 year programme. In terms of Chalk stratigraphy, structural interpretation and drift mapping the current maps are judged to be inadequate for the LOCAR thematic programme. Mapping priorities can be altered so that the Newbury sheet could be the subject of resurvey commencing in Spring 2000 as part of BGS' 15 year funded programme.

GROUNDWATER LEVEL MONITORING NETWORK

The Environment Agency's existing groundwater level monitoring network of 124 boreholes is shown in Map 4.5. Levels at these boreholes are variously dipped at 6-monthly, monthly and weekly intervals or are monitored by data loggers, as indicated on Map 4.5.

GROUNDWATER QUALITY MONITORING NETWORK

The Environment Agency's existing groundwater quality monitoring network of 28 boreholes is shown in Map 4.4. The frequency of measurement and length of record is highly variable and information is not readily available to provide a summary of these attributes.

GROUNDWATER MODELS

Some 10 numerical groundwater models have been developed that include all or part of the Pang and Lambourn catchments. These all use the finite difference approach and are described in the review report by Bradford in the Appendix.

A more detailed review of the hydrogeological data available for the Pang/Lambourn catchment area is given in the Appendix.

4.2.5 Ecology

Apart from a network of sampling locations and some long-term data there is no specific ecological infrastructure.

DATA

The majority of reports, publications and data pre-date the generation of Local Environment Agency Plans. The biological information was found to be generally descriptive, including comparatively few numerical data sets.

River Lambourn

One third of the *c*.45 data sources for the Lambourn provide information at catchment, extended reach scale or cover particular topics of relevance to all LOCAR catchments. The majority of this third describe aquatic communities and exclude extensive numerical data, 6 - covering macro-invertebrates, 5 - general habitats/conditions, 2 - fish, 2 - plants, 1 - mammal (otter). Ecological studies have generally been restricted to one or two reaches and catchment wide studies on ecological aspects are rare. The most detailed work was carried out in the 1970's and some aspects of these studies are being repeated now (see Appendix for details) but these do not include integrated catchment-wide work. Currently the river is routinely monitored at two sites and records extend back to the early seventies. One of these sites is also examined as part of the Environmental Change Network and diatoms, macrophytes and invertebrates are monitored. This programme has run for the last two years and will continue into the foreseeable future.

The widespread occurrence of *Ranunculus* (water crow's foot), populations of fish (such as trout, bullheads and grayling) and diverse invertebrates (250 species at one sampling site; Berrie et al, 1973) led to the Lambourn becoming one of the 27 rivers designated as a Site of Special Scientific (SSSI). A wide range of ecological studies has been undertaken on the Lambourn. The reach at Bagnor has received one of the most intensive and long term ecological studies of any river in the UK with over 30 scientific papers written (Wright & Symes, 1999). Plant distributions were mapped every month between 1971 and 1979 and intensive sampling programmes for fish, invertebrates and plants undertaken every June and December, allowing their response to flow to be analysed. The programme was re-established in 1997. In addition, modelling of instream physical habitat for trout, invertebrates and macrophytes was undertaken at Hunt's Green (Johnson *et al*, 1993).

The Lambourn has been identified as a target spawning ground for salmon, as part of the salmon restoration programme in the Thames catchment. This programme involves regular fisheries surveys, with the most recent undertaken in Oct-Nov 1999.

River Pang

The biological information traced on the Pang is comparatively very limited in volume. Titles and summarising information available indicate 5 of the 11 data sources listed in the Appendix provide accounts of catchment-scale studies. As with the Lambourn, they are in the main descriptive rather than data-rich. Four sources covered general topics and one (raw data) described fish populations.

The Pang has relatively little ecological data and most of the ecological studies have addressed low flow issues that had arisen as a result of groundwater pumping. Continued monitoring activity is concerned with assessing the durability of Pang ALF (Alleviation of Low Flows) enhancements and ecological health of the river and the state of its fishery. For example, a recent survey was undertaken to assess recolonisation of fish following the 1997 drought. The absence of trout in many reaches led to the installation of a brown trout spawning box containing gravel and fish eggs, which aids recolonisation. Further surveys are planned to assess its success.

Additional interest lies in the restoration of a water meadow at the Dairies, near Tidmarsh. Routine monitoring takes place at one site on the Pang for which there is a long data run.

4.3 BASELINE REQUIREMENTS

4.3.1 Hydrological baseline requirements

RAINFALL

The current EA/MO period raingauge networks (Map 4.4) form the core of the 'baseline' requirement for assessing daily rainfall patterns, as outlined in the strategy in Chapter 2. It is proposed that 4 additional gauges will be installed at selected 'main' recharge sites. This will improve the spatial coverage by including more gauges at high altitudes in the Pang.

Snow melt is not important enough to warrant specialised instrumentation.

The strategy includes a network of six sites giving hourly rainfall in the Pang and Lambourn. There are currently 5 sites in and around the two catchments. However, two new sites will be added as part of automatic weather stations (AWS). It is proposed that the baseline measurements also include two further sites, making 9 in all, one of which will be associated with a forest 'main' recharge site, as specific data will be required for process studies.

Weather radar data from Chilbolton may be available to the Science Programme. Five-minute, two kilometre spatial resolution radar data are available from the Meteorological Office. This would provide the detailed spatial structure of rainfall events and would complement ground level measurements. Purchase should be considered as part of Science Projects rather than as a baseline information.

CLIMATE

It is proposed that automatic weather stations (AWS) be installed at the extremes of altitude, and in order to cover the spatial distribution of the Pang/Lambourn, preferably one in each catchment. It is proposed that one of these is installed over short grass, the index vegetation for Penman potential evaporation calculation, and the other in arable land, the dominant land use for the Pang and Lambourn. Once installed, the AWS will measure the effects on climate of any changes in the crop during a normal agricultural rotation.

These two sites will be located at two of the recharge sites (Frilsham Meadow GR 4538 1745 in the Pang, altitude 80 m, and at Warren Farm GR 4358 1819 in the Lambourn altitude 200 m).

EVAPORATION AND SOIL MOISTURE EQUIPMENT FOR THE RECHARGE SITES

Actual evaporation varies with soil type, vegetation and depth to groundwater. Preliminary measurement and modelling studies have suggested that in an average year on Chalk the evaporation from grassland and forest are similar and higher, by 50-100 mm, than from a cereal crop. On clay (and in dry years) the evaporation totals are smaller with the larger reduction coming from the grassland. There is, however, some controversy over these figures and no simultaneous measurement of forest/cereals and grassland has yet been made. It is proposed that direct evaporation is measured at the main recharge sites.

The primary evaporation measurement is eddy correlation (using the HYDRA). However this has operational and financial constraints, not least the need to find soil/vegetation domain patches large enough to give adequate fetch (200 to 300m diameter circle). It also needs to be supplemented by soil moisture budgeting and profiling at a wider range of sites. Recent advances in the technology of eddy correlation and logged soil moisture sensors means that for the first time (in the UK at least) routine monitoring of these variables can be made within a catchment experiment.

It is proposed that the 7 recharge sites (Map 4.6) would be split into 3 'main' sites, instrumented to include HYDRA evaporation flux stations, and 4 'subsidiary' sites that would in the first instance have just soil moisture and unsaturated zone instrumentation (plus groundwater monitoring if selected).

The layout of the instrumentation at the sites is shown in Figure 4.3.1.1. Three neutron probe access tubes are proposed at each recharge site (with six at the forest site because of the greater spatial variability), giving a total of 30 tubes. It is recommended that these are monitored in the first year to identify the spatial heterogeneity and a decision made after the first year as to the practicality of maintaining this density of tubes. It is also proposed that 5 Theta probes are installed at each site to give near continuous near surface moisture content where neutron scattering is suspect. Theta probes profiling down to 1 m could then be calibrated by neutron scattering data to give accurate, continuous water contents through the upper soil profile.

It is proposed that the bulk of the neutron access tubes are installed to 4 m, but that at the 3 'main' recharge sites one tube is extended to 9 m. A deep tube (30-50 m) is proposed to investigate the deep unsaturated zone.

Soil moisture tension will be measured at all sites with a combination of 12 near-surface (<1 m) puncture tensiometers and 10 equitensiometers profiling to 10 m at each site. Three soil moisture suction lysimeters (porous cups) will also be installed at each recharge site to allow collection of soil water samples.

LOCATING RECHARGE/UNSATURATED ZONE SITES

There would be many scientific and practical advantages in locating SVAT/soil/recharge sites at the same location as the boreholes in the proposed groundwater monitoring network:

- limited numbers of access agreements;
- savings on fieldwork expenditure;
- more widespread application of data from individual instruments, e.g. raingauges, AWS;
- estimation of recharge actually above a borehole, and comparison of response times at the water table;

- information on the water and chemical composition of the complete unsaturated zone during drilling and logging of borehole cores;
- the chance to install and log deep tensiometers for measurement of hydraulic potential, by jacking gypsum blocks against 'clean' borehole sides.

It is proposed that 7 recharge sites are set up, to sample the dominant soil/land use domain sites shown in Table 4.8 below. These sites have been assessed both in terms of the spatial coverage of the predominant soil/vegetation domains and to use existing sites where there are soil moisture data to build upon and good access. Wherever practically possible and where this coincides with the hydrogeological strategy, boreholes would also be located at these sites.

Table 4.8 Chosen domains for installation of main recharge monitoring sites in the Pang/Lambourn, and instrumentation proposed. Minor crops are shown for completeness, and to be considered in case aerial extent increases. Areal coverage of soils and land use is given for the Pang

	Chalk soils (36.9%)	Clay-w-flints (23.5%)	Reading Beds (20.5%)
Forest (broadleaf) **(20%)**		Soil Moisture (3[1]) Beech Wood 4536 1767	Soil Moisture (6), HYDRA, net rainfall Hermitage 4515 1728
Permanent grass **(18%)**			Soil Moisture (3), HYDRA Hermitage 4524 1725
riparian	Soil Moisture (3), AWS. Frilsham 4538 1745		
grass ley		Soil Moisture (3) 4358 1819	
winter wheat **(Total cereals 34%)**	Soil Moisture (3d[2]), HYDRA, Churn farm 4515 1855	Soil Moisture (3), AWS, 4356 1815	
spring barley			
field maize **(Other arable 28%)**			
oil seed rape			

1 number of soil moisture tubes shown in brackets
2 'd' denotes deep (9m) tubes, otherwise 4m.

There are 3 'main' recharge sites where measurements of climate, soil moisture and evaporation are combined. These include the broadleaf forest site at Hermitage where, in addition, there will be net rainfall gauges, canopy evaporation measurements, some climate measurements (attached to the Hydra logger) and deeper soil moisture tubes. The cereal and grass ley sites present a problem for long term monitoring as the crop is likely to change from year to year. It is proposed that the soil stations remain in place and in the long term a representative mix of crop types will be monitored.

There are some crop/soil type combinations which will not be sampled, because they do not occur or only to a very minor extent. It may be that short-term studies will be necessary to cover these, especially if they are likely to increase in influence during the period of the study, for example forest plantation on Chalk (also covered at Black Wood, Hampshire) or increased areas of field maize or rape. This also indicates the importance of regular survey (seasonally and annually) of the vegetation coverage in the catchments. For example, between 1990 and 1997, the coverage of grass in the Pang declined from 6948 ha to 4055 ha while tilled land increased from 7542 ha to 10433 ha.

DEEP UNSATURATED ZONE

This will be monitored by the deep (30-50 m) neutron access tube, and by jacking 'Plaster of Paris' encased tensiometers against the sides of boreholes drilled for the hydrogeological programme. Pore water content and chemistry will be measured from cores taken during borehole installation. The core will also be fracture logged and the borehole wall video scanned.

FLOW GAUGING REQUIREMENTS

Main structures

The structures in the Pang and Lambourn are generally reliable in terms of their ratings and operation throughout most of their containment ranges. Out-of-bank flows do not appear to have been a problem on most of the structures in recent memory, although overspilling has occurred at Frilsham. However, because of the inherently shallow gradients of the streams, and the low crest heights adopted to minimise constrictions in cross-sectional area, most of the structures at one time or another have had problems with non-modularity. This has been caused either by:

- natural downstream bed controls;
- weed growth causing a raising of tailwater levels at a given flow;
- backing up from river confluences where the confluent river is in spate.

A great deal of attention has been paid by the EA to correcting flows for non-modularity, however this has to be recognised as a difficult task. Except in the case of the first reason above, it is not simply a matter of permanently changing a rating to incorporate reduction factors that are assumed to stay constant at a given flow. These will be dependent on measured tailwater levels, and the problem will be different over each event and will be specific to the conditions pertaining at the time.

EA Thames Region are aware of this problem, and will collaborate with LOCAR to resolve some of these problems by:

- making corrections for non-modularity;
- installing systems for measuring tailwater levels where these do not currently exist, or improving operational procedures where they do exist;
- minimising the modularity problem by a regular programme of weed clearance at all sites.

Rating the Tidmarsh site is proposed, to provide an extra 'main' flow site to complement Pangbourne, both because of problems of interaction with Sulham Brook and because

Tidmarsh is the main water quality/sediment flux site for the Pang. Good flow measurements at this site would also help to assess the potential impact of Pangbourne Pumping Station on Pangbourne flows.

The Welford site on the Lambourn will be refurbished, but recommissioned only as a rated section with a good hydraulic control. The indications of greater than expected flow augmentation from groundwater in the reach between Shefford and Welford emphasise the importance of Welford for flow incrementation studies.

Subsidiary gauging stations

It is proposed that a small structure, e.g. a thin plate weir, should be installed on the Bourne tributary of the Pang. This is to establish the differences in the flow regime of water draining from the Palaeogene deposits, and also because the hydrochemical surveys have highlighted a different chemical signal that has a major impact on the Pang itself.

SPRING OUTFLOWS (ESP. BLUE POOL)

Measuring the discharge from the Blue Pool (a major spring in the lower reaches of the Pang – Map 4.6) provides a unique opportunity for relating the magnitude and response time of spring discharge to the groundwater table.

Discharge from the Blue Pool could either/or:

- be measured directly, by structure or rated section upstream of its confluence with the Pang;
- be measured directly at each individual spring source;
- be estimated by incremental difference in the main river.

The cost implications of all three are similar and it is proposed that a detailed hydrometric survey is carried out to determine the best option.

ABSTRACTIONS AND SEWAGE RETURNS

The main abstractions are the public water supply boreholes at Compton, Bradfield and Pangbourne, and historical and observed abstractions will be requested from Thames Water.

Discharge from STWs will be measured by occasional volumetric measurements (diurnal and seasonal) or estimated from population equivalent figures. In addition the transfers of water into and out of the catchment will be estimated.

WATER QUALITY MEASUREMENTS

It is proposed that a low-flow, water quality survey is carried out and data analysed before the final choice of sampling sites is made in the Pang and Lambourn. The cost of this is allowed for in the general one-off baseline survey allocation. However, as the final number of sites will have a major impact on recurrent expenditure, only 5 sites in the Pang and Lambourn should be considered for baseline monitoring. At each of these sites continuous monitors should be installed to measure Temperature, pH, Dissolved Oxygen, Conductivity, Chlorophyll-a and Nitrate if a suitable electrode can be found, and weekly samples taken for chemical analysis. The proposed sites are shown on Map 4.6. Two extra sensor heads should be purchased to allow for routine exchange of units.

It is also proposed to monitor rainfall chemical inputs to gauge the significance of atmospheric loadings of chemicals and this will be undertaken at Yattendon, near the main meteorological network site at Frilsham Meadow. Samples will also be taken from a rainfall gauge in the Lambourn.

INFRASTRUCTURE FOR STUDY OF SEDIMENTS ON THE PANG AND LAMBOURN

Deployment of 5 turbidity sensors linked to the water chemistry monitors is proposed in line with sites identified for Water Quality excepting Blue Pool where sediment concentration are likely to be very low.

The routine field monitoring, flow–related sampling and laboratory analysis should be integrated with analytical chemistry. The Pang and Lambourn bed material survey should be linked with ecological monitoring surveys. Access to Acoustic Doppler velocity meter and conventional current meters will be required.

4.3.2 Hydrogeological baseline requirements

INTRODUCTION

As noted in Chapter 3, the baseline data requirements required to characterise the catchments for the LOCAR thematic programme can be classified into two groups; one off data sets and time series monitoring. Evidently the one off data sets are those which are not expected to change frequently with time and include: Geology, digital terrain model, river bed levels, borehole datum levels and locations, Ordnance Survey coverage and aquifer parameters. Time series monitoring requirements will include groundwater levels and groundwater quality.

ONE OFF DATA SETS

A good understanding of the geology of the catchment area is fundamental to the hydrogeological conceptual model. The geological map coverage of the Pang/Lambourn catchment area dates from 1860 for part of the Lambourn catchment to some partial resurveying of the upper Pang area (sheet 254) in the early 1970s. Recent developments in the understanding of the lithostratigraphy of the Chalk aquifer (Appendix) highlight the relationship between the stratigraphy and certain topographic features. Additionally, some of the newly defined members of the succession have distinctive geophysical log signatures. Identification of these stratigraphic horizons (particularly those which act as preferential flow horizons) is essentially to understanding the groundwater flow within the catchment areas. Thus it is recommended that revision mapping of the geology of the Pang/Lambourn catchments should form a fundamental part to the JIF/LOCAR baseline knowledge for future research initiatives.

TIME SERIES MONITORING

Ambient monitoring should potentially be met through the existing networks. However, in order address the objectives of LOCAR a number of "facilities" consisting of particular combinations of boreholes and hydrological monitoring sites are required. Where such combinations are not currently available additional boreholes will need to be drilled. Such boreholes will additionally provide augmentation of the existing groundwater level monitoring network. Additionally, with regard to groundwater quality measurements, it is recognised by the Environment Agency that their network measurements are not generally carried out to a research standard. Thus monthly groundwater sampling and analysis (at research standard) from a minimum of twenty boreholes throughout the catchment area is required.

Thus validation and strengthening of the hydrogeological component of the conceptual model of the Pang/Lambourn catchment will be aided by the installation of a number of boreholes, each one designed to achieve a number of objectives. The number of boreholes (of differing designs for different collective objectives) is constrained by a number of factors, some of which can not be evaluated within the TOR of the Task Force (e.g. access). However, it is possible to provide the following recommendations, while recognising that such constraints might limit their application:

- as many as possible of all new boreholes and piezometers should be multi-objective;
- all pilot holes and boreholes to be geophysically logged including detailed fracture logging (borehole imaging and core logging), flow logging;
- in order to understand the flow regime to the north-east of the upper reaches of the river Pang a minimum of three new boreholes will be required. The first borehole of the set should penetrate the full thickness of the active zone of saturated groundwater flow, be cored, tested and logged and equipped with three nested piezometers. The other boreholes will be drilled to the same depth as the first (not cored or tested but logged) and again each equipped with nested piezometers;
- in order to investigate surface water/groundwater interaction an inclined borehole is required under a reach of the river that is in evident hydraulic communication with the groundwater body. This will be accompanied by two relatively shallow, vertical boreholes (one on each side of the river – cored tested and logged) and 4 piezometer nests at varying distances from the inclined bore adjacent to the river. Four additional boreholes will be sited in a transect from approximately 60 m away from the river across the river and up to the hill top on the opposite bank. This linear profile penetrating the full thickness of the “active” saturated zone, aligned down the regional hydraulic gradient is required to characterise 3-D head distribution;
- it is necessary to understand the hydraulic regime at the lower and upper boundaries of the Chalk aquifer. Thus a minimum of two boreholes are required; one to prove the base of the aquifer at the Gault interface and one to penetrate the overlying Palaeogene beds into the Upper Chalk;
- a major feature of the hydraulic regime of the Pang catchment is the Blue Pool spring. Flow from this feature is a significant component of the Pang’s total flow. It is necessary to provide a facility to investigate the local geology and provide a facility to monitor groundwater levels and their relation to recharge and surface flow;
- due to their ecological importance, wetlands are an important issue for LOCAR. Thus baseline data of surface water/groundwater interaction at a river corridor wetland site is required;
- a facility is necessary to characterise the hydraulic regime of the saturated and unsaturated zones of the Chalk to enable investigation of controls on transport.

4.3.3 Ecological baseline requirements

PRELIMINARY

In order to meet the LOCAR aims as outlined in the introduction it is necessary to provide an infrastructure to facilitate information gathering. This would include not only the provision of apparatus but an ‘environment’ in which data can be gathered. In order to achieve this the following baseline requirements are needed. Note that the baseline requirements discussed below are considered from an ecological viewpoint but will include aspects relevant or central to other disciplines.

- for each area a set of large scale digitised maps will be required – this is an essential precursor to any survey work;

- a GIS including blue line, digital terrain model, high resolution land-use data, field boundaries, deep and drift geology, small area statistics, soil, occurrence of designated areas (e.g. SSSI's). This would form the central core of information on each catchment;
- for each area, an attempt should be made to produce a catalogue of landowners (including tenants) and any perceived problems with access. Meetings may be required to explain the objectives of LOCAR. (These points were raised at the meeting with the Environment Agency and although they have much of the information, it was understood that they are unable to make this available. However there may have been some change and it is worth checking what the current policy is at the EA HQ in Bristol);
- the ability to measure discharge throughout the catchment including headwaters would seem to be a necessary precursor to any subsequent research. This may not require permanent gauging sites but should, at the very least, show where major changes in discharge occur in relation to surface/groundwater interactions etc. The infrastructure in each catchment should accommodate this need.

ONE OFF DATASETS

Geomorphological surveys — these would provide the baseline against which developments over the LOCAR study period can be measured. The survey should include substratum analyses to provide information on bed particle size and siltation. Ideally the geomorphological survey would be done in association with River Habitat Surveys including mammal and bird records and macrophyte distribution mapping etc and these latter modules would be repeated throughout the study period (time-series). If this did not occur at least there would be matching habitat/geomorphology data for the catchment as a whole.

- Instream sub-surface inflows – identification of areas of upwelling. This dataset will provide basic information for a number of research issues including salmonid spawning, water quality and siltation studies (as part of the hydrological survey).

TIME SERIES MONITORING

- Chemical monitoring of main river and tributaries for major ions, nutrients, micro-organics and metals. Catchment wide studies require a wide network of sites and this information is central to subsequent research.
- Fine sediment dynamics. Measures of sources, storage and mobilisation should be made on a weekly basis at key sites with supplementary information from sediment traps, surface material run-off and field observations of sediment sources (see Walling & Amos 1999, "Source, storage and mobilisation of fine sediment in a chalk stream system", Hydrological Processes 13, 323-340). Supplementary continuous measurements of turbidity should be gathered at strategic points to monitor sediment inputs (as in LOIS). Collation of these data will depend on the geomorphological and sediment studies element of the infrastructure.

4.4 PROPOSALS

4.4.1 Hydrological

The basic approach for the surface hydrology of the catchments will be to estimate fluxes that contribute to the catchment water balance, and to estimate internal fluxes such as aquifer recharge that help to explain surface-groundwater interactions.

CLIMATE, INCLUDING RAINFALL AND EVAPORATION

This will require the following:

- 4 period (weekly) gauges at recharge sites (£4,000);
- installation of 2 AWS in each catchment for climate and potential evaporation (£21,000);
- installation of 2 extra recording gauge to bring the total to 9 (£3,000);
- measurements of actual evaporation at 3 sites using eddy correlation techniques such as HYDRA with interception sites for tall vegetation £149,000+20,000).

The costs of purchase and installation for these instruments total **£197,000.**

SOILS AND UNSATURATED ZONE HYDROLOGY, AND RECHARGE ESTIMATION

This will involve the following equipment to be quantified at 7 'recharge' sites:

- soil water content at 21 (3 tubes at each) shallow sites (4 m) plus 3 deep sites (9 m), using neutron probes (weekly), Theta capacitance probes giving near surface continuous records at 35 sites (a profile of 5 probes at each recharge site);
- a 30-50 m experimental access tube is proposed to cover the deep unsaturated zone;
- soil tensions near surface using a profile of 12 puncture tensiometers;
- soil tensions through the unsaturated zone using a profile of 10 equi-tensiometers at each site;
- shallow groundwater logging using dipwells and piezometers will need to be collaborative venture during the hydrogeological instrument installation;
- soil water extraction using 3 suction lysimeters at each site will provide samples for chemical analysis.

The total cost will be **£200,000.**

CHANNEL FLOWS

Integrated (sub-) catchment and incremental flows will be estimated using the following techniques An agreement would need to be reached with the EA for all flow gauging instrumentation once installed to become part of the EA network.

- Improvements to, and re-establishment (Welford), of existing EA stations. Better treatment of non-modular flows, weed clearance and calibration for out-of-bank flows. £40K should be allocated as a contribution from LOCAR to the EA, to include the above, and the installation of 2 new stations on the Bourne and Blue Pool. (£40,000).

The total cost will be **£40,000**.

BASELINE HYDROLOGICAL SURVEY

Hydrological baseline/incremental stream flow survey, including stream temperature profiles

Total cost will be **£4,000**.

WATER QUALITY AND SEDIMENT

Much of the water quality work relies on recurrent expenditure for manual and flood event sampling, sampler operations, maintenance of continuous monitors and laboratory sample manipulation and analysis. As indicated in section 4.1, there are 3 distinct reach types within the Pang system with varying hydrochemical responses. This makes within catchment monitoring necessary for baseline measurement. Given the relatively small additional cost turbidity sensor heads are also proposed (£2k per site) for each monitor. The following will need to be purchased and installed:

- continuous water quality monitors totalling 5 for the Pang/Lambourn. These would measure temperature, conductivity, pH, chlorophyll, dissolved oxygen, and possibly also nitrate (£55,400);
- epic samplers for ad hoc storm sampling are included by default in the WISER system;
- parallel turbidity measurements will be required (£12,500);
- spares for the rotational exchange of water quality and turbidity monitors (£10,000).

The estimated total water quality and sediment monitoring costs will be **£77,500**.

RECURRENT COSTS

Using a unit cost of £50 per sample analysis, recurrent cost for chemical sample analyses are estimated as follows.

River water and rain water chemistry at 6 sites on a weekly basis for the first year and monthly basis for the following three years, **£31,000**.

4.4.2 Hydrogeological

GEOLOGY

Forty per cent of the total topographic catchment area and surrounding 5km wide “buffer” zone has been covered by recent geological survey work of the British Geological Survey. The remaining 60% occur equally on the Newbury sheet, which is due for resurvey in 2002/03, and the Abingdon sheet that is not part of BGS’ current 15 year programme. In terms of Chalk stratigraphy, structural interpretation and drift mapping the current maps are judged to be inadequate for the LOCAR thematic programme. Mapping priorities can be altered so that the Newbury sheet could be the subject of resurvey commencing in Spring 2000 as part of BGS’ 15 year funded programme. The remaining area could be surveyed with LOCAR/JIF funds at a total cost of £53,000 that would result in the following deliverables:

- new geological maps at 1:10,000 draft and provided digitally at 1:50,000 scale;
- application of the new Chalk stratigraphy (see Appendix 1);
- technical report for the catchment area, including structural analysis.

Estimated total cost **£53,000**.

GROUNDWATER DIVIDE – NORTH EAST OF PANG

Consideration of the 1976 groundwater level contour map and various studied since indicate uncertainty over the position of the groundwater divide defining the start of groundwater flow from the north east to the river Pang. The 1976 drought will have resulted in low regional groundwater levels and lack of base flow in much of the river. However in wetter seasons there will be a significant baseflow component to the upper reaches of the river. A minimum of three boreholes will be required to define the location of the divide and for the purposes of this costing exercise it is assumed that none of the existing boreholes in the area can be used. It is proposed that one borehole of 100 m depth should be cored, tested and logged and equipped with three piezometers at varying depth. Two further 100 m deep boreholes will also be drilled (not cored or tested but logged) and each equipped with three piezometers at varying depths.

Estimated total cost £88,000.

SURFACE WATER/GROUNDWATER INTERACTION

Figure 4.4.2.1 shows the proposed installation required to investigate surface groundwater interaction. The separate elements are as follows:

- 1 inclined borehole under the river (25 m drilled length) cored, and geophysically logged;
- 2 vertical boreholes adjacent to river and at each end of the inclined borehole, cored, tested and geophysically logged;
- 4 Piezometer nests adjacent to river at varying distances from the inclined borehole, 40 m depth, geophysically logged and equipped with 3 piezometers at varying depths;
- 2 Piezometer nests at same distance from, but on opposite sides of river, up hydraulic gradient from inclined borehole. 60 m depth and geophysically logged;
- 1 hillslope borehole (not cored) as part of cross-section, equipped with 3 piezometers at varying depths;
- 1 cored, geophysically logged and tested hole further up hydraulic gradient to 105 m depth (i.e. at interfluve). Equipped with 3 piezometers at varying depths.

A possible site for this facility could be focussed on the river Pang at Frilsham Meadow south of the M4 motorway (SU 538 735). Associated flow gauging and soil moisture measurements are detailed elsewhere.

Estimated total cost £165,000.

CHARACTERISATION OF UPPER AND LOW BOUNDARIES TO CHALK AQUIFER

(i) 1 Chalk borehole through the full thickness of the Chalk to the Gault Clay. Cored, geophysically logged and equipped with piezometers in the Chalk and the Upper Greensand. Estimated total depth 200 m. To establish/confirm the hydrochemical and hydraulic regimes towards the lower boundary of the Chalk aquifer and its degree of connection with the Upper Greensand.

Estimated total cost £53,000.

(ii) 1 Tertiaries borehole, ideally located in close proximity to a spring to enable future study of the spring hydraulics. Cored, geophysically logged and tested, equipped with piezometers in the different main divisions. Estimated total drilled depth drilled 70 m. An associated piezometer nest (3 piezometers) in 70 m uncored borehole –

geophysically logged. To determine hydrochemical and hydraulic regimes in the Tertiaries and the region of Upper Chalk overlain by the Tertiaries.

Estimated total cost £38,000.

BLUE POOL SPRING INVESTIGATION

Monitoring of groundwater levels and chemistry in the region around the Blue Pool Spring. One borehole of estimated depth 50 m cored, logged and completed with 3 piezometers at various depths, located behind the Blue Pool. One borehole of estimated depth 20 m completed with 3 piezometers at various depths, located between the Blue Pool and the River Pang.

Estimated total cost £29,000.

WETLAND INVESTIGATION

A facility is proposed to investigated a wetland at the perennial head of the Lambourn (SU 380 753) or similar site. Figure 4.4.2.2 shows the proposed layout of the facility. An initial investigation borehole will be drilled some 50m from the river (D in Figure 4.4.2.2) to a total depth of some 100 m to prove the site geology and completed with three piezometers at varying depths (2 in the Chalk and one in the alluvium). A second borehole, G, will then be drilled to the same depth as D (100 m) and completed as open hole (as far as possible) for subsequent aquifer tests. Borehole G will have three associated observation boreholes located at varying radial distances and directions (E, H, I) completed into the top of the Chalk (assume 30 m completed depth). Three 10 m deep boreholes (A, B and C) will be sited along the river and completed with piezometers in the top of the Chalk and in the alluvium. Two further boreholes will be drilled up topographic slope away from the river into the Chalk (assume 30 m and 50 m deep). An inclined borehole (drilled length 25 m) will be located beneath the stream bed. This site will also include soil moisture measurement facilities and rated gauging points for the spring stream and Lambourn.

Estimated total cost £117,000.

EXPERIMENTAL BOREHOLE ARRAY

An array of four cored boreholes (nominal depth 100 m) will be drilled to provide an experimental facility to investigate both the saturated and unsaturated zones. This site will be developed in conjunction with soil moisture measurement facilities described elsewhere. Each borehole to be completed with 3 piezometers.

Estimated total cost £117,000.

GEOPHYSICAL SURVEY

Localised geophysical survey to assist with location of the boreholes required for the above facilities.

Estimated total cost £14,000.

RECURRENT COSTS

Groundwater chemical analyses from 20 sites on a monthly basis for 4 years.

Estimated total cost £48,000.

4.4.3 Ecological

PRESSURE TRANSDUCERS

The increase in volume due to the growth of macrophytes displaces water during the summer and bankfull levels are frequently observed in rivers where the weeds remain uncut. It is important to know how these changes effect estimates of discharge with more conventional techniques and most importantly the dynamics of the floodplain environment.

Estimated total cost £3,000.

ONE OFF SURVEY

Baseline ecological characterisation

The catchments offer a diverse range of geology with its concomitant effect on flow regime and instream and riparian habitat. It is important that a base-line descriptive data set is collected which will provide the background necessary for subsequent studies in these catchments. The data need to describe the broad range of environmental conditions to be found along the main rivers and their tributaries. The River Habitat Survey methodology provides a convenient and tested technique for describing river habitat and this, in conjunction with habitat patch (mesohabitat) mapping will present a detailed account of the lotic environment. Supplemental surveys will provide information on algal communities on hard surfaces and faunal communities of individual mesohabitats.

Estimated total cost £20,000.

RECURRENT SURVEY

Two repeat ecological characterisation surveys @ £7,500 each.

Estimated total cost £15,000.

4.4.4 Summary Total Costs

Table 4.9 Pang/Lambourn Infrastructure. Capital items/one off surveys

		Cost	Sub Total
One off Surveys	Geology	£53,000	
	Geophysics	£14,000	
	Ecological characteristics	£20,000	
	Hydrological baseline/incremental flows/stream temperature surveys	£4,000	**£91,000**
Hydrology	4 period raingauges	£4,000	
	2 Automatic weather stations	£21,000	
	2 additional recording rain gauges	£3,000	
	3 HYDRA	£149,000	
	Interception sites for tall vegetation	£20,000	
	7 soil moisture/recharge sites	£200,000	
	2 flowgauges & improve EA gauges	£40,000	
	5 Water quality monitoring systems	£55,000	
	5 Turbidity systems	£12,500	
	Routine spares quality and turbidity sensors	£10,000	**£514,500**
Hydrogeology	Groundwater divide N E Pang	£88,000	
	Surface/groundwater interaction	£165,000	
	Establishment Chalk lower boundary	£53,000	
	Establishment Chalk upper boundary	£38,000	
	Monitoring@ Blue Pool spring	£29,000	
	Wetland investigation	£117,000	
	Experimental borehole array (to investigate controls on transport)	£117,000	**£607,000**
Ecology	Pressure transducers	£3,000	**£3,000**
Site acquisition	22 sites @ 2500 per site		**£55,000**
Field and laboratory equipment	Sampling equipment for labs	£ 7,500	
	Pump for shallow water sampling	£1,900	
	Mobile pump for chemical sampling	£3,200	
	Bladder pump and control unit	£2,000	
	Double packer for 85mm- 185mm boreholes	£2,000	
	Data logger interrogation unit	£250	
	3 water level dippers	£1,000	**£17,850**
Grand Total Infrastructure Capital/one off surveys			**£1288,350**

Table 4.10 Pang/Lambourn Recurrent Costs

		Cost	Total
	Surface water chemical analysis	£31,000	
	Groundwater chemical analysis	£48,000	
	Land rental other sites – nominal sum	£10,000	
	Ecological survey (2 off)	£15,000	
Grand Total recurrent costs			**£104,000**

5 The Tern Catchment

5.1 INTRODUCTION

The River Tern and its two main tributaries, the Meese and Roden arise on Rhaetic and Liassic clays and mudstones or Permo-Triassic Sherwood sandstones of the North Shropshire Plain. The catchments of these rivers are predominantly rural. However, over the years human development pressures have had an impact on the locality. Since the sixteenth century land drainage activity and agricultural “improvements” have led to a loss and degradation of river corridors and a decline in the flora and fauna in areas near the Tern and Strine. Glacial deposits cover much of the low-lying areas and are responsible for many minor topographic features of high conservation interest such as the classic “kettle holes” and peaty mosses, Whixall and Wem Moss. Maps 5.1 and 5.2 show the physiography and geology of the catchment and Map 5.3 shows the distribution of annual rainfall across the catchment. These maps also indicate the surface water and groundwater catchments.

Groundwater is pumped from the Permo-Triassic sandstone aquifer. Certain areas of the catchment have falling groundwater levels and/or problems of low river flows in summer mainly as a result of licenses being granted in the 1960’s that have authorised over abstraction of groundwater. Generally speaking most of the severe impacts do not relate to the Tern system.

The Tern catchment was originally proposed for inclusion in the LOCAR programme for two main reasons:

(i) it provides a Sherwood Sandstone dominated lowland permeable catchment;

(ii) considerable groundwater and hydrological data are available in the middle reaches because of the development of the Shropshire Groundwater Scheme (SGS).

The Technical Expert group agreed that for the purposes of the Thematic Programme the catchment should include all the tributaries of the Tern to the junction with the River Severn. However, for the purposes of infrastructure development and enhanced monitoring it was agreed that the focus should lie on the Middle and Upper Tern north of the confluence with the Meese.

5.1.1 Dominant catchment characteristics

- complex geology. The catchment including the Roden spans many differing lithologies from the upper Carboniferous to the lower Jurassic clays;
- the aquifer Sherwood Sandstone (Permo-Triassic) boundaries are predominantly controlled by faulting, which is not well defined, but very complicated;
- because of faulting aquifer thicknesses can vary over short distances from 50 m to 200 m;
- ill-delineated and characterised drift (glacial) deposits including boulder clays and more granular tills patchily cover parts of the catchment, influencing recharge;
- with the exception of the upper Tern and the Coal Brook the catchment and tributaries are well gauged;
- the catchment can be split into three characteristic domains: (i) Lower Tern, including Meese (flat dominated by agriculture, some industry); (ii) Middle Tern, including Platt and Potford Brook (influenced by pumping from the Shropshire Groundwater

Scheme, so well gauged, well investigated, many observation boreholes, good monitoring network, historic and current soil moisture network); (iii) Upper Tern (river corridor springs and seeps, natural ecology and geomorphology, wetlands);

- the Coal Brook is influenced by runoff and soil erosion from the upper Carboniferous mudstones (Keele Beds) with apparent indirect recharge;
- overbank flooding in the Stoke on Tern to Wolleston area provides the opportunity to monitor effects on recharge to the Sherwood Sandstone and complex groundwater/surface water interactions;
- comparative studies are possibly comparing a natural (upper Tern) subcatchment with degraded (pumped) subcatchment (Platt/Potford Brook);
- considerable scope for building on EA infrastructure in Middle Tern and joining collaboratively to install new infrastructure;
- appropriate sites for studies of surface water/groundwater interaction were found in the upper Tern and by extension/development of EA sites in the Potford Brook;
- lowest gauge on the Tern is below the confluence with the Roden;
- catchment is intensively agricultural with land uses; woodland, grassland, root crops, vegetables. Spray irrigation is in widespread use and will have hydrological, water resources and water quality implications.

Industry (dairy, sugar beet factory) is present in the lower catchment with the attendant possibility of pollution and water quality degradation.

5.1.2 Strategy

The strategy for the Tern relies on building upon the hydrological infrastructure in place as developed for the Shropshire Groundwater Scheme and expanding this to include a better monitoring system in the upper Tern. Improved groundwater monitoring in the Meese and Roden will be achieved by installation of loggers etc into existing boreholes. The catchment is, on the whole, well gauged, with the exception of the Coal Brook and Upper Tern.

The Platt/Potford Brook subcatchment lies at the heart of the SGS and should be taken as the focus of the LOCAR studies. Investigations that the infrastructure will support will be based on the Upper Tern subcatchment to Norton-in-Hales, a flood plain reach between Stoke-on-Tern and Wollerton and the Coal Brook subcatchment. The latter allows investigations of the complex interaction, both surface and subsurface processes, between the Keele Beds (Carboniferous) and the Sherwood Sandstone.

The main elements of strategy are listed below:

(i) develop the Platt/Potford Brook catchment as the core of the monitoring system;

(ii) develop some infrastructure at the Stoke-on-Tern to Wollerton floodplain reach to monitor surface water/groundwater interactions;

(iii) include Meese in catchment but do not develop infrastructure;

(iv) develop infrastructure in the Upper Tern for comparative studies including a gauging station at Norton-in-Hales;

(v) install gauging station on the Coal Brook for monitoring, with emphasis on sediment transport;

(vi) better define geology including faulting and drift distribution;

(vii) characterise drift and provide infrastructure for recharge studies;

(viii) develop water quality monitoring network;

(ix) cover, major land-uses, and drift for soil moisture monitoring;

(x) upgrade groundwater monitoring in upper Tern subcatchment;

(xi) include Roden in catchment but do not develop infrastructure.

5.2 EXISTING INFRASTRUCTURE AND DATA

5.2.1 Hydrology

WATER BUDGETS

It is not possible to close the water balance of groundwater fed catchments from consideration of the surface balance alone, because of the large number of unknowns in the equation. However, it is instructive to assess the relative magnitudes of the major measurable fluxes, in order to set targets for accuracy and precision. The budget for the main and subcatchments of the Tern above Eaton-on-Tern are summarised in Table 5.1.

Table 5.1 Long term water budgets for the Tern catchment using the common data period 1972-1997

Catchment	Area (km^2)	Mean annual rainfall - P (mm)	Mean annual flow - Q (mm)	Estimated mean annual losses P-Q (mm)[1]	Penman PE (mm)[2]
Tern at Eaton	192.0	707	269	438	500
Tern at Ternhill	92.6	730	280	450	500

1 Evaporation, plus net outward groundwater flow, plus non-returned abstractions (mm), minus imports.

2 Mean annual Potential Evaporation from the Flow Regimes and Environmental Management Map (Institute of Hydrology).

The budgets indicate the high evaporation losses relative to rainfall (PE/P is 0.62) and emphasise the importance of obtaining rainfall, streamflow and evaporation measurements to within 5% of their actual values.

RAINFALL

In a flat region of gentle topography the influence of orography will be minimal. Most of the higher ground is to the north east, and the SAAR distribution (Map 5.3) indicates a positive gradient in the average annual rainfall values with altitude. In spite of the presence of the Welsh hills to the west there are no discernible longitude effects at the regional scale. The rainfall surface in the Tern as a whole can therefore be described using data from the current period raingauge network of 11 gauges, or 9 for the Upper Tern (see Map 5.3 and Table 5.2). The strategy for rainfall should therefore be to only install extra gauges at specific process study sites where they can fulfil specialised and network roles.

There are currently only three recording raingauges in the Tern attached to telemetry systems (Rainfall Intensity Stations), and one other at Shawbury Aerodrome Meteorological Site. The

EA have noted the need for at least one more recording gauge in the Upper Tern above Market Drayton.

CLIMATE

By the criteria of the analysis carried out in Chapter 2 of this report, there should be 2 continuously recording climate stations (AWS) in the Tern, on the grounds of horizontal extent in a west-east and north-south direction.

Currently, measurements are available only for RAF Shawbury, which is a synoptic station visited every 3 hours for the Meteorological Office. Measurements at a synoptic station will be comprehensive, but data will probably have to be purchased from the Meteorological Office at a commercial rate. The station will include barometric pressure and solar radiation, but not net radiation, the most important term for calculation of evaporation. It would not be difficult to add a net radiometer to the suite of instruments currently in use if permission could be gained. One problem with this site is that it is not actually in the upper Tern but in the Roden in the western portion of the region and outside the main target area of the study. There was an AWS for a period at RAF Ternhill, but this was shut down due to vandalism.

EVAPORATION

It is important that evaporation rates in the catchment are estimated accurately, because recharge to the aquifer is highly dependent on the rainfall that manages to escape the evaporation process. Potential evaporation estimates, an index of atmospheric demand in the absence of other bio-physical controls on the vegetation, are available from MORECS and account for about 500 mm per year (IH Flow Regimes and Environmental Measurements map). PE can also be estimated for the catchment from Shawbury data, but there are currently no direct measurements of actual evaporation made.

SOIL HYDROLOGY

To achieve the LOCAR strategic objectives, both soil water content and soil tension estimates will be required to a reasonable degree of accuracy. There is a long history of soil moisture readings being carried out in the Tern, as part of the investigation into the alleged impact of the SGS groundwater pumping on soil moisture levels that started in the early 1970s (Map 5.4). There are currently 8 sites being monitored in the Tern for Phase 1 of the SGS with 2 access tubes at all but one of the sites (15 in all). So far no evidence has been produced that there is an impact on soil moisture (ADAS, 1997; 1998), although soil moisture content readings alone cannot always be relied upon to uncover such evidence. The EA discontinued their networks of tensiometers because of a lack of reliability in the technology at the time, and few reliable data exist.

FLOW MEASUREMENTS

There are 16 river gauging stations in all, of which 8 are on main river either logging data at 15-minute intervals or transmitting via telemetry to a central location (Table 5.3). Most of the others are concerned with direct measurement of discharges from the Shropshire Groundwater Scheme, and can be considered essentially as input measurements for the river system. The LOCAR Science programme could focus on any of the main structures but the baseline monitoring programme will have special emphasis on those in the Middle and Upper Tern (Map 5.4).

There are a number of sub-catchments that are critical to the Science Programme, some of which are already gauged, e.g. Potford Brook/Platt Brook, and some of which require extra facilities, e.g. Tern above Norton-in-Hales and the Coal Brook.

Table 5.2 Current and past network of raingauges in and around the Tern catchment contributing to the estimation of Standard Average Annual Rainfall (SAAR) for the period 1961-1990

Gauge	Number	East	North	Start	End	Type	SAAR (mm)
Sugnall Hall	90358	3799	3312	1968	pres	Daily	733
Eccleshall, Sugnall Hall	90359	3798	3312	1931	1953	Daily	737
Whitmore P.S	90537	3799	3401	1926	1989	Daily	794
Loggerheads, Ashley School	90688	3742	3357	1968	1978	Daily	750
Maer Hall	430586	3794	3382	1895	1961	Daily	766
Sidway Hall Farm	430629	3757	3398	1964	1971	Daily	772
Willoughbridge	430630	3753	3399	1974	1981	Daily	772
Willoughbridge	430632	3752	3399	1981	pres	Daily	773
Pipe gate	430663	3737	3407	1961	1964	Daily	754
Nortin-in-Hales School	430715	3702	3386	1921	1945	Daily	729
Norton-in- Hales	430726	3700	3385	1973	1983	Daily	751
Loggerheads	430909	3675	3342	1936	1957	Daily	698
Market Drayton, Devon House	430910	3675	3341	1961	1983	Daily	701
Market Drayton STW	430916	3670	3333	1962	1978	Daily	707
Market Drayton WRW	430917	3669	3333	1978	pres	Daily	705
Prees, Higher Heath WRW	430989	3573	3351	1981	1990	Daily	711
Sandford	431004	3582	3340	1973	pres	Daily	706
Ternhill Met. Office	431086	3642	3309	1958	1976	Daily	660
Ternhill Airfield	431087	3635	3311	1979	1982	Daily	677
Hawkstone Park	431102	3583	3301	1962	1983	Daily	727
Stoke on Tern, Mayfields	431151	3642	3290	1984	pres	Daily	682
Hodnet	431165	3615	3284	1972	1983	Daily	702
Stoke on Tern	431171	3639	3285	1972	1984	Daily	682
Shakeford	431255	3677	3284	1972	1983	Daily	721
Peplow	431310	3634	3249	1972	1976	Daily	668
Peplow, Home Farm	431312	3636	3247	1978	pres	Daily	679
Child's Ercall	431318	3666	3254	1971	1983	Daily	689
Child's Ercall STW	431324	3662	3248	1973	1986	Daily	677
Child's Ercall Airfield	431357	3665	3233	1986	pres	Auto	670
Greenfields	431395	3614	3261	1981	1995	Auto	685
Norbury Junction	431663	3794	3228	1910	1991	Daily	716
Adbaston	431822	3764	3276	1972	1979	Daily	712
Cheswardine Hall	431945	3724	3308	1922	1950	Daily	741
Cheswardine	431951	3721	3295	1971	1981	Daily	724
Cheswardine, The Lilacs	431952	3720	3296	1981	1986	Daily	726
Sambrook 11	432068	3712	3246	1973	1979	Daily	677
Sambrook 13	432069	3713	3246	1979	1982	Daily	677
Shawbury SAWS	433712	3552	3228	1988	1992	Daily	660
Adderley, Raven House	552329	3661	3401	1935	1960	Daily	701
Audlem, Mere Farm	552375	3692	3410	1961	pres	Daily	695
Audlem, Mere Farm	552376	3692	3410	1991	pres	Auto	695
Audlem	552414	3656	3432	1936	1968	Daily	738
Bishopscourt Met office	973979	3562	3427	1946	1947	Daily	808

Table 5.3 Main flow gauging structure details for the Tern catchment, plus small subcatchments of interest to LOCAR (flows in m^3s^{-1})

River	Station	Area km^2	East	North	Record	Q95	Sens-itivity %	Mean Flow	Q10	Max. Rec Flow	Structure design max.	Comments and hydraulic performance
Tern	Walcot	852.0	3591	3123	1960-pres	2.272	2.8	6.78	13.05	60.0	26.0	Flat-V Crump weir. Rated section 59-76; gabion control 76-78; was prone to weed growth. Recent ultrasonic checks. Cableway
	Eaton	191.7	3649	3232	1972-pres	0.653	9.3	1.64	2.876	20.0	13.0	Double Bay Crump. Crests same height; bad bend upstream; cableway
	Ternhill	92.6	3628	3315	1972-pres	0.395	9.1	0.82	1.331	21.8	2.00	Rectangular Notch and broad crest Unknown rating above notch; always in-bank flows so far
Roden	Rodington	259.0	3589	3142	1961-pres	0.407	7.5	1.91	4.183	30.6	18.0	Trapezoidal flume flanked by broad crested weir. Model tested in compound form; tailwater tapping; weed growth a problem
Strine	Crudgington	134.0	3641	3175	1982-pres	0.192		0.67	1.301	8.4		Electro-magnetic. Bubble level sensor; weed growth a problem.
Meese	Tibberton	168.0	3681	3205	1973-pres	0.444	13.7	1.16	2.074	8.2		Crump weir. Good hydraulics
Bailey Brook	Ternhill	34.4	3628	3315	1970-pres	0.108	18.2	0.43	0.903	15.1		Rectangular Notch and broad crest with same problems as Ternhill
Platt Brook	Platt	15.7	3628	3229	1973-pres							Flat-V.
Potford Brook	Sandyford Bridge	25.0	3635	3222	1972-pres							Flat-V. Contains Platt Brook flows; moved in 1987 to prevent backup

Notes: Q95 – flow exceeded 95% of the time, Q10 – flow exceeded 10% of the time. Sensitivity - %age increase in flow for a 10mm rise in stage.

The concerns over the impact of the SGS on river flows has led to an emphasis on accurate low flow estimation. In designing the structures, EA engineers faced the problem that if weir heights were to be raised to provide modular flow at flood flow levels, they would be in danger of exacerbating the impacts of the floods upstream of the weirs.

Unfortunately, structures that can cope with a restricted flow range are of limited use to scientific programmes, where the integrated water balance fluxes require accurate and precise measurements to be made throughout the flow range. Many of the weirs in the Tern do have provision for non-modular flow corrections to be made, either by crest tapping or by downstream stage measurement. However the experience with crest tappings has not been good. It is only recently, for instance, that a purging system has been introduced as a trial on the Crump weir at Walcot, and this seems to have cured the siltation problem. Walcot has also very recently been fitted with a downstream level measurement system.

The existence of this high quality structure on the Tern at Walcot, and structures on the Meese, Strine and Roden, mean that the flow at Eaton can also be calculated by difference. This might be an important alternative source of flow data for LOCAR as Eaton is not a good hydraulic structure.

- The gauge on the Strine at Crudgington is an electromagnetic device that has worked well, and technically the technique has potential for a number of sites across the LOCAR catchments. This type of gauge has many advantages over conventional structures, but the high costs are comparable.

OTHER INPUTS AND OUTPUTS

Flows in parts of the Tern may be complicated by inputs and outputs of water from the Shropshire Union Canal. The British Waterways map indicates this may have more effect on the Greater Tern than on the Upper Tern catchment, with flow to the canal from Knighton Reservoir in the Meese, and flow from the canal to Aqualate Mere also in the Meese. These inflows are implicated in water quality problems of the Mere owing to the relatively high phosphorus load of the canal.

FLOW INCREMENTATION

Low flow surveys have been carried out by the EA at 30 sites within the Tern and a further 12 in the Strine. Inspection of the river channels in the Tern, particularly in the lower reaches, encourages the view that the hydraulic ‘resistance equation’ method of interpolating flow along specified reaches will be better suited to the Tern than to any of the other LOCAR catchments because of deeper more uniform flows. As in the other catchments, this will give invaluable information on whether particular reaches are gaining or losing flow and will aid assessment of the aquatic habitat.

5.2.2 Surface water quality

The Tern is a catchment that contrasts with the other LOCAR catchments in the importance of water quality as an environmental issue, in that:

- It lacks the natural buffering characteristics provided by Chalk geology
- It has been subject to a patchwork of environmental manipulations in the areas of agriculture, urban development and industry (albeit mainly associated with agriculture)

The extent of interest shown by the EA in the water quality of the Tern is manifest as the large number of enquiries and incidents that have prompted river water quality sampling programmes to be set up over varying time spans. At least 40 sites on the main branch of the Tern have been sampled at one time or another for various reasons, some specific, i.e. agricultural or industrial pollution incidents, WQ threshold exceedances at STWs etc., and others as part of a general programme of environmental monitoring. There may be up to 20 further sites on the subcatchments of the Meese, Strine and Roden, and other small streams as well. Much of this data resides on the EA water quality database for the Severn-Trent area, which has recently been obtained by IH as a direct transfer from the EA. Data prior to 1986 are not yet available because they currently exist in a separate archive on the Severn-Trent plc database.

Most of the data is obtained only on a 3-monthly basis, with some important sites done more frequently than this. The major site on the Tern is Allscott, upstream of Walcot, but downstream of and including the Meese and the Strine, but not the Roden. It appears that samples are taken here weekly and analysed for up to 30 determinands, a major benefit to LOCAR as analysis of the data could provide the basic information required to underpin the rationale behind the LOCAR water quality sampling programme in the catchment.

CONTINUOUS MONITORING

In the Tern, there is already a continuous monitor in operation at Walcot, built by pHOX systems and measuring the variables - temperature, dissolved oxygen, turbidity, conductivity, pH - plus ammonia. This is a sophisticated industrial system that extracts water from the river for analysis in a purpose built enclosure. It is experimental at present and is run by the EA's Nottingham labs, so negotiation would have to take place for the data and to ensure that the unit has the support of LOCAR to continue in operation in the future.

5.2.3 Geomorphology and sediment transport

AVAILABLE SEDIMENT DATA

Suspended solids and limited laboratory-based turbidity measurements from the Tern are included in the Environment Agency Midland Region Water Quality Archive. Some sites are only covered intermittently or at 1–3 month intervals. Summary data is given for selected sites in Table 5.4.

Table 5.4 Suspended solids (in mg/l) from 6 years of Environment Agency Water Quality Archive

	Mean	Max	Min	No.
Main Tern				
Tern at Atcham	12.44	185	2	348
Tern at Allscott	13.44	192	2	180
Tern at Ternhill	12.11	76	2	37
Tributaries of Tern				
Potford Brook at Sandyford Bridge	15.08	139	2	37
Roden at Roddington	10.82	191	2	163
Coal Brook at Old Mill	13.94	167	2	34
Meese at Great Bolas	11.84	69	2	153

Although further reference will be made to the above data summary, it is apparent that peak concentrations have been missed, and therefore few conclusions can be drawn. The availability of continuous monitoring data for turbidity is limited to the Walcot site on the Lower Tern. This measurement is combined with other measures of water quality and is from an absorptiometric sensor. Past experience also suggests that within-river sensor systems, separated from other water quality sensors, would perform more effectively, as there are many opportunities for blockage and/or drop out of sediment in pumped systems.

No regular survey data have come to light giving details of bed material size distributions. Cross-sectional data may be available for reaches that have undergone engineering works, but regular intensive cross sectional survey is not carried out.

There has been no emphasis on particulate chemistry within the routine water-column chemistry sampling. It is thought that one sample of bed material may be taken on an annual basis for List 1 Dangerous Substances at two sites within the Tern.

Digital terrain, soils and land-cover data (held by CEH-IH and CEH-ITE) will be of value. In addition, the Environment Agency holds relevant River Habitat Survey data and some oblique air photography covering flood events in the Tern.

5.2.4 Hydrogeology

GEOLOGY

The topographic catchment of the river Tern, including the tributaries of the Roden, Meese, and Strine, is shown along with the outcrop geology on Map 5.2. A discussion of the geological setting is provided in the Appendix. The last full field-based survey of much of the data was carried out 30-75 years ago. Much new information has become available since then (not least as a result of the Shropshire Groundwater investigation) and advances in geosciences have increased the understanding of both bedrock and superficial deposits in the region. Geological map coverage is complete at 1:10K or 6 inch to one mile scale and at 1:50K and 1 inch to one mile scale, but of variable vintage as indicated in Table 5.5.

Table 5.5 Geological sheet coverage of LOCAR catchment area

Nantwich 122 1967 (1 inch)	Stoke-on-Trent 123 1994 (1:50K)
Wem 138 1924 (1 inch)	Stafford 139 1927 (1 inch)
Shrewsbury 152 1932 (1inch)	Wolverhampton 153 1929 (1 inch)

Revision mapping is planned within the current British Geological Programme for the Stafford sheet (139) starting in 2000/01; the geological database for the Nantwich, Wem and Shrewsbury sheets was deemed to be relatively satisfactory at the last major review in 1989. Since that time a considerable amount of work has been carried out for the Cheshire Basin Project and new borehole and other data has been acquired that indicate revision is required to the geological model presented by the latter three maps. This work falls within the remit of the BGS' Continuous Revision and Data Acquisition Project. However, no work is currently planned for the Wolverhampton sheet during the initial phases of the LOCAR programme.

GROUNDWATER LEVEL MONITORING NETWORK

The Environment Agency’s existing groundwater level monitoring network is shown in Map 5.5. This extensive network has been developed within the Shropshire groundwater scheme and consequently is concentrated in the central area of the Tern catchment area and is somewhat deficient in the northern and eastern parts of the aquifer.

GROUNDWATER QUALITY MONITORING NETWORK

The Environment Agency’s existing groundwater quality monitoring network is shown in Map 5.4.

A more detailed review of the hydrogeological data available for the Tern catchment area is given in Appendix and a summary of the available data is presented in the metadata catalogue in the Appendix.

5.2.5 Ecology

INFRASTRUCTURE

Other than a network of sampling locations throughout the catchment and some historical data there is no specific ecological infrastructure.

DATA

River Corridor Surveys were carried out on the River Tern and its major tributaries between 1991 and 1995. These include a general description of the river with photographs. They do not include fisheries or invertebrate information.

[River Corridor Survey for R. Tern taken in December 1995; Ecological Surveys of R.Roden in October 1991,1992, and 1995; R. Meese in June 1992, R. Strine in December 1991]

Fishery surveys have been carried out since 1973, however the early surveys are available only as hard copy. Post 1985 surveys are stored electronically in some form. The 1998 survey results are stored electronically and a report is currently in preparation.

[Strategic sampling on the R. Tern August 1973, June 1976, May 1978, June 1979, May 1980, June 1981, May 1982, June 1983, May 1984, June/July/September 1986, May/August 1987, July 1988, June 1989, May 1990, August 1992, March/April/May 1993, August 1993, April 1994, July 1994, April 1995, June 1996, May 1997, July 1998

Strategic sampling on the Roden, June 1976, May 1978, May/June 1980, February 1982, July 1984, August 1986, June 1989, May 1990, September 1991, April 1992, August 1993, June 1994, August 1995, June 1997.

Strategic sampling on the Meese, June 1976, May 1978, June 1980, July 1982, July 1984, May 1990, April 1992, May 1992, July 1995, April 1995, April 1996.

In addition, strategic sampling was carried out in the following streams in the April/ May period in 1992, Pipe Strine, Platt Brook, Littleshall Brook, Sleap Brook, Back Brook. Strine Brook, the River Strine and Lonco Brook were also sampled in May 1996]

The invertebrate information is mostly routine with the exception of surveys between 1995 and 1997 that were carried out specifically to monitor the Groundwater scheme.

Routine surveys were carried out in the Tern catchment three times per year between 1989 and 1993. Thereafter sampling has been undertaken twice a year. Data collected from 1989 is stored electronically. Identification of invertebrate taxa is routinely taken to family level but some surveys in association with the groundwater include species level data. There are data (hard copy) from the seventies from the initial Shropshire Groundwater Scheme investigations but their current location is unknown at the time of writing.

Additional surveys are conducted in response to pollution incidents and some work has been carried out in response to the urban waste water directive. This latter includes macrophyte survey data upstream and downstream of Market Drayton STW.

[1994 sampled streams – R. Tern, - Stoke Brook, Bailey Brook, Coal Brook, Loggerheads Brook, Lakemoor Brook; R. Meese, - Lonco Brook, Back Brook, R. Strine, Red Strine, Wall Brook, Pipe Strine, Strine Brook, Humber Brook, Crow Brook and Ochre Brook,

1995 sampled streams – R. Tern, R. Meese, Stoke Brook, Bailey Brook, Coal Brook, Loggerheads Brook Lonco Brook, Pipe Strine, Strine Brook, Humber Brook, Wall Brook, Red Strine and R. Strine.

Sparse routine sampling took place in 1999].

ADDITIONAL DATA HELD BY OTHER ORGANISATIONS

All information held by English Nature is related to two specific sites, Aqualate Mere SSSI and NNR which lies in the headwaters of the Meese and Fenn's, Whixall, Bettisfield, Wem and Cadney Mosses SSSI and NNR, the outflow of which partly feeds the Roden.

Botanical survey data are available for terrestrial and aquatic habitats associated with Aqualate and an invertebrate survey is currently being undertaken. At Fenn's there is a wide range of survey information relating to habitats and species of the peatland complex, studies of the peat body and surveys of dipwells, ditch water level and rainfall. Both sites have comprehensive management plans and there is an extensive bibliography on the Fenn's and Whixall management plan (see Appendix).

The Shropshire Wildlife Trust has some material on about five sites in the catchment which have high wildlife value and is working with the Environment Agency to investigate the susceptibility of a number of wildlife sites to water abstraction. The Shropshire Ornithological Society published a tetrad breeding bird atlas in 1992 following seven years of fieldwork. The Shropshire Botanical Society have very comprehensive computerised records which may be of relevance. The Market Drayton Branch of the Trust has paper records of general naturalist interest.

5.3 BASELINE REQUIREMENTS

5.3.1 Hydrological baseline requirements

RAINFALL

The current period gauge rainfall network of 11 gauges gives good coverage (Map 5.4). However it is proposed to enhance the networks by installation of 3 new period (weekly) gauges at 2 new soil moisture sites – see Map 5.6).

CLIMATE

Two new climate stations (AWS) are proposed in the upper Tern, with one in the lower reaches and one in the more hilly upper reaches. There are currently two subcatchments of the Tern being proposed for intensive study, the upper Tern above Norton-in-Hales, and the Platt Brook – Potford Brook system in the middle reaches of the Tern. An AWS in each of these areas will provide local climate information for the Science Programme, as well as elucidating the regional patterns.

In the middle Tern, there is currently focus on a site at Greenfields, near Hodnett on the Potford Brook, where a pumping station is situated contributing to the Shropshire Groundwater Scheme. A series of monitoring boreholes are already in place to assess the effect of the pumping on groundwater levels, and this is clearly viewed as a good site to focus work on surface/groundwater interaction. The pumping station itself is in a compound leased for the purpose, and with a minimal amount of landscaping suitable sites can be found in the compound for an AWS and a period raingauge. The AWSs will also have a soil moisture probe, probably a Delta-T capacitance unit, fitted, and will be viewed as long term soil moisture reference sites under grass.

EVAPORATION

Direct evaporation measurements will not be part of the baseline infrastructure.

SOIL MOISTURE, UNSATURATED ZONE AND RECHARGE

There will be a number of different approaches made within LOCAR to estimating recharge to the aquifer below the soil zone. In general the depth to water table in the Tern is far less than in the chalk catchments of the Pang, Lambourn, Frome and Piddle, so the unsaturated zone can be investigated using the same techniques as for the soil moisture.

Clearly the depth of groundwater is for the most part below the rooting zone of most crops grown in the Tern and would not normally be expected to be in contact with the transpiration zone of the overlying crop. However, crops with a high water requirement such as potatoes and sugar beet are commonly found in the flood plains around the SGS wells, and the high irrigation requirements of the catchment suggests that this will be an important issue to farmers and water resource engineers alike.

A major issue in the Tern is whether crops habitually use water below the rooting zone as far as the water table, in such a way that lowering of the water table would induce stress in the crops. If the only way to establish this is by defining the zero flux plane (ZFP), then it is unfortunate that there are currently no tensiometer networks in the Tern.

Re-establishment of tensiometer networks in the Tern is proposed under LOCAR as a baseline requirement, providing mutual benefits for the Science and the EA operations. However, there is the continuing problem of attempting to install both soil moisture access tubes and tensiometers in fields where there is continual disturbance through farm traffic for fertilising, ploughing seeding etc. When confronted with this problem in the Pang, IH soil scientists used an access tube that could be disconnected some way below ground level. This allowed machinery to gain access to carry out normal operations, although it was often found to be difficult to relocate the position of the tube afterwards for re-instatement. The EA have also used this technique in the Tern, but have also leased exclusion zones within fields and fenced them to keep out stock and machinery.

The main drawback with exclusion zones is the lack of realistic management of the soil surface, even if the same crop is planted inside as outside the fence. One solution would be to use the exclusion compound to locate the heads of the access tubes for tensiometers and neutron probes, but to angle the drilling so that the actual measurements are taken vertically below the crop outside the fence. It will be more difficult to locate the depth below ground level of the instrument using this method, but not impossible, perhaps using tracker techniques. There are physical problems associated with lowering a neutron probe at an angle, but these would not be insurmountable.

Although this technique has been considered with the specific problems of soil moisture measurements in the Tern in mind, it may also have generic application to the other LOCAR catchments as well.

Four soil moisture sites are proposed as baseline for the Tern, arranged on similar lines as in the Pang/Lambourn (Chapter 4), but with less emphasis on the deep unsaturated zone. If sufficient extra equipment is purchased, then tensiometers can be installed at some of the EA soil moisture sites, Map 5.4, to improve coverage and allow a wider application of the EA water content data. Sites chosen are shown on Map 5.6, and are listed below :-

- Arable site on the upper Coal Brook
- Riparian site of ecological value at Norton in Hales to link with hydrogeology
- Riparian pasture site at Stoke on Tern
- Arable slope site at Greenfields

STREAMFLOW

PROPOSALS FOR NEW GAUGES

Much of the Programme will be targeted towards small subcatchments of the Upper Tern. Three main subcatchments have been identified, and it is proposed to ensure continuous flow records for:

- The Tern above Norton-in-Hales as representative of a rural, undulating, little-disturbed catchment, with valley bottom wetlands.
- The Coal Brook tributary of the Tern emanating from a similar catchment to the above, but with high water tables and susceptible to high rates of soil erosion.
- The Potford Brook, which is a more low-lying catchment where the flow regime is affected considerably by pumping for the SGS.

Of these, Potford is already well gauged, with a first class Flat-V weir. This was moved in 1987 to combat backing up problems, so the older records may be suspect. The Norton site is in a reach of considerable ecological significance, and there are numerous sites that could be gauged provided ecological damage is minimised, e.g. barriers to fish movement. The Severn Trent PLC have a sewage treatment works (STW) in a locked compound which, with negotiation, could feasibly be a source of power and some security for instrumentation. Alternatively there is a site upstream of the roadbridge which offers good access for machinery, a relatively straight reach, but some constriction at the bridge which would be exacerbated by cross sectional restrictions at a structure. Electro-magnetic gauging would be a practical option here, but it will be expensive and could instead be covered by a much cheaper Ultrasonic gauge. Either of these would have a low visual impact and would not attract passing interest. The permission of the landowner might be more difficult to obtain than at the STW.

The Coal Brook site would be a difficult (and expensive) proposition for siting a conventional structure, on account of the very high groundwater levels, and the problems of site disturbance in an area of some landscape value. It is proposed therefore that flow gauging is carried out using permanent Ultrasonic equipment.

WATER QUALITY

Chemical sampling programme

One of the major questions in LOCAR surrounds the ideal frequency of sampling to pick up the true variability of chemical concentrations in rivers, and hence to provide accurate flux measurements. For some determinands that do not vary with flow, weekly sampling will be adequate, but for strongly flow related determinands, such as nitrate, sampling frequencies are ideally varied to suit flow conditions. This is difficult to achieve with weekly spot sampling, which on balance tends to bias samples to below average flows.

It is proposed therefore to carry out a weekly spot sampling programme. This could eventually be reduced to monthly sampling once the variability in chemistry is established. Sampling should be augmented by an ad hoc flow-related sampling programme to enable a concentration-flow 'rating' approach to be used for flux estimation, at least at the main flow gauging sites. Information obtained can then be used to correct the results of the spot sampling at other nested sites contributing to the overall catchment fluvial load (the same arguments apply to sediments as to chemistry).

Continuous monitoring

The standard Institute of Hydrology instrument for continuous monitoring, developed as a reliable system under LOIS, is based on the HYDROLAB monitor. This is capable of collecting data for temperature, pH, dissolved oxygen, and conductivity in a single unit with the potential to add sensors for chlorophyll-a and nitrate. Use of the unit is flexible in that it can be cleaned, calibrated and downloaded in the field, or replaced by a second unit and returned to the laboratory for thorough maintenance. It is proposed that one of these is deployed at each of the 6 flow gauging stations.

GEOMORPHOLOGY AND SEDIMENTS

Measurement Sites and monitoring equipment

There are nine flow gauging stations operated by the Environment Agency in the Tern catchment. In the event that the full catchment down to the Severn is adopted, then turbidity monitoring should be considered at each site. However, if the small catchment and reach approach is adopted, then additional suspended sediment sites should be considered at Norton in Hales and the lower part of the Coal Brook. These two sites, plus the Tern (at Walcot and Ternhill) and possibly the sites in the lower reaches of the Meese, Roden and Potford Brook would also need to be covered. If the Upper Tern (and subcatchments) is chosen to be the target LOCAR catchment, then the baseline monitoring of turbidity and suspended sediment should be at the eventual 6 gauging sites. Further discussion with the Technical Expert Group is required to ensure links to the Groundwater strategy.

The gauging huts in the lower Tern are a good size and none of the sites present difficulties regarding the maximum head limitations of automatic bulk samplers, these being within 3 metres of the river water surface. Generally, Midland Region gauging stations are likely to provide adequate space for additional loggers and samplers. Reliable flux measurement may present difficulties at Eaton, due to the double channel and debris blockage problems.

Although telemetry is widely available, not all sites have mains electricity. There is limited cutting to counter weed growth at some sites. There is less of a problem in representing the suspended sediment flux across the full range of flows than is the case in the other LOCAR catchments. However, the emphasis in flow gauging station design is still upon low flows because of the importance of the Shropshire Groundwater Scheme.

As with the other LOCAR catchments, the collection of further baseline information on the bed sediments, channel and riparian zone topography would be worthwhile.

5.3.2 Hydrogeological baseline requirements

INTRODUCTION

As noted in the previous two chapters, the baseline data requirements required to characterise the catchments for the LOCAR thematic programme can be classified into two groups; one off data sets and time series monitoring. Evidently the one off data sets are those which are not expected to change frequently with time and will include: Geology, digital terrain model, river bed levels, borehole datum levels and locations, Ordnance Survey coverage and aquifer parameters. Time series monitoring requirements will include groundwater levels and groundwater quality.

ONE OFF DATA SETS

As noted earlier, no significant geological mapping has been carried out in this area for the last 30 or more years. Since that time various advances in geological knowledge indicate that significant revision of the geological model is now required; not least for the Drift deposits which overlie parts of the aquifer. This will form an essential component of LOCAR baseline information.

TIME SERIES MONITORING

Ambient monitoring should potentially be met through the existing networks. However, deficiencies in the groundwater level monitoring network away from the central part of the aquifer have already been noted. Thus additional holes will be required in these areas. With regard to groundwater quality measurements, it is recognised by the EA that their network measurements are not generally carried out to a research standard. Thus monthly groundwater sampling and analysis (at research standard) from a minimum of twenty boreholes throughout the catchment area is required.

Validation and strengthening of the hydrogeological component of the conceptual model of the Tern catchment can be aided by the installation of a number of boreholes, each one designed to achieve a number of objectives. The number of boreholes (of differing designs for different collective objectives) will be constrained by a number of factors, some of which can not be evaluated within the TOR of the Task Force (e.g. access). However, it is possible to provide the following recommendations while recognising that such constraints might limit their application:

- as many as possible of all new boreholes and piezometers should be multi-objective;
- all pilot holes and boreholes to be geophysically logged including detailed fracture logging (borehole imaging and core logging), flow logging;
- the recharge effect of flood events requires investigation through monitoring two specially constructed shallow boreholes;
- surface water/groundwater interaction should be investigated a two sites within the catchment. One will be a new facility as described for the Pang in Chapter 3. The other facility will be a development of an existing Shropshire Groundwater Scheme site;
- a single deep borehole is needed to prove the Permo-Triassic sequence at the northern end of the catchment;

- the importance of runoff from Carboniferous outcrop on recharge to the Permo-Triassic aquifer needs to be evaluated;
- a minimum of four new boreholes are required to augment the existing groundwater monitoring network, particularly in the upper reaches of the Tern and to the south-east of the River Meese. Additional provision of data loggers in existing boreholes is also required;
- the structural boundaries of the aquifer need to be investigated. This can be achieved through investigation of existing boreholes in the viscinity of a major fault;
- a minimum of two shallow boreholes are required to investigate the nature and thickness of the superficial deposits.

5.3.3 Ecological baseline requirements

PRELIMINARY

In order to meet the LOCAR aims it is necessary to provide an infrastructure to facilitate information gathering. This would include not only the provision of apparatus but an ‘environment’ in which data can be gathered. In order to achieve this the following baseline requirements are needed. Note that the baseline requirements discussed below are considered from an ecological viewpoint but will include aspects relevant or central to other disciplines.

- For each area a set of large scale digitised maps will be required – this is an essential precursor to any survey work.
- A GIS including blue line, digital terrain model, high resolution land-use data, field boundaries, deep and drift geology, small area statistics, soil, occurrence of designated areas (e.g. SSSI’s). This would form the central core of information on each catchment. It should be able to be serviced, accessed and run from the relevant research sites.
- For each area, an attempt should be made to produce a catalogue of landowners (including tenants) and any perceived problems with access. Meetings may be required to explain the objectives of LOCAR. (These points were raised at the meeting with the EA and although they have much of the information, it was understood that they are unable to make this available. However there may have been some change and it is worth checking what the current policy is at the EA HQ in Bristol).
- The ability to measure discharge throughout the catchment including headwaters would seem to be a necessary precursor to any subsequent research. This may not require permanent gauging sites but should, at the very least, show where major changes in discharge occur in relation to surface/groundwater interactions etc. The infrastructure in each catchment should accommodate this need.

ONE OFF DATASETS

- Geomorphological surveys - these would provide the baseline against which developments over the LOCAR study period can be measured. The survey should include substratum analyses to provide information on bed particle size and siltation. Ideally the geomorphological survey would be done in association with River Habitat Surveys including mammal and bird records and macrophyte distribution mapping etc and these latter modules would be repeated throughout the study period (time-series).

If this did not occur at least there would be matching habitat/geomorphology data for the catchment as a whole.

- Instream sub-surface inflows - identification of areas of upwelling. This dataset will provide basic information for a number of research issues including salmonid spawning, water quality and siltation studies. (included in hydrological baseline requirements)

TIME SERIES MONITORING

- River Habitat Surveys with macrophyte mapping and geomorphological add-ons (see Newson et al. 1998 "The geomorphological basis for classifying rivers" Aquatic Conservation 8: 415-430, and the EA's River Habitat Survey Methodology for the general approach). Ideally these should be carried out at least once per year from source to mouth, but budgetary considerations preclude this.
- Faunal communities in representative river sectors. This would be carried out in association with RHS etc (see above) at a reduced number of sites. The information will elucidate the interactions between habitat availability, biotic communities and physical variables such as discharge and geomorphological determinands.
- Fine sediment dynamics. Measures of sources, storage and mobilisation should be made on a weekly basis at key sites with supplementary information from sediment traps, surface material run-off and field observations of sediment sources (see Walling & Amos 1999, "Source, storage and mobilisation of fine sediment in a chalk stream system", Hydrological Processes 13, 323-340). Supplementary continuous measurements of turbidity should be gathered at strategic points to monitor sediment inputs (as in LOIS). Collation of these data will depend upon the sedimentological infrastructure discussed earlier.

5.4 PROPOSALS

5.4.1 Hydrological

The basic approach for the surface hydrology of the catchments will be to estimate fluxes that contribute to the catchment water balance, and to estimate internal fluxes that help to explain surface-groundwater interactions.

CLIMATE, INCLUDING RAINFALL AND EVAPORATION

This will require the following:

- Additions to the EA/MO raingauge networks will comprise 3 period and 4 recording gauges. Two of the latter will be attached to AWSs (£6,000)
- Installation of 2 AWS in each catchment for climate and potential evaporation (£21,000)

The detailed costs of purchase and installation for this will be **£27,000**

SOILS AND UNSATURATED ZONE HYDROLOGY, AND RECHARGE ESTIMATION

This will involve the following storages and processes to be quantified at 4 new soil moisture sites (plus augmentation of some existing EA sites):

- soil water content using neutron probes (3 tubes per site) and Theta capacitance probes (5 per site);

- soil tensions near surface using 12 puncture tensiometers;
- soil tensions through the unsaturated zone using 10 equitensiometers and borehole gypsum blocks;
- shallow groundwater logging using dipwells and piezometers.

The total cost will be **£120,000**

CHANNEL FLOWS

Integrated and incremental flows will be estimated using the following techniques:

- improvements to existing EA stations, especially their high flow calibrations using portable calibration equipment (included in equipment pool);
- installation of 2 new stations on selected subcatchments (£70,000).

The total cost will be **£70,000**.

HYDROLOGICAL BASELINE SURVEY

Hydrological baseline/incremental flow survey

The estimated cost of purchase and/or staff time is **£6,000**.

WATER QUALITY AND SEDIMENT

Much of the water quality work relies on recurrent expenditure for manual and storm sampling, sampler operations, maintenance of continuous monitors and laboratory sample manipulation and analysis. This also applies to bedload (not thought to be very important in LOCAR catchments though gravel beds do exist) and suspended sediment sampling. However, the following will need to be purchased and installed:

- continuous water quality monitoring systems at 6 sites, using the IH WISER system. (£63,000);
- turbidity measurements from separate sensors will be required (Epic samplers for ad hoc storm sampling are included by default in the WISER system) (£15,000);
- spare water quality and turbidity monitors for routine exchange. (£10,000).

The costs will be **£88,000**.

RECURRENT COSTS

Using a unit cost of £50 per sample analysis, recurrent cost for chemical sample analyses are estimated as follows.

River water and rain water chemistry at 8 sites on a weekly basis for the first year and monthly basis for the following three years, **£35,000**.

5.4.2 Hydrogeological

GEOLOGY

As has been noted earlier, the last full field-based survey of the area was carried out 30-70 years ago. Much new information has become available since then and advances in geoscience have increased the understanding of both bedrock and superficial deposits in the region. This will be the basis for the new mapping that will be carried out mostly by desk revision. Equally no provision has been made for remote sensing inputs, although this would be required if it is subsequently decided that definition of separate hydrogeological domains within the superficial deposits is necessary. Thus the data will still be limited in respect of what could be acquired through a comprehensive survey that would include fieldwork and remote sensing. Information received from boreholes drilled as part of the programme will also require the geological model to be further refined.

Deliverables:

- map of bedrock structure;
- GIS, maps, sections and explanations of bedrock thematic geology;
- GIS, maps, sections and explanations of characterisation of superficial deposits;
- interpretation of seismic data.

Estimated total cost £45,000.

IMPACT OF FLOODS ON AQUIFER RECHARGE

Two shallow boreholes (30 m) will be located on the flood plain of the river Tern near Stoke on Tern near an outfall of the Shropshire (SJ 640 280) groundwater scheme. This is an area that is regularly flooded and so the boreholes will be completed in subsurface chambers which can be totally sealed against ingress of flood waters. The boreholes will be equipped with automatic data loggers to record groundwater levels resulting from flood events.

Estimated total cost £19,000.

SURFACE WATER/GROUNDWATER INTERACTION

This will be studied at two sites in the Tern catchment, one yet to be located and one at Greenfields farm at the head of the Potford Brook.

To be located

A new river flow gauging station is proposed for the upper Tern catchment at Norton in Hales. In association with this new installation a facility to investigate shallow groundwater/surface water interaction is proposed. The design will follow that already discussed for the river Pang.

Estimated total cost £65,000.

GREENFIELDS FARM

This site has an existing abstraction borehole and three observation boreholes (at distances of 10 m, 20 m and 100 m) for the groundwater scheme with associated power supply and telemetry facility. The observation boreholes will be fitted with piezometers at three separate depths each. It is proposed to add an additional cored borehole to a depth of some 25 m to prove the geological succession adjacent to the river channel. This site will also have soil moisture measurement facilities and an Automatic Weather Station installed.

Estimated total cost £13,000.

GEOLOGICAL SUCCESSION

A deep borehole (c. 150 m) will be drilled in the vicinity of Norton-in-Hale to investigate the Permo Triassic sequence in that part of the catchment.

Estimated total cost £41,000.

RUNOFF/RECHARGE FROM THE CARBONIFEROUS TO THE AQUIFER

Two shallow boreholes equipped with piezometers will be installed in the Coal Brook (which joins the Tern at Market Drayton) to monitor groundwater in the Sherwood Sandstone of the valley floor. One to be located down stream of the boundary between the Sherwood Sandstone and the Coal Measures and one to be located close to the proposed flow gauge. Another borehole will be drilled to a depth of some 25 m in the Keele beds. Surface geophysics will be used to identify the location of the boundary between the Sherwood Sandstone and the Carboniferous Coal Measures of the headwaters of the Coal Brook.

Estimated total cost £38,000.

AUGMENTATION OF THE GROUNDWATER MONITORING NETWORK

The Environment Agency has a relatively detailed groundwater level monitoring network associated with the Shropshire Groundwater Scheme. However this does not extend into the upper reaches of the Tern (above Market Drayton) nor to the south-east of the river Meese. Four boreholes (2 cored 2 un-cored) are planned – locations to be decided in discussion with the Environment Agency. These will be nominally of 100 m depth each fully cored and logged and completed with automatic data loggers. Four of the boreholes will be completed with three piezometers each to allow monitoring of vertical head differences in the upper layered part of the Sherwood Sandstone.

Estimated total cost £96,000.

Within the topographic catchments of the Platt and Potford Brooks the Environment Agency's existing monitoring network will be upgraded by the installation of additional data loggers and boreholes. Pending more detail design work a nominal sum of £50,000 is allocated for this work.

Estimated total cost £50,000.

BOUNDARY DEFINITION

Existing boreholes will be logged and investigated to assist definition of structural boundaries to the aquifer..

Estimated total cost £10,000.

GEOPHYSICAL SURVEY

Localised geophysical survey to assist with location of the boreholes required for the above facilities.

Estimated total cost £14,000.

DRIFT CHARACTERISATION

Three shallow boreholes (c. 20 m) will be drilled to characterise the drift cover in three locations within the catchment.

Estimated total cost £29,000.

RECURRENT COSTS

Groundwater chemical analyses @ £50 each from 20 sites on a monthly basis for 4 years.

Estmated total cost £48,000.

5.4.3 Ecological

PRESSURE TRANSDUCERS

The increase in volume due to the growth of macrophytes displaces water during the summer and bankfull levels are frequently observed in rivers where the weeds remain uncut. It is important to know how these changes effect estimates of discharge with more conventional techniques and most importantly the dynamics of the floodplain environment.

Estimated total cost £3,000.

ONE OFF SURVEYS

Ecological characterisation of catchment.

The catchments offer a diverse range of geology with its concomitant effect on flow regime and instream and riparian habitat. It is important that a base-line descriptive data set is collected which will provide the background necessary for subsequent studies in these catchments. The data need to describe the broad range of environmental conditions to be found along the main rivers and their tributaries. The River Habitat Survey methodology provides a convenient and tested technique for describing river habitat and this, in conjunction with habitat patch (mesohabitat) mapping will present a detailed account of the lotic environment. Supplemental surveys will provide information on algal communities on hard surfaces and faunal communities of individual mesohabitats.

Estimated total cost £20,000.

One off fish survey

There are few background data on the composition and distribution of fish populations that cover the length of the river in a systematic manner and the proposed survey will provide this information.

Estimated total cost £20,000.

ANNUAL SURVEYS

Annual ecological survey for two years.

These annual surveys will take place on a reduced set of sites and will provide information on the dynamics of habitat change and associated biotic communities. Such data will provide the necessary background to studies that will examine the processes of change in relation to a wide range of environmental variables. Process-based research will be able to draw on the information obtained in these routine repeated surveys.

Estimated total cost £20,00 per annum, £40,000 in total.

5.4.4 Summary Total Costs

Table 5.6 Tern Infrastructure. Capital items/one off surveys

		Cost	Sub Total
One off Surveys	Geology	£45,000	
	Geophysics	£14,000	
	Ecological characteristics	£20,000	
	Fish Survey	£20,000	
	Hydrological baseline/incremental flows	£6,000	£105,000
Hydrology	3 periodicand 2 recording rain gauges	£6,000	
	2 Automatic weather stations	£21,000	
	4 soil pore water/recharge sites	£120,000	
	Flowgauge Norton in Hayle	£35,000	
	Flowgauge Coal Brook	£35,000	
	6 continuous water quality monitoring systems	£63,000	
	Turbidity systems	£15,000	
	Routine spares water quality and turbidity	£10,000	£305,000
Hydrogeology	Impact of floods on aquifer recharge	£19,000	
	Surface/groundwater interaction site	£65,000	
	Surface/groundwater @ Greenfields	£13,000	
	Geological investigation @ Norton in Hayle	£41,000	
	Recharge/runoff from Carboniferous	£38,000	
	Augmentation of EA network	£96,000	
	Data loggers for EA boreholes	£50,000	
	Boundary definition	£10,000	
	Drift characteristics	£29,000	£361,000
Ecology	2 Pressure transducers	£3,000	£3,000
Site acquisition	21 sites @ 2500 per site		£52,500
Field and laboratory equipment	Mobile laboratory secure unit	£5,500	
	Sampling equipment for lab	£7,500	
	Pump for shallow water sampling	£1,900	
	Mobile pump for channel sampling	£3,200	
	Bladder pump and control unit	£2,000	
	Double packer for 85-185mm boreholes	£2,000	
	Data logger interrogation unit	£250	
	3 water level dippers	£1,000	£23,350
Grand Total Infrastructure Capital/one off surveys			£849,850

Table 5.7. Tern Recurrent Costs

		Cost	Total
	Surface water chemical analysis	£35,000	
	Groundwater chemical analysis	£48,000	
	Ecological characterisation survey (2 off)	£40,000	
	Land rental other sites – nominal sum	£10,000	
Grand Total recurrent costs			**£133,000**

6 Non-Science Issues

Major non-scientific issues that have emerged during the work of the Task Force, that will need to be considered by the LOCAR Steering Committee are briefly outlined below. Their significance does not necessarily impinge on the science but will undoubtedly affect the timescale for implementation, the capital cost of implementation and the recurrent budget during the five years of the programme.

Clearly the implications for recurrent budget are fundamental to the programme and how much science can be carried out with the infrastructure and the data generated.

6.1 PROJECT MANAGEMENT OF IMPLEMENTATION PHASE

The costings for options and proposals detailed in Chapter 7 include installation including supervision of drilling, but do not include the following:

(i) detailed design;

(ii) contract writing and letting;

(iii) quality assurance;

(iv) budgetary control/cash flow of approx. £3.6M;

(v) management of the integrated infrastructure installation (i.e. programming);

(vi) negotiation with EA for collaborative efforts;

(vii) completion reporting;

(viii) public relations activities.

It is assumed that public relations would be dealt with by the programme science coordinator and budgets for public meetings would be found separate from the implementation strategy.

The effort involved in completing all the other tasks over a two year period is estimated at £200,000. A breakdown of project management costs (based on BGS staff costs plus 46% overhead) is given in Table 6.1.

6.2 ACCESS

Although sites have been earmarked as being appropriate access is likely to be a major issue. Land agents familiar with the areas and landowners in the catchments will have to be employed. Allowance for these costs has been made. It is suggested that knowledge gained by the EA be employed to devise strategies for land acquisition in each catchment. They are likely to be different in each catchment.

6.3 REGULATORY ISSUES

Any structure that appears above the land surface (e.g. classical gauging station) will require planning permission and, naturally, it will be essential that the EA is fully behind LOCAR/JIF proposals to secure approval. For gauging stations this will require a feasibility study, agreement of the EA including environmental and conservation sections (which may not be forthcoming), detailed design, planning permission, construction and commissioning. Clearly the timescales (section 6.5) for such an activity are likely to be between 18 months and 2 years.

Table 6.1 LOCAR Infrastructure Implementation – Project Management

(in £)	Year 1		Year 2	
	Days	Cost	Days	Cost
G6	40		37	
G7	95		80	
SSO	90		50	
HSO	80		50	
SO	180		135	
Total Staff		104270		82287
Recurrent (T& S etc)		8443		5000
Total		112713		87287
Grand Total		£200,000		

Boreholes that are required to be pumped (by science projects) will have to have an abstraction licence issued by the EA. This is a detailed legal process and objectors (activists) could slow or stop the process. A one year period should be allowed from application for a permit to drill and test (required for all boreholes) to the issue of an abstraction licence.

Tracer tests that may be required in science projects and use LOCAR/JIF boreholes will require the permission of the EA.

6.4 STORAGE AND MAINTENANCE

Storage facilities will be required for drilling samples, water samples, pore water samples, equipment (chemical measurement, pumps, packers, etc). Clearly the field equipment should be maintained by the catchment management staff but stored as near as possible to the catchments. It is suggested that facilities could probably be made available at CEH/BGS Wallingford and IFE Dorset for the Pang/Lambourn and the Frome/Piddle. Storage facilities for the Tern have not been investigated, but it is suggested that secure compounds with Severn Trent Water or EA might be a possibility.

Approximately 2-2.5 km of core are proposed in this report. Storage facilities for these have not been costed or investigated, but this core should be regarded as a very important national resource and would be best stored at BGS Keyworth.

6.5 TIMESCALE AND PROGRAMMING

It is clear from the preceeding argument that the infrastructure implementation stage is likely to take between 18 months and 2 years. It is therefore essential to begin planning and letting contracts as soon as possible, but certainly in April 2000 so that much of the drilling can take place in the summer/autumn of 2000.

Detailed design of some of the study sites requires a phased approach so that some boreholes can be used in an exploratory fashion with investigative geophysics to help with detailed design prior to the bulk of the construction.

In order to assist in detailed re-analysis of the available data/knowledge for design purposes it may be appropriate to let a very early directed science call for 6-12 months to carry out some of the baseline survey work, or to involve masters degree students.

It seems unlikely that all the facilities will be fully operational before the end of 2001.

6.6 CATCHMENT MANAGEMENT

A realistic assessment of the work involved on each catchment in order to maintain infrastructure and keep a steady, quality flow of monitoring data to the LOCAR Data Centre is required. It is estimated that one grade 7 (principal) or SSO (senior) level staff member should be appointed LOCAR catchment manager. It is envisaged that he will be required for half his time during operation of the catchments. He should be assisted by two staff members at HSO and ASO for each catchment. It is envisaged that these latter would be based at:

Univeristy of Birmingham	–	Tern
CEH – Wallingford	–	Pang/Lambourn
CEH – Dorset	–	Frome/Piddle

They have been costed at half-time for the first ten months (June 2000-March 2001) and three-quarters time for the next year (April 2001-March 2002) followed by two years and two months full-time. This ramping up of activity is to allow for the installation of the infrastructure which is costed separately. Table 6.2 details these costs. The resultant total for four years operation is £799,444.

Table 6.2 Catchment Management Costs

One Grade 7 half time for four years.

One HSO and one ASO per catchment, half time for first 10 months, three quarters tiome for next financial year and full time for remaining two years and two months.

	Jun 2000 – Mar 2001	Apr 2001 – Mar 2002	Apr 2002 – Mar 2003	Apr 2003 – Mar 2004	Apr 2004 – May 2004	TOTALS
TOTALS	£104,372	£175,957	£233,454	£243,375	£42,286	£799,444

6.7 JIF BID VS. JIF/LOCAR PROPOSALS

It is important that the JIF/LOCAR proposals incorporate the approved proposals for infrastructure development that were included within the JIF bid. A comparison between proposals made in this report with those of the JIF bid is found in Table 6.3.

Areas of discrepancy are noted below:

(i) £30K less to be spent on climate infrastructure that was originally proposed in the JIF bid;

(ii) no telemetry proposed in this report;

(iii) no specific equipment for 3D stream velocity monitoring.

The justification for these changes is simple. A considered approach employing an agreed strategy, after study of existing facilities (not carried out for JIF bid) has changed priorities marginally. For instance, the telemetry has been left out entirely because of budgetary constraints, since it is a non-essential item.

Table 6.3 Comparison of JIF funded proposals and total LOCAR infrastructure proposals

Sub-category	JIF		LOCAR
Climate	£261K		£231K
3No AWS		6 No AWS	
3 No Hydra		3 No Hydra	
36 No rain gauages		15 No rain gauges	
2 No net rainfall plots			
Unsaturated Zone	£155K		£405K
Flow Gauging	£166K		£288K
Telemetry	£79K		nil
3 base stations			
50 sensors			
Groundwater	£1025K		£1382K
drilling and monitoring equipment			
Ecology			
smolt counter	£118K	smolt counter	£118K
2No fish trackers		1 No. fish tracker	
Hyporheic zone temp	£22K	covered by baseline surveys	?
3D stream velocity			
Water Quality	£64K		£232K
3 No monitors etc			
Sediments	£106K		£124K
20 No turbidity probes			
Portable laser diffraction Equipment			

7 Summary of Costings

In bringing together the costings for both capital and recurrent proposals for infrastructure and monitoring on the three catchments it was necessary to maintain consistency in scientific approach that would result in costed proposals falling within the perceived budget. The budget was defined as:

JIF capital funding	=	£2M
LOCAR capital and recurrent	=	£3M

This has been achieved with a total proposed expenditure over four years to end May 2004 at £4,989,500. Table 7.1 shows the breakdown of this proposed expenditure in terms of capital and recurrent spend and includes totals for each catchment. The installed and managed cost of the infrastructure (including one-off surveys) amounts to £3,578,000. Recurrent surveys total £482,000.

The LOCAR/JIF project will be implemented in a phased manner. This report represents the completion of Phase I (Outline Design). Phase II (Implementation Stage), which needs to be started as soon as possible, includes the setting up of the catchments. It is envisaged that this will take up to two years to complete, so project management costs include inflation in year 2. Phase III (Catchment Management Stage), overlaps with Phase II. Phase III is predicted to cost £1,361,500 over a four year period.

The recurrent surveys are lump sums for dispersal over three or four years and do not include inflation. Project Management and Catchment Management staff costs have been inflated at the NERC advised figure of 4.5% per annum for 2001/2002 and beyond.

In order to compare the funding of different topic areas, the costings have been broken down on Table 7.2: for capital spent into one-off surveys, hydrology, ecology and hydrogeology (not including site acquisition or miscellaneous field and laboratory equipment): for recurrent surveys, into chemical analyses, ecology and land rental.

Table 7.1 LOCAR/JIF Instrastructure/Monitoring: Summary of Costs

	Capital	Recurrent	
Frome/Piddle	£1,083,000	£245,000	
Pang/Lambourn	£1,288,500	£104,000	
Tern	£ 850,000	£133,000	
	£3,221,000	**£482,000**	
Equipment Pool	£ 157,000		
	£3,378,000		
Project Management	£ 200,000		
Sub-total	**£3,578,000**		
Catchment Management			
Grade 7, half-time for 4 years			£132,921
3 HSOs half-time 10 months, ¾ next year, full time 2 years 2 months			£410,555
3 ASOs half-time 10 months, ¾ near year, full time 2 years 2 months			£255,968
Sub-total			£799,500
Vehicles (hire 4WD when required and 3 vans)	£ 45,000		
Recurrent Expenditure (subsistence/travel)		£ 80,000	
3 x computer	£ 5,000		
Sub-totals	**£ 50,000**	**£879,500**	
Totals	**£3,628,500**	**£1,361,500**	
***GRAND TOTAL**	**£4,990,000**		

*No contingency has been allowed

(Revision 3, post 28/1/00)

Table 7.2 LOCAR/JIF Infrastructure Costings broken down by topic area

Capital

Catchment	One-off Surveys	Hydrology	Hydrogeology	Ecology
Frome/Piddle	139,000	516,000	297,000	85,000
Pang/Lambourn	91,000	514,000	607,000	3,000
Tern	105,000	305,000	361,000	3,000
Totals	335,000	1,335,000	1,265,000	91,000

Recurrent Surveys

	Chemical Analysis	Ecology	Land Rental
Frome/Piddle	105,000	130,000	10,000
Pang/Lambourn	79,000	15,000	20,000
Tern	83,000	40,000	10,000
Totals	267,000	185,000	30,000

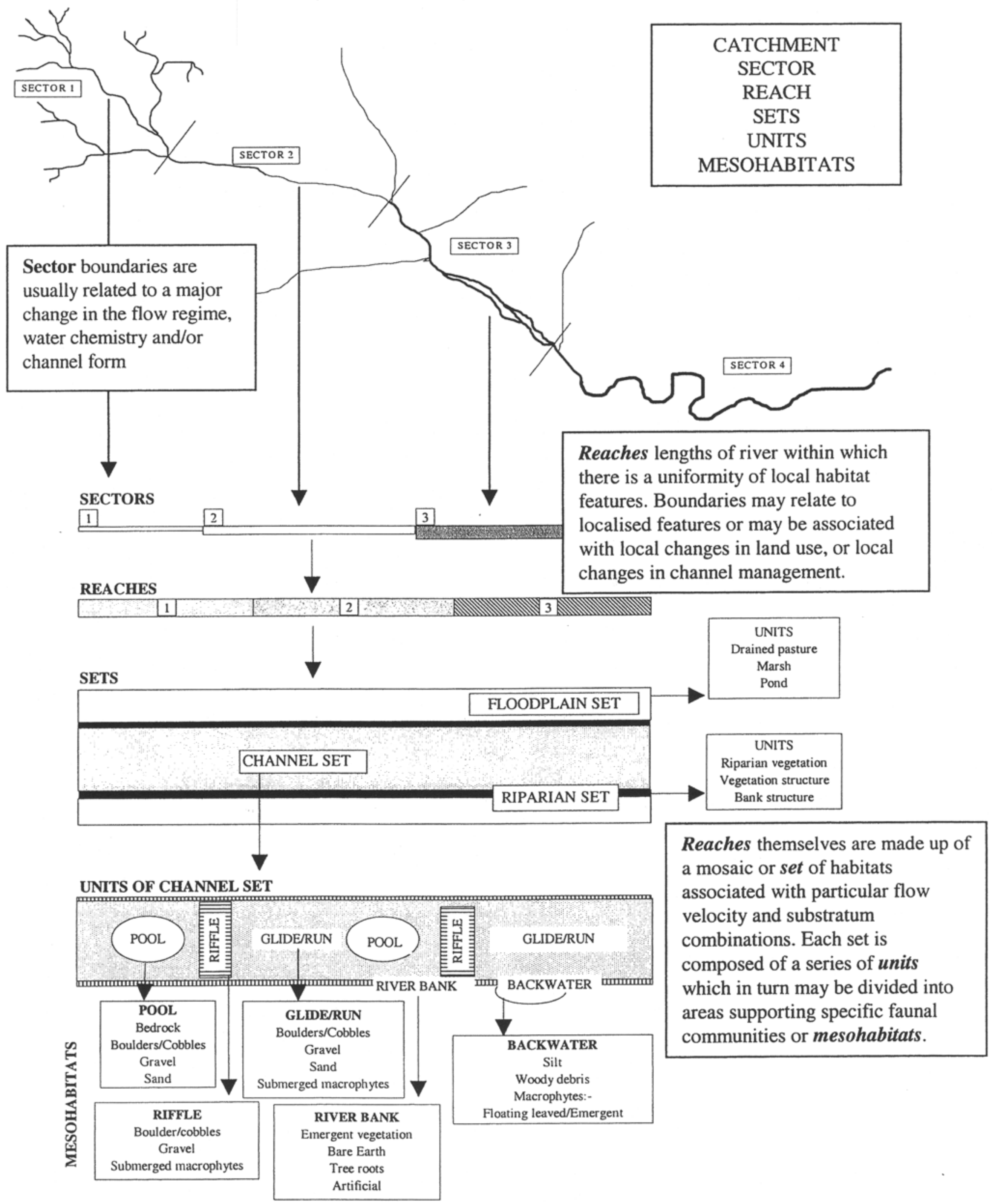


Figure 2.4.1.1 Conceptual division of a river system into areas which have ecological significance and which link to hydrological features

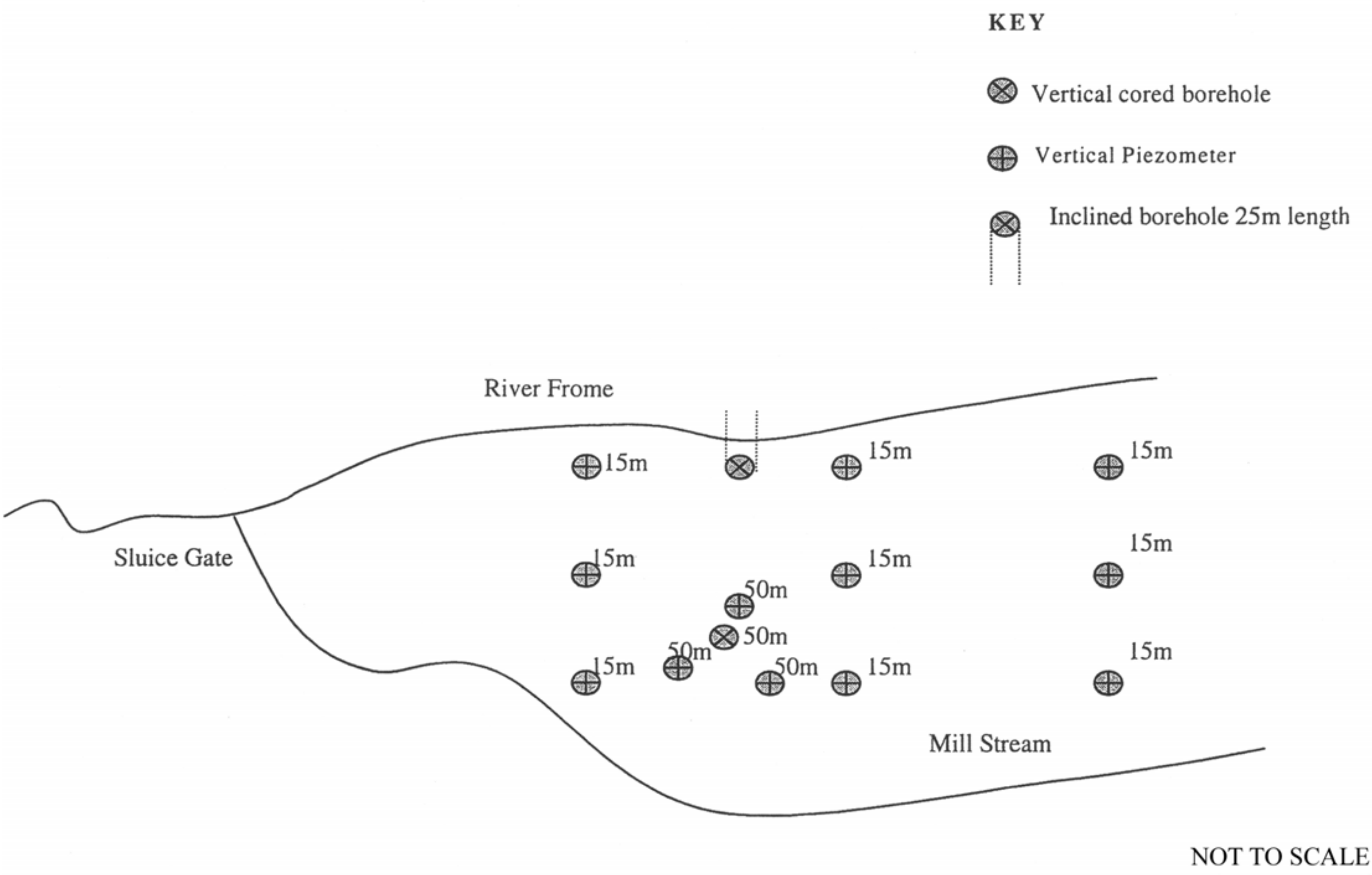


Figure 3.4.2.1 Sketch plan of proposed facility to investigate surface water/groundwater interaction at IFE River Laboratory site

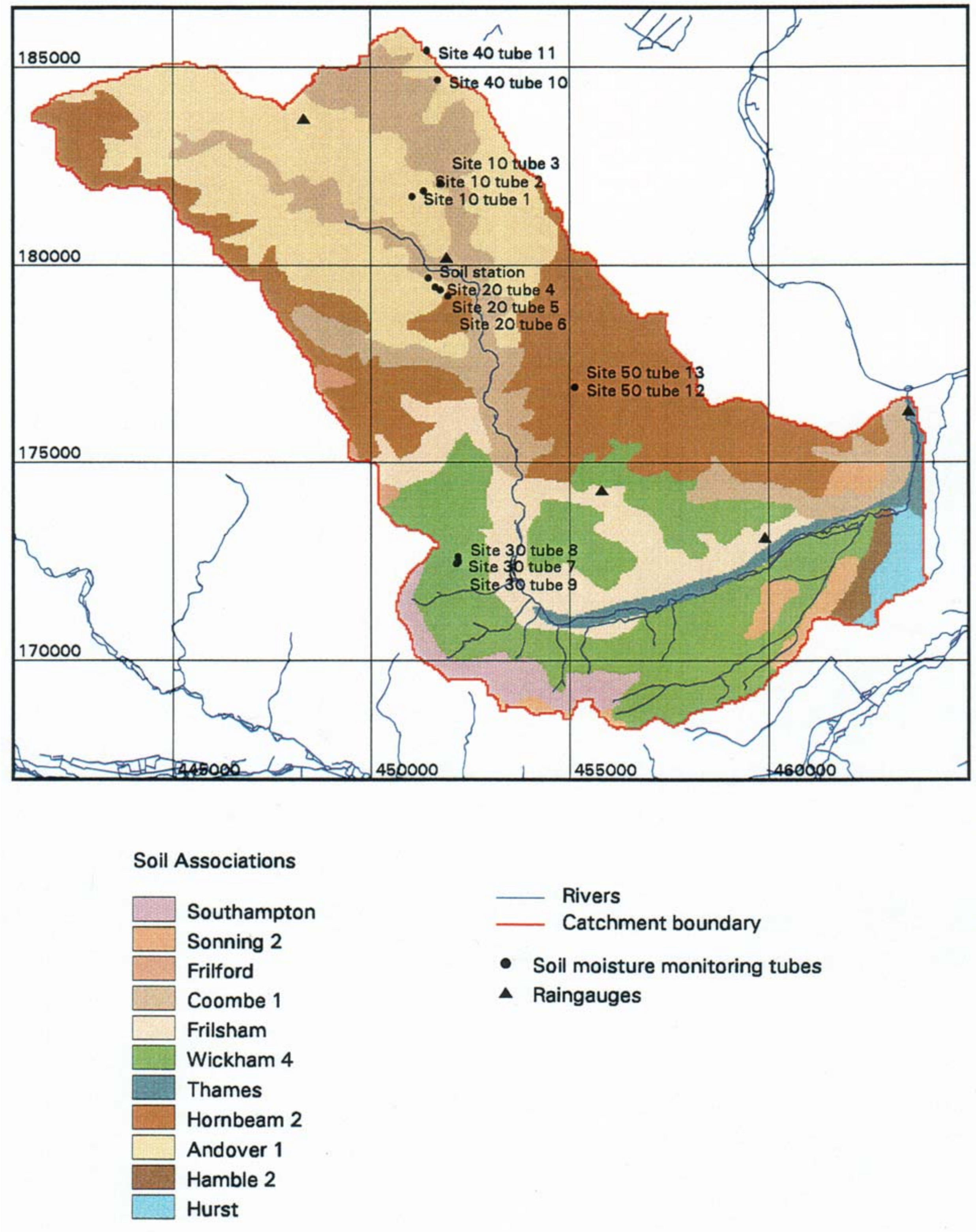


Figure 4.2.1.1 Soil types in the Pang catchment from the Soil Survey of England and Wales 1:250,000 series. Also shown are the Institute of Hydrology soil moisture sites

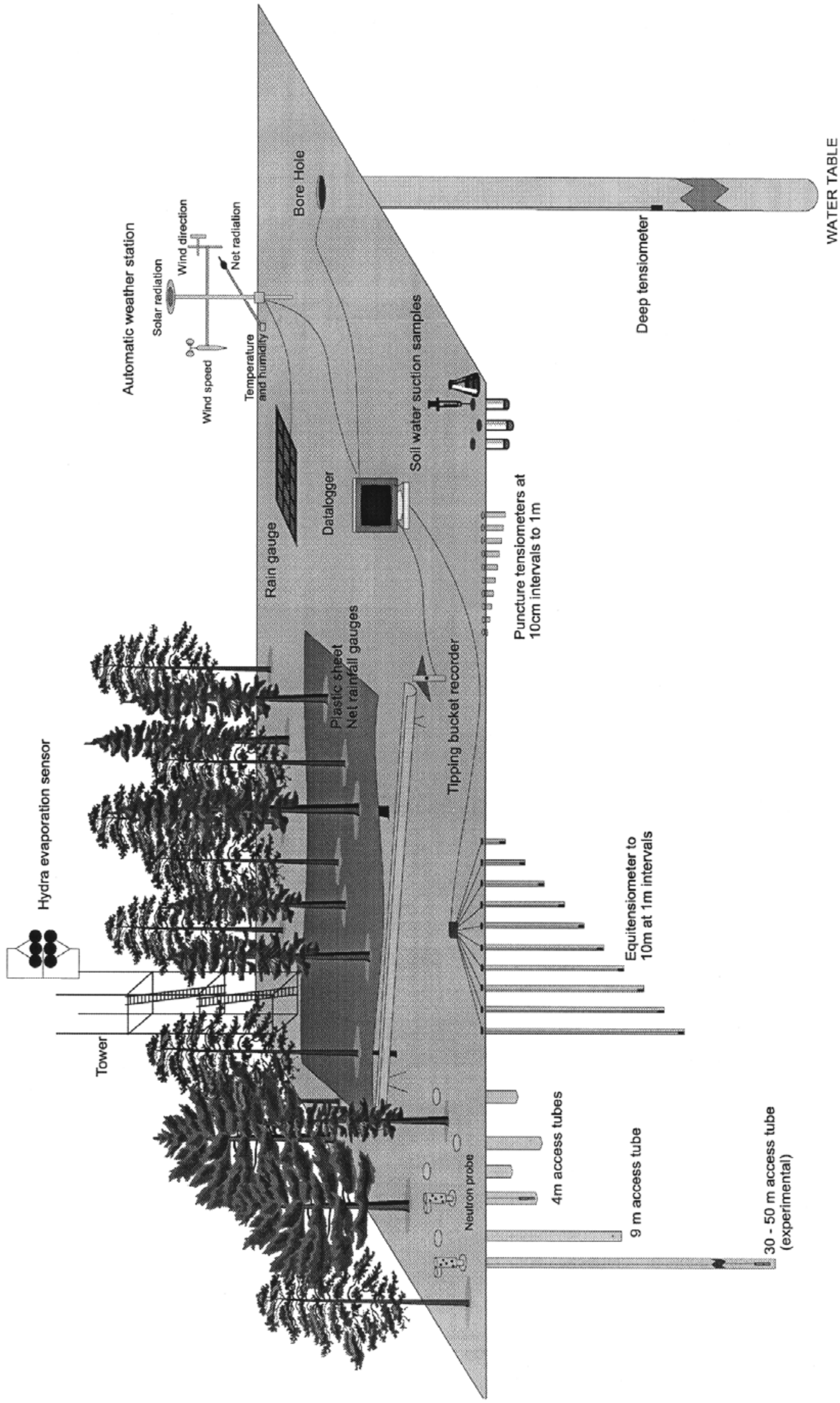


Figure 4.3.1.1 Layout sketch of instrumentation at evaporation, soil moisture and 'recharge' sites (including specialised forest instrumentation)

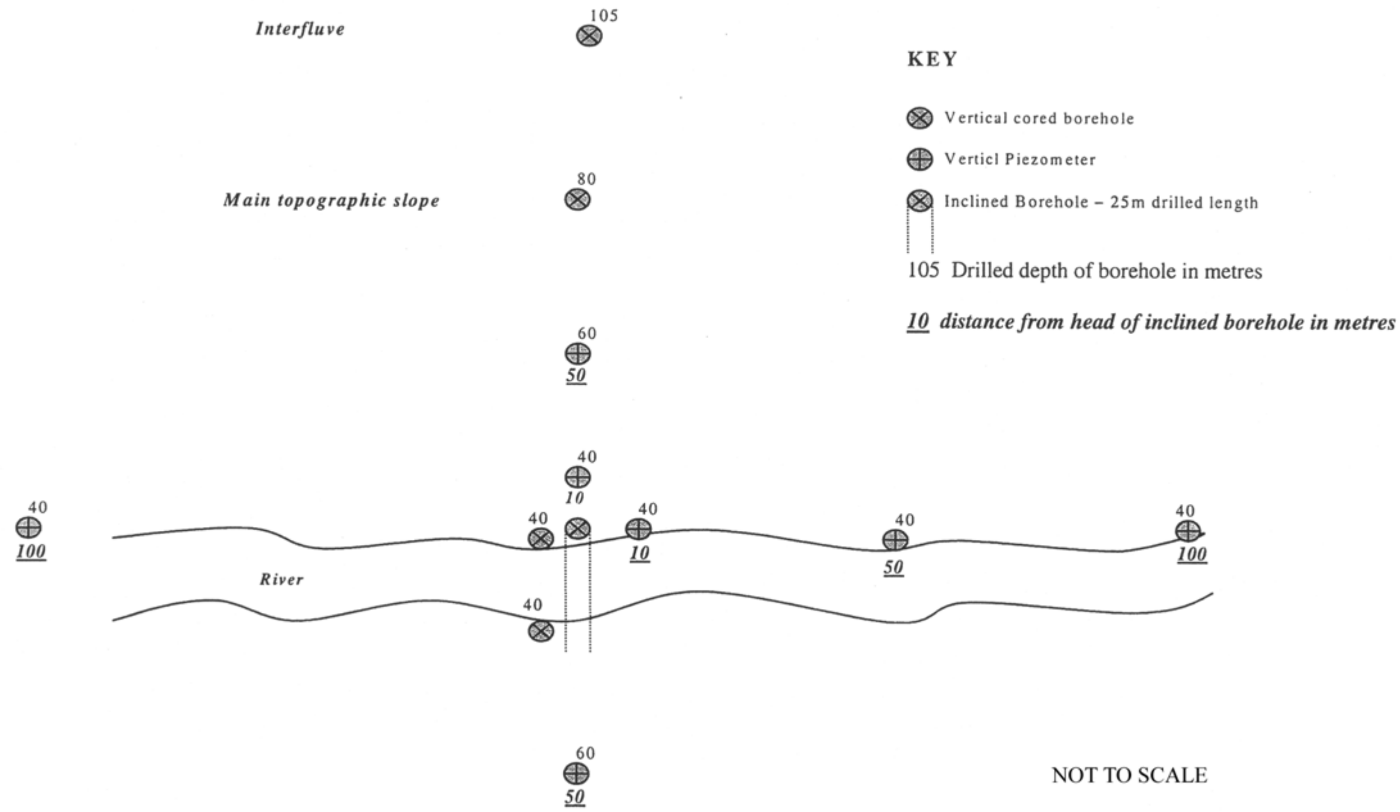


Figure 4.4.2.1 Proposed borehole array to investigate surface water/groundwater interaction

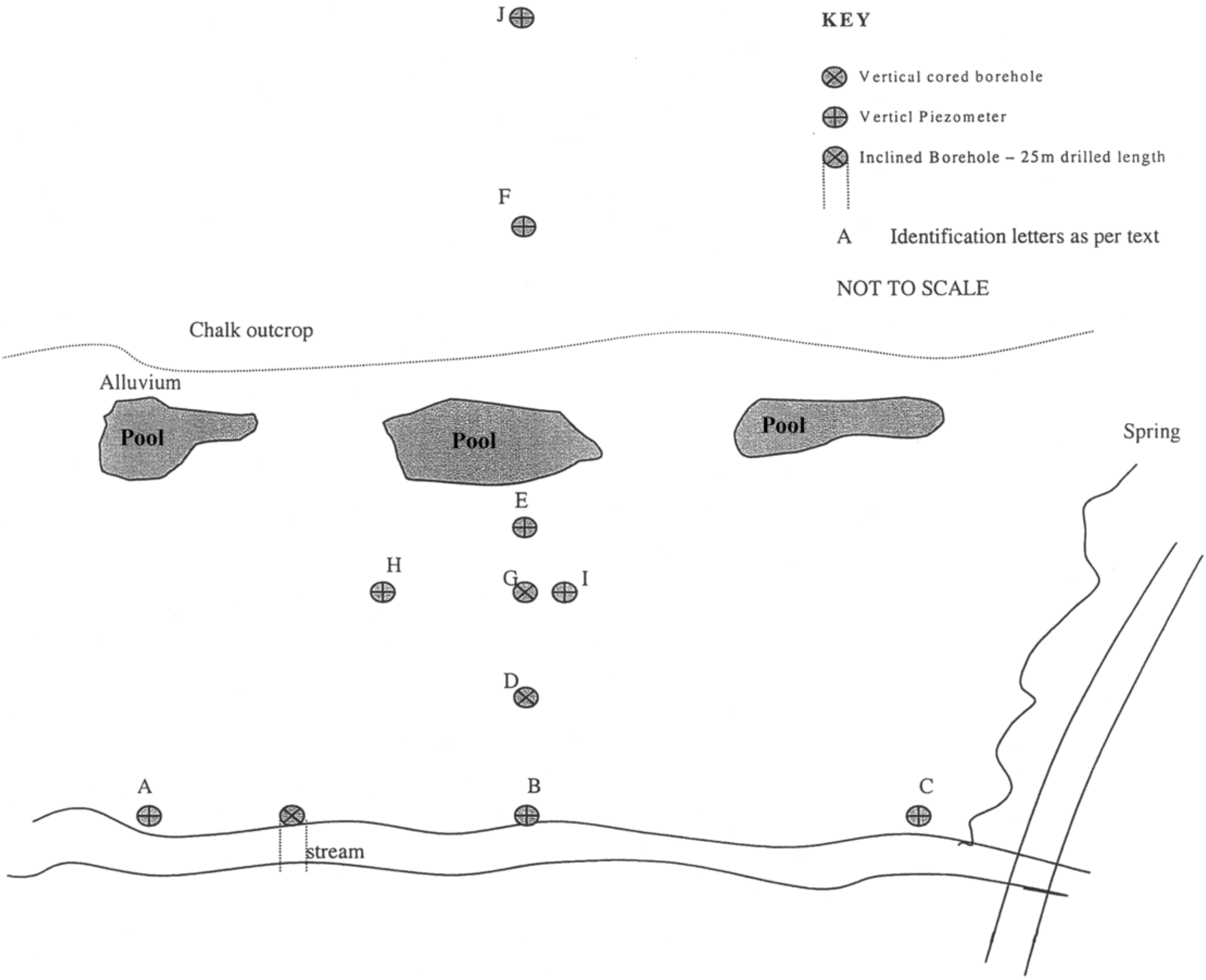
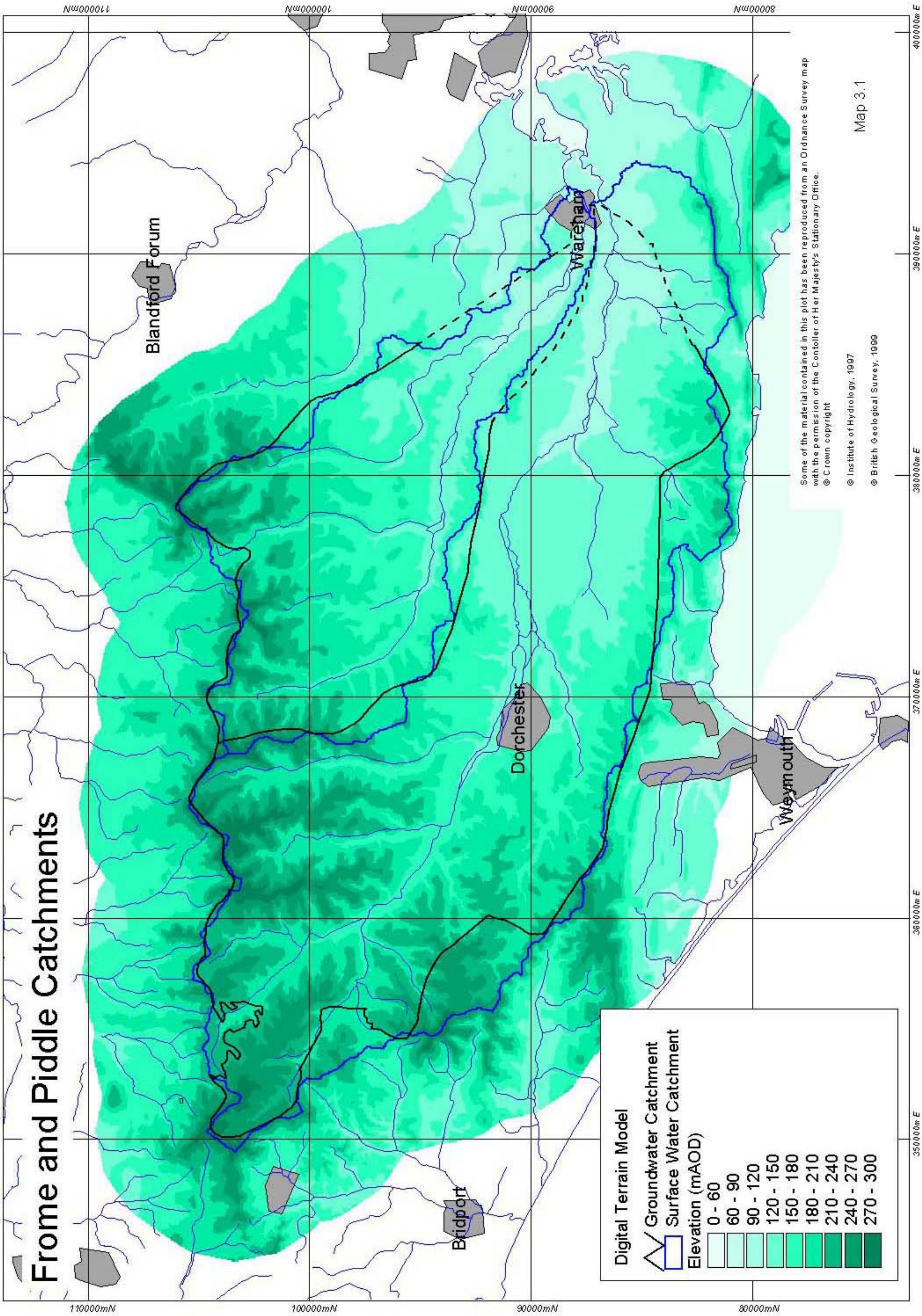


Figure 4.2.2.2 Sketch to show proposed layout of piezometers and boreholes to investigate wetland area at perennial head of the River Lambourn


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Digital Terrain Model
Groundwater Catchment
Surface Water Catchment
Elevation (mAOD)
0 - 60
60 - 90
90 - 120
120 - 150
150 - 180
180 - 210
210 - 240
240 - 270
270 - 300
Map 3.1
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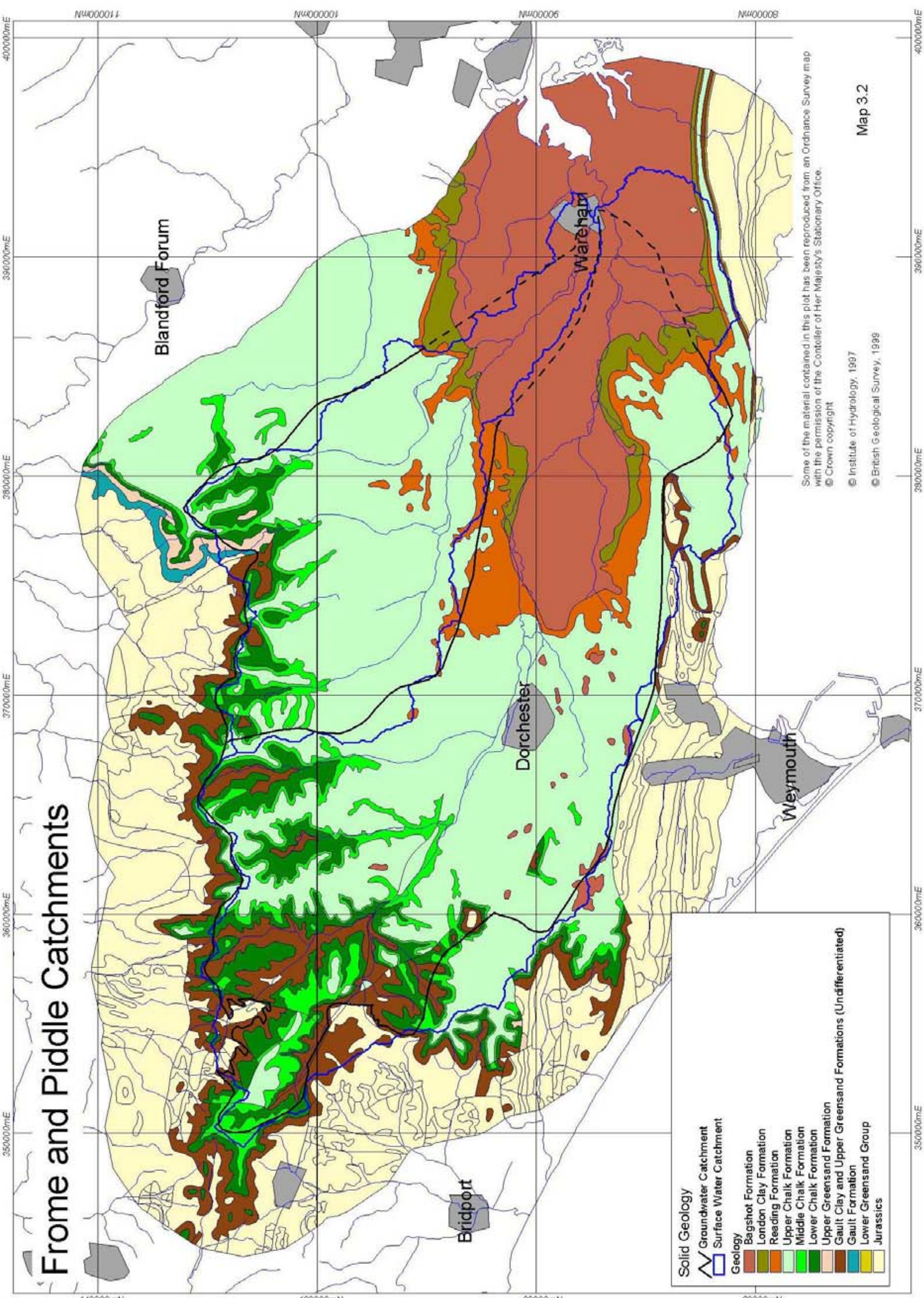
110000mN
100000mN
90000mN
80000mN
350000m E
360000m E
370000m E
380000m E
390000m E
400000m E

Map 3.1


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Map 3.2
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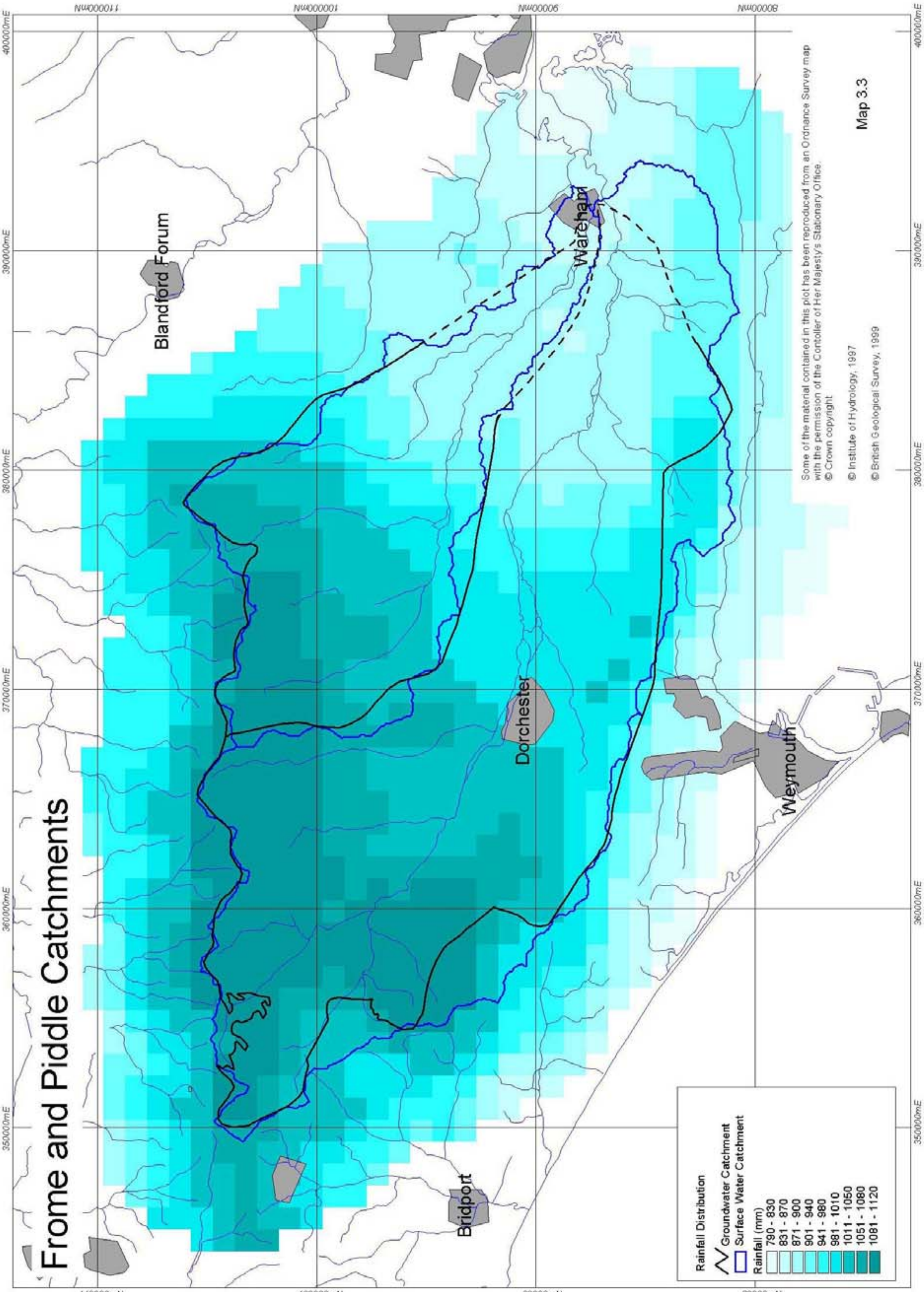
Solid Geology
Groundwater Catchment
Surface Water Catchment
Geology
Bagshot Formation
London Clay Formation
Reading Formation
Upper Chalk Formation
Middle Chalk Formation
Lower Chalk Formation
Upper Greensand Formation
Gault Clay and Upper Greensand Formations (Undifferentiated)
Gault Formation
Lower Greensand Group
Jurassics

Map 3.2


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Map 3.3
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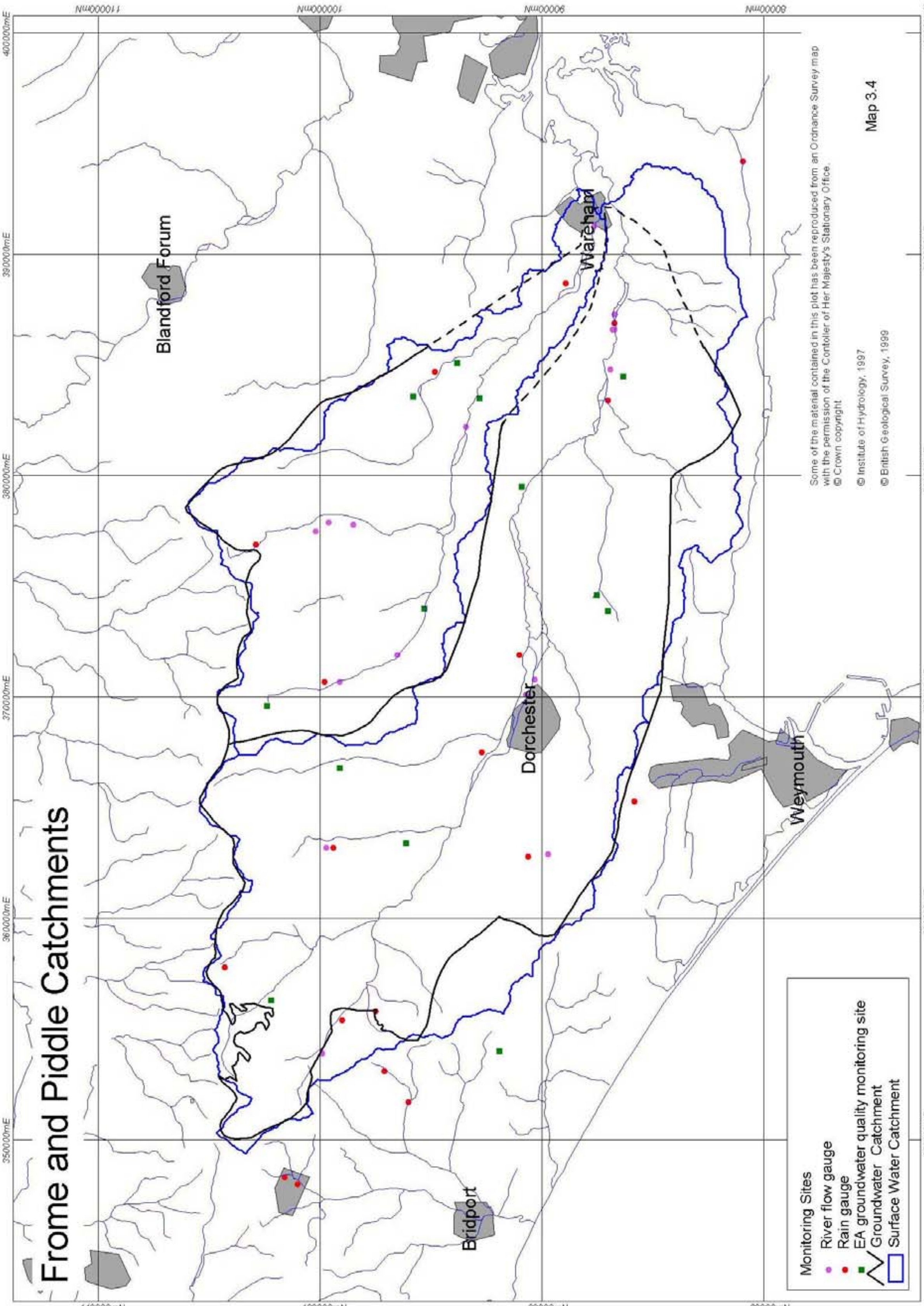
Rainfall Distribution
Groundwater Catchment
Surface Water Catchment
Rainfall (mm)
790 - 830
831 - 870
871 - 900
901 - 940
941 - 980
981 - 1010
1011 - 1050
1051 - 1080
1081 - 1120
110000mN
100000mN
90000mN
80000mN
350000mE
360000mE
370000mE
380000mE
390000mE
400000mE

Map 3.3


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Monitoring Sites
River flow gauge
Rain gauge
EA groundwater quality monitoring site
Groundwater Catchment
Surface Water Catchment
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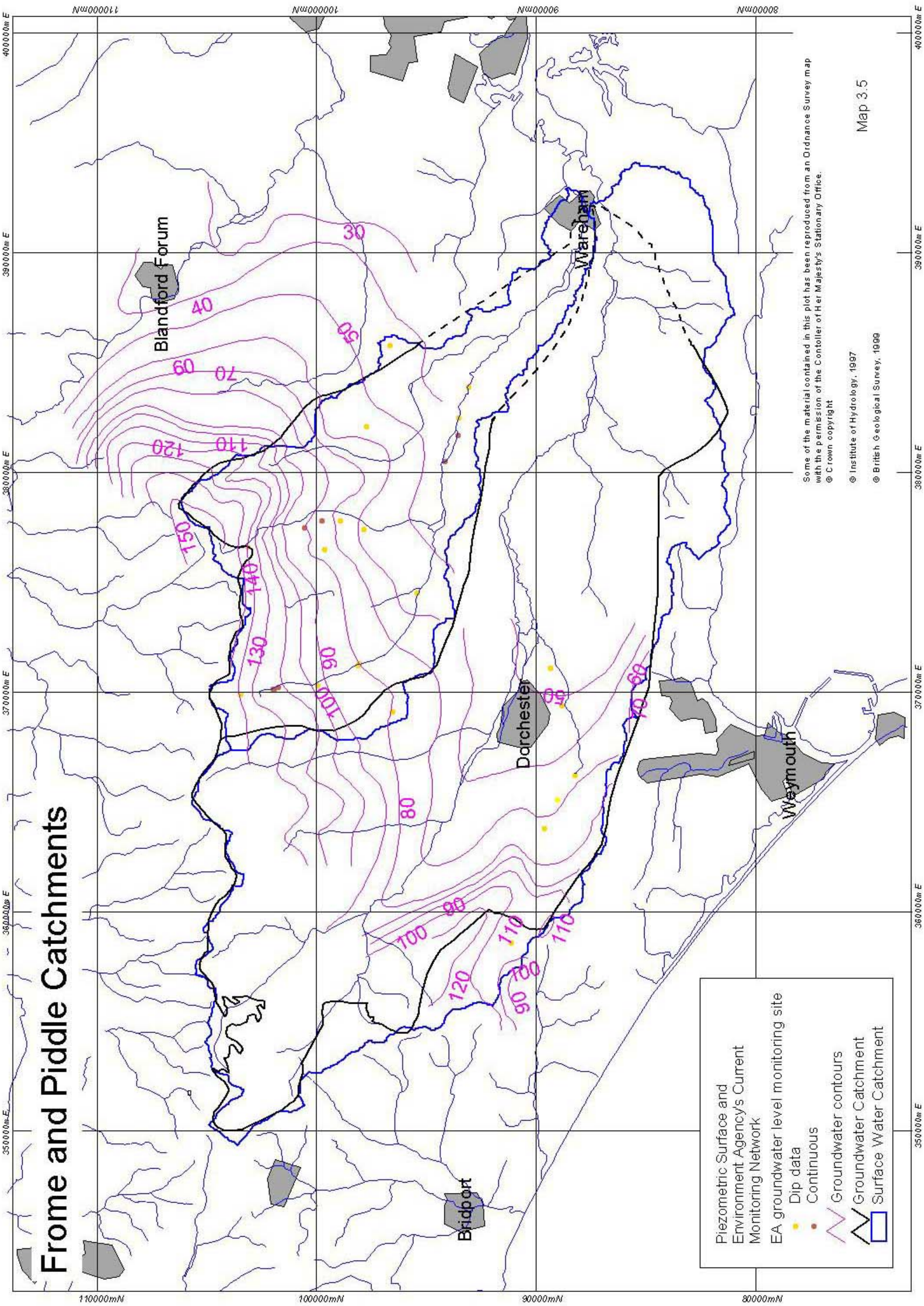
Map 3.4

Map 3.4


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Piezometric Surface and Environment Agency's Current Monitoring Network
EA groundwater level monitoring site
Dip data
Continuous
Groundwater contours
Groundwater Catchment
Surface Water Catchment
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Map 3.5
110000mN
100000mN
90000mN
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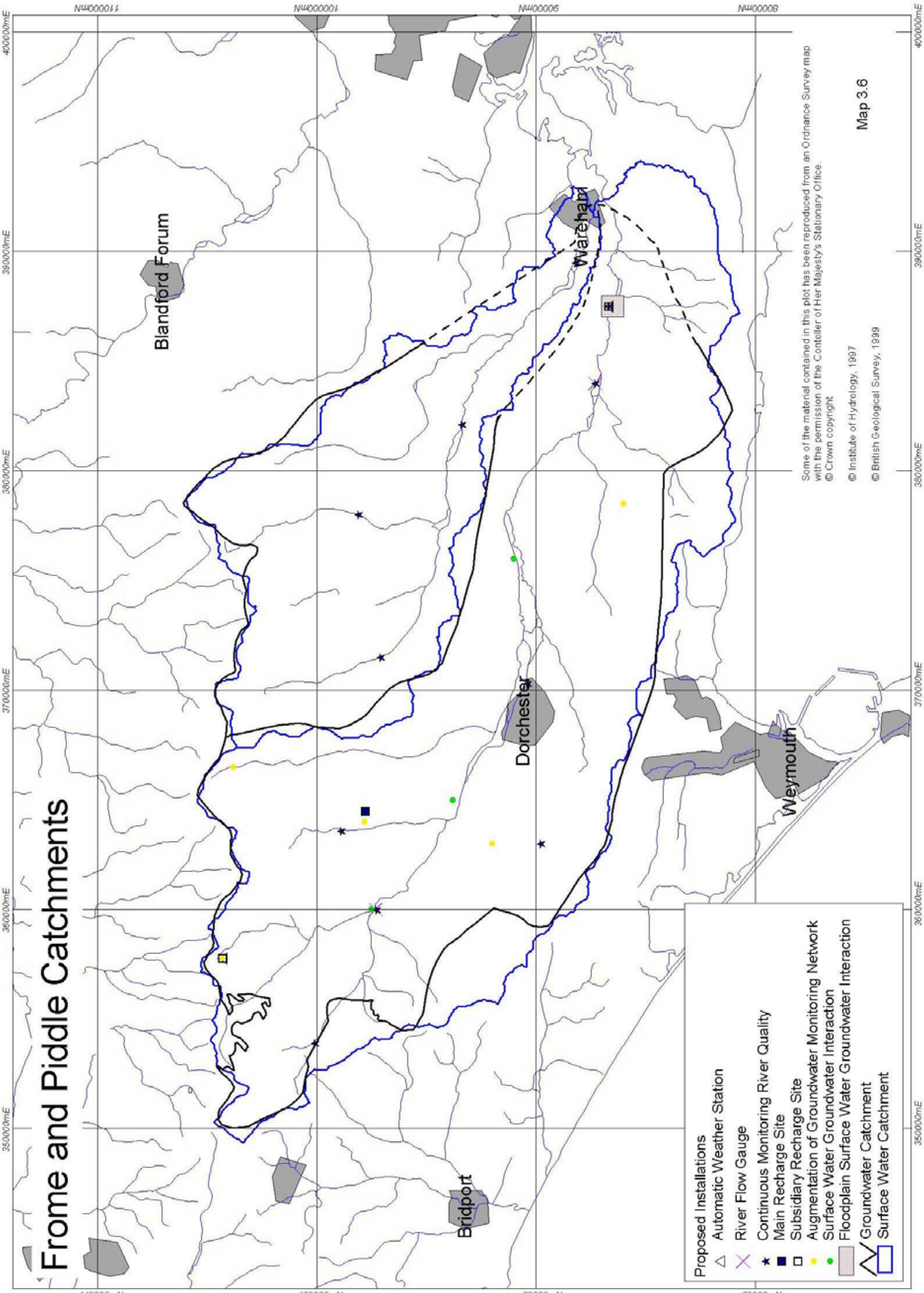
350000m E
360000m E
370000m E
380000m E
390000m E
400000m E

Map 3.5


Frome and Piddle Catchments
Blandford Forum
Wareham
Dorchester
Weymouth
Bridport
Proposed Installations
Automatic Weather Station
River Flow Gauge
Continuous Monitoring River Quality
Main Recharge Site
Subsidiary Recharge Site
Augmentation of Groundwater Monitoring Network
Surface Water Groundwater Interaction
Floodplain Surface Water Groundwater Interaction
Groundwater Catchment
Surface Water Catchment
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Map 3.6
110000mN
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90000mN
80000mN
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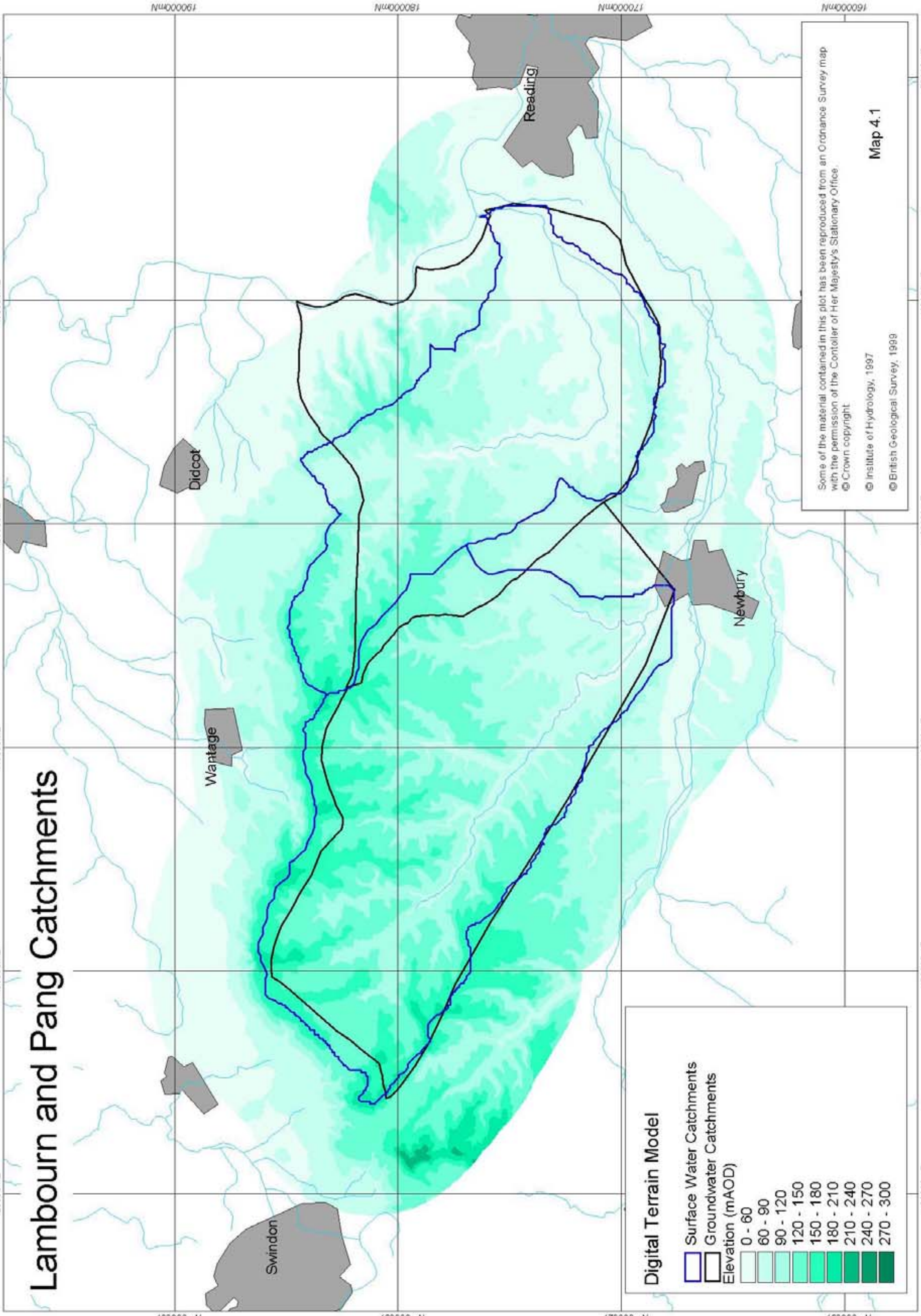
360000mE
370000mE
380000mE
390000mE
400000mE

Map 3.6


Lambourn and Pang Catchments
Digital Terrain Model
Surface Water Catchments
Groundwater Catchments
Elevation (mAOD)
0 - 60
60 - 90
90 - 120
120 - 150
150 - 180
180 - 210
210 - 240
240 - 270
270 - 300
Swindon
Wantage
Didcot
Newbury
Reading
Map 4.1
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190000mN
180000mN
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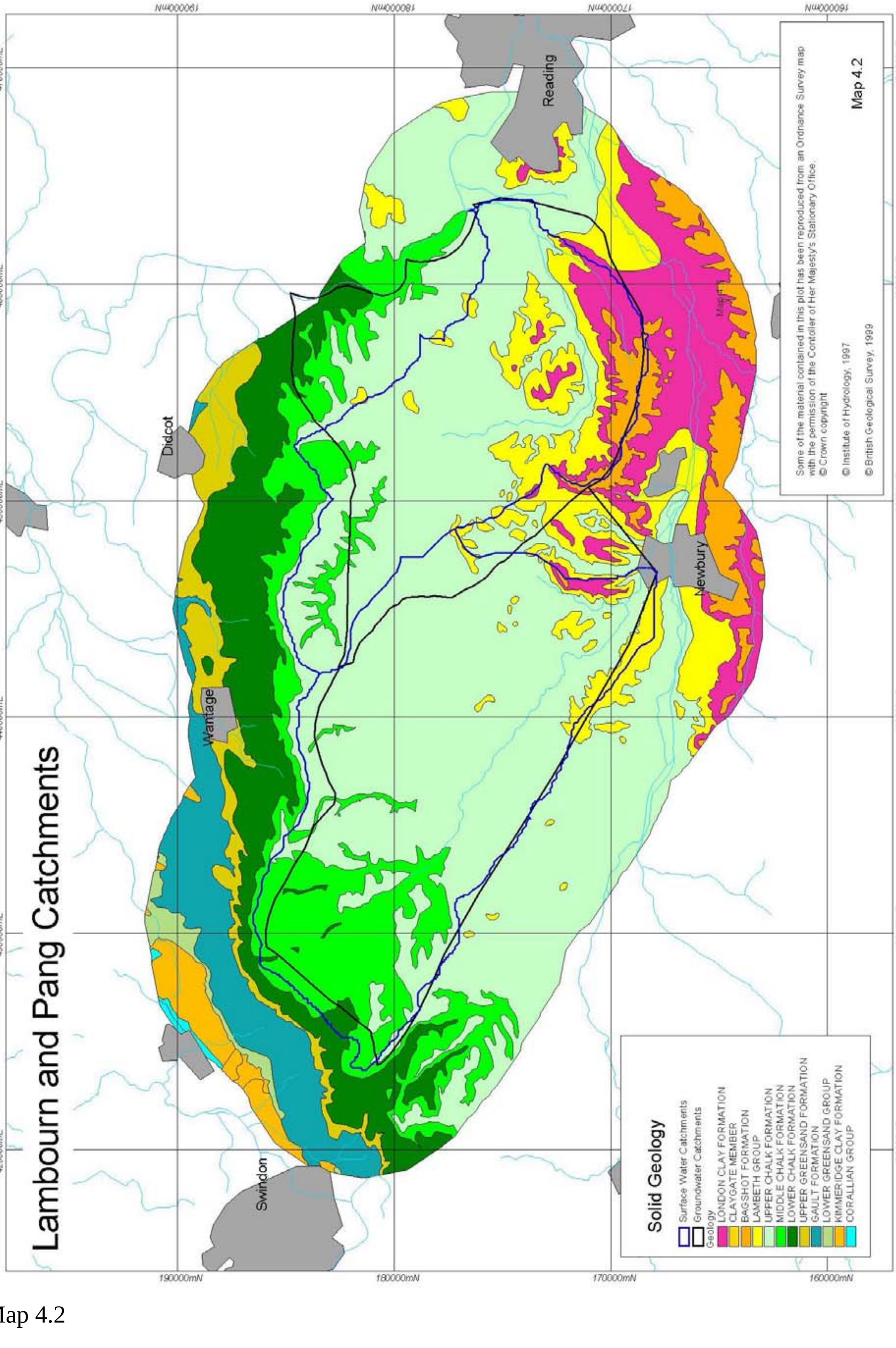
420000mE
430000mE
440000mE
450000mE
460000mE
470000mE

Map 4.1


Lambourn and Pang Catchments
Solid Geology
Surface Water Catchments
Groundwater Catchments
Geology
LONDON CLAY FORMATION
CLAYGATE MEMBER
BAGSHOT FORMATION
LAMBETH GROUP
UPPER CHALK FORMATION
MIDDLE CHALK FORMATION
LOWER CHALK FORMATION
UPPER GREENSAND FORMATION
GAULT FORMATION
LOWER GREENSAND GROUP
KIMMERIDGE CLAY FORMATION
CORALLIAN GROUP
Reading
Didcot
Wantage
Newbury
Swindon
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Map 4.2
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450000mE
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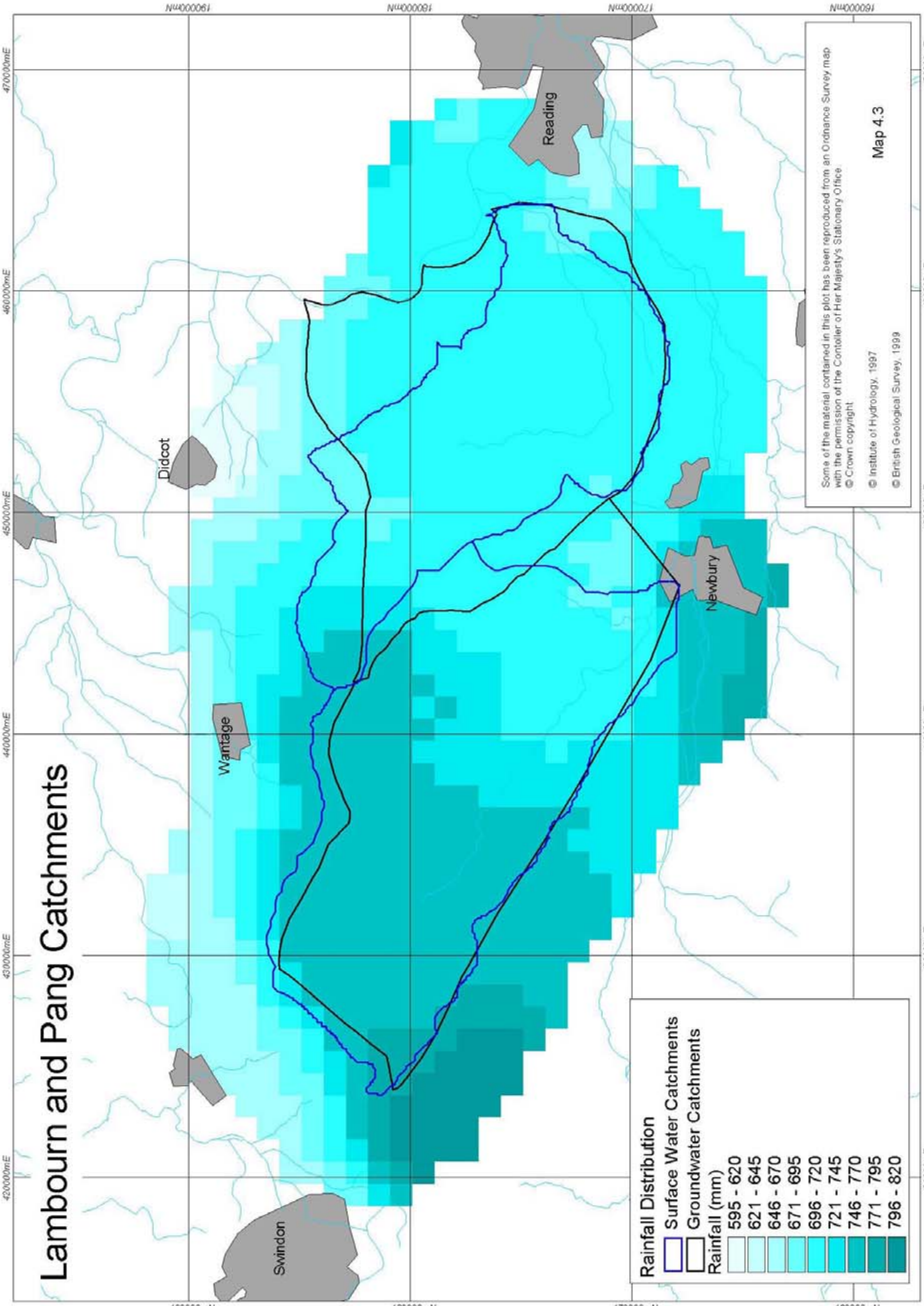
Map 4.2


Lambourn and Pang Catchments
Rainfall Distribution
Surface Water Catchments
Groundwater Catchments
Rainfall (mm)
595 - 620
621 - 645
646 - 670
671 - 695
696 - 720
721 - 745
746 - 770
771 - 795
796 - 820
Reading
Didcot
Wantage
Newbury
Swindon
Map 4.3
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190000mN
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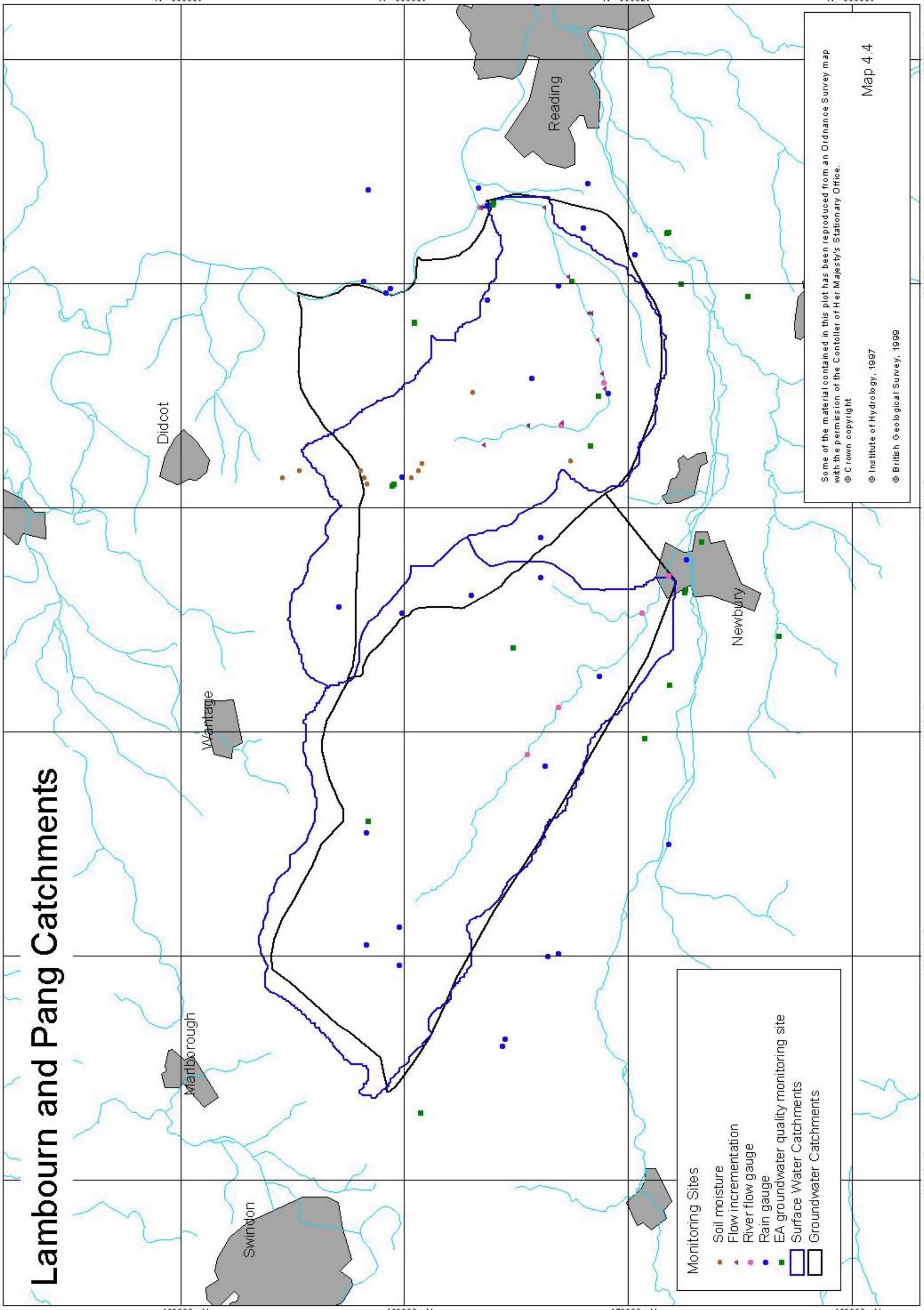
160000mN
420000mE
430000mE
440000mE
450000mE
460000mE
470000mE

Map 4.3


Lambourn and Pang Catchments
Reading
Didcot
Wantage
Marlborough
Swindon
Newbury
Monitoring Sites
Soil moisture
Flow incrementation
River flow gauge
Rain gauge
EA groundwater quality monitoring site
Surface Water Catchments
Groundwater Catchments
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Map 4.4
190000mN
180000mN
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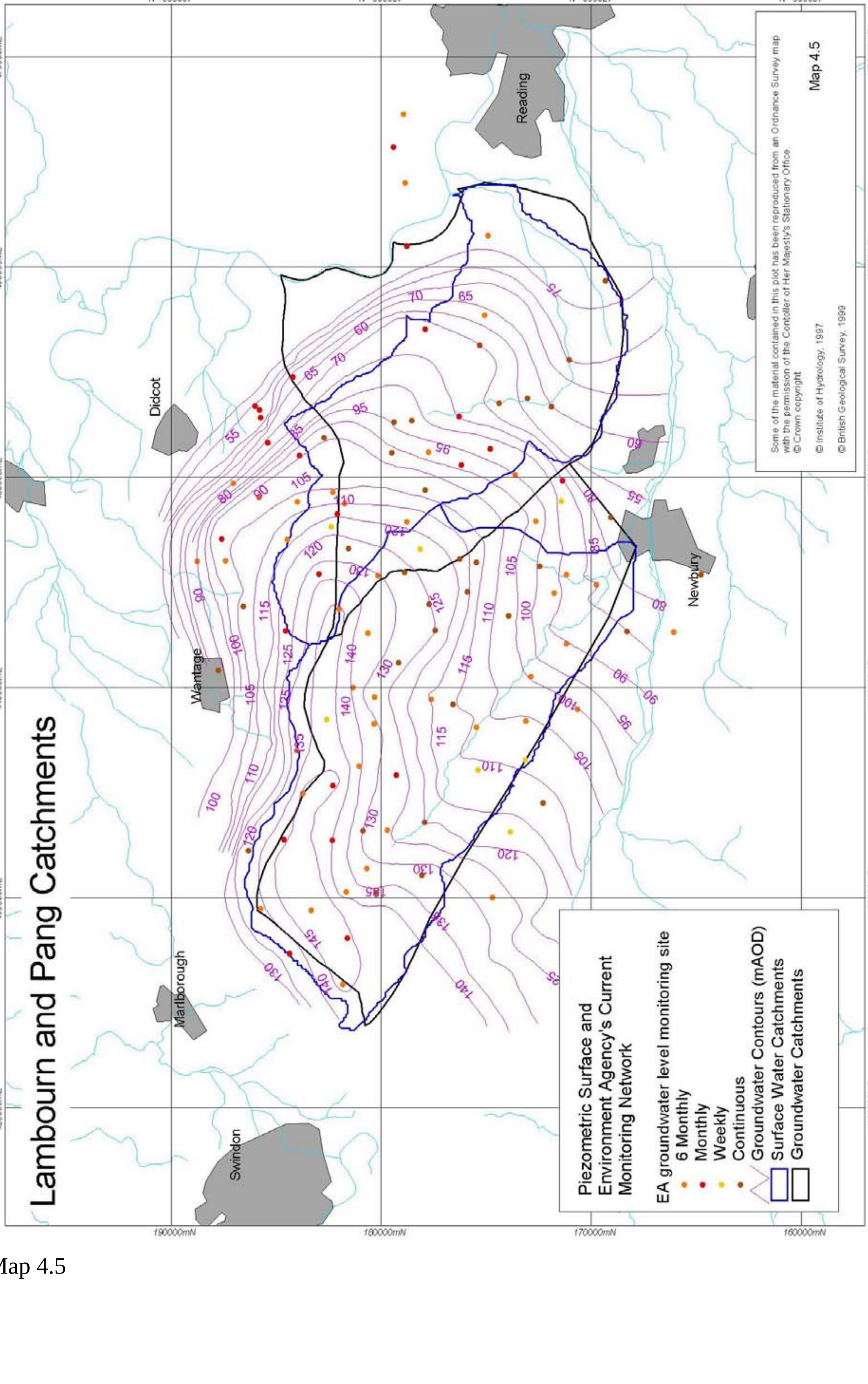
440000m E
450000m E
460000m E
470000m E

Map 4.4


Lambourn and Pang Catchments
Piezometric Surface and Environment Agency's Current Monitoring Network
EA groundwater level monitoring site
6 Monthly
Monthly
Weekly
Continuous
Groundwater Contours (mAOD)
Surface Water Catchments
Groundwater Catchments
Reading
Didcot
Wantage
Newbury
Marlborough
Swindon
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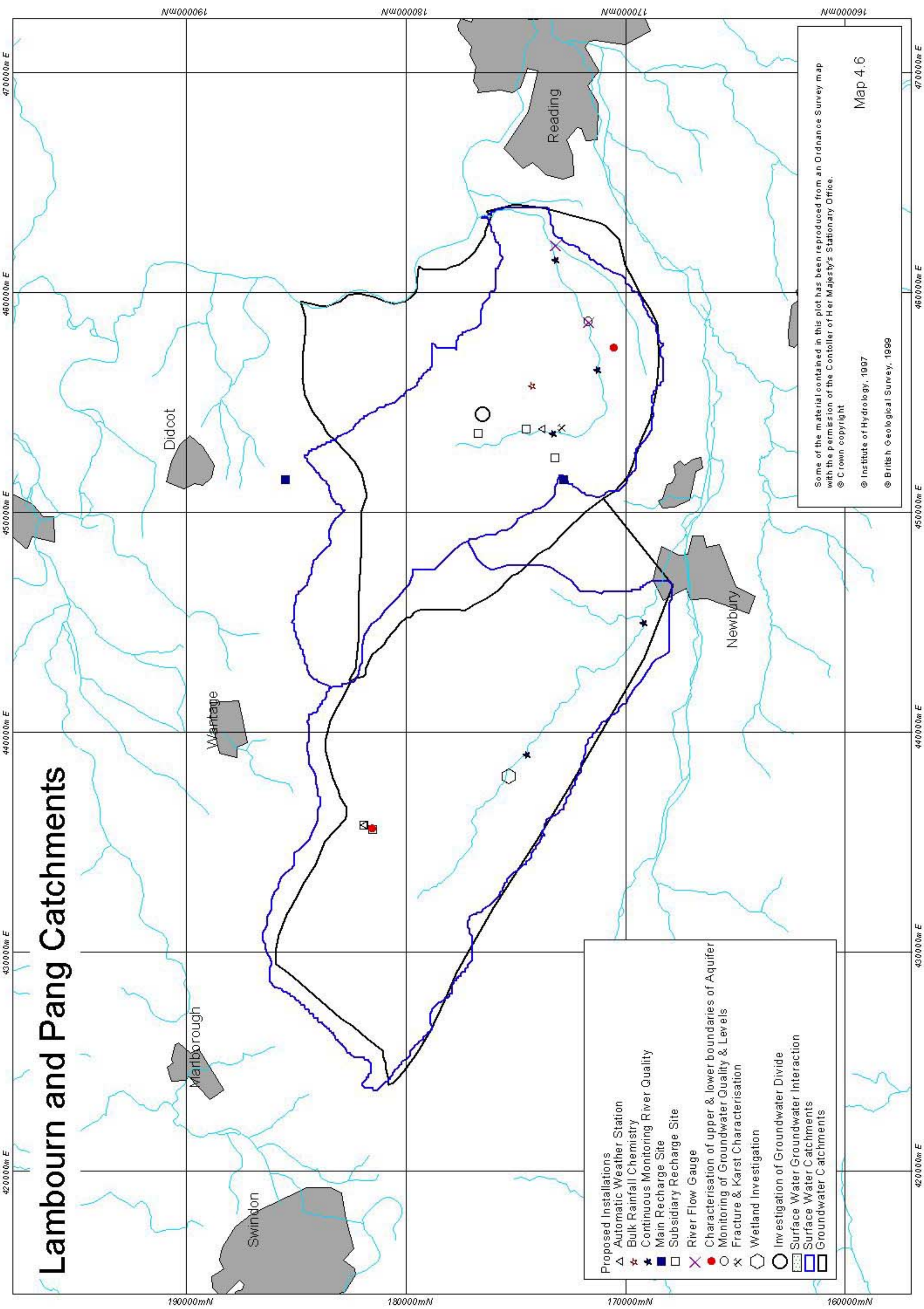
Map 4.5

Map 4.5



Lambourn and Pang Catchments
Map 4.6
Reading
Didcot
Wantage
Newbury
Marlborough
Swindon
Proposed Installations
Automatic Weather Station
Bulk Rainfall Chemistry
Continuous Monitoring River Quality
Main Recharge Site
Subsidiary Recharge Site
River Flow Gauge
Characterisation of upper & lower boundaries of Aquifer
Monitoring of Groundwater Quality & Levels
Fracture & Karst Characterisation
Wetland Investigation
Investigation of Groundwater Divide
Surface Water Groundwater Interaction
Surface Water Catchments
Groundwater Catchments
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190000mN
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420000m E
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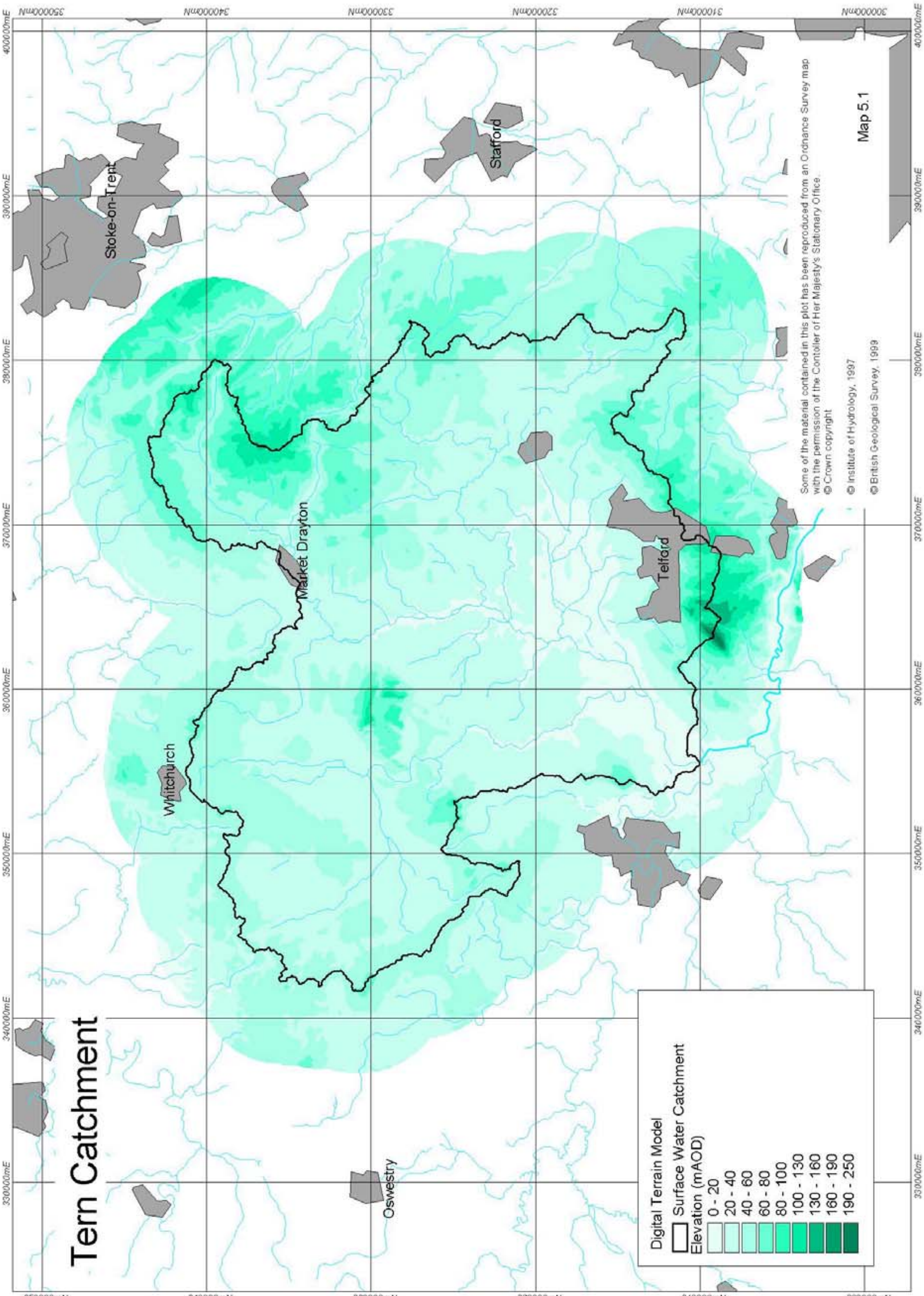
450000m E
460000m E
470000m E

Map 4.6


Tern Catchment
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
Map 5.1
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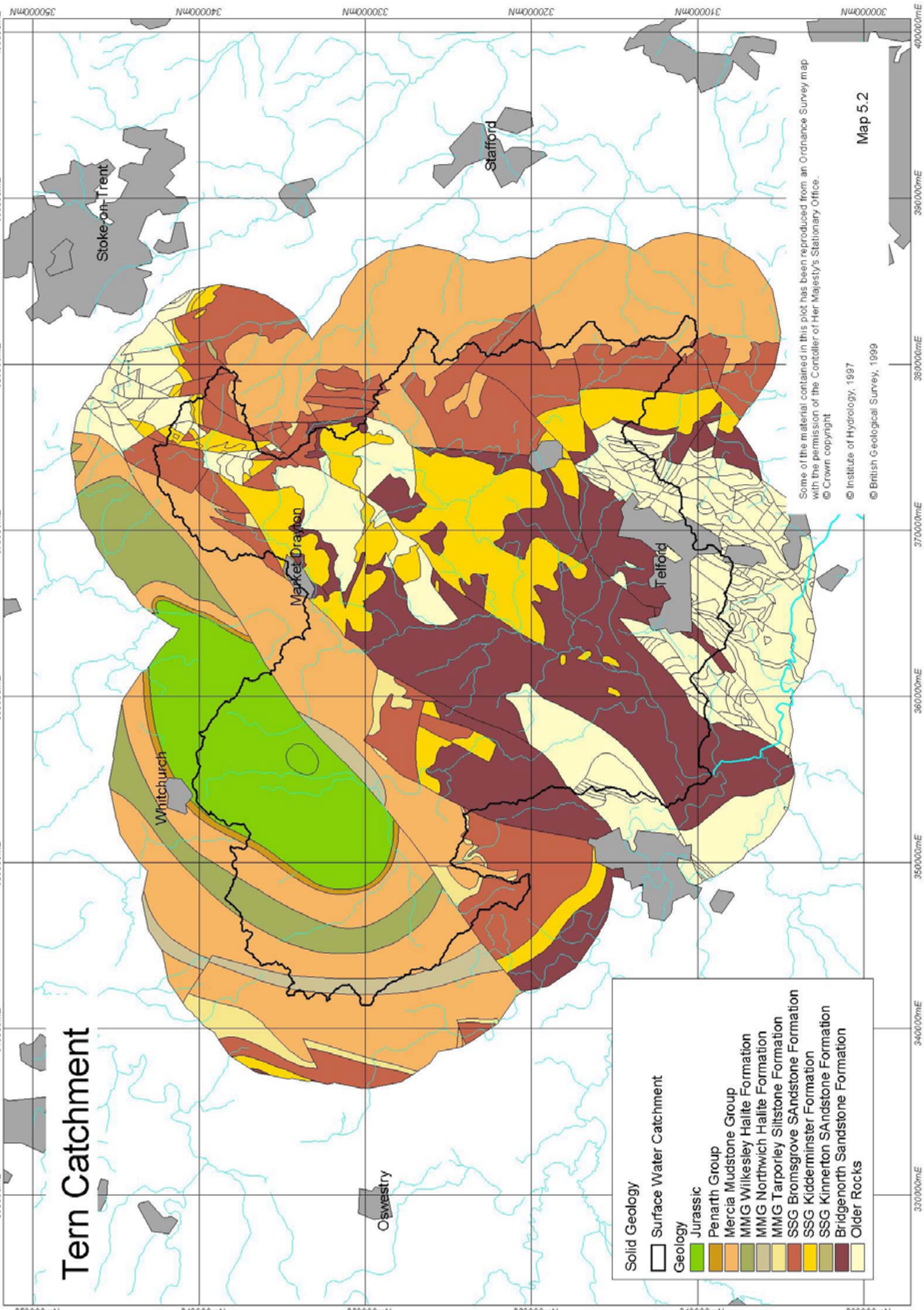
Digital Terrain Model
Surface Water Catchment
Elevation (mAOD)
0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 130
130 - 160
160 - 190
190 - 250

Map 5.1


Tern Catchment
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
Map 5.2
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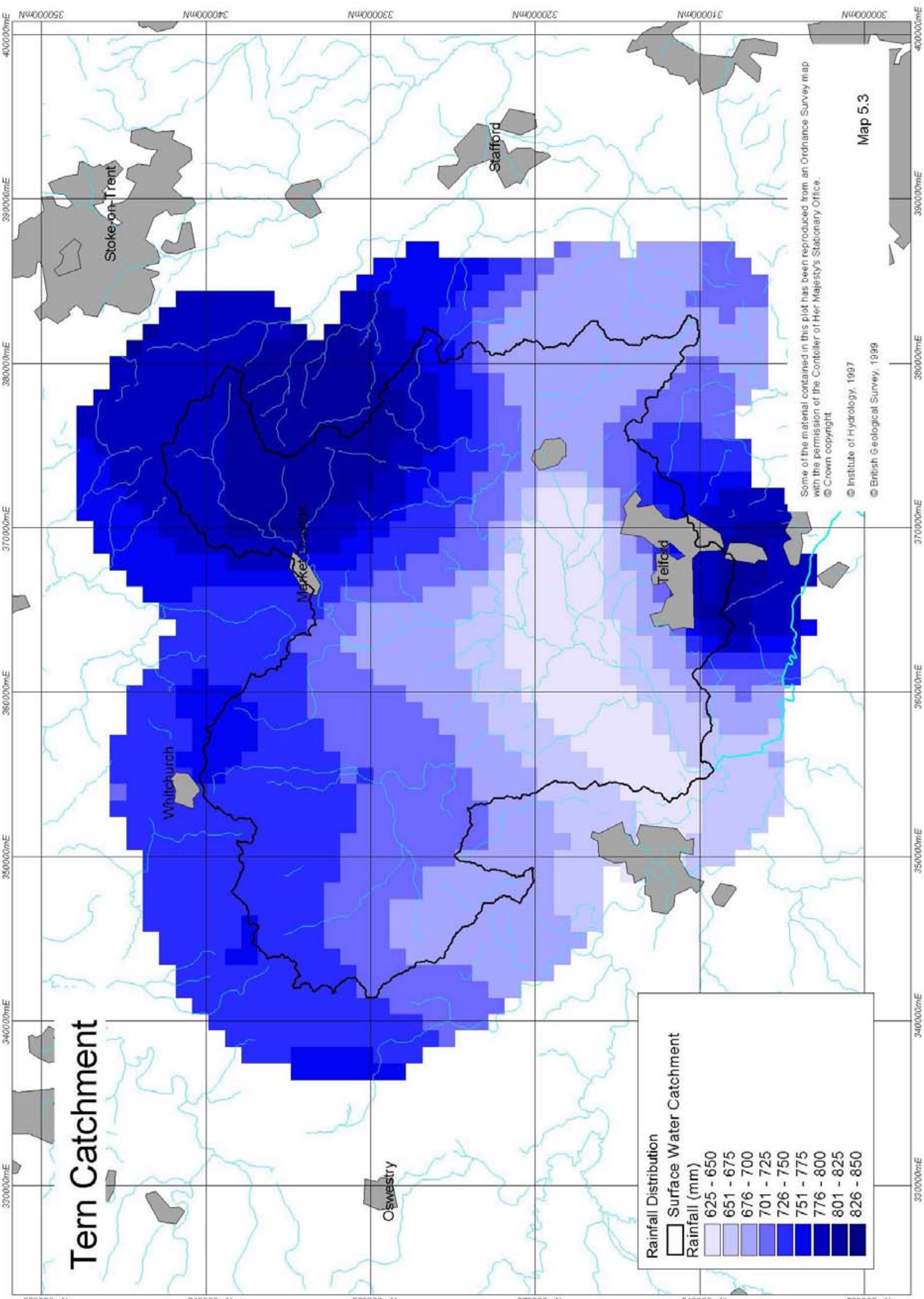
Solid Geology
Surface Water Catchment
Geology
Jurassic
Penarth Group
Mercia Mudstone Group
MMG Wilkesley Halite Formation
MMG Northwich Halite Formation
MMG Tarporley Siltstone Formation
SSG Bromsgrove SAndstone Formation
SSG Kidderminster Formation
SSG Kinnerton SAndstone Formation
Bridgenorth Sandstone Formation
Older Rocks

Map 5.2


Tern Catchment
Map 5.3
Rainfall Distribution
Surface Water Catchment
Rainfall (mm)
625 - 650
651 - 675
676 - 700
701 - 725
726 - 750
751 - 775
776 - 800
801 - 825
826 - 850
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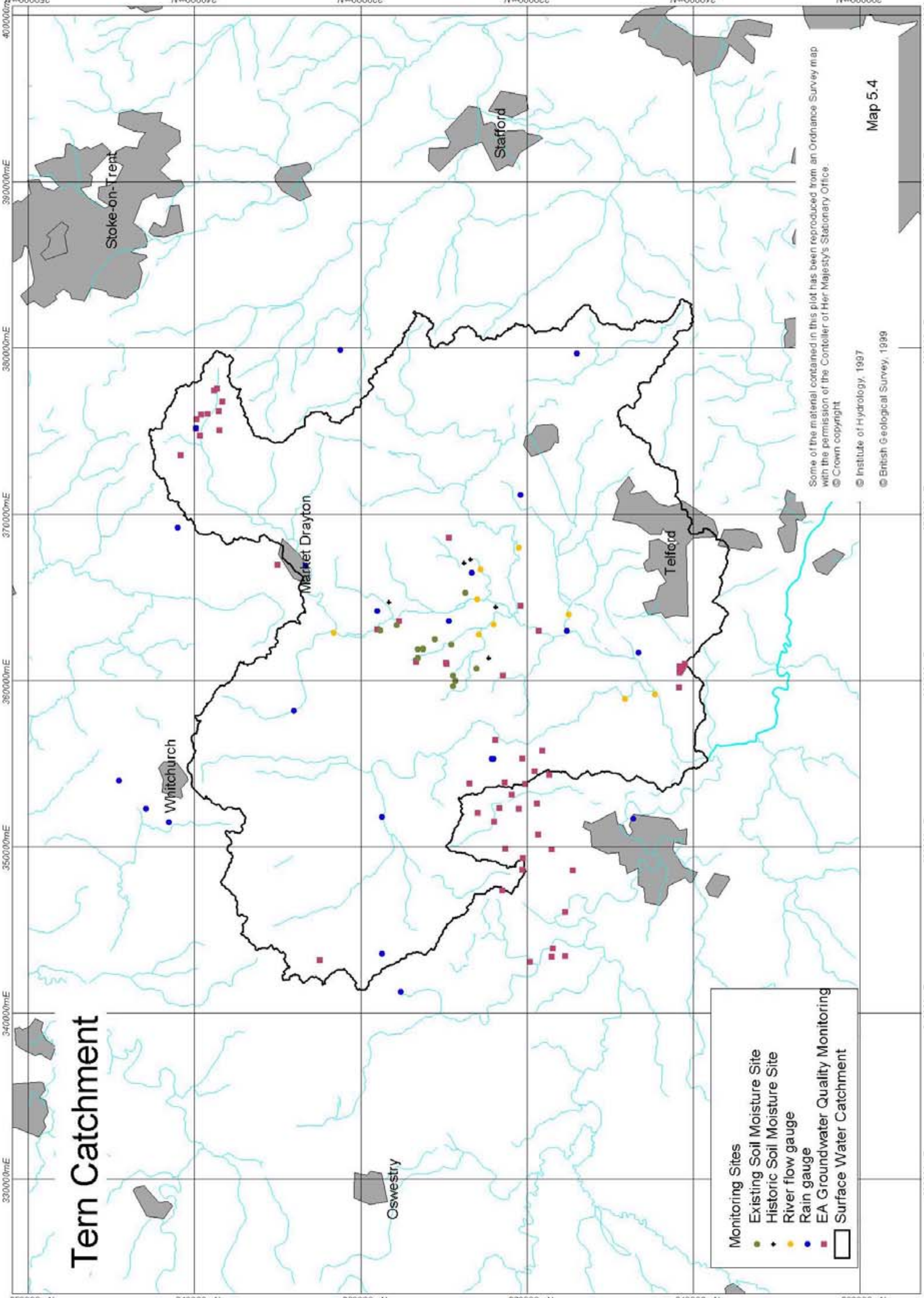
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
350000mN
340000mN
330000mN
320000mN
310000mN
300000mN
330000mE
340000mE
350000mE
360000mE
370000mE
380000mE
390000mE
400000mE

Map 5.3


Tern Catchment
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
Monitoring Sites
Existing Soil Moisture Site
Historic Soil Moisture Site
River flow gauge
Rain gauge
EA Groundwater Quality Monitoring
Surface Water Catchment
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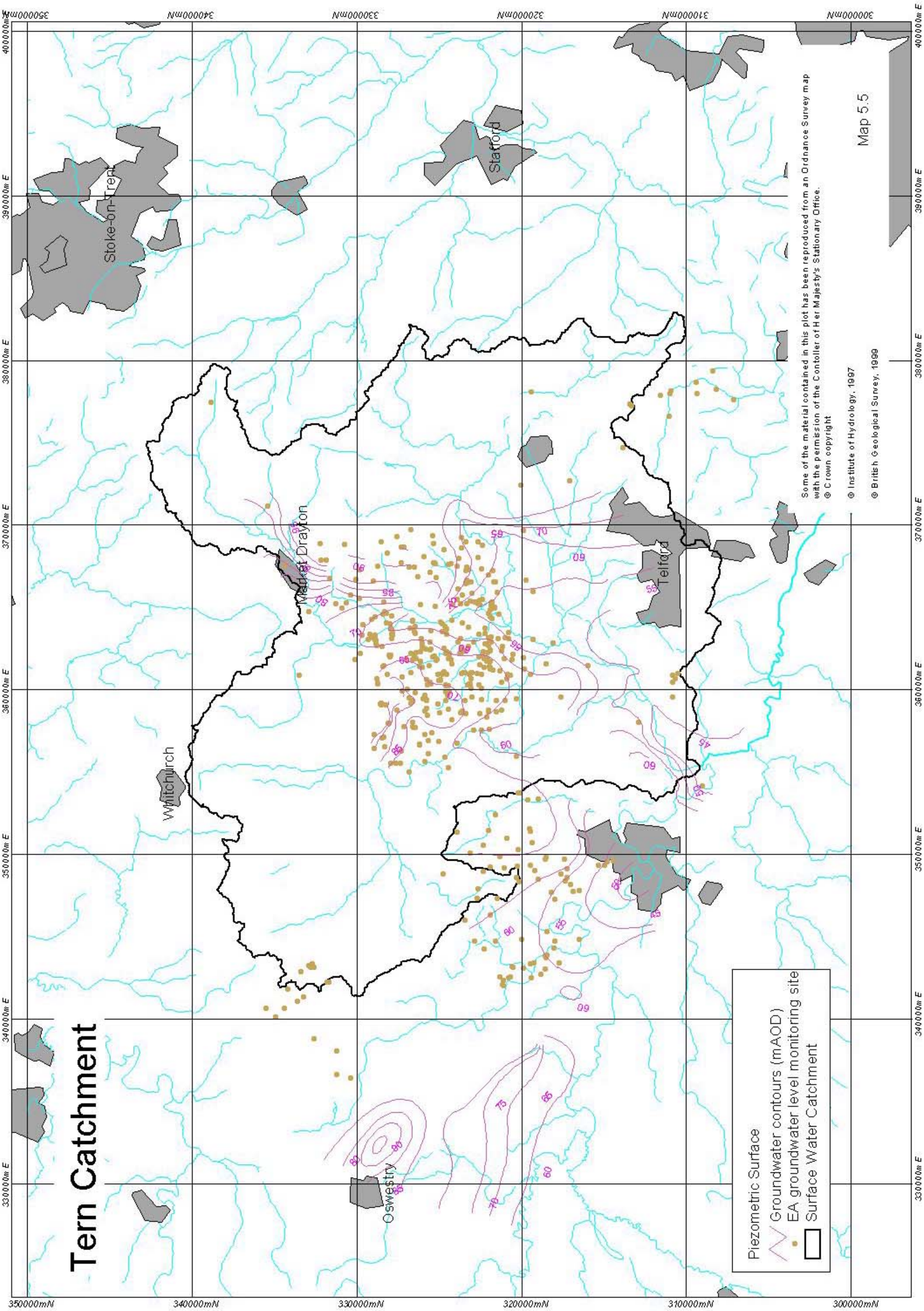
Map 5.4

Map 5.4


Tern Catchment
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
Piezometric Surface
Groundwater contours (mAOD)
EA groundwater level monitoring site
Surface Water Catchment
Map 5.5
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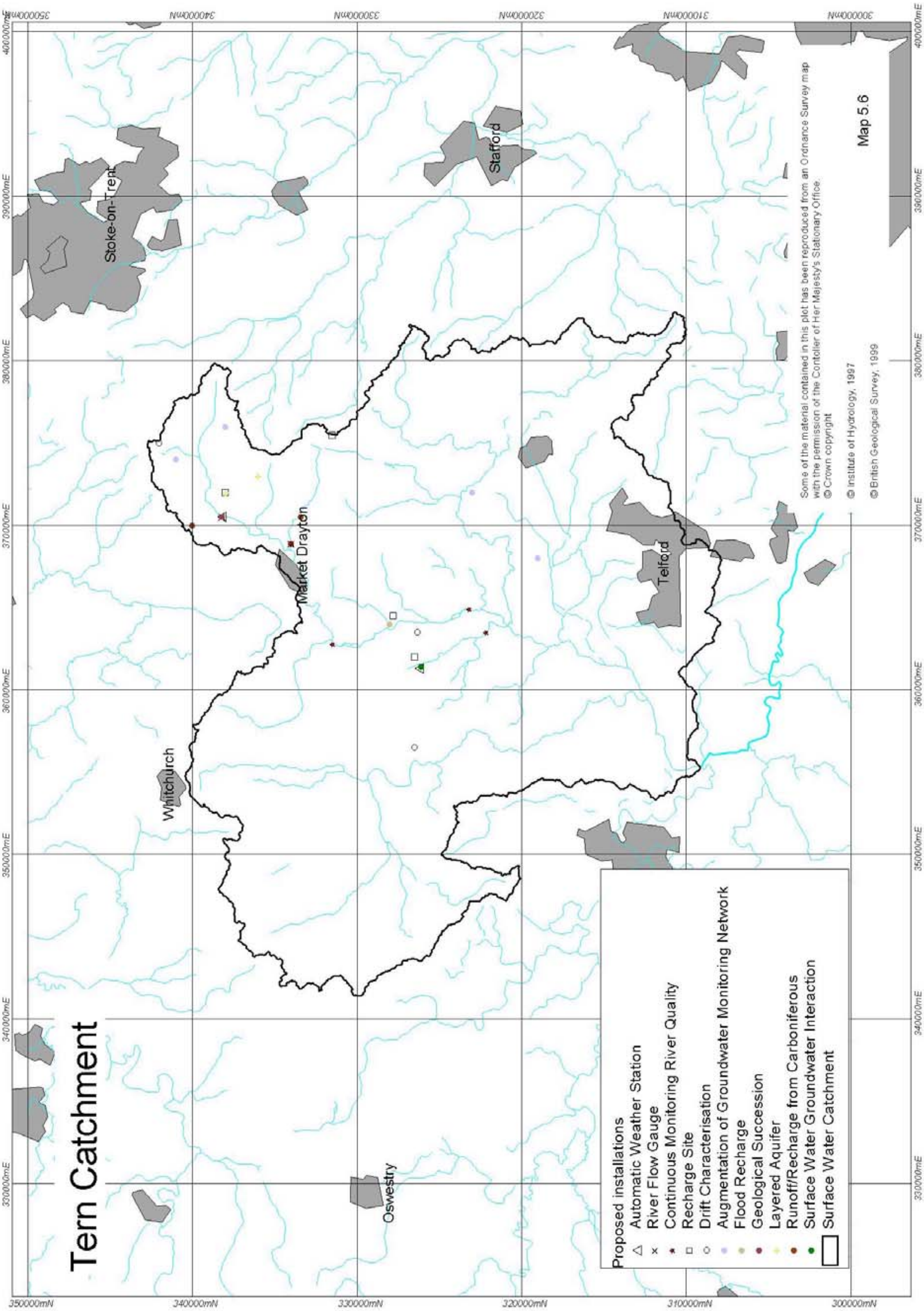
Map 5.5



Tern Catchment
Stoke-on-Trent
Stafford
Market Drayton
Telford
Whitchurch
Oswestry
Proposed installations
Automatic Weather Station
River Flow Gauge
Continuous Monitoring River Quality
Recharge Site
Drift Characterisation
Augmentation of Groundwater Monitoring Network
Flood Recharge
Geological Succession
Layered Aquifer
Runoff/Recharge from Carboniferous
Surface Water Groundwater Interaction
Surface Water Catchment
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Map 5.6

Map 5.6

Glossary

AAR	Average annual rainfall
ADAS	Agriculture Development Advisory Service
ALF	Alleviation of low flows
AOD	Above ordnance datum
AWS	Automatic weather station
BGS	British Geological Survey
CEH	Centre for the Environment and Hydrology
CHASM	Catchment Hydrology and Sustainable Management
DERC	Dorset Environmental Records Centre
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DWT	Dorset Wildlife Trust
EA	Environment Agency
EN	English Nature
GIS	Geographical information system
HYDRA	Integrated eddy-correlation system for direct evaporation measurement
IFE	Institute of Freshwater Ecology
IH/IOH	Institute of Hydrology
JIF	Joint Infrastructure Fund
LOCAR	Lowland catchment research
LOIS	Land-ocean interaction study
MO	Meteorological Office
MORECS	Meteorological Office rainfall and evaporation calculation system
NERC	Natural Environment Research Council
NICHE	National Infrastructure for Catchment Hydrology Experiments
NNR	National Nature Reserve
NRFA	National River Flow Archive
NVC	National Vegetation Classification
NWA	National Water Archive
PE	Potential evaporation
QADF	Average daily flow (m^3s^{-1})
Q1	Flow exceeded 1% of the time
Q10	Flow exceeded 10% of the time

Q95	Flow exceeded 95% of the time
RHS	River habitat surveys
RSPB	Royal Society for the Protection of Birds
SAAR	Standard annual average rainfall 1961-90
SGS	Shropshire Groundwater Scheme
SNCI	Sites of Nature Conservation Interest
SSSI	Site of Special Scientific Interest
STW	Sewage treatment works
SVAT	Soil-vegetation-atmosphere interactions
TOR	Terms of reference
WISER	IH Wallingford integrated system for environmental monitoring in rivers
WQ	Water quality
ZFP	Zero flux plane