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Institute of Hydrology

GREAT-ER

Four month progress Report: June 1996 - September 1996

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Contents

1. Progress Report

1.1 OBJECTIVES OF THE REPORTING PERIOD

As discussed in further detail within IH Working Note Number 4 the specific objectives of the period 1/6/1996 to 30/11 96, in which this reporting period lies, were to:

1. collate and quality control hydrological and artificial influence data within the Yorkshire region;

2. finalise the hydrological data requirements for Italy, in conjunction with the University of Milan;

3. to set up remote access to the UK EA's data held on the LOIS database and source/secure access to other available data types identified as being required by the ECETOC task and within the IH remit;

4. Undertake a provisional calibration of Micro LOW FLOWS V2.1 and review best available techniques for estimating flow velocities at ungauged sites.

1.2 PROGRESS DURING THE REPORTING PERIOD

The main activities of the Institute of Hydrology during the reporting period have been:

1. a literature review of methods for estimating river velocities and/or channel geometries from hydrological and catchment characteristic indices. These are discussed in Chapter 2;

2. initiation of the artificial influence data collation programme for the Yorkshire rivers in collaboration with the UK Environment Agency;

3. on site installation of the WIS and Micro LOW FLOWS software at the University of Osnabruck in July and the associated setting up of remote log in and SQL accounts on the Institute of Hydrology computing facilities for University of Osnabruck staff;

4. a field visit to the Lambro catchment (from the 23 to the 25th of September) with associated meetings regarding the acquisition of requisite hydrological data and identification of a suitable hydrological modelling approach for the Lambro basin. The latter item for discussion arose out of the meeting held on the 14th of June at the Institute of Hydrology between IH staff and the Universities of Milan and Osnabruck.

Minutes from the meeting with the EA about data acquisition and the meeting with the Universities of Osnabruck and Milan are presented in Chapter 3.

1.3 PROBLEMS ARISING DURING THE REPORTING PERIOD

Problems that have arisen during the reporting period have been associated with items (ii) and (iii). It was agreed with Environment Agency staff that the initial transfer of abstraction licence data and discharge consent data would be restricted to the River Went as a trial. Once data format problems had

2. Velocity estimation

2.1 INTRODUCTION

Information on velocity is essential to a wide range of processes, including entrainment, transport and deposition of sediment, the routing of flows through networks and the dispersion of pollutants (Knighton & Cryer, 1990). It is the latter which is of greatest significance within the GREAT-ER project, and is fundamental to the work to be undertaken by the University of Gent. A literature review has therefore been undertaken by the Institute of Hydrology in order to identify the best possible method for estimating flow velocities from the information readily available.

2.2 LITERATURE REVIEW

In its simplest term, channel flow (Q) at a point can be approximated as the product of the average velocity (V) and the cross-sectional area (A).

$$Q = AV$$

Leopold and Maddock (1953) have shown that the relationships between channel measures; width, depth, and velocity, and discharge at a channel cross section are described best by the power functions:

$$W = aQ^b \qquad D = cQ^f \qquad V = kQ^m$$

where:

W	= top width
D	= mean depth
V	= mean velocity
a, b, c, f, k, m	= numerical constants and exponents

A fourth power function describing area is sometimes also presented:

$$A = nQ^p$$

Leopold and Maddock (1953) showed that because these channel measures are all linked to discharge they can be related together, such that:

$$b + f + m = 1.0$$
$$ack = 1.0$$

The data used for determining the coefficients in these equations are obtained from stream gauging station discharge measurements. A common approach to determining these parameters is through the use of multivariate regression on log-transformed data.

These relationships along the stream have been shown to change with catchment area (Leopold and Maddock, 1953). Variations in the parameters in the equations along a stream and among catchments also result from differences in sediment load, channel roughness, channel slope, and bed size material (Gregory and Walling, 1974). Betson (1971) made the assumption that for a given physiographic region the effect of variations in sediment load and grain size along with roughness should tend to factor out. This leaves channel slope as a major factor causing variations in the channel morphology. Manning's equation (Chow, 1964) relates discharge to the channel slope, roughness and channel dimensions.

$$V = \frac{1.49\ R^{2/3}\ S^{1/2}}{n}$$

where:

V	= average cross-section velocity (ms^{-1})
R	= hydraulic radius (m)
n	= Manning's roughness coefficient
S	= channel slope

Flow resistance factors include section irregularities, channel slope, obstructions, vegetation, channel meandering, suspended material, bed load, and channel and flood plain conditions. The greater the resistance to flow the in higher the roughness coefficient (Jarrett, 1984). Streams flowing on higher gradients are generally shallower with larger bed materials, which affect the flow resistance more than the bed materials in flatter slope streams with larger flow depths (Jarrett, 1984).

Assuming that for a given physiographic region roughness can be factored out, thus after drainage area the principal cause of variation along sites is channel slope (Betson, 1979). Therefore, in a given physiographic province the two primary causes for variation in hydraulic geometry among sites are catchment area and channel slope, both of which are readily available from topographic maps (Betson, 1979). In most regions the channel slope at a channel cross section is highly correlated with the contributing catchment area (Betson, 1979). Based on the above observations Beston (1979) developed regression equations which were specific to the Cumberland Plateau Province:

channel width (m) $= a\ (Q/Ad)^b$
cross-section area (m^2) $= n\ (Q/Ad)^p$

where:

a, b, n, and *p*	= model parameters
Q	= stream discharge (m^3s^{-1})
Ad	= drainage area (km^2)

The parameters were predicted from the following equations:

$a = 6.08Ad^{0.45}$
$b = 0.245$
$n = 1.39Ad^{0.84}$
$p = 0.847S^{-0.104}$

and $S =$ channel slope ($m.km^{-1}$)

The long profile of a river represents its height along the distance of the stream. Long profiles tend to be concave and channels have progressively gentler gradients from the source to the mouth. Hack (1957) found that long profiles of similar sized streams were progressively steeper on limestone, shale, sandstone, and igneous rock.

Whilst a typical long profile is smoothly concave, the channel bed is usually undulating with pools separated by topographic highs, or riffles. At low discharges the contrast between the slow moving pools and fast flowing riffles is evident in many British rivers (Lewin, 1981). In the context of GREAT-ER it would not be practical to consider flow velocities at such a small scale.

Nixon (1959) analysed bank full dimensions and discharges of British rivers. Dimensions of 27 channels with a wide range of discharges were represented by fractional-power relationships of canal regime form:

$$W = 2.99Q^{1/2}$$
$$D = 0.55Q^{1/3}$$
$$V = 0.61Q^{1/6}$$

where:

W = banktop width
D = mean depth
V = mean velocity

The velocity relationship shows a slightly greater increase with discharge than was found for US rivers by Leopold and Maddock (1953).

Charlton *et al.* (1978) derived the following relationships for gravel-bed rivers:

$$W = 3.74Q^{0.45}$$
$$D = 0.31Q^{0.40}$$
$$V = 0.86Q^{0.15}$$

Riddell (pers. comm. to Lewin, 1981) measured channel geometry at 17 lowland and 17 upland sites in Scotland at bank full discharges. The width relationships are very similar, but depth and velocity relationships show some divergence with $D \propto Q^{0.32}$, $V \propto Q^{0.16}$ for upland streams, but $D \propto Q^{0.40}$, $V \propto Q^{0.07}$ for the lowland streams.

Lewin (1981) found that a comparison of the trends found in these investigations showed the width-discharge relationships to be very similar in different samples and environments, whereas mean depth for a given discharge appears to be lower, and mean velocity higher, in upland rivers.

For single catchments, Gregory and Walling (1974), bankfull channel dimensions may be plotted against catchment area or a drainage network measure such as total channel length. Use of a surrogate for discharge avoids the problematic estimation of bankfull discharge. Park (1976) determined the following relationships between drainage area and bankfull width, depth and cross section area along the River Dart in Devon.

$W \propto A^{0.32}$
$D \propto A^{0.16}$
$CSA \propto A^{0.48}$.

Channel dimensions can be predicted for any point on the network by estimating the area draining to that point. The 46 measured sections receive runoff from areas rising from 0.1 to 40 km^2.

Warn (1995) highlights that in theory the equations of River Chemistry need to know the time taken for a body of water to travel between different points within the catchment and that velocity is a function of river flow. However he goes on to suggest the pragmatist's view that water quality models, such as SIMCAT, do not have to know the time of travel as a function of river flow because the effect is small compared with other errors in the data. SIMCAT uses an empirical model to estimate velocity from flow. This model has the form:

$$V = \alpha \left(\frac{Q_d}{Q} \right)^{\beta}$$

where:

Q	= average flow
α	= average time of travel at Q bar
Q_d	= river flow on day (d)
β	= constant which typically has a value of 0.5 in UK rivers.

2.3 DEVELOPMENT OF A METHOD FOR GREAT-ER

It must be considered that GREAT-ER will ultimately be applied on a Pan-European scale. The power functions described above were developed for specific physiographic regions or catchments. The estimates of the constants and parameters are specific to those physiographic regions or catchments and are not applicable elsewhere due to contrasts in fluvial and climatological environments. The applicability of these power functions is not practical at a regional scale due to the necessity for a considerable amount of data.

Clearly, there is no a specific method which can be applied directly for the estimation of velocity for GREAT-ER, therefore the data available in the pilot study Ouse and Lambro catchments should be considered and a method developed initially for this pilot studies which can also be applied elsewhere in Europe.

In the UK Ouse basin the data available for determining velocity for a stretch of river include catchment area, channel slope, standard average annual rainfall (SAAR) (1941-1970), Hydrology of Soil Types (HOST), potential evapotranspiration (PE), stream order, flow estimates and a flow duration curve. Similar data will be available for the Lambro catchment.

Two models for estimating velocity will be tested on the Aire, Don and applied in the Lambro. One will be the SIMCAT empirical model the other will be based on those models which incorporate estimates of channel geometry and (possibly) roughness. The trials will undertaken in both the upland and lowland parts of the catchments with the objective of identifying whether the model parameters differ between and channel roughness according to HOST classes. The models will be calibrated on local data undertaken as part of a very limited field experiment to be executed on the UK rivers by the Institute of Hydrology. The relationships could be calibrated for a river in the Ouse catchment, such as the Aire, by measuring river channel dimensions at certain points and comparing these to the results of the estimates of channel dimensions and velocity.

In the Lambro the testing of the method would be dependent on the University of Milan being in a position to undertake some velocity measurements during the monitoring programme and being able to tie these measurements in with the stage board readings (and associated flows) at nearby gauging station. IH would like to stress that this requirement has not been discussed with the University of Milan and is not thought to be within the remit of their current work package.

3. Minutes of Meetings Called by the Institute of Hydrology

3.1 MINUTES OF MEETING OF IH, UNIV. MILAN AND UNIV. OSNABRUECK. HELD 14TH JUNE 1996 AT IH, WALLINGFORD

Present

Andy Young	Institute of Hydrology
Clare Round	Institute of Hydrology
Claudio Gandolfi	University of Milan
Michael Matthies	University of Osnabruck
Gwyn Rees (in part)	Institute of Hydrology
Alan Gustard (in part)	institute of Hydrology

Record of Discussions and actions

The meeting opened at 9.30 am with Andy Young providing an overview of the hydrological model and data requirements. Andy Young described the method used for estimation of the flow duration curve and the Q95 at the ungauged site in the UK.

ACTION - IH: Provide a copy of Report 108 and R & D Note 274, describing low flow estimation techniques in natural and artificially influenced catchments, to UM and UO. Also provide with a list of other IH reports.

An overview of the rainfall, potential evapotranspiration and Hydrology of Soil Types (HOST) databases, which underpin these estimation methods, was given.

Emphasis was placed on the necessity to improve the representativeness of catchments, to use standard data sets and to incorporate seasonality of climate in the Italian hydrological model as a result of the greater influence of climate over flow regimes.

Claudio Gandolfi then described the Po basin, with use of maps, with particular emphasis on the Lambro catchment. The Lambro runs from approximately 1400 m at its source to 200 m at the confluence with the Po. The upper end of the catchment is underlain by limestone and dolomitic rocks with a moraine cover. The plain consists of a thick alluvial layer of coarse sand/gravel. There is a good knowledge of the hydrogeology. Due to the elongated nature of the catchment there are short pathways to the river resulting in flash floods. This may be of greater importance than soil type in the estimation of flows. There are natural lakes in the catchment which mitigate variations in flow, but this is considered to be less important at low flows.

The discussion then focused upon the artificial influences within the Lambro catchment. There are volumetric limits on abstractions from the river. There are no major abstractions to the north of Milan and approximately 90% of water supply to Milan is from groundwater. A considerable proportion of discharges do not receive treatment. Whilst these may only be a small quantity, in terms of quality they are very important due to their untreated nature. Identification and quantification of the artificial influences is considered to be a problem due to the lack of detailed information.

ACTION - UM: Characterise recent artificial influences (most recent couple of years), including quantification and identification of interactions between them.

The National Hydrographic Service hold all hydrological data for every year since 1937. Meteorological (temperature, rainfall) and hydrometric (flow) data are available from this source. Most of the river flow data requested is available in published reports. The most recent publication is 1985. Verification of the 1937 to 1985 data is currently being undertaken by UM. Both daily and monthly data are available. Following discussion it was decided that for the purpose of the hydrological model only monthly data will be required for looking at long term averages.

The hydrometric data availability and its quality were discussed for the Lambro settentrionale, which is the study catchment. The hydrometric data quality is variable. Some data is not officially published (as a result of its quality) but is available. Stage-discharge relationships are not always established. Some available stage-discharge relationships may not be very good and/or stage measurements may be uncertain due to limited maintenance. No stage-discharge relationships have been calibrated. Stage measurements are available for every 5 to 6 minutes, but only in its raw form with no quality control. The UM has undertaken to source flow data for all gauging stations within the Lambro catchment.

Claudio Gandolfi indicated that the distribution of the hydrometric stations within the Lambro was not very good, thus the reliability of the calibrated hydrological model would be uncertain. UM requested time to check what other data collection is currently being undertaken. In the late 1980's river authorities were established, who are now collecting and centralizing information.

ACTION - UM: UM will meet with various agencies in July in order to obtain all available data. By September, IH is to be provided with information regarding what information is available, the time periods covered and the levels of detail. UM will begin to enter daily hydrometric data onto computer.

Water quality issues were discussed. In the late 1980's to the early 1990's water quality sampling was undertaken, but did not include LAS and Boron. There are 6 stations along the Lambro, and it is proposed to use the same ones for the monitoring. There is a dense network of canals in the Po basin, which is of greatest importance to the south of Milan. The importance of these canals, in terms of water quality, is uncertain. Hydrologically these canals cannot be modelled.

The digitized data requirements were decided upon. As most European countries have contour maps at 1:50, 000 scale, from which the catchment boundaries can be defined, this scale was selected as the standard scale for the case study catchments. These maps will also provide essential information for the calculation of slope which will be incorporated into the procedure for estimating velocity. Spatial data will be digitized at a level of maximum detail, with a view to simplification of river networks.

ACTION - IH: Send criteria to UM and UO for digitized spatial data. For the Lambro these include the river network, land use (for diffuse runoff model), lithology and contours (vector).

ACTION - UM: Digitize contour maps, landuse maps, lithology maps and river networks as vector Arc Info coverages.

Claudio Gandolfi informed the group that in Italy population data is available (1981) at the municipality level for 3 categories: civilian, industrial and technical. More information and classifications of industry were included in 1989 but is not yet available. The group would like to reiterate that the industry partners should be responsible for the sourcing of market data and population data.

ACTION - Industry partners: Source and make available population and market data.

Following lunch a discussion regarding the Italian hydrological model ensued. For IH to develop a hydrological model for the entire Po basin, as is believed to be the requirement from ECETOC and defined in the IH work programme, the provision of the relevant time series and spatial data beyond the Lambro catchment will be necessary. Great concern was expressed by UM and IH regarding the funding of such data sourcing and provision. This requirement is not specified in the contracts between ECETOC and UM or IH. The identification and sourcing of this data is prerequisite for IH to be in the position to construct the hydrological model.

ACTION - ECETOC: ECETOC must consider the funding of data sourcing for the Po basin.

Data transfer between UM, IH and UO was discussed in the context of the UO diagram, as presented at the Bagdon Hall meeting. Data will be transferred as ASCII files with spatial data in Arc Info format. Hydrological, meteorological and volumetric data will be sent directly to IH. Other data will be sent to UO.

ACTION - UM: Milan will send hydrological data, when available, straight to IH for quality control who in turn will transfer data to UO. Quality and demographic data will be sent from UM to UO.

ACTION - UG: Geert Boeije to clarify data transfer between UO and UG, and agree on waste water system between UM and UG.

Gwyn Rees (IH) demonstrated the FRIEND project and the European Water Archive to Claudio Gandolfi and Michael Matthies.

Dates were set for subsequent meetings:

1st July IH to UO for the installation of WIS and provision of remote access.
23rd to 24th September IH to UM for data collation progress meeting and catchment visit.

3.2 MINUTES OF MEETING OF IH AND ENVIRONMENT AGENCY, HELD ON 3RD JULY 1996 AT LEEDS EA

Present

Andy Young	Institute of Hydrology
Clare Round	Institute of Hydrology
Richard Bradney	Environment Agency
Richard Maxted	Environment Agency

Record of Discussions and actions

The meeting opened at 9.30 with Andy giving an overview of the GREAT-ER project, the hydrological modelling work that will be undertaken within Yorkshire and the benefits to the Environment Agency.

Andy put forward the proposed approach to calibrating Micro LOW FLOWS, which includes the validation of the natural estimates and then population of the artificial influence databases with correctly identified and quantified artificial influences, and calibration using the best available information. Richard Maxted indicated that naturalised flow records are available in parts of Yorkshire, with particular reference to the Went catchment. Richard Maxted suggested that elements of the naturalisation program developed for the SWAP and trialed in the Went, which naturalises flows in small to medium catchments using decomposition, would be applicable to GREAT-ER.

Richard Maxted informed IH that some of the rating curves at gauging stations will be changing, which will affect, in particular, low and high flow records. It was proposed that IH should identify which gauging stations will be used in the naturalisation procedure, and the EA will prioritise the revision of the rating curves and flow records at these gauging stations.

Richard Maxted indicated that the procedure for the estimation of area within Micro LOW FLOWS is not always accurate enough, with particular reference to the River Went, which is affected by a gorge, and catchments with very steep headwater valleys in the Pennines. The actual catchment boundaries will be incorporated into Micro LOW FLOWS before naturalisation of flow records.

ACTION EA: The EA will send maps to IH in order for the catchment boundaries to be digitized.

Andy Young went on to discuss the data requirements for Micro LOW FLOWS. A document was presented to the EA regarding the input data requirements for the bulk loading of artificial influence data. It was decided that the EA should provide the data in the format which would be quickest for them and IH will alter these to the necessary format. The data requirements were discussed in detail, with the EA indicating that they could provide most of the data, although the extent of some of it is unsure. The use of data that is already held by IH was dismissed as its format will have been changed considerably and may be unreliable.

ACTION EA: The EA will provide IH with the most up to data validated data sets.

It was decided that, because naturalisation has been undertaken for the Went, this should be set up as a pilot catchment to see if thee are any problems with the data provided by the EA and its interpretation. Data will then be sourced for the rest of the Yorkshire region.

ACTION EA: The EA will send the naturalised flows for the Went to IH on a floppy disk.

Clare Round informed the EA of the IH review of existing data available for Yorkshire reservoirs, and of the tiered system for data requirements based upon the capacity of the reservoir. Richard Maxted provided IH with files of the Aire, Calder and Don reservoirs.

It was decided that with the large amount of data transfer and communication between the EA and IH, it would be ideal if Richard Maxted and Richard Bradney could have access to the internet.

ACTION EA: Richard Maxted will discuss the possibility of gaining internet access.

Some data will be sent to IH on magtapes.
ACTION IH: Provide the EA with a box of magtapes.

It was decided that time scales for data provision are required..

ACTION IH: IH will provide the EA with a GANTT chart.

4. References

Betson, R. 1979. A geomorphic model for use in streamflow routing. *Water Resources Research,* 15 (1), 95 - 101.

Charlton, F., Brown, P., Benson, R. 1978. *The hydraulic geometry of some gravel rivers in Britain.* Report INT-180, Wallingford: Hydraulics Reserch Station.

Chow, V. (Ed.) 1964. *Handbook of applied hydrology.* McGraw-Hill, New York.

Gregory, K., Walling, D. 1974. *Drainage basin form and processes: a geomorphological approach.* John Wiley, New York.

Hach, J. 1957. Studies in longitudinal stream profiles in Virginia and Maryland. *U.S. Geological Survey Professional Paper 294,* Washington, D.C.

Jarrett, R. 1984. Hydraulics of high gradient streams. *Journal of Hydraulic Engineering,* 110 (11), 1519 - 1539.

Knighton, A., Cryer, R. 1990. Velocity-discharge relationships in three lowland rivers. *Earth Surface Processes and Landforms,* 15, 501 - 512.

Leopold, L., Maddock, T. 1953. The hydraulic geometry of stream channels and some physiographic implications. *U.S. Geological Survey Professional Paper 252,* Washington, D.C.

Lewin, J. (Ed.) 1981. *British rivers.* George Allen and Unwin Ltd. 90 - 125.

Nixon, M. 1959. A study of the bankful discharges of rivers in England and Wales. *Proceedings of the Institution of Civil Engineers*, 12, 157 - 175.

Park, C. 1976. The relationship of slope and stream channel form in the River Dart, Devon. *Journal of Hydrology*, 29, 139 - 147.

Riddell, J. Pers. comm to Lewin, J. 1981.

Warn A.E. 1995. SIMCAT V4.13 - A Guide for Users. National Rivers Authority