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The Utility of GIS Delivered Environment Models in the Characterisation of Surface Water Bodies under the Water Framework Directive Low Flows 2000 – a Case Study.

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Abstract: The implementation of the Water Framework Directive (WFD), requires Water Resource Managers to characterise and assess the status of surface water bodies and apply management practices in order to achieve Good Ecological Status (GES), at a national scale. GES is assessed by considering the biological, hydromorphological and physico-chemical characteristics of a water body. There is a need for a suite of tools which will aid in carrying out this assessment quickly and reliably at a large number of sites. Low Flows 2000 (LF2000), combines aquatic environmental and hydrological models within a user-friendly GIS interface. The software can be used to estimate both the natural statistical properties of river flow and the influenced statistical properties, through the integration of water use pressures relating to abstractions, discharges and flow regulation, at any point within a river system without recourse to calibration. By combining this functionality with a measure of the aquatic ecological sensitivity to water use pressures LF2000 is being used operationally by the statutory UK Environmental regulators to support the initial characterisation of water use pressures on surface water bodies under the WFD.This paper will discuss how LF2000 is being used in this context and concludes with a look to the future. A summary of a prototype water quality modelling extension to LF2000 that has been developed will be presented alongside the planned implementation of generalised rainfall runoff models. This will illustrate how LF2000 will provide a suite of tools which can contribute to both initial and further characterisation under the WFD and prioritisation of a programme of measures.

Keywords: Water Framework Directive, Water Resource Management, Pressures, Hydrological Models.

1 INTRODUCTION

The Water Framework Directive (WFD) [2000/60/EC] requires that all water bodies within member states must achieve or maintain 'Good Ecological Status' (GES) by 2015. GES is assessed by considering the biological, physico-chemical, hydromorphological and characteristics of a water body.

The first stage in this process is the identification of water bodies which are at risk of not achieving, or maintaining GES, hereafter referred to as 'at risk'. The initial characterisation and identification of these water bodies is required to be completed by the end of 2004. Monitoring programmes will then be established for the water bodies considered to be 'at risk'. Following this, programmes of measures will be implemented.

This paper will focus on the use of Low Flows 2000 (LF2000) to characterise the surface water pressures which will, combined with other information, be fed into a risk assessment methodology in order to identify surface water bodies which are 'at risk', related to hydromorphological factors.

Within the UK the regulatory body for England and Wales, the Environment Agency, has a wide remit which includes the management of water resources through integrated management. Legislation, relating to the authorisation of abstraction and discharge pressures has existed since the Water Resources Act of 1963 and the Control of

Pollution Act 1974. The Water Act of 2003 updated the aforementioned Acts, and the subsequent Acts relating to them, to be inline with EU legislation and reflect changes in water resource issues. This legislation allows the Environment Agency to issue abstraction licenses and consents to discharge and facilitates the management and control of pressures within catchments.

In line with the requirements of the WFD the Environment Agency is moving towards integrated catchment management. This has led to the development of Catchment Abstraction Management Strategies (CAMS) [Environment Agency, 2002a]. Initiated in April 2001, the development of CAMS for all strategic water management units, 129 catchments, within England and Wales will be completed by 2008. Within CAMS information on the pressures within the catchment is used to establish the resource status of the catchment. An assessment of the ecological requirements of the water body is then used to determine the status of the catchment with respect to the water resource requirements. Consultation with local stakeholders leads to the development of a catchment scale abstraction licensing strategy.

The CAMS strategy encompasses many of the overarching hydromorphological concepts of the WFD. However, the requirement of the WFD to identify all water bodies 'at risk' by the end of 2004 has provided an additional challenge to the Environment Agency that the implementation of current management strategies is not able to address.

The initial characterisation and identification of 'at risk' water bodies requires a large number of assessments to be made in a rapid and consistent manner. The primary tool used within the process of identifying surface waters under pressure resulting from abstractions, discharges and flow regulation has been LF2000.

2 LF2000 - BACKGROUND

LF2000 [Young et al. 2003] consists of environmental hydrological models within a GIS based framework. The PC based software has the ability to estimate natural and influenced flow statistics on any river on the 1:50000 network, within England and Wales.

Catchments are defined using a digital terrain model or an analogue approach, whereby grid cells are assigned to river reaches on a nearest neighbour basis. The catchment is used to derive catchment characteristics such as the runoff and hydrogeological characteristics. These are used to estimate the flow variability, represented by the relevant flow duration curve (FDC), at an annual and monthly resolution.

2.1 Regionalised Hydrological Models

The hydrological models which underpin LF2000 consist of a regionalised model to estimate the natural temporal variability of flows and a regionalised rainfall-runoff model.

At the catchment scale, hydrogeology is the dominant factor in determining the temporal variability of natural flows as represented by FDC, once normalised for size and climatology. For example, flows are less variable in base-flow dominated chalk catchments than within impermeable clay catchments. The regionalised model to estimate the normalised flow variability uses a Region Of Influence (ROI) approach, whereby a standardised annual or monthly FDC is based on observed data from a selected data pool [Holmes et al., 2002b]. The datapool is derived using similarity measures related to the distribution of HOST classes, a hydrologically based soil classification system, to derive catchment similarity [Boorman et al., 1995]. The standardised FDC is then rescaled using a value of runoff, estimated using historical rainfall and PE data together with a soil moisture model, to predict the FDC in units of cubic metres per second. [Holmes et al., 2002a].

2.2 LF2000 – Pressure Information

In addition to the hydrological models used to assess natural flow conditions, the LF2000 database, based on the CEH Water Information System (WIS), [Moore, 1997] allows pressure information to be incorporated into the system. The pressure information corresponding to abstractions, discharges and impoundments is stored within the database as 12 monthly volumes.

The 12 monthly volumes for an abstraction represent the average monthly volumes of water abstracted from the surface water body or groundwater unit. User-defined Transmissivity and Storativity values are used within an analytical solution to the Theis equation to determine the impact at the surface

water body of groundwater abstractions [Bullock et al., 1994].

The monthly volumes for discharges represent average monthly volumes of water discharged directly to the surface water body, excluding stormwater runoff that may be intercepted by sewer systems.

For impoundments the 12 monthly volumes represent the average monthly compensation and/or regulated release volumes. LF2000 incorporates the impact of impoundments by omitting the catchment area above the impoundment from the natural flow estimation procedure and adding the compensation or regulated volumes to the resultant natural flow regime [Bullock et al., 1994].

In application, the pressures within the target catchment area are first identified. The relevant pressure information is then used in conjunction with the natural monthly FDC to produce estimates of the influenced monthly FDC. These are aggregated to produce an influenced annual FDC.

3 LF2000 – THE WFD

The Environment Agency has used LF2000 as part of the CAMS process [Young et al., 2003] and as part of the standard licensing procedure. A modified version of LF2000 has been an integral part of the methodology developed to implement the first stage of the WFD; the characterisation and identification of surface water bodies which are at risk due to surface water pressures.

3.1 Characterising pressures on Surface Water Bodies within England and Wales.

The main objective was to characterise the natural and modified flow regimes of over 6000 surface water Assessment Points (AP) within England and Wales. The data from this assessment is used subsequently, with a measure of ecological sensitivity, as input to the risk assessment process to assess whether the water body is 'at risk'. An assessment of this risk is also estimated using the pressure scenarios predicted for 2015.

3.2 Method

Pressure Assessment
Over 6000 locations within the UK were designated as APs at which the risk of not achieving GES should be determined. These were defined, using the guidance output from the working group of the common implementation strategy, on the basis of typology, geographic features and ecological and chemical conditions.

An estimate of the natural flow regime was made, using LF2000, at each AP. Pressure information, which included abstractions, discharges and impoundments, was then incorporated within the LF2000 database and the impact of this on the natural flow regime assessed. A number of flow statistics were used for this assessment, for example, the difference in the flow regime at exceedence percentiles of Q95, Q70 and Q50.

Ecological Sensitivity and Risk Assessment.
The output data from LF2000 was subsequently used by the Environment Agency, together with the ecological sensitivity, as part of the risk assessment procedure. A brief description of the way in which the ecological assessment was made, and how this was used with the results from LF2000 follows.

The ecological model used to define the ecological sensitivity of each surface water body to flow derogation resulting from pressures, which is not the subject of this paper, was based on the Lotic Invertebrate Index for Flow Evaluation (LIFE) score [Extence et al., 1999]. The LIFE score gives an indication of the types of ecological community present within a river reach. The relationship between LIFE score and flows means that it can give an indication of the ecological sensitivity to changes in the flow regime. The LIFE score can be estimated at any site based on empirical relationships with the physical and chemical characteristics within natural catchments. Each AP was assigned the LIFE score estimated at the nearest General Quality Assessment site, at which the Environment Agency regularly assess the quality of the water body. The ecological sensitivity was then derived from the estimated LIFE score using the criteria outlined within the technical framework used for the implementation of CAMS [Environment Agency 2002b].

Within the risk assessment procedure the information on the impact of pressures on the natural flow regime, together with the

ecological sensitivity at each AP is combined to provide an indication of whether a surface water body is 'at risk'. It is probable that within an ecologically very sensitive river this risk will be high whatever the impact of pressures. Similarly an AP with a high impact of pressures is likely to be 'at risk' whatever the ecological sensitivity of the reach.

This screening methodology identifies water bodies which are 'at risk' and allows subsequent monitoring to be carried out strategically and efficiently.

3.3 Pressure Assessment - The role of LF2000 in the risk assessment process

LF2000 is an integral part of this screening assessment as it has been used to provide estimates of the natural and influenced FDC at a large number of points within England and Wales.

Within England and Wales the Environment Agency has authorised over 40,000 abstraction licenses and over 86,000 discharge consents. There are also approximately 2250 impoundments. It is therefore no small task to characterise and model the surface water pressures within England and Wales.

Intelligent filtering of abstraction licenses, whereby only those for which the abstraction volumes are greater than 5% of the natural Q95 at the AP are assumed to be significant, reduced the number of abstractions to be characterised to 9000. Annual abstraction volumes for 2001 were available nationally. These were distributed throughout the year based on the seasonal patterns within higher resolution data from example licenses. Discharges are poorly quantified as volumetric data does not commonly form part of the consent compliance checking. The explicit representation of discharges was therefore restricted to Sewage Treatment Works. Industrial consents were included implicitly by applying percentage returns to abstractions.

Information on impoundment releases is sparse and not collated nationally. There was no measured data on which to base the monthly values for just over 200 of the impoundments considered. Gustard et al., [1987] summarised the compensation flows of all impoundments with the UK with capacities greater than 500ML. For the impoundments without measured data generic rules were developed to relate the compensation values provided to monthly release volumes. An assessment of this method indicated that compensation releases tended to be overestimated.

3.4 Results

The results of the analysis, together with assessments of ecological sensitivity are being used by the Environment Agency to aid in the initial characterisation of surface water bodies and the assessment of the pressures and ecological impacts within river basins to identify AP 'at risk'. At the time of writing it is understood that the results will not be within the public domain prior to the submission of these reports to the EU in Autumn 2004.

A preliminary indication of the ability of LF2000 to achieve the objectives of the analysis i.e to estimate the pressure impact at each AP, was achieved by comparing the natural and influenced LF2000 estimated FDC with flows at gauging stations. An example is illustrated within Figure 1 for Q95. This illustrates that the LF2000 influenced Q95 estimates provide a significantly improved estimate of the gauged Q95 over the LF2000 natural Q95 estimate. This indicates that the methodology is effectively representing the water use patterns, hence the impact of pressures, within the gauged catchments.

Figure 1. LF2000 estimates of natural and influenced Q95 values relative to gauged values of Q95.

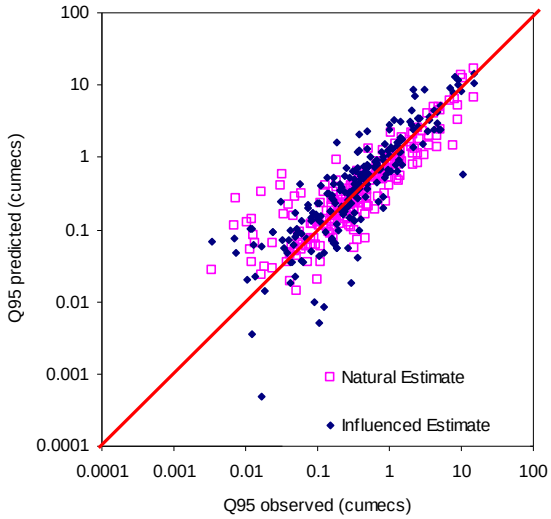
3.5 Summary

LF2000 is a tool by which a rapid assessment of the natural and modified flow estimates at a large number of sites across England and Wales can be made. This has enabled the first stage of the WFD, the characterisation and subsequent identification of surface water bodies that are 'at risk', to be completed within a limited time-frame.

3.6 LF2000 – Future Developments

As a consequence of the deficiencies in the extent and quality of data describing water use the estimation of actual flow regimes has been a two stage process; the estimation of natural flows regimes coupled with the application of simple deterministic procedures for incorporating the impacts of water use. As our understanding of the characteristics of

pressures and the quality of measured pressure



data improves holistic modelling of the system will become possible. This will enable a greater range of catchment data to be used within modelling approaches and will allow feedback mechanisms to be built directly into models.

In addition, the potential for integrating a water quality model within the current system has also been explored leading to the development of a prototype water quality module within LF2000. This directly couples hybrid stochastic-deterministic point source water quality models to the underpinning hydrological models within LF2000, such that the interactions between water use - dilution and water quality can be investigated dynamically. The methodologies within this software are based on those developed as part of the GREAT-ER project [Schowanek et al., 2001].

Whilst the FDC can provide a significant amount of information which can aid in managing water resources within a catchment the limitations of using statistical measures are recognised. Time series flow data enables assessments of yield for water resource schemes, the in-stream flow requirements of aquatic flora and fauna and the impacts of climate change at the catchment scale to be made. There is therefore a need to develop models to provide time series of flows within surface water bodies at ungauged sites. Regionalised continuous simulation models are currently being developed. These use regionalised rainfall runoff models, combined with parameters which are derived from catchment characteristics, to develop continuous time series of flow data [Young, 2002]. The planned incorporation of this within the LF2000 framework will allow practitioners to meet the needs of the WFD with greater certainty.

4 CONCLUSIONS

LF2000 is a user friendly GIS Framework underpinned by hydrological models and a flexible database.

LF2000 has been used as part of the screening process within the WFD to identify pressures on surface water bodies. This assessment is fed into a risk based approach for identifying water bodies at risk of not achieving or maintaining GES. Pressure information was used to determine the degree of influence, at over 6000 locations within England and Wales providing rapid, consistent results on the degree of modification at each AP. The outputs of this have been combined with a measure of ecological sensitivity to changes in the hydrological regime to provide an assessment of the risk that the surface water body will not achieve GES. The Environment Agency for England and Wales, using this data, will therefore achieve their aim of identifying surface water bodies at risk of not achieving or maintaining GES by the end of 2004.

In addition, a number of modules which deal with alternative aspects of the WFD are currently being developed. A prototype water quality module has been developed that can provide information on the impact on water quality of point source discharges at a catchment scale. Methods by which continuous time series of flows can be estimated at the ungauged site are also being developed.

LF2000 provides a suite of tools, which enables the regulator to assess and mange water resources at the catchment scale in a rapid, consistent manner. These tools can play an important role in allowing the regulatory body to manage water resource effectively and meet the requirements of the WFD.

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