NRA - ANGLIAN OI 558

THE UNIVERSITY
OF BIRMINGHAM

REVIEW

OF

BGS DRAFT REPORT

THE PROTECTION OF EAST ANGLIAN WETLANDS
Phase 2

National Rivers Authority, Anglian Region

Operational Investigation: 558

February, 1995

HYDROGEOLOGY RESEARCH GROUP
SCHOOL OF EARTH SCIENCES

Contents:

1. INTRODUCTION

1.1 Client

This Report was commissioned by the National Rivers Authority (NRA), Anglian Region as part of an ongoing Operation Investigation into wetlands hydrology.

1.2 Terms of Reference

The Terms of Reference for this Report are:

To review a Report prepared by the British Geological Survey (BGS), entitled:

> The Protection of East Anglian Wetlands, Phase 2 Report DRAFT,
>
> which will be referred to for clarity in this text as the BGS Draft Report.

The BGS Draft Report relates the findings of the Phase 2 of Anglian Regional Operational Investigation:558.

1.3 Comment

The review has been carried out by Professor J.W. Lloyd and Dr. J.H. Tellam of the School of Earth Sciences of Birmingham University. Mathematical aspects have been reviewed by Dr. A.W. Herbert of that School.

It is appreciated from the start that the subject of wetlands hydrological analysis is very difficult, so that any criticisms noted below are to be understood in that context. This review is not intended to provide detailed alternative analysis procedures to those proposed by BGS, but to provide constructive comment on the appraisal of the methodology applicability, the structure of the BGS Draft Report, and points of definition.

2. OBJECTIVES OF THE BGS DRAFT REPORT

2.1 Terms of Reference

The objectives of the BGS Draft Report have evolved from Phase 1 of the Operational Investigation: 558. From Appendix B of the Phase 1 report it is understood that the Terms of Reference (Proposal) for the BGS Draft Report are:

> Firstly, a set of characteristic (hypothetical) situations will be investigated using analytical and numerical models in order to gain insight into the possible effects of groundwater abstraction.
>
> Secondly, a further group of wetland sites will be investigated with the specific aim of gaining further understanding of wetland hydrology and the validity of the proposed methodologies.
>
> Additionally, a set of brief investigations will address peripheral issues that have been identified and on which some guidance would benefit the NRA.

Within the text of the BGS Draft Report no terms of references are given but a 'purpose' is noted, which is:

> 'To provide a methodology that can be implemented by the Anglian Region of the NRA to quantitatively assess the impact of current and proposed abstractions on wetlands'

The 'purpose' would appear to be somewhat at variance with the Terms of Reference (Proposal) and it is suggested that more clarity would be advantageous. For this Review the 'purpose' is assumed to be the Terms of Reference.

2.2 Phase 1

It is appreciated that BGS and NRA Anglian Region are fully cognizant of the Phase I findings. In the BGS Draft Report a concise summary of these findings would be of benefit, perhaps as an appendix, so that the document is more complete, and the reason why the ' purpose' has evolved is more clearly demonstrated. The methodologies proposed may be of value elsewhere, so that a comprehensive document would be preferable.

2.3 Targetted Readers

From the Phase 1 Terms of Reference it is understood that the methodology proposed 'must be appropriate for the use by graduates, but who may not necessarily have further degrees in hydrogeology'. It is assumed that, if the methodology is accepted by the NRA, a procedure 'guide' will be prepared and that the BGS Draft Report is, therefore, a rationale report for experienced NRA hydrogeologists.

3. CONTENT OF THE BGS DRAFT REPORT

3.1 Introduction

For this Report the format of the BGS Draft Report will be followed for referencing, but as the 'methodology' is not clearly structured within that report some aspects have to be moved for coherent discussion.

3.2 Wetlands and Water Use

Section 2 of the BGS Draft Report considers the problems of assessing the water needs of a wetland, wetland water budgets, wetland types, and the water requirements of different plants. In Section 2.4 a description of a water balance model (MIROS) and its application is given. As this model is used in the assessment methodology, it will be discussed in Section 3.5 (Methodologies) of this report.

In developing a wetland assessment methodology, it would be useful to introduce a definition of the term 'wetland'. This is a difficult task; the definition need not be universal, but could be specific to East Anglia; maybe an operational definition is appropriate (e.g. sites on a certain reference list)?; or maybe the SEV index could be used?

In examining wetland budgets the use of evapotranspirational demand as adopted by BGS is a very sensible approach to quantifying wetland water needs. However, the source of the water (ie. the components of the water balance) can also have profound effect, as each has its own water quality/nutrient characteristics, and this point could be noted. As the Report points out, flow is important within a wetland; perhaps surface water flow velocities which, in particular, can be important for invertebrates should be noted.

The question of data and instrumentation is raised for the methodology being developed. If no new instrumentation is to be used at the sites in question, then in most cases it will be very difficult to make anything other than a guess at the water balances. Instrumentation has to be viewed within the NRA plans which are unclear from the BGS Draft Report. Monitoring is commented upon in Section 3.5 of this report.

The importance to wetlands of flood water inundation is said to be limited in East Anglia: parts of the Broadlands may be an exception?

The 'wetlands and water use' section concludes with two important points: firstly, defining groundwater catchments is difficult without some form of modelling; and secondly, the internal flow mechanisms within a wetland can be very important. With regard to the latter point perhaps it should be noted that, in the extreme case, draining a piece of land may cause the disappearance of a wetland, yet the water inputs may be largely unchanged as far as the catchment is concerned.

Within the discussion of wetland classifications, criticisms are made of the Birmingham University (East Anglian) classification scheme. While agreeing with these criticisms , two points should be noted. Firstly, if the existing data are inadequate to classify a wetland unambiguously, the data are also inadequate for any other assessment method: where part of a wetland is in one class, and part in another, the class recorded should reflect the larger or the more important part, or both classes; the investigation of hydrologic variations within a wetland area are outside the scope of both the Birmingham University classification scheme and the BGS Draft Report. Secondly, the Birmingham scheme can be quantified: as more work is carried out using, for example, the MIROS model , wetland classes will become more meaningful, especially if sensitivity studies are carried out using real site data (McInnes, 1992). In this way the Birmingham scheme can be used to encode experience, rather than being used in a forecasting, *a priori*, mode.

Notwithstanding the above comments, the qualitative application of the Birmingham classification scheme is clearly no more than a very broad first sweep, and a more quantitative approach, such as attempted in the BGS Draft Report, is to be welcomed.

From the limited information given on the sum exceedance value (SEV) studies, it would appear that this approach could be very useful. Timing of water level changes is not taken into account in the SEV index, but it is uncertain how important a factor timing is ecologically. Perhaps the SEV approach could be linked into that of (plant) species competition currently being developed at Glasgow University (Hills et al., in press). It is encouraging that a simple hydrological parameter has been developed which has some ecological significance. More studies are needed to confirm its use.

3.3 Impact of Groundwater Abstraction on Wetlands

This section could perhaps benefit from some simple diagrams to explain the principles. There are also problems of definition; for example, is 'semi-confined' the same as 'leaky' or a mixture of 'unconfined' and 'confined'. The term 'aquifer/catchment' is unclear. The premise that any abstraction of groundwater must be balanced by an equivalent reduction in the outflow from the aquifer system is not necessarily true, as abstraction could increase recharge. These are small points requiring minor modifications for clarity.

The importance of peat is noted as a high porosity unit in wetlands but the point should be made that following dessication during drought, peat may not re-saturate to the same storage capacity as prior to drought. The same constraint could be imposed upon wetland hydrogeology by intermittent drawdown due to abstraction.

Apart from the minor definition queries the understanding of effects of changes in water levels and the effects of abstraction on the levels are comprehensively discussed. It must be noted, however, that the Birmingham University wetland classification was not meant to provide scope for assessing drawdown significance in a wetland, as alluded to above.

Within the discussion of abstraction on wetland water levels the effect of a well is confused with the effect of abstraction from a well and drawdown response. The discussion about well position with respect to catchment and the reference to the modelling in Appendix 3A would benefit from further explanation. The effects of boundaries are quite rightly noted but one would assume that these define a wetland catchment, at least in part, so well position in a catchment and water level response to abstraction must be important. Having identified boundaries, however, it should be noted that river boundaries are notoriously difficult to understand, and image well analysis for rivers can lead to large errors. Further, with respect to modelling of the Chalk aquifer generally, directional hydraulic conductivity can be a dominant factor so that abstraction position in relation to hydraulic conductivity zonation and the ensuing effects on a wetland may be complicated. These factors are discussed at more length below.

The possible influence of Quaternary features on the wetlands is highlighted, as is the problem of the availability of the appertaining hydrogeological data. This is an important aspect of many East Anglian wetlands and could receive more prominance in the report.

The section in the BGS Draft Report covering the 'quantification of the effect of abstraction on wetland flows' would appear to encapsulate the main analytical innovation introduced in the study. The analysis is considered below in the 'Methodologies' discussion.

3.4 Methodologies

3.4.1 Introduction

The aims of the project are very difficult to achieve. Wetland hydrology/hydrogeology is not well understood, yet wetland systems are potentially very sensitive to changes in water level of magnitudes considered negligible in most other situations. Even with detailed long-term investigations, success in assessing the effects of changes in surface or groundwater contributions to a wetland water balance cannot be assured. Hence, any assessment scheme based on sites with no prior hydrological information will necessarily have to make some considerable assumptions. The following comments on the proposed methodologies should be considered in the context of the difficulty of the task.

The methodology is based on the three general assumptions given in the BGS Report and summarised below. Whilst the general tenor of each assumption is reasonable, the real difficulty is in deciding the range of conditions over which the assumptions can be reasonably applied.

Assumption 1 suggests that differences within wetlands are greater than between wetlands. This is certainly true when considering very small scale variations - variations at a scale at which there is no hope of viable prediction. But at a scale of integration of, say, tenth wetland area upwards the differences between sites would possibly become much more important: compare Catfield and Badley Moor Fens.

Assumption 2 indicates that seasonal variation is relatively easy to incorporate once 'the effects of climate are taken into account'. However, as the wetlands are never likely to achieve a steady-state, seasonal variation in inputs may need to be considered from the outset. As, quite rightly pointed out elsewhere in the Report, extreme climatic events can give rise to unexpected results.

Assumption 3 stresses the importance of site management in being able to "control" the local conditions, *provided* the site water quantity and quality can be satisfied. The difficulty here is being able to satisfy the quality criteria.

3.4.2 Methodology Proposed

The methodology proposed suggests seven steps, each of which involves the collation of more data and/or the development of more sophisticated analyses. Steps 1-5 list sensible actions for a preliminary assessement of whether a wetland site is likely to be at risk. In practice, these steps will probably not be carried out in the order suggested. For example, deciding on which aquifer feeds the wetland (Step 4) is really necessary before deciding on transmissivity and storage (Step 1), or calculating well abstraction influences (Step 2). Given the marked variations in hydraulic conductivity in the chalk areas, is the use of approaches such as Theis (Step 2) fail-safe? Is the one centimetre drawdown criterion proposed intended to include a safety factor? - if so, is there any evidence to support this? (perhaps from the numerical experiments of the type described in Appendix A3, or of the type carried out by the University of Birmingham (1991)?) Depending upon the professional background of the future users of the methodology, some of the proposed actions may be very difficult to carry out : the assignment of transmissivity and storage (Step 1) and deciding which aquifer is involved (Step 4) are not necessarily straightforward, even for a hydrogeologist in some cases. Use of image well theory (Step 6) can quickly become awkward, and again requires some reasonable hydrogeological knowledge. In this case, the use of a 'user-friendly' numerical model would seem most appropriate: numerical models are discussed at greater length below. Although not necessarily advocating the classification, it is noted that in carrying out the work in Steps 1-5, the wetland will have been effectively classified using the Birmingham University scheme.

Steps 6 and 7 include the novel elements of the methodology. Step 6 proposes that the calculation of the drawdown at a wetland be performed using either the Theis equation or the new well function equation: the latter approach is discussed in Section 3.4.3 below. Does the Theis method always give the "worst-case"drawdown, particularly in view of the variations in transmissivity and storage commonly observed in the region? Again, as noted above, using image wells appears to be rather crude and labour-intensive, and requires a certain degree of expertise, especially when compared with commonly available user-friendly numerical models; or will image well models be built with pre-processors?

Step 7 considers the assessment of the importance of the drawdown, which is discussed in Section 3.4.4 below. Step 7 also suggests that the change in flow to the wetland as calculated using the new well function model can be compared with an assessment of the pre-abstraction wetland water balance, where available, as predicted using MIROS. This model is discussed in Section 3.4.5, below.

3.4.3 The New Well Function Model (Coded as WETLWELL)

The background to this new analytical model is described in the BGS Draft Report in Sections 3.4 and 3.5, and Appendices A2, A3 and (4).

The hydrology/hydrogeology of a wetland and the effects of abstraction from wells are dependent upon the many factors listed in Section 3.4 of the BGS Draft Report. Although the wetland shown in Figure 3.1 of that Report may be the most commonly occurring situation found in East Anglia, it certainly does not represent the only type of wetland present (e.g. Badley Moor). The modelling work in Appendix A3 confirms that, if close enough, aquifer boundaries must be taken into account in assessing the effect on wetlands of groundwater abstraction: the lack of importance of the pre-abstraction wetland groundwater catchment is also confirmed, though as mentioned in Appendix A3, the wetland catchment area developed after pumping begins would be of importance for water quality.

The new well function approach is interesting and provides an easily used new tool. However, it is uncertain that a basically analytical model is the most appropriate for investigating wetlands, especially in the East Anglian context. An analytical model cannot take into account the range of complexities listed in Section 3.4 of the BGS Draft Report, including recharge, variation in hydraulic properties, effect of boundaries , and shape of wetland. Indeed, Appendix A3 stresses the importance of boundaries and, although advocating the use of image wells, such calculations can very soon become extremely cumbersome and inappropriate for use by non hydrogeologists. It is unclear why the use of a numerical model, perhaps with specially-adapted pre- and post-processors, was not proposed. A code such as ASM (Kinzelbach and Rausch , 1990) could easily be used (Klinck, 1991).

A problem often experienced at the wetland itself, is the effect of water level on evapotranspiration, Sy, and transmissivity. Could this be a significant problem in wetlands where, especially, evapotranspiration is the dominant sink? Or is it assumed that the change in water level for ecological reasons must be less than will give rise to this problem?

Appendix A2 provides details of the new well function model. The basis for the analysis is an application of the reciprocity theorem. Is BGS certain that, given the presence of local leakage, the theorem can be directly applied in this situation? The equations are solved for leakage proportional to the radial variation of reciprocal drawdown, s(r), beneath the wetland, and then much of the discussion involves leakage proportional to the single value of true drawdown beneath the centre of the wetland. Would it be more straightforward to set the flux proportional to the single value of drawdown? An implication of the analysis is that R is small on some scale defined by the distance to the abstraction well? - otherwise the simple representation of the leakage is likely to be a significant approximation? It would be good to see some verification of the model. The evaluation of parameters and the assymptotic expansions of the Bessel functions have not been checked, and are assumed to be accurate.

A comparison of the well function model with numerical results could be very instructive in terms of assessing the importance of the variables which are listed in Section 3.4 of the BGS Draft Report but which have not taken into account in the analytical solution. This numerical experimentation could take into account a point mentioned by BGS - the case of underflow, where the groundwater flows below the wetland.

3.4.4 Assessing the Importance of Predicted Drawdown: the '10% Rule'.

Assessing the importance of a given drawdown is fundamental to the protection of a wetland. It is an extremely difficult task. The 10% rule appears as good as any criterion, but does seem to assume that an average lowering of water level, admittedly by a small amount, has no effect on the wetland ecology: 'Wetland plant communities are attuned to the present regime of groundwater inputs, and changes of piezometric head that are well within the present range of levels will not have serious effects' . What could be the effect of continuous lowering of average summer water levels as opposed to seasonal (ie. short-term) changes? Some evidence has been provided by BGS, although Table 4.3.1 is missing from the copy of the Report used in this review. On the other hand, given the uncertainties in the other parts of the assessment procedure, is the drawdown equivalent to 10% distinguishable or an improvement over some arbitrary negligible fixed drawdown figure? Perhaps only experience can answer these questions - after the approach has been 'calibrated'

3.4.5 The Wetland Water Balance Model (MIROS) and the Sum Exceedence Value (SEV)

MIROS appears to be a fairly conventional lumped parameter model, though specifically designed for the East Anglian wetlands. It has been applied to a range of wetlands where data of variable abundance exist (though the agreement between MIROS and field measurements has not been discussed.) It is not easy to see how the success of such trials can be properly gauged.

It is also difficult to gauge the importance of the necessarily large number of assumptions used in developing MIROS, and a programme of sensitivity analyses would be very useful. For example, the effects of the recharge assumptions, the actual evapotranspiration rates on the wetland, and the alpha (delay function) values could all be investigated. Specific questions include the importance to the assessment in carrying out a monthly calculation involving SMD as opposed to a daily calculation, the factors for estimating recharge in areas of different lithology (eg. 30% seems high for till), and mixing local precipitation and MORECS AE/SMD data. The impression is that catchment runoff is defined as effective rainfall (P-AE-SMD) minus recharge, and this becomes surface water inflow to the wetland: is this impression correct? The importance of wetland Sy could relatively easily be gauged; a figure of 20% is assumed, yet very large variations have been reported in the literature.

The use of the delay function concept is interesting. Is there some theoretical background to support its use? How does it relate to more fundamental properties of the aquifer system? How sensitive is it to differences in values and distributions of transmissivity, storage and recharge, and to aquifer size? One way to avoid some of the potential problems with alpha would be to use a numerical model as the basis for the groundwater calculations, and adapt a pre-processor to guide choice of values and distributions of recharge, the latter being based on the assumptions used in MIROS.

In connection with assessing the overall validity of the MIROS model, it may be worthwhile to carry out comparisons between MIROS predictions and a hypothetical prototype wetland set-up using a numerical model.

The idea of the sum exceedance value (SEV) is a good development which appears to have a sound connection to observed ecological parameters. SEV values have been cleverly used to estimate the equivalent size of the groundwater catchment in particular wetlands. The approach assigns all errors in other parameters and concepts to the predicted groundwater catchment term, and again a sensitivity analysis might be of interest. The approach, of course, does not deal with the catchment location and shape which is of importance for water quality considerations.

The MIROS model has been used to estimate the drawdown giving rise to a particular change in wetland SEV (>20). To do this, change in wetland groundwater catchment area is assumed to be proportional to drawdown, which is probably not an unreasonable assumption, though one which depends on other factors remaining unchanged. Because catchment area is uncertain, the MIROS calculations are presented as graphical relationships between drawdown, SEV, and catchment areas. The graphs can be used to indicate the maximum SEV to be expected for a given drawdown. This appears to be a promising approach, though it is dependent upon obtaining spring flow data (or making some assumptions about spring flow), upon the validity of the MIROS model, and upon the direct relationship between catchment size and wetland groundwater discharge. As suggested in previous sections of this report some sensitivity analysis using more sophisticated numerical simulation of real or even hypothetical wetlands would provide more confidence in the approach. The work justifying the approach has concerned Great Cressingham Fen which is discussed in the BGS Phase 1 report, but is not covered in detail in the Draft Phase 2 report.

It is disappointing to see that there appears to be no relationship between dehydration indices and estimated drawdowns at the range of wetlands shown in Figure 4.4. of the BGS Draft Report (The text on p. 34 claims there is a relationship, though the caption to Figure 4.4 confirms there is not).

A distinct advantage in using MIROS for determining allowable drawdown is that allowance is made for the importance of groundwater in the wetland water balance. Although the idea of the SEV links hydrology and ecology, its use depends on the MIROS model giving a rather accurate prediction of the water balance components. Given the large inherent uncertainties, is there any advantage in using SEV over taking a series of allowable averaged drawdowns below a wetland, graded according to importance of site? For example, a one centimetre drawdown might be allowed at an SSSI through to a 0.5 m drawdown at a less important site?

3.5 Monitoring

This aspect has been sensibly addressed by BGS. Certain minor questions arise such as the meaning of the term 'dipwell' and the statement that fen peat tends to produce uniformity in hydraulic properties. With respect to the latter, detailed peat studies indicate the contrary.

For the proposed BGS assessment methodology the use of MORECS data is recommended; meteorological monitoring specifically for many wetland sites is therefore sensibly avoided. However, as MORECS data are area-generalised and not site specific, it would be sensible for the NRA to run correlation comparison between those East Anglian wetlands that have automatic weather station data and the relevant MORECS data, in order to examine the reliability of MORECS, particularly in stressed periods.

The need for the measurement of water levels is obvious but difficult to appraise on a site by site basis, as explained by BGS. It is debatable as to whether monthly data are adequate for wetland characterisation.

The problem of the feasibility of collecting large amounts of water level data is alluded to, and it is recommended by BGS that nested piezometer data on a site by site basis is not likely to be economical. However, it is unclear from the report as to the extent that actual field water level data are required to provide a meaningful assessment using the proposed WETLWELL methodology. Some statements of minimal requirements for pre- or non-pumping test periods, would be advantageous, even though there is the suggestion (NRA requirement?) that assessment in some cases will be without field data.

In an initial assessment phase, as is being considered, it is assumed that firstly, some value(s) should be determined for the wetland free-water surface and secondly, groundwater level(s), below the wetland.

Spring flows, channelling of wetlands and other human intrusion controls on both flows and heads, can only be accounted by monitoring on a site basis, as is quite rightly noted.

4. CONCLUSIONS

The BGS Draft Report covers a large amount of in-depth discussion of wetland hydrological assessment and highlights the difficulties of realistic assessment, even where comprehensive data sets are available. BGS have carried out the 'purpose' of the study although inevitably certain questions may be raised about the methodology proposed.

The Report structure is difficult to follow in places and would benefit from more clarity with respect to :

(i) wetland definition

(ii) hydrological/hydrogeological definitions

and (iii) systematic description of the entire proposed methodology

The proposed methodology of MIROS-SEV-WETLWELL is novel and an interesting approach. As required by the NRA, and dictated by the lack of data, it is simplistic and presumably 'user-friendly'. It is impossible to judge whether it would be more reliable an assessment tool than other methods, and because of the overall uncertainty in wetland hydrology, is clearly open to easy criticism.

The MIROS and SEV methods developed would appear to be very worthwhile and should prove to be a good starting point for wetland assessment, and will no doubt improve with further testing and correlation. The question really is whether the basic premise of adopting a radial analytical procedure as in WETLWELL, is sensible.

Radial analyses of groundwater flow are based upon aquifer geometry and hydraulic properties that are radially homogeneous and infinite. While accepting radial analyses are common in hydrogeological interpretations, it is very questionable whether they are meaningful for the particular geometry and hydraulic properties found in chalk/drift aquifer dominated wetlands, particularly with the small water level changes under consideration. From the hydrogeological standpoint the use of WETLWELL is difficult to support.

The above statement is not a criticism of the BGS work, as an approach that can be used by non-hydrogeologists would appear to the NRA goal, and BGS have therefore tried to produce a simple method. Perhaps, the use of non-hydrogeologists in wetland vunerability assessment could be re-considered by the NRA?

Irrespectively, it is suggested that the WETLWELL approach could be substituted by a simple, user-friendly numerical distributed groundwater model. With an adequate pre-processor and some training it is probable that non-hydrogeologists could achieve a better assessment with such a model than with WETLWELL.

References

Hills, J M., Murphy, K J, Pulford, I D, and Flowers, T M, in press. The use of survival strategy theory to classify and predict changes in European wetland vegetation. Functional Ecology, in press.

Kinzelbach, W, and Rausch, R, 1990. Aquifer simulation model. International Groundwater Modelling Centre, Delft, The Netherlands.

Klinck, B A, 1991. The assessment of vulnerability of East Anglian wetlands to abstraction. Unpub. MSc Project Report, University of Birmingham. 88 pp.

McInnes, R, 1992. Scottish wetlands; classification and simulation modelling of wetland vulnerability. Unpub. MSc Project Report, University of Sterling.

University of Birmingham, 1991. The hydrodynamics of East Anglian Fen systems, Phase III. Unpublished final report to National Rivers Authority, Nature Conservancy Council, Broads Authority.

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