MISE EN OEUVRE DE LA MÉTHODE IFIM (INSTREAM FLOW INCREMENTAL METHODOLOGY), POUR MODÉLISER L'HABITAT DES SALMONIDÉS DANS LA RIVIÈRE ALLEN, ANGLETERRE.

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RÉSUMÉ (traduit par les éditeurs)

Située au sud de l'Angleterre, la rivière Allen est considérée comme un exemple typique de cours d'eau calcaires, avec une réputation historique de rivière à truite et saumon de très bonne qualité. Des réductions significatives des populations de salmonidés ont suivi les premières utilisations des eaux souterraines dans le bassin hydrographique de la rivière Allen, en 1946. Ceci a conduit l'Autorité de Rivière de la Région du Wessex à entreprendre des études sur l'hydrologie, la biologie et les pêcheries. Dans ce contexte, l'Institut d'Hydrologie étudie plus particulièrement l'effet de la réduction de débit sur l'habitat potentiel des salmonidés. L'étude fait appel à la méthode des microhabitats (IFIM) (BOVEE, 1982), et à son module de simulation de l'habitat (PHABSIM). Cette simulation résulte du couplage entre données biologiques relatives à différents stades de développement de la truite et du saumon et données physiques, de façon à analyser l'habitat disponible (SPU : surface pondérée utile) en fonction des débits. Les courbes de disponibilité ont été développées par le NRA de la région Wessex par plongée subaquatique et pêche dans différents cours d'eau calcaires comparables à la rivière Allen. L'évolution de la réduction d'habitat, en fonction du débit, a été simulée par rapport à une série temporelle de valeurs moyennes hydrologiques historiques et reconstituées. Ces résultats sont étudiés sous la forme de courbes d'habitats classées. Elles démontrent l'effet de la réduction de débit pour chaque classe d'âge et ont permis d'aborder une négociation sur la base d'une diminution de 50 % des prélèvements.

USING THE IFIM TO MODEL SALMONID FISH HABITAT IN THE RIVER ALLEN, ENGLAND.

ABSTRACT

The River Allen, situated in southern England, is regarded as a classic example of a chalk stream and historically has a reputation as a high quality trout and salmon fishery. Significant reductions in salmonid populations have been observed, following the start of groundwater abstraction within the Allen catchment in 1946. This has prompted the National Rivers Authority Wessex Region to initiate detailed hydrological, biological and fisheries studies to investigate the perceived problem. Within these studies the Institute of Hydrology was commissioned to investigate the effect of the abstraction regime upon salmonid habitat availability (JOHNSON *et al.,* 1993).

The study used the Instream Flow Incremental Methodology (IFIM) (BOVEE, 1982), implemented using the Physical Habitat Simulation (PHABSIM) model. PHABSIM hydraulic model simulation results were combined with habitat suitability data for life-stages of trout and salmon to develop habitat (weighted usable area) vs discharge relationships. Habitat suitability indices were developed by National Rivers Authority (NRA) Wessex Region staff by snorkelling and wading in a number of chalk streams similar in character to the Allen.

To assess the impact of groundwater abstraction upon habitat availability, weighted usable area vs discharge relationships were combined with a twenty year time series of mean monthly "historical" and "naturalised" flows. The resulting time series of historical and

naturalised weighted usable areas were analysed using a standard duration curve program. These habitat duration curves demonstrate the effect of the abstraction upon the availability of habitat for each species life-stage considered. The results provided by this analysis were used to negotiate a proposed 50 % reduction in the levels of abstraction within the Allen catchment.

INTRODUCTION

The River Allen is a chalk stream situated in the south of England. It rises near the village of Wimborne St Giles, Dorset, from the Upper Chalk, an aquifer which covers the majority of the 178 km^2 Allen catchment (Fig. 1). The length of the river from its perennial source to its confluence with the River Stour is 18 km, but after a high winter rainfall season it may extend to 23 km. The observed 95 percentile (Q95) flow and mean flow at the Loverly Mill flow gauging station (1970-1981) are 0.176 and 1.0 cumecs respectively.

In 1946 groundwater abstraction for public water supply (PWS) was initiated using Chalk boreholes in the river valley at Stanbridge Mill. Initially, licensed abstractions were limited to 2.9Ml/d, but in 1970 the licensed maximum abstraction was increased to 13.1Ml/d. Subsequently, 3 stream augmentation boreholes have been constructed and abstraction at Stanbridge Mill increased to its current licensed limit of 25Ml/d (NEWMAN and SYMONDS (1991)). Results produced from a catchment groundwater model concluded that even with active stream augmentation, the Q95 flows at the river flow gauges at Loverley Mill and Walford Mill were reduced by 40 % and 45 % respectively at maximum abstraction levels. The River Allen has been identified as one of the top 40 rivers in England and Wales suffering from unacceptably low flows (NRA, 1993).

NRA fisheries data including records of catches and stocking pre-dating 1970, combined with data on the quality of neighbouring rivers, demonstrated a significant change following the increased abstractions. There have been persistent complaints from an active River Association about declining standards of a once excellent salmonid fishery. These were supported by records showing the decline in the numbers of fish caught on Gaunts Water, within the catchment, from over 250 in 1965 and 1966 to less than 100 in 1973 (SIR RICHARD GLYN (1976) in NEWMAN and SYMONDS (1991)). In 1992 the NRA commissioned the Institute of Hydrology to apply the IFIM at two study sites on the Allen to investigate the effects of the abstractions upon habitat availability for trout and salmon. The results of this study would then be used to help the formulation of an Action Plan to propose mitigation measures. The IFIM was implemented using the PHABSIM model developed by the U.S.Fish & Wildlife Service.

IFIM STUDY AREA AND PHABSIM MODEL CALIBRATION

Appropriate sites for the IFIM study were selected by visually surveying the reaches of the Allen, thought to be impacted by abstraction, from the river bank. An assessment of the distribution of different habitat types present within this area resulted in the identification of two study reaches, some 400 m apart, for IFIM application, as shown in Figure 1. The upstream site was selected because it contained a good representation of the variety of habitat types present within the sector of river under examination. The downstream site is in a reach thought, on the basis of discharge measurements made by the NRA, to be most impacted by the abstractions.

At each site a representative reach was chosen to enable the sampling of all of the essential features of the different habitat types present. Transects were placed at intervals along each reach to sample the available habitats and to satisfy the data requirements of the PHABSIM models. The upstream study reach consisted of 12 transects and the downstream 8 with the average inter-transect distance being 11.5 m. PHABSIM calibration data were then collected from each study reach in the manner recommended in JOHNSON *et al.* (1994).On the upstream site three sets of flow calibration data were obtained at discharges of 0.73, 0.39 and 0.51 cumecs. On the downstream site these data were obtained at discharges of 0.89, 0.51 and 0.19 cumecs.

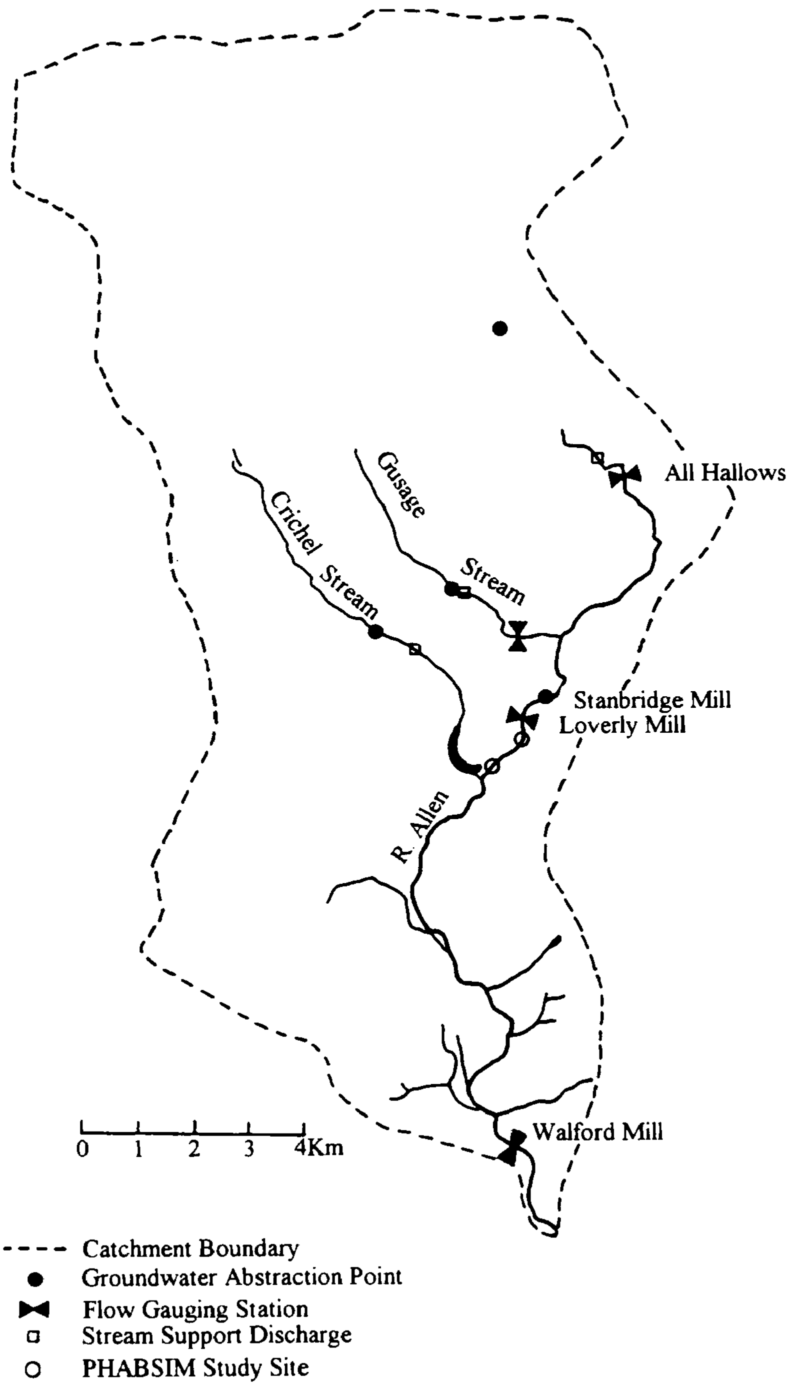

Figure 1 : La rivière Allen dans son bassin versant. Localisation des stations d'étude de l'habitat par la méthode PHABSIM.

Figure 1 : The River Allen catchment and location of PHABSIM study sites.

Over the period that the above work was carried out, some growth of aquatic vegetation, dominated by *Ranunculus*, occurred. In order to assist the hydraulic modelling procedure, some cutting of this vegetation was undertaken on the downstream site, in the manner that would normally be used on the river for angling purposes, prior to the second set of flow observations.

The PHABSIM hydraulic models were calibrated using data collected at each of the three measured calibration flows. Water surface profiles were simulated using the WSP step-backwater model. Starting values for water surface elevations at the downstream limit of the site were simulated using the IFG4 stage-discharge regression model. Point velocities across individual transects were simulated using a single-flow IFG4 calibration based on observations made at the highest of the three observed calibration flows. Calibrated hydraulic models were used to simulate water depths and velocities over a range of discharges (0.1 to 3.9 cumecs) designed to cover the extremes of the historical and naturalised mean monthly flow records used in the subsequent time series analyses.

TARGET SPECIES AND HABITAT SUITABILITY DATA

Brown trout (*Salmo trutta*, L. 1758) and salmon (*Salmo salar*, L. 1758) are the two most vulnerable fish species on the Allen. Most of the concerns voiced over the Allen relate to the reduced sport for trout anglers and to the decline in its status as a breeding area for migratory salmon and brown trout. In order to assess the impact of the historical groundwater pumping regime upon the availability of physical habitat to life-stages of these species the following species life-stages were selected for the IFIM modelling exercise:

Brown trout

- — adult (> 27cm)
- — juvenile/fry (<13cm)
- — spawning

Atlantic Salmon

- — adult (<14cm)
- — spawning

A two year period of observations of fish species in Dorset chalk streams by staff from NRA Wessex region facilitated the production of habitat suitability curves for life-stages of brown trout and salmon. BOVEE (1986) defines categories of habitat suitability curves according to the methods used in their construction, ranging from category I (curves developed from existing literature) to III (curves produced by field survey work which are adjusted to account for the availability of habitats at the time and place of sampling). The curves produced were, in the main, Category II or "utilisation" curves. Curves for substrate were adjusted for availability of habitat and are thus Category III. For the adult and juvenile/fry life-stages the transferability of the Category II curves should be good as the source streams were chosen to be similar in size and character to the Allen and observations were made while flows were well above "low levels", over a good range of habitat types. Salmon and trout were living in sympatry in the streams, as would be the case naturally on the Allen. These data are clearly preferable to the Category I curves used previously in UK research and lend considerable weight to the findings of this assessment. These data are shown in Figure 2 below.

WEIGHTED USABLE AREA vs DISCHARGE COMPUTATIONS

The computation of weighted usable area (WUA) for the selected study reaches was carried out using the HABTAT model, within PHABSIM, using the procedures recommended in MILHOUS *et al.* (1984 &1989). Within the HABTAT model the amount of WUA available at each of the simulation discharges is based on the summation of individual "cell" values of WUA over a computational grid defined, in this case, by data points spaced across the study transects described above. Cell values of the microhabitat variables depth, mean column velocity and substrate type were produced as output from hydraulic model simulations at each of the required flows. At each flow level, individual cell suitabilities were calculated for

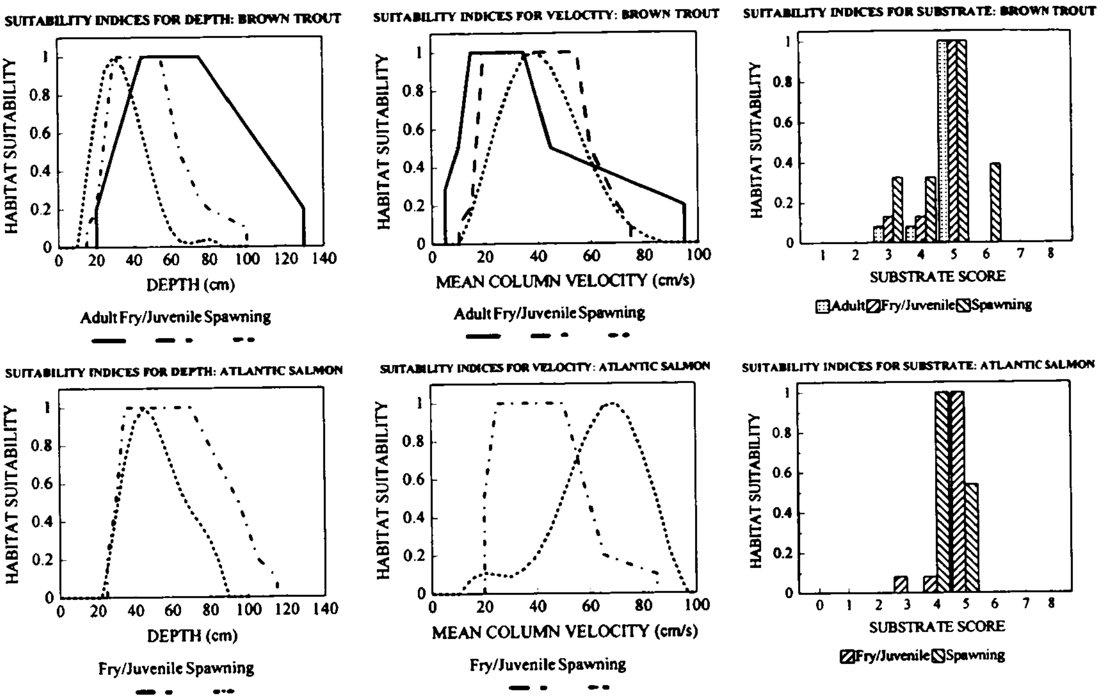

Figure 2 : Indices de préférences d'habitat pour différents stades de développement de la truite et du saumon.

Figure 2 : Habitat suitability indices for life-stages of trout and salmon.

each target species life-stage by computing a 'Composite Suitability Factor' (CSF) (MILHOUS *et al.* (1989)) using the HSI data described above. Cell WUAs were then calculated by multiplying each cell area by its CSF. Total WUA within the reach (in m^2/1000m), available to a given target species life-stage at a given flow, was calculated by summing the individual cell WUA values and multiplying the result by 1000 divided by the total length of the study reach. This procedure was carried out at each of the simulated flows to give the WUA vs discharge functions for each target species life-stage as shown in Figure 3.

HABITAT TIME SERIES ANALYSIS

In order to assess the effects of the historical abstraction regime upon the variation of available habitat area over time, weighted usable area vs discharge relationships at the two study sites were coupled with time series of mean monthly "historical" and "naturalised flows". Naturalised flows were produced as output from a linked catchment groundwater-surface water model. The resulting historical and naturalised mean monthly flow records for the period 1970 to 1992 were combined with the WUA vs discharge output given above to produce time series of historical and naturalised available habitat at both study sites, for each of the target species life-stages under consideration.

The habitat (WUA) time series produced above were then analysed using a standard duration curve program. The reduction in yearly levels of habitat duration for all of the target species life-stages indicated that the impact of the abstractions was greater at the downstream site, and that the most impacted target species life-stage considered was fry/juvenile trout. Historical and naturalised flow duration curves and the corresponding fry/juvenile trout habitat (WUA) duration curves at the downstream study site are shown in Figure 4.

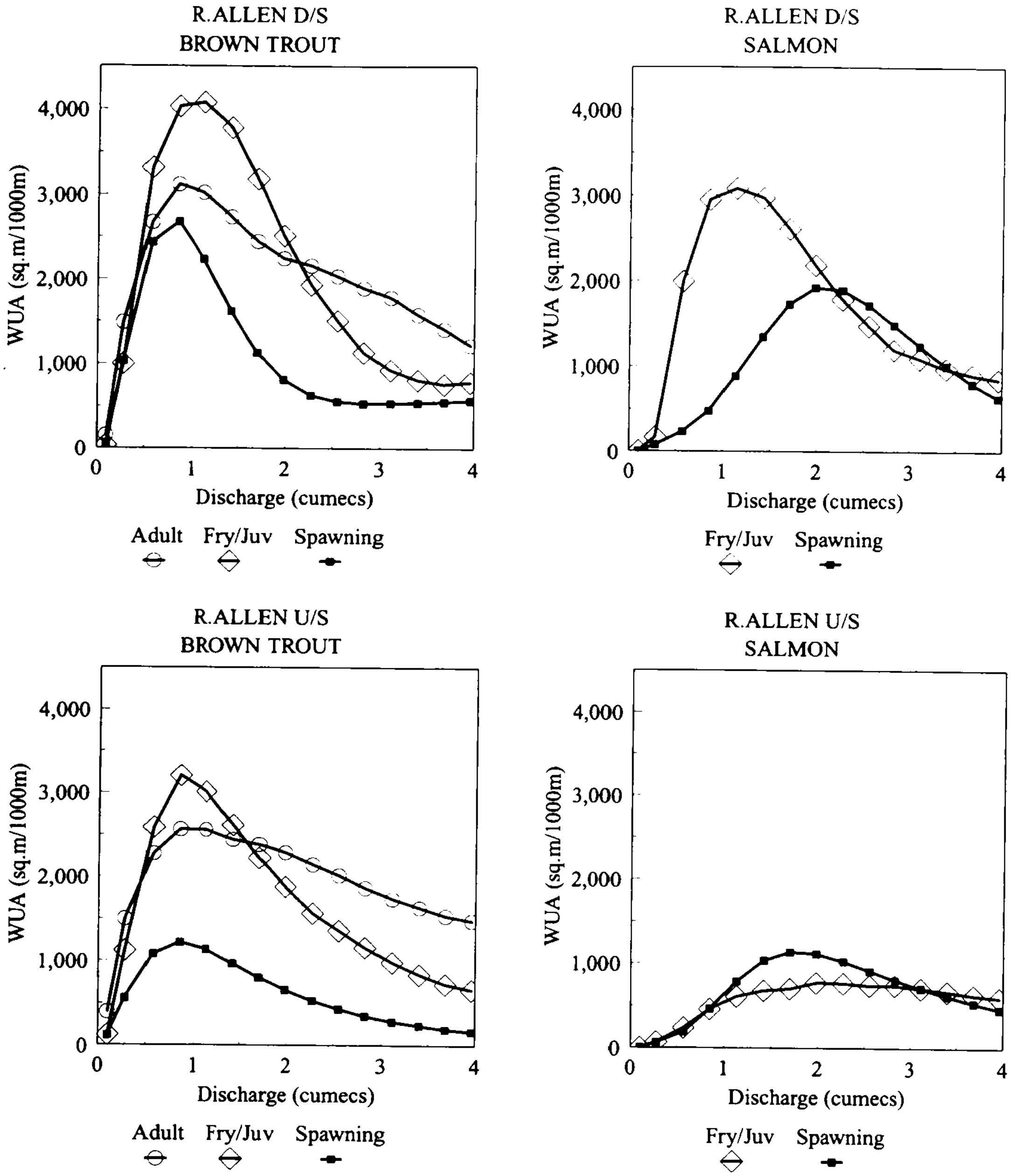

Figure 3 : Surfaces Pondérées Utiles (WUA) en fonction du débit (avec D/S : station aval ; U/S : station amont).

Figure 3 : PHABSIM Weighted Usable Area (WUA) vs discharge results (D/S : downstream station ; U/S : upstream section).

In order to investigate seasonal variation in the impact of the abstractions, habitat time series simulations were repeated on a seasonal basis. Simulations were carried out for the summer (April-September) and winter (October-March) periods (simulations for spawning life-stages were conducted for winter months only). Fry/juvenile trout habitat (WUA) duration curves for the two periods are shown in Figure 5. Results indicate that the impact of abstraction is almost entirely confined to the summer months with reductions in WUA available to target species for the winter months only becoming significant above the 90 percentile exceedance level.

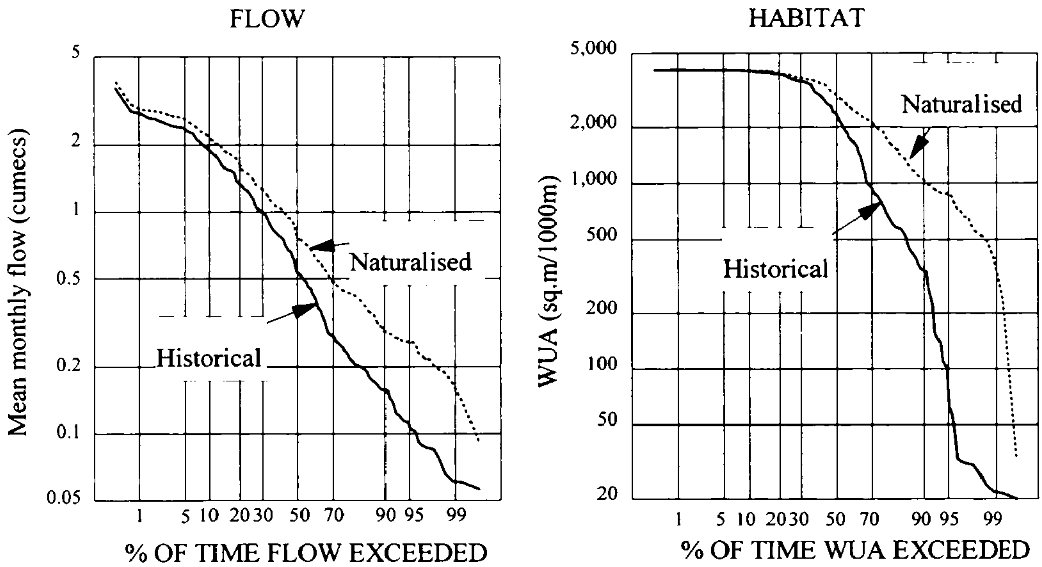

Figure 4 : Station aval : courbes des durées d'habitat classées (WUA) des stades alevins et juvéniles de truites correspondant à des débits naturels et reconstitués.

Figure 4 : Downstream site: historical and naturalised flow and fry/juvenile trout habitat (WUA) duration curves.

For the fry/juvenile life-stage of trout, further flow scenarios with 25, 50 and 75 % reductions in the historical abstraction regime were also modelled to assist the NRA with the production of recommendations for mitigation procedures. The resultant summer WUA duration curves at the downstream site for the three flow scenarios (historical, naturalised and 50 % reduction in historical abstraction) are also shown in Figure 5.

CONCLUSIONS

The flow duration curves (Fig. 4) suggest that the absolute impact of abstraction upon discharge remains roughly constant at around 0.25 cumecs reduction for any given flow percentile. Consequently the relative effect of abstraction increases rapidly at lower flows (higher exceedance percentiles). For the summer months, discharge at the 95 percentile exceedance level was depleted by 55 %. Of the various scenarios modelled the greatest losses in WUA predicted were for summer fry/juvenile trout WUA at the downstream site. In this case WUA at the 95 percentile exceedance level declined by 94 %. At the 50 percentile exceedance level the corresponding reduction predicted was 51 %.

It is possible from the results and analysis presented above to choose a prescribed minimum summer discharge corresponding to any given (high) exceedance percentile of available habitat area for the most sensitive of the target species, fry/juvenile trout. For example, to ensure that in the summer available habitat area for trout fry remains always above its historical 50 per cent exceedance value of around 1509m^2/1000m (at the downstream site), would require a minimum discharge of 0.33 cumecs (75 % of the historical summer mean flow) to be maintained. There is clearly an outstanding issue in deciding exactly which percentile exceedance of available habitat area we can define as being `ecologically acceptable'. Further model applications to similar issues and definitive observations of habitat suitability under a range of reduced flow conditions, will give a clearer picture of the level at which sustained periods of low habitat availability become critical to species success.

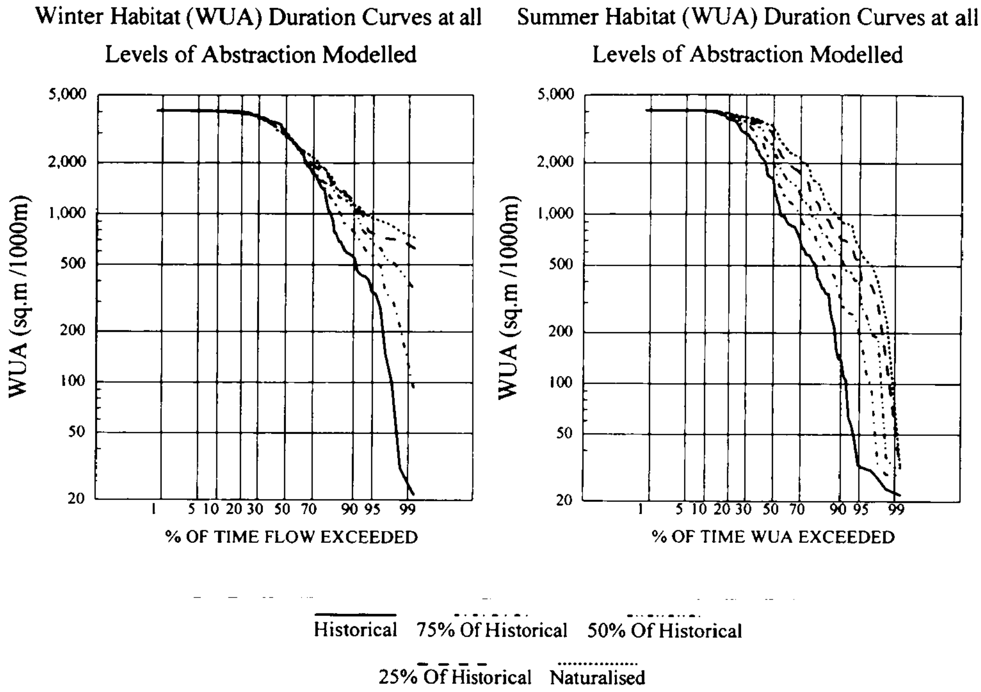

Figure 5 : Station aval : courbes des durées d'habitat classées des truites alevins/juvéniles pour tous les niveaux de réduction de débits analysés.

Figure 5 : Downstream site : summer and winter fry/juvenile trout habitat (WUA) duration curves for all levels of abstraction examined.

Tableau I : Présentation des résultats obtenus à partir de PHABSIM en nombre de jours ou une proportion donnée de maximums de durées d'habitat classées n'est pas dépassée.

Table I : Presentation of PHABSIM outputs as number of days the given proportions of maximum available WUA are not exceeded.

Percentage of maximum WUA	Number of days this WUA value not exceeded			
	Natural Flows	At 50% PWS Abstraction	Historical Abstraction	Percentage Improvement
15	2	9	31	76
26	9	25	69	73
35	18	45	87	61
100	151	160	169	50

The results presented here were used by the National Rivers Authority in negotiations with Bournemouth Water PLC to formulate an Action Plan for the River Allen. The output from the study was presented along with the results of the other work carried out on the river, by the NRA, as shown in the example given in Table I. The outcome of these negotiations was an agreed proposal to reduce current abstraction rates by 50 per cent.

REFERENCES

BOVEE K.D., 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. U.S Fish & Wildlife Service Instream Flow Information Paper No.12, FWS/OBS-82/26, 248 p.

BOVEE K.D., 1986. Development and Application of Habitat Suitability Criteria for Use in The Instream Flow Incremental Methodology. US Fish & Wildlife Service Instream Flow Information Paper No. 21, 235 p.

JOHNSON I.W., ELLIOTT C.R.N., GUSTARD A., 1994. Data requirements and collection procedures for application of the Instream Flow Incremental Methodology in the UK. Institute of Hydrology report to the National Rivers Authority, 32 p.

JOHNSON I.W., ELLIOTT C.R.N., GUSTARD A., CLAUSEN B., 1993. River Allen Instream Flow Requirements. Institute of Hydrology Report to Report to National Rivers Authority Wessex Region, 42 p.

MILHOUS R.T., WEGNER D.L., WADDLE T.J., 1984. User's guide to the Physical Habitat Simulation System. Instream Flow Information Paper 11, U.S. Fish & Wildlife Service FWS/OBS-81/43 Revised, 475 p.

MILHOUS R.T., UPDIKE M.A., SCHNEIDER D.M., 1989. Physical Habitat Simulation System Reference Manual - Version II. Instream Flow Information Paper No. 26, U.S. Fish & Wildlife Service Biol. Rep. 89(16), 191 p.

National Rivers Authority, 1993. Low Flows and Water Resources - Facts on the Top 40 Low Flow Rivers in England and Wales. 258 p.

NEWMAN A.T., SYMONDS R.D., 1991. The River Allen - A Case Study. *In* Procs. BHS 3rd National Hydrology Symposium, Southampton, 1991, 64 p.