Institute of Freshwater Ecology

Literature Review of the Severn-Thames Transfer

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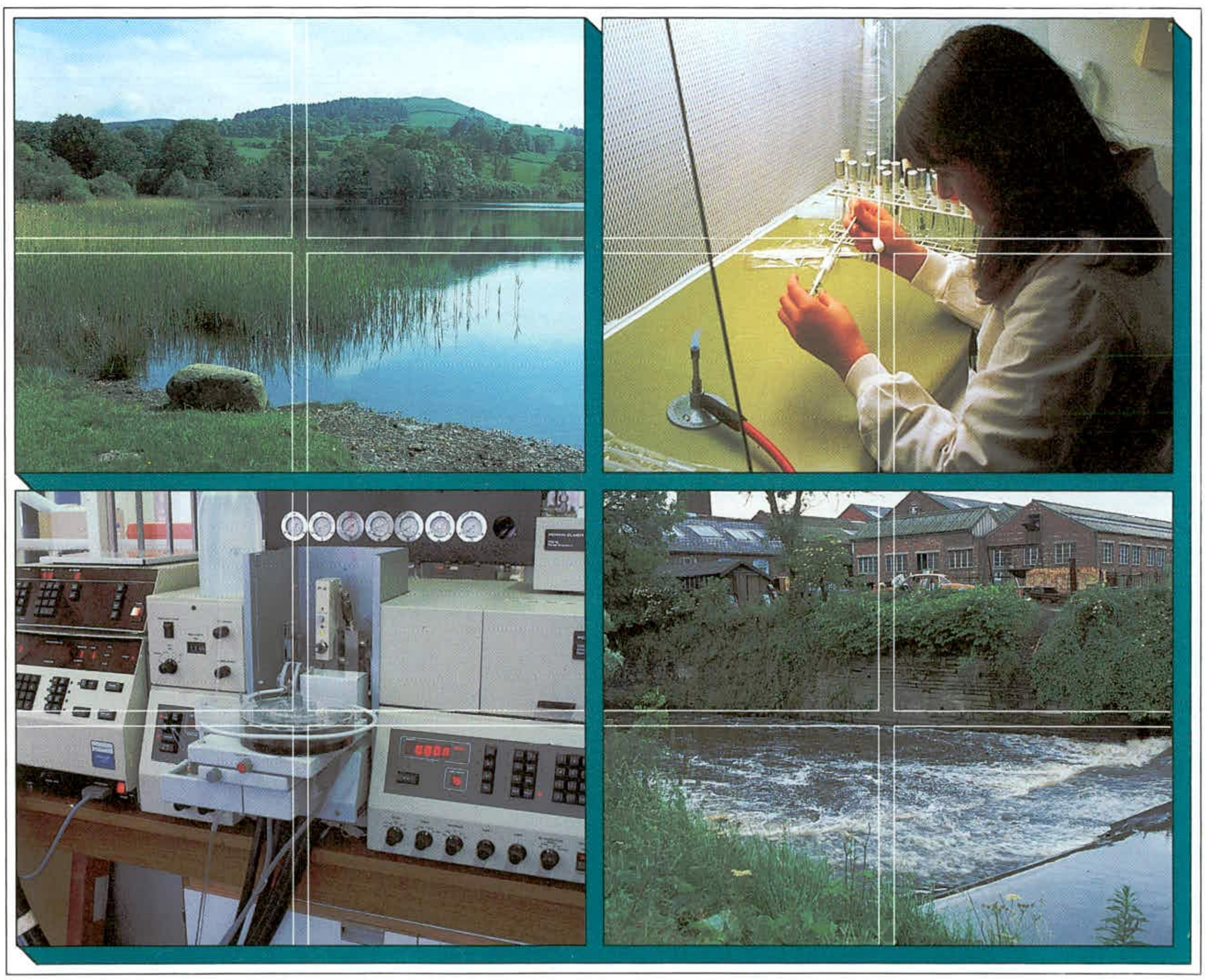

Natural Environment Research Council

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EXECUTIVE SUMMARY

This project on the proposed Severn-Thames water transfer had two initial objectives:

a) to review literature on the ecological impacts of water transfer schemes,
b) to identify Key issues relating specifically to the Severn-Thames scheme and to scope appropriate studies to investigate these issues.

The literature review revealed an abundance of general papers on potential ecological effects of water transfers, both on the donor and the recipient river. There were few documented case studies in which causal effects were clear, and many schemes involved the transference of water volumes were far greater than those envisaged in the Severn-Thames scheme. Some useful information was obtained from accounts of water resource schemes other than those involving inter-basin transfers.

The transference of plant and animal species not already present in the recipient river was described in some papers from North America and South Africa. Other papers emphasised the changes in physical habitat associated with a modified flow regime, together with some observations on floral and faunal changes. No papers described the ecological consequences of mixing waters with different chemical constituents.

The key issues relating to the Severn-Thames transfer are based on information gleaned from the scientific literature plus ideas developed in consultation with IFE colleagues.

The Key Issues are:

a) Changes in the water chemistry.
b) Changes in the flow regime and temperature.
c) Movement of sediments.
d) Transfer of algae and invertebrates.
e). Development of lentic populations of algae and nutrients in the Thames-side reservoir and their transference to the river.
f) Changes in micro-habitat distribution, growth and survival of newly-hatched fish.

1. INTRODUCTION

The AIM of this report is to review current literature on the environmental implications of inter-basin transfers of river water. Key issues requiring further study are identified, and outline project proposals, including costs and timescales, are presented.

Previous reports to Thames NRA (CWPU 1980; Atkins 1992) examined the possible effects of transferring river water from the lower Severn to the upper Thames, and the information in these reports is used as a starting point. Specific issues raised therein are dealt with in the appropriate sections below.

A major problem with these reports and many others in the scientific literature that deal with water transfer schemes (e.g. Biswas 1981) is that they contain little direct evidence of environmental effects. Many only hypothesize about likely effects and then list those issues that the author(s) considers to require further investigation. Other publications concentrate on the effects of reduced flows in the donor river, which is outside the remit for this report.

Few papers describe actual effects of water transfers and some of those that do so, particularly those from China (e.g. Liu & Ma 1983; Liu & Zuo 1983), North America (e.g. Hirsch et al. 1990) and the ex-USSR (e.g. Antypko et al. 1982), deal with schemes that are considerably greater than the proposed Severn-Thames transfer. In a review of interregional water transfers, Golubev & Biswas (1978) noted that the least solved question was 'the methodology to assess environmental costs ... and to forecast their impacts on nature'. However, there have been a number of studies on the environmental effects resulting from flow changes caused by other water development schemes from which useful lessons can be drawn.

In the following sections, information on observed physical and chemical changes associated with water transfers and other water resource developments are examined (Sections 2 & 3), and then the environmental consequences of such changes are reviewed (Section 4). Where possible, emphasis has been placed on describing observed environmental consequences of water transfers and other flow modifications, although hypotheses about likely effects are also included as appropriate.

Inevitably there are important gaps in the published database, and these are identified in Section 5, which summarizes the key issues and outlines the priorities for further investigations. But a useful warning concerning the lessons that can be drawn from studies in other catchments comes from Dávid (1985), who concluded from analyses of water transfer practices that most of the problems that arise from such schemes are unique, as are their solutions..

In any discussion, river ecosystems should be viewed from four dimensions:

a) longitudinally from upstream to downstream sections,
b) transversally across the river channel,
c) vertically from the interstices of bottom sediments to the water surface,

d) temporally, in relation to diel, seasonal, annual and long-term events.

Aspects of each of these dimensions are included in the rest of this report. Of special importance are the upstream-downstream linkages as exemplified in the River Continuum Concept. This suggests that plant and animal community structures and functions adjust to changes in stream flow, channel morphology, detritus loading, size of organic particles and thermal responses. As these variables change from the headwaters to the mouth of a river, then so will the plant and animal communities (Vannote et al. 1980). Inputs of water and associated nutrients and biota have the potential to alter this continuum, either adversely or beneficially.

In considering the issues most relevant to the proposed Severn-Thames transfer, it has been assumed that the Severn water will be held in a small reservoir outside the Severn floodplain, but close to the abstraction point. At transfer rates of 200 to 400 Ml day^{-1}, the turnover period in this reservoir would be about one week. Transferred water would then be held near the Thames, but outside the floodplain, before entering the Thames near Buscot.

The storage volume that will be available in the Thames-side reservoir is not known at the present time as it depends upon the scale of gravel extraction at the proposed Down Ampney site. The Atkins (1992) report refers to a capacity of 6000 Ml, but the Howard Humphreys' (1992) report gives a figure of 25 000 Ml, which gives a turnover period of approximately 50 to 100 days at the proposed pumping rate. As the turnover rate is directly linked to storage capacity, the latter will affect potential impacts on the Thames biota.

The volume of transferred water discharged at Buscot would be at least twice that of the natural discharge of the Thames. The duration of water retention in the Thames-side reservoir may have marked effects on the level of suspended solids, temperature and dissolved oxygen (Edwards & Crisp 1982), and also on the phytoplankton and zooplankton populations.

2. PHYSICAL EFFECTS

2.1 Flow patterns

In any assessment of the environmental changes arising from a water transfer scheme, the important consideration is not simply the magnitude of the transfer discharge but the ratio between this discharge and that of the recipient river. A feasibility study indicated a maximum transfer rate (based on pump capacity) of 400 Ml day^{-1}, with a predicted frequency of transfer close to one year in two. Most transferred inputs to the Thames would take place in the late summer and autumn when mean discharges (based on 1987-1992 data) are: September, 150 Ml day^{-1} ; August & September, 200-250 Ml day^{-1}; October to December, 600 Ml day^{-1} (Atkins 1992). However, the abstraction from the Severn may take place during periods of higher discharge, with water being retained in a holding reservoir in the Thames catchment.

Consequently, the principal physical change arising from the proposed transfer will be to increase the minimum flows in the River Thames in dry summers; there will be no alteration in the frequency or magnitude of natural flood events, although this is a feature of some U.K. water transfer schemes (Higgs & Petts 1988). Although the modified flow patterns will be within the natural limits of the Thames, the changes imposed by the transfer may occur at an unnatural frequency.

Higgs & Petts (1988) noted that the provision of reliable water supplies from a variety of sources, including water transfers, has led to the progressive increase in dry weather flow discharges in most rivers in central, southern and eastern England. One of their figures (derived from data provided by Thames Water) shows that the dry weather flow of the Thames at Teddington has increased from about 12.5 l s^{-1} km^{-2} in 1935 to nearly 20 l s^{-1} km^{-2} in 1985 as a result of the return of treated effluent. In the Thames catchment there are opportunities for the re-use of water, for example the effluent from Swindon is discharged into the River Ray, which creates opportunities for reabstraction at Farmoor reservoir.

Summary: Changes in the flow regime will be within the range of discharges currently encountered, but their periodicity is likely to be different.

2.2 Erosion of the channel

The main channel of the River Thames at Buscot is about 25 m wide, it has a sinuous form with a predominately gravel and sand substratum. The depths are mostly less than 2 m and the channel is maintained for navigation. Most banks (c. 80%) have a vertical profile but there are a few cattle drinks, reedbeds and some riparian tree cover. Boat locks and by-pass channels are present.

Brookes (1995) observed that in active sinuous and straight channels, which include most lowland rivers in the U.K. including the Thames, high flows are insufficiently powerful to cause erosion of the river banks. Consequently there is no migration of the river courses across the floodplain. The gross channel morphology of the Thames is not expected to change in response to transfer discharges (natural flood events provide much higher discharges and impacts). Moreover, channel capacity and discharge increase substantially downstream (15-30 km) of Buscot, with inputs of tributaries such as the Cherwell and Thame around Oxford.

It is not expected that an increase in channel capacity will be necessary. This was necessary for the Ely Ouse-Essex Stour transfer, in which dredging of the headwaters of the Stour was required to accommodate the increased discharge. Even so, fishery users did not consider the changes to be detrimental as they gained an extra 16 km of fishable water (Linfield 1985).

Summary: No gross changes in channel morphology are expected.

2.3 Sediment and sediment transport

There is a proposal to intercept some of the suspended solids from the River Severn water by settlement in a storage area adjacent to the Severn (English et al. 1979; CWPU 1980) before transfer takes place. This is required for a number of reasons, including protecting the pumps and pipeline and to minimise maintenance requirements. The transferred water is then likely to be held in a reservoir in the Thames catchment, which will be operated as a balancing and blending system. Consequently, changes in sedimentation characteristics in the Thames are more likely to arise by the mobilization of materials already present, through increases in flow, rather than resulting from increased sediment load from transferred water.

The natural seasonal cycle in river discharge prompts autumn/winter washout of sediments that have been deposited in the summer. Transfer of Severn water in late summer may introduce some sediment to the Thames, but associated increases in water velocity may inhibit any increase in settled bed material near the discharge point.

Carling (1995) has reviewed the implications of sediment transport for instream flow modelling at the micro-, meso- and macro-scale. Only the first two scales are of relevance to the proposed transfer; as noted in Section 2.2, no changes at the macro-scale are expected.

At the meso-scale, sediment is more prone to entrainment in the water column when flows are increasing but, in many rivers, high flows of at least two-thirds bankful are necessary to mobilize the coarse fraction (>5 mm) in natural rivers. However, in the Thames it is difficult to relate discharge volumes to water height because of the effect of the many weirs and sluices. Although fine sediments could be mobilized at lower flows, higher flows are needed initially to flush them from the interstices of the coarse material on the channel bed. At flows that are sufficiently high to mobilize fine material, injection of the fines into coarse substratum can occur. As flows decrease (e.g. after a transfer), siltation of the river bed is more rapid (Carling 1995).
There is likely to be considerable between-year variation in the timing and extent of sediment accumulation and loss, and in the consequential indirect impacts on the biota. Hence, precise predictions of subsequent within-river changes will be problematic.

Reice et al. (1990) state that, in general, the velocities needed to mobilize sand (grain sizes from 0.05 to 0.5 mm) are lower than for other particle sizes of sediments. As particle size increases, the critical velocity increases due to mass. As particle size decreases from sand to silt and clay (from 0.05 to 0.001 mm), the critical velocity also increases because of the adhesive properties of the fine particles. Therefore, re-distribution of bottom sediments varies in its nature according to the precise changes that occur in river current velocities.

At the macro-scale, sediment-free water discharged from a reservoir into the Missouri River, USA, had the potential to erode the river bed and banks (Hesse et al. 1982). Even in the much smaller River Rheidol, Wales, channel changes were induced by the injection of sediment from a tributary. Dispersal of the particles both longitudinally and laterally occurred, with lateral deposition creating side berms and confining the main flow line. As a consequence, the Rheidol was reduced to one-third of its previous channel capacity (Petts 1984).

The concept of storage ('dead') zones (Reynolds 1995) has relevance to sediment movement and deposition. Sear (1995) reported the accumulation of fine sediment berms in areas of dead water in the North Tyne following regulation of its flows from the Kielder reservoir. Other morphological changes were the development of sediment bars at the confluence with tributaries and the appearance of vegetation on former gravel shoals that had accumulated sediment deposits (Section 4.2.2)..

Carling et al. (1992) have described the behaviour of fine particles and flocculent material that settle or erode within storage zones in the upper Severn. If such zones occur also in the Thames, their effects on the river system may be altered by the insertion of increased flows during low flow periods.

In a U.S. stream, discharges from filter back-washing were 3 to 4 times base flow and occurred from 10 to 60 times per day, each for about 10 minutes. In addition, pulses of wash-water gave discharges of 40-50 cubic feet s^{-1}. Fine sediment in the water rose from 10-20 to >300 mg l^{-1} over 2 minute periods of wash release (Erman & Ligon 1988). Fluctuating flows without sediments had little impact on invertebrate populations but, where the bottom sediments were perpetually unstable, depressed invertebrate populations were found up to 2 km downstream (the river then discharged into a reservoir).

Summary: **Changes in the distribution of fine materials on the river bed and in the water column are expected as a result of water transfers. However, until data on sediment dynamics on the Thames at Buscot are available, the significance of possible changes are unknown.**

2.4 Temperature changes

Some changes in the diel and seasonal water temperatures of the Thames below the transfer input point at Buscot may result from input of water from the Severn. As with the impact of pollutants (Section 3.3), the level of change that may occur will depend on the dilution effect of the normal Thames flow. Examination of data on the water temperatures of the lower Severn and upper Thames were not part of this contract, but the values are not likely to be exactly the same. In addition, lengthy storage in the Thames-side reservoir may modify the amplitude of seasonal and diel fluctuations in water temperature, as occurred through discharge from Cow Green reservoir into the River Tees. In that situation there were also delays in the spring rise and autumn fall in temperature (Edwards & Crisp 1982).

CWPU (1980) only referred to water temperature changes in relation to the River Evenlode route option, and Atkins (1992) recommended more detailed assessment of water temperature changes that might occur.

Summary: **The direction and magnitude of water temperature changes in the Thames, downstream of Buscot, cannot be predicted until specific transfer conditions are defined.**

3. CHEMICAL EFFECTS

3.1 Changes within the pipeline

Retention of water within the pipeline could lead to problems of water quality. Experimental studies by Coates & Ruffle (1982), in relation to the Tyne-Tees-Wear transfer, suggested that the levels of dissolved oxygen (DO) could fall to 1 mg l^{-1} in a period of 10 to 60 days, depending upon the initial condition of the water. These authors also suggested that a high concentration of sulphides could occur in the pipeline as a result of degradation of sulphates. Cascading the water at the outlet was proposed as a solution although, in relation to the Severn-Thames transfer, Atkins (1992) suggested the maintenance of a low pumping rate between transfers. The option of transferring water first to a holding reservoir before it enters the main Thames channel may be a means of overcoming such problems, particularly if the water is aerated in the reservoir.

Summary: It is important to maintain the quality of water in the pipeline, especially the level of dissolved oxygen.

3.2 Mixing of Severn and Thames water

Schemes involving the transfer of water between river systems is described from many parts of the world (General review, Biswas 1981; Canada, Sewell 1995; USSR, Voropaev & Velikanov 1985; USA, Micklin 1985), although none addressed the problem of mixing water from different catchments. A selection of environmental appraisals within England and Wales was the subject of a report to the NRA (Howard Humphreys 1994).

Water quality changes to the receiving river may result from direct contrast in water chemistry on a simple proportional basis, or from chemical responses to the mixing process. To overcome any such mixing problems, the Welsh Water Authority proposed a direct pipeline from the River Wye to a 272.6 Ml storage reservoir, before release of water into the River Usk (Goodman 1980).

Both the CWPU (1980) and Atkins (1992) reports examined the impacts of mixing on the water chemistry of the Thames as a result of water transfer from the Severn. Atkins (1992) considered that any changes would be restricted to a short section of river below the Buscot discharge point. Increase in channel size and the addition of tributary streams would diminish any effects further downstream. This report suggested that the total hardness, pH, BOD and other dissolved components did not differ markedly between the two rivers. In contrast, the CWPU Report (1980) predicted a reduction in alkalinity and total hardness, an increase in chloride, sulphate and total organic nitrogen levels and unchanged levels of orthophosphate in the low flow rates occurring in the summer and autumn. These conclusions were based on assumed transfer rates of 225 and 680 Ml day^{-1} from Haw Bridge (Severn) to Eynesham (Thames), although the current suggestion is that the rate will be from 200 to 400 Ml day^{-1} (Thames NRA, pers. comm.).

Although the mean concentrations of certain chemicals may be similar in the Severn and Thames, they may differ in the way they vary seasonally. For example, from computer simulations Birtles & Brown (1978) predicted no change in the mean levels of orthophosphate in the Thames as a result of the transfer. However, they did expect a decrease in the higher percentile values. Increases or decreases in the frequency of extreme values of many substances may be important to the biota of the Thames, especially if the substances are hazardous (Section 3.3).

In assessing the effect of mixing Severn and Thames water, the chemical changes within the two holding reservoirs also need to be considered. Impoundments can cause a pronounced smoothing of the short-term fluctuations in ionic concentrations, which are typical of many natural rivers (Edwards & Crisp 1982). For example, the observed concentration of calcium in the River Tees upstream of Cow Green reservoir during 1975 ranged from 3.5 mg l^{-1} at high discharge to 37.2 mg l^{-1} at low discharge. In comparison, calcium concentrations in the water released from the reservoir ranged from 6.4 to 8.8 mg l^{-1} (Crisp 1977).

Summary: Increases and decreases in the concentrations of various chemicals are likely to be small, but the seasonal variation in concentrations may change.

3.3 Transfer of herbicides, pesticides and other pollutants

3.3.1 Problems associated with intermittent pollution incidents

The transfer of herbicides, pesticides and other hazardous materials into the Thames from pollution incidents in the lower Severn has potentially serious consequences. The risk of such an event is demonstrated by an incident of herbicide pollution caused by the release of 2-3-6 trichlorobenzoic acid (TBA) into the Ely Ouse and transferred via pipeline to the River Stour, although the effects on the Stour biota were not recorded (Guiver 1976).

CWPU (1980) expressed concern about the possible intermittent transfer and discharge of hazardous materials, and the desirability of carbon filtration to remove organic materials at downstream abstraction points. Although monitoring of the quality of the Severn water will assist in the operation of water transfers, an unknown factor is the synergistic effect of mixing toxic chemicals from the River Severn with any that occur in the Thames (Sections 4.3.4 and 4.4.4). The extent to which joint effects deviate from a simple additive effect may depend upon several factors, including the time over which any biotic response is measured and the type of toxicant and its proportional contribution to the toxicity of the mixture (EIFAC 1980).

Yount & Niemi (1990) reviewed the impacts of pesticides and other chemicals on invertebrate and fish communities, giving examples mostly from U.S.A. rivers and streams. They distinguished between intermittent, pulse events and longer-term, sustained inputs. From the examples cited, they concluded that recovery from pulse events was often rapid, especially where inputs from unaffected tributaries assisted the biota to recolonize affected river sections. This would be the situation with the Severn-Thames transfer, whereby cessation of water transfers that are creating pollution problems, would enable normal Thames flows to assist recovery. An example is the River Rhine, which has suffered several pollution incidents that caused massive kills of fish and invertebrates. However, the invertebrate populations were able to recover completely after no more than two generations, the short-lived species recovering faster than long-lived species (Van Urk et al. 1993).

The impact of herbicides on the aquatic flora is related to the immediate, short-term effect and, more importantly, to the longer-term problem of recolonisation. However, there is often difficulty in differentiating between the effect of a herbicide and those of other factors that could bring about long-term changes. Both the concentration and the exposure time are important in determining any effect. If the concentration of the herbicide is at a toxic level, then some or all plant species could be killed; but at lower concentrations, plant growth could be reduced (Barrett & Wade 1988).

In contrast to these problems, water transfer can be used to mitigate the effects of pollution in the recipient river. Diversion of extra water via the Ely Ouse transfer was used to reduce the effect of a release of liquid ammonia into the Essex Stour (Guiver 1976). Similarly, an oil pollution in the River Tees was successfully treated by a major release of water from the Tyne-Tees transfer (Cave 1985).

3.3.2 Background levels of pesticides and herbicides

A valuable review of the impacts of low but persistent levels of pesticides and herbicides on river biota is given by Ashby-Clarke et al. (1994). They report a range of effects, including reduced species diversity of invertebrates (zooplankton and macroinvertebrates) through increased mortality or drift, and changes in fish behaviour. The report gives some information on pesticide and herbicide levels from the Severn-Trent Region but mostly from small streams. It stresses the lack of knowledge of sediment-bound compounds and their toxicity, which is of concern to the proposed Severn-Thames transfer in view of the potential transfer of suspended solids. The report also points to the lack of research of herbicides on non-target plants species but notes that, as the action of many herbicides is the inhibition of photosynthesis, non-target species are at risk.

The importance of persistent micro-contaminants was also emphasised by Hendriks (1995). Heavy metals and less persistent organic substances can accumulate in lower trophic levels, whereas more persistent organic chemicals (e.g. PCBs) can pass through the food chain and accumulate at higher trophic levels, such as in fish.

Sublethal effects create a particular problem because they are difficult to detect. Moreover, the impacts may be indirect, for example Snieszko (1974) implicates sub-lethal levels of pesticides and other pollutants on an increased risk of disease in fish (Section 4.5).

Summary: **Transfer of hazardous chemicals either from pollution incidents or as persistent low-level contamination of Severn water, could have serious environmental consequences. The risk of pollution incidents is not known, but will depend on the level of pollution and the degree of dilution by the Thames discharge.**

4. BIOLOGICAL IMPLICATIONS

4.1 Algae

4.1.1 Flow changes

Water transfers may affect the algal populations in the recipient river through: a) alteration of the flow regime of the river; b) transfer of algae from the donor river; c) a combination of the two processes. The changes that accrue may differ between the planktonic algae and those attached to the substrata (periphyton). However, the CWPU (1980) Report concluded that algal growth was controlled chiefly by the underwater light regime.

Acs & Kiss (1993) examined the effect of disturbances in the River Danube, Hungary, on the algal flora attached to artificial substrata. They found that floods provided the most significant disturbances, with the impact being greater if the floods were repeated every 8 days than if the repetition was at 14 day intervals. They concluded that, as different periphyton species are attached in different ways and with differing efficiencies, the changes in total mass occurring as a result of changes in water discharge lead to changes in species diversity.

Whitton (1975) considered that true plankton are not normally resident in most floodplain rivers (such as the Thames), and he stressed the greater importance of drift from periphytic communities. Despite Whitton's comments, phytoplankton species can and do occur in many rivers and may form a valuable food source for many invertebrate and fish species (as in the Great Ouse, Mann et al. 1995).

The normal sequence of algal growth in the Thames is an increase in diatoms in the spring, followed by green algae in the summer and sometimes a further growth of diatoms in the autumn. Under low flows, blue-green algae may become established in the late summer (Sexton, 1988). The precise timing of this sequence is likely to vary between years. For example, in the River Great Ouse, the timing of the spring phytoplankton bloom depended partly on the light regime, but also on the river discharge during the winter/early spring period. During years with late winter rains, there was a clear phytoplankton maximum in May, which was followed by a steady decline. In a year with a prolonged drought starting in March, phytoplankton growth started earlier and continued though July (Marker & Collett 1995).

In most rivers, higher algal populations occur in the lower reaches; for example the populations of Stephanodiscus at Montford Bridge (River Severn) were 1.3 to 1.8 times greater than at Melverley, some 16.5 km upstream (Reynolds 1995). In the Thames, diatoms were often proportionally and absolutely a minor component at stations in the upper Thames (Reynolds 1995). Therefore, although the algal populations of the Severn and Thames are very similar (Collie 1978), a water transfer from the lower Severn to the upper Thames, either directly or via a holding reservoir, could have a marked effect on the species composition of the Thames algal community. It could also increase the time available for the transferred algae to reproduce by, in effect, increasing the length of the water course down which they travelled.

Whether or not an algal inoculum from the Severn will affect the Thames populations, either qualitatively or quantitatively is difficult to predict. Much will depend upon the effects of retention in the Severn and Thames holding reservoirs, and whether or not the nutrient levels in the Thames are sufficient to support an increased algal population.The level of sunlight is also important and this may be high in years when there are low flows and when water transfers are necessary. The growth of algae under such conditions may create other changes. Thus, Moore (1976) noted that benthic and epiphytic growths of algae could become detached during periods of rapid photosynthesis. As transfers are likely to occur after a period of dry (sunny) weather, wash out of such materials may well be a consequence of the increased flows (see Section 4.2.2).

Differences in water chemistry between the Severn (primarily surface water) and the Thames (primarily groundwater) may also affect the growth of transferred algae and those resident in the Thames. However, it is not possible to comment upon the potential importance of such effects without more chemical information associated with mixing of Severn and Thames water.

Steel (1986), quoted by Sexton (1988), constructed a model to predict the effects of flow on algal growth in the lower Thames and it is possible that this model could be adapted to predict changes associated with increased minimum flows at Buscot. However, it would also need to include an assessment of the impact of an algal inoculum from the Severn. For example, Solomon (1975) describes the case of the Ely Ouse-Essex Stour transfer, in which high counts of the diatom Stephanodiscus at the intake were mirrored by high counts at the abstraction points on the Stour and Blackwater. Previously, Stephanodiscus had been seen only rarely in Essex rivers, Melosira being the most numerous diatom. Increased chlorination (up to 9.6 mg l^{-1}) of the transferred water removed the problem but, in February 1973, water abstraction from the Stour and Blackwater had to be suspended because of high Stephanodiscus concentrations, even though there were no correspondingly high concentrations in the Ely Ouse. It appeared that the original inoculum of Stephanodiscus had been enough to create a new problem alga in the Stour.

The importance of storage ('dead') zones in rivers in the development and maintenance of river phytoplankton stocks (Reynolds 1988, 1995) is now generally recognized. What is less clear is how such areas of the river, in which flow is negligible, are altered by changed flows, especially by the input of artificially high flows from a water transfer.

Summary: There is a strong likelihood that planktonic and attached algae will be affected, both quantitatively and qualitatively, by the transfer but it is not possible to predict the precise nature of the changes.

4.1.2 Sediments and turbidity

Reynolds et al. (1990) observed habitat differences between diatoms and chlorophytes in a circulating channel. They concluded that either channel deepening or increased turbidity though winter flow, or both, would favour the development of diatoms, such as Stephanodiscus and Cyclotella, which are better able to intercept light and take advantage of short photo-periods (Reynolds 1995). Conversely, decreasing discharge, falling river levels and a reduction in suspended sediment load (turbidity) would favour chlorophytes, e.g. Scenedesmus and Chlorella-like species. With seasonal fluctuations in flow, the boundary between diatom and chlorophyte dominance can move upstream or downstream. Thus, the potential impact of transfer-induced changes in flow pattern can be readily appreciated, even if the precise quantitative and qualitative changes cannot be predicted.

Differences in the effect of water transfers are likely to take place between an input directly to the Thames channel and an input into a small holding reservoir. Thus, Herrmann (1983) suggested that influx of water with high silt and nutrient content into a lake (reservoir) may have beneficial effects, such as reduction in turbidity, oxidation of organic material and coliform reduction, but also may have detrimental effects such as algal blooms, siltation, build-up of inorganic substances and lower re-aeration.

Summary: Changes in the composition and distribution of planktonic and attached algae may result from the transfer.

4.1.3 Temperature effects

Reynolds & Glaister (1992) used thermal-line scanning to examine the surface temperatures of a 10 km section of the Severn. In general, warmer zones corresponded to the storage ('dead') zones to which reference has already been made. Changes to the Thames temperature regime as a result of the transfer could influence the growth of phytoplankton species in both the storage zones and in the flowing channel. The influences could differ between algal species. However, by combining temperature and turbidity data (Section 4.1.2), the cell-replication rates (= growth) of individual algal species can be predicted using a model developed by Reynolds (1989).

Summary: The effects of temperature changes (when known) on algal populations are predictable.

4.1.4 Chemical effects

The CWPU (1980) Report concluded that the chemical changes described in section 3.2 are not likely to affect the distribution of the biota of the Thames, and that nitrogen and phosphate were not limiting to algal growth. This was considered to be controlled chiefly by the underwater light regime (see section 4.1.1).

Summary: Changes in the level of chemical nutrients are not likely to affect the algal populations.

4.2 Macrophytes

4.2.1 Flow changes

Water flow affects river plants both directly by the force and turbulence of its movement, and indirectly through their metabolism by affecting the supply of nutrients and the removal of by-products. Often the flows experienced during floods are more important than the average flows, and there is a strong correlation between current-velocity tolerance and plant morphology (Westlake 1975). These short-term impacts of floods may be equated to short-term transfer events, but such extrapolation remains to be tested.

Water flow frequently varies with season through changes in the discharge rate, but the seasonal growth of plants can reduce flow velocities and encourage sediment deposition. This has important implications regarding the development and distribution of populations of invertebrates (Section 4.3.1) and fish (Section 4.4.1).

Major changes in flow may eliminate or strongly suppress the growth of a plant population. River plants have developed various strategies to overcome the effects of water flow, for example: greater structural strength, greater flexibility and by restricting their growth to non-critical seasons of water flow (Dawson 1988). Increased flow in the summer by water transfer has the potential to disrupt the benefits of such strategies and, if artificially increased flows persist for several weeks, may lead to a change in the composition of plant species in some habitats.

In the River Adour, southern France, changes in the hydrological regime between years affected the invasion of riparian plant species. Non-native plants were favoured by direct exposure to floods and by high flood frequencies, and the response to year to year changes in hydrology was rapid in both native and non-native communities. Moreover, variations in water level have the potential to disrupt flowering and therefore to reduce the contributions of in situ species to the seed bank in the river margin (Décamps et al. 1995).

Summary: Changes in current velocity are not likely to have major effects on the aquatic macrophytes, unless the increased flows persist for several weeks.

4.2.2 Sediments and turbidity

In general, the biomass of submerged aquatic macrophytes is proportional to the light levels reaching the river surface (Dawson & Kern-Hansen 1979). However, in most rivers the development of macrophytes is limited to depths of less than 1-2 metres, because of the attenuation in light level. In the River Thames, Nuphar was found to grow in water up to a depth of 2 metres (Mann et al. 1972). Increased turbidity resulting from the mobilization of sediment material and the displacement of periphyton can affect the underwater growth of aquatic plants (Vermatt & de Bruyne 1993). The detachment of periphyton growth under low flow conditions has already been noted (Section 4.1.1).

Although the light climate has a major influence on the potential occurrence of submerged macrophytes, it did not explain completely the observed distribution of plants in the River Vecht, The Netherlands. Here, wave action caused by boat traffic (mainly recreational) had a negative effect on the distribution of water plants (Vermatt & de Bruyne 1993). It seems likely that this impact will be greater under low river flows; hence, increased dry weather flows from the proposed transfer may have a beneficial effect.

Deposition of sediment can lead to the growth of aquatic plants, as occurred in the North Tyne following regulation of its flows using water from Kielder reservoir (Sear 1995). However, slow-growing species may be buried or eliminated by a rapid accumulation of silt (Edwards 1969). Movement of, and reduction in, areas of fine sediment may favour species associated with clean gravel, such as Ranunculus (Ladle & Casey 1972). However, the short time-scale of the proposed transfer events may inhibit such changes and they remain to be investigated.

Summary: **Major increases in turbidity may impair the underwater growth of macrophytes and decrease the maximum depth in which macrophytes can grow.**

4.2.3 Temperature effects

Low flows are often associated with summer conditions and relatively high water temperatures. Such conditions, which also include a reduced oxygen holding capacity by the water and decreasing light levels after mid summer, can lead to a decline in the seasonal growth of many macrophytes (Dawson 1988).

Summary: **Although plant metabolism is influenced by temperature, it is not possible to predict the changes that may result from water transfer.**

4.2.4 Chemical effects

Water flow facilitates a near continual supply of nutrients to riverine plants, either directly in the water or indirectly through the supply and refurbishment of sediments (Dawson 1988). This changing environment means that nutrients are not often a limiting factor for growth, particularly in lowland rivers such as the Thames and Severn.

Summary: **Changes in the nutrient supply to aquatic macrophytes as a result of water transfer is not expected to affect plant growth or species composition.**

4.3 Aquatic invertebrates

4.3.1 Flow changes

Discharge has a major influence on river invertebrate populations, both directly and via its influence on the temperature regime (see Section 4.3.3) (Stanford & Ward 1983). Substantial changes in the species composition of the macroinvertebrate community of the Great Fish River, South Africa, occurred as a result of a water transfer scheme (O'Keefe & de Moor 1988). In the U.K., an experimental release of Ely Ouse water into the River Colne, combined with heavy rainfall, caused a marked reduction in the numbers of Gammarus (Boon 1988).

A 20 year study of the River Glen, Lincolnshire (Bickerton 1995), revealed a strong correlation between the macroinvertebrate fauna and summer flows, although the precise relationships were site-specific. The situation was most complex in the middle sections of the river, where the high diversity of fauna was supported by a rich diversity of habitats, each of which responded differently to annual differences in flow. In general, mid-channel riffle areas, which were characterised by high current velocity, high DO and low siltation, supported such taxa as Rhyacophilidae, Simuliidae and Elmidae. Marginal areas with emergent vegetation were distinguished by a silted substratum, low DO and low current velocities. here the fauna included Sialidae and a range of molluscs and beetles.

Invertebrates are the main source of food for fish in most lowland rivers and, in the River Missouri, USA, most taxa were found associated with the aufwuchs or the river bed (Hesse et al. 1982). Similar results have been recorded for YOY (young-of-the-year) fish in the River Great Ouse (Mann et al. 1995) and in a preliminary study of the Thames at Abingdon (IFE Report to Thames NRA, due October 1995).

Transfer of Severn river water to one or more holding reservoirs and subsequent release into the Thames may have local implications for fish diets. Studies on the Great Ouse (Mann et al. 1995) and the Thames (IFE report to Thames NRA, due October 1995) indicate that zooplankton populations can build up in the shelter of marinas and other backwater areas but, with changes in river levels between such areas and the main river, such zooplankton (typically Rotifera, Copepoda and Cladocera such as Bosmina sp. and Daphnidae) can be drawn into the river where they supplement the diets of YOY fish. High concentrations of juvenile and older fish are also often found in the Great Ouse marinas and also in Thames' marinas, such as the one at Abingdon.

In a Montana stream, physical disturbances affected the distribution and abundance of benthic insects, with short-lived species rapidly colonizing disturbed areas (McAuliffe, 1984). From an experimental study, Malmqvist & Otto (1987) hypothesized that maximum diversity of benthic invertebrates is attained at intermediate frequencies or intensities of perturbations. They suggested that this was because sufficient immigration of animals to disturbed areas can occur without a few dominant species being able to out compete weaker species. Thus, depending on their frequency and duration, water transfers may have beneficial effects on a recipient river, although the species composition of the benthic fauna may be altered.

Summary: **Flow changes are likely to alter the composition of the benthic invertebrate community and may influence the distribution of zooplankton, either through its effects on the resident Thames biota, or by transference of invertebrates from the Severn.**

4.3.2 Sediments and turbidity

The movement of suspended or bed particles at the micro-scale (Carling 1995) is of importance to the ecology of the river. Supplies of nutrients, removal of metabolic waste products as well as direct physical impacts on invertebrates and algae are affected by such movement.

Fast current, high turbidity and substratum instability were identified as the key elements in reducing populations of benthic invertebrates in the main Missouri channel, with most invertebrate populations developing closer to the shore (Carter et al. 1982). Small filter-feeding organisms are particularly at risk; Cladocera and Copepoda had their filtering apparatus clogged by suspended clay particles, although the effect was less with coarser earth and sand particles (EIFAC 1964).

Using artificial samplers incorporating natural substratum, Erman & Ligon (1988) found that a fluctuating backwash containing fine sediment from a filter, treating abstracted water, created an unstable benthic substratum in a U.S. stream and, thereby, reduced the density of the invertebrate populations. The effects were apparent up to 2 km downstream of the discharge point.

Summary: **Any changes in the movement and distribution of bottom sediments will affect the benthic invertebrate populations, but the changes are not likely to be large in comparison with natural fluctuations.**

4.3.3 Temperature effects

Temperature is considered to be an important driving force in directing biotic responses in flowing waters as insect energetics are closely tied to thermal patterns (Stanford & Ward 1983). The thermal requirements of aquatic insects vary considerably between species, and between the life stages (eggs-larvae-pupae-adults) of the same species. Studies of natural and artificial thermal discharges into streams and rivers have shown that temperature increases can affect aquatic insects at the species and the community level, although data interpretation has been hampered because other factors (e.g. DO concentration change) interact with temperature (Elliott 1991).

Summary: **The effect of small temperature changes on many aquatic invertebrates is not known.**

4.3.4 Chemical effects

The direct effect of chemical nutrients on invertebrate populations is not known, but there may be an indirect effect if algal and macrophyte populations are affected, the former being an invertebrate food source and the latter generally providing shelter.

The synergistic effects on invertebrate populations of adding toxicants from the Severn to the Thames is not known. Current information is ambivalent, with the joint effects of some mixtures of toxicants from sewage and industrial wastes (see Section 4.4.4) being additive, whereas pesticide mixtures resulted in more than additive effects (EIFAC 1980).

Summary: **The effect of changes in chemical nutrients on aquatic invertebrates is not known. Mixtures of toxicants may have simple additive effects, or may have synergistic effects.**

4.4 Fish

4.4.1 Flow changes

River flows can influence the distribution of fish, especially the young-of-the-year (YOY) in two ways. First, by the direct impact of the current velocity on the fish, the level of which is determined largely by the fish's swimming ability. Second, by the impact of flows on the availability of different velocity habitats (see Section 4.2.1).

Although fish have different habitat requirements at all stages of their life-cycle, YOY fish are particularly sensitive to river flow velocities. These sensitivities differ between species and they change with the development of the fins and muscles of each species during its first summer.

High current velocities can displace YOY fish downstream, unless the fish can find shelter in low velocity habitats (backwaters, weed beds). However, this may not always occur, as is demonstrated by the Trent-Witham-Ancholme transfer scheme. This was designed to transfer surplus water from the lower Trent to the middle Witham via the Fossdyke Canal. The transfer enhances the flows in the Witham and enables mixed Trent/Witham water to be abstracted further downstream and then transferred to the headwaters of the Ancholme. A further abstraction from the lower Ancholme to Cadney Reservoir provides supplies for industrial areas of Humberside. by which very low flows in the upper Witham were enhanced. Pre- and post-transfer surveys of fish stocks revealed no detriment to the fisheries (Linfield 1985). These stocks are dominated by roach, gudgeon, dace, chub and pike (Anglian NRA fish survey reports).

There are few measurements of the velocities that can cause the displacement of YOY fish, but Mann (1995a) and Mann & Bass (1995) give data on the critical water velocities (CV_{50}) of YOY dace and roach. Both these species occur in the River Thames. The CV_{50} values refer to the water velocities that displaced 50% or more of a sample of fish within 3 minutes (based on experiments carried out in an artificial channel). The best models predicting CV_{50} incorporated both fish length and water temperature:

Dace	(length range 8.8 to 17.3 mm)	$F = -19.39 + 1.46L + 0.90T$	$r^2 = 0.888$
Roach	(length range 6.3 to 15.0 mm)	$F = -14.06 + 1.38L + 0.69T$	$r^2 = 0.812$

where F = water velocity (cm s^{-1}), L = fish length (mm) and T = water temperature (°C)

More recent work at the IFE Eastern Rivers Laboratory (Garner, unpublished) has shown that these equations may overstate the swimming abilities of these very small fish because, within the experimental channels, individual fish were very adept at utilizing the low flows associated with the bed of the channel (the flow measurements above are mean channel velocities). Garner's equations, based on the precise location of individual YOY fish within the channel are:

Dace	$F = -12.9 + 0.79L + 0.823T$	$r^2 = 0.742$
Roach	$F = -3.49 + 0.46L + 0.50T$	$r^2 = 0.691$

Chub $F = -2.96 + 0.60L + 0.39T$ $r^2 = 0.594$

Stahlberg & Peckmann (1987) also observed that the gudgeon, Gobio gobio, stayed near the bed of an artificial channel where water velocities were low relative to the velocity in the main water column. From their studies on several small fish species, these authors concluded that 400 mm s^{-1} was the maximum velocity that could be withstood for at least 15 minutes by most fish less than 120 mm in length.

The importance of temperature to swimming performance was demonstrated for Chalcalburnus chalcoides, a European cyprinid fish similar to the bleak, Alburnus alburnus, found in the Thames. Kaufmann & Wieser (1992) found a 30% reduction in critical swimming speed of small fish (2 to 100 mg wet weight) when water temperature fell from 20 to 15°C.

Note that these current velocities are higher than those preferred by the fish. Roach larvae (7.5 mm in length) selected areas of the River Hull (usually macrophyte beds) where current speeds did not exceed 20 mm s^{-1}, even though their fatigue velocity (50% of larvae displaced after one hour) was 69 mm s^{-1} (Lightfoot & Jones 1979). In addition, there is some evidence from an IFE study on the minnow Phoxinus phoxinus (Garner unpublished data) that preferred water velocities can alter as the distribution of current velocities across the river channel change with increase or decrease in discharge.

Also, roach larvae (mean length 10 mm) had foraging speeds of about 20 mm s^{-1} in aquaria, as compared with a CV_{50} of 100 mm s^{-1} (Wanzenböck & Schiemer 1989). These authors suggested that swimming speeds under these still-water conditions are similar to the preferred velocity for roach larvae that are holding station in a river.

In the River Frome, England, newly-hatched dace larvae were found only along the river margins where the velocity was less than 20 mm s^{-1} (Mills 1991). This marginal area represented only 2 to 3% of the surface area of the river, a similar proportion to that measured in the River Great Ouse (Mann & Bass 1995). In the Great Ouse, variations in water velocity from -21 to +135 mm s^{-1} were recorded at a single point one metre from the bank over a period of a few hours. The fluctuations were caused by the opening and closing of nearby navigation locks and automatic sluices. The negative value represents upstream flow caused by current eddies. The higher values had the potential to displace fish larvae downstream.

In an experimental study comparing a regulated and an unregulated stream, using North American stream fishes, Bain et al. (1988) found that over 90% of small fish species and size classes were restricted to microhabitats characterized by shallow depth, slow current velocity and concentrated along the stream margins. These fish had a reduced abundance in the regulated river and were absent from the site showing the greatest flow fluctuation. Conversely, another fish group (larger fish) utilized deep or fast (or both) microhabitats in midstream - and their density was higher in the regulated stream and peaked at the sites with the greatest flow fluctuations. Thus, highly variable and unpredictable flow regimes appear to affect fish differently, depending on the way they use the stream habitat , and such regimes can act to reduce community diversity (see Section 4.3.1 on the effects of flows on benthic invertebrate communities).

These data highlight the potential for disruption of the distribution of fish larvae as a result of increased flows caused by river transfer. However, in the Rivers Frome and Great Ouse, most fish larvae were shielded from the main effects of current velocity by sheltering among macrophyte plants (Section 4.2.1). Preliminary data indicate a similar situation regarding 0+ fish in the River Thames at Abingdon (IFE Report to Thames NRA due October 1995) and emphasise the importance of these marginal habitats.

Summary: **Changes in current velocity will affect the distribution of 0+ fish, especially those species that hatch during mid to late summer.**

4.4.2 Sediments and turbidity

The principal impact of sedimentation on fish occurs during their egg and early larval stage. Thus, Mills (1981) found increased mortality of dace eggs in areas where they had been covered by a deposit of fine sediment (<0.25 mm). Egg survival approached zero when the fine fraction of substratum particles rose to 25% by weight, compared with 80% survival when it contributed only 10%. The probable cause was a decrease in oxygen reaching the eggs. Dziekonska (1958) attributed the precocious hatching and subsequent high mortality of common bream, Abramis brama, embryos to low DO concentrations in the River Vistula, Poland, although these were not caused by siltation. Similar problems arising from low DO concentrations have been described for pike, Esox lucius (Raat 1988).

Erman & Ligon (1988) found that the survival of rainbow trout, Oncorhynchus mykiss, eggs in gravel redds was reduced to 42% by sediment deposition. Moreover, the reduced population densities of benthic invertebrates (section 4.2) apparently caused small fish to be displaced further downstream.

Carling (1995) noted that changes of river discharge can often result in rapid siltation, especially as flows decrease (e.g. after a transfer of water has taken place). Also, turbulent pulses can inject fine material into the interstices of coarse bed material at flows sufficient to entrain sand (i.e. to move sand in the water column).

Although the siltation of gravel spawning sites (dace, chub Leuciscus cephalus, barbel Barbus barbus) is of particular concern, silt can be deposited on substrata higher in the water column. For example, roach in the River Great Ouse lay their eggs on the exposed, underwater adventitious roots of willow, Salix, but not if they are in parts of the river where they collect silt (Mann, personal observation).

Changes in the turbidity of river water, through suspended inorganic or organic matter, have been examined in relation to the reactive distances of fish to prey and on their feeding success (e.g. Barrett et al. 1992). The results of various papers reviewed by these authors are contradictory. Some suggest that turbidity can decrease fish growth rates, although this effect has usually occurred at turbidity levels that are much higher than are usually observed in most disturbed streams. Others come to the opposite conclusion. Much will depend upon the particular fish species; for example the ruffe, Gymnocephalus cernuus, with its highly developed lateral line system and prediliction for feeding at low light levels, would be less disadvantaged than its close relative, the perch, Perca fluviatilis (Craig 1987).

A general summary of the effects of finely-divided, inert solids on fisheries is given by EIFAC (1964):

25 p.p.m.	No harmful effect.
25 - 80 p.p.m	Suitable for moderate to good fisheries.
80 - 400 p.p.m.	Not likely to support good freshwater fisheries, but some fisheries do exist at the lower end of the range.
Over 400 p.p.m	At best, only very poor fisheries are possible.

With levels of several thousand p.p.m., fish may not be killed as a result of several hours or days exposure, but siltation of spawning and feeding areas may have severe effects.

The sensitivity of the Thames fish populations to the nature of the bottom sediments is shown by the 31 to 64% reduction in the standing crop of chub and roach as a result of routine maintenance dredging. In the River Cole tributary, fish biomass in some sections were still only 10% of pre-scheme levels eight years later. However, rehabilitation of fish populations was possible by adding crushed limestone and flint gravels to the substratum; this enhanced invertebrate and macrophyte colonisation and provided some cover for fish (EIFAC 1984; Spillett et al. 1985).

Summary: Deposition of sediments on fish eggs will decrease the numbers that develop and hatch. Increased turbidity may affect the feeding rate of some fish species.

4.4.3 Temperature effects

It is well known that water temperature can affect the growth of fish, whose metabolism increases with increase in water temperature (Mills & Mann 1985; Mann 1995a,b). This is of particular importance for YOY fish because the speed at which they grow largely determines their survival rate, i.e. the faster they grow, the more quickly they become too large to be eaten by invertebrate predators. Consequently, an elevated river temperature regime (within the lethal temperature limits of the species) will increase the survival rate of YOY fish, other parameters being constant, whereas a decrease in temperature will reduce the survival rate. Year to year differences in the survival of YOY fish is reflected in the subsequent age structure among older fish (Mills & Mann 1985).

As Severn -Thames transfers are most likely to take place in late summer-early autumn, the species more likely to be affected are those that are spawned in mid-late summer (bleak, chub), rather than those that hatch earlier in the year (dace, perch, gudgeon). The effect on intermediate species will vary between years according to when they hatch. In the Great Ouse, peak spawning times of roach varied between early and late May over the years 1988 to 1993, inclusive (Mann 1995b).

Although water temperature has a pronounced influence on fish growth rates, these rates may be limited by the availability of prey organisms of the right type in sufficient quantity. In the Great Ouse, the growth of YOY roach fitted a temperature-based model over the early part of the summer, but then growth rates became less than the model predicted. The conclusion was that food had become limiting, and this was supported by the synchronous switch by roach from an invertebrate to an aufwuchs diet (Mann et al. 1995).

Summary: **Small changes in the temperature regime will affect the rate of growth and development of fish, especially YOY fish. This may affect their survival rate and the subsequent age structure and species composition among older fish.**

4.4.4 Chemical effects

The maintenance of adequate levels of dissolved oxygen (DO) in the water is of great importance to fish; hence the need to ensure that transferred supplies have not become de-oxygenated (Section 3.1). As a general guide, the following DO levels will allow most temperate fish species to maintain healthy populations, according to Dobihal & Blazka (1974), quoted by Holcik (1989):

Temperature (°C)	5	10	15	20
Dissolved oxygen (mg O_2 l^{-1})	4.75	6.00	7.25	8.50

The influence of toxic chemicals will depend on the nature of any that are transferred and their combined effect with any already present in the Thames. An EIFAC (1980) report noted that the acute lethal toxicity of commonly occurring constituents of sewage and industrial wastes (ammonia, phenol, cyanide, copper, zinc, cadmium, nickel, chromium, mercury and other metals and substances) was 0.4 to 2.4 times that predicted from the sum of the proportions. The effect of some chemical combinations were additive in the short-term but more than this in the long-term. With pesticide combinations, the joint effect tended to be more than the additive effect.

Less is known concerning sub-lethal effects, but the EIFAC (1980) report concluded that the effects of industrial and sewage wastes on fish growth were usually less than the additive effect.

In predicting the toxicity of river water, a major limitation is often that not all the pollutants have been identified (Brown et al. 1970). These authors also reported that long-term field studies revealed substantial mortalities of rainbow trout, even at concentrations 20% less than lethal concentration, especially with respect to chromium and cadmium. In general, the recommended concentrations of toxic substances should be less than 10% of the lethal concentration, although much lower concentrations are required for some materials (EIFAC 1980).

Summary: Any marked decrease in the level of dissolved oxygen could adversely affect the fish population; extreme low levels could cause fish kills. The effect of a transfer of toxic substances is unpredictable.

4.5 Transfer of fish diseases and parasites

Water transfers potentially have two effects in relation to fish disease:

a) the transference of infectious diseases - particularly transference of organisms such as viruses, bacteria, protozoa, parasitic helminths - to waters in which they do not occur, or in which their incidence is low.

b) the promotion of non-infectious diseases in fish in the recipient water, caused by adverse environmental conditions, which can occur as an extra impact on fish already under stress.

In the first case, diseases or parasites could be transferred between catchments via their fish host, via an intermediate host, or possibly as individual pathogens. One item of potential concern with regard to the Severn-Thames scheme is the transfer of eels carrying the nematode parasite *Anguillicola crassa*. However, the concern is much reduced by the presence of *Anguillicola* in the eel population of the Thames estuary (Pilcher & Moore 1993).

The impact of environmental stress on the susceptibility of fish to disease was reviewed by Snieszko (1974). He listed several environmental phenomena as important in this respect: significant modifications of water temperature ('thermal pollution'), low or extremely high levels of DO, eutrophication (which often causes frequent and wide fluctuations in DO and pH), sewage, industrial pollution and pesticide inputs (see Section 3.3).

The impact of low levels of DO on fish has been discussed in Section 4.4.4, but supersaturation can cause stress among fish. In the Columbia River, U.S.A., where supersaturation is caused by water under pressure in turbines and spillways, gas bubble disease is chronic in the fish community and more than 50% of fish may be lost through gas embolism (Snieszko 1974).

Price (1985) noted that there was a significant variation in susceptibility to disease among fish populations, both between different species and between different populations of the same species. This could mean that the transfer of pathogens from the Severn to the Thames may have effects not seen among Severn fish populations.

The differences in the parasite load of Severn and Thames fish is not known, but both fish communities are likely to carry many species. In the 1970s, Thames Conservancy staff found more than 75 species of parasites in 28 species of freshwater fish in the Thames catchment (Sweeting 1979).

Summary: **Fish parasites and pathogens could be introduced via the water transfer; the dangers associated with such transference are not known but they are considered to be low.**

4.6 Transfer of biota

4.6.1 Algae and macrophytes

The transference of the diatom Stephanodiscus along the Ely Ouse-Essex Stour intake has already been mentioned (Section 4.1.1). The effects of algal transfer from the Severn to the Thames are likely to be changed by storage of water in a Thames-side reservoir, where other algal species may thrive.

Summary: **The transference of algae via the water transfer is very likely, but its effects on the Thames population is uncertain. There is less risk of macrophytes being transferred to and established in the Thames.**

4.6.2 Invertebrates

The transfer of viable invertebrates from the Severn to the Thames will be restricted to resilient life stages of those species capable of surviving the lotic conditions of settlement reservoirs and the turbulence within the pumps and pipeline. Most riverine species are unlikely to survive for long periods in the settlement reservoirs, but the seeding and colonisation of these reservoirs may result in the introduction of lentic species. The survival of these species in the Thames will depend on the physical conditions therein, but it is envisaged that some species may colonise off-river marinas where the habitat resembles that of the settlement reservoirs.

Summary: **The transference of some invertebrate species is likely, but many species may already occur in the Thames. Species favouring low flow conditions may become established in the holding reservoirs and in Thames backwaters.**

4.6.3 Fish

The transference of fish species between catchments is recognized as a potential hazard of water transfer schemes. Yu (1983) predicted that water transfer (1000 $m^3 s^{-1}$) from the Chang Jiang (Yangtse) river could cause mortalities of young and eggs through the intake pipes, but that survivors could add to the fish populations in the recipient reservoir inland. Davies et al. (1992) report such fish movements as result of water transfer schemes in South Africa.

That fish can be transferred as a result of water transfers is shown by the movement of the pike-perch (zander), Stizostedion lucioperca, from the Ely section of the River Great Ouse to the Suffolk Stour via a water pipeline, despite an 8mm mesh on the intake screen.

Another example is the colonization by roach of Llandegfedd reservoir on the River Usk, despite screens of 380 μ, probably because some water was able to by-pass the screen (Solomon 1975).

The risk of the transfer of pike-perch is of some concern as this species occurs in the River Severn and, although some specimens have been found in the Thames, it is not currently established in the upper Thames. If the conditions in the upper Thames are suitable for pike-perch it is likely that, in the long-term, the species will spread there from the population downstream, although such progress may be inhibited by the many weirs on the river. There is a danger that transfer of eggs from the Severn could increase the rate of colonization, although this risk could be reduced by avoidance of water abstraction from the Severn during the spawning period (April-June).

However, the transference of other new fish species from the Severn to the Thames is less likely as there is a great similarity between the respective fish communities. A possible exception is the transfer of young eels (elvers), which migrate in large numbers up the River Severn in late spring and throughout the summer. Although the highest catches of elvers at the Upper Lode Weir, Tewkesbury (just upstream of the proposed abstraction point) is in May, smaller catches of elvers are made throughout the summer, and juvenile eels are caught primarily during July and August (White & Knights 1994), when water transfers may take place. Few eels are found in the upper Thames waters, although the numbers in the estuary support a small commercial fishery and some stocking of young eels in the upper catchment, probably from the Severn, has already taken place (Naismith & Knights 1993).

Summary: Transfer of fish to the Thames is not likely to be a serious problem, except for the pike-perch, which may colonise the upper reaches at a greater rate than may occur by upstream migration from stocks already present in the lower Thames.

5. SUMMARY OF KEY ISSUES

The information given in Section 4 shows that physical and chemical changes and their biological consequences can be related, for the most part, only on a correlative basis. Although the underlying mechanisms of some relationships are known, their quantification requires more study. Thus, any selection of priority issues will contain a subjective element.

The following issues arising from the proposed transfer of water from the Severn to the Thames, are considered to be those of greatest concern:

a) Changes in water chemistry,
b) Changes in flow regime and associated changes in the temperature regime,
c) Movement of sediments,
d) Transfer of algae and invertebrates from the Severn,
e) Development of lentic populations of algae and zooplankton in the Thames holding reservoir.
f) Effect of increased summer flows on the spawning of fish and the distribution and diets of young-of-the year fish.

On the basis of the literature review, other effects are of some interest but are not expected to be of major concern in the River Thames ecosystem.

Changes a-c are likely to have their greatest effect on the species diversity and distribution of the benthic invertebrate community. Changes in the zooplankton community may also occur, either as a direct effect of flow changes, but also by washout of zooplankton from the Thames bankside holding reservoir. Changes in the phytoplankton community may arise also from changes to the hydrological cycle and from the input of algae from the reservoir. These may be derived from the Severn or may have developed independently in the storage reservoir. The effects on the survival and growth of young fish may be transmitted to the age structure and species composition of older fish.

6. STUDY PROGRAMME

6.1 Introduction

"Detailed research into the ecological impacts of inter-basin transfers is virtually non-existent on a global scale" (Davies et al. 1992). Consequently, the proposed Severn-Thames water transfer scheme presents an important opportunity to increase knowledge of its effects at several levels.

The importance of organising hydrobiological monitoring on streams being affected, prior to design and construction of water transfers, was emphasised by Padmanabhan et al. (1990). Both diagnostic monitoring (which permits the establishment of trends or changes in the aquatic ecosystem) and prognostic monitoring (which will help to predict biological consequences of these changes or of transformation of ecosystems) should be conducted on a regular basis and under a prescribed programme. Monitoring should continue on the same basis after the interbasin water transfer scheme is implemented in order to help evaluate the impact and, hence, to formulate any necessary remedial measures.

Previous desk studies, commissioned by Thames NRA, considered several Severn-Thames transfer options. In particular, they concentrated on the practicalities, costs and environmental impacts of different transfer routes, the potential for increased eutrophication of the Thames, short-term variations in discharge, and accidental releases and introductions of pollutants and biota. They did not examine in any detail the ecological changes that may occur in the Thames. However, some past studies of the River Thames may provide valuable data.

Of special interest is the IFE survey (Furse 1978) of invertebrates and plants between Buscot and Benson (below Didcot). Both groups were identified to species level and, at 5 of the 18 sections investigated, 10 sub-samples were taken from each mid-river, marginal and macrophyte zone. Recently there has been an IFE study to identify some stored Thames NRA invertebrate samples from 1990. Data from these sources could be compared and further examination of the stored material carried out.

The following Study Programmes provides the opportunity to decide:

- which topics are of greatest concern to Thames NRA,
- which of the data currently available should be assessed,
- what new data need to be collected and interpreted.

The programme is intended to form the basis for further discussion between IFE/CEH and Thames NRA, in order to identify a collaborative research strategy that will:

a) demonstrate clearly that the development of NRA policy regarding a Severn-Thames transfer has been reached after full consideration of all relevant issues;

b) establish the status quo of the river conditions and biota in the Thames prior to any transfer of water from the Severn;

c) enable the nature and severity of the impacts of the proposed transfer on the water quality and ecology of the Thames to be predicted;

d) identify whether or not measures could be taken to ameliorate the severity of any predicted impacts;

e) establish which existing conditions in the River Thames are most likely to be influenced by the proposed transfer. Sufficient detail will be included to facilitate rigorous assessment of post-transfer changes.

6.2 Summaries of the research proposals

The following section provides a summary of the key elements within the research proposals. Full details of the proposals are given in Section 6.3. Links between projects are indicated, but note that A,B,C & D underpin the remaining projects.

A) **Water chemistry**

a) Evaluate the previous studies on the water chemistry of the Lower Severn and Upper Thames.
b) Evaluate predictions of water chemistry stability during storage and pipeline transfer of Severn water.
c) Investigate the potential release of contaminants from water-borne particles and the perturbation of sediment reactions following the mixing of Severn and Thames water.

[Links with all other projects]

B) **Geomorphological data**

a) Measure and interpret seasonal physical changes using data from new geomorphological surveys. These will involve scales ranging from the river reach to the microhabitat requirements of individual species, and can include the use of recently developed models on the habitat requirements of 0 group fish.
b) Assess the range of 'natural' variability by comparing this information with earlier geomorphological data [e.g. River Thames Soundings (1979) and NRA River Corridor Surveys], which were generally collected during summer months.

[Links with all other projects]

C) **Sediment studies**

a) Evaluate the predicted range in particle size and the quantities of sediment transferred from the Severn to the Thames.
b) Investigate the extent of downstream dispersion, settlement and resultant turbidity generated by sediment in the Thames during and after transfer events.
c) Investigate the consequences of transferring water from the Severn in relation to seasonal changes in the patterns of sediment deposition and erosion.

[Links with all other projects]

D) **Review of information on Thames biota**

The results of this proposal will determine the need for, and extent of, further studies of Thames biota (Proposals E-L).

a) Evaluate archived biological data and assess the importance of information gaps for algae, macrophytes, invertebrates and fish, which relate to the Thames upstream and downstream of Buscot. This review will establish the information available on the community structure prior to any transfer.
b) Identify suitable monitoring techniques to assess the effects of the proposed transfer on biological water quality, fisheries management, conservation aspects and biodiversity status.
c) Identify invertebrate species of particular importance for conservation.

[Links with projects E to L]

E) **Plankton in the Thames-side lagoon**

To predict potential changes to planktonic organisms within the Thames-side storage lagoon prior to release of water into the Thames, and the subsequent impacts on river phytoplankton and zooplankton.

[Links with F,G,H]

F) **River Thames zooplankton**

Review published information on the impacts of river regulation on zooplankton (utilised as food by young fish), and recommend methods for sampling populations and detecting changes.

[Links with E,G,H]

G) **Blackfly (Simulium) larvae**

Survey the populations of filter-feeding blackfly larvae, including pest species, which will respond to changes (as a result of the transfer) in water velocity and the quantities of food particles suspended in the water column.

[Links with E,F]

H) **Distribution of YOY fish**

Survey the pre-transfer distribution of young-of-the-year (YOY) fish upstream and downstream of Buscot in relation to season, habitat and diet preferences, and establish whether or not certain species are likely to be affected by the proposed transfer.

[Links with F,I,J,K]

I) **Fish year class strengths**

Utilise Thames NRA fisheries data to establish trends in year class strength and growth rates in the area of Buscot with a view to monitoring the impact of water transfer.

[Links with H,J]

J) **Fish spawning sites**

Locate major spawning sites for selected fish species in the area of Buscot and assess the potential impacts of the proposed water transfer.

[Links with H,I]

K) **Invasive plants**

Assess the potential for increased management costs, adverse effects on water quality and environmental degradation caused by the introduction/establishment of invasive plant species.

[Links with H,L]

L) **Macroinvertebrates**

Assess potential change to biological assessment of water quality (RIVPACS). Investigate the distribution and abundance of any invertebrate species of importance for conservation, determine their habitat requirements and assess their vulnerability to impacts of change.

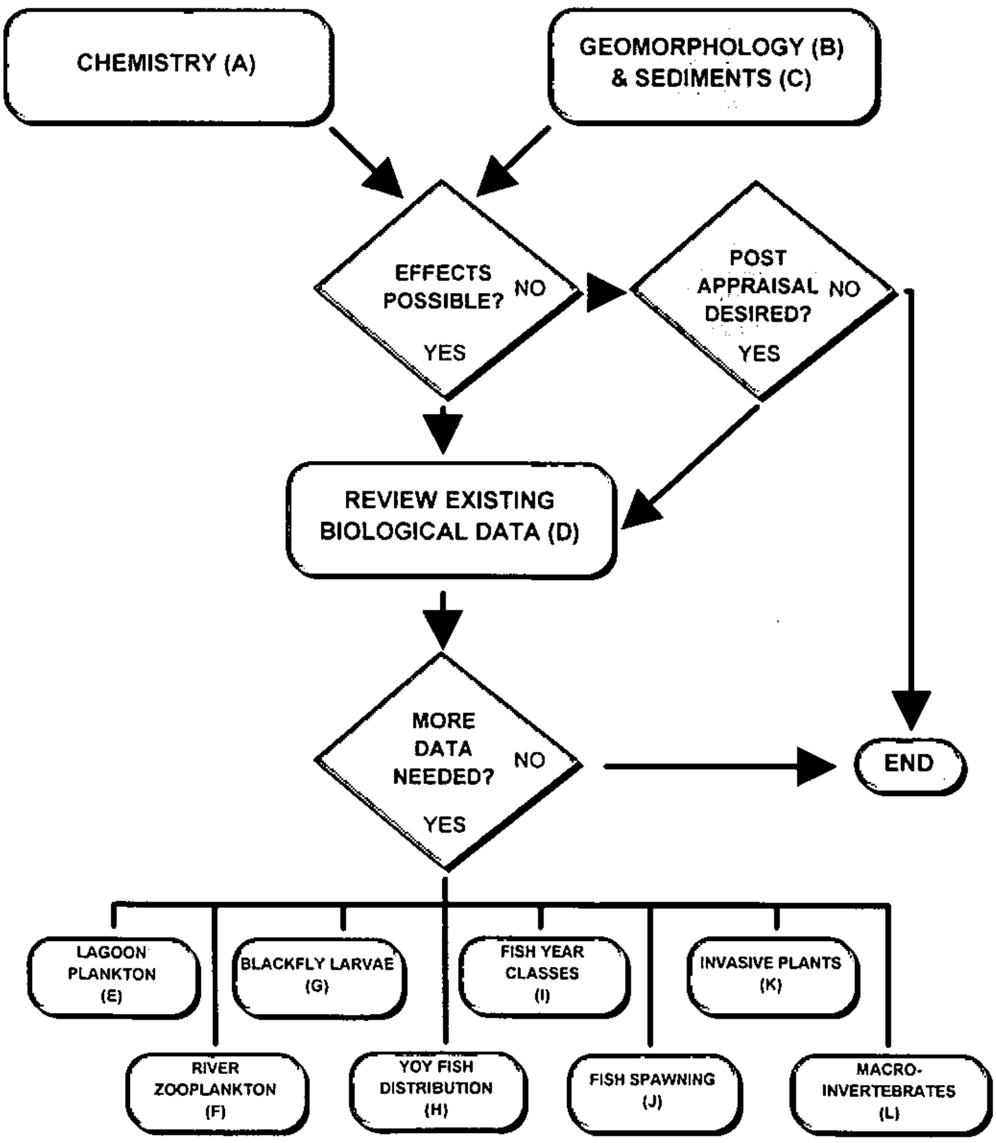
[Links with K]

6.3 Flow chart

The need or desirability to carry out some of the research proposals will depend upon the results of, in particular the chemical, geomorphological and sediment studies, plus the review of biological information. To assist in the decision making regarding the need for particular research projects, the following Flow Chart has been designed:

STUDY PROGRAMME - FLOW CHART

(A-L = Project proposals)



6.4 Time-scales

The following list indicates those parts of Proposals A-K that can be started in the current (1995-96) financial year. However, as indicated in the flow chart, decisions to carry out projects E-L may depend to a large extent upon the results of the biological review (D).

Proposal A: Review of NRA chemical data and assessment of previous chemical research on the proposed water transfer scheme.

Proposal B: Winter geomorphological survey of the Thames in the vicinity of Buscot.

Proposal C: Analysis of existing NRA data on suspended solids in the Severn and Thames.

Proposal D: Collation of NRA information on the biota of the Thames near Buscot.

Proposal E: None - use of the algal model requires information from other projects.

Proposal F: Literature review of river regulation impacts on zooplankton.

Proposal G: None.

Proposal H: None.

Proposal I: None.

Proposal J: None

Proposal K: Examination of data sets on plant distribution.

Proposal L: None

6.5 Summaries of costs

The 12 projects (A-L) have been formulated to answer specific questions arising from the proposed Severn-Thames transfer. Consequently, they are very much biased to NRA needs. Nevertheless, the IFE has ongoing and planned work of associated interest in several of the projects and could contribute work of part or similar value to some, but not all, of the 12 projects. The estimated prices are the Full Economic Costs (FEC) to IFE for each project.

Project proposal	Estimated Cost (FEC)
	£K
A) Water chemistry	Not costed (see full project details)
B) Geomorphology	26
C) Sediments	32.5
D) Review of biological data	15
E) Algal model - unverified	10
- verified	25
- river algal model	35
F) River zooplankton	6
G) Blackfly larvae	9
H) YOY fish - distribution	12
- diets	20
I) Adult fish - year-class strength	100
- growth	10
J) Fish spawning (cost per species)	10 & 10 capital outlay
K) Invasive plants	3
L) Macroinvertebrates	3

6.6 Full Project details

Project A: Chemical studies

[Prepared by Dr W.A.House, IFE The River Laboratory]

Background

Detailed methodology can only be proposed after consideration of the chemical data for the rivers and must include aspects of the seasonal variations, transfer rates, mixing ratios, storage residence times and treatment in the reservoirs and settling impoundments. However, the key aspects of the study of the chemistry are listed below:

Methods

1) Evaluation of the available chemical data and interpretation to date to include a review of any previous research on this proposed transfer scheme.
2) Examination of the composition of the source and receiving waters on a monthly basis over about the last 5 years. Prediction of the stabilities of these waters with respect to mineral deposition and gas concentrations (carbon dioxide and oxygen) using a chemical equilibrium program similar to WATEQ (already in operation in a PC form).
3) Estimation of chemical changes during transit and storage with particular attention to the formation of low dissolved oxygen and potential for sulphate reduction and formation of nitrite/ammonium in transit. These studies would also try to identify any instabilities that could affect water quality.
4) Laboratory experiments with fine suspended material from the source water collected by continuous-flow centrifugation or tangential-flow filtration, to examine the release of contaminants (e.g. metals, nutrients, pesticides) to the receiving waters at different times of the year. Only that sediment fraction likely to be transferred would be examined.
5) Similar work to the above, but with the whole sediment fraction from the receiving water diluted with source water. this would enable a determination of the perturbation of the sediment reactions caused by the mixing of the two waters. Again, seasonal dependence would need to be addressed. Both (4) and (5) could include the determination of the equilibrium phosphate concentration (EPC) and bio-available phosphorus for the suspended sediments from the two rivers. This would enable some estimates of the seasonal changes in dissolved phosphorus caused by the transfer of fine particulate matter.

Costs

With reference to the background to the proposals (outlined above), the cost of this work will be influenced by the data available and the priorities identified by Thames NRA. For these reasons, costings are not included at present.

Project B: Geomorphological studies

[Prepared by the IFE, The Eastern Rivers Laboratory]

Background

Data provided by geomorphological surveys of the Thames at Buscot are required for the assessment of the potential impacts of a Severn-Thames transfer. Information on the seasonal and spatial distribution of habitats and associated water velocities will aid interpretation of the changes resulting from the proposed transfer, including impacts on the biota. Of particular concern are marginal habitats as these provide the interface between aquatic and terrestrial habitats. In these areas, biological productivity and biodiversity are maximised. They include habitats of specific importance, such as those used as spawning substrata for certain fish and as refugia for a wide range of macroinvertebrates and for young-of-the-year (YOY) fish. Data currently available to Thames NRA include River Thames Soundings (1979), River Corridor Surveys and, most recently, River Habitat Surveys.

Objectives

1) Provide an analysis of currently available geomorphological data and undertake winter and summer surveys of within-river habitats upstream and downstream of the proposed transfer discharge point.
2) Assess the vulnerability of the available river habitats to changes resulting from the proposed Severn-Thames transfer.
3) Predict any structural changes to within-channel habitats that will impact the fauna and flora.
4) Recommend any constraints on transfer discharges that may be required to maintain or enhance habitat structure of significance to the fauna and flora.
5) Provide a baseline from which to measure post-transfer changes, upstream and downstream from the proposed transfer discharge point..

Methods

1) Winter and summer surveys involving mapping and measuring the areas of within-river habitats over a predetermined river reach. Collection and assessment of contemporary data on water depths and velocities would be undertaken.
2) It is proposed to resurvey the river transects used in the River Thames Soundings (1979), namely at 50m intervals on straight river sections and approximately 20m intervals on bends.
3) The following techniques of river transect mapping have previously been used by four IFE staff on the R.Great Ouse, where boat traffic is also present. Namely: at each transect a rope labelled at 1m intervals is held under tension across the river; a light inflatable boat is moved along the rope measuring depth and substrate type with a survey pole and grapnel; water velocity is measured with an electromagnetic flow meter. The survey boat retreats to the river edge and the weighted rope is allowed to sink when boats approach the transect point.

It is proposed to record data at 1m intervals in marginal zones changing to 3m intervals in the main channel (in the absence of submerged plants). An average of 25 transects per kilometre would be surveyed.

Deliverables

Information on seasonal extremes of within-river habitat distribution and their physical characteristics in the vicinity of the discharge point for the proposed Severn-Thames transfer. Predictions of subsequent changes to the habitats present driven by the proposed transfer. Interpretation of the consequences for the flora and fauna.

Costs

The costs of analysis of currently held data, acquisition and analysis of new data (winter and summer), are based on a river length of 5km (2km upstream and 3km downstream from the proposed discharge point).

Staff: £24,200

Equipment £1000 (field "notepad" for data recording) plus £60 (materials)

Project C: Sediment studies

[Prepared by Mr G.Leeks, Institute of Hydrology & Institute of Freshwater Ecology]

Objectives

1) Estimation of river sediment loads at Tewkesbury
2) Assess possible impacts upon sediment deposition and movement in the reach of the Thames below Buscot.

Methods

1) Analyses of existing NRA archive and research data on suspended solids in Thames and Severn.
2) Installation and maintenance of turbidity monitoring and flow related automatic bulk sampling to infill archive data at Tewkesbury and Buscot.
3) Manual sampling to check calibration of turbidity and autosamplers.
4) Particle size analyses of suspended sediments in Severn and Thames.
5) Bed sediment survey.

Project details

In order to assess the importance of sediment transfers from the Severn to the Thames, it would be necessary to establish the suspended sediment discharge of the Severn at Tewkesbury. Currently available records do not permit a satisfactory estimation of total sediment loads, as these records under-represent the intermittent high flows, during which most fluvial sediment is transported. Incidentally, information on typical suspended loads during high flows would also be useful in the development of operating rules for the river abstraction.

Measurements of suspended sediment concentration will be derived using the IH WISER (Wallingford Integrated System for Environmental monitoring in Rivers). This system combines stage measurement with two measures of turbidity (nephelometric and absorptiometric), integrated logger (for control and archiving) and automatic, flow-related bulk sampling. The samples obtained would also be of value for the water chemistry aspects of the impact assessment. Bulk samples and manual samples will be used to calibrate/check continuous turbidity measurements. Bulk samples will be subjected to particle size analyses. This can give a valuable indication of mobility of material through the settlement lagoon and permit comparisons to be made with the size distribution of material transported though the Thames reach. The particle size data would also be useful for the water chemistry work. For example, contaminants often associate with the finer end of the suspended sediment size ranges.

A survey of bed material, including the use of freeze coring techniques, will also be required to indicate the likely impacts of the additional sediment inputs to the bed of the Thames.

Deliverables

In short report form:
1) Baseliné data on sediments in fluvial transport at abstraction point and on the river bed in the receiving water course, to judge changes in channel properties.

2) Estimates of possible contributions of sediment from Severn to Thames over period of study, with estimates of longer term annual loads.

3. Bulk samples of water/sediment for additional analyses.

4. Suspended sediment particle size distribution data.

5) Reconnaissance Survey of Thames below Buscot, including bed material size distribution.

Relevant Experience

The Sediment and Waterbourne Fluxes section of IH has carried out a large range of research on river sediment loads. This work has included both short and longer term work on headwater, upland and lowland rivers in England and wales. This research has included sediment transport monitoring of both bed-load and suspended sediments, process studies of channel stability and flux estimation, under short and long term commissions to NRA, DoE, MAFF, Severn Trent PLC and Welsh Office. A significant part of this work has been in the Severn Basin. This section is also responsible for sediment flux studies in the large scale Humber river basins in the NERC Land-Ocean Interaction Study (LOIS).

Costs	£K
Staff	11
Equipment	15
Subcontracts (to IFE)	
Particle size analyses	2
Freeze Coring	3
Total Cost	32.5

NB. Equipment costs are mainly for the purchase of two WISER systems. These costs would be significantly reduced by excluding flow-related logger-controlled automatic bulk sampling. However, this equipment would also be of considerable value for the water chemistry component of the study and has permitted a low level of manual sampling staff costs.

Subject to approval by IH finance officer.

Project D: Review of biological data

[Prepared by Dr P.D.Armitage & Mr M.T.Furse, IFE, The River Laboratory]

Objectives

1) To collate relevant data held by the NRA, IFE and other bodies on instream biota (fish, macroinvertebrates, macrophytes, algae) in areas above and below the discharge point.
2) To establish a routine monitoring regime to assess the possible effects of the transfer on instream biota.

Methods

1) Search NRA records etc for studies carried out in the transfer area.
2) Examine these records and those from other sources to produce a description of instream biota before implementation of the transfer scheme.
3) On the basis of results from (2) set up a monitoring scheme to assess possible changes arising from the scheme. This will include a fish survey, macroinvertebrate studies (for both quality and "mesohabitat" aspects) and macrophyte mapping.

Project details

In order to assess the possible changes arising from implementation of the scheme, it is necessary to establish baseline conditions. Without these data it is impossible to comment meaningfully on possible change. It is also necessary to examine records over the longest possible period of time. Without knowledge of the natural variation in biotic parameters, the task of attributing changes in parameters to the activities associated with transfer is difficult.

A number of projects have been undertaken on various aspects of the biology of the Thames, and the NRA undoubtedly holds much information. In general, these studies have not been collated to give a coherent account of conditions in the river. This proposed project will examine these data with a view to building up a comprehensive body of information, which can be used as the baseline from which to measure change.

The prime aim will be to maximise information retrieval with minimum cost by making use of existing data.

Deliverables

The precise product from this work will depend on the quality and extent of the data available, but it is envisaged that information will be obtained on the following aspects:

1) Fish populations: composition, growth and age structure.
2) Biological quality assessment based on macroinvertebrates,
3) Comprehensive fauna lists.
4) Records of macrophyte growth.

5) A comprehensive account of the pre-transfer conditions in relation to the biological data available.
6) A detailed long-term monitoring plan for future assessments.

Costs

Overall costs up to £15,000, depending on the amount of information available and its condition.

Project E: Lagoon plankton

[Prepared by Prof. J. Hilton, IFE, The River Laboratory]

Algal and zooplankton modelling in holding reservoirs

Background

If nutrient rich water is allowed to stand in a lake or reservoir, it will develop algal and zooplankton communities at biomass levels that are limited by a complex interlinking of factors such as the light input, water temperature, algal species, nutrient levels, flushing rates etc. If high algal concentrations develop in the proposed holding reservoir after transfer of water from the Severn, then the periods of discharge to the Thames may be limited by the amount of algae in the water of the reservoir.

Objectives

To predict the likely pattern of algal species distribution, and algal and zooplankton biomass, in the holding reservoir throughout a year of typical or extreme use.

Methods

Most models predicting algal biomass are based on simple regressions, which require large amounts of data to calibrate. In addition, these regression models can only "predict" reliably within the range of calibration parameters. When reservoir changes or new reservoirs are proposed, these types of models are very unreliable.

The IFE has developed an advanced model of algal growth which is based on fundamental principles. Consequently, the reliability of its predictions in "new" circumstances is much better than the regression models. The model uses input data on water temperature, nutrient concentrations in the inflows, and water flows to predict the change in biomass of up to 8 different algal types e.g. large green algae, nitrogen-fixing blue-green algae, small diatoms etc. (It is unlikely that models will be developed that will accurately predict the growth of individual algal species in competition with others as this is an example of a "chaotic" system).

It is possible to use the IFE model in two modes: a) open predictions, b) verified. In the former case, open predictions can be made, but there is no check that all appropriate factors have been taken into account in setting up the model. Hence, the predictions are less confident, but they are the best available. When data are available from an existing system, the predictions can be verified by comparison with observation in order to increase the confidence in the predictions.

Deliverables

Predictions of algal biomass and species composition in the holding reservoir under a number of defined operating scenarios.

Costs

Open predictions:	£10,000	(first 2 scenarios)
Verified predictions	£25,000	(first 2 scenarios)

The IFE model can also be used for river algal growth, but the modification of the model is more extensive so that the cost is higher, say £35,000 for the first 2 predictions.

Project F: River zooplankton

[Prepared by Mr J.A.B.Bass and Dr L.May, Institute of Freshwater Ecology]

Background

The transfer and storage of water from the lower reaches of the River Severn, prior to discharge into the River Thames, is likely to alter the phytoplankton community in the Thames. The subsequent impacts on the zooplankton, in terms of extended seasonal presence and increased population densities, has important implications for higher trophic levels. The macroinvertebrate community, which includes species used as water quality indicators, is likely to respond to the changed food supply. Growth and survival of the juvenile fish that feed on zooplankton could be changed, with consequences for the balance between species within this popular coarse fishery.

Methods

It is proposed to conduct a literature review covering evaluation of river regulation impacts on zooplankton (other than those associated with river transfers, which are dealt with in this current review). This review would utilize the comprehensive library and associated facilities provided at the IFE Windermere Laboratory.

The review will be followed by an assessment of possible sampling strategies pertaining to the dynamics of zooplankton communities in the River Thames. Choice of the optimum strategy will require details of the mechanics of the proposed transfer, including information on storage retention times and changes to the hydrological regime of the Thames.

Relevant Experience

Dr Linda May maintains her own extensive collection of references to the Rotifera (this group is numerically dominant in river zooplankton). Her past involvement with rotifer ecology, physiology and taxonomy will be invaluable to the review of their role in river zooplankton dynamics.

Mr Jon Bass has experience of planning river zooplankton sampling strategies and has been involved in the collection, identification and data interpretation of zooplankton samples from the Great Ouse (1988-1994), Yorkshire Ouse, Trent and Thames (1995). He also holds an extensive collection of reprints on river zooplankton relating to the Rotifera, Copepoda and Cladocera.

Costs

Overall costs: £6000

Time-scale

Approximately 3 months

Project G: Blackfly larvae

[Prepared by Dr M.Ladle, Institute of Freshwater Ecology]

Potential biting fly (Simuliidae) problems

Background

Simuliidae are particularly sensitive to changes in flow velocity, suspended material and ecotone (marginal conditions). The nature of the overwintering community of simuliid species will undoubtedly be altered by the water transfer. However, we can say with confidence that the "Blandford Fly", Simulium posticatum, known to be present in several Thames tributaries around Oxford, will NOT be affected by the transfer of water during late summer and autumn, when the insects are high and dry as eggs in the river bank. If, however, water transfer extended into the winter or spring periods, changes to the water velocity and to the concentrations of suspended solids/algae could exacerbate the existing health problem with these insects.

Objectives

To establish the composition and abundance of simuliid associations in the region affected by the proposed transfer, with monitoring upstream and downstream of Buscot.

Methods

Survey areas of the river in the vicinity of the proposed transfer inputs that are suitable for supporting simuliid larvae. Take quantitative samples for estimates of species composition and population density, and make appropriate corrections for abundance based on expert opinion.

Deliverables

Description of overwintering simuliid associations and assessment of possible problems arising from the proposed transfer.

Costs

Approximately £9,000.

Project H: YOY fish distribution & diets

[Prepared by Dr R.H.K.Mann and Mr J.A.B.Bass, Institute of Freshwater Ecology]

A. Impact of discharge changes on the distribution of young-of-the-year fish

Background

Although alterations to gross channel morphology are not expected as a result of increased discharges from the proposed transfer, the increase in water velocity over lengthy time periods will favour adult rheophilic species, such as the chub and dace. In addition, the distribution of the young-of-the-year (YOY) of most species could be affected. These small fish avoid downstream displacement by selecting areas of comparatively low water velocity, but such areas may be greatly reduced as a consequence of water transfer. As a result, many YOY fish may be displaced downstream, possibly over barriers that prevent or inhibit upstream movement of both small and large fish. This depletion of the youngest age groups may affect the future age/size structure of the fish populations in some areas of the river, which would have important repercussions for the sport fishery.

Objectives

To provide a baseline to assess future changes, a survey of the distribution of YOY fish during late summer, both upstream and downstream of Buscot, is proposed. The upstream sites will provide a useful reference for any changes that may occur that are not caused by the transfer. The baseline will also provide information of species that are particularly at risk, and thus will facilitate the implementation of any necessary compensatory habitat alterations.

Methods

Random Point Sampling using electrofishing will be carried out at two sites upstream of the transfer discharge point and at approximately five sites downstream. This survey will be carried out in late July or August. The microhabitat preferences of YOY fish will be identified in relation to a suite of environmental variables, principally: macrophyte habitat, water depth, water velocity, distance from river bank. This procedure will follow the technique used by the IFE in recent studies of YOY fish in the River Great Ouse.

A detailed map will be made at each site, showing the range of habitats available and indicating, especially, the velocity profile of the channel. The species composition at each site will be recorded, as will the length-frequency distributions of the component fish species. The details in the maps will be compared with general information on habitat availability as noted in a river corridor survey. It is expected that the latter information will be available from other studies; if this is not the case, then this study would include such a survey.

It would be advisable to carry out the electrofishing survey in more than one pre-transfer year, so that the range of year to year changes in microhabitat distribution are identified.

This information can be used to determine the effects of any hydrological changes arising from the transfer.

Deliverables

A report giving details of the general distribution of YOY fish from just upstream of Buscot downstream towards Oxford. Information will be given on the habitats selected by different fish species and on the range of habits available. These data will provide a baseline for comparison with the post-transfer situation, and will provide information in association with hydrological data to predict likely changes. The YOY distribution data could be used also to indicate the distribution of spawning sites for different species (see Project J).

Costs

Approximately £12,000

B. Impact of discharge changes on the diets of YOY fish

Background

The diets of YOY fish in the River Thames near Abingdon were the subject of a small IFE study (for Thames NRA) in 1995. This study included comparisons of the diets of roach and other fish species between habitats, a comparison between species, and seasonal changes. An extension of this programme to examine YOY diets in the Buscot area is proposed, as the impacts of increased discharge on potential prey organisms is likely to be high. Reduced growth rates and condition of YOY fish would have implications for their overwinter survival. This study would be best carried out in collaboration with studies of zooplankton and benthic invertebrates.

Objectives

To determine the seasonal and inter-specific changes in the gut contents of YOY fish, and to use this information for subsequent comparison with post-transfer data.

Methods

It is recommended that detailed study of microhabitat variation in fish diets (as in the 1995 Abingdon study) is avoided. Instead, it is proposed to collect samples of YOY fish by a combination of pond net sweeps, electrofishing and micromesh seine netting from two locations upstream of Buscot and five locations downstream towards Oxford. There would be considerable benefit to subsequent data interpretation if these sites are the same as those selected for the study of YOY distribution. The frequency of data collection would be similar to that used in the 1995 Abingdon study, namely seven visits from May to September.

Deliverables

A report showing the seasonal changes in the diets of YOY fish at sites upstream and downstream of Buscot, plus information on between species differences. The data will be compared with information on zooplankton and invertebrate studies, and from studies of the microhabitat preferences of YOY fish in the Thames.

Costs

Approximately £20,000

Project I: Fish year classes

[Prepared by Dr M.Ladle, Institute of Freshwater Ecology]

Background

Many river fish populations appear to be responsive to sedimentation. Gravel spawners, in particular, would be seriously affected by deposition of silt or sand on and in the surface of gravels. This will be of particular significance for dace (for example) should silt-laden water be transferred. The impact of transfers, in this respect, will differ with the time of year. Late summer and autumn transfers are likely to affect spawning and the young-of-the-year (YOY) of chub and bleak, whereas late winter to early summer transfers will have implications for a wide range of coarse fish species (dace, roach, barbel, pike).

Shifts in water temperature and/or water quality may also affect year-class strength and growth of a wide range of fish species, both through impacts on YOY fish (see Project H) and later stages of life. For example, a serious decline in dace stocks in the River Tyne has been attributed to releases of cool water from Kielder reservoir.

Objectives

To determine the impact of water transfer on year-class strength and growth of selected fish species.

Methods

The most effective approach to monitoring the impacts of water transfers seems likely to be by examination of alterations in year-class strength and modifications of growth. Such changes could be determined best through sampling populations during and after transfer and determining the ages of individual fish from their scales. A second approach lies in the possibility of using back-calculated growth rates of fish from transfer and non-transfer sites, to establish the influences on "growth at age" for particular species. These would give a good idea of the overall effect of interacting changes resulting from water transfer.

Deliverables

Measures of the impact of water transfer on year-class strength and growth of selected fish species. Recommendations for fishery management action.

Costs

Year-class strength: uncosted due to the longer time scale of work required.
Growth studies: pre- and post-transfer, approximately £10,000.

Project J: Fish spawning

[Prepared by Dr M.Ladle, Institute of Freshwater Ecology]

Background

It is unlikely that the locations and natures of the spawning sites of most fish species in the Thames system in the vicinity of the proposed transfers are known. Radio-tagging technology is now suitable for the study of even the smaller species such as dace.

Objectives

To establish the main spawning sites of selected fish species.

Methods

By radio tagging and tracking a relatively small number of individuals in the vicinity of the proposed transfer input at pre-spawning time to locate the major spawning grounds. This approach could be in association with the location of shoals of fish using sonar equipment, a method currently in use by Thames NRA.

Deliverables

The likelihood of the spawning activities of a particular species being affected by a given pattern of water transfer will be predicted from its known spawning requirements.

Costs

Capital outlay (fixed and mobile tracking stations): approximately £10,000.

Cost of work per species: approximately £10,000

Project K: Invasive plants

[Prepared by Dr F.H.Dawson, Institute of Freshwater Ecology]

Background

Water transfer could rapidly increase the rate of invasion of alien plant species in the Thames system. Their effects range from a) reduction in design flow; on-bank or in-stream changes in channel stability (which would change maintenance requirements) to b) accentuating physico-chemical changes through the physiology.

In addition, invasive plants tend to rapidly produce monospecific stands to the detriment or near elimination of native species or communities. They can also have indirect effects on other biota, including causing fish kills. Whilst such changes can appear minimal, they often have a cumulative long-term effect on management costs for channel maintenance, they create adverse effects on water quality, and they accelerate environmental degradation

Methods

Data sets on plant distribution, physiology etc. are now available to allow scenarios to be predicted depending on the specifications for channel dimensions and flow control. Ameliorative measures can also be considered.

In a river channel, native plant species may also adversely affect the efficiency of water transport. These effects could be tested by physico-chemical models on likely or current plant species.

Costs

Initial survey of the importance of macrophytes: £3000.

Project L: Macroinvertebrates

[Prepared by IFE, The Eastern Rivers Laboratory]

Background

Standardised sampling, sorting and identification procedures for macroinvertebrates provide the NRA with a biological measure of water quality (RIVPACS). Such data are generally analyzed at the Family level but species evaluations can be achieved by re-examination of samples. RIVPACS can be used for the Buscot reach of the Thames to generate predictions that are modified to accommodate changes in physical and chemical characteristics associated with the proposed Severn-Thames transfer. This approach may highlight those invertebrate species or families that are potentially vulnerable to such habitat changes. Examination of archived NRA invertebrate data (and samples) would also reveal any species of conservation interest that currently occur in this part of the Thames.

Objectives

1) Determine what impact, if any, the proposed Severn-Thames transfer would have on biological assessments of water quality.
2) Assess whether macroinvertebrate species of conservation interest may be affected by the proposed transfer plus, if appropriate, recommendations for their more detailed study.

Methods

1) The NRA have the facility to generate and assess results from appropriate modifications to RIVPACS predictions. Some collaborative interpretation by IFE staff can be provided.
2) Searches of relevant archived data and samples for species of conservation interest. Assessment of published information on their specific habitat requirements, together with predictions of the consequences of the proposed water transfer.

Deliverables

1) An assessment of possible changes to biological water quality status as a result of the Severn-Thames transfer.
2) Information on the present status of macroinvertebrate species of conservation interest, and assessment of how this may change as a result of water transfers.

Costs

Approximately £3000, depending on the quantity and format of archived NRA data. This cost does not cover the re-examination of samples.

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