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Flow protection criteria for adult salmon – phase III case studies

Science Report: SC040040/SR

SCHO0606BKYT-E-P

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Steve Killeen Head of Science

Executive Summary

The Environment Agency has a duty to balance the requirements of water abstractors with those of the environment. In the case of salmon, flow can affect salmon stocks by varying the timing of their upstream migration, changing exploitation rates in the fisheries and altering non-fishery related losses to the spawning stock. A reduction in flow can cause delay of fish entering the fishery as well as additional mortality reducing the spawning stock.

Science Project SC010016/SR, Flow protection criteria for adult salmonids, (phase II) (Greest *et al*., 2005) used data from telemetry studies and fish counters to develop a statistical model to assess the potential impact of abstractions and water resource schemes on adult salmon entering freshwater. The model quantifies the impact in terms of delay and mortality at tidal limit as well as the level of uncertainty. The results from the model simulations could be used in the decision making process to evaluate the impact of an altered flow regime on the number of salmon available to the fishery and for spawning.

The main aim of phase III of the project was to further develop the application to management by testing the model in case studies, and exploring how the methodology may be implemented in the Environment Agency.

This report should be read in conjunction with SC010016/SR

Contents

1. Introduction

1.1 Background

River flow can affect salmon stocks by varying the timing of their upstream migration (Alabaster 1990, Jonsson 1991, Solomon et al 1999), changing exploitation rates in the fisheries (Smith and Laughton 1993) and altering non-fishery related losses to the spawning stock (Aprahamian, et al 1988). A reduction in flow can cause delay of fish entering the fishery as well as additional mortality reducing the spawning stock (Smith et al 1994, Solomon et al 1999). Nevertheless, the extent to which this may happens varies greatly according to the physical and geographical characteristics of the river concerned (Jensen at al 1998, Erikano et al 1999, Karrpinen et al 2004). Science project "Flow protection criteria for adult salmonids, phase II" (Greest *et al*., 2005) used data from telemetry studies and fish counters to develop a statistical model to assess the potential impact of abstractions and water resource schemes on adult salmon entering freshwater. The model quantifies the impact in terms of delay and mortality at tidal limit as well as the level of uncertainty. The results from the model simulations are used in the decision making process to evaluate the impact of an altered flow regime on the number of salmon available to the fishery and for spawning. The main aim of this phase of the project was to further develop the application to management by testing the model in case studies and exploring how the methodology may be implemented in the Environment Agency.

The Environment Agency is responsible for the management of water resources in England and Wales and has a duty to balance the requirements of water abstractors with those of the environment. The primary way that this is done is through a system of issuing licences for abstracting water. When considering an application for a new licence (or a variation to an existing licence) the possible effect on the aquatic environment must be taken into consideration.

In April 2001, the Environment Agency launched Catchment Abstraction Management Strategies (CAMS), which takes a more holistic approach in managing water resources effectively (Environment Agency, 2002) and make information readily available to the public. CAMS allow the "in-river needs" and the needs of the abstractors to be balanced in an open way. It sets out a strategy for achieving the sustainable management of water resources within a catchment or group of catchments.

The Habitats Directive and the Wild Birds Directive (implemented in the United Kingdom through the Habitats Regulations) establish a legislative framework for protecting and conserving Europe's wildlife and habitats. At the centre of the policy is the creation of a coherent ecological network of protected areas across the EU - known as Natura 2000 for habitats and species considered to be of outstanding international significance and therefore of importance to the maintenance of biodiversity in the European Union. Its purpose is to maintain or restore the habitats and species at a favourable conservation status in their natural range. As one of the competent authorities, the Environment Agency must assess the possible effects of various permissions on, or potentially affecting, a Natura 2000 site. Such permissions include licences to abstract water.

Existing permissions must be reviewed as well as assessing new ones; the Agency calls this review of existing permissions the Review of Consents.

The information requirements of these initiatives have been considered in this project, together with the problem of deciding what is acceptable in terms of loss and delay of salmon to the sustainability of the population.

1.1.1 Project Objectives

The specific objectives set for this phase of the project were as follows:

1. **Development of spreadsheet**
    - Further develop the prediction spreadsheet for running simulations of different flow scenarios.
    - Incorporate management options in to the spreadsheet for decision-making.
2. **Validation**
    - Ensure spreadsheets give correct predictions by comparing the results between the statistical package WinBugs and Excel.
3. **Case Studies :**
    - Undertake four tidal limit case studies on the River Tamar using the following data:

        a) No river-specific fish counter or telemetry data
        b) Telemetry data
        c) Counter data
        d) Telemetry and counter data

    - Run dummy abstraction scenarios on an example river and report results in tables and graphs.
4. **Sensitivity Testing**
    - Test sensitivity of predictions to alternative ‘user’ inputs e.g. different arrival patterns of salmon to the estuary.
5. **Implementation**
    - Determine how the methodology will fit in with current Agency procedures and how it will be used.
    - Develop an implementation plan.

2 Prediction spreadsheet

All of the model development was carried out in phase II (Greest *et al*., 2005). The model describes the relationship between the proportion of available fish moving each day and the daily mean flow. The allowance for fish loss rates and seasonality and the integration of multiple studies into a single hierarchical Bayesian model provided a basis for the management of river flow for salmon.

As part of this phase, an Excel spreadsheet was developed to run simulations of different flow scenarios to determine the impacts of different management decisions on the delay and loss of salmon to a river. Two management targets were used for these assessments. Firstly the loss of fish to the system and secondly the delay of salmon entering the river. Both have implications on the population and the associated fishery.

In order to run simulations on a particular river, a number of river specific inputs have to be made to the spreadsheet.

1) Firstly the model must be calibrated to reflect the assumed river-specific salmon migration-flow response curve – this may be based on salmon migration data for the river being studied or from a suitable surrogate.
2) The population of salmon arriving in the estuary and waiting to enter freshwater must be defined. For most purposes it will suffice to use an arbitrary value for this (a figure ≥ 100); only when applied to conservation limits/spawning targets are more accurate estimates of run size needed.
3) The estimated seasonal patterns of fish arrival in the estuary in question must be entered into the spreadsheet. Sub-components of these patterns may be used. For example it is possible to assess the impact of the total population arriving throughout the year, (as shown in Figure 1a) or the multi sea winter salmon arriving in May/June (Figure 1b) or for a number of fish arriving in a particular month (Figure 1c).

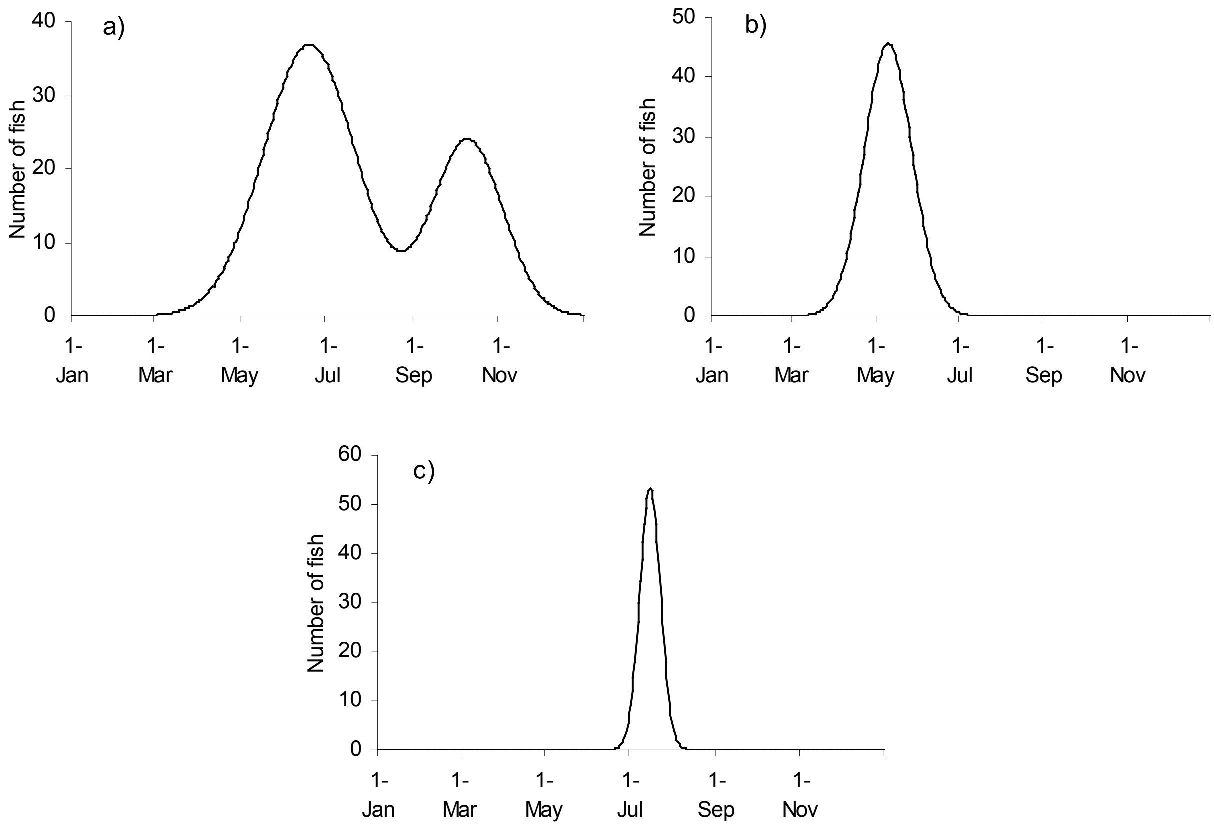


Figure 1 Different arrival patterns of salmon on the River Taw.

4) Next, the distance from tidal limit at which salmon are thought to be available to that particular river needs to be entered. This variable was included to overcome the difference in size of some rivers and to attempt to resolve the issue of joint estuaries. The distance refers to a point at which salmon are thought to be ‘available’ to the river of interest and therefore potentially affected by any management action in terms of flow. This needs to be agreed locally on the basis of experience and the final decision will depend on the number and respective sizes of rivers entering the estuary and their respective runs of migratory salmonids according to the following rationale.

In principle, the nominal release point (distance from tidal limit) should be set as far down the estuary as is reasonable. A nominal release point too close to tidal limit will fail to capture the potential impacts on survival of the fish having to negotiate a long estuary. In the case of a larger river entering such an estuary then the nominal release point could be set well down the estuary, close to the open sea, where the flow from that river would still exert considerable influence on the estuary and where most of the salmon passing through would be destined for the major tributary. Conversely, in the case of a river that is only a minor contributor in terms of both water and fish to a long estuary, the nominal distance from tidal limit entered into the spreadsheet would be set fairly close to the mouth of that river, ie in a zone where the flow from that river would be expected to have its maximum effect on estuary dynamics and where a large proportion of salmon frequenting that zone are destined for that river.

Choice of correct release point is particularly critical if it is necessary to estimate absolute numbers of fish lost under given flow scenarios, however if it suffices merely to compare proportions of the salmon run lost under different scenarios, then this factor is less critical.

5) The proposed abstraction scenario may then be applied to the spreadsheet, into which the relevant hydrometric data should be entered. These data should include either naturalised or benchmark daily flows and actual scenario flows encompassing the period under study. In addition other possible flow scenarios which it is desired to investigate should be tabulated. The spreadsheet is currently set up to look at an abstraction in terms of prescribed flow, percent take and maximum take, but can be modified to deal with hydrometry data expressed in any form. The respective estimates of fish loss may be compared with either an actual flow regime or a naturalised flow regime, depending on what is required. The model is currently set up to assess the effects of actual flows in recent years and changes to those flows from various abstraction regimes. The user can select any year from the data available locally upon which to base an assessment of fish loss resulting from a given flow scenario. For the case studies in this report, the scenarios were run on a dry year, wet year and an average year. For an "average" year assessment, the spreadsheet repeatedly selects a different year from all the years available and averages the results.

Once the river specific inputs (flow, distance from tidal limit, run size, length of arrival period and abstraction rule) have been applied to the spreadsheet, clicking the 'Run Model' button on the spreadsheet (Figure 2) runs the model for a number of iterations. The results are then reported with the mean and 95% confidence intervals.

Figure 2 shows an example of the prediction spreadsheet. All cells in *italics* require input from the user. The results reported are total percentage fish lost, percentage of total fish entering freshwater by a given date and percentage of surviving fish entering freshwater by a given date. Results are given for the actual flow regime and the proposed flow regime.

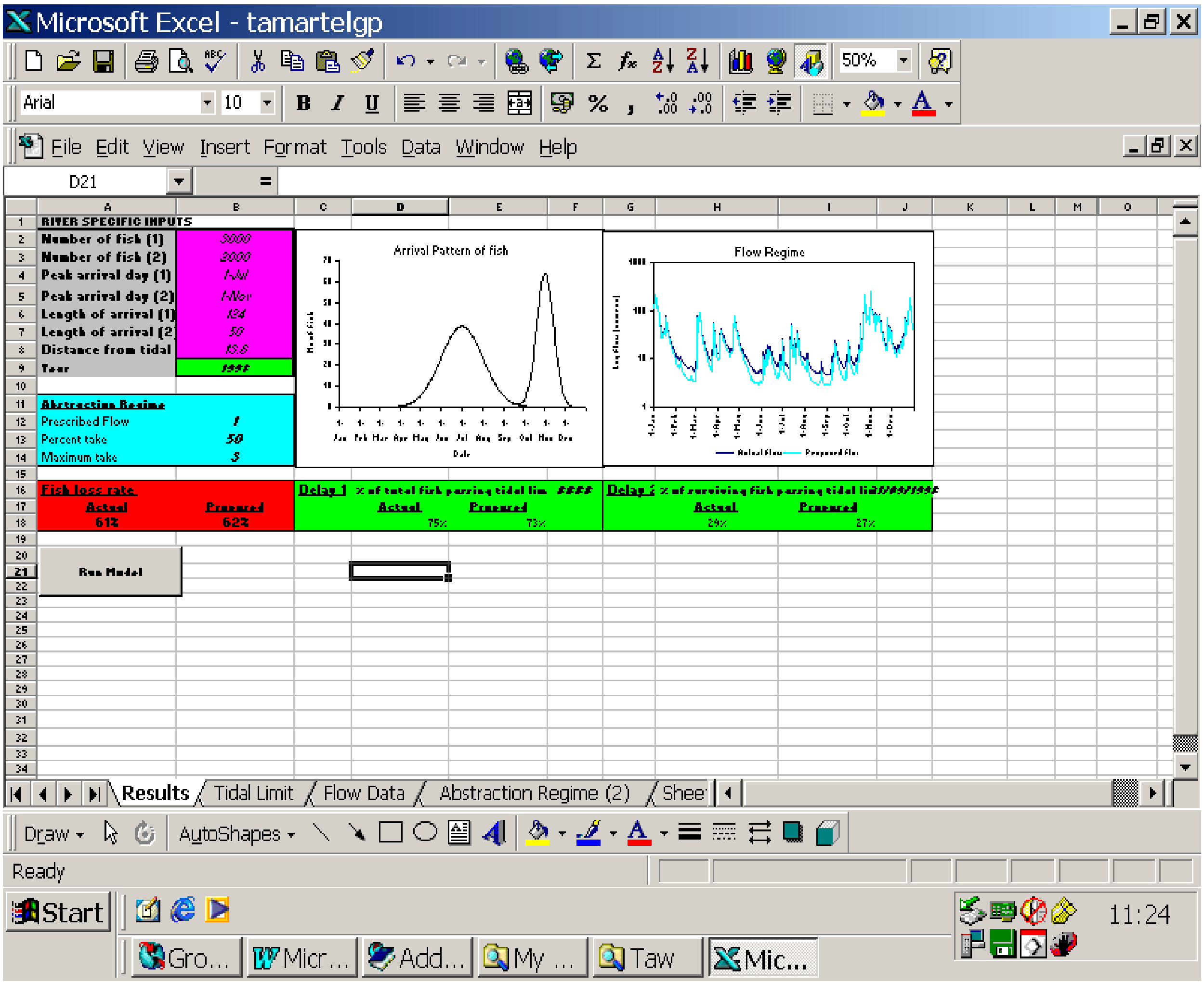


Figure 2. Example of prediction spreadsheet

3 Validation

3.1 Methods

The prediction spreadsheet was set up in Excel and validated with the statistical package WinBugs. In order to ensure the spreadsheet was giving correct results, predictions of fish loss were compared with the statistical package WinBugs for a dry year, a wet year and an average year (Figure 3).

3.2 Results

Many differences between WinBugs and Excel were found and both the spreadsheet and WinBugs code had to be modified before agreement was achieved. The four data points for each year represent the four spreadsheets that were set up for the case studies on the River Tamar. After these modifications the results from the WinBugs statistical package and Excel matched very well, confirming that both were set up correctly and giving correct results.

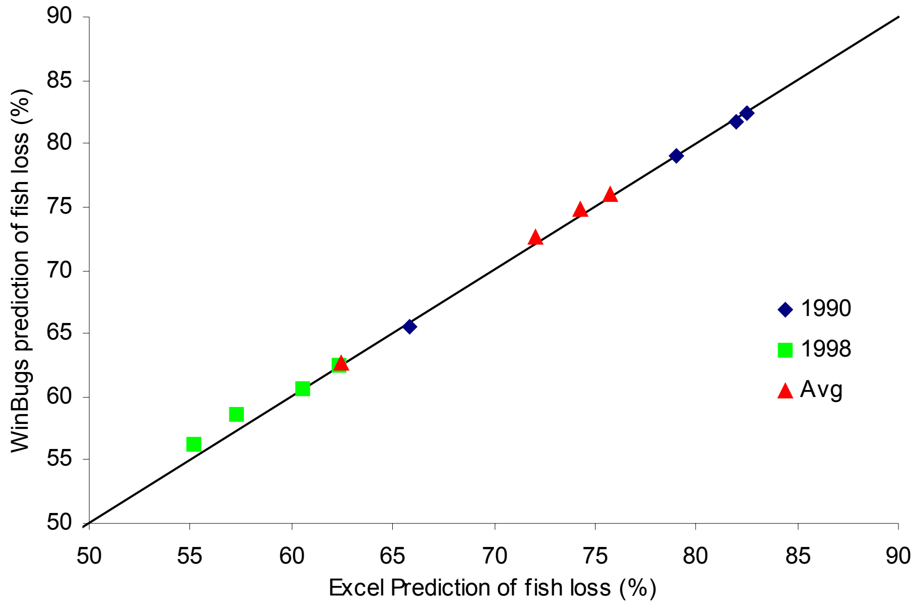


Figure 3. Validation of Excel spreadsheet with WinBugs code

4 Case Studies

4.1 River Tamar – alternative fish migration data sources

4.1.1 Methods

The River Tamar was chosen to assess the performance of models using different sources since it has data on fish movement from a telemetry study and also a fish counter. It was therefore possible to compare the results from each data type, and also investigate how to approach a river with no telemetry or counter data. Four separate spreadsheets were set up as previously mentioned and the model was run to compare the estimates of fish loss rate and the associated confidence intervals from each.

4.1.2 Results

The flow migration curves for the four scenarios were taken from WinBugs (Figure 4). It can be seen that the confidence in the estimates of the flow migration curve improves with more data. Estimates of the salmon's response to flow are most precise with both sets of data are used (Figure 4d) This is because the counter provides more specific information throughout the whole year.

These curves were then used in the spreadsheet to compare the accuracy of annual fish loss rate assessments.

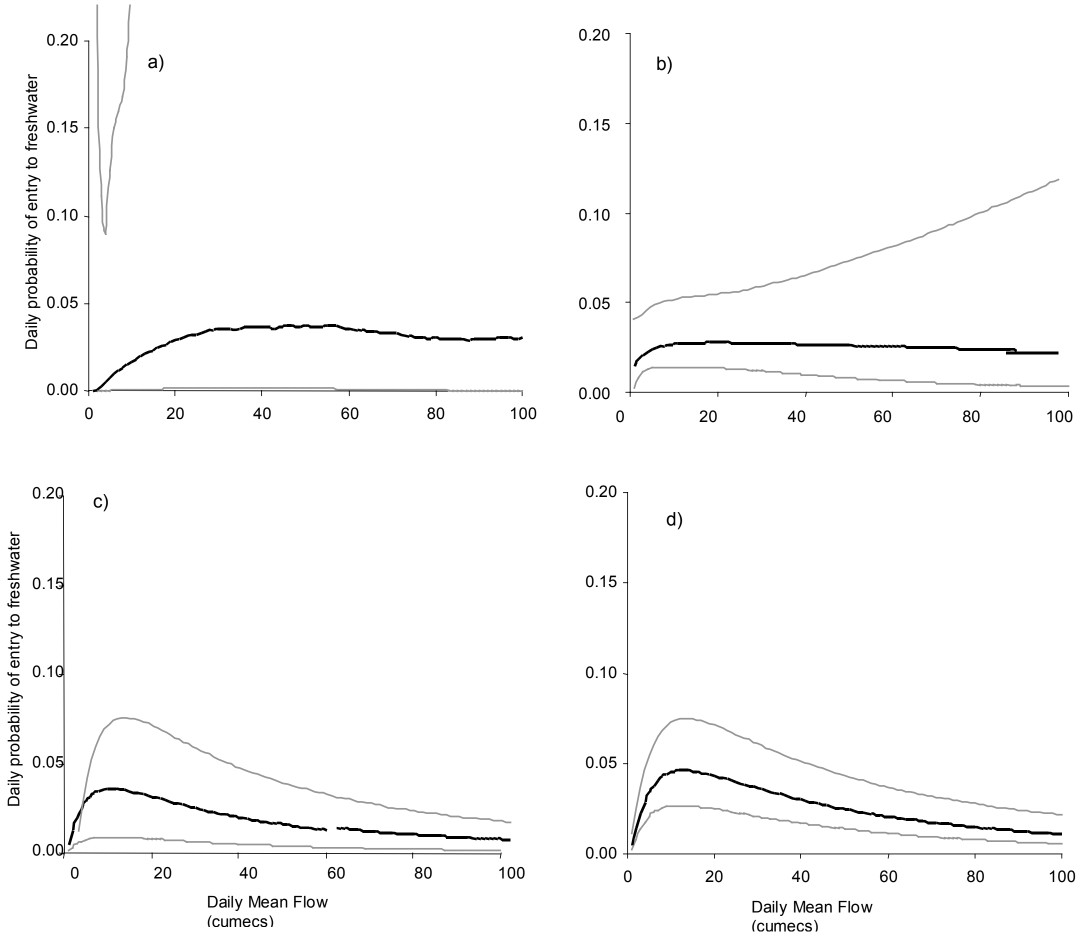


Figure 4. Flow migration curve for a) the River Tamar without any telemetry or counter data, b) the River Tamar with telemetry data, c) the River Tamar with counter data and d) River Tamar with telemetry and counter data. Grey lines are 95% confidence limits

Figure 5 shows that the estimates of total annual fish loss-rate from the four spreadsheets were similar with varying degrees of confidence associated with them. The 'no data' scenario has very wide confidence intervals around the estimate of fish loss which shows that any conclusions about fish losses on a river with no telemetry or counter data would need to be treated with caution. The scenario with the narrowest confidence intervals was the case study with telemetry data. The confidence intervals did not appear to improve greatly with the inclusion of both telemetry and counter data because all of the information on loss rates is derived from the telemetry data. The estimate of fish loss rate from counter and telemetry data is midway between the estimates from the separate telemetry and counter data scenarios which shows that both sets of information are contributing to the overall estimate, but the confidence in this estimate is not improved.

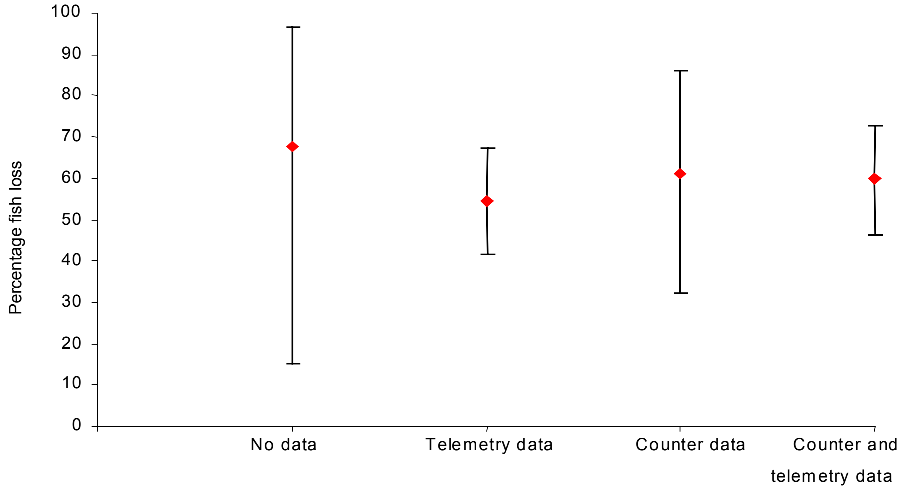


Figure 5. Results of estimates of total annual fish loss rates for different levels of data on the River Tamar, 1995.

4.2 River Taw - hypothetical abstraction scenarios

The original intention was to run hypothetical abstraction scenarios using the River Tamar telemetry data model. However, this was not completed because there was little detectable response to changing flows based on the telemetry data alone, i.e. the probability curve is fairly flat across much of the flow range compared to the other rivers studied (Figure 6). The scenarios were therefore carried out on the River Taw since response to flow was more pronounced and the model produced provided a good fit to the data.

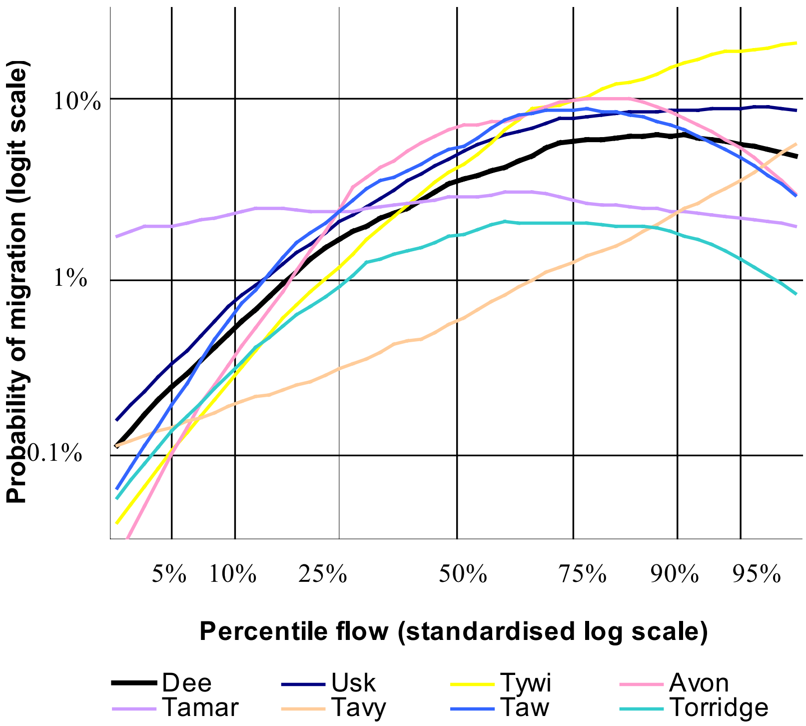


Figure 6. Comparison of flow migration curves for all rivers with telemetry data only.

4.2.1 Methods

The River Taw case study was carried out to investigate the impacts of hypothetical abstraction scenarios. Five different operating rules were run on the River Taw (Table 1). The Q_{95} on the River Taw is 1.24 m^3s^{-1}, which means that for all of the abstraction rules, apart from abstraction rule V, the prescribed flow is set just below the Q_{95}. These abstraction rules were then input to the spreadsheet and applied to a wet year, dry year and an average year. The point at which salmon were said to be available to the River Taw was 13.8km from tidal limit. This was an arbitrary value and chosen since it was the average of all of the telemetry studies.

Table 1. Operating rules for five arbitrary abstraction scenarios on the River Taw.

		Rule				
		I	**II**	**III**	**IV**	**V**
Operating rules	Prescribed flow (m^3s^{-1})	1	1	1	1	2
	Percent take	100	50	50	50	100
	Maximum take (m^3s^{-1})	3	1	2	3	1
Total annual scheme yield (Megalitres)	Wet year (1998)	94,537	31,536	62,447	89,592	31,536
	Dry year (1995)	77,583	27,847	48,559	65,124	24,824
	Average year (1989 – 2003)	86,203	29,861	55,391	77,022	28,741

4.2.2 Results

The results of fish loss and delay were then compared against the total annual scheme yield produced from each of these abstraction rules.

The flow regimes resulting from these abstraction rules in a dry year (1995) are given in Figure 7. Rule 1 maximises the amount of water taken, since it allows a 100% take of 3 m^3s^{-1}. This abstraction rule was found to have the greatest impact on both total annual fish loss (Figure 8a) and the percentage of surviving fish able to enter freshwater prior to a given date (Figure 8b). The differences in the loss and delay of fish were found to be greater between a wet and dry year than between abstraction rules in any given year.

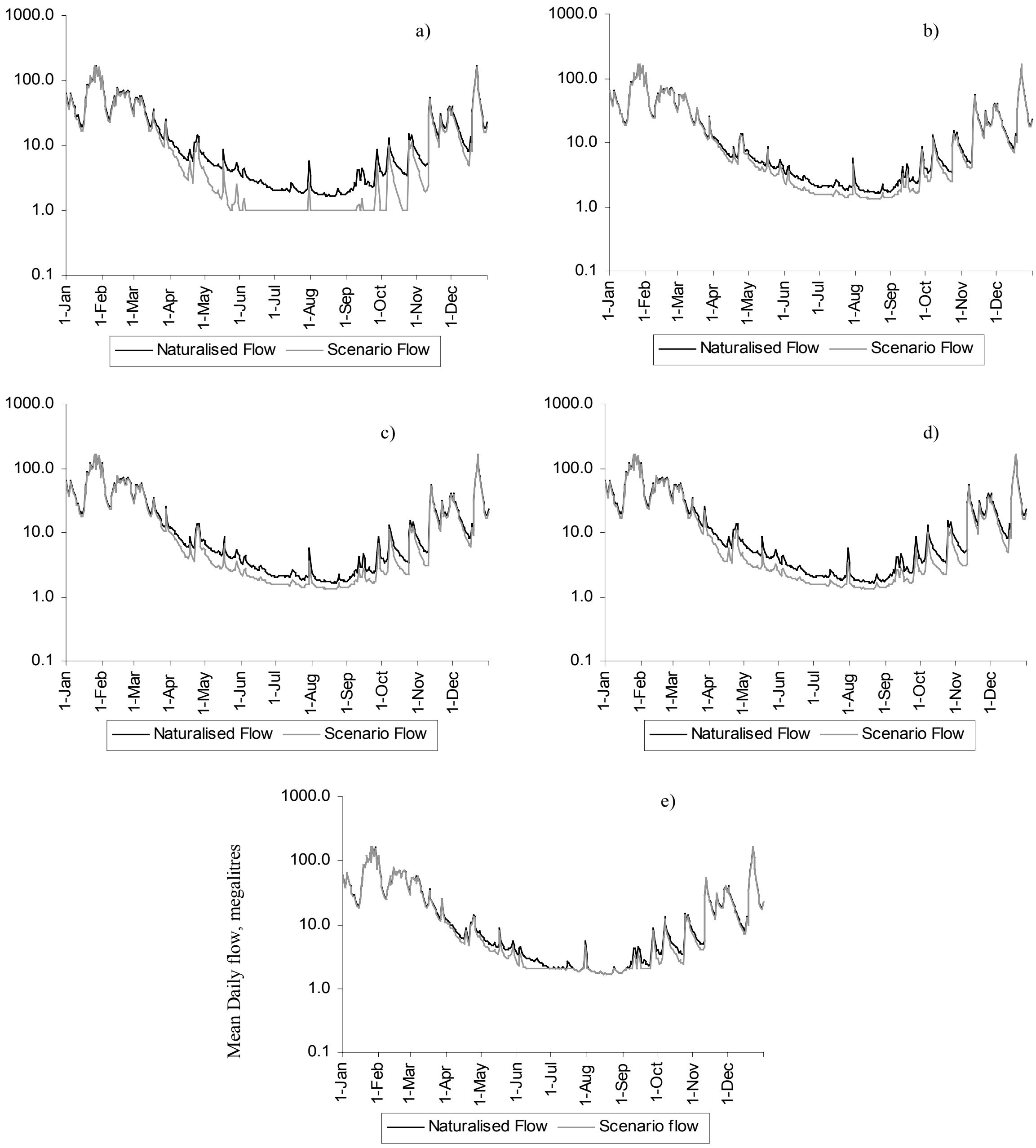


Figure 7. Hydrographs of flow regime in 1995 with abstraction rules, a) Rule I, b) Rule II, c) Rule III, d) Rule IV and e) Rule V.

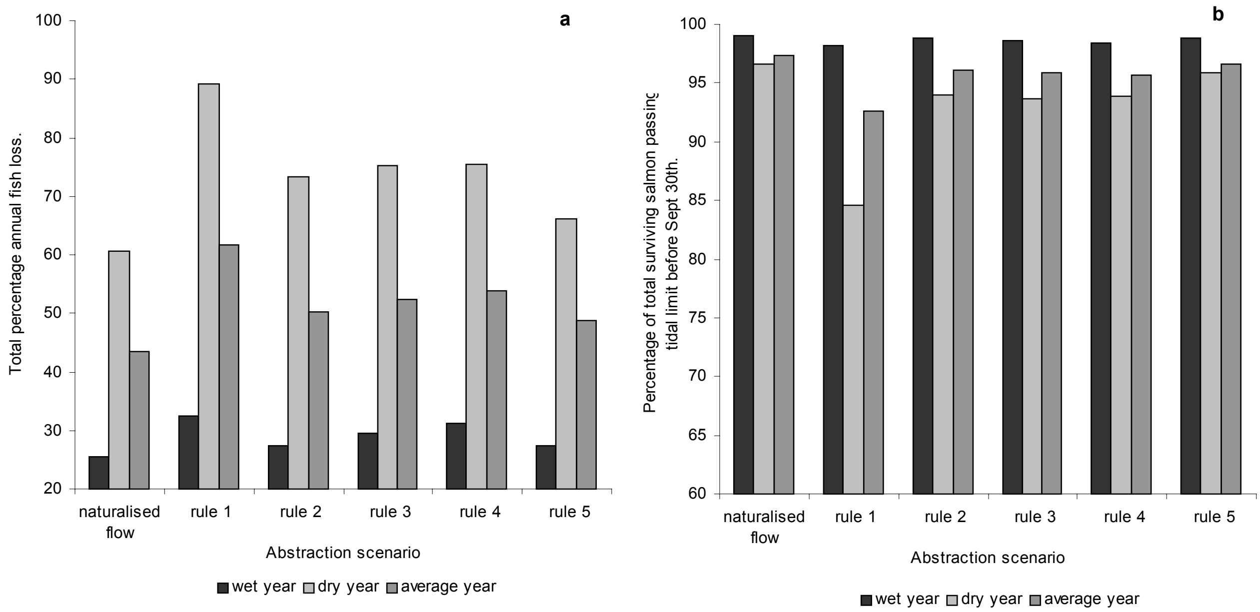
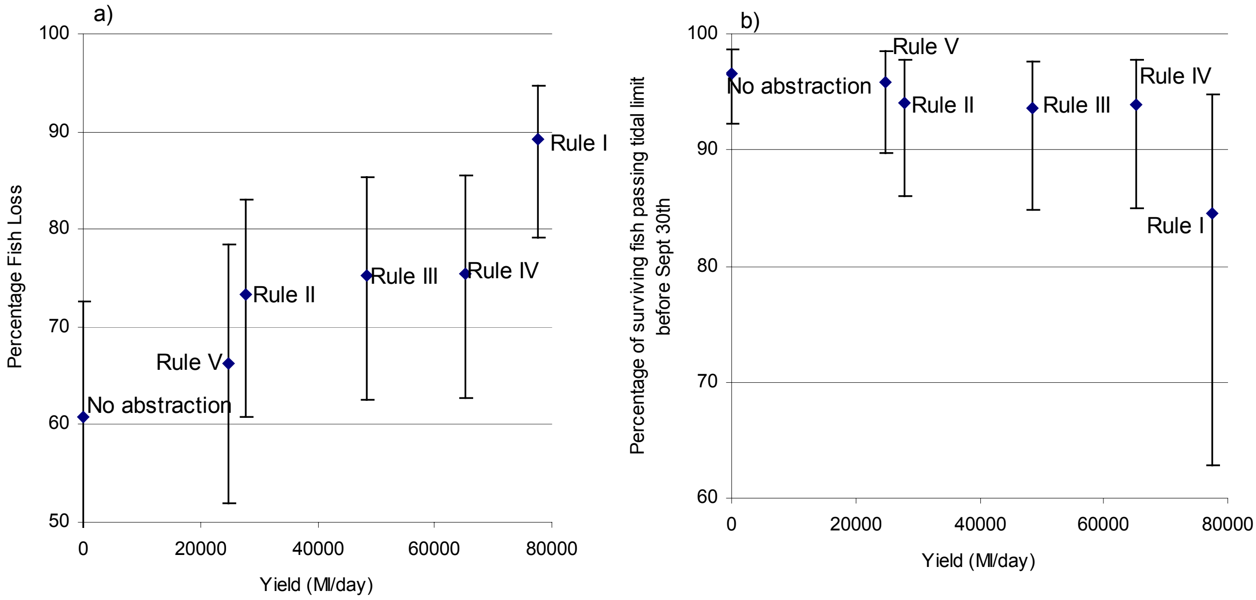


Figure 8. Results of model simulations on the River Taw under five different abstraction rules in a dry year. a) Total percentage fish loss at the end of the year and b) percentage of the total surviving salmon passing tidal limit before September 30th.

Abstraction rule I yielded the greatest amount of water, but has the greatest impact on salmon (Figure 9). Abstraction rules II, III, IV have a similar impact on salmon in terms of loss and delay, but yield different amounts of water. Abstraction rule IV yields double the amount of water of abstraction rule II, yet the impact on salmon is similar. By examining results in this way, we are able to assess whether it is possible to abstract the same amount of water, but reduce the impact on salmon. In this case it seems that the prescribed flow is important to the protection of salmon and not the maximum take.



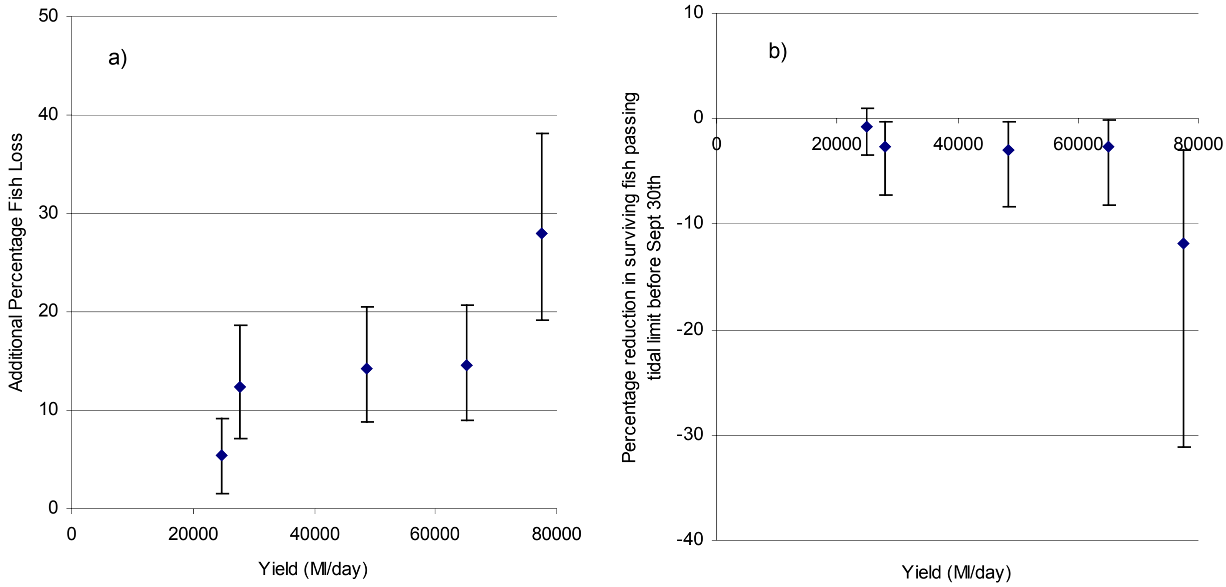
a) Total annual percentage fish loss

b) percentage of surviving fish entering freshwater before September 30th

Figure 9. Results of simulations against total annual scheme yield produced from abstraction regime on the River Taw for a dry year, with 95% C.L.

Another useful way of interpreting the results is to compare the losses and delays of salmon under the proposed scenario with those that occur under a naturalised or actual flow regime. The additional losses and delays as a result of the abstraction rules are derived separately in the statistical model and these additional losses may not necessarily match the differences calculated by subtracting one from another. If the confidence intervals around the estimates are all positive then we can be confident that there is a significant increase in the total annual loss rate or delay as a result of the proposed flow regime.

The additional fish losses resulting from the proposed abstractions were significant for all abstraction rules (Figure 10a). The additional delays in salmon migration were significant for all of the abstraction rules except abstraction rule V (Figure 10b). We therefore have little confidence that this abstraction would have a significant effect on the timing of the salmon migration.



a) Additional percentage fish loss

b) Percentage reduction of surviving fish entering freshwater before September 30th

Figure 10. Additional fish losses and delays as a result of the proposed abstraction rules on the River Taw for a dry year, with 95% C.L.

5 Sensitivity Testing

Since running the simulations is dependent on entering a number of river specific inputs, it was useful to assess how sensitive the model and the results were to these inputs.

5.1 Arrival Patterns

It is difficult to determine exactly what the arrival pattern of salmon to the estuary would be in any particular year and so it is useful to see how sensitive the model is to these arrival patterns. Six different possible arrival patterns were examined. Each was a monthly pattern with the timing varying through the year for 1995 (Figure 11).

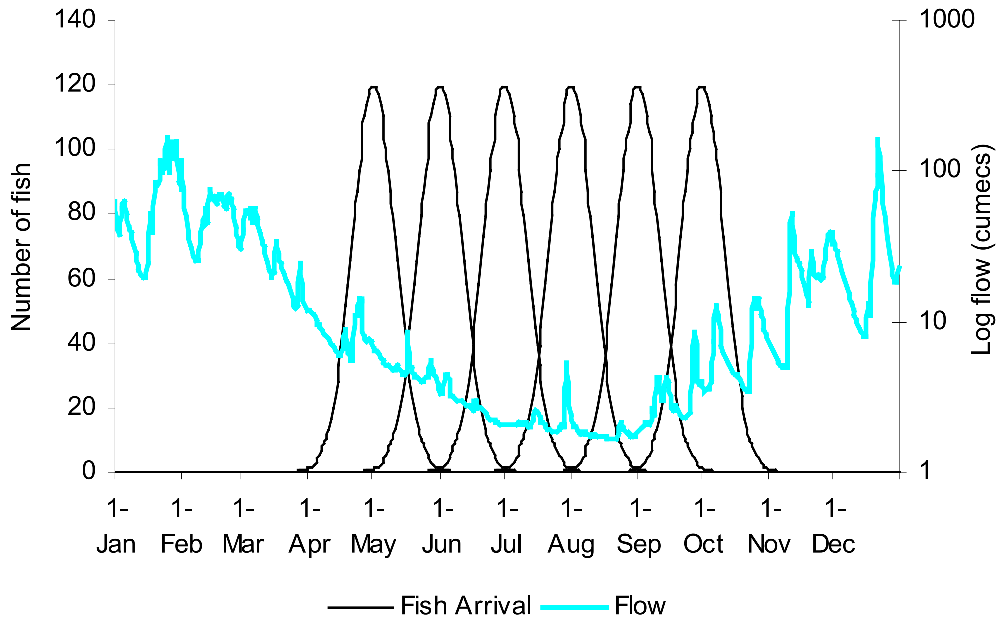


Figure 11. Possible alternative patterns of salmon arriving to the estuary of the River Taw in 1995.

The results of the different arrival patterns vary significantly depending on the peak arrival date (Figure 12). The greatest losses of fish from the estuary were seen when the peaks of salmon arrive in July and August. This corresponds to the time of the lowest flows (Figure 11) and so losses of fish in the estuary will naturally be greater at this time of year. However, these differences in fish losses vary not only according to the absolute flow available but also to the seasonal flow-migration response (Greest et al 2005). The way in which a salmon responds to a given flow changes through the year (Figure 13). This means that the number of salmon successfully migrating in to freshwater will be greater in May than October for the same given flow. The reason for this is unknown, but may be due to the difference in the behaviour of fish migrating at these times or it could be related to the river temperature. Further investigation of these factors should be considered along with a better method of determining the arrival of salmon to an estuary.

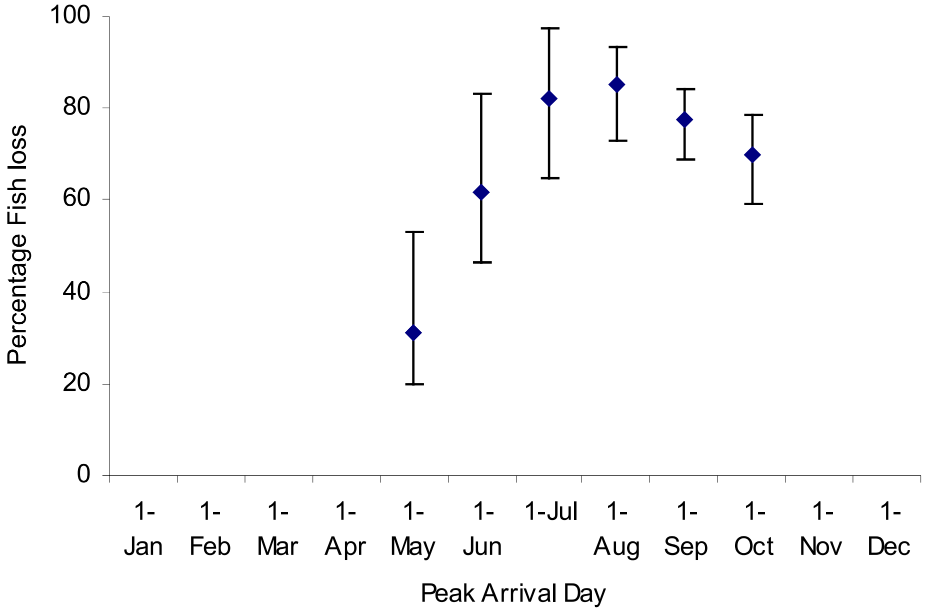


Figure 12. Results of different patterns of arrival on the River Taw in 1995.

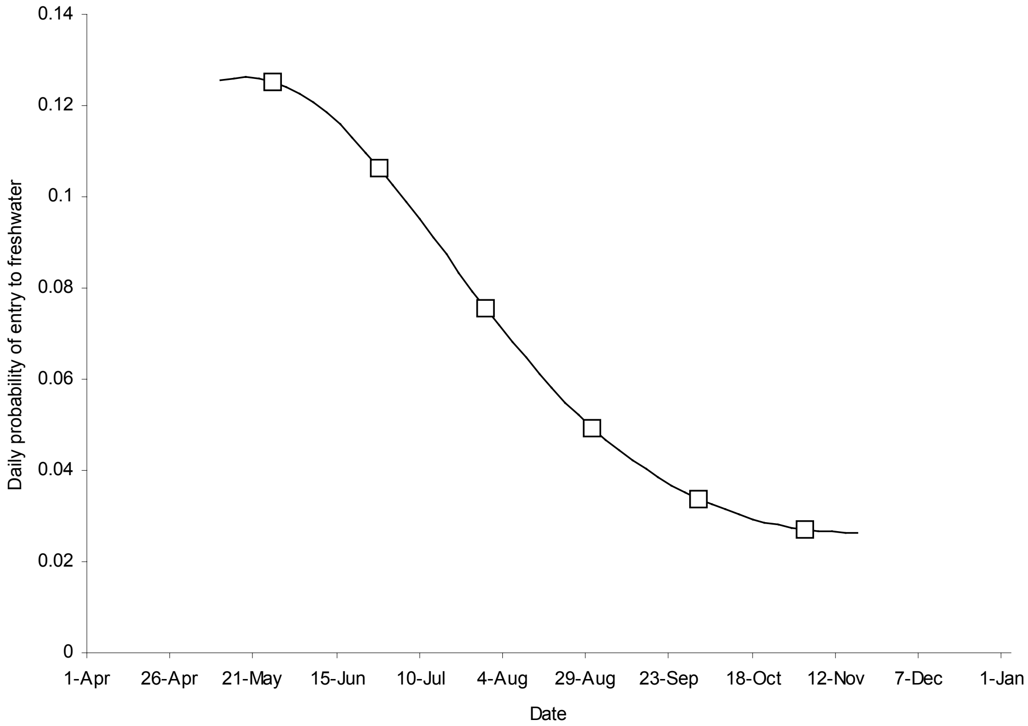


Figure 13. Change in maximum height of daily probability curve for different times of year for the River Taw at average flow.

5.2 Release Points

The point at which salmon are thought to be available to a particular river is very difficult to assess. For the River Taw, five different release points were examined (Figure 14) and these were compared between a dry year and a wet year.

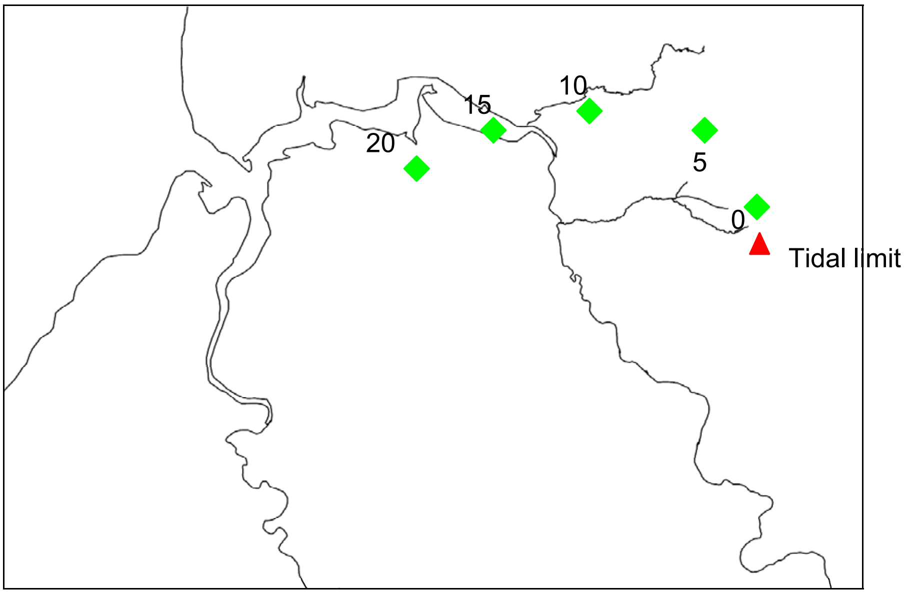


Figure 14 Map of River Taw showing five release points, 0km, 5km, 10km, 15km and 20 km from tidal limit.

The results show that the fish loss rates increase with increasing distance from tidal limit (Figure 15). This is quite an obvious result, since the further away from tidal limit the fish are assumed to be available, the longer it will take them to get to tidal limit and the longer they are exposed to the harsh environment of the estuary. However, it does demonstrate the variability in results, and how the distance from tidal limit at which fish are designated as available to the river, is critical in making management decisions (See section 2). It is therefore essential that a robust approach to determining this be adopted. However as previously mentioned, if simply making comparisons between flow scenarios, then it may not be so critical.

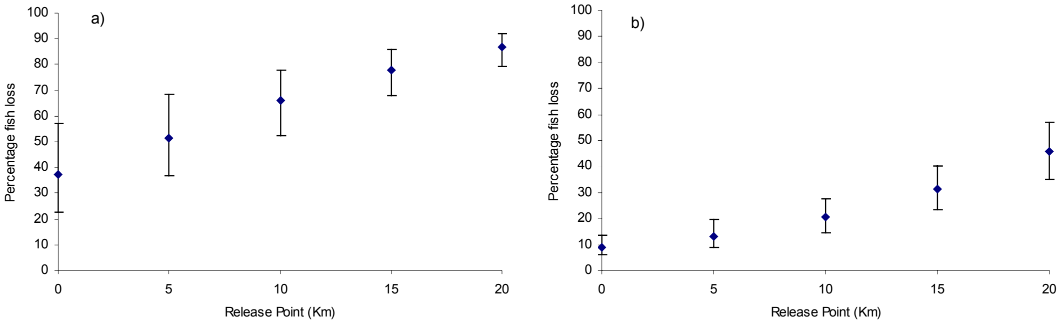


Figure 15. Fish loss rates from different release points on the River Taw in a) Dry year (1995) and b) a wet year (1998) (Naturalised flows).

6 Implementation

6.1 Catchment Abstraction Management Strategies

Catchment Abstraction Management Strategies (CAMS) is one area where this model may be used.

CAMS are strategies for the management of water resources on a catchment scale in the Environment Agency. To manage water resources effectively, we need to understand how much water is available and where it is located. In CAMS, this is achieved by undertaking a resource assessment, covering both surface water and ground water. The surface water resource assessment requires the definition of 'ecological river flow requirements'. These are based on the sensitivity of the local ecology to flow variations (i.e. their vulnerability to abstraction impacts). River flow requirements are developed by giving environmental weighting scores to reaches that represent the sensitivity of the river reach to changes in flow. Reaches are banded according to their low flow abstraction sensitivity as Very High, High, Moderate, Low or Very Low. These requirements represent the minimum flow regime that we are aiming to protect and which then affects the amount of water that is available for abstraction. These river flow requirements are then compared with a scenario flow that assumes all licences are being fully utilised (i.e. the full licensed quantity is being abstracted). This comparison reveals a surplus, balance or deficit of water. The size of the surplus/deficit corresponds to a resource availability status for the unit that indicates whether the catchment resources are in balance or not.

The salmon migration model may be used in CAMS to assess whether the river flow requirements provide sufficient protection for adult salmon entering freshwater or to determine the effects of the fully licensed flow.

An example is shown in Table 2 where fish losses under a naturalised flow scenario in an example river are compared with the flow regimes under Very High and High River Flow Objectives. It can be seen that even under the Very High flow scenario, predicted fish losses are significantly higher than under un-impacted conditions, especially in a dry year such as 1995. This has clear implications for RAM in CAMS, namely that migration flows will in many cases have to be accounted for separately from the general ecological assessment if migratory salmonid populations are to be protected.

Table 2. Comparison of predicted losses of tagged fish under different CAMS River Flow Objectives. Medians with 95% confidence limits

	Predicted tag loss (percentage)			Additional percentage tag loss compared with naturalised flow		
Confidence Limits	**2.5%**	**Median**	**97.5%**	**2.5%**	**Median**	**97.5%**
Naturalised Flow (1995)	47.8	60.6	72.4	-	-	-
Very high RFO (1995)	53.6	66.8	78.2	2.1	5.9	10.0
High RFO (1995)	57.4	70.2	80.9	4.5	9.1	14.2
Naturalised Flow (1998)	18.5	25.5	34.8	-	-	-
Very high RFO (1998)	19.9	27.2	36.4	0	1.6	4.1
High RFO (1998)	20.8	28.3	37.6	0	2.7	5.4

6.1.1. Review of RAM framework – an additional case study

The RAM framework was reviewed in 2006. Water Resources requested that this model be used to investigate the impacts of proposed flow scenarios on the migration of adult salmon. This work was carried out in addition to this project and is summarised in Appendix I.

6.2 Habitats Directive Review of Consents

The Atlantic salmon, *Salmo salar*, is listed in annexes II and V of the European Union's Habitats Directive as a species of importance to the UK and therefore must be protected. The Habitats Directive and Regulations will impact on a wide range of people and organisations whose activities may affect Natura 2000 sites. This includes existing consent holders and future applicants for Agency permissions and approvals, such permissions include licences to abstract water. As one of the competent authorities under the Habitats Regulations, the Environment Agency must assess the possible effects of the various permissions on, or potentially affecting a Natura 2000 site. This includes reviewing existing permissions as well as assessing new ones.

Four stages have been defined for the review of consents. These are:

Stage 1: Is the permission relevant?
Stage 2: Is the permission likely to have a significant effect?
Stage 3: Could the permission cause an adverse effect on site integrity?
Stage 4: Determination of the permission.

The flow model demonstrated here may be used to make assessments of permissions in Stage 3 of the risk assessment process. Abstraction may be assessed by running scenarios as previously demonstrated. When examining the possible changes which may be made to abstraction licences at Stage 4 the model will be useful.

6.3 Reviewing abstraction licence applications

Another area where this model may be used is in reviewing individual abstraction licence applications. The Environment Agency manages water resources in England and Wales through a system of issuing licences for abstracting water. By licensing, the level of abstraction to protect both water supplies and the environment is regulated. Licences would be reviewed in the same way as demonstrated on the River Taw by running scenarios and determining the impacts.

6.4 Sustainable Abstraction

The choice of appropriate management targets for the conservation of Atlantic salmon stocks and the optimisation of fishery performance is an important step when defining operating rules for water resource schemes. The challenge faced by Water Resources managers and Fisheries managers is deciding what level of fish loss or delay is sustainable to the population. One area investigated as part of this project was linking the results of the model to conservation limits. Conservation Limits (CLs) indicate the minimum desirable spawning stock levels below which stocks should not be allowed to fall (Environment Agency, 2003). The use of conservation limits in England and Wales has developed in line with the requirement of ICES and NASCO to set criteria against which to give advice on stock status and the need to manage and conserve individual river stocks

Linking the results from the predictive spreadsheet to Conservation Limits was investigated on an example river. The conservation limit was converted from numbers of eggs deposited to the equivalent numbers of adults and compared with the numbers of adults successfully entering freshwater and spawning (Figure 16).

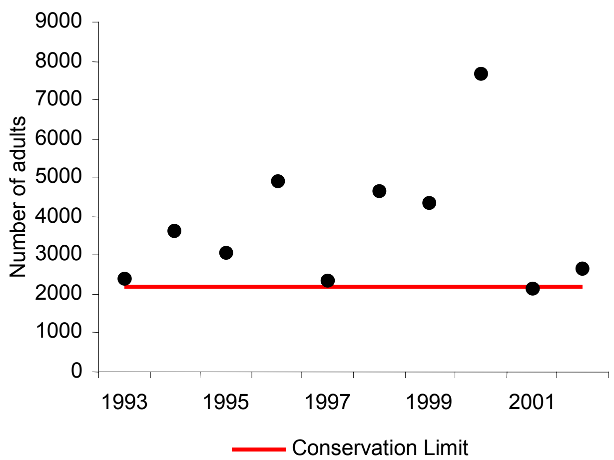


Figure 16. Numbers of adults successfully entering the example river compared to the Conservation Limit.

Simulations were then run in the spreadsheet to predict what the fish loss rate was under the flow conditions recorded from 1993 to 2003 (Figure 17a). From this the total number of salmon arriving in the estuary could be calculated.

Abstraction rule IV (Table 1) was then applied to the spreadsheet and the scenarios re-run to calculate the fish loss rates under this abstraction rule. The loss rates were found to be between 7% and 14% greater under the new flow regime (Figure 17b).

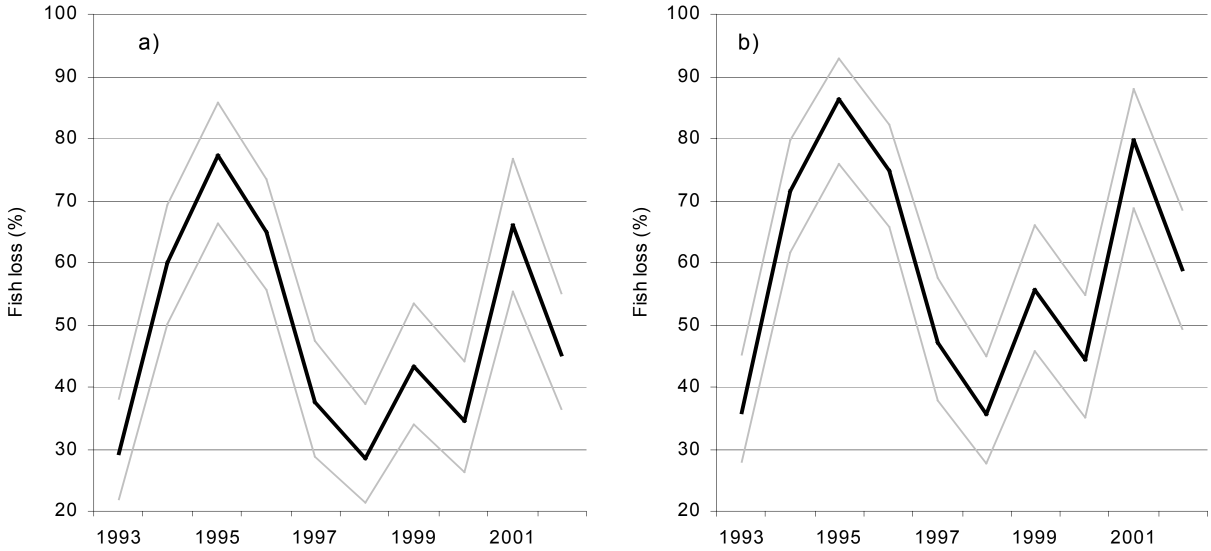


Figure 17. Fish loss rates for a) actual flow regime and b) proposed flow regime on an example river from 1993 to 2002. Outer lines indicate 95% percentiles.

Given the fish loss rates under the new flow regime, the numbers of adults which would have successfully entered the study river and therefore contributed to the egg deposition for each year was calculated and compared with the original numbers of adults and the conservation limit (Figure 18).

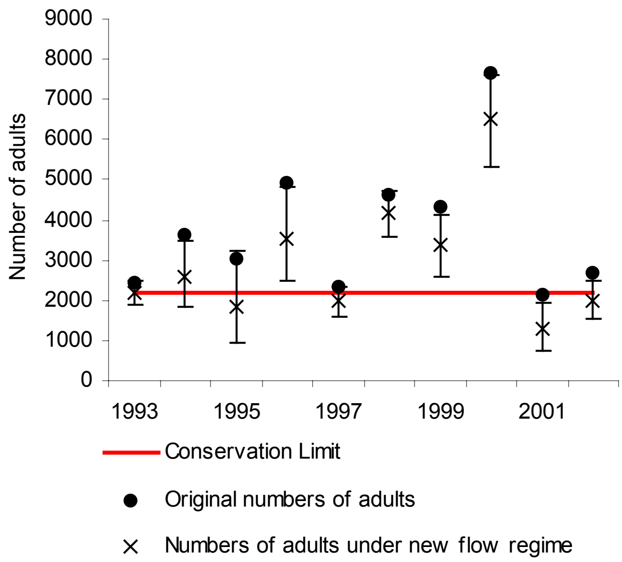


Figure 18. Numbers of adults successfully entering freshwater

Under this new flow regime, the numbers of adults successfully entering freshwater dropped between 9% in 1993 and 40% in 2001. This represents a substantial decrease in the egg deposition and as a result under this new flow regime, this river would fail to comply with the conservation limit. In order to comply with the conservation limit, the required spawning stock level must be met four years out five (i.e. 80% of the time). Since 50% of the years now fall below the required level of returning adults, the river is failing to meet its conservation limit.

This starts to put the impact of abstractions in to context and we can start to the think of the implications of new abstractions and water resource schemes in terms of the sustainability of salmon populations. There is large uncertainty associated with these estimates and flow cannot be assumed to be the only factor affecting the compliance with the conservation limit. However it is a useful way of thinking about the data and applying the scenarios to management decisions.

7 Conclusions

- This phase of the work on salmonid migration and river flow has demonstrated that a model derived from salmon telemetry and counter data can successfully predict the impacts of various river flow scenarios upon rates of loss of salmon as they ascend estuaries towards freshwater.

- The performance of models using telemetry data only, counter data only and a combination of the two were assessed for the river Tamar. The confidence in the estimate of fish loss did not seem to improve with the addition of counter data on the River Tamar, however the overall estimate of annual fish loss recorded was between the two scenarios of telemetry data only and counter data only respectively.

- Using the model in its current form, estimates of the impacts of any abstraction or water resources scheme on a river with no data on adult salmon migration could be made but the confidence intervals around the estimates would very wide. Performance of the model could be improved by addition of data from new rivers with counter or telemetry data. For rivers with no data, it is suggested that versions of the model already developed for other, similar and geographically close rivers could be used as surrogates.

- The model worked well for reviewing individual abstraction scenarios. The biggest differences in fish loss and delay were observed between wet and dry years rather than different abstraction scenarios, though differences between scenarios were nevertheless significant. The biggest impacts of abstraction were observed in dry years.

- The model was found to be relatively sensitive to the different user inputs. It is crucial to determine the pattern of salmon arriving in the estuary because both freshwater flows to the estuary, and the response of salmon to those flows vary greatly between seasons.

- Predicted loss rates also varied greatly depending on whereabouts in the estuary the nominal “release point” is set. This is less important where it is desired to indicate the changes in proportion of fish lost under different flow scenarios, however if absolute estimates of fish loss are required then release point is critical. Determining appropriate release points is a contentious issue to and it may be that more work is needed to explore this and to develop guidelines.

- There is good potential for application of the model within the Environment Agency. In CAMS it could be used alongside the existing ecological assessments to help determine River Flow Objectives. The methodology may be useful for Habitats Directive Review of Consents on some of the sites where assessments are still to be undertaken. The model could also be used in reviewing individual licence applications.

- Using the outputs from these models in conjunction with river-specific Conservation Limits can provide guidelines as to what levels of fish loss are sustainable to the population and ultimately whether a given abstraction scenario is likely to result in a river failing its salmonid Spawning Targets or Good Ecological Status under Water Framework Directive.

- The model needs further refinement in order to make it sufficiently flexible to be used on rivers with fish counter data only or on rivers where there are no data

8 Recommendations

1. Investigate more complex patterns of salmon arriving in the estuary. Investigate the possibility of using other sources of data to determine the arrival pattern, for instance rod catches, or patterns of arrival at nearby estuaries on the same coastline.

2. Investigate the assumption of seasonality within the statistical model by including temperature data.

3. Investigate the development of models which can utilise rod catch data

4. Seek to gain greater understanding of the behaviour of salmon from different rivers with common estuaries.

5. Undertake further trialling of the models as follows:

    - comparisons with local methodologies developed for the Teifi, Itchen and Wye, consider whether the levels uncertainty generated by the model would enable management decisions to be made.
    - Trial the model on new rivers with fish counters situated at/near tidal limit.
    - Undertake pilot trials of the model in selected CAMS, Habitats Directive Review of Consents sites, and individual licence applications

6. Develop an implementation plan for the rollout of this methodology, as proposed:

    - Assess the utility of the Winbugs and Excel Spreadsheet versions of the model with a view to use by Area fisheries and water resources staff.
    - “Roadshow” around Regions to demonstrate the use of the final version of the model
    - Produce an electronic user manual to accompany the model.
    - Undertake full roll-out when confidence of area users is achieved

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10 Appendix

10.1 Results of modelling work on Rivers Taw and Avon

10.1.1 Introduction

The RAM framework, which forms part of CAMS (see section 6.1), was reviewed in 2006. Water Resources requested that the salmon flows model was used to investigate the impacts of proposed flow scenarios on the migration of adult salmon. Two contrasting rivers were chosen for investigation and these were the Rivers Taw and the River Avon.

10.1.2 Methods

Naturalised flow and seven different flow scenarios were investigated using the salmon flows model. The different flow scenarios are demonstrated in Figure 19 for the River Taw in 1995. Four of the scenarios are a percentage reduction on the naturalised flow (5%, 10%, 20% and 50%) and the final three are the proposed sensitivity flow bands for RAM version 4. These three abstraction sensitivity bands, ASB1, ASB2 and ASB3 will replace the old five-band system of RAM version 3 (Environment Agency, 2002). ASB1 represents a stretch of river that has a low sensitivity to abstraction and therefore allows more water to be licensed. ASB2 represents a stretch of river that has a medium sensitivity to abstraction and ASB3 represents high sensitivity to abstraction.

Naturalised flows for the River Taw, previously obtained from Environment Agency Devon Area hydrologists, were passed to Entec to generate flow scenarios for investigation. Entec generated the naturalised flows and the subsequent flow scenarios for the River Avon.

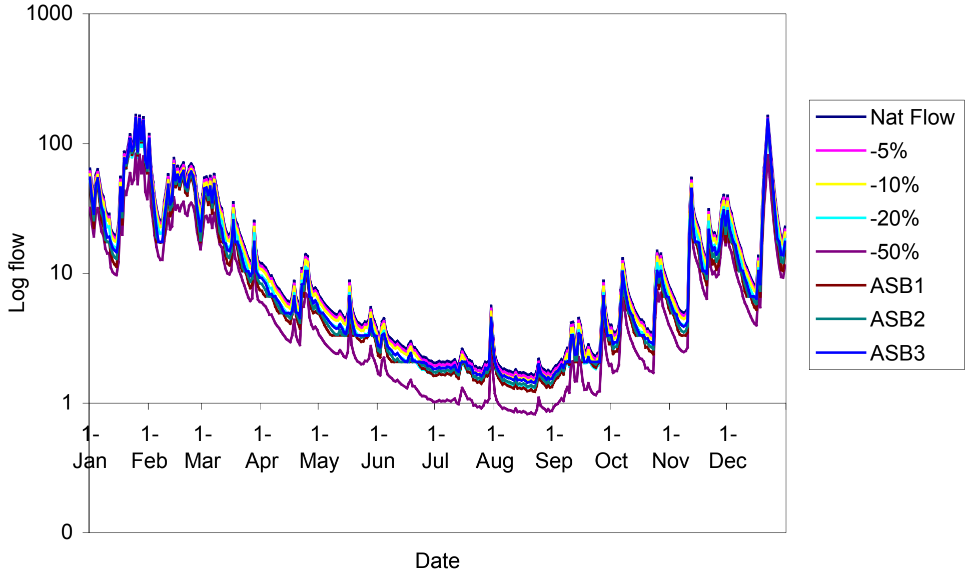

Figure 19. Naturalised and derived flow scenarios for the River Taw in 1995.

The naturalised flows and the proposed flow scenarios were then used in the salmon migration model to determine the total percentage of salmon failing to enter the river under each of the flow scenarios. The additional loss of salmon compared to the naturalised flow regime was also recorded for each proposed flow scenario. All flow scenarios were investigated for 1995 and 1998 and the flow scenarios ASB1 and ASB3 were investigated for all years with available data.

The patterns of salmon arriving to the estuaries were based on local information (K. Broad, pers comms) and historic net catch information (Environment Agency, 2005). The arrival patterns were found to differ between the two catchments (Figure 20). The number of salmon entering both rivers was set at 3000. This was an arbitrary value and is not significant to the results of these analyses since we are only concerned with the percentage differences.

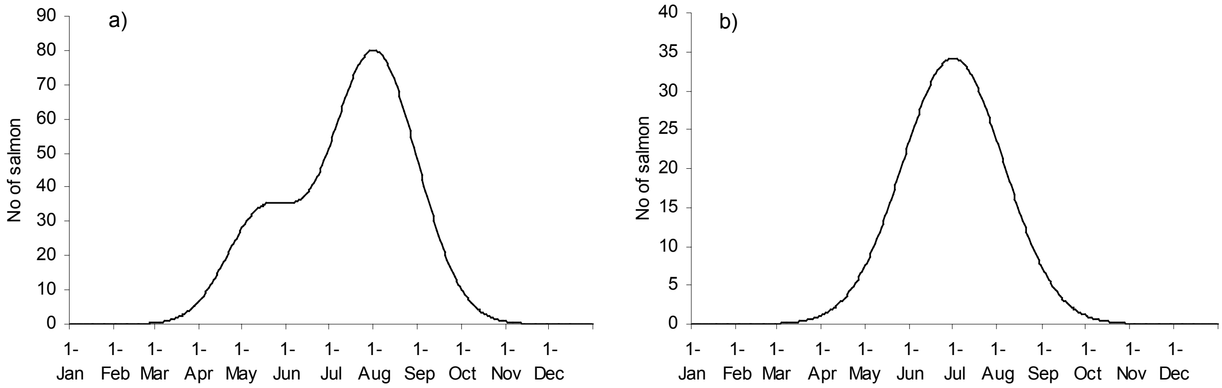

Figure 20. Pattern of salmon arriving to the estuaries of a) the River Taw, and b) the River Avon.

10.1.3 Results

River Taw

The total percentage fish loss for the River Taw increased with increasing abstraction (Figure 21). The greatest losses were observed with the 50% abstraction rules, but significant losses were observed for all flow scenarios. The additional loss of salmon varied from 2% for a 5% abstraction to an additional 25% loss for 50% abstraction (Figure 22).

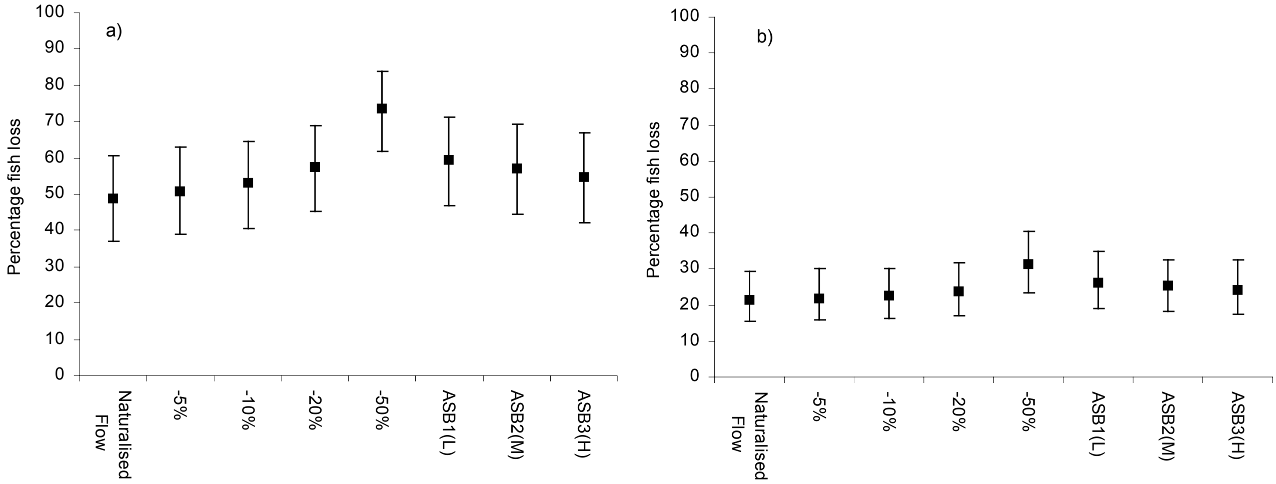

Figure 21. Total percentage fish loss under different flow scenarios on the River Taw for a) 1995 and b) 1998.

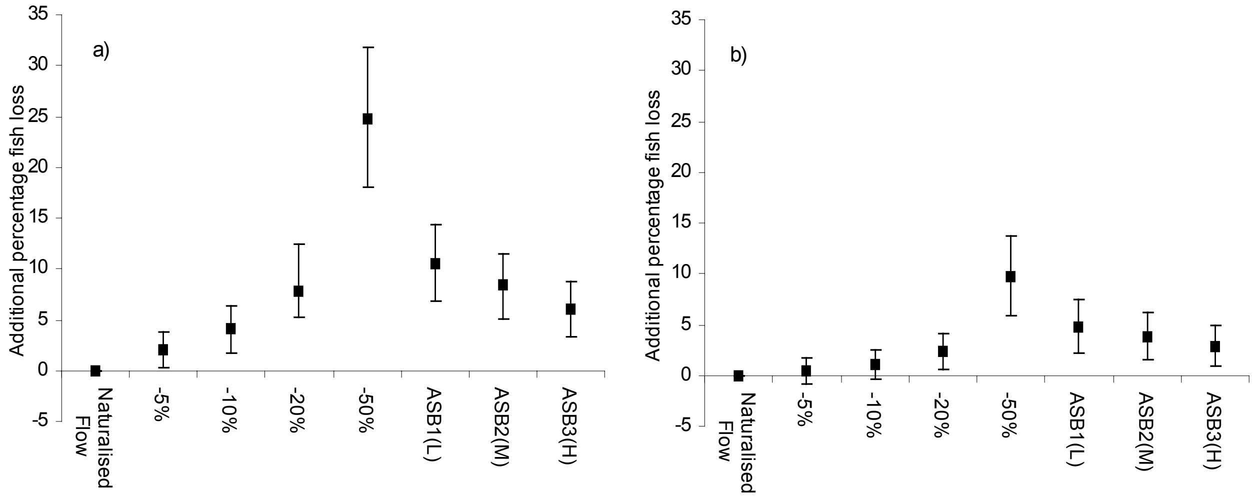

Figure 22. The additional percentage of fish lost under different flow scenarios for a) 1995 and b) 1998.

The additional losses are derived separately in the statistical model. These additional losses may not necessarily match the differences calculated by subtracting one annual loss rate from another. If the confidence intervals around the estimates are all positive then we can be confident that there is a significant increase in the total annual loss rate as a result of the proposed flow regime. In 1995, all of the flow scenarios produced a significant increase in the total annual loss rate on the River Taw, but in 1998, the abstraction rule of 5% and 10% did not give significant additional losses. Therefore we have little confidence that these flow scenarios would have a significant effect on the number of salmon migrating in to freshwater in 1998.

In all years investigated on the River Taw (1993 to 2002), the maximum percentage of fish lost as a result of the ASB1 (low sensitivity to abstraction) flow band was an additional 10.6% in 1995. For the flow band ASB3 (high sensitivity to abstraction) the maximum additional loss was 6% in 1995 and 2001. In all years the additional losses as a result of these proposed flow bands were significant (Figure 23).

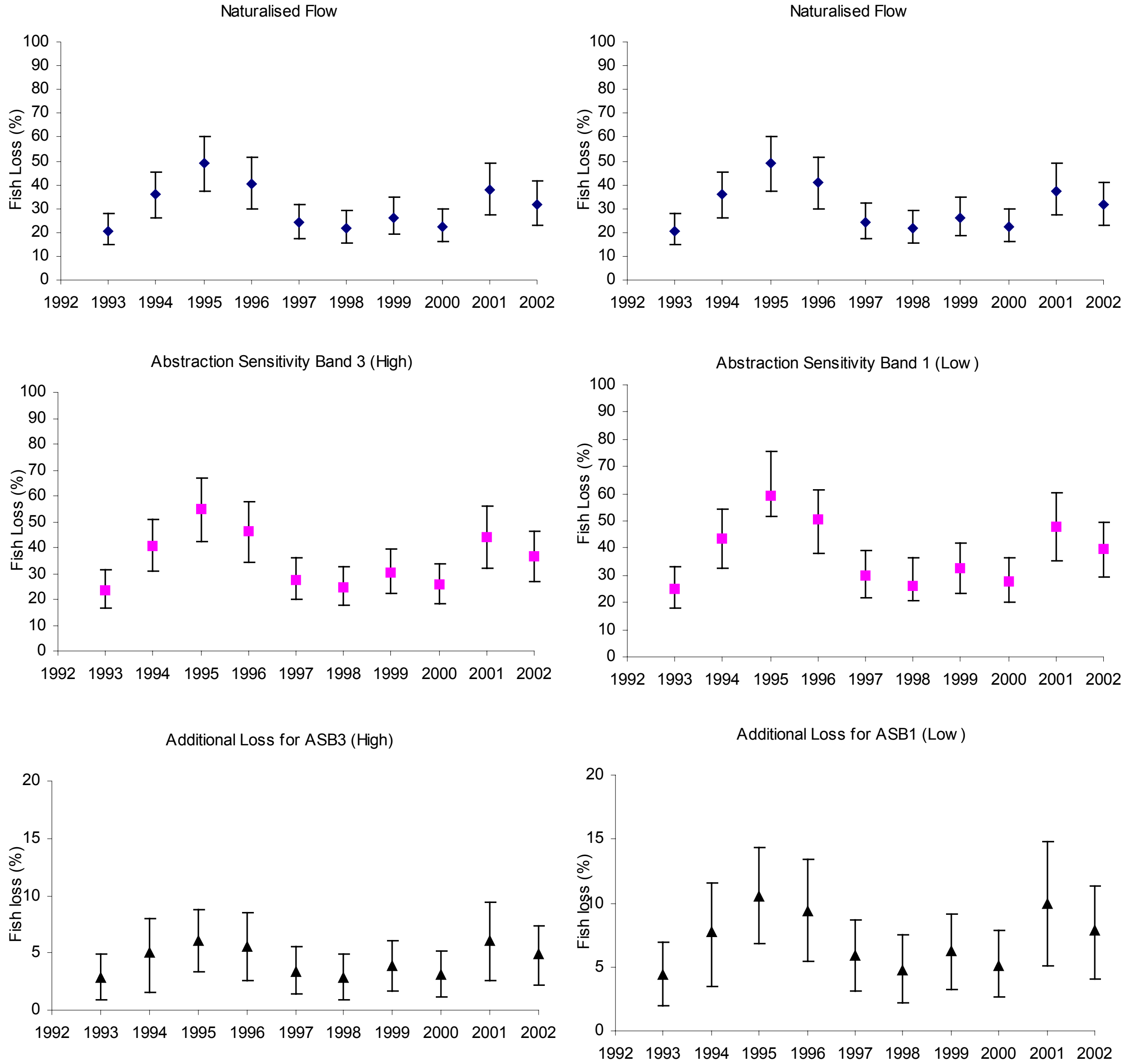

Figure 23. Comparison of total percentage of fish lost for each year from 1993 to 2002 for naturalised flow and ASB1 (L) and ASB3 (H) flow bands together with the additional losses as a result of these flow scenarios on the River Taw.

River Avon

The annual percentage fish losses increased with increasing abstraction (Figure 24) as on the River Taw, but the differences between the two years were not as great. The scenario which results in the 50% reduction in naturalised flow causes the biggest and most significant reduction in the numbers of salmon entering freshwater. In both years, all of the flow scenarios, produced a significant increase in the number of salmon failing to enter freshwater (Figure 25)

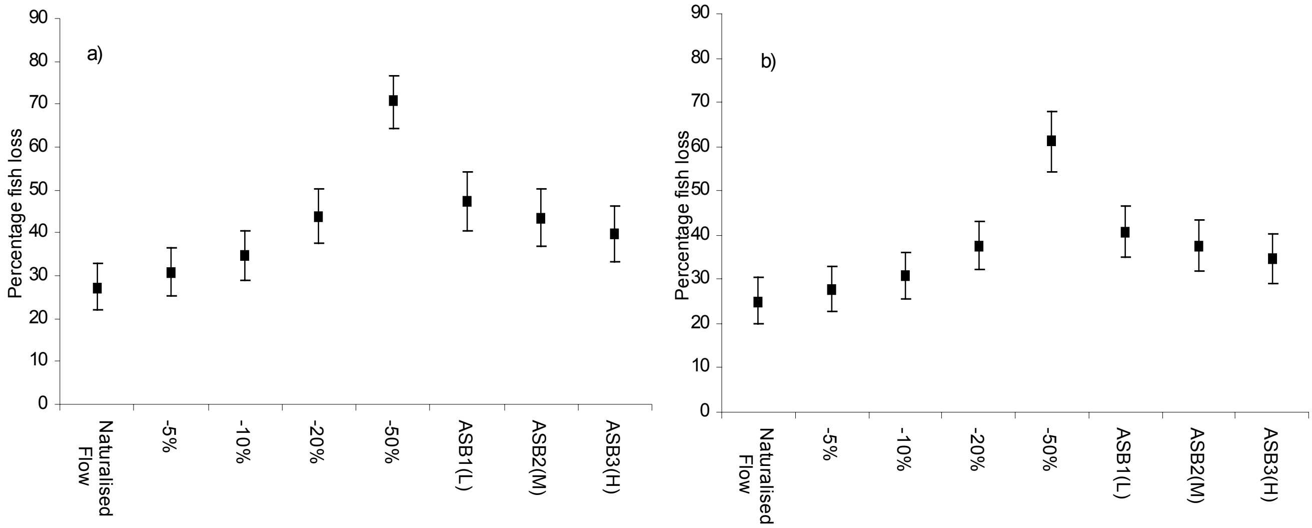

Figure 24. Total percentage fish loss under different flow scenarios on the River Avon for a) 1995 and b) 1998.

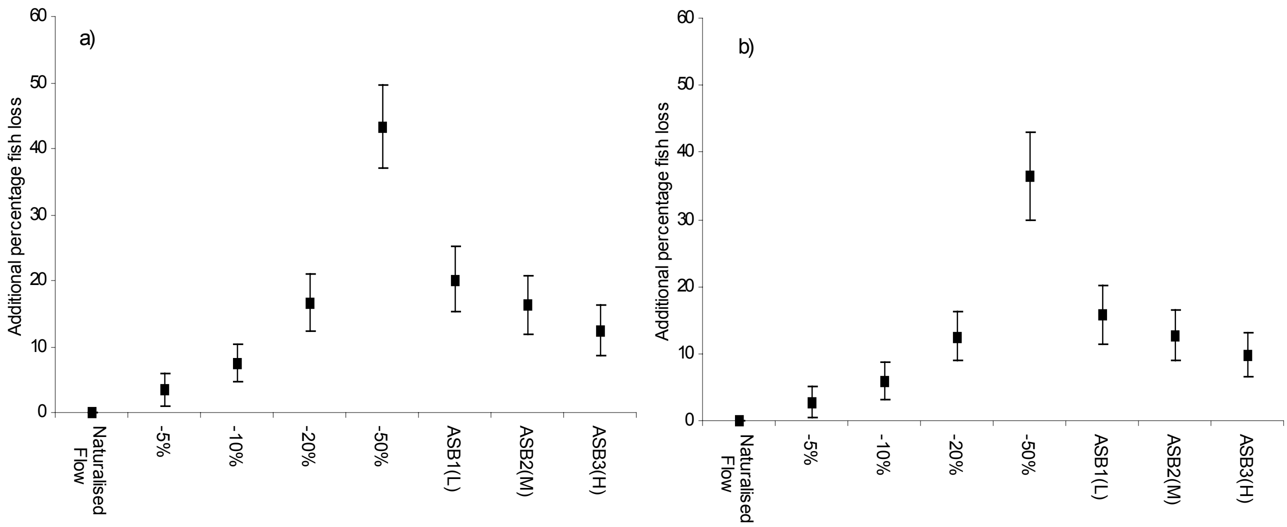

Figure 25. The additional percentage of fish lost under different flow scenarios for a) 1995 and b) 1998.

In all years investigated on the River Avon, the maximum percentage of fish lost as a result of the ASB3 (H) flow band was an additional 15.6% in 2002. For the flow band ASB1 (L), the maximum additional loss was 21.1% in 2003. The additional losses as a result of these proposed flow bands were significant in all years. (Figure 26).

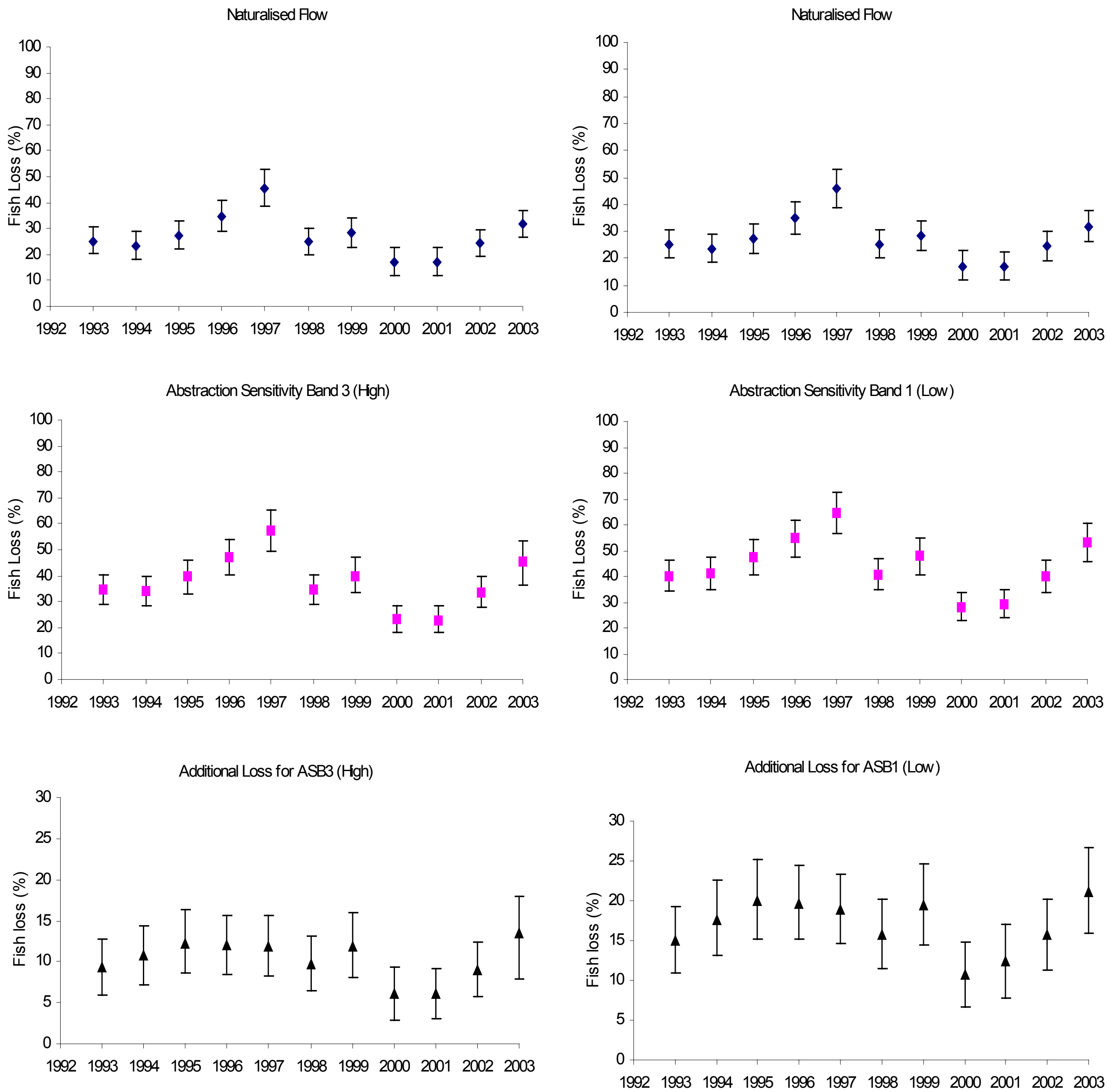

Figure 26. Comparison of total percentage of fish lost for each year from 1993 to 2003 for naturalised flow and ASB1 (L) and ASB3 (H) flow bands together with the additional losses as a result of these flow scenarios on the River Avon.

Comparison of results from Rivers Taw and Avon

When the additional losses from the two rivers were compared (Table 3), major differences between the two rivers were observed. In 1995 the additional losses in the River Avon were double those in the River Taw and in 1998 the additional losses were three times as great.

Table 3. Comparison of the additional losses of salmon for 1995 and 1998 for the Rivers Taw and Avon.

	1995		1998	
	River Taw	River Avon	River Taw	River Avon
-5%	1.9	3.4	0.5	2.7
-10%	4.1	7.4	1.0	5.9
-20%	7.8	16.6	2.3	12.5
-50%	24.8	43.3	9.7	36.5
ASB1 (L)	10.6	20.01	4.7	15.8
ASB2(M)	8.4	16.2	3.8	12.7
ASB3 (H)	6.0	12.3	2.9	9.7

10.1.4 Conclusions

The total percentage of fish lost on both rivers increased with increasing abstraction. The difference in the percentage of fish lost in a dry year compared to a wet year was greater than the difference between high and low sensitivity bands on the River Taw. In contrast, the difference between high and low sensitivity bands on the River Avon was greater than the difference between years. However, 1995 was not typical of a dry year on the River Avon and greater differences may have been observed if a true 'dry' year was chosen.

The total losses of salmon, as a result of the proposed flow regimes, were greater on the River Avon than the River Taw. The River Avon historically had a very good population of large multi-sea winter salmon and these salmon tend to migrate to freshwater earlier in the year than the smaller grilse. The multi-sea winter salmon migrate in to freshwater from January to June, and this tends to coincide with the falling flows on a chalk river like the River Avon. If flows are already low and are then reduced further, the numbers of salmon that are able to successfully enter freshwater decreases. Salmon on the River Taw are largely grilse with a smaller number of multi-sea winter salmon. Grilse tend to enter freshwater later in the year and so the numbers of salmon entering the River Taw are distributed throughout the year (Figure 20a). Also, the River Taw catchment is carboniferous and so the pattern of flow is different to the River Avon. The flows tend to be peaky compared to the more stable base flows of the chalk rivers. The characteristics of the estuary may also be an important factor in the successful migration of salmon to freshwater under reduced flows. Finally when the flow migration curves for these two rivers are compared (Figure 6), it can be seen that the daily probability of migration is lower for the River Avon than the River Taw. This means that it will take salmon longer to enter freshwater on the River Avon than the River Taw and so at lower flows, losses will be greater.

This statistical model of salmon migration and flow demonstrates that any reduction in flow reduces the number of salmon successfully entering freshwater. The balance between the needs of the abstractors and the needs of the environment somehow has to be met. Therefore what level of loss is acceptable and sustainable to the population has to be determined. The salmon population on the River Avon is currently failing its salmon conservation limit and strict measures have already been put in place to reduce the exploitation. Additional losses to the population as a result of abstraction are therefore not acceptable and must be kept to a minimum. Given that most of the rivers in England and Wales are currently failing their conservation limits, the sensitivity to abstraction should be more precautionary, at least for those rivers which are ‘failing’ or ‘at risk of failing’ their conservation limit. In these rivers, the River Avon is currently failing its conservation limit (95%<p) and at risk of failing its conservation limit in 2010. The River Taw is probably at risk of failing its conservation limit (50% < p < 95%) now and in 2010.

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