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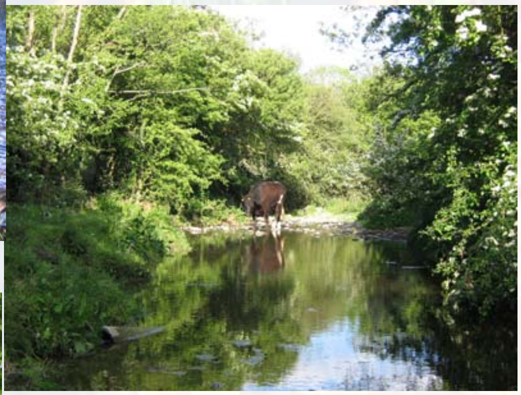
Dublin City Council
Comhairle Cathrach Bhaile Átha Cliath

Eastern River Basin District Project

Abstraction Pressures - National POM/Standards Study
The Assessment of Abstraction Pressures in Rivers in Ireland



May 2009 **Final Report**

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The Abstractions Pressures Project Steering Group consisted of Brian McKeown and Brian Smyth Dublin County Council (Chairmen), Ray Earle Project Co-ordinator ERBD, Oliver Fogarty DEHLG, PJ Shaw DCMNR, David Harrington Wicklow County Council, Edwina Moore Kildare County Council, Cliona Murphy Kildare County Council, Tim O'Leary Meath County Council, Donal Daly EPA, Deirdre Tierney EPA, Micheál MacCarthaigh EPA, Rebecca Quinn EPA, Catherine Bradley EPA, Jimmy King CFB, Trevor Champ CFB, Eileen Loughman Health Service Executive Kildare, Lily Byrne Health Service Executive Dublin North East, Aine O'Connor National Parks and Wildlife Service.

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- Des Boyhan of DCC who provided input and oversight to the survey component of this work.

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Glossary of Terms

A

Abstractions Is the process of taking water from any source, either temporarily or permanently.

Adult life stage Typically, salmon or trout (2+) years or older.

Average daily flow The arithmetic mean of individual daily mean discharges during a period of record.

ADF Average daily flow.

B

Biological Modelling Uses habitat suitability information and combines this with information on channel structure, modelled water surface levels and velocities and combines this with habitat suitability information to produce an index of the quantity and quality of available habitat.

C

Calibration flow Flow at which satisfactory field measurements have been made, and used to calibrate hydraulic model(s).

Compensation flow Mandated flow expected to be maintained downstream from a water storage facility or water intake to protect instream uses, including fishery habitat.

Constant Habitat Impact Curve A curve/graph that determines the impact (in terms of habitat loss/gain) of any given combination of abstraction and minimum instream flow.

Cover Areas of shelter that provide resting places, visual isolation, or protection from predators for aquatic organisms.

Cross section A vertical cross section taken across the stream.

Current meter	A device used to measure the velocity of water in a body of water.
	D
Discharge	The rate of flow, or volume of water flowing past a given point within a period of time, expressed as cubic metres per second.
	E
Envelope Curves	Curves encompassing all the suitable habitat suitability curves for each life stage and fish species.
Evaluation species	Species used to estimate effects of changes in flow on the aquatic ecosystem; Atlantic salmon and brown trout for this study.
	F
Feno pins	Feno pins are steel survey pins, which are driven into the ground, and then anchored by three strong steel anchor prongs, which are driven out into the surrounding ground.
Flow duration analysis	Duration analysis of stream flow data of a selected time step (e.g., daily or monthly).
Fry life stage	Typically, salmon or trout (0+) years old.
	G
Gauging station	Point on a stream or water body where water surface elevations or flow are systematically measured.
	H
Habitat	The place where an organism or population lives and its surroundings, both living and nonliving; used herein to refer to the physical aspects of habitat represented as weighted usable area.
Habitat suitability	Relationship describing usability of different values of physical criteria habitat variable (depth, velocity, substrate/cover) that compose the physical habitat of species.

HSC Habitat suitability criteria.

I

Instream Flow Incremental Methodology A method to quantify the effects of alterations of streamflow on the aquatic ecosystem.

IFIM Instream Flow Incremental Methodology.

J

Juvenile life stage Fish larger than fry; assumed to be (1+) years old.

L

Life stage An arbitrary age classification of an organism used in this study to describe adult, juvenile, fry and spawning periods in the life of selected species.

M

Manning's Roughness A factor used when computing the average velocity of flow of water in a channel which represents the effect of roughness of the confining material upon the energy losses in the flowing water.

Median monthly flow Median value of all the daily flows during a particular month for some period-of-record.

Median monthly habitat Habitat available half the time during a particular month in the record; defined in this study as habitat available at the median monthly flow.

Mesohabitat Collective term for different stream habitat types (e.g., riffle, run, pool).

Minimum Instream Flows Mandated flow expected to be maintained in a river channel to protect instream uses, including fishery habitat.

P

Passby flow	The flow rate below which a withdrawal can not be allowed.
PHABSIM	Physical Habitat Simulation Program; a set of software and methods used to compute relationships between physical habitat and streamflow.
Physiographic Region	A portion of the Earth's surface with a basically common topography and common morphology.
Pool	Part of a stream where velocity is reduced, usually with deeper water than surrounding areas.

R

Reach	Any defined length of a river or stream.
Renormalised minimum	The amount of weighted usable area available for the most limited weighted usable area life stage at each flow, rescaled to a range of zero to unity.
Reproducing trout stream	Stream with naturally reproducing trout population(s).
Riffle	Shallow rapids in a stream where obstructions create waves.
RMWUA	Renormalized minimum weighted usable area.
Run	A part of a stream characterised by rapid velocity and few waves over a significant length.

S

Segment	A certain length of a study stream.
Simulation flow	Any flow rate for which depth, velocity and weighted usable area have been computed.

Spawning life stage Life stage defined as including redd construction, laying and incubation of eggs, and young fish up to the time of emergence from the substrate.

Study region A part or complete physiographic region assumed to have homogeneous topographic, geologic, hydrologic, and habitat characteristics.

Study site A representative portion of a study segment selected for detailed data collection and modelling.

Study stream A stream selected from lists of trout streams and assumed to be representative of other trout streams in the same study region.

Substrate The material on the bottom of the river channel such as rocks, gravel, or sand.

T

Time series A set of values arranged in chronological order.

V

Velocity Adjustment Factor The ratio of the discharge for which velocities are being simulated to the sum of simulating cell velocities times cell areas.

W

Weighted usable Unit of measurement of habitat used in Instream Flow

Wetted perimeter The length along the bottom and sides of a stream channel, perpendicular to the flow that is in contact with the water at a particular flow rate.

WUA Weighted usable area.

WWTP Wastewater treatment plant.

1.0 Introduction

1.1 Project Overview and Objectives

This report describes the method and results of the instream flow assessment method for rivers in Ireland. This work is part of the National Programme of Measures and Standards (POMS) Study to assess abstraction pressures in Ireland (established December 2005) by approval of the Project Steering Group on 13th March 2008. The National POMS study was commissioned by the Department of Environment Heritage and Local Government (DEHLG) under the Eastern River Basin District project.

The aim of the study is to pilot a method to determine instream flow protection requirements for Irish rivers affected by abstraction pressures. The method has been piloted for one physiographic region and is based on protection of salmonid fisheries (Atlantic salmon and brown trout).

The modelling was performed with the PHABSIM (Physical HABitat SIMulation) model developed by the U.S. Fish and Wildlife Service (1974), which is part of the Instream Flow Incremental Method (IFIM) (Bovee, 1982). IFIM/PHABSIM has been used successfully worldwide to set minimum instream flow requirements in individual rivers. This study differs from typical applications of IFIM/PHABSIM in that it assesses the potential to aggregate results from individual river models to develop a tool that can be used across a study region. The basic approach is to conduct instream flow assessments at individual stream segments selected as being representative of the study region, and then determine if the results of the individual stream assessments can be regionalised to develop the method.

The project's approach is adapted from a regional methodology developed by the Susquehanna River Basin Commission, located in Pennsylvania, United States. Their study *Instream Flow Studies Pennsylvania and Maryland* (SRBC, 1998) appears to have been the first (and to our knowledge only) use of IFIM to develop regional or general criteria for determining the impacts of abstractions for a number of streams classified into similar groups. The SRBC method has been developed into an effective regulatory programme that has the support of both the environmental and fisheries regulatory agencies.

The endpoint of the proposed work is planned to be a series of curves of constant habitat impact that would describe how changes in stream flow (as caused by abstractions) would change habitat available to each species. The curves estimate the average annual reduction in habitat resulting from each combination of abstraction and minimum instream flow; seasonality is also considered. The curves would allow tradeoffs to be assessed between the quantity of water abstracted from a stream and the minimum instream flow required to protect fisheries. They could also be used to determine the impact of a proposed abstraction at any site to which they are applicable in the region.

To be used as part of a future abstractions assessment process or regulatory programme, Ireland's regulatory agencies would need to establish the degree of habitat loss(es) that is considered acceptable to achieve 'good' ecological status or maintain 'high' ecological status where it currently exists, which could take into account the sensitivity of the stream's biological resources. The determination of which habitat impact curve to use will also have to consider costs both to the environment and to those abstracting and using the water. While curves with the lowest habitat impact provides the greatest protection to fishery habitat, the greater the protection of fisheries the higher the percent of time that withdrawals can not be made because of minimum instream flow requirements.

1.2 Need for Study

Surface water abstraction is an important component of Ireland's water supply. An update of the abstractions register completed under another component of this national Abstractions POMS study shows that surface water abstractions comprises some 75% by volume of public and private water supplies across the country. Table 1-1 shows the distribution of surface water abstractions nationally per river order.

Table 1-1: Surface Water Abstractions in Ireland by River Order

	No. of Abstractions	Volume Abstracted (m^3/day)	Percentage of Total Volume
Order 2	206	539,214	31.5%
Order 3	56	111,105	6.5%
Order 4	26	58,354	3.4%
Order 5	13	75,685	4.4%
Order 6	10	207,850	12.2%
Order 7	2	32,394	1.9%
Unknown Order	28	7,815	0.5%
Lake	230	678,261	39.6%
Total	**571**	**1,710,678**	

These abstractions have the potential to create pressures on aquatic biota in streams. These pressures can be abated by establishing ecological flow requirements downstream of abstraction points in Ireland's surface waters. Thus, establishing instream flow requirements could be a significant programme of measures to protect fisheries resources.

An initial abstraction pressure assessment was performed in Ireland by individual river basin district (RBD) projects and reported by the EPA in the national Article V report, *The Characterisation and Analysis of Ireland's River Basin Districts* (EPA, 2005). For rivers, the risk assessment compared net abstractions (total abstractions minus total discharges) to an estimate of Q_{95} flows.

Risk levels were set at threshold values for highly sensitive surface waters established in guidance documents from the UK and Northern Ireland. River water bodies were classified as "at risk" when the net abstraction compared to the Q_{95} flow was greater than 40%, and "probably at risk" when the net abstraction was between 10 and 40% of the Q_{95} flow.

The initial risk assessment was revisited because better information was available for each component of the risk assessment: Q95 flow estimates for the actual catchment (in terms of river water bodies) for each abstraction; number and quantities of abstractions, and number and quantities of discharges. The CDM report *Revised River Risk Assessment for Abstraction Pressures* (ref. 39325/AB40/DG48 -S) found that 238 river waterbodies covering 1,485 km of river were either 'at risk' or 'probably at risk' from abstraction pressures (Table 1-2). These results, however, have to be examined in context as the majority (>90%) of the river waterbodies determined to be 'not at risk' from abstraction pressures simply are either in river systems with no surface water abstractions or have no abstraction in their upstream catchments. This means that over half of the river waterbodies with an abstraction in the waterbody itself or its contributing catchment has an abstractions-related risk to the ecological status of the river.

Table 1-2: Count of RWBs and Total River Length by Risk Category for the Revised Risk Assessment

Risk Category	Count of RWBs	River Length (km)
2b (Not at risk)	4,168	18,486
2a (Probably not at risk)	60	472
1b (Probably at risk)	141	960
1a (At risk)	97	525

At present, no registration or licensing programmes exist for surface water abstractions in Ireland. Current legislation related to abstractions is summarised below;

The Water Supplies Act (1942) allows sanitary authorities to take supply of drinking water from "a source of water", but does not include consideration of environmental issues. The Local Government (Water Pollution) Act 1977 and (Amendment) Act, 1990 allows that Local Authorities (LAs) can serve notice to any person abstracting water, requiring specified information to be provided (Section 23) and requires that LAs keep a register of abstractions >25 m^3/d (Section 9). The European Communities (EIA) (Amendment) Regulations (S.I.93/1999) requires environmental impact assessments (EIAs) for interbasin transfers that meet certain thresholds (e.g., where the annual volume of water abstracted would exceed 2 million m^3).

The Water Framework Directive (Directive 2000/60/EC and S.I. No.722/2003 – European Communities (Water Policy) Regulations 2003) requires in its Programme of Measures section (Article 11.3(e)) that

> "controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement for prior authorisation for abstraction and impoundment. These controls shall be periodically reviewed and, where necessary updated. Member states can exempt from these controls, abstractions and impoundments which have no significant impact on water status."

To meet the requirements of the WFD, Ireland needs to modernise its laws and regulations concerning abstractions. As noted in Section 1.1, the work documented by this report could be used as part of a future abstractions assessment process or regulatory programme.

1.3 Methods for Determining Instream Flow Needs

Internationally, a number of methods have evolved for estimating instream flow requirements in rivers (also known as ecological flows or environmental flows) whose flows are affected by abstractions. Because the Water Framework Directive sets its goals related to the ecological status of rivers, the method chosen to determine environmental flow requirements must consider the linkage between hydrologic flows and ecology. Only two general approaches for establishing instream flow requirements address this linkage: the Instream Flow Incremental Method (IFIM) and holistic or building block methods. As Ireland does not have the data or in-country expertise to apply the holistic/building block method (CDM Document Reference 39325/AB40/DG 27 – S), IFIM is at present the most suitable method. It can be supported with the level of data available in Ireland.

A CDM separate report examined *Environmental Flow Methods Focusing on Their Use with Various Biotic Groups to Assess the Effects of Abstraction Pressures in Ireland* (Ref. 39325/AB40/DG27). This report found that hydrological methods are the most commonly used environmental flow methods used worldwide. These methods tend simply to select a flow metric, while others are based on observations of aquatic habitat conditions, however, they do not explicitly consider biotic groups as required under the Water Framework Directive. When ecology is directly considered, fish appear to be the most common biotic group used for setting minimum flows, by means of the widely used habitat simulation models (*e.g.* PHABSIM). While little literature is available to address the effects of reduced flow or abstraction pressures on non-fish biotic groups, some countries (*e.g.*, South Africa and Australia) consider the entire riverine ecosystem (known as holistic methods) by means of expert panels; these are exceptions rather than the norm and would not be able to be adopted directly into Ireland as the ecological data required is not available, which would also hinder the use of expert opinions. These holistic methods were developed in southern hemisphere countries that do not have high profile fisheries (Tharme, 2003).

IFIM is a collection of computer models and analytical procedures designed to predict changes in the habitat off aquatic organisms (*e.g.* fish or invertebrates) due to flow changes.

A major component of IFIM is the PHABSIM system, which is a collection of computer programmes by which available habitat area is calculated as a function of discharge. Upon agreement with the Project Steering Group (Section 1.1.4) PHABSIM was chosen as the model to be used in this project. Application of a PHABSIM approach consists of three components: (1) field work to define channel structure and stage-discharge relationship, (2) hydraulic and habitat simulation modelling and (3) developing habitat suitability criteria used for biological simulation (Figure 1-1).

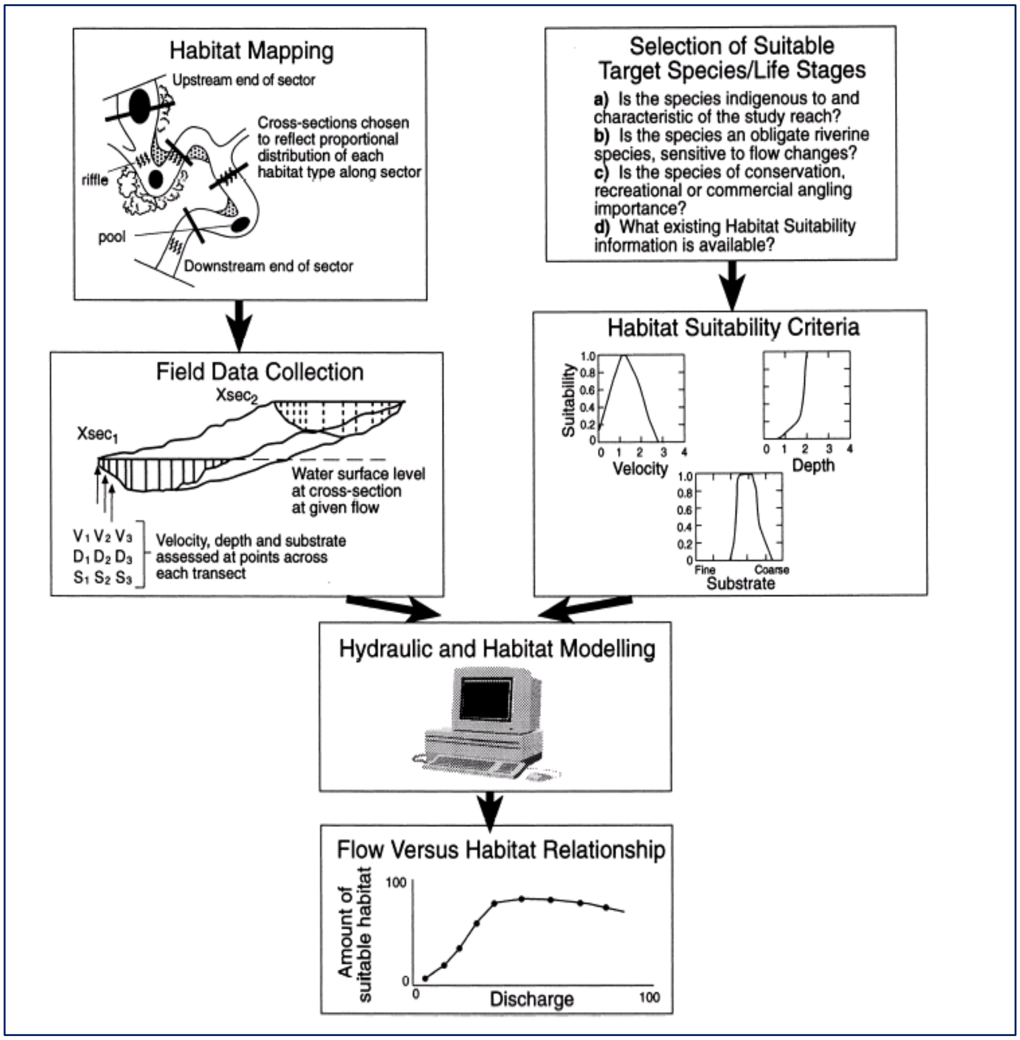


Figure 1-1: Overview of IFIM/PHABSIM

1.4 Project Methodology

Figure 1-2 is a graphic of the tasks in the project's workflow. The work in each task is outlined below. The details of the work conducted for Tasks 2 through 4 are described in Technical Memoranda (references in text below) that were reviewed and approved by the Project Steering Group; Sections 2 through 5 summarise this work.

The remaining sections of this report provide the details of the Tasks 6 and 7 (modelling simulations and development and results of the impact assessment method).

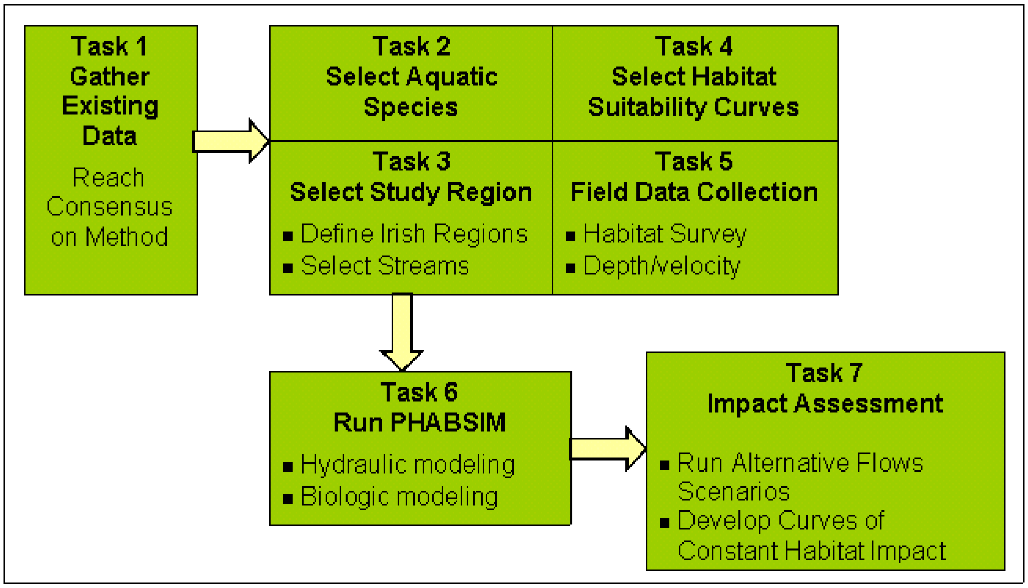


Figure 1-2: Flow Chart of Incremental Method for Instream Flow Project

TASK 2: Determine Aquatic Biota Groups. The selection of the aquatic biota groups were made in conjunction with the Project Steering Group. The fish species Atlantic salmon and brown trout were selected based on their recreational, economical, and ecological importance.

Technical Memorandum: A*quatic Biota Species Selection* (Ref. 39325/AB40/DG04 – S).

TASK 3: Determine Study Region and Streams for Study. To develop a regional procedure for assessing impacts of abstractions on any stream in a region, the streams need to be classified according to important characteristics related to fishery habitat. Once the streams have been classified, typical streams can be used to estimate the effects of abstractions on other streams within the region. To do this, study regions were created based on a common physiography and one region -- the Central Plain -- was selected for study. The study rivers/streams were then randomly selected within the study region. Field verifications were conducted at potential streams to determine if there were any reasons (access, land owner permission, man-made influences, absence of reproducing fish, or poor water quality) that would render the stream unusable for this study. The target was to obtain 30 stream segments in the Central Plain study region.

Technical Memorandum: *Selection of Study Area/Streams for Instream Flows* (Ref. 39325/AB40/DG05 – S).

TASK 4: Determine Habitat Suitability Criteria. Habitat suitability criteria are used to describe usability of depth, velocity, substrate and cover for each life history stage (adult, juvenile, fry, spawning) for each evaluation species. Habitat suitability curves (HSCs) were compiled from the literature and evaluated for applicability to Irish rivers. HSCs were finalised following a workshop with interested members of the Project Steering Group.

Technical Memorandum: *Selection of Habitat Suitability Curves* (Ref. 39325/AB40/DG06 - S).

TASK 5: Collect Field Data: Several types of field data were collected:

- **Mesohabitat Data** – Selected stream segments were surveyed for mesohabitat types (riffles, runs, pools and glides), and a representative reach of that segment was selected for detailed study. The length of mesohabitats within the representative reach were measured and representative transect locations were identified.

- **Transect Geometry** – The location and elevation of various points along each transect was collected using Total Station survey equipment.

- **Depth and Velocity Data at Transects** – Depth and velocity measurements were made along each transect at various flow conditions with the intent of collecting 3 or more sets of data to characterise a range of flows.

- **Substrate and Cover Data** – Data on substrate and cover were collected at only one flow condition using standard categories.

Technical Memoranda:

First Fieldwork Progress Report (Ref. 39325/AB40/DG15 - S)

Second Fieldwork Progress Report (Ref. 39325/AB40/DG33 - S)

Third Fieldwork Progress Report (Ref. 39325/AB40/DG44 - S)

Fourth Fieldwork Progress Report (Ref. 39325/AB40/DG49 - S)

TASK 6: Develop Habitat versus Flow Relationships for the Study Sites. Habitat versus flow relationships are developed at each transect using field data and modelling of in-stream hydraulics and fish habitat availability. The hydraulic model is then used to simulate depth and velocity for a range of flows. Simulated depth and velocity values and the substrate and cover measurements are combined with the Habitat Suitability Criteria for each fish species and life stage to determine habitat available over a range of flows.

TASK 7: Develop and Apply Impact Assessment Methods for Study Streams. The impact assessment method is based on comparisons of the change in habitat available for natural flow conditions compared to the habitat available for modified conditions where flows are reduced due to abstractions.

1.5 Study Organisation

A Project Steering Group provided general oversight and input to the study. The steering group included representatives of both public and private sectors, and was chaired by Brian McKeown and Brian Smyth of Dublin City Council. Ray Earle Project Co-ordinator ERBD liaised with the consultants.

The participants of the Project Steering Group are listed below by the organisations they represented:

- Central Fisheries Board (CFB) – Trevor Champ and Jimmy King,
- Department of Agriculture (previously Department of Communications, Marine and Natural Resources (DCMNR)) – PJ Shaw,
- Department of the Environment, Health and Local Government (DEHLG) – Oliver Fogarty,
- Environmental Protection Agency (EPA) – Catherine Bradley, Donal Daly, Micheál MacCarthaigh, Rebecca Quinn, and Deirdre Tierney,
- Health Service Executive (HSE) Eileen Loughman (Kildare) and Lily Byrne (Dublin North East),
- Kildare County Council (KCC) - Edwina Moore and Cliona Murphy,
- Meath County Council (MCC) - Tim O'Leary,
- National Parks and Wildlife Service (NPWS) - Aine O'Connor,
- Wicklow County Council (WCC) - David Harrington,

CDM staff conducted the fieldwork. Dr. Ian Maddock (University of Worcester) provided technical input to help develop the habitat suitability curves and PHABSIM modelling. Dr. Thomas Hardy (Utah State University) provided technical PHABSIM support to the study.

2.0 Species Selection

2.1 Overview and Method

The IFIM approach includes development of habitat suitability for individual aquatic species. For this study, we wanted to select two species that would be present in most Irish rivers and would be sensitive to abstraction pressures. The selection of aquatic species for this study is described in CDM technical memorandum A*quatic Biota Species Selection* (Ref. 39325/AB40/DG04 – S) and summarised below.

An initial list of 10 species was developed in consultation with a subset of members of the Project Steering Group with particular expertise in Irish aquatic life (Table 2-1). These species were evaluated using the following set of selection criteria:

- Economic, recreational and ecological importance,
- Natural reproduction,
- Presence of habitat suitability curves (HSCs) for each species; a minimum of two curves for each freshwater life stage is strongly preferred, and
- Discussions with members of the Project Steering Group.

Table 2-1: Candidate Species for Instream Flow Study

Common Name (*Latin Name*)
Atlantic salmon *Salmo salar*
Bream *Abramis brama*
Brook lamprey *Lampetra planeri*
Brown trout *Salmo trutta*
Freshwater pearl mussel *Margaritifera margaritifera*
River lamprey *Lampetra fluviatilis*
Roach *Rutilus rutilus*
Sea lamprey *Petromyzon marinus*
Twaite shad *Alosa fallax*
White-clawed crayfish *Austropotamobius pallipes*

Perspective on the selection of species for this study can be gained by understanding species used by other countries to establish instream flows. The findings of a separate project report are summarised in a text box on the subsequent page.

All species in Table 2-1 naturally reproduce in Irish rivers. They include native fish species, species that have been naturalised and have significant life stages in freshwater, recreationally important coarse (non-native) fish, and freshwater aquatic species listed in Annex II of the EU Habitats Directive.

The species in Table 2-1 were researched for background data as well as information on their economic, recreational, and ecological importance. We also included relevant data on various regulations or licensing. The details of the criteria selection are contained in Table 1 of a CDM technical memorandum A*quatic Biota Species Selection* (Ref. 39325/AB40/DG04 – S).

Finally, the existence of habitat suitability curves for each of the species was reviewed. Because this study is premised on using existing HSCs, we strongly preferred having at least two curves from which a composite 'generic' curve could be derived.

These curves must also be present for all riverine life stages of the selected species. Habitat suitability curves are discussed in greater detail in Section 3.0.

A CDM separate report examined Environmental Flow Methods Focusing on Their Use with Various Biotic Groups to Assess the Effects of Abstraction Pressures in Ireland (Ref. 39325/AB40/DG27). This report found that hydrological methods are the most commonly used environmental flow methods used worldwide. These methods tend simply to select a flow metric, while others are based on observations of aquatic habitat conditions, however, they do not explicitly consider biotic groups as required under the Water Framework Directive. When ecology is directly considered, fish appear to be the most common biotic group used for setting minimum flows, by means of the widely used habitat simulation models (e.g. PHABSIM). While little literature is available to address the effects of reduced flow or abstraction pressures on non-fish biotic groups, some countries (e.g., South Africa and Australia) consider the entire riverine ecosystem (known as holistic methods) by means of expert panels; these are exceptions rather than the norm and would not be able to be adopted directly into Ireland as the ecological data required is not available, which would also hinder the use of expert opinions. These holistic methods were developed in southern hemisphere countries that do not have high profile fisheries (Tharme, 2003).

2.2 Results

The salmonids brown trout and Atlantic salmon were chosen for this study. While these were the only species for which sufficient habitat suitability curves were found, they also have other characteristics that make them suitable as the basis for evaluating the effects of abstractions in rivers.

- In the national article V report, *The Characterisation and Analysis of Ireland's River Basin Districts* (EPA, 2005), the background information on reference conditions for Irish rivers has suggested that for the majority of rivers, "the fish populations to be expected in reference conditions will be dominated by salmonid species such as trout and salmon (Salmo trutta and Salmo salar)."
- Brown trout are found in almost every river in Ireland, and absences are probably pollution related (Champ, 2006).
- Atlantic salmon are found in every river that provides access (no impassable barriers) to the sea.
- River flows are an important and sensitive factor in a salmonid's life cycles.
- The relationships between river flow and sustained salmonid fisheries have been the subject of much international research and are at least conceptually understood.

Further, Ireland has a long existing institution for fisheries issues and widespread data for fish populations that could form the basis for a future regulatory programme should the scientific work in this study ultimately lead in that direction.

While the selection of Atlantic salmon and brown trout was agreed by all, the Project Steering Group had a number of concerns with the selection that could drive future research activities. These include further consideration of:

- Coarse fish (bream and roach) because of concern by the CFB staff that the impact of abstraction pressures on fish might not be adequately described by selection of salmonids alone,

- The freshwater pearl mussel because of the dramatic decline in its populations in Ireland (and over much of the rest of its range).

3.0 Habitat Suitability Curves

3.1 Introduction

Habitat suitability curves (HSCs) describe the relationship between the suitability for each fish life stage and the habitat variables (depth, velocity and substrate). With two fish species, four life stages per species and three habitat variables, a total of 24 HSCs were developed to support this study. Details of the development of these HSCs is described in CDM technical memorandum *Selection of Habitat Suitability Curves* (Ref. 39325/AB40/DG06 - S) and summarised below.

This project uses existing HSCs along with site-specific data on typical stream characteristics in the Central Plain region (the project study area; its selection is described in Section 4.0) to develop the relationship between fish habitat and altered river conditions due to abstractions. While it is possible to develop HSCs by conducting stream surveys, this is a time consuming and costly process, and ultimately provides information on habitat preferences only for the stream that has been investigated. As the aim of this work is to develop a method that can be used over a broad region, we have based the study on developing composite HSCs from a suite of available curves from previous surveys and studies.

HSCs have not been previously developed for streams in Ireland. The lack of such curves and the possible need to develop some curves for Irish conditions has been discussed in the Project Steering Group meetings. The Steering Group agreed to move forward with the study on the basis of a composite of existing curves, but requested that the National Technical Coordination Group (NTCG) be advised of this concern and the potential future need to develop curves based on Irish rivers.

Composite HSCs were developed using the following approach:

1. An extensive review of the curves found in the literature, other published reports and unpublished documents,

2. An inquiry was sent to Instream Flow News (IFN) discussion list at the USGS Fort Collins Science Centre to solicit additional curves,

3. The available curves were screened to remove those that were deemed unsuitable (for reasons explained below),

4. Composite curves were developed by drawing an envelope around the remaining curves,

5. Composite curves from the literature were reviewed by the Project Steering Group to adjust for known habitat preferences in Irish rivers.

3.2 Background of HSCs

3.2.1 Types of HSCs

At a fundamental level, habitat suitability curves represent a functional relationship between an independent variable (depth, velocity, and substrate) and the response of a species and life stage to a gradient of the variable expressed over a scale of 0 (unsuitable) to 1 (ideal). Habitat suitability criteria can be expressed in a number of categories and formats. The category refers to the method used to develop the criteria. In general, suitability curves are classified according to the following categories:

- Category 1 – This category is based on professional judgment or literature curves derived from experts' accumulated knowledge of habitat use by a species' life stage.

- Category 2 – This category is based on microhabitat data collected at locations where target species have been observed in the field. Curves in this category are also known as habitat utilisation curves.

- Category 3 – This category is less site specific than Category 2 and takes into account possible bias due to environmental conditions at the time of observation.

Category 1 curves have been developed for use in this study by obtaining Category 2 and Category 3 curves from the literature, screening them for their relevance to the study streams, adjusting for known habitat preferences in Irish rivers, and combining them as described below.

The HSCs for both the Atlantic salmon and brown trout were collated from various researchers listed in Section 10. The majority of the curves were developed in the US and the UK, with a small minority in Canada, New Zealand, France, Finland, and Norway.

3.2.2 Explanation of HSCs

In general, a dependence of river salmonid abundance on habitat implies that it should be possible to develop predictive relationships between abundance and stream habitat features. However, habitat to fish relationships can be particularly complex and dynamic. Although there is a lot of information available on which factors affect populations, difficulty arises when attempting to quantify this optimum level. Figure 3-1 referenced from Armstrong *et al.* (2003) illustrates two types of population responses to habitat variables.

The first diagram (a) in Figure 3-1 illustrates how the fish population increases as the habitat variable increases until it reaches a peak population where it then levels off and the habitat is no longer limiting. The second diagram (b) depicts how the population increases with increasing a habitat variable (e.g. velocity) until such a point when the further increase of the variable can have a negative effect on the population. Several factors not used in PHABSIM can also have an effect on the production of trout and salmon, such as temperature, rate of water flow, and fluctuations in discharge. However, Armstrong *et al.* (2003) stated that recent studies agree that depth, velocity, substrate and cover are the most important abiotic habitat features for salmonids.

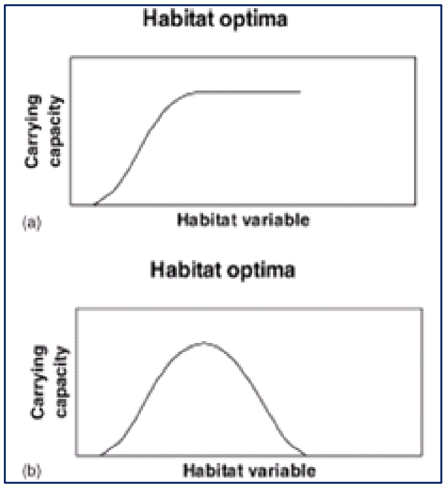


Figure 3-1: Salmonid Population Responses to Changing Habitat Variables

HSCs are graphs for each fish life stage and habitat variable. The curves have the format of Suitability Index (SI) on the y-axis and habitat variable on the x-axis. The SI ranges from 0 to 1, where 1 indicates that the value of the habitat variable provides the most utilised habitat by that life stage of fish. For velocity and depth criteria, the x-axis denotes the actual velocity in metres/second and the depth in metres. For the substrate criteria, the x-axis represents the Wentworth size classifications shown in Table 3-1.

The Wentworth standard coding system was used by Trihey and Wegner (1981) in the PHABSIM field data collection procedures. This system adopts a range of 1-10, with no values below 1 or above 10.

Table 3-1: Wentworth Size Classification for Substrate

No.	Size Class	Particle size (mm)
1	Plant detritus/ organic material	
2	Clay/earth	< 0.0039
3	Silt	0.0039 - 0.062
4	Sand	0.062 - 2
5	Gravel	2 – 64
6	Cobble	64 - 250
7	Boulder	250 - 4000
8	Bedrock (solid rock)	
9	Terrestrial vegetation	
10	Man-made bank material	

Some of the substrate HSCs found in the literature used a different coding system than the Wentworth scale; those HSCs were converted to the Wentworth scale using judgment so that all curves could be compared on the same scale.

An examination of HSCs derived from different studies showed that many have curves that are quite similar, while some have curves that indicate more variability in habitat preference. Reasons for this can include the type of curve (*e.g.* Category 1, 2 or 3), the nature of the study stream (*e.g.* upland versus lowland), and the sampling strategy used to observe fish presence.

An important element to the shape of HSCs are the following four values as illustrated in Figure 3-2:

- Minimum acceptable value – The lowest value of the range where habitat is deemed suitable for fish to live.
- Minimum ideal value – The lowest value of the range where habitat is ideal/optimal for fish to occupy.
- Maximum ideal value – The highest value of the range where habitat is ideal/optimal for fish to occupy.
- Maximum acceptable value – The highest value of the range where habitat is deemed suitable for fish to live.

These values are critical on any HSCs as they determine the shape and amount of habitat available for the discharge versus habitat availability relationship.

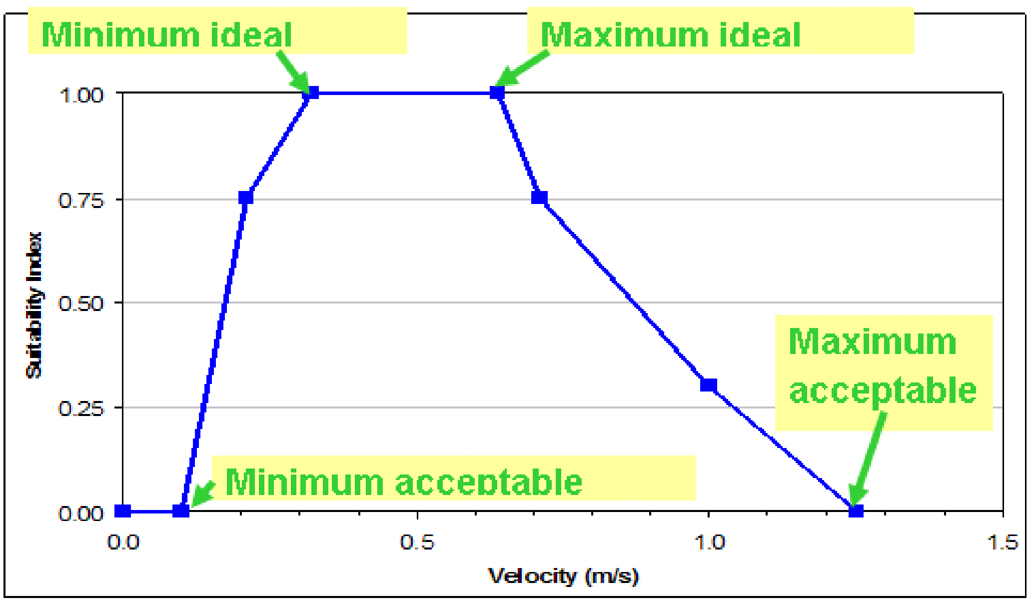


Figure 3-2: Four Critical Points on Habitat Suitability Curves

3.2.3 The Influence of the Shape of HSCs on Habitat Availability

In PHABSIM, the hydraulic models utilise depth and velocity data to model changes in discharge. Since substrate size does not vary with flow, only the depth and velocity HSCs influenced the shape of the habitat availability versus flow relationships; the substrate HSC influenced the total magnitude (but not the shape) of the habitat availability versus flow relationships.

A broad HSC as illustrated in Figure 3-3 with low slopes indicates habitat that is less sensitive to flow changes; hence flow reductions due to abstractions have less of an impact on habitat availability. A narrow HSC as illustrated in Figure 3-4 indicates habitat that is more sensitive to flow changes; hence abstractions will have a more significant impact. In addition, a reduction in flow does not always result in reduced habitat. For some species, at some sites, abstraction can improve habitat.

For example, for a species / life stage that prefers slow and shallow water, abstraction may increase the amount of river area (and time) where these conditions occur.

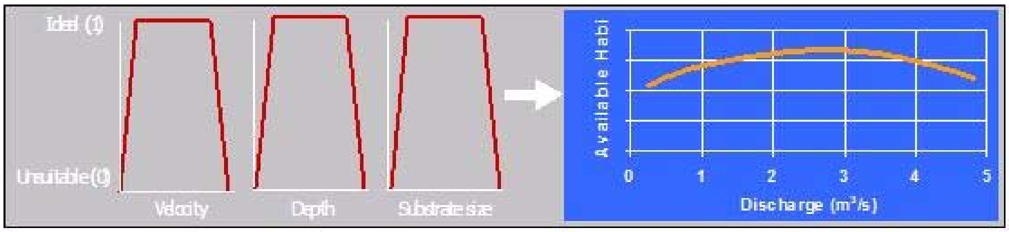


Figure 3-3: Influence of Broad-shaped HSCs on Habitat Availability

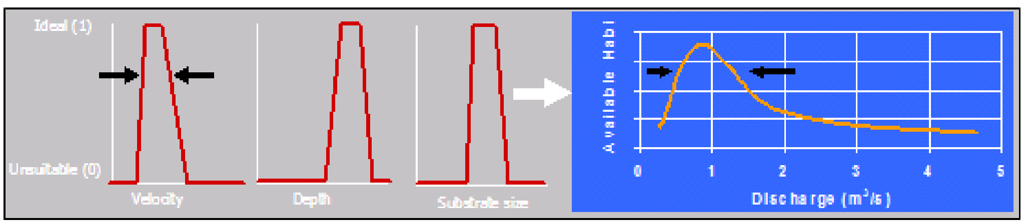


Figure 3-4: Influence of Narrow-shaped HSCs on Habitat Availability

3.2.3 Explanation of the Different Life Stages

Review of the existing literature on HSCs revealed differences by researchers in defining the life stages of fry and juvenile fish. It was decided with the agreement of the CFB to transfer some of the curves originally defined by Aki-Maki Petays (2001) and Dunbar et al. (2002) as juvenile fish to the fry life stage. The changes were based on the researcher's description of the fish as young of the year, less than 9 cm and fish between 0-7 cm. Table 3-2 summarises the researcher's definitions of fry and juvenile life stage and shows where changes were made (yellow fill cells). Note that initial HSCs described in the CDM technical memorandum *Selection of Habitat Suitability Curves* (Ref. 39325/AB40/DG06 - S) did not have this distinction between juvenile and fry life stages.

Table 3–2: Definitions of Fry and Juvenile Life Stages

Species	Author	Location	Definition		
			Fry	Juvenile	
Atlantic salmon	Aki – Maki Petays (2001)	Finland	*Yellow shaded cells were moved to Fry life stage*	Size < 9 cm	Age 0
				Size > 9 cm	Age 1
	Dunbar *et al.* (2002)	UK	*Yellow shaded cells were moved to Fry life stage*	Size 0 – 7 cm	
				Size 8 – 20 cm	
	Gibbins *et al.* (2000)	UK	"Newly emerged" (no HSC developed)	Age (0+)	
	Heggenes (1990)	Norway	Smallest parr or yearlings or young of the year	Larger parr in the 2nd to 3rd year	
			Size < 7 cm	Size > 7cm	
	Scruton (1995)	Canada	Small parr, yearlings or young of the year	Larger parr	
			Size < 6 cm	Size > 6 cm	
	Stanley and Trial (1995)	US	No definition between fry or juvenile provided; HSCS retained as Fry as originally defined		
Brown trout	Bovee (1978),	US	No definition between fry or juvenile provided; HSCs retained as Fry as originally defined		
	Maddock *et al.* (2001)	UK	Age (0+)	Parr (+1), Juvenile (+1)	
	Raleigh (1986)	US	Emergence from the gravel to 1st year	2nd year to adult	
	SRBC (1998)	US	Size < 2 in (5cm)	Size 2 -6 in (5 – 15 cm)	

3.2.4 Fish Periodicity Chart

An important input to the IFIM approach requires understanding of the months that life stages of Atlantic salmon and brown trout are present in Irish rivers. This information was provided by the CFB and is summarised in Table 3-3.

One caveat on Table 3-3 is that while adult Atlantic salmon are found in Irish rivers throughout the year, they are not found in all Irish rivers throughout the year. Further discussions with Jimmy King of the CFB indicates that adult salmon are found in smaller rivers only in the breeding season (October through to March).

During this time they are represented by the spawning life stage in this analysis; in other months of the year (when they are represented by the adult life stage), they will seek refuge in larger rivers with pools either resting to return to sea or awaiting high flows so they can swim upstream to their spawning grounds.

Table 3-3: Periodicity Chart for Atlantic Salmon and Brown Trout

Species	Life Stage	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Atlantic salmon	Spawning	✓	✓	✓							✓	✓	✓
	Fry						✓	✓	✓	✓	✓	✓	✓
	Juvenile	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Adult	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Brown trout	Spawning	✓	✓	✓							✓	✓	✓
	Fry						✓	✓	✓	✓	✓	✓	✓
	Juvenile	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Adult	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3.3 Composite Habitat Suitability Curves

3.3.1 Introduction

The process for developing composite HSCs from the curves identified in the literature review included:

- Screening the curves to remove those that were unrepresentative of project study conditions,
- Developing draft envelope curves that encompassed the maximum habitat suitability defined in all the curves that remained after screening and cross-checking them for inter-curve consistency by life stage,
- Reviewing and adjusting the draft envelope curves in a workshop with Irish experts to reflect knowledge of fish habitat preferences in Irish rivers, and
- Finalising the HSCs for use in PHABSIM modelling.

3.3.2 Compositing HSCs

The first step in developing HSCs involved screening the curves identified in Section 3.2 to remove any which may be unsuitable. Curves may be unsuitable if they were collected in dissimilar stream types and/or geographic regions from the Central Plain region. Generally, unsuitable curves that were excluded from the analysis fit within the final envelope HSCs shown in Figures 3-6 to 3-8 and thus their removal had little impact on the final results. The number of suitable curves remaining for the four life stages; Spawning, Fry, Juvenile and Adult for the depth, velocity and substrate criteria are summarised in Table 3-4.

A draft composite HSC was created by drawing an envelope curve around the remaining curves for each habitat variable and each life stage for both species. This involved combining the remaining curves by taking the maximum values of the curves. This envelope curve results in the broadest range of conditions that may be suitable. Figure 3-5 illustrates the development of one envelope curve from the HSCs of four researchers.

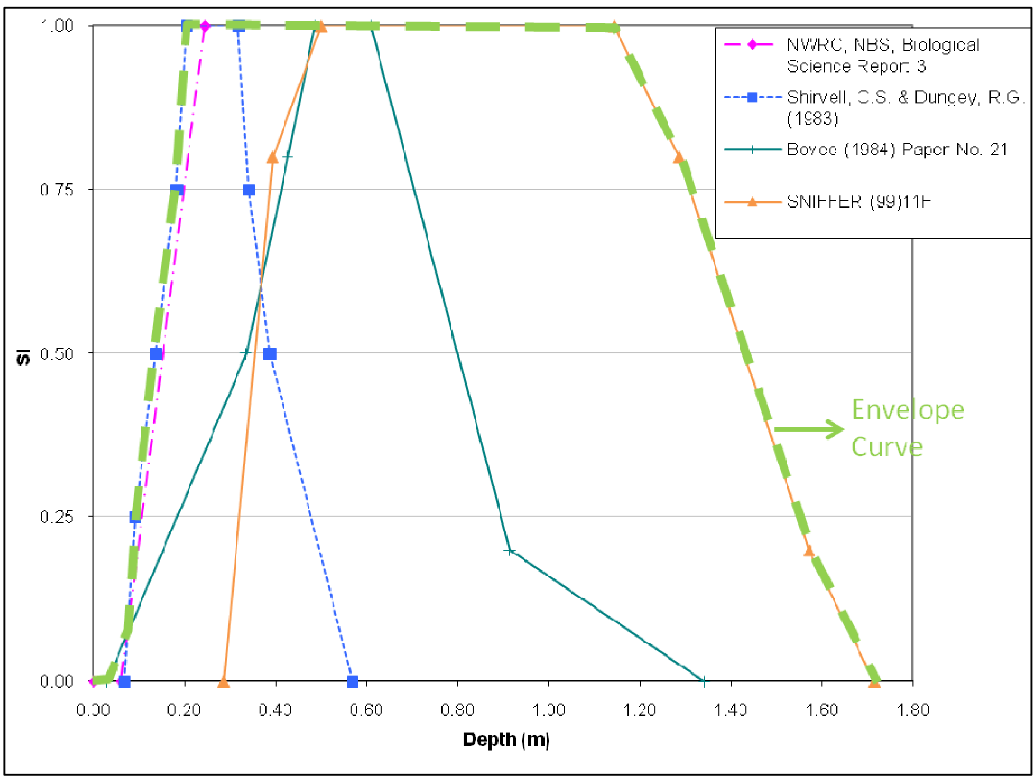


Figure 3-5: Development of an Envelope Curve for Brown Trout Spawning Depth

Once each of the envelope curves were developed, they were checked to determine if they agreed with our understanding of the biology.

For example, the fry velocity curve should be left of the juvenile curve because juveniles prefer slower moving water and thus would have higher SI values at lower velocities (personal communication; Hardy, 2007).

Table 3-4: Number of Suitable HSCs remaining for Atlantic Salmon and Brown Trout

Species	HSC Life Stages	Velocity	Depth	Substrate
Atlantic salmon (*Salmo salar*)	Spawning	1	1	1
	Fry	5	5	2
	Juvenile	3	3	1
	Adult	1	1	1
Brown trout (*Salmo trutta*)	Spawning	9	9	2
	Fry	9	9	2
	Juvenile	9	9	2
	Adult	10	10	2

3.3.3 Workshop

A workshop was held on 13th November 2007 to consider all comments received on the initial envelope curves. The main aim was to discuss possible modifications and to achieve a consensus for each HSC for all life stages and habitat variables for both species. The workshop was attended by a representative from the Central Fisheries Board, the Environmental Protection Agency, the Department of Communication, Marine and Natural Resources, and the Department of the Environment, in addition to Dr. Ian Maddock (University of Worcestershire) and personnel from CDM.

Each life stage and habitat variable was considered individually. The initial envelope curve was used as a starting point for discussions, and particular attention was paid to the position of the minimum acceptable point, minimum ideal point, maximum ideal point and maximum acceptable point for each life stage and habitat variable (Table 3-5). Where adjustments were made, these were based on fish observation, field data available for Irish rivers (source: King *pers. comm.*), expert opinion, and/or comparisons between requirements for Atlantic salmon and brown trout. The changes that were made are shown in Figures 3-6 and 3-7 with the final envelope curve (marked in blue) shown with the initial envelope HSC (in red) on the same graph.

3.4 Summary of Recommended HSCs

Table 3-5 summarises the four critical points for each life stage and habitat variable. Note that this table does not include all data that describe each point on the HSCs, but highlights four points (*i.e.* minimum usable, minimum ideal, maximum ideal and maximum usable) on each curve that altogether describe the general characteristics of each curve.

Figures 3-6 and 3-7 display the recommended HSCs for Atlantic salmon and brown trout, respectively. The display is formatted to facilitate comparison among the fish life stages. Figure 3-8 displays the final HSCs for each species' life stage and habitat variable on the same graph.

Table 3-5: Initial and Proposed Critical Points on each of the HSC Envelopes

			Initial Value				Proposed Value			
Species	**Life Stage**	**Habitat Criteria**	**Min. usable point**	**Min. ideal point**	**Max. ideal point**	**Max. usable point**	**Min. usable point**	**Min. ideal point**	**Max. ideal point**	**Max. usable point**
Atlantic salmon	Spawning	Depth	0	0.2	0.4	0.9	0.10	0.2	1.5	2.5
		Velocity	0.25	0.6	0.8	1	0.15	0.19	0.73	1.37
		Substrate	4.9	5	6	6.1	4.9	5	6	8.1
	Fry	Depth	0	0.1	0.4	1	0.07	0.1	0.4	1
		Velocity	0	0.1	0.3	1	0	0.18	0.60	1.15
		Substrate	*See Note				3	5	6	7
	Juvenile	Depth	0.05	0.13	0.55	1.1	0.1	0.2	0.7	1
		Velocity	0.03	0.15	0.45	1.1	0.03	0.15	0.45	1.1
		Substrate	2	4	8	8.1	4	6	7	8
	Adult	Depth	0.36	1.07	∞		0.75	1	∞	
		Velocity	0	0.29	0.64	1.25	0.05	0.29	0.64	1.25
		Substrate	0.90	1.1	9.9	10	1	1.1	9.9	10
Brown trout	Spawning	Depth	0	0.12	0.91	1.34	0.07	0.12	∞	
		Velocity	0	0.19	0.73	1.37	0.15	0.19	0.73	1.37
		Substrate	* See Note				4.5	5	6	6.1
	Fry	Depth	0	0.02	0.52	1.45	0.07	0.10	0.60	1
		Velocity	0	0	0.44	1.03	0	0.18	0.60	1
		Substrate	1	4	5	8	1	4	5	7
	Juvenile	Depth	0	0.30	1.22	3.6	0.1	0.3	1	1.5
		Velocity	0	0	0.8	1.44	0.03	0.1	0.4	1.1
		Substrate	1	5	6	9.1	1	5	6	10
	Adult	Depth	0	0.5	2.38	3.6	0.3	0.7	1.5	2.5
		Velocity	0	0.1	1	2	0.05	0.1	0.76	1.20
		Substrate	1	1	5	9.0	1	5	7	10

Note: Initial HSCs are not reported because changes made to either reinterpretating substrate HSCs or moving curves from juvenile to fry render the initial curve non-representative.

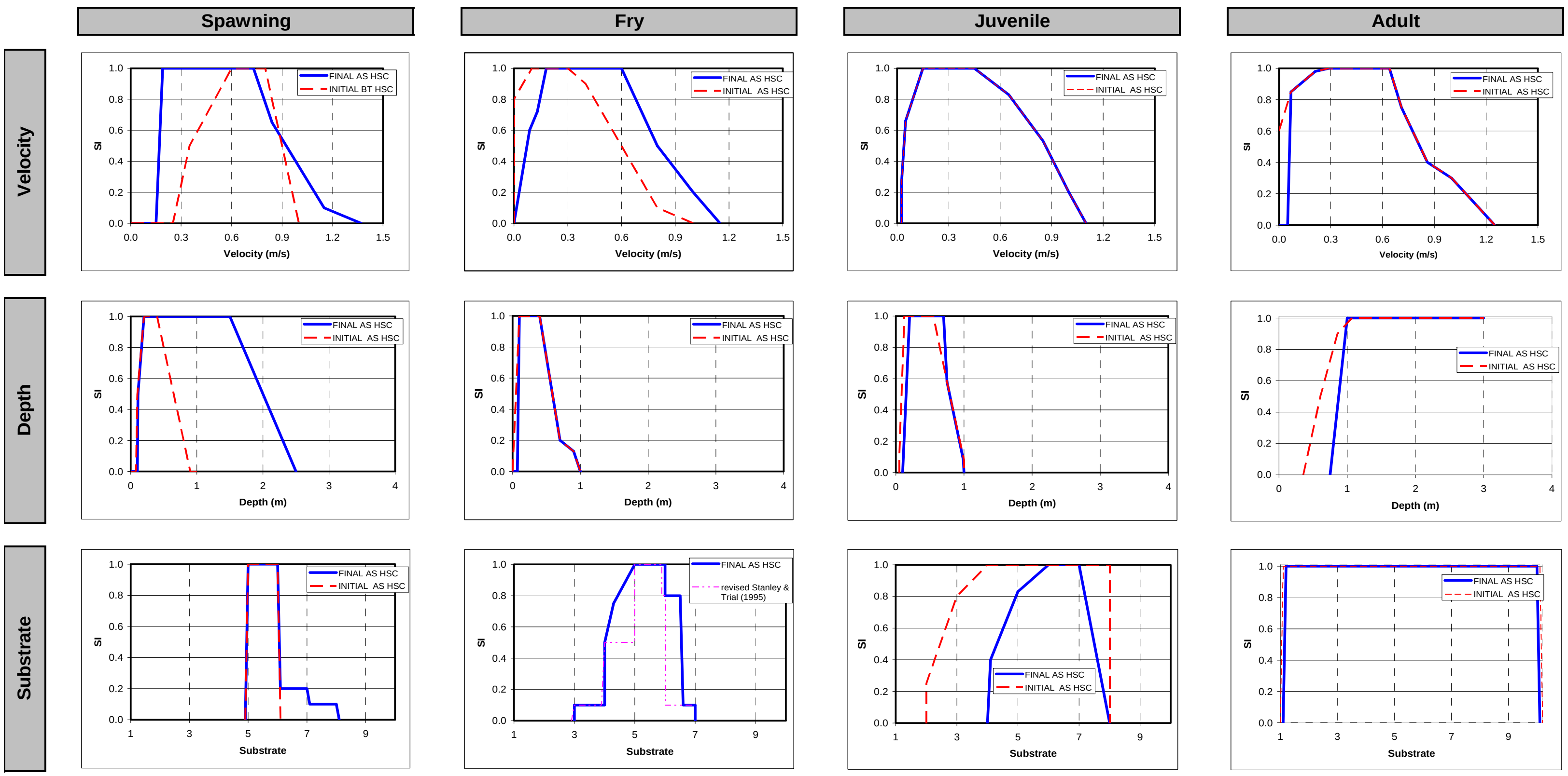


Figure 3-6: Summary of Recommended HSCs for Atlantic Salmon

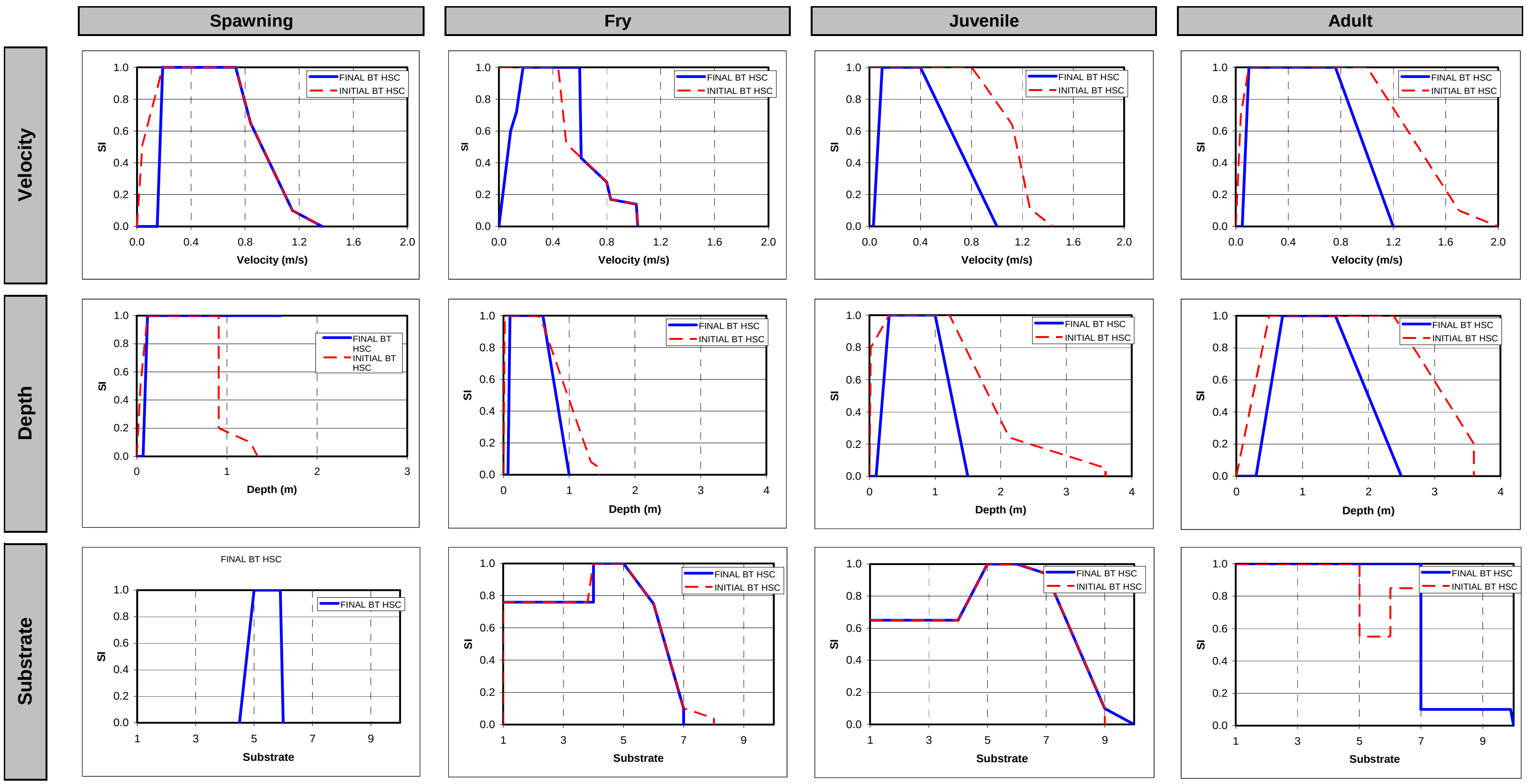


Figure 3-7: Summary of Recommended HSCs for Brown Trout

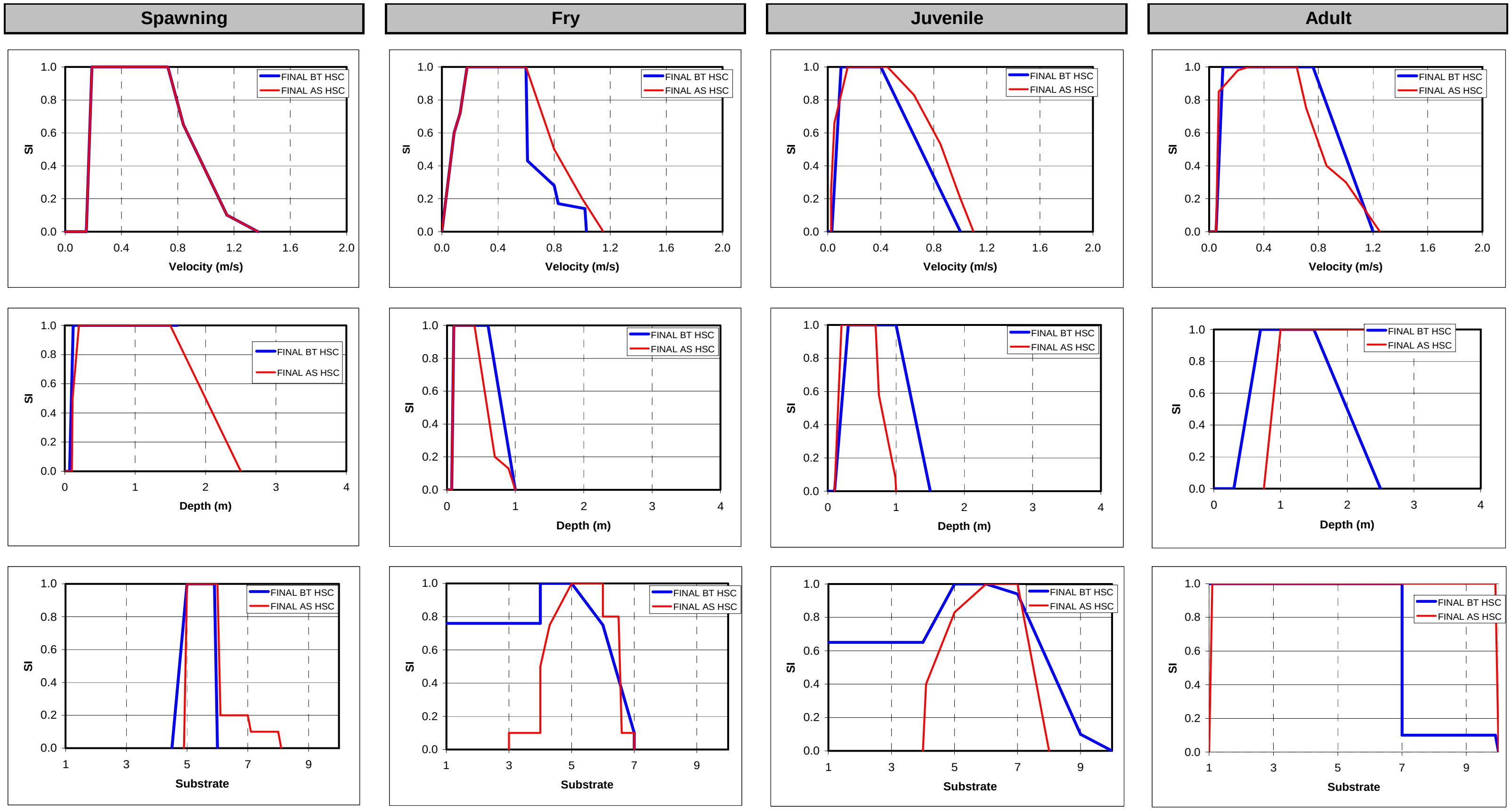


Figure 3-8 Summary of Recommended HSCs for Atlantic Salmon and Brown Trout

4.0 Selection of Study Regions/Streams

4.1 Overview

River habitat in Ireland is quite variable and includes swift flowing mountain streams, spatey smaller streams in the lowlands, discontinuous streams typical of karstic and drumlin topography, converging on the wide and relatively shallow main stem rivers in the lowlands. Since no one single approach would be applicable across this range of habitats, a single region was needed where the rivers would have similar flow/habitat relationships as a pilot region for this method in Ireland. A detailed description of the steps involved selecting the study region and stream segments for the instream flow pilot is provided in the CDM Technical Memorandum *Selection of Study Regions/Streams for Instream Flows* (Ref: 39325/AB40/DG05).

A literature review of previous land form characterisation studies for Ireland showed that none of them adequately described how the physical geography of Ireland influences the nature of its rivers. Thus, this project undertook defining hydraulically centric physiographic regions for Ireland. A basic premise of this work was that the structure and dynamics of stream habitat were determined by the surrounding watersheds (Frissel *et al*., 1986), and that similar watersheds can be grouped into a physiographic region. A single physiographic region was selected as a study region.

The streams within the study region were then classified and two classes were selected for study: (1) streams in order 2 through 4 with low to medium slopes and (2) order 5 streams. The premise of this classification is that most streams in the selected study region would be broadly similar because they arise from the same physiography, however, some can have distinct characteristics. Grouping by stream order follows that approach of Frissel *et al.* (1986) which suggests that these classes could be similar enough to be the foundation of a regionalised method. Reaches for field work were then chosen in proportion to the size of each group, with modifications made for order 5 and 6 to allow for a large enough sample to determine if there were differences.

Finally, it was necessary to select stream reaches for field sampling based on a number of criteria. A random stratified sampling procedure was used to select 100 reaches for possible field work. These reaches were reviewed for any reasons (access, land owner permission etc.) that would make the stream unusable for the study. Mesohabitat surveys and cross section identification was performed for 30 reaches.

4.2 Creating Physiographic Regions

This section summarises the work undertaken to create physiographic regions and select a study region. Physiography typically defines regions using geology and land structure. While some previous work has been done to divide Ireland into various landform- or geologic- based regions, no existing scheme is applicable for this project. Thus, we used existing Geographic Information Systems (GIS) data within a broad, integrative framework to develop physiographic regions that fit the project's objectives. Review of initial draft regions was provided by staff at ESBI, the Central Fisheries Board, and the Department of Communications, Marine and Natural Resources (DCMNR; note DCMNR is now the Department of Agriculture).

4.2.1 Background

A simple definition of a physiographic region is "a portion of the Earth's surface with a basically common topography and common morphology" (www.geography.org). Other physiographic maps consider an area's topography, soil, bedrock, moisture levels, and drainage.

Three previous researchers divided Ireland into regions based, at least in part, on landform or geology. Horner (2000) describes research by the Irish geographer T.W. Freeman (1950), who characterised Ireland into 12 regions mainly based on physical features and farming. Sweeney (2003) defines eight landscape units for Ireland primarily considering geology, soils, and rainfall; he further describes the strong influence this physical framework has had on the economic and social geography of the island. Davies and Stephens (1978) divided Ireland into 19 geomorphologic regions, each region being defined by lithological and structural factors. This latter work was the primary reference to inform the development of physiographic regions for this study.

4.2.2 Methodology

Physiographic regions for the abstractions study were defined using available GIS layers, and informed by previous work described above.

The following layers were used to develop draft physiographic regions:

- National Rivers (EPA / Compass)
- Migratory Salmonid Habitat (CFB)
- Elevated Area (EPA / Compass)
- Rainfall (Met Éireann)
- Bedrock (GSI)
- Primary Catchments (EPA / Compass)

GIS was used to examine common features of the datasets listed above.

Our objective was to define a small number of regions with boundaries that follow primary catchment boundaries wherever a sensible assignment could be made. When the primary catchment boundary could not be used, a sub-catchment boundary was adopted wherever possible.

4.2.3 Description of Physiographic Regions

Four physiographic regions were defined based on the data listed above. Although rainfall, aquifer type, bedrock, and elevated areas were all considered, the boundaries were largely based on the structure of the river network (short vs. chaotic vs. well develop dendritic), presence of well developed karst geology, and stream slopes. The four physiographic regions are (Figure 4-1):

- Region 1 - Coastal,
- Region 2 – Lowland Karst,
- Region 3 – Drumlin, and
- Region 4 - Central Plain.

After initial boundaries were drawn, calculations were made of the percentages of each river catchment in the four regions. Each catchment was then assigned to a region on a majority basis. In all but a few cases, only one physiographic region represented nearly all of the area of the catchment. In this process we were largely able to meet the objective that regional boundaries follow primary catchment boundaries. However, there were several exceptions to this, such as the Moy, Corrib, Suir, and Munster Blackwater catchments.

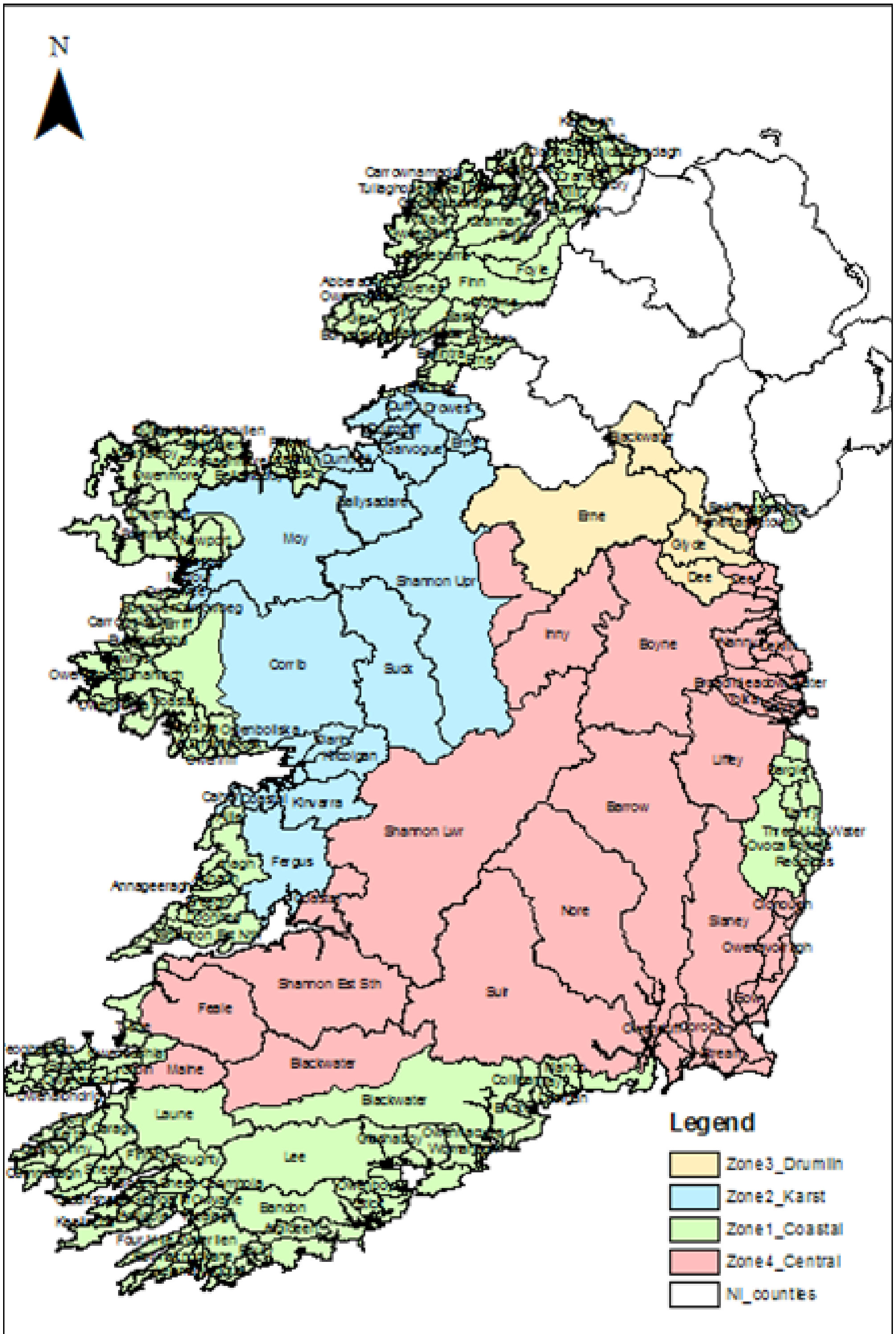


Figure 4-1: Map of Four Physiographic Regions

Note: All unnamed catchments are called coastal.

4.3 Selection of the Study Region

The following criteria were established to assist in selecting a study region:

- Size. Selection of a large geographic area maximises the utility of the method.
- Ability to Regionalise Results. Similarity of flow/habitat relationships across streams of a similar type in a study region was necessary to extrapolate the modelling results from the group of study streams to the region as a whole.
- Abstraction Pressure. This method can be used to establish instream flows for both current and proposed (or increased) abstractions. The selected region should be one with numerous, high volume, current or future abstractions from rivers.

Initially, the habitat for brown trout and Atlantic salmon were considered as a criterion in selecting a study region. However, based on the advice of the Project Steering Group that brown trout are found everywhere in Ireland and Atlantic salmon would be found generally everywhere if it were not for the presence of physical impediments, this criterion was excluded.

Both Region 1 (Coastal) and Region 4 (Central Plain) cover large areas of Ireland. They are similar in total area and both have a large number of stream types of similar nature that allow for the application of a method to be used over much of its physiographic region. Regions 2 and 3 are the two smallest of the four physiographic regions.

An initial national abstractions register was assembled using data provided by each of the RBD projects. We have taken that register, provided some additional quality checking and identified 566 abstractions from surface waters. Although this register may be incomplete, it is the best source of abstractions information available. Table 4-1 provides data on the number and total volume of abstractions by physiographic region. It shows that while the Coastal region has the largest number of abstractions, the largest volume of abstractions occurs in the Central Plain region.

Table 4-1: Surface Water Abstractions by Region

Physiographic Region	No. of Abstractions	Volume (m^3/day)
Region 1: Coastal	260	472,717
Region 2: Lowland Karst	99	326,469
Region 3: Drumlin	54	90,710
Region 4: Central Plain	139	815,614
Others (coastal islands and Shannon Estuary)	14	4,477

Note: Data based on 2007 version of abstractions register

Based on the above criteria, the Lowland Karst and Drumlin regions (Regions 2 and 3) were eliminated for specific reasons noted below.

- Variability and unpredictability define the nature of river response in a well developed karst region. This variability makes it quite unlikely that the flow/habitat relationships from a group of Karst Rivers would be able to be regionalised.

- The drumlin region was omitted because the discontinuous nature of the rivers and river-lake network patterns would make river study quite difficult. According to the CFB report "*Quantification of the Freshwater Salmon Habitat Asset in Ireland*", most of this area is also considered to be non-self-sustaining for salmon and hence would eliminate the salmon as a study species.

Physiographic Regions 1 and 4 have similar ratings among the selection criteria for this pilot work. We have selected the Central Plain region as a pilot region for this study because:

- This region has experienced significant population growth, which is straining existing water supply infrastructure.

- Many new or expanded water supply schemes are expected to be explored in this region over the next several years.

- We have taken a broad band approach to defining the physiographic regions based on assumed similarity among flow/habitat relationships for rivers in the region. This assumption will be tested as we perform the field work and use the model to examine the relationships. Given the relative uniformity of the Central Plain region, we expect to find these rivers to be more similar than those of the Coastal region. Thus, the Central Plain Rivers offer a better opportunity to extrapolate the modelling results to a class of rivers within a region, allowing any future work in the more complex Coastal region to benefit from lessons learned in developing a regional Central Plain method.

The selection of a study region was discussed with the Project Steering Group on the 12th October 2006. The Steering Group agreed to select the Central Plain as the study region.

4.4 Stream Classifications

4.4.1 Overview

Although the majority of streams in the Central Plain region would be broadly similar because they arise from the same physiographic conditions, some have distinct characteristics. Therefore, the rivers need to be classified to allow us (1) to identify stream reaches that are suitably similar to be the focus of this study and (2) to develop a regional approach for assessing the effects of abstractions on any river from the same class in a region.

Many different stream classification systems have been defined. For the purpose of this work, we need to consider groups of streams in the context of the entire catchment. Frissell *et al.* (1986) defined a hierarchical framework that starts with a physiographic region, and then defines stream system classes as streams draining similar lithology, geomorphology, and land-use history. These classes are defined for progressively smaller features: stream segments, reaches, pool/riffle units, etc. In this view, the structure and dynamics of stream habitat is determined by the surrounding watershed.

Following Frissell's approach, we examined the characteristics of the streams within the Central Plain physiographic region with the aim of creating classes of streams. We have used stream order as a fundamental variable for sorting streams because the class of any particular system is partly determined by the class of the higher level system of which it is part. Frissell wrote that "Habitats within segments of the same class might be compared to evaluate the effects of management activities that have occurred in one watershed but not in the other. Segments of the same class should potentially have similar kinds of reaches, pools and riffles, and microhabitats, if their watersheds are in similar states. The slope, valley walls, bedrock floor topography and contributing drainage basin of a segment constrains the kinds of smaller-scale habitat that can evolve there."

4.4.2 Description of River Waterbodies in the Central Plain Region

The data on streams in the Central Plain region was derived from the national river waterbodies GIS file for Ireland. The national river GIS layer contains some 16,000 records of 2nd to 7th order river waterbodies -- 4,642 of these waterbodies are located in the Central Plain region. Two definitions arising from the creation of reportable waterbodies as part of the WFD describe how rivers were divided into constituent pieces;

- A river 'segment' is defined as a length of a river between the tributaries or in the case of the most downstream segment, the freshwater/saltwater node.
- A river 'waterbody' is an aggregation of river segments along a river that are in the same stream order.

For the WFD Article V Characterisation work, a smaller set of 4,468 river waterbodies were defined as the 'reportable waterbodies.' The difference between the national river file and the WFD reportable river file occurs only for 2nd order rivers; 2nd order river waterbodies were only included as reportable rivers if their catchment area was greater than 10 km^2. In the Central Plain region, there are 1,497 WFD reportable river waterbodies.

In order to summarise the data comprehensively, the waterbodies were described in terms of length, slope, catchment area and depth, respectively. This data was used to define stream classifications in Section 4.4.3.

1. **Length** - The 2nd to 4th order river waterbodies comprise 90% of the total length of rivers in the Central Plain region. The number of river waterbodies decreases with increasing stream order – representing the strong dendritic character of the Central Plain rivers.

The average length of the waterbodies increases with increasing stream order, except between Order 6 and 7. This is because there are only two 7th order river waterbodies in the Central Plain region.

2. **Slope** – The high slope rivers have a gradient between 0.02-0.04 and the very high slope rivers have a gradient greater than 0.04. The high and very high slope rivers generally occur around inliers (areas of elevations above 200 m). Some exceptions included the Lower Slaney and Corock Estuaries.

3. **Catchment Area** – Catchment areas are only available for reportable river waterbodies (hence the minimum catchment area for Order 2 rivers is 10 km^2). The mean area ranged from 17.5 km^2 for Order 2 rivers to 10,228 km^2 for Order 7 rivers.

4. **Depth** – It was possible to obtain limited data on water depth from the Environmental Protection Agency (EPA) and the Office of Public Works (OPW) from 70 active gauges on 5th, 6th and 7th order river waterbodies. The EPA collects mean depth during the summer, with mean depths between 0.2 and 0.4 m, with a maximum mean depth of 0.66 m. The OPW provides an approximate mean level over a period of approximately 3 months (June to August), with typical depths between 0.14 and 0.66 m. The EPA and OPW typical depth data for 5th, 6th and 7th order streams were similar.

   The data indicates that these higher order rivers are relatively shallow during low flow conditions; these rivers may be sufficiently similar to smaller streams to be included in the regionalise approach. To test this premise, the 5th and 6th order streams were treated separately for field work and modelling purposes and then compared with the results of work done on the aggregate of 2nd through 4th order streams. However, upon field inspections Order 6 rivers were deemed too deep and wide and unlike the characteristics of the 2nd through 5th order rivers for inclusion in this study. We excluded 7th order streams from further analysis because there are only two in the study area, both located on the lower end of the River Shannon.

4.4.3 Results for Stream Classes for the Central Plain Region

The characteristics of the streams within the Central Plain physiographic region described in Section 4.4.2 were used to develop four classes of streams that we believe represent four flow/habitat relationships, and thus, have the potential for similar kinds of reaches, pools, riffles, and microhabitats (Frissel, 1986). The two variables predominately used to develop stream classes were stream order and slope. The stream classes are:

- **First-order Streams** – These streams are typically quite small and may have intermittent or very low flows. According to the CFB report "*Quantification of the Freshwater Salmon Habitat Asset in Ireland*" (McGinnity et al., 2003), 1st order streams are not considered significant producers of salmonids. For this reason, 1st order streams were not selected for study.

- **High and Very High Slope Streams** – Davies and Stephens (1978) characterised the Central Plain Region as having discontinuous mountains, which they termed inliers. The streams that drain from this high ground are likely to be flashy and have habitat dominated by boulders. Thus, their flow-habitat relationships are considered to be different than those of flatter inland rivers. As shown in Figure 3-2, the streams with high and very high slopes tend to be found primarily where land elevation exceeds 200 m. We used slope greater than 0.02 (high and very high slope) to identify such streams – they were excluded from the streams to be studied.

  The number of very high slope rivers equates to 658 river segments, with 92% of these occurring with 2nd order streams. The number of high slope rivers was 673 segments, with 87% of these occurring within 2nd order streams.

- **Potentially Deeper Streams** – In Section 4.4.2, the depth of 5th through 6th order streams (which largely comprise the main stem rivers) were evaluated using available data to determine if they are likely to have different flow-habitat relationships than lower order (possibly shallower) streams. The available depth data suggests that the 5th through 6th order streams are relatively shallow and thus can not be discounted at this time. (Note: that subsequent field work showed 6th order streams were not similar and they were removed from the analysis).

- **Lower Order Streams** – This class includes all 2nd to 4th order streams with low or medium slope, which comprise most of the stream length in the Central Plain region. They are expected to have similar flow-habitat relationships.

In Section 4.5, we present the method for selecting streams for field work. These streams will be chosen from the potentially deeper streams and lower order stream classes. These include all 2nd to 5th order streams with low to medium slope (slope less than 0.02).

4.5 Selecting Stream Reaches for Field Work

4.5.1 Methodology

Once the streams were classified the next step was to identify streams suitable for field work.

Initially, stream reaches were created to produce manageable reach lengths to facilitate field work. Exclusion criteria was developed that removed stream reaches that did not have natural flow patterns. The remaining stream reaches were aggregated and then subjected to random stratified sampling to select 100 target reaches. These target reaches were reviewed to determine if there were reasons why they were not acceptable for field work. The Project Steering Group was also asked to provide input on acceptability. Finally, 30 reaches are selected for field work.

The field work consisted of a mesohabitat survey and measurement of cross-sectional flow at various stream levels; this data was needed as input to the PHABSIM model. The field work was completed at a sufficient number of streams to allow results to be compared and generalised. We targeted 30 stream reaches for sampling.

4.5.2 Dividing Streams to Create Reaches

The first step was to divide the Central Plain rivers into lengths that form manageable study reaches (greater than 2 km but less than 8 km in length). Guidelines to divide the rivers were developed and are described in detail in the CDM technical memorandum *Selection of Study Regions/Streams for Instream Flows* (Ref: 39325/AB40/DG05). They were applied separately to 5th order streams, while aggregation across 4th to 2nd order streams was allowed.

4.5.3 Exclusion Criteria

Criteria for excluding stream reaches were developed in conjunction with the Project Steering Group. The intent of exclusion criteria was to remove additional stream reaches from consideration if they were considered significantly unnatural in either physical structure or flow patterns. A discussion was held with the Project Steering Group about whether to exclude river networks that had been arterially drained or channelised. The Project Steering Group felt that these rivers needed to be included as candidates for field work because they form a large majority of Irish rivers, particularly in the Central Plain region, and they are generally regarded as having healthy fish populations.

The four exclusion criteria are listed below.

1. **Heavily Modified Waterbodies (HMWBs).** These were designated during the Article V Initial Characterisation work. Three river waterbodies were identified as provisional HMWBs within the Central Plain physiographic region. These included the Santry River, the mid Dodder River and the Lower Liffey River.

2. **Effluent Dominated Streams**. For this project, the definition of an effluent dominated stream is a stream that receives sufficient flow from wastewater treatment plants (or other point source discharges) to mask natural flow variations, particularly at low flows.

   Using preliminary data from the SWRBD's national POM/S project on Municipal and Industrial Regulations, which covered only a small portion of Ireland's WWTPs, three locations in the Central Plain region were identified as being at risk. The downstream river reaches were deleted to the point where the affected reach either joined a main stem river or a major tributary of equal catchment area. Some 14,970 km^2 of the Triogue River downstream of Portlaoise, 19,140 km^2 of the Delvin River downstream of Garristown and 20,940 km^2 of the Ara River downstream of Tipperary were deleted. Since Q95 flows are not available for many rivers, the Project Steering Group were also asked to review the list of 100 candidate river reaches and advise on whether they would consider any to be effluent dominated.

3. **Compensation Flows/Regulated Rivers**. Within the Central Plain region, the only rivers with compensation flow are those from the Poulaphouca, Leixlip, and Golden Falls Reservoirs. These flows disqualify the main stem of the Liffey River downstream of Poulaphouca Reservoir from consideration for field work. The main stem of the River Shannon and the Dawn River downstream of the Ballyshonock Reservoir in Waterford were also excluded.

   Regulated rivers in the Central Plain region include the Liffey, Shannon and Brosna. As above the Liffey and Shannon have already been excluded. The section of the River Brosna (65km) excluded is downstream of Mullingar town stretching to the confluence point on the Shannon.

4. **Streams affected by Backwater**. Stream reaches that are influenced by the backwater of lakes or reservoirs have altered flow characteristics that make them unsuitable for study. This exclusion criterion could not be evaluated using data available in GIS format so it was evaluated by the Steering Group following the selection of the 100 candidate reaches (Section 4.5.4).

4.5.4 Random Selection Process

A stratified random sampling design was used to select 100 candidate river reaches. The stratified design ensured that the candidate river reaches included individual reaches from 6th order, 5th order and 4th-2nd order reaches.

In the initial selection the number of reaches selected for Order 5 and 6 rivers was too small to be meaningfully compared. Therefore, twice the number of segments were selected for these larger rivers. Table 4-2 shows the distribution of the original and revised 100 randomly selected reaches by stream order.

Table 4-2: Distribution of Reaches for Stratified Sampling

Stream Order	Length (km)	% of Total	# of Reaches	Revised # of Reaches
2nd	6,873	50%		
3rd	3,516	26%		
4th	1,955	14%		
Sum 2nd-4th	12,344	90%	90	80
5th	813	6%	6	12
6th	510	4%	4	8
Total	13,667	100%	100	100

4.5.5 Review Candidate Reaches

The candidate reaches selected using the selection process described in Section 4.5.4 were reviewed for suitability for field work. Table 4-3 shows the number of stream reaches in each order category and the corresponding length. In addition to the exclusion criteria listed in Section 4.3, the reaches were evaluated for site access and safety issues. See CDM technical memorandum 39325/AB40/DG05 for detailed tables and figures on the 100 candidate reaches.

Table 4-3: Results of the Distribution of 100 Reaches

Stream Order	Length (km)	# of Reaches
2nd	158,191	37
2nd--3rd	83,266	17
3rd	33,031	6
3rd--4th	60,144	10
4th	66,874	10
5th	86,055	12
6th	53,426	8
Total	540,987	100

4.5.6 Results of Candidate Reaches Review

After review of the 100 candidate stream segments by the Project Steering Group and other professionals involved with the project, the number was reduced to 83 possible segments. Then using the percentages given in Table 4-3, the first 28 2nd to 4th order streams in the list of 100 candidates were selected to represent 80% of the streams. The top four 5th order streams were then selected to represent 12% of the streams. Finally, the top three 6th order rivers were then chosen to represent 8% of the rivers. Table 4-4 lists the remaining 30 study reaches after culling unsuitable reaches from the randomly selected list of 100 candidate reaches; their locations are shown in Figure 4-2. Appendix A contains a more detailed location map for each of the 30 stream segments.

Once the 30 stream segments were selected an initial site reconnaissance was carried out to assess if all the segments were suitable for fieldwork. Most of the segments were suitable except Segments 95 and 96. These rivers were deemed unsuitable because they were too deep and uncharacteristic of Central Plain rivers. An additional 2 sites (Segments 35 and 48) were also visited during the initial site reconnaissance and these replaced the Slaney (Segment 95) and Suir Rivers (Segment 96).

Table 4-4: 30 Study Stream Reaches

No.	Length (m)	Stream Order	EPA Code	EPA Name	LA	RBD	DTM Area (km^2)
1	2430	2			WX	SERBD	4.1
3	2539	3-2			OY	SERBD	8.6
4	3263	2			MH	ERBD	5.1
5	5701	4	26I01	Inny [Shannon]	WH	SHIRBD	438.7
6	7624	3	16T02	Thonoge	TY	SERBD	28.50
7	3018	2			LS KE	SERBD	39.2
8	2463	2			LD	SHIRBD	8.6
9	5536	2			CK	SWRBD	12.6
10	5970	2			MH	ERBD	13.9
11	7214	3-2			KK	SERBD	48.8
12	7866	4	07B01	Blackwater [Kells]	CN	ERBD	125.1
14	7545	4-3	22M01	Maine	KY	SWRBD	111.9
15	4902	3-2			TY	SERBD	24.8
16	3730	3-2			KK CW	SERBD	18.8
19	6498	2			TY	SERBD	13.6
20	6334	4	12S03	Sow	WX	SERBD	88.4
23	4151	3-2	14L01	Lerr	KE	SERBD	26.4
24	2328	2			CN	ERBD	5.4
25	5887	3-2			TY	SERBD	13.7
27	2154	2			LK	SHRBD	4.5
28	5602	2			LK	SHRBD	7.9
29	2170	3-2			LK	SHRBD	4.6
30	7753	3-2	15C04	Cloghnagh	KK	SERBD	18.1
31	7509	4-3	24C01	Camoge	LK TY	SHRBD	43.9
35	5735	3	14T02	Tully(stream)	KE	SERBD	208.5
36	7961	5	24C01	Camoge	LK	SHRBD	219.7
43	7624	5	16C03	Clodiagh [Tipperary]	WD	SERBD	127.7
48	4551	3	16B02	Blackwater [Kilmacow]	KK	SERBD	37.5
90	7800	5	25K01	Kilcrow	GY	SHRBD	393.8
92	7841	5	16T01	Tar	TY	SERBD	241.9

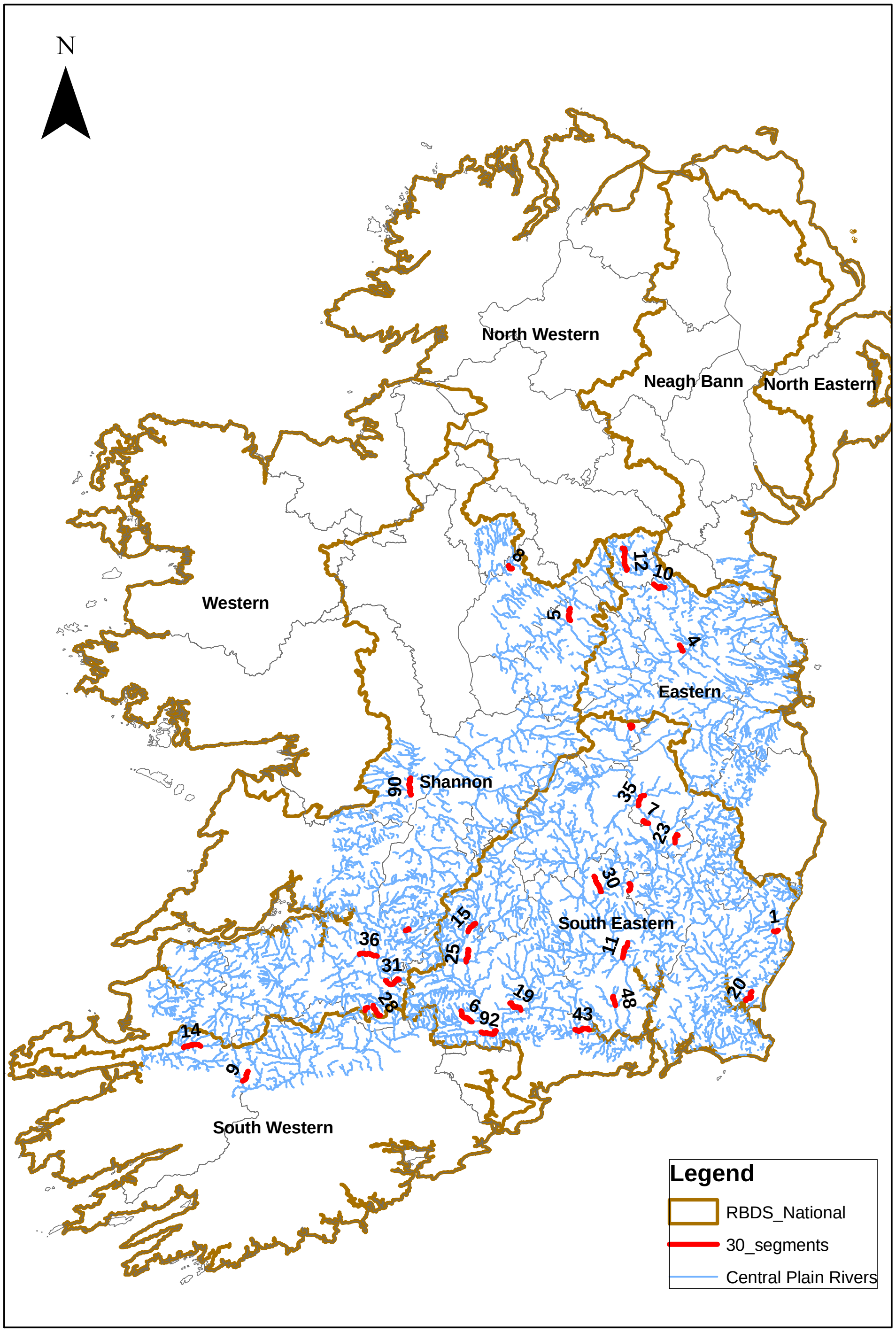


Figure 4-2: Distribution of 30 Study Stream Reaches in the Central Plain Region

5.0 Field Data Collection Procedure

5.1 Overview

Following the selection of study reaches, the field work was undertaken to support hydraulic and biological modelling. There are many interactions among field data collection, hydrologic analyses, and hydraulic model calibration and each is discussed separately in the following sections. The hydrologic conditions (detailed in Section 6) were used to help determine when the field crews could be dispatched.

Field data was collected in accordance with procedures described by Bovee (1997) and followed guidelines specifically developed for this project CDM technical memorandum *Scope for PHABSIM fieldwork* (Doc. Ref. 39325/AB40/DG09). The fieldwork consisted of three activities: study site selection, mesohabitat characterisation and site surveys. The work was conducted at 28 segments in the Central Plain region of Ireland (Figure 4-3). The field work was carried out by CDM personnel and staff from a survey firm. Health and safety issues in conducting the field work for CDM staff were addressed through preparation of a project health and safety plan. The survey subcontractors developed their own health and safety plan, which was reviewed by CDM.

During the process of field data collection, a number of issues arose that rendered some of the study segments unsuitable for further fieldwork. These findings are discussed in Section 5.3.3.

5.2 Method Summary

5.2.1 Study Site Selection

The work was conducted at a number of segments in the Central Plain region of Ireland. As described in Section 4.0, 100 stream reaches were selected randomly, then some were removed from the study list due to access or other issues identified by initial site visits during January and March 2007, and finally the first 30 segments of these screened 100 sites were selected (Doc. Ref. 39325/AB40/DG05). A rapid site reconnaissance was conducted to visit the 30 study segments with a few additional backup sites if any of the initial sites were deemed unsuitable. A rapid survey typically involved assessing river conditions from one or two bridge crossings or the adjacent stream bank for the factors described below. This was partly to eliminate any obvious poor segment choices but also to identify requirements (access/boats) for future field work. Each river was assessed for the following factors:

- Access (presence of steep banks, safe car parking, fencing/security, dense bank vegetation, segments in a culvert)
- Water quality,
- River depth (would a boat be needed?),
- Area subject to vandalism,

- Adjacent lands/surroundings.

Once suitable study segments were selected, the relevant local authorities were contacted to gain authorisation for conducting the fieldwork. Seventeen local authorities received a letter detailing the project and fieldwork, a list of personnel carrying out the fieldwork, the health and safety plan and a map of the study sites in their jurisdiction. One local authority did not grant permission and this study segment was dropped from the study.

5.2.2 Mesohabitat Characterisation

The objective of the mesohabitat characterisation was to first survey the stream reaches selected for study to ascertain typical stream characteristics such as pool, glide, run and riffle mesohabitat types. Table 5-1 defines the characteristics of the mesohabitats sampled (Hawkins et al., 1993 and personal communication; Maddock, 2007)

Table 5-1: Mesohabitat Characteristics

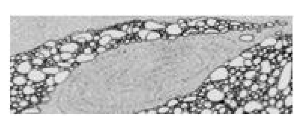
	Name	Description	Appearance
Turbulent	Riffle	Common type of turbulent fast water mesohabitats in low gradient alluvial channels. Substrate is finer than other turbulent mesohabitats, with some substrate breaking the surface.	
Non-Turbulent	Run	Moderately fast and shallow gradient with ripples on the surface of the water. Deeper than riffles with little if any substrate breaking the surface.	
	Glide	Smooth 'glass-like' surface with visible flow movement along the surface, relatively shallow (compared to pools) depths.	
	Pool	Relatively deep and slow flowing, with fine substrate. Usually little surface water movement visible. Can be bounded by shallows (riffles, runs) at the upstream and downstream ends.	

Figure 5-1: Mesohabitat Characterisation at a Glide Habitat, Segment 23, Kildare

Figure 5-1 shows the measurement of a glide habitat in Kildare. Each stream reach was surveyed by walking on foot either along the stream bank or in the stream covering a sufficient length of the reach to ascertain its typical characteristics. The typical characteristics include stream dimensions (width, depth, gradient), channel shape, degree and type of meanders, etc., and the general proportions of mesohabitats (riffle, run, glide or pool). Observations were recorded in the field log book. Upon completion, a representative portion of the stream reach was selected for detailed measurements (full surveying as described below). This portion contained either three repetitions of each of the mesohabitat types present, or 300 m of stream, whichever was greater. The proportion of each mesohabitat type in the representative section was measured and initial cross section (transect) locations typical of each mesohabitat type were selected.

5.2.3 Full Survey Procedure

The number and location of PHABSIM study transects was based upon the habitat types identified in Section 5.2.2. A full survey was conducted at the representative cross sections at each study segment. At least three target flow rates (low, medium and high flow) were surveyed at each study segment. Initially, the first two rounds of fieldwork were surveyed to a local datum but upon agreement with the Abstraction Steering Group, the members agreed to extend the surveying to the Irish National Grid. This would allow for traceability and the ability to revisit these sites should the future need arise. This work was included as part of the final round to minimise cost to the project.

The following procedure was followed when conducting the fieldwork:

1. The x, y location of the fenopins was surveyed to a local benchmark. Benchmarks were located so that they could not be easily moved (on bridge piers, roads, trees etc.).

   The sites were closed and an acceptable limit of error achieved before proceeding. Relative accuracy requirements for elevations were 30 mm for ground elevations and 3 mm for water surface elevations.

2. A number of cross-section verticals (depending on the channel characteristics) were established. The minimum distance between the verticals was 0.5 m in Order 2 and 3 streams, 1 m in Order 4 and 5 streams, unless the Order 5 river was wide and uniform in shape, where a 2-m minimum interval was used. Verticals were also place wherever there was a change in the slope of the channel bottom along the cross section.

3. The water surface elevation was also surveyed at up to three points across the cross section (near left bank, mid channel, and near right bank).

4. Substrate was determined by visual observation at each vertical using the Wentworth size classes and codes based on the Trihey and Wegner (1981) coding system. Cover was also noted.

5. During the initial survey round, the survey of the cross section extended beyond the pins to the top of the bank and a couple of metres onto the flood plain.

6. Velocity measurements were made with a Marsh-McBirney electromagnetic meter. Measurements were usually made at each vertical at 0.6 of the depth. Although, in depths greater than 0.75 m, an average of readings at 0.2 and 0.8 of the depth were made instead.

5.3 Results of the Fieldwork

5.3.1 Study Site Selection Results

A rapid site reconnaissance was conducted in March 2007 to visit the 30 study segments with two backup sites if any of the initial sites were deemed unsuitable. Table 5-2 shows the location and river order of the 32 segments visited.

Table 5-2: Initial Site Reconnaissance, 5-9th March 2007

Seg No.	Name	Location	Order	Comments
1		Ballycanew, Wexford	2	Yes suitable for surveying
20	Sow River	Castlebridge, Wexford	4	Yes suitable for surveying
16		Coan, Kilkenny	3-2	Yes suitable for surveying
30	Clodiagh	Castlecomer, Kilkenny	3-2	Yes suitable for surveying
11		Thomastown, Kilkenny	3-2	Yes suitable for surveying
48	Blackwater (Kilmacow)	Mullinavat, Kilkenny	3	Yes suitable for surveying
43	Clodiagh (Tipperary)	Portlaw, Waterford	5	Yes suitable for surveying
6	Thonoge	Ballylooby, Tipperary	3	Yes suitable for surveying
15		Dundrum, Tipperary	4-3	Yes suitable for surveying
19		Clonmel, Tipperary	4-3	Yes suitable for surveying
25		Ballygriffun, Tipperary	3-2	Yes suitable for surveying
92	Tar	Newcastle, Tipperary	5	Yes suitable for surveying
95	Suir	Newcastle, Tipperary	6	Not suitable for surveying, too deep therefore not representative
27		Kilfinane, Limerick	2	Yes suitable for surveying
28		Kilfinane, Limerick	2	Yes suitable for surveying
29		Cappamore, Limerick	3-2	Yes suitable for surveying
31	Camoge	Knocklong, Limerick	4-3	Yes suitable for surveying
36	Camoge	Grange, Limerick	5	Yes suitable for surveying
14	Maine	Castleisland, Kerry	4	Yes suitable for surveying
9		Knocknagree, Cork	2	Not suitable for surveying, permission from Cork CoCo not obtained
90	Kilcrow	Portumna, Galway	5	Yes suitable for surveying
7		Athy, Kildare	2	Yes suitable for surveying
23	Lerr	Castledermot, Kildare	3-2	Yes suitable for surveying
35	Tully Stream	Cloney, Kildare	3	Yes suitable for surveying
3		Edenderry, Offaly	3-2	Yes suitable for surveying
4		Trim, Meath	2	Yes suitable for surveying
10		Moynalty, Meath	2	Yes suitable for surveying
5	Inny (Shannon)	Coole, Westmeath	4	Yes suitable for surveying
8		Monaduff, Longford	2	Yes suitable for surveying
24		Kilinkere, Cavan	2	Yes suitable for surveying
12	Blackwater (Kells)	Virginia, Cavan	4	Yes suitable for surveying
96	Slaney	Ballycarney, Wexford	6	Not suitable for surveying, too deep therefore not representative

To summarise, the following 3 river segments were deleted leaving 27 study segments:

- One river segment in Cork as permission was not granted by Cork County Council,
- Two river segments, one in Westmeath and the other in Offaly, which were considered to be none representative because they were located in boggy land.

Figure 5-2: River Slaney (Order 6) deleted from Study as not Representative of Central Plain Rivers

5.3.2 Mesohabitat Characterisation Results

A survey of mesohabitats was performed in May 2007 on the 27 river segments remaining after the initial site visit was conducted in March 2007. Table 5-3 shows the length of each habitat type and river order for all 27 rivers. The total length and percentages of all habitats is summarised for each river. The glide habitat was most dominant with 59.5% of the habitat or 5,337 metres of the total length (8,973 metres) characterised over the 27 rivers. Waterfalls and chutes were not characteristic of Central Plain rivers; hence no cross sections were placed at these types of habitats. Therefore, the pool habitat was least dominant with 1.9 percent of the habitat or 172 metres.

Table 5-3: Total Length of Habitat Types for 27 River Segments

Seg. No	Order	Length (m) of Habitat Type: Run	Glide	Riffle	Pool	Waterfall	Chute
1	2	226	67				
4	2	36	322				
6	3	150		171			
7	2	156	206		9		
8	2	194	110	4	30		
10	2	110	213	16	5		
11	3-2	112	170		22		
12	4	47	207				
14	4-3	122	177				
15	4-3	122	177				
16	3-2	104	296	10			
19	2	93	165	0	18		
20	4	167	125	0	8		
23	3-2	71	230	60			
24	2	125	133		31		
25	3-2	130	311				
27	2		300				
28	2	142	83.5	13.5	6		
29	3-2	233	124				
30	3-2	175	120	1	43		
31	4-3	202	161	41		20	5
35	3	50	287				
36	5	54	246				
43	5	154	140	42			
48	3	58	334	4			
90	5		300				
92	5	37	334	6			
Total (m)		3,070	5,337	369	172	20	5
% of Total		34.2	59.5	4.1	1.9	0.22	0.06

Six rivers were removed during the fieldwork program for various reasons discussed in Section 5.3.4. Table 5-4 compares the distribution of habitat lengths and percentages for the original 27 and 21 remaining rivers.

Table 5-4: Total Length of Habitat Types for 21 River Segments

No. of Segments		Length (m) of Habitat Type: Run	Glide	Riffle	Pool	Waterfall	Chute
27	Total (m)	3,070	5,337	369	172	20	5
	% of Total	34.2	59.5	4.1	1.9	0.2	0.1
21	Total (m)	2,239	4,656	322	211	0	0
	% of Total	30.1	62.7	4.3	2.8	0	0

Once the mesohabitat characterisation was completed, cross sections were placed at suitable representative sites at each mesohabitat. Where possible suitable sites were generally easily accessible, there was a good line of sight for the surveyors, and the water was free from excessive weed growth or bank overhang vegetation. Representative cross sections were selected based on the percentage of habitat types present in a river. In general, three cross sections were selected for each river, with four cross sections selected where pool habitat existed. At the end of the field data collection programme a total of 70 cross sections remained for further analysis in PHABSIM. They comprised of 31 glides, 32 runs, 4 pools and 3 riffles.

5.3.3 Full Survey Results

Field data was collected at the representative cross sections to collect information necessary to develop a relationship between stage and discharge over a range of flows, and to model fish habitats. The field program started in January 2007 and was completed in September 2008. Due to a lack of on-line flow gauges in Irish rivers during the survey period and the unpredictable weather patterns, capturing the different flow regimes proved quite difficult. Table 5-5 summarises the field program and the conditions encountered.

Table 5-5: Summary of the Field Data Program

Fieldwork Type	No. of Segments	Time (months)	River Flow Conditions
Initial site reconnaissance	10	Jan – Mar '07	Medium - High
Rapid site assessments	32	Mar '07	High Flow
Mesohabitat characterisation	30	May-June '07	Low - Medium
First Round	25	May-July '07	Medium
Second Round	26	Sept. '07	Low
Third Round	8	Nov. '07	Low
Fourth Round	22	Jan, Mar, July-Aug. '08	High

5.3.4 Problems Encountered during Field Data Collection

A number of problems were encountered during the fieldwork that reduced the number of segments from 27 to 21. Table 5-6 details the remaining study segments after the fieldwork was completed.

- Two rivers (Segment 19 and 20) were dredged during the surveying; hence they were deleted from further analysis as their profiles had changed considerably (Figures 5-3 and 5-4).

- One river (Segment 30) was dredged and filled with large boulders to facilitate the building of a road along the river banks (Figure 5-4).

- A fieldwork error occurred at one river (Segment 31) rendering the field data unusable for further analysis/modelling.

- Segment 8 showed small variations in flow throughout the fieldwork program. The measured flow rates used in the hydraulic calibration process need to be sufficiently different to obtain a valid hydraulic calibration.

- For Segment 28 (Order 2), the changes in transect geometry, as a result of high flows caused the pool habitats to be washed away. However, the riffle and run habitats/cross sections remained intact. Figure 5-6 shows evidence of these high flow changes.

Table 5-6: Summary of Remaining Study Rivers After Fieldwork

No.	EPA Name	LA	RBD	Length (m)	Order
1		WX	SERBD	2,430	2
4		MH	ERBD	3,263	2
6	Thonoge	TY	SERBD	7,624	3
7		LS KE	SERBD	3,018	2
10		MH	ERBD	5,970	2
11		KK	SERBD	7,214	3-2
12	Blackwater [Kells]	CN	ERBD	7,866	4
14	Maine	KY	SWRBD	7,545	4-3
15		TY	SERBD	4,902	4-3
16		KK CW	SERBD	3,730	3-2
23	Lerr	KE	SERBD	4,151	3-2
24		CN	ERBD	2,328	2
25		TY	SERBD	5,887	3-2
27		LK	SHIRBD	2,154	2
29		LK	SHIRBD	2,170	3-2
35	Tully (Stream)	KE	SERBD	5,735	3
36	Camoge	LK	SHIRBD	7,961	5
43	Clodiagh [Tipperary]	WD	SERBD	7,624	5
48	Blackwater (Kilmacow)	KE	SERBD	4,551	3
90	Kilcrow	GY	SHIRBD	7,800	5
92	Tar	TY	SERBD	7,841	5

Figure 5-3: Dredged River (Segment 20) showing the before and after Photos

Figure 5-4: Dredged River (Segment 19) showing the before and after Photos

Figure 5-5: Dredged River (Segment 30) showing a Deposit of Boulders on one Bend to Support a New Road along the River Bank

Figure 5-6: Segment 28 showing a Deposit of Debris on the Inner Bend of a Former Pool Habitat now Exhibiting Riffle Characteristics after High Flows

5.4 Conclusion

A number of problems were encountered in the field reducing the number of segments available for modelling from 27 to 21. However, a good variance in river size/order remained for further analysis. The data for each round and study segment were quality checked and formatted for use in the PHABSIM model. A review of the distribution of the measured flows was performed simultaneously as the fieldwork progressed. Appendix A contains the layout and location of all study segments.

6.0 Hydrologic Analyses

6.1 Overview

The hydrology of the rivers formed an integral part in applying the instream flow method to the study segments. The hydrologic data compiled for each study segment included:

- Flow duration curves for the entire period of record,
- Median monthly flows for all sites for the entire period of record where more than 21 days of data existed in a month,
- Annual mean and median flows for all sites for the entire period of record,
- Time series of median monthly flows for the habitat versus flow relationships discussed in Section 7.0.

Time series analysis of flows can use any time step; this study used median monthly flows. A monthly time step represents a reasonable level of effort from an analytical and practical standpoint, and median flows are typically considered the best measure of central tendency. The rationale for using the monthly median flow was the assumption that the fishery population can adjust to the amount of habitat naturally available half the time. Monthly median flows are the median value of all the daily flows during a particular month. In our analysis, months with less than 21 days of recorded flows were excluded since there was not enough data to calculate the median flow.

This section sets out the selection of the appropriate hydrometric gauges for each study segment and the subsequent development of hydrology at these sites. It also details the statistics developed from the hydrology to be used in the assessment of the flow and habitat time series impact detailed in Section 7.0.

6.2 Hydrologic Analyses

6.2.1 Procedure

Two minimum criteria were established for the selection of hydrometric gauges that would be used to derived the hydrology needed for this study: (1) the stream had to have a natural flow (*i.e.*, it could not be altered by dam releases or other human-caused inflows such as wastewater treatment plants or outflows such as abstractions), and (2) the period of record should be 10 years or longer.

Using these criteria, gauges were then selected for each of the 21 study segments by either;

1. Using a suitable hydrometric gauge that was present on the same stream as the study segments. Five suitable gauges were identified.

2. For the remaining ungauged segments, reviewing the characteristics of nearby hydrometric gauges to assess if the drainage area, rainfall and

conditions in the field were sufficiently similar to the study segment to allow for transposition of its record to the study segment. The analyses resulted in only a few suitable choices of gauges.

3. For the segments that still remained, using the EPA/ESBI method to develop estimates of the Q5, Q50, and Q95 percentile flows. Using these flows, along with the criteria in step 2, the pool of candidate hydrometric gauges was widened and the gauge that fit best between the measured field flows and the EPA/ESBI method derived flows was selected.

6.2.2 Selecting Hydrometric Stations on Gauged Streams

Six of the study segments had hydrometric stations located on the gauged streams in close enough proximity to the study site to allow the gauged record to be transposed to the study site. These are shown in Table 6-1. However, the gauge on Segment 6 was not used as it had only 2 years of record.

Table 6-1: Hydrometric Gauges Situated on Study Segment Streams

River Segment No.	Name	Study Catchment Area (km^2)	Hydrometric Gauge No. and Body Responsible	Gauge Catchment Area (km^2)	Period of Record
6	Thonoge River	9.24	16134 EPA	0	2006-2008
12	Blackwater (Kells) River	121.84	07033 OPW	124.8	1980-2008
14	River Maine	41.60	22014 EPA	45.6	1985-2008
43	Clodiagh River	124.37	16020 EPA	124.5	1976-2008
92	River Tar	211.78	16012 OPW	229.6	1964-2001
90	River Kilcrow	204.72	25020 OPW	185.9	1986-1999

The remaining five hydrometric gauges were checked to determine if they had natural flow using the list of 114 natural flow gauges developed by EPA/ESBI as part of their ungauged flow method estimation technique. Three of the five gauges were not included in the list of 114 natural gauges, so we investigated why they were not included. Abstractions were found on all three rivers, while a discharge was found on two of the three rivers. Table 6-2 provides information on the daily abstraction rate, discharge rate, the average daily flow (ADF) and Q95 flow of the rivers with hydrometric gauges. Both the abstractions and discharges are minor in comparison to both Q95 and the ADF flow, thus the gauges were retained to develop the hydrology.

Table 6-2: Hydrometric Gauges not Included on the ESBI List

River No. Gauge No.	Type Abs.	Abstraction Rate (m^3/s)	WWTW/ IPPC/ Section 4's (m^3/s)	Stream Average Daily Flow (m^3/s)	Stream Q95 (m^3/s)
Segment 43 16020	GW	0.002	0.0004	5.04	0.56
Segment 90 25020	GW	0.001	0.0019	3.87	2.03
Segment 14 22014	SW	0.001	-	1.44	0.38

6.2.3 Selecting Hydrometric Stations on Ungauged Streams

Candidate hydrometric gauges for use in the hydrology analysis for ungauged streams were selected by starting with the 1,956 gauges in the EPA register and deleting 1,350 of them because they were recorded as obsolete (488), suspended (229), inactive permanently (92), unknown (80), measurement sites (12) and staff gauge only (449). Of the remaining stations, 248 hydrometric gauges located in the Central Plain region were considered to be the initial best set of gauges for use based on the assumption that in regional hydrology differences in hydrology are related to differences in physiography.

The criteria that were used for gauge selection for ungauged streams were:

- Similar drainage area to the study segment catchment area,
- Similar precipitation amounts,
- At least ten years of gauged record,
- A natural flow regime or listed on the ESBI list of 114 gauged catchments,
- Professional judgment based on the conditions encountered during the field data collection.

This analysis produced very few acceptable matches between hydrometric stations and the study sites. The main issue was that the majority of the remaining study sites are on streams with small watersheds and very few of the hydrometric gauges are located in small catchments. One of the few available hydrometric gauge records for small catchments (07021) ultimately could not be used because of the presence of a wastewater treatment plant discharge upstream of the hydrometric gauge, which served to alter the low flows measured at the gauge.

The selected approach was to consider the gauges recommended by the EPA/ESBI method for determining the value of the Q5, Q50, and Q95 'natural flows' in ungauged catchments. Two variations of the method exist, one for catchments with a significant component of conduit karst. We used the second method for catchments containing all other rock types, which is known as the Non-Karst Method.

The EPA/ESBI Non-Karst method is based on a comparison of the study stream to the five closest reference streams within the EPA/ESBI dataset of 114 non-karst natural streams.

The eight significant hydrogeologic factors for the catchment area in the EPA/ESBI methodology (in descending order of weighting) are:

1. Rainfall (average annual 1961-1990);
2. Percentage of 'made' land;
3. Percentage of high-permeability subsoil;
4. Percentage of poorly-drained soil;
5. Percentage of well-drained soil;
6. Percentage of low-permeability subsoil;
7. Percentage of diffuse karst;
8. FARL (flood attenuation from reservoirs & lakes), is a function of the area of a lake, the areas of the subcatchment upsteam of the lake and the total catchment area.

The flows from the five closest reference stream/gauges recommended by the EPA/ESBI method were transformed by a ratio of the catchment area of the study segment to the catchment area of the hydrometric gauges and then they were plotted as flow duration curves. Flow duration curves represent the percentage of time that a given flow is equalled or exceeded without regard to the sequence of recorded flows. Typically, flow durations characterise the range of flow rates for the period over which data was collected. The records are ranked and the corresponding flow percentiles allocated. Flow durations are computed by sorting the daily mean flows for the period of record from the largest value to the smallest value and assigning each flow value a rank, starting with 1 for the smallest value. The frequencies of exceedance are then computed for computing plotting position.

The measured flows were added to the graphs, and a hydrometric gauge was selected based on the criteria in Section 6.2.2 and the best fit between the measured flows and the flow duration curve.

During this process we were unable to find a suitable hydrometric gauge to use for three of the segments.

1. Segment 36 (Camoge River, Order 5). For safety reasons, data for the third round of surveying (high flows) was captured from the staff gauge level of a nearby hydrometric station. Unfortunately, no rating curve is in place for station 24002 at Gray's Bridge, and the estimate of flow was based on a previous staff level measurement in 1994. An accurate calibration of water surface elevations could not be achieved at this river and so it was removed from further analysis.

2. Segment 11 (Order 2-3). The nearby hydrometric gauge 14057 did not correlate to the measured flows. Also, the recommended gauges from the EPA/ESBI method were unsuitable in terms of area transposition and poor fit.

3. Segment 14 (River Maine, Order 3-4). The existing gauge 22014 is unsuitable due the absence of a number of years of flow records between 1991 and 2002. Also, there is an extreme variation in flow percentiles for lowest measured flow between gauges, making gauge transposition impossible.

Table 6-3 details the hydrometric gauges selected to represent hydrology for the remaining 18 rivers.

Table 6-3: List of Gauges Selected to Represent Hydrology at the Study Segments

No.	Hydro. Station	Gauge Catchment Area (km^2)	Study Catchment Area (km^2)	Gauge Precipitation (mm)	Study Precipitation (mm)	Begin - End Date	Years of Record
1	06030	10	4	1001	946	1975-2008	33
4	24022	41	4	1029	878	1984-2008	24
6	06030	10	9	1001	1164	1975-2008	33
7	14057	32	37	912	837	1995-2008	13
10	06030	10	5	1001	1010	1975-2008	33
12	07033	125	122	1059	1057	1980-2005	25
15	25040	28	15	1033	1105	1980-2008	28
16	25040	28	19	1033	1158	1980-2009	28
23	14057	32	26	912	873	1995-2008	13
24	26056	88	4	1027	1113	1981-2008	27
25	25040	28	13	1033	992	1980-2009	28
27	06030	10	11	1001	1177	1975-2008	33
29	06030	10	3	1001	1191	1975-2008	33
35	14007	95	204	847	847	1980-2001	21
43	16020	124	124	1114	1114	1976-2007	31
48	25040	28	37	1034	1034	1980-2009	28
90	25020	186	205	1082	1082	1986-1999	13
92	16012	230	212	1132	1132	1964-2001	37

6.3 Developing Flow Duration Curves for the Study Sites

Once the hydrometric stations were selected, the flow records were analysed to develop the statistical hydrologic parameters needed for the modelling. Flow duration curves were created for the 21 segments by using an area weighted transposition where by stream flows at the nearby suitable gauge were multiplied by the ratio of the drainage area of the study segment to drainage area at the hydrometric gauge. Figure 6-1 shows a typical FDC for a study segment.

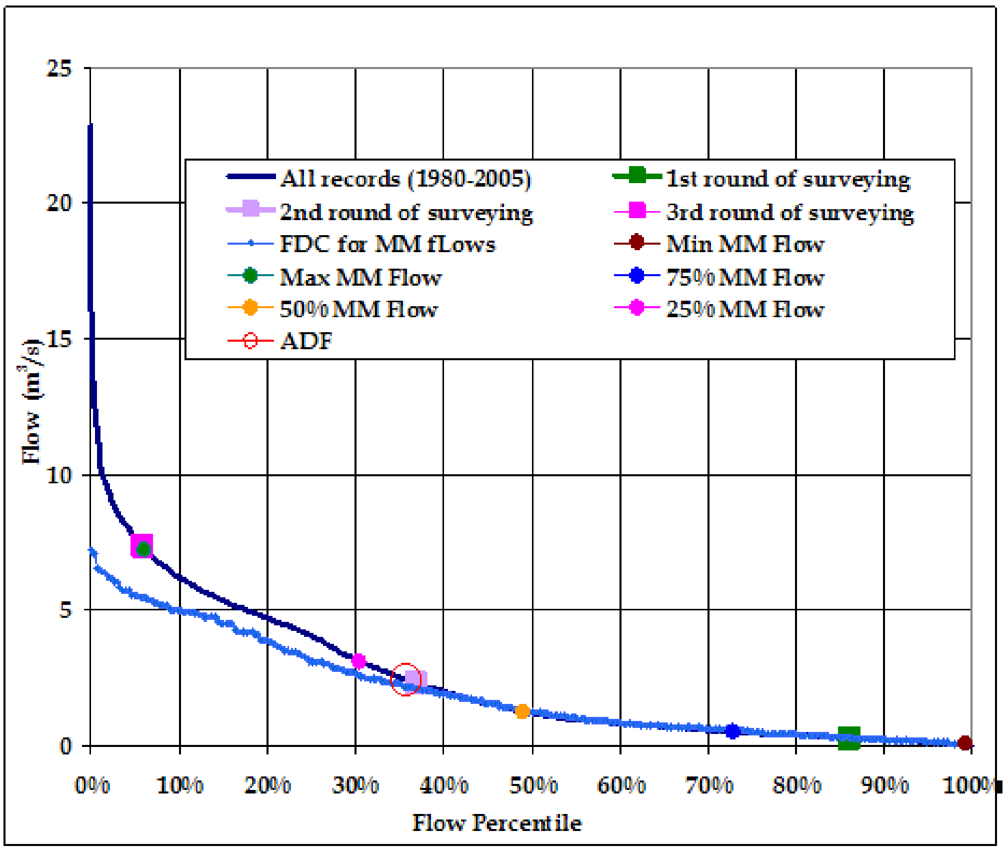


Figure 6-1 Typical FDC with Measured Flows, Median Monthly Flows and ADF (Segment 12)

The entire flow record of the hydrometric gauge for each study segment was used to determine:

- Median monthly flows; these flows are the median of individual daily flows for all complete months (for which at least 21 days are reported) during the period of record at the stations.

- The minimum, maximum, 25th, 50th and 75th percentile median monthly flows. These values were used to select the different simulation flows for use in the PHABSIM model.

- The average daily flow (ADF) for the entire period of record.

The flow duration curve in Figure 6-1 also shows the three measured flow rounds, median monthly flows, the five median monthly flow statistics and the average daily flow values. Appendix B contains all the flow duration curves developed as part of this study.

6.4 Selecting Flows for Model Simulation

The median monthly flows that were calculated from the flow duration curve records for each study segment (Section 6.3) were used as the basis for the selection of flows in the PHABSIM hydraulic and habitat model simulations. The intent of the model simulations is to represent the full range of flows except for those flows that represent hydrologic extremes. As the basis of this study is median monthly flows, the targeted full range of flows would extend from the minimum median monthly flow to the maximum median monthly flow.

Since the flow duration curves are only estimates of the flows in the study segments, care needed to be taken in using flows beyond the range of measured flows as representative of actual flows in the segments. Typical engineering practice is to limit the extent of extrapolation to a flow equal to 1.5 times the highest measured flow and 0.6 times the lowest calibration flow. According to the U.S. Fish and Wildlife Survey, the absolute maximum range for extrapolation is to a flow 2.5 times the highest measured flow and 0.4 times the lowest measured flow.

Eighteen different flows were selected to represent a range of flows to be modelled in PHABSIM. These were based on the median monthly flows calculated for each study segment. The following list was followed as a guideline for specifying the eighteen different simulation flows:

- Minimum, maximum, 25th, 50th and 75th percent probability of exceedance values for the median monthly flows,

- Five simulation flows between the minimum median monthly flow and the 75th percent probability of exceedance values,

- Three simulation flows between the 75th and 50th percent probability of exceedance values,

- Three simulation flows between the 50th and 25th percent probability of exceedance values,

- Two simulation flows between the 25th percent probability of exceedance and the maximum median monthly flow.

In addition to the above 18 flows, it was on occasion necessary to include an additional simulation flows that was either less than the minimum median monthly flow or greater than the maximum median monthly flow. In these cases, two flows would be removed from the high flow simulation values.

The spread of the 18 simulation flows is not evenly distributed but emphasises more the lower end of the flow range. This is to enable more detail when determining minimum instream flows.

These eighteen simulation flows were checked to insure they were within the acceptable model flow extrapolation range discussed above. The next section describes the context and processes of PHABSIM modelling in greater detail.

7.0 Hydraulic and Biological Modelling

7.1 Overview

The computer software PHABSIM was used to model the data collected during fieldwork on the study segments. PHABSIM considers flow-dependent changes in physical components of the system that are evaluated to derive an estimate of fisheries habitat quality and quantity (*Hardy, 2005*). PHABSIM reproduces the relationship between river flow and physical habitat availability for various life stages of an aquatic species. PHABSIM uses two main model types: hydraulic models and biological (habitat) models; the structure of PHABSIM was discussed in detail in Section 1.3.

Hydraulic models were calibrated using the field data at each cross section. For each flow regime, calibration targets were the measured flow, the average of the water levels at each cross section, and the velocity measured at each vertical along a cross section; Section 5 describes how verticals (measurement points) were selected along each cross section. The model uses the cross-section geometry and measured flow as its primary inputs. The hydraulic model output is the water depth and velocity at each vertical along the cross section.

Habitat modelling uses the calibrated hydraulic models, the 18 simulation flows (Section 6.4) and the habitat suitability curves (Section 3) to calculate the habitat potential that is a combination of habitat quantity and quality, known as weighted usable area (WUA). WUA is an index of the capacity of a stream reach to support the species and life stage being considered, expressed as actual area predicted to be available per unit length of stream at a given flow.

The following sections detail this two-stage process. The habitat results are discussed in more detail in Section 8.

7.2 Hydraulic Modelling

The hydraulic simulation programs in PHABSIM are calibrated in three steps: measured flows, water levels and velocities, though these are not all independent.

7.2.1 Developing Simulated Flows from Measured Data

The first goal in modelling is to reproduce the measured flows within the model. This is done by specifying the geometry of the channel and the measured water levels. For many cross sections, water level measurements across a section varied by several hundredths (or in some cases tenths) of centimetres so an average of measured water levels was used for model input.

Variation in water levels across a cross section is expected. For instance, for several habitat types the water surface is rippled and the target of the field survey is to obtain an average measurement between peaks and troughs of the ripples. Similarly, there can be superelevation of the water level on one side of a river if the section is at or near a bend. In a few cases the water level elevation differences could not be explained and are assumed to be outliers; these were removed from the analysis.

Water levels were also examined for consistency with flow. In general lower flows should have lower water levels. This, however, was not the case for a few study segments that became progressively denser with aquatic plants during the field program. The first field measurements were made in early summer when these segments had almost no aquatic plant growth. Measurements made later in the year had a calculated lower flow but higher water level. Two factors contribute to this apparent inconsistency. First the aquatic plants can occupy a substantial volume of the cross section, thus raising the water level higher than it would be if no aquatic plants were present. Second, obtaining good estimates of flow is challenging in heavy aquatic growth conditions as the flow is channelled through areas with less dense growth. Measurements at dense aquatic growth cross sections were studied in detail. In several cases, the first round of flow measurements was not used because the model could not reproduce the measured flows under the two different channel conditions (some aquatic growth and dense aquatic growth). In this case a fourth round of heavy aquatic growth measurements was sought and the model was then run with three rounds of data representing dense aquatic growth conditions.

A related constraint in the PHABSIM hydraulic models is that the model only allows for single cross-section geometry across the range of flows being simulated. Several of the stream segments selected for study had their stream beds altered during the course of the study. Some alterations were man-caused (dredging or filling) or natural but so significant (such as high flows washing out a pool habitat) that the study segments simply had to be dropped (Section 5 describes these cases). In other cases, the change in channel geometry was less (such as when the rocks in a ripple cross section shift or the channel thalweg deepens or deposition across the section occurs after flooding flows). In these later cases we selected an 'average' channel bathymetry that allowed for minimisation of the differences between the calculated flows from the field data and the model's representation of those flows using the field data as input across all flow regimes at a cross section.

7.2.2 Water Surface Elevation Modelling

Three approaches are available within PHABSIM to model water surface elevations. The options available for computing water surface elevations are:

1. **Stage-Discharge (SQ)** – This model performs a log-log regression between observed stage and discharge rounds at each cross section. Each cross section is independent of all others in the data set.

2. **MANSQ** – This option uses Manning's equation. The model uses a β coefficient to adjust the error between observed and simulated water surface elevations at all measured discharges. Each cross section is independent of all others in the data set.

3. **Water Surface Profile (WSP)** – This option uses a standard step backwater method to determine water surface elevations. The model adjusts the Manning's roughness at a measured water surface elevation and then adjusts the roughness modifiers at the additional water levels. This option requires all cross sections to be related to each other in terms of a surveyed or hydraulic control. This option was not utilised in this project as no survey controls were surveyed except in case of the pool downstream control.

The goal of the water surface elevation modelling process was to match the computed elevations to the measured elevations. Since exact matches are not always possible, differences less than or equal to 3 cm were targeted. If the calibration resulted in differences greater than 3 cm, then additional analyses were performed to investigate the reason for the differences. If an explanation could be found that was judged not to affect the remainder of the modelling, then the calibration was judged acceptable.

After the fieldwork program and hydrologic analysis, 18 study segments remained to be modelled in PHABSIM. During the calibration process, Segment 1 was excluded from the analysis. This segment is an Order 2 tributary of the Owenavorragh River in Co. Wexford. The existence of a backwater effect from the confluence with the main river caused problems with the hydraulic modelling at high flows at the most downstream cross section.

Water level calibrations were done at three cross sections per study segment except in the case of Segments 15, 16, and 24 where four cross sections were used. The additional sections were necessary for pool habitats to capture habitat at the centre of the pool and also the downstream hydraulic control of the pool.

Fifteen segments were modelled using the MANSQ option and two by the SQ modelling option; selection of the model to use was based on achieving the best fit with measured data. Table 7-1 gives the water level calibration results in terms of difference between observed and modelled water levels.

When the 17 study segments were calibrated, an acceptable water level elevation model was available for 54 cross sections. Each cross section is calibrated at 3 different flows. Twenty five cross sections out of a total of 162 (54x3) were outside the calibration target of 3 cm. The differences ranged from 4 cm to 7 cm. Investigations into the reasons for these differences centered on the use of an average cross-section bathymetry resulting in slight changes in measured versus simulated flows and the presence of weeds in the cross sections. Other reasons could have included undetected survey errors or disturbed benchmarks. The water level calibrations were considered acceptable because the hydraulic models were internally consistent (e.g., no crossing water levels with increasing flows).

7.2.3 Velocity Modelling

In PHABSIM, the IFG4 program is used to simulate the velocity distributions along a cross section over a range of discharges. PHABSIM simulates velocities for a single cross section at a time and as such treats each cross section independently from the others. The model develops computational cells along cross sections with each cell having its own depth, velocity and substrate.

Table 7-1 : Water Level Hydraulic Modelling Results

No.	Order	Water Surface Model Used	Difference between observed and predicted water levels (m)															
			C/S 1				C/S 2				C/S 3				C/S 4			
			R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
4	2	MANSQ		0.05	0.04	0.01		0.03	0.03	0.00		0.01	0.02	0.00				
6	3	MANSQ		0.01	0.00	0.01		0.01	0.00	0.01		0.01	0.00	0.01				
7	2	MANSQ	0.01	0.02	0.00		0.03	0.03	0.00		0.02	0.01	0.00					
10	2	MANSQ	0.00	0.00	0.00		0.00	0.01	0.00		0.02	0.01	0.00					
12	4	MANSQ	0.05	0.05	0.00		0.06	0.06	0.00		0.03	0.02	0.00					
15	4-3	MANSQ	0.00	0.01	0.00		0.00	0.02	0.00		0.00	0.01	0.00		0.02	0.02	0.00	
16	3-2	MANSQ	0.01	0.01	0.00		0.03	0.04	0.00		0.00	0.01	0.00		0.00	0.01	0.00	
23	3-2	MANSQ		0.03	0.03	0.00		0.03	0.04	0.00		0.04	0.04	0.00				
24	2	MANSQ	0.00	0.01	0.00		0.00	0.01	0.00		0.02	0.01	0.00		0.02	0.02	0.00	
25	3-2	MANSQ	0.02	0.03	0.00		0.00	0.00	0.00		0.01	0.02	0.00					
27	2	MANSQ	0.06	0.06	0.00		0.07	0.07	0.00		0.07	0.07	0.00					
29	3-2	MANSQ	0.01	0.02	0.00		0.01	0.00	0.00		0.01	0.01	0.00					
35	3	SQ		0.00	0.00	0.00	0	0.04	0.02	0.01	0	0.04	0.02	0.01				
43	5	MANSQ	0.02	0.01	0.00		0.04	0.02	0.00		0.04	0.02	0.00					
48	3	SQ	0.01	0.00	0.01		0.01	0.00	0.02		0.01	0.00	0.01					
90	5	MANSQ	0.02	0.03	0.00		0.03	0.02	0.00		0.03	0.01	0.00					
92	5	MANSQ		0.04	0.00	0.04		0.04	0.00	0.05	0.00	0.00	0.00	0.05				

A number of approaches are available in PHABSIM to estimate velocity distributions at a cross section.

1. **No measured velocities** – This option is used where no velocities are measured at a cross section. The program uses a rearranged Manning's equation to solve for velocity. This option was not used in this project as velocities were collected at all cross sections.

2. **Single velocity set** – This option uses an initial solution of Manning's equation to obtain an estimated Manning's n at each vertical along a cross section. Depth is measured as the difference between simulated water surface elevation and bed elevation at each vertical. Manning's n can be changed manually to improve calibration results. See Figure 7-1.

3. **Multiple velocity sets** – This option can be used if more than one set of velocity measurements were collected over a range of discharges. The IFG4 program uses an empirical power law to model the relationship between discharge and velocity at each vertical. See Figure 7-2.

4. **Single velocity sets over a range of discharges** – This option utilises a number of measured velocity sets at each cross section but treats these sets independently. This method utilises the highest observed velocity data set to simulate at the higher flows and the lower observed velocity set to simulate at the lower flows.

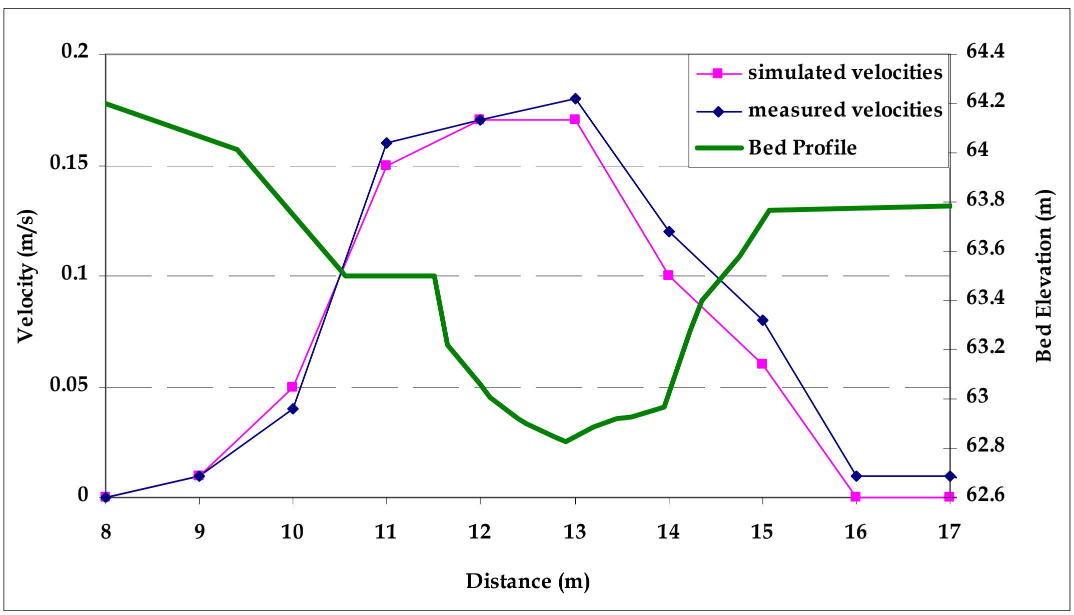


Figure 7-1: Example of Observed and Simulated Velocity at One Calibration Flow using a Single Velocity Calibration Set

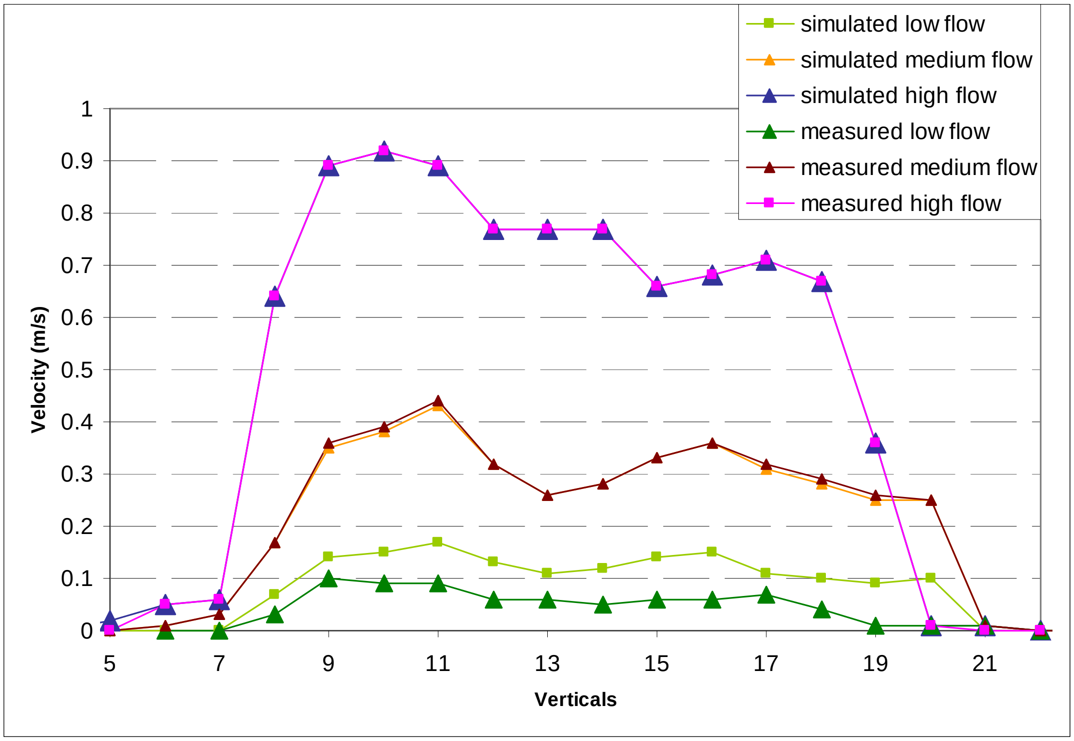


Figure 7-2: Example of Observed and Simulated Velocity at Three Calibration Flows using Multiple Velocity Calibration sets

Our approach to velocity calibration was to first try to use approaches 3 and 4 -- the multiple velocity sets or dividing the velocity sets over flow ranges for each cross section. The primary reason was ease in the ability to view the consistency of the velocity patterns across different flow regimes (note these approaches assume the equivalent of a similar roughness coefficient across the flow regimes. When this calibration approach did not yield sufficient results, then a single velocity set was used to calibrate to cross section velocity data. In this approach, the Manning's n value was changed manually to achieve good velocity calibration, were Manning's 'n' is the roughness coefficient.

On completion of the velocity calibrations for each of the study segment, the results are checked against three criteria to ensure internal consistency and good fit have been obtained.

- The results are reviewed to ensure that reasonable Manning's n values have been selected by the model or input manually at each vertical for each cross section.
- The general pattern captured during the observed velocity measurements should basically be replicated by the simulated velocities over the range of discharges.
- The shape and values of the velocity adjustment factor (VAF) should be within the guidelines. The VAF is an index of the difference between the requested simulated discharge and computed discharge.

A number of researchers have developed guidelines regarding the range of VAFs. Bovee (1998) specified an acceptable VAF range between 0.2 – 5. Milhouse (1989) specified a range between 0.1 and 10. All but four segments had VAFs above 2, with the maximum being a VAF of 5.

In all, the velocity calibration process resulted in an acceptable velocity model at 54 cross sections.

7.3 Biological Modelling

PHABSIM has several habitat modelling options. In this project, the HABTAE model was used. The end product of the HABTAE program is a description of weighted usable area (WUA) as a function of discharge, for each cross section as well as the aggregate for a study site.

After the hydraulic models were calibrated for the 54 cross sections, the available habitat was estimated using the HABTAE routine. WUA was computed for spawning, fry, juvenile, adult life stages for Atlantic salmon and brown trout.

7.3.1 Inputs to the HABTAE model

The following data are required for the habitat modelling in PHABSIM:

1. Simulated water surface elevations and velocities for the eighteen simulation flows discussed in Section 6.4; calibrated hydraulic models for the 54 cross sections,

2. HSCs for both Atlantic salmon and brown trout for all life stages, as detailed in Section 3.0,

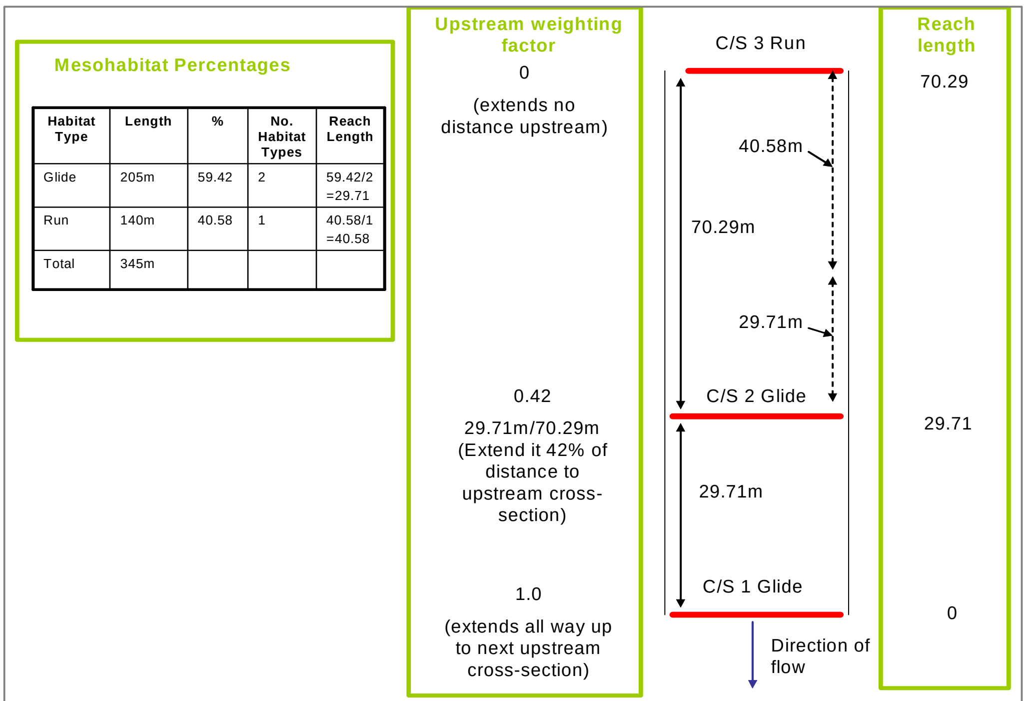
3. The habitat parameter of percentage length of each mesohabitat type, as described below.

The HABTAE model requires that the lengths of the types of mesohabitats found in a study segment be assigned cross sections. These lengths are used in the model to determine the WUA by extending the habitat computational cells in the longitudinal dimension for each cross section. PHABSIM modelling convention is to normalise the proportionate lengths to a cross section with a total length of 100 m.

Figure 7-3 provides an example of how the assignment of mesohabitat length by cross section is done. In this case, the study segment has two mesohabitat types: glide and run. The total length of glide habitat is 205 m (or 59.4% of the total length), while the run habitat is 140 (40.58%). These percentages are the same as their proportional length if the total cross section length had been 100 m.

HABTAE requires two input parameters: the reach length and the upstream weighting factor. The reach length is the distance from the previous cross section, and is set at zero for the first cross section. During the fieldwork program cross sections were placed in a unique habitat feature (Section 5.2.2) and the distance between the cross sections measured (reach length). The habitats present between the cross sections were also measured during the mesohabitat characterisation (Section 5.3.2) and are used to determine how far the habitat type at the cross section extends in the upstream direction (reach length weighting factor).

The reach length weighting factors are the actual values utilised in the habitat models in conjunction with the reach lengths to derive the longitudinal distance of cells for a specific habitat at each cross section. Figure 7-3 illustrates the relationship between mesohabitat percentages, reach length and weighting factors all of which are needed for habitat mapping in PHABSIM.



Habitat Type	Length	%	No. Habitat Types	Reach Length
Glide	205m	59.42	2	59.42/2 =29.71
Run	140m	40.58	1	40.58/1 =40.58
Total	345m			

Figure 7-3: Relationship between Mesohabitat Percentages, Reach Lengths and Weighting Factors in PHABSIM

The WUA was computed within a reach at a specific flow by multiplying the surface area of each cell by its combined suitability and dividing by the reach length. The combined suitability of the cell was derived from the depth, velocity and substrate attributes which were evaluated against both fish species and life stage habitat suitability curves. The process was repeated for all simulated discharges and the relationship between habitat and discharge was developed as shown in Figure 7-4.

7.3.2 Biological Modelling Results

Examples of WUA graphs are shown in Figures 7-4 and 7-5. Both graphs show the curves for each life stage: spawning, fry, juvenile and adult. Figure 7-4 is for a small river, while Figure 7-5 is from an Order 5 river.

Figure 7-4 shows that the habitat for the first three life stages increases with flow until a maximum value of usable habitat is found between 0.38 and 0.52 m^3/s. At higher simulated flows, the available habitat decreases; the decreases are a response to increasing depth or velocity at higher flows as dictated by the HSCs for salmon.

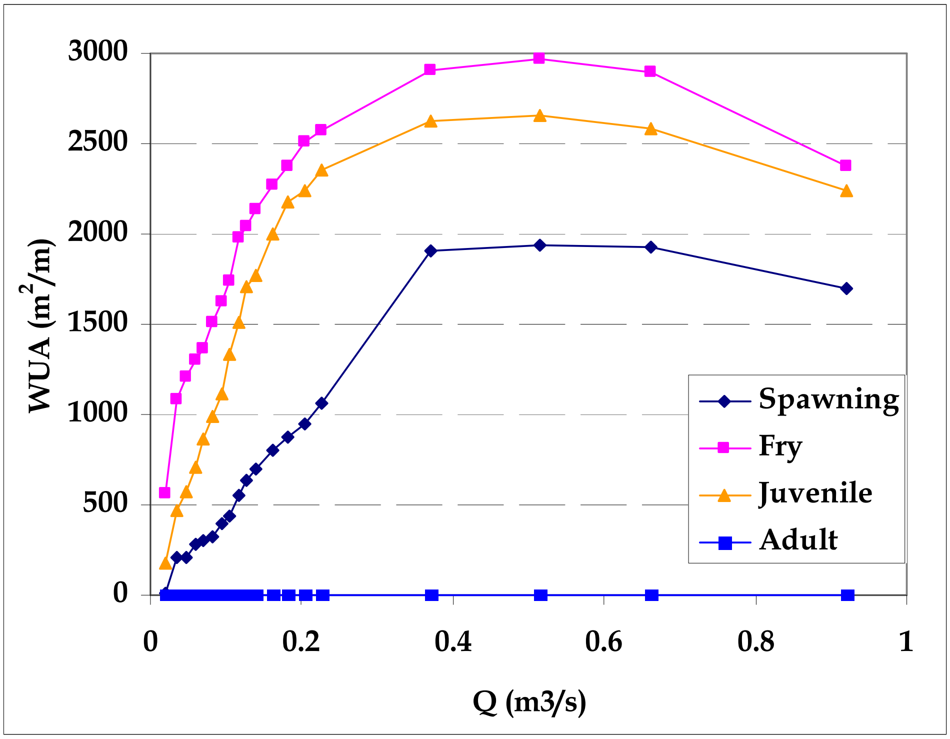


Figure 7-4: Output from Habitat Modelling in PHABSIM (WUA Curve) for Atlantic Salmon in a Small River

An interesting result shown in this WUA graph is the lack of available habitat for adult Atlantic salmon. Figure 7-4 depicts the results for a small river with typical shallow depths. The HSC for adult Atlantic salmon depth requires a minimum depth of 0.75 m (for cover and manoeuvrability) for there to be available habitat. Without this depth, the model predicts there is no usable habitat. The same result was found in all small rivers, except in a few rivers where marginal habitat (sufficient depth) occurred when very high flows were simulated. The ability of a river to support adult salmon (recalling that adult salmon which are spawning are handled as a separate life stage) became an important variable in the development of the impact assessment method in Section 8.0.

In contrast to Figure 7-4, the WUA curves for a larger Order 5 river has a different shape for the fry and juvenile life stages. In this case the maximum habitat is available at the lowest flows and available habitat decreases as the flows increase. Inspection of the HSCs for fry and juvenile salmon inform this pattern, these life stages have their maximum ideal suitable depths at 0.4 metres and 0.7 metres, respectively (Table 3-5). As flows increase in larger rivers the depths exceed these maximum suitable values and the availability of suitable habitat decreases. A similar trend is true for velocity, and the effect shown in Figure 7-5 of decreasing WUA with increasing flow is due to the combined effect of both parameters.

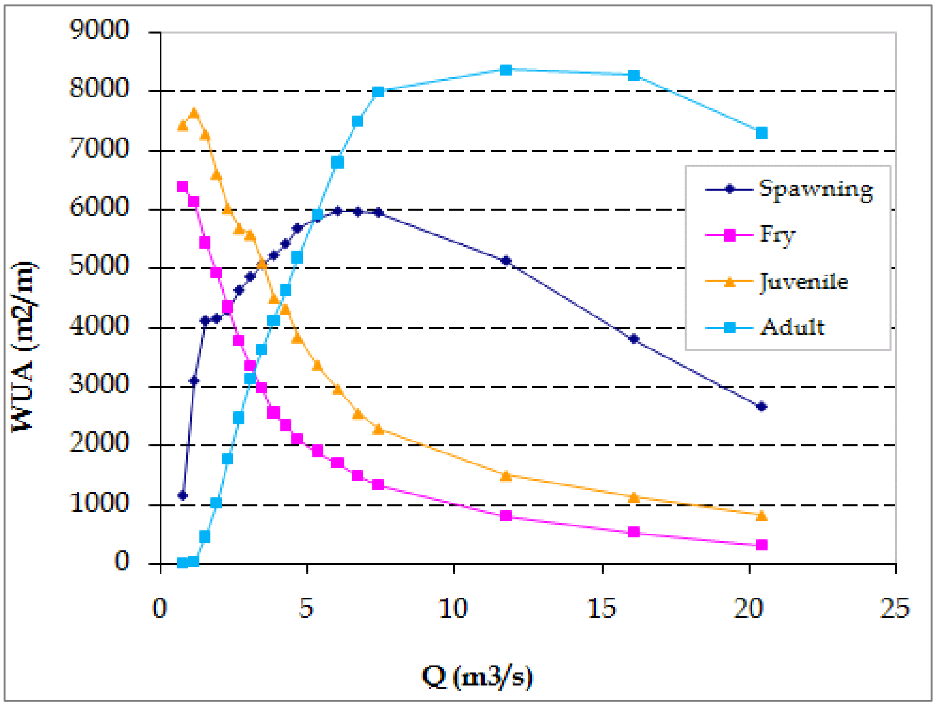


Figure 7-5: Output from Habitat Modelling in PHABSIM (WUA Curve) for Atlantic Salmon in an Order 5 River

7.4 Using the PHABSIM Modelling Output

At this stage, suitable hydraulic models have been developed to determine characteristics of the study segments in terms of depth and velocity as a function of discharge. This information was combined with HSCs and substrate data to produce a measure of available habitat as a function of discharge. The typical habitat-discharge relationship provided in Figures 7-4 and 7-5 represents one of the basic outputs from the habitat modelling phase of PHABSIM. However, the main objective of this project was to examine how changes in stream flow would impact habitat available to each species. The next section describes the interpretation of the WUA results and development of an impact assessment method.

8.0 Interpretation of PHABSIM Results

8.1 Overview

This section describes (1) how the calibrated PHABSIM models for 17 individual stream segments were used to understand how the habitat available for salmonids changes with reduced flow, and (2) how the analysis of these results determines if it is possible to use the results of the individual models to regionalise the results. The analyses in this report focuses on developing a scientific basis for an approach for determining minimum instream flows to sustain fisheries in rivers whose flows are affected by abstractions. The basis of the impact assessment method is habitat change, which is determined by comparing the amount of habitat available for natural conditions to the habitat available for modified (lower flow) conditions.

The impact assessment method used in this study is an adaptation of a method used by the Susquehanna River Basin Commission. In their study *Instream Flow Studies Pennsylvania and Maryland*, the SRBC (1998) developed a multi-step procedure to derive constant habitat impact curves (CHI curves) from their modelling of individual streams. A summary of their procedure, and the modifications made as part of this study is provided below. The subsequent sections provide more details of the analyses.

1. Combine the WUA versus flow relationships for each life stage into a composite (across life stages) renormalised minimum WUA (RMWUA) versus flow relationship for each species and study segment. Details of RMWUA curve development are found in Section 8.2.

2. To determine the annual average reduction in habitat from an abstraction, first select a critical renormalised minimum WUA curve to evaluate change in habitat.

   - Following the SRBC approach, we first considered a 'minimum life stage' impact assessment, but this was found to yield unsatisfactory results for larger rivers.

   - Modify the impact assessment to a 'maximum impact' approach, which allows for better assessment of larger rivers (Figure 8-3).

3. Using a time series of monthly median flows determine the change in habitat under natural and modified flow conditions for a range of abstractions and instream flow combinations.

4. For each flow combination (abstraction and instream flow) determine the average of the change in habitat. In the SRBC approach, changes from the entire time series of monthly median flows were averaged. We modified this approach to further divide by the average initial habitat because the other data points had very large impacts or gains and were skewing the results.

5. Plot the results of Step 3, where the axes are abstracted and instream flows and the value plotted is the average change in habitat.

6. Contour the plot in Step 4 to define curves of constant habitat change (known as constant habitat impact curves).

The impact of seasonality was also assessed by repeating the procedure without the spawning and fry life stages.

8.2 Renormalised Minimum Weighted Usable Area

This section describes and provides example calculations for the derivation of RMWUA curves. A RMWUA curve is developed for a combination of life stages of a single fish that will be present at the same time, and describes the habitat available at any given flow relative to the peak habitat available over the entire range of flows on a study segment. The RMWUA relationship has been normalised so direct comparisons of habitat availability among the study segments is possible. Thus, the RMWUA relationships are the foundation for exploring the ability to group the study segment results into a regional approach to determine instream flow requirements.

8.2.1 RMWUA Curve Development

Following the approach of the SRBC (1998) study for Pennsylvania, this method assumes that the life stage with the minimum WUA at a given flow, compared to the maximum habitat for all life stages present at that time of year, is the most habitat limited, and therefore the most crucial life stage to be protected. The life stages were combined based on the time of the year that each life stage is present. This resulted in eight different combinations of life stages being present for both fish species based on the periodicity chart in Table 3-3 of Section 3.2.3. Adult Atlantic salmon were not used in the life stage combinations in small rivers since little or no WUA exists for this species (for large rivers they were included). Table 8-1 details the different combinations of life stages as well as the results of the RMWUA procedure for Segment 10. The table shows that that there is no WUA for adult Atlantic salmon as this is an Order 2 river.

The RMWUA habitat variables in Table 8-1 were computed using the following procedure:

1. The simulated flows and WUA results are tabulated for each of the four life stages for Atlantic salmon (a similar table is prepared for brown trout).

2. For each life stage, the WUA results are normalised by dividing the WUA for each flow by the maximum WUA value for that life stage over the entire flow range. These values range from zero to unity and are called Normalised Weighted Usable Areas.

Table 8-1: Results of Life Stage Combinations, Segment 10, Moynalty, Atlantic Salmon

Drainage area at site: 5.28 km²

Average daily flow: 0.1159 m³/s

Simulated Flow (m³/s)	Weighted Usable Area				Normalised Weighted Usable Area				Minimum Normalised Weighted Usable Area							
	Adult	Juvenile	Spawning	Fry	Adult	Juvenile	Spawning	Fry	S/J/A	J/A	F/J/A	S/F/J/A	S/J	J	F/J	S/F/J
0.008	0	155	0	163	0	0.08	0.00	0.07	0	0	0	0	0.00	0.08	0.07	0.00
0.014	0	237	0	259	0	0.12	0.00	0.11	0	0	0	0	0.00	0.12	0.11	0.00
0.0194	0	307	0	390	0	0.16	0.00	0.17	0	0	0	0	0.00	0.16	0.16	0.00
0.025	0	359	0	547	0	0.18	0.00	0.23	0	0	0	0	0.00	0.18	0.18	0.00
0.031	0	422	69	677	0	0.22	0.03	0.29	0	0	0	0	0.03	0.22	0.22	0.03
0.037	0	483	89	865	0	0.25	0.04	0.37	0	0	0	0	0.04	0.25	0.25	0.04
0.042	0	528	104	1,022	0	0.27	0.05	0.44	0	0	0	0	0.05	0.27	0.27	0.05
0.052	0	624	267	1,211	0	0.32	0.12	0.52	0	0	0	0	0.12	0.32	0.32	0.12
0.061	0	702	305	1,345	0	0.36	0.13	0.58	0	0	0	0	0.13	0.36	0.36	0.13
0.070	0	805	373	1,492	0	0.41	0.16	0.64	0	0	0	0	0.16	0.41	0.41	0.16
0.080	0	888	446	1,582	0	0.45	0.20	0.68	0	0	0	0	0.20	0.45	0.45	0.20
0.092	0	1,019	545	1,727	0	0.52	0.24	0.74	0	0	0	0	0.24	0.52	0.52	0.24
0.104	0	1,128	600	1,819	0	0.58	0.26	0.78	0	0	0	0	0.26	0.58	0.58	0.26
0.116	0	1,244	691	1,925	0	0.64	0.30	0.82	0	0	0	0	0.30	0.64	0.64	0.30
0.129	0	1,331	839	2,038	0	0.68	0.37	0.87	0	0	0	0	0.37	0.68	0.68	0.37
0.253	0	1,785	1,859	2,334	0	0.91	0.82	1.00	0	0	0	0	0.82	0.91	0.91	0.82
0.378	0	1,957	2,265	2,262	0	1.00	1.00	0.97	0	0	0	0	1.00	1.00	0.97	0.97
0.650	0	1,883	2,246	1,790	0	0.96	0.99	0.77	0	0	0	0	0.96	0.96	0.77	0.77
Maximum	**0**	**1,957**	**2,265**	**2,334**					**0**	**0**	**0**	**0**	**1**	**1**	**0.97**	**0.97**

Table 8-2 (Continued): Results of Life Stage Combinations, Segment 10, Moynalty, Atlantic Salmon

Flow		**Renormalised Minimum Weighted Usable Area**							
$m^3/s/km^2$	% Average Daily Flow	S/J/A	J/A	F/J/A	S/F/J/A	S/J	J	F/J	S/F/J
0.00	5.93	-	-	-	-	0.00	0.08	0.07	0.00
0.00	10.16	-	-	-	-	0.00	0.12	0.11	0.00
0.00	14.39	-	-	-	-	0.00	0.16	0.16	0.00
0.00	18.62	-	-	-	-	0.00	0.18	0.19	0.00
0.01	22.85	-	-	-	-	0.03	0.22	0.22	0.03
0.01	27.08	-	-	-	-	0.04	0.25	0.25	0.04
0.01	31.31	-	-	-	-	0.05	0.27	0.28	0.05
0.01	38.24	-	-	-	-	0.12	0.32	0.33	0.12
0.01	45.18	-	-	-	-	0.13	0.36	0.37	0.14
0.01	52.11	-	-	-	-	0.16	0.41	0.42	0.17
0.02	59.04	-	-	-	-	0.20	0.45	0.47	0.20
0.02	68.12	-	-	-	-	0.24	0.52	0.54	0.25
0.02	77.19	-	-	-	-	0.26	0.58	0.59	0.27
0.02	86.26	-	-	-	-	0.30	0.64	0.66	0.31
0.02	95.33	-	-	-	-	0.37	0.68	0.70	0.38
0.05	187.56	-	-	-	-	0.82	0.91	0.94	0.85
0.07	279.79	-	-	-	-	1.00	1.00	1.00	1.00
0.12	481.48	-	-	-	-	0.96	0.96	0.79	0.79

3. For each of the eight life stage combinations, the normalised WUA values for each simulation flow in step (2) are referenced to determine the minimum value among the respective life stages. These are the Minimum Normalised WUA values.

4. The Minimum Normalised WUA values in step (3) are renormalised to range from zero to unity by dividing each minimum normalised WUA by the maximum value for each combination of life stage over the range of flows; the result is the RMWUA curve.

5. Finally, the 18 simulation flows are converted to a percent average daily flow (% ADF); the normalisation to a % ADF flow will allow the curves to be compared across the study segments. A graph of RMWUA against percent ADF was created for each of the 17 study sites for both Atlantic salmon and brown trout. The RMWUA graph for Segment 10 is shown in Figure 8-2. The RMWUA graphs for all 17 study sites are shown in Appendix C.

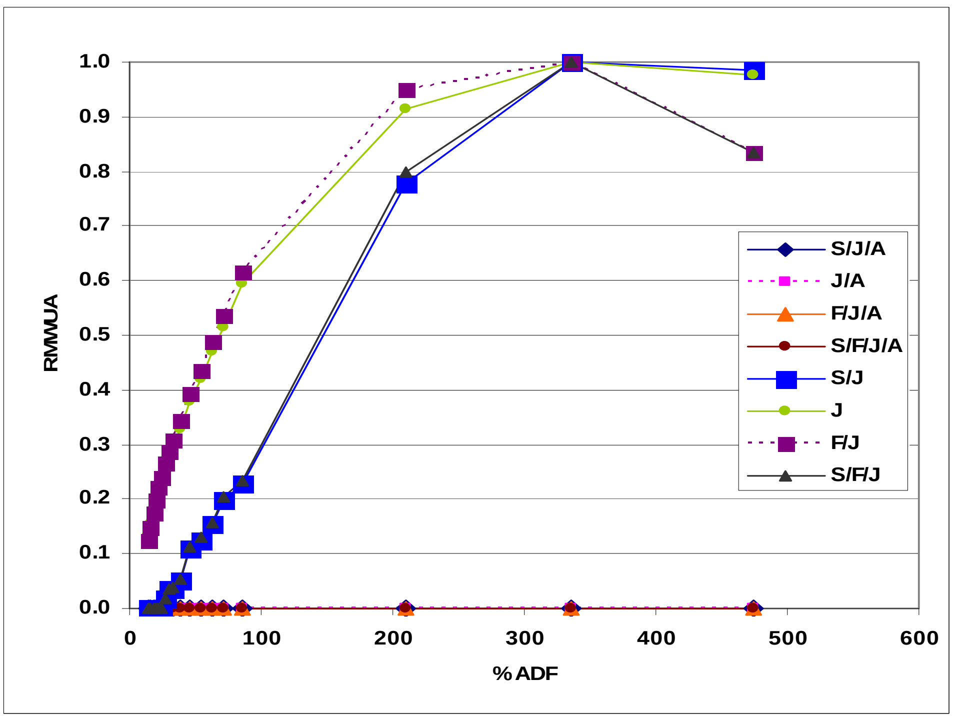


Figure 8-1: RMWUA for Segment 10, Moynalty Co. Meath for Atlantic Salmon

8.2.2 Differences in RMWUA Curves

Examination of the RMWUA graphs for individual rivers showed very different shapes and scales for small and large rivers. Figure 8-2 shows the difference in shape and scale between two small rivers (Segments 6 and 10, Order 2 and 2-3) on the top and two larger rivers (Segments 90 and 92, Order 5) on the bottom. Small rivers tended to be characterised by curves with broad tops, with the peak of the RMWUA curve occurring between 200 and 300% of the average daily flow.

These curves indicate that over most of the flow range simulated, a reduction in flow rate will result in a reduction in habitat. The RMWUA curves for larger rivers, on the other hand, were very steep and reach peak values at flows less than the average daily flow. For these curves, habitat losses will only occur over flow ranges that correspond with the rising limb of the RMWUA curve; on the descending limb decreases from natural flows will 'improve' habitat.

In general, small rivers included study segments of river orders 2, 2-3, and 3, and larger rivers were of river orders 4 and 5. Two exceptions were:

- Segment 35 – Categorised as an order 3 river, this segment's RMWUA curve fit with those of larger rivers. This matched our observations in the field where Segment 35 was a wide, deep river with predominantly glide habitat and is comparable with the less "energetic" characteristics of Order 5 rivers.
- Segment 15 – The RMWUA curve for this segment (an Order 3-4) grouped with smaller rivers, which again matched the field observations of this small, shallow and narrow river similar in characteristics to other Order 2 rivers in the study.

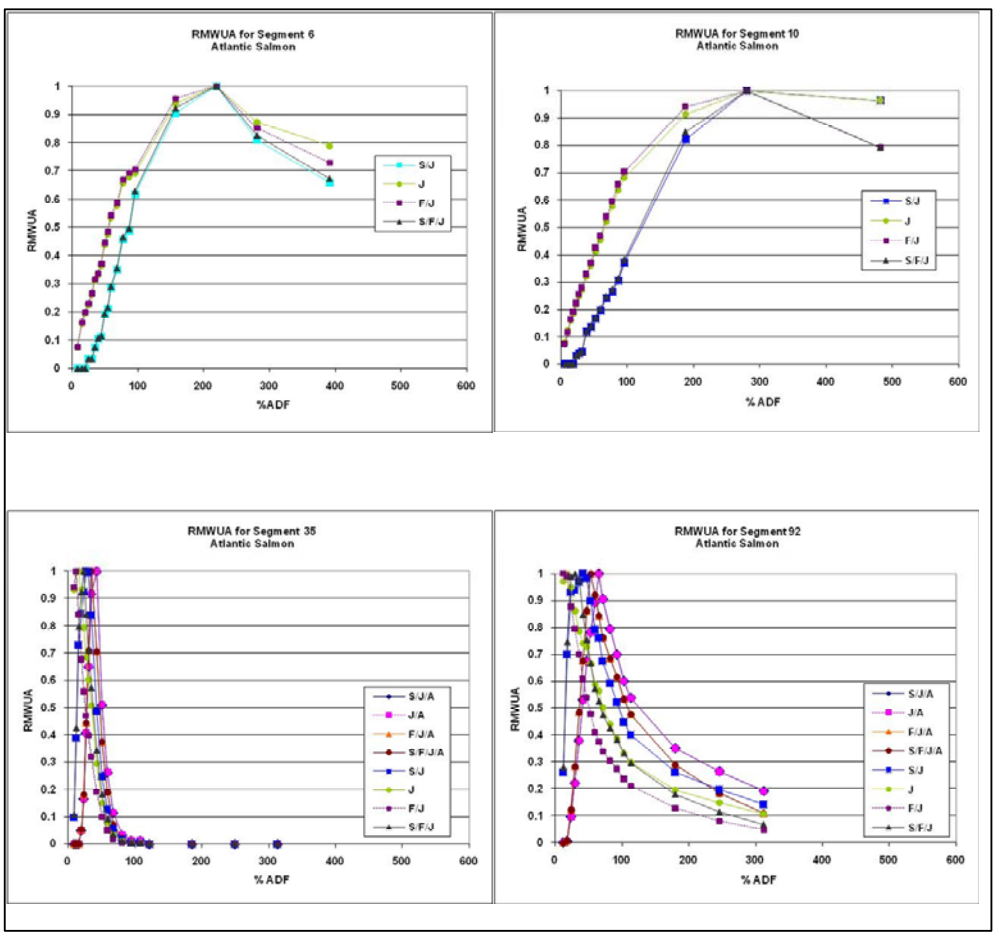


Figure 8-2: Comparison of RMWUA Curves for Small versus Large Rivers

8.2.3 Wetted Perimeter as a Surrogate for River Size

Because of the exceptions listed above, river order could not be used as an appropriate representation of river size. Therefore, an approximate wetted perimeter was calculated to determine if it was a good surrogate for river size with respect to the RMWUA characteristics.

Wetted perimeter (P) is the "length of the wetted surface measured normal to the direction of flow" (Chadwick, 1998). The calculations were idealised as all cross sections were assumed to be trapezoidal; thus, the wetted perimeter can be calculated by using the formula:

$$P = b + 2 \times y\sqrt{1 + x^2}$$

where;

b = the distance along the cross section (or bottom width),
x = the slope of the river bank,
y = vertical distance from the river bed to the water surface.

Table 8-3 presents the results of wetted perimeter calculations at each cross section for each round of flow, with P1 representing the low flow water level, P2 the medium flow water level, and P3 the high flow water level.

The results were consistent and show that all small rivers have wetted perimeters less than 6 m, even in high flow conditions. Large rivers in this study had values between 9-16 m. Therefore, we defined small rivers as having a wetter perimeter less than 6 m and large rivers having a wetted perimeter greater than 9 m. As shown in Table 8-3, the 17 study segments were divided into 12 small rivers and 5 large rivers.

Table 8-3: Approximate Wetted Perimeter Values for Study Segments

Segment No.	River Order	Wetted Perimeter (m)			Size Category
		PI (Low Flow)	P2 (Medium Flow)	P3 (High Flow)	
4	2	2.2	2.4	4.1	Small
6	3	2.9	3.2	3.4	Small
7	2	3.2	3.5	3.7	Small
10	2	2.7	2.8	3.1	Small
15	3-4	2.1	2.1	2.7	Small
16	2-3	5.2	5.4	5.6	Small
23	2-3	3.8	3.78	4.6	Small
24	2	1.7	1.8	2.1	Small
25	2-3	2.4	2.7	4.1	Small
27	2	2.2	2.3	3.3	Small
29	2-3	1.5	1.7	2.0	Small
48	3	5.1	5.2	5.5	Small
12	4	9.4	9.7	10.5	Large
35	3	9.7	10.0	11.5	Large
43	5	14.1	14.4	15.1	Large
90	5	14.5	14.8	15.4	Large
92	5	13.1	13.6	15.0	Large

8.3 Impact Analysis

8.3.1 Overview

Once the combination of life stages and RMWUA values were computed, the next step involved determining the extent of the impact of abstractions and minimum instream flows on habitat. This information was used to develop criteria for minimum instream flows (also known as compensation or passby flows which are the flows below which no water abstraction may be allowed). Habitat impact was defined as the percentage difference between available habitat with and without the abstraction/compensation flow where positive values indicate habitat loss and negative values habitat gain.

As discussed earlier, the RMWUA values are used to compare habitat values between different study segments. Therefore, they are used as the measure of habitat in the impact analyses. The impact analysis was performed on both an annual and seasonal basis where the fish periodicity chart was used to define when only the adult and juvenile life stages are present.

8.3.2 Development of Constant Habitat Impact Curves

A program was created in Microsoft Excel to automate the creation of constant habitat impact curves. The following procedure was followed to develop habitat impact curves for the 17 study segments:

1. The ADF and time series of monthly median (MM) flows were calculated for each segment using the method discussed in Section 6.3. The MM flows were converted to percent ADF to enable direct comparisons of the RMWUA habitat curves among the segments.

2. A maximum impact RMWUA curve was generated for each species and segment by combining the RMWUA curves of the eight life stage combinations (Section 8.2.1) according to the following method. At lower flows, when the slopes of the RMWUA curves are positive, the maximum impact curve was comprised of the minimum RMWUA values over all the life stages since this would result in the greatest change in habitat for any given change in flow. When the slope of RMWUA curves was negative (at higher flows) then the maximum impact curve was set to the maximum RMWUA values such that decreases in flow due to abstractions would result in the least habitat gain (or greatest impact in terms of habitat loss). This step was repeated to generate a maximum impact RMWUA curve for each species for each segment. Figure 8-3 shows an example maximum impact RMWUA curve for brown trout in Segment 92.

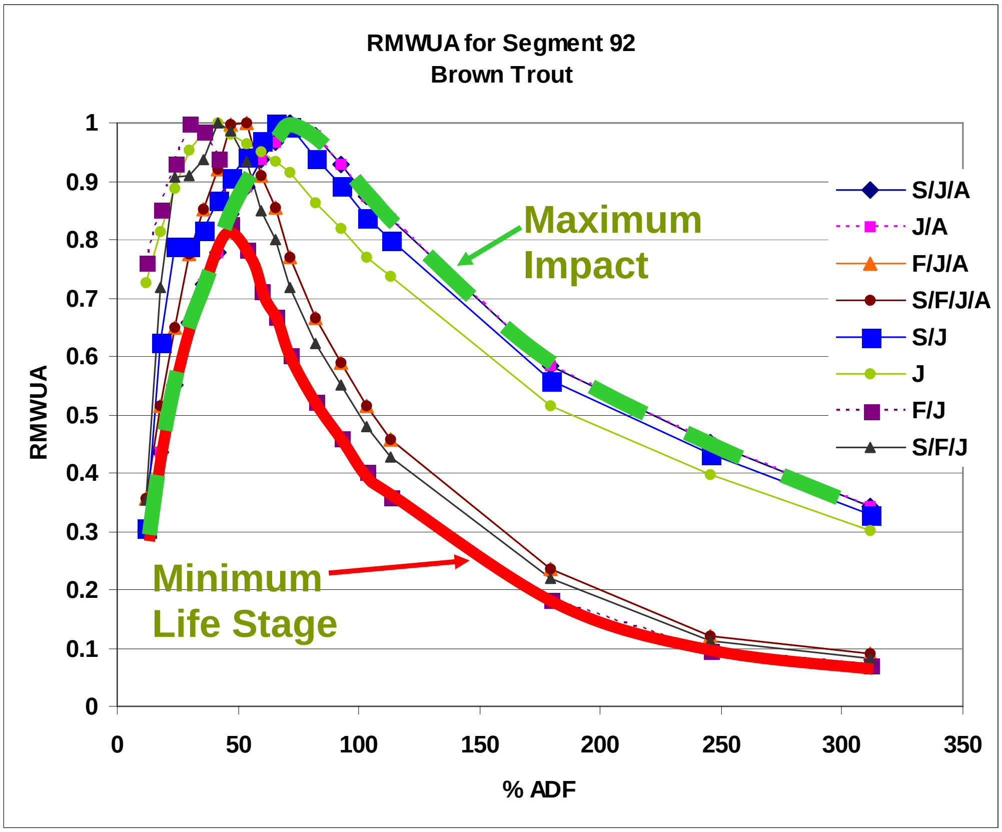


Figure 8-3: Maximum Impact RMWUA Curve for Segment 16 Brown Trout

3. The time series of MM flows calculated in step (1) were adjusted according to the specified abstraction and compensation (minimum instream) flows. If the initial MM flow was less than the compensation flow then abstractions would not be allowed and the 'adjusted' flow would be retained at the initial MM flow, which would result in no change in habitat. If the MM flow exceeded the compensation flow then the adjusted flow in the river would be set equal to the minimum of either the compensation flow or the MM flow less the abstraction flow.

4. For each initial and adjusted MM flow from step (3), the amount of habitat available was calculated for each species using the maximum impact RMWUA curves from step (2). The impact of the abstraction on the amount of available habitat was calculated as the change in habitat between the initial and adjusted flows. The impact was defined as the loss in habitat with positive values indicating habitat loss and negative values indicating habitat gain.

5. Step (4) was repeated for each MM flow in the historical record. The overall impact for each abstraction/compensation flow combination was defined as:

- average habitat loss = $\frac{\text{the average change in habitat}}{\text{the average initial habitat}}$

- where both averages taken over all MM flows in the entire historical record.

6. Steps (3) through (5) were repeated for up to 400 combinations of abstraction flows and compensation flows (e.g., 20% ADF abstraction and 10% ADF compensation). Abstraction flows ranged from 0 and 100% ADF, while compensation flows ranged from the minimum simulated flow (5-15% ADF) to 100% ADF. Both flows were simulated in 5% increments. The minimum simulated flow was used as the minimum compensation flow because for lower compensation flows the RMWUA curves would need to be extrapolated beyond the range of simulation flows, which was not feasible for some segments. The result was an overall average impact for each abstraction and compensation flow.

7. The results of step (6) were plotted on a grid with abstraction flow as % of ADF on the y-axis and compensation flow as % of ADF on the x-axis. Contour lines were generated using ArcGIS which represent curves of constant habitat impact in 2 to 10% increments. For large rivers, the results were shown on a grid that ranged to 100% ADF for both the abstraction and compensation flow. The constant habitat impact curves for smaller rivers are displayed on smaller grids (0 to 50% ADF for abstractions and 0 to 36% ADF for compensation flows) because these graphs are sufficient to display a full range of reasonable habitat losses. On the x-axis, a line representing the %ADF equal to the minimum median monthly flow is used to illustrate the lowest flow point that could have been used in the analysis; the lowest flow value that was used was determined using the guidelines for extrapolating model results (Section 6.4) and in many instances was a slightly higher value. On the y-axis, the %ADF equal to the Q95 flow is shown; the Q95 flow is often used as a 'hands-off' flow in instream flow regulations (i.e., a minimum flow to which abstractions can occur).

8. Steps (1) through (7) were repeated to generate a single set of constant habitat impact curves for each segment and each species.

Alternative metrics of habitat loss were also evaluated but found to be less appropriate than the percent habitat loss calculated in step (5) above. The SRBC (1998) used a slightly different averaging method where the percent habitat loss was calculated as the average of the percent loss for each MM flow (which was calculated for each MM flow), instead of the overall average loss divided by the overall average initial habitat. The SRBC method was found to skew the overall average impacts since the percent change in habitat could be very large when the absolute habitat values for the initial and adjusted MM flows were very small. As a result, the modified averaging method was found to be more representative of the overall impact.

8.3.3 Interpretation of Constant Habitat Impact Curves

In order to become familiar with these curves, the following paragraph **describes** through an example how this approach could be used on a proposed abstraction on a small river in the Central Plain region. The following flow statistics (calculated in Section 6) are known about the river.

	Flow (m^3/s)	*Flow (% ADF)*
Average Daily Flow =	0.4163	-
Q95 Flow =	0.067	16.1
Minimum Median Monthly Flow =	0.026	6.2

The following figure 8-5 is the constant habitat impact curve generated for this small river.

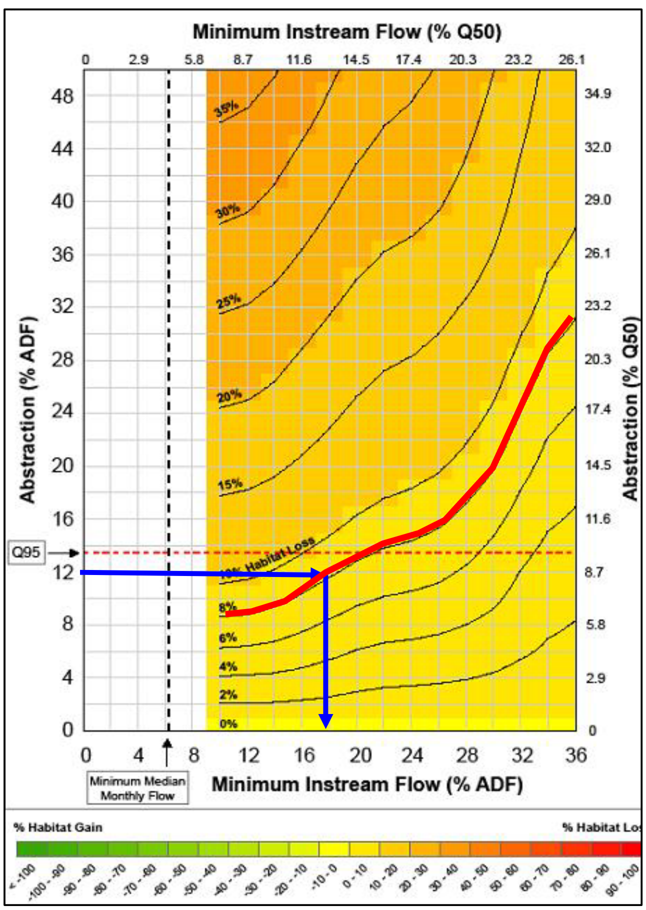


Figure 8-4 Interpretation of CHI Curve

Steps involved:

1. It's important to remember when understanding these curves that both axis are presented as percent average daily flow (% ADF).
2. Select a proposed abstraction rate → 0.05 m^3/s or 12% ADF.
3. Assume that an allowable habitat loss had been specified by regulation → 8% habitat loss.
4. Determine what the minimum instream flow needs to be from the graph → 18 % ADF or 0.075 m3/s

8.3.4 Results of the Constant Habitat Impact Curves

Sixteen sets of habitat impact curves for Atlantic salmon and seventeen sets of curves for brown trout based on the average impact percentage are included in Appendix D. Since there was no habitat for the spawning, fry and juvenile life stages of Atlantic salmon in Segment 27 due to absence of suitable substrate, it was excluded from further analysis of Atlantic salmon habitat impacts, but was included in the analysis of brown trout.

Figure 8-5 is an example of the constant habitat impact curves for Atlantic salmon on a small river (Segment 4). This graph shows that habitat losses increase with increasing abstractions and decreasing passby flows.

A common feature of constant habitat impact curves for small rivers is a region where the curve is horizontal as in Figure 8-4 between passby flows from 5 to 20% ADF) for flows where the maximum impact RMWUA curve is zero. At these flows there is no change in the average habitat loss due to an abstraction since the compensation flow has no effect on the amount of habitat at these flows.

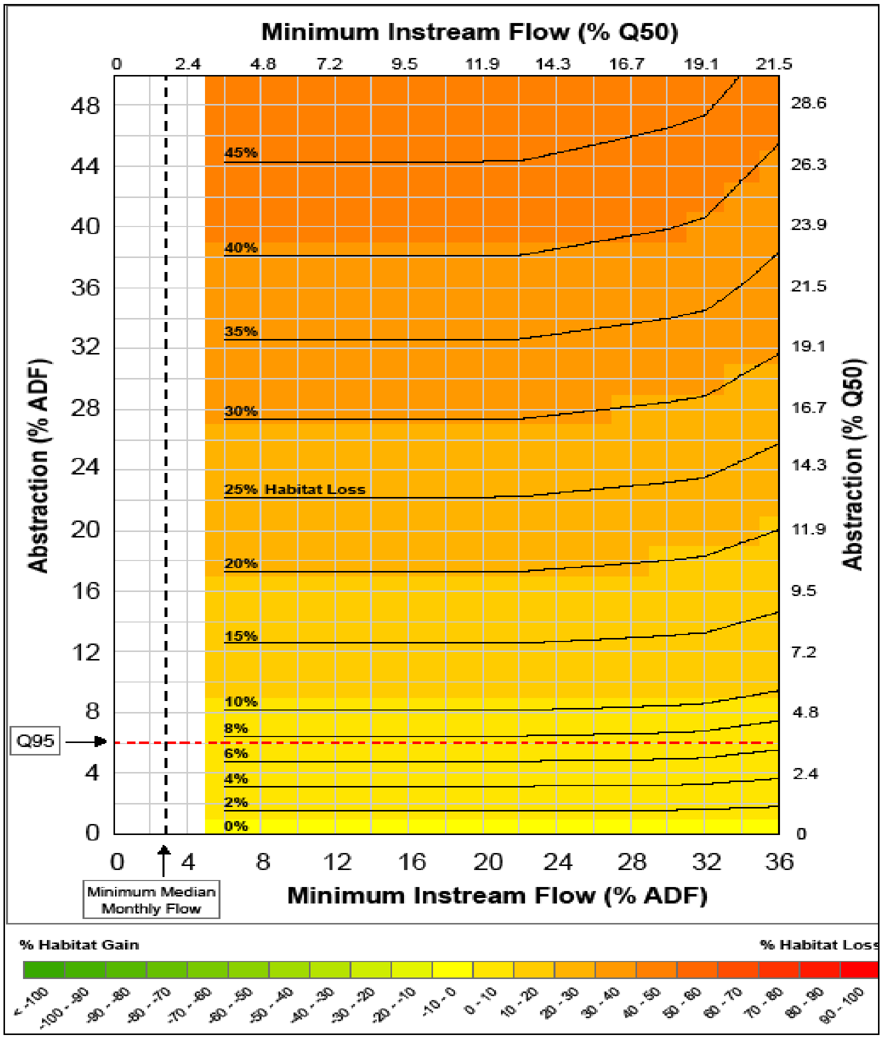


Figure 8-5: Curve of Constant Habitat Impact for Segment 4 Atlantic Salmon

In contrast, Figure 8-6 shows a curve of constant habitat impact for Atlantic salmon in a large river (Segment 35). This curve is typical of 3 of 5 Atlantic salmon large river constant habitat impact curves and all of the brown trout large river curves.

These large river curves differ from the curves for smaller rivers in that it is possible to define a compensation flow at which there is no habitat impact; that is, a flow above which abstractions result in habitat improvements (which more conservatively would be considered to be habitat neutral). The improvements occur when fish prefer lower flows as indicated by habitat suitability curves that begin decreasing at higher flows. However, even though fish will prefer lower flows they will remain in the rivers even if the flows increase.

To the left of this line (i.e., at lower values of minimum instream flow), the large river constant habitat impact curves resemble those for small rivers, only they tend to be of lesser magnitude. The two curves which did not follow this large river pattern are:

- Segment 43 – for the range of flows shown spawning Atlantic salmon are the critical life stage and there is no suitable substrate for spawning salmon in Segment 43 so the RMWUA curve shows no available habitat.

- Segment 12 – this large river has insufficient depth (<0.75 m) to provide suitable habitat for adult salmon (the controlling life stage) until flows reach above 70% ADF.

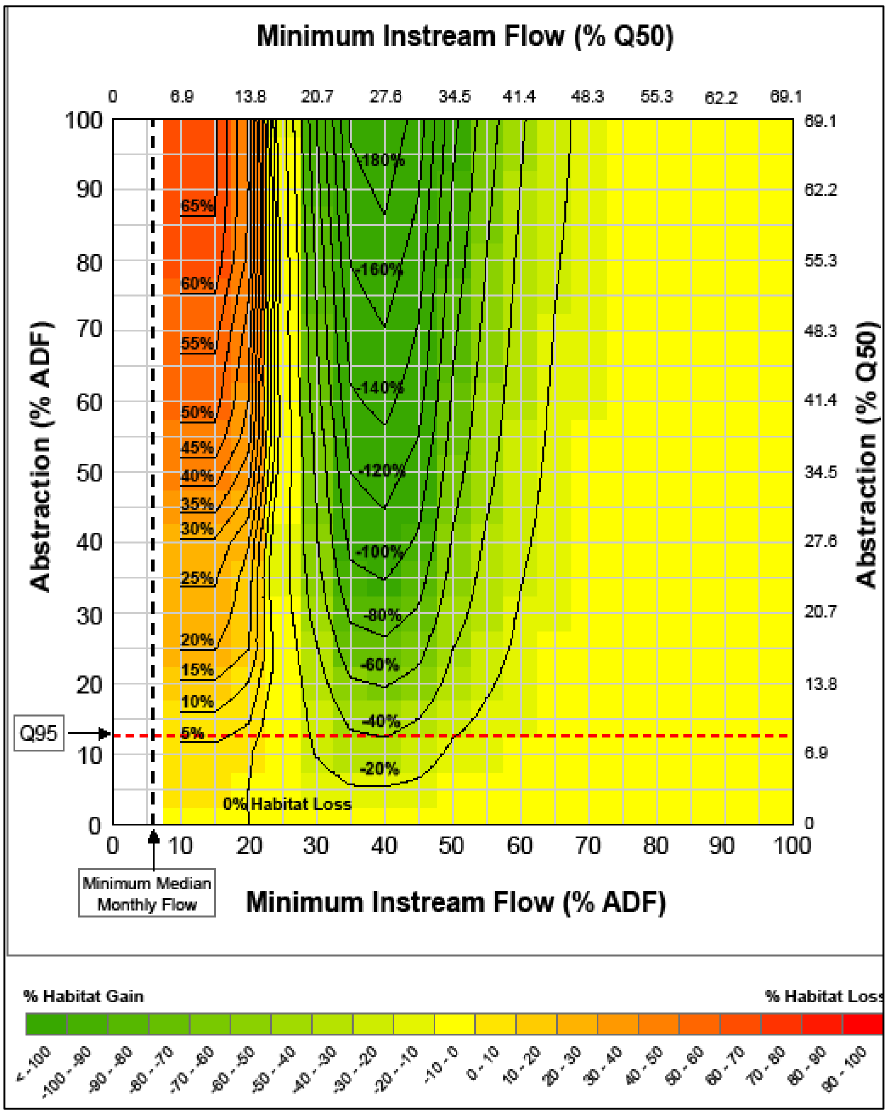


Figure 8-6: Typical Curve of Constant Habitat Impact for a large River, Segment 35 Atlantic Salmon

8.3.5 Regionalisation of Constant Habitat Impact Curves

A comparison of the constant habitat impact curves for individual rivers shows curves for small rivers tend to be quite similar while those for large rivers tend to be different.

The differences in the individual river CHI curves preclude regionalisation and suggest that the impacts of water abstractions on fish habitat are site specific. An attempt to correlate the differences in response among large rivers with flow, albeit with a small data set, showed only a weak correlation. This is attributed to variability in the controlling life stage of the maximum impact RMWUA curve. Therefore, for large rivers, proposed abstractions must be evaluated on a site-specific basis (see Table 8-1 for the list of large and small rivers). These findings, however, are based on a small data set and that it is possible that additional data would permit identification of a dependent variable that would allow a regional method to be developed.

The similarity among the CHI curves for small rivers makes them good candidates for regionalisation. A combined set of constant habitat impact curves for small rivers were generated by taking the mean impact at each point on the abstraction versus compensation grid and then regenerating the contour lines. Figure 8-7 shows the average constant habitat impact curves for small rivers for Atlantic salmon and brown trout, respectively.

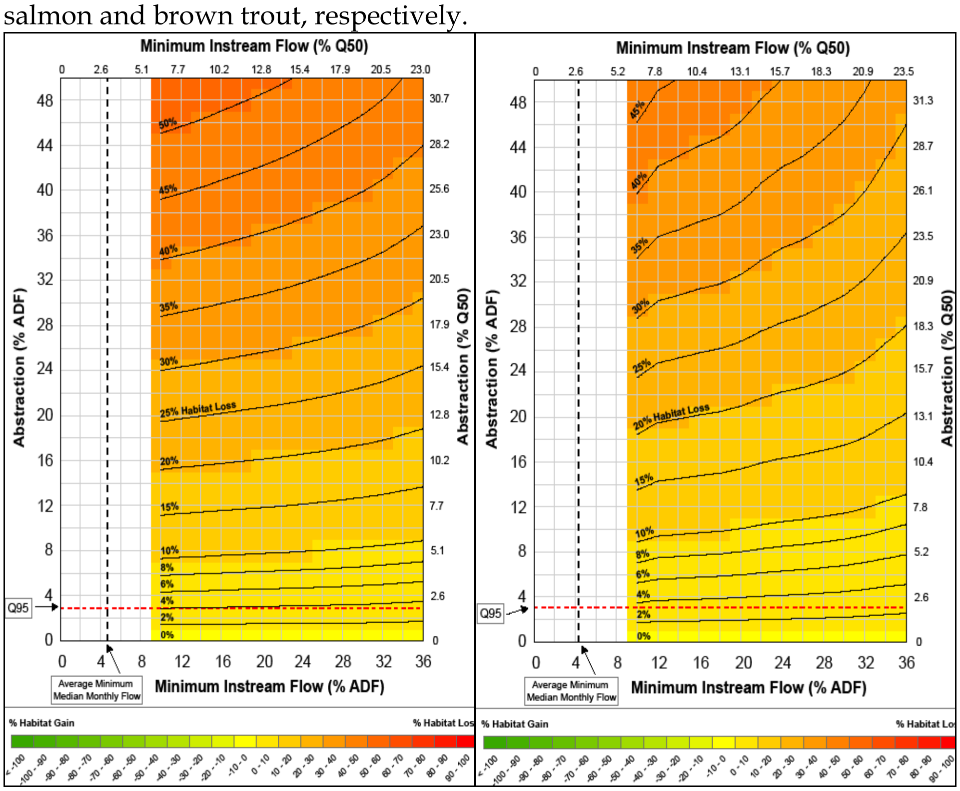


Figure 8-7: Average Curve of Constant Habitat Impact for Atlantic Salmon (left) and Brown Trout (right) in Small

The similarities among the curves appear to arise for two major reasons: (1) the river themselves tend to be similar in terms of morphology and microhabitat validating the similarity of streams within a physiographic region concept adapted from Frizzel *et al*., and (2) the controlling life stage was common across most segments with spawning Atlantic salmon and adult brown trout being the primary determinates of the minimum available habitat.

The degree of variance of each small river from the composite CHI curves was determined by calculating the average difference between its individual CHI curves and the composite curve of all small river segments. The calculation was done by first determining the difference at each compensation-abstraction point in the grid shown in Figure 8-7 and then averaging each nodal difference. The average difference was considered the most appropriate metric for comparing how different the sets of constant impact curves were from one another since it provides not only the magnitude of the difference, but also whether the impacts in each segment were greater or less than the aggregated small river impacts. The average difference between each segment and the combined small rivers average are listed in Table 8-4 for each species. Positive values indicate that individual segment impacts are greater than combined average.

Table 8-4: Average Difference between Points of CHI for each Segment and the Composite for Small Rivers

Segment No.	*Atlantic Salmon*	*Brown Trout*
4	4%	-2%
6	11%	11%
7	-12%	-3%
10	9%	6%
15	-2%	-1%
16	1%	-2%
23	-8%	-13%
24	1%	1%
25	-7%	3%
27	--	-4%
29	12%	3%
48	-11%	--

The differences in Table 8-4 ranged from -13% to 12%. Across the individual rivers, the values of constant habitat impact are most similar at low flows and diverge as either abstraction flows or compensation flows increase.

Explanations for the variance were sought, including flow, stream depth and velocity. Flow appeared to have a significant relationship with the shape and magnitude of the CHI curves, and this was confirmed by comparing the average daily flow of individual segments with the average difference of the individual CHI curves to the composite CHI curve of those segments. Figure 8-8 shows segments with higher ADFs resulted in lower impacts than Segments with lower

ADFs (Figure 8-8). This relationship was stronger for Atlantic salmon than for brown trout.

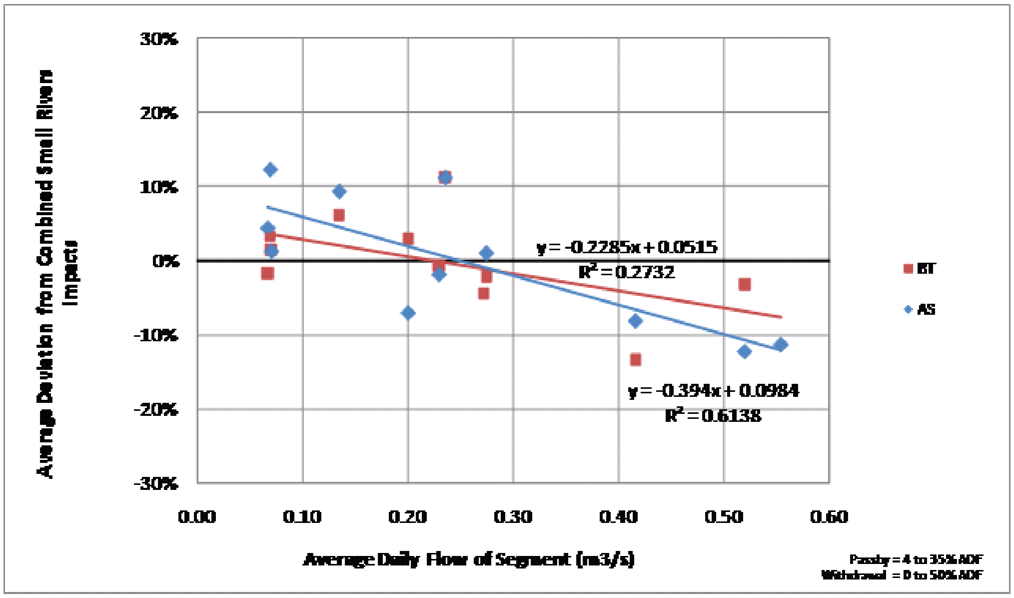


Figure 8-8: Average Difference in Impact of each Segment versus Average Daily Flow

The CHI curves for Atlantic salmon could also be grouped by those with slower and faster velocities; seven segments had gentle flows while the remainder had notable faster flows. Similarly a relationship was found between relatively shallow and deep streams and the shape and magnitude of CHI curves for brown trout in small rivers. While each of these groupings, and the relationship with flow, could add refinement to the methods for determining instream flow requirements, they also would add layers of complication to a future regulatory programme.

Thus, the overall composite curves (Figure 8-7) are sufficiently similar to serve as the composite CHI curve for small rivers in the Central Plain.

8.3.6 Impact of Seasonality on Constant Habitat Impact Curves

The impact of seasonality on the habitat loss curves was assessed by regenerating the sets of constant habitat impact curves excluding the fry and spawning life stages, which are only present during the months from June to March. The same procedure as described in Section 8.3.2 was followed but using only the juvenile and adult life stages to generate the maximum impact RMWUA curves. This resulted in significant changes to the maximum impact RMWUA curves for most of the segments for Atlantic salmon, but few changes for brown trout. In the original analysis of year-round impacts that included all life stages, the RMWUA curves for the juveniles and adults were frequently used as the maximum impact RMWUA curves for brown trout; for Atlantic salmon, the adult life stage generally had no habitat at any flow (except for the large river segments) and the maximum impact RMWUA curves were mainly governed by the fry and spawning life stages. The modified RMWUA curves that excluded the younger stages are included in Appendix E.

The combined constant habitat impact curves for small river segments are shown in Figures 8-9 and 8-10 for Atlantic salmon and brown trout, respectively. The seasonal constant impact curves for each segment and species that are different from the year-round impact curves are included in Appendix F.

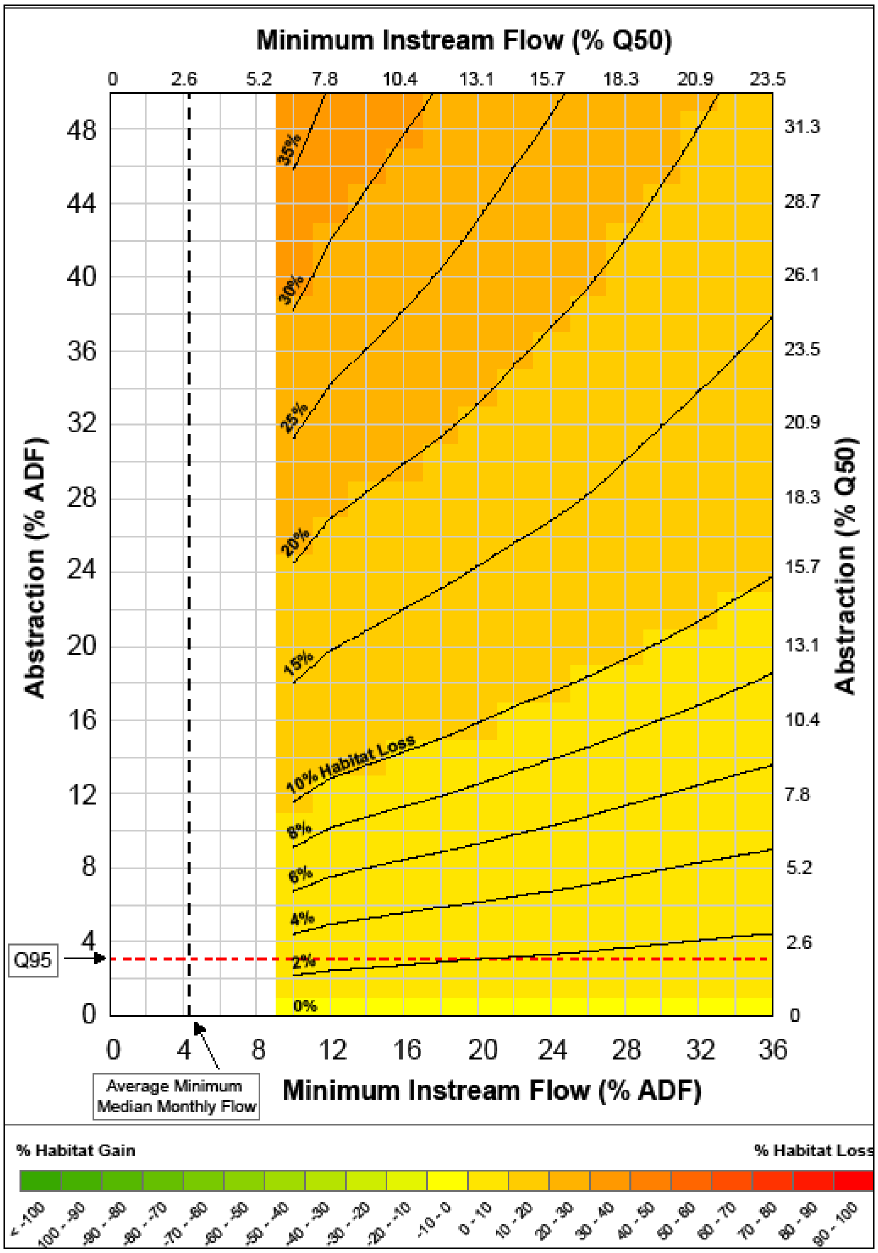


Figure 8-9: Seasonal Constant Habitat Impact Curves for Atlantic Salmon in Small Rivers excluding Fry and Spawning Life Stages

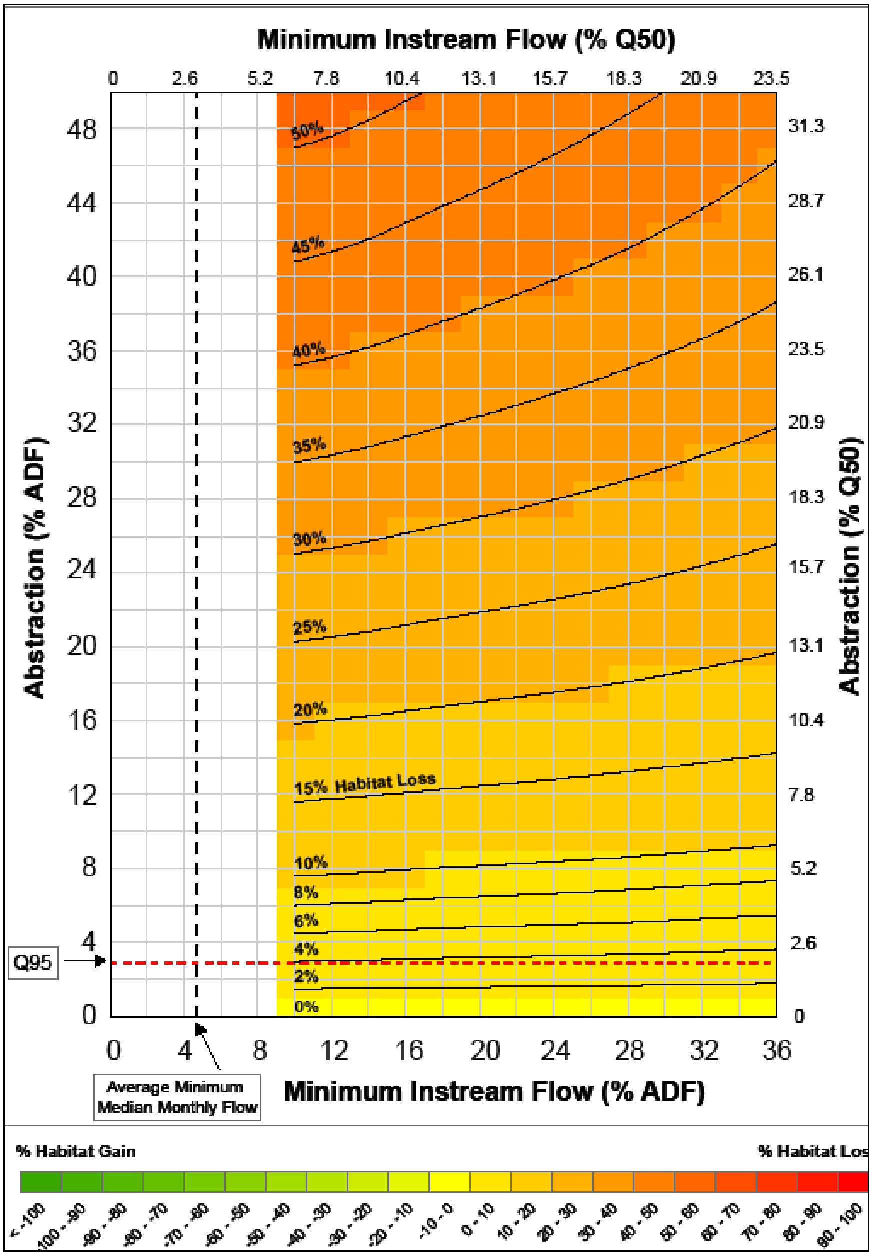


Figure 8-10: Seasonal Constant Habitat Impact Curves for Brown Trout in Small Rivers excluding Fry and Spawning Life Stages

The impact of seasonality was assessed by calculating the average difference between the original constant habitat curves, which included all four life stages, and the seasonal curves, which excluded the spawning and fry stages. The average difference for each segment is listed in Table 8-5. As discussed above, the impacts of seasonality were more significant for Atlantic salmon than for brown trout. The impacts were also much less significant for the larger river segments than for the smaller segments.

Table 8-5: Average Difference between Seasonal and Year-Round Habitat Loss Curves for each Segment.

Segment Size	*Segment No.*	*Atlantic Salmon*	*Brown Trout*
Small	4	-7%	1%
	6	-10%	0%
	7	-5%	0%
	10	-9%	0%
	15	-3%	0%
	16	-6%	0%
	23	-11%	0%
	24	-2%	0%
	25	-3%	0%
	27	--	0%
	29	-6%	-5%
	48	-1%	-10%
Large	12	0%	0%
	35	0%	-5%
	43	0%	0%
	90	2%	-3%
	92	0%	0%

This analysis indicates that seasonal effects do not need to be considered for brown trout. And that while there are some differences that could allow for slightly lower minimum instream thresholds to be set, these would only be applicable during April and May. During these months river flows are generally high compared to later in the summer, making a seasonal adjustment unnecessary.

9.0 Project Findings and Next Steps

9.1 Findings

Currently, in Ireland there is no established method to evaluate the impact of abstractions on a river's ecology. This project sets out to demonstrate a physical-habitat-based assessment method through conducting a pilot study of fisheries habitat in the rivers of the Central Plain region of Ireland. The method that was developed would allow for a consistency of approach for addressing the majority of abstractions in the Central Plain. The method would allow regulators to establish a future procedure for determining instream flow protection levels for small rivers; it would also provide useful information for larger rivers to frame site-specific studies that will still be needed for larger abstractions. The method is protective of salmonid fisheries, which were selected because of their presence across Ireland, their sensitivity to flows and their high recreational and commercial value. It not only improves the understanding of the relationships between flow changes and fish habitat in Irish rivers, it provides a habitat-based method that can be used to quantitatively estimate the loss in habitat.

The study objectives were met through conduct of a multi-stage methodology to progress the study. A Project Steering Group was established to provide technical support and guidance throughout the various stages of the study. The main outcome of the project was a procedure to the assess the effect of abstractions and compensation flow on habitat for reproducing Atlantic salmon and brown trout in small rivers in the pilot Central Plain region of Ireland. Throughout the individual stages of the methodology, a number of conclusions were identified, including:

- It is possible to use existing habitat suitability curves (HSCs) from rivers worldwide that are similar to the Central Plain rivers to develop HSCs for use in Irish rivers. These curves were developed from available research on habitat suitability criteria. The Project Steering Group, however, indicated that they would like these curves to be verified through the conduct of field studies on habitat preferences.

- Four physiographic regions represent the hydraulically relevant features of Irish rivers. These regions were needed to develop a regional procedure; the streams in a region must be classified according to important characteristics relating to ecology.

- A number of rivers in Ireland are randomly and frequently dredged by adjoining land owners, without authorisations, for various reasons such as flooding control.

- Small rivers are susceptible to significant hydraulic changes due to flooding, possibly exacerbated by development in the upstream catchments.

- There are insufficient hydrometric stations in Ireland that gauge flows on rivers with small catchments.

- The use of the random stratified sampling method may be reconsidered for future fieldwork. In future studies, the existence of reliable hydrometric gauges on study rivers, should be the controlling factor for stream selection.

The end point of the PHABSIM modelling and impact assessment method resulted in a number of significant outcomes. These included:

- The constant habitat impact curves showed that large rivers cannot currently be regionalised. Unless additional data finds a common basis for regionalisation, proposed future abstractions would need to be evaluated on a site specific basis. From Table 9-1 large rivers comprise of orders 4, 5 and 6 rivers and 38 (or 31%) of the abstractions in central plain rivers are located on the large rivers.

- The impact of abstractions on smaller streams is greater than on larger streams. The utility of a composite impact assessment curve for small rivers is higher than might be initially evident. Table 1-1 showed that most of the known abstractions for rivers in Ireland are located on small order rivers. The same is true of the Central Plain rivers for which the composite CHI curves were developed; Table 9-1 shows that over 65% of the currently known abstractions are located on smaller rivers. As the number of known abstractions increases, the percentage found on small rivers will likely also increase.

Table 9-1: Number of Abstractions in the Central Plain Region

Order 2	26
Order 3	19
Order 4	12
Order 5	14
Order 6	12
Lakes	30
Unknown	11
Total	124

- PHABSIM results (available habitat as Weighted Usable Area as a function of flow) for the modelled study segments showed no habitat available for adult Atlantic salmon in many of the smaller rivers. This was confirmed with personnel from the Central Fisheries Board and reflects the absence of water depths greater than 0.75 m to serve as sufficient depth for cover and manoeuvrability.

- The results of the renormalized minimum weighted usable area curves showed the shape of the curves to be similar between the small order rivers (i.e. broad, gentle slopes) compared to the larger rivers (narrow, steep slopes). This shows that the effect of abstractions on habitat is greater in smaller rivers.

- Habitat gains or "habitat neutral" were evident in large rivers beyond a minimum compensation flow threshold. Depending on the fish species studied, these flows range from about Q46 to Q92. This occurs when fish prefer lower flows as shown in the habitat suitability curves. However, even though fish will prefer shallower water they will reside in the rivers even with increasing depth.

- The wetted perimeter metric was successful in classifying the study segments in to size classes; this will need some refinement to be used as part of a regulatory scheme.

- The impacts of seasonality were more significant for Atlantic salmon than brown trout. The impacts were also much less significant for the larger rivers compared to the smaller rivers.

9.2 Next Steps

Having developed individual and composite curves of constant habitat impact, the next questions that need to be addressed are how much habitat impact is allowed and how to incorporate the findings of this study in a future abstractions assessment or licensing programme. In terms of the first question, it is readily evident that curves with lower percentage impact provide more protection to riverine habitat and their fisheries, but this higher degree of protection comes at the cost of reducing abstractions volumes and/or increasing the required instream flow needs. Moving the decision into a regulatory setting mandates that the decision of which impact curve(s) to use must be made with full consideration of the costs to the environment and those abstracting and using the water. A facilitated meeting among science-based and policy-grounded stakeholders is a possible way forward.

It must also be acknowledged that protection of fisheries and river ecology through setting minimum instream flow requirements will result in periods of time when abstractions from small rivers would not be permitted, and that to achieve these goals it will be necessary to make sure investments in public outreach and water infrastructure. Specifically, additional work will be needed to upgrade the hydrometric network in Ireland so water abstractors will know when instream flow thresholds are being approached and reached. In addition, an alternative means of water supply (storage reservoirs, alternative sources, conjunctive use of sources) might be required. In areas with insufficient water resources to meet demand, it will also be necessary to develop aggressive demand management programmes including water conservation by individuals and businesses and strong programmes to reduce unaccounted for water.

This pilot study examined one of four physiographic regions in Ireland. Given that the pilot was a success for a majority of targeted abstraction types, it should be expanded to other physiographic regions. The next region to be studied should be the Coastal physiographic region which has the second largest volume of water abstractions. In this region the catchments and rivers tend to be smaller, steeper, and more spatey. The ability to apply the method to the discontinuous rivers of the Drumlin region needs to be carefully considered. It should be applicable where there are flowing rivers but not when the streams are merely expressions of the groundwater table interlinking lake networks.

During the course of the study, some specific data needs were identified, which included:

- Additional data and monitoring is needed to improve the understanding of the effects of abstractions on surface waters. An important action would be to expand the number of hydrometric stations in small (<20 km^2) catchments. Existing hydrometric stations on these small catchments with only water levels readings should be reviewed to determine if a stage-discharge curve can be developed. Also, the existing hydrometric stations on small catchments downstream of WWTPs should be flagged in their records as the WWTP flow can mask low flow variations.

- The existing habitat suitability curves were developed from existing research and should be tested for their validity in Irish rivers. The evaluation species used in this study were Atlantic salmon and brown trout. As noted above, the Project Steering Group has asked that they be validated with studies in Irish rivers. In addition, while agreeing that salmonids are the most sensitive species, concerns were raised that the flow needs of salmonids may not match the critical instream flow needs of coarse fish. This could be evaluated after developing habitat suitability curves for coarse fish.

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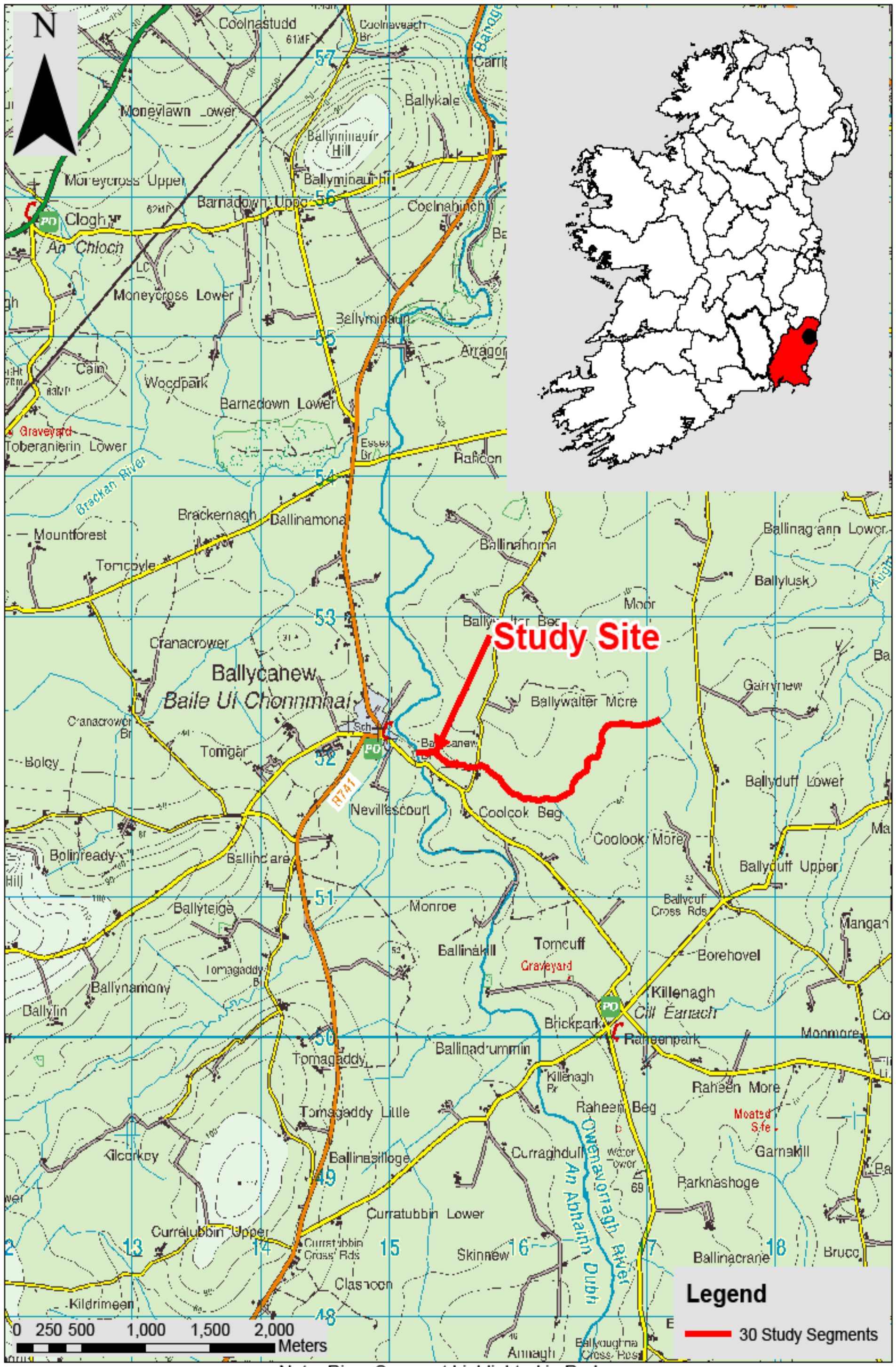
Websites: Central Fisheries Board at www.cfb.ie
Environmental Protection Agency Hydrometric Data at http://hydronet.epa.ie/introduction.htm
Office of Public Works at www.opw.ie

Appendices

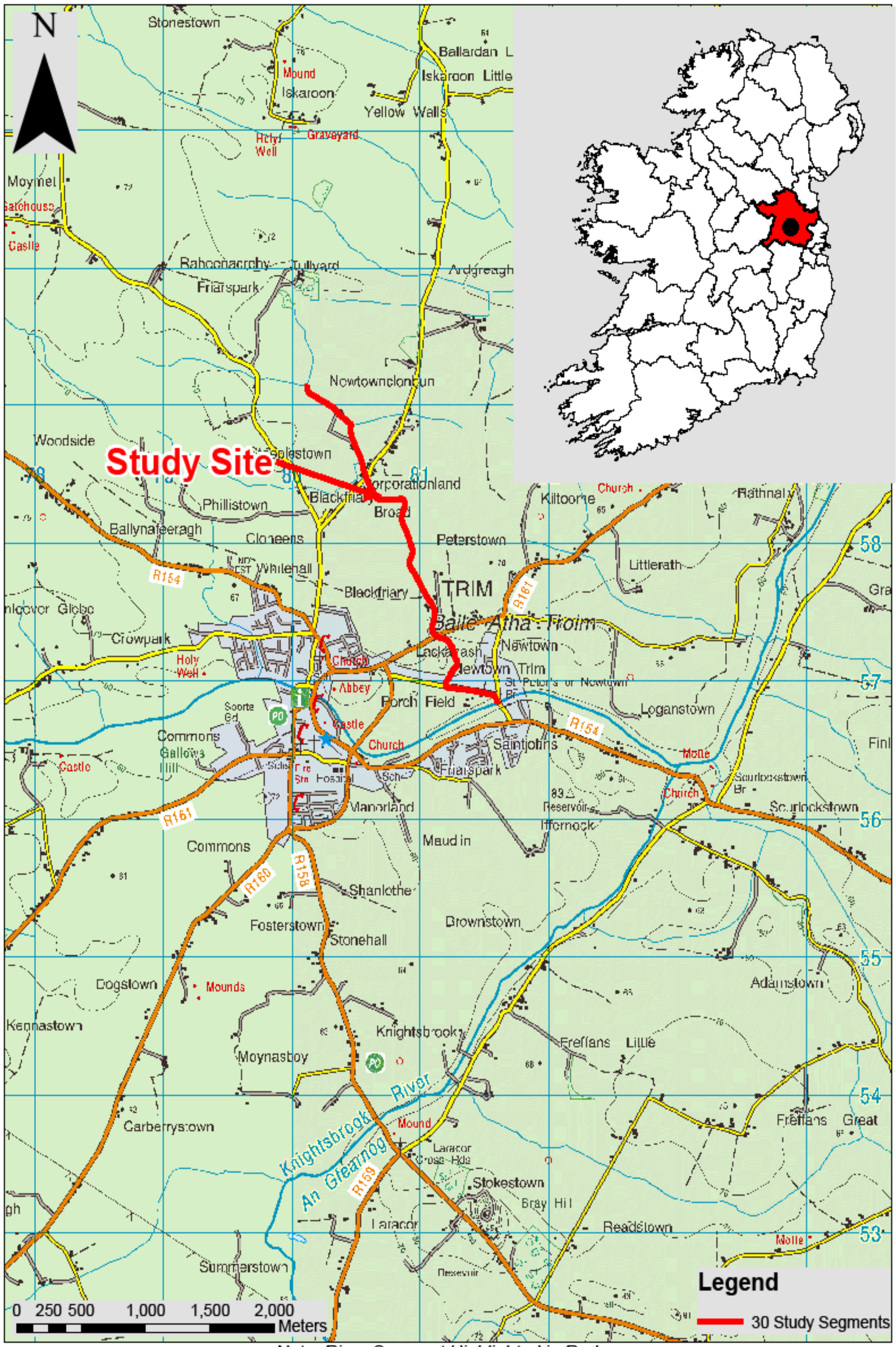
Appendix A – River Segment Location Maps

Segment 1 - Ballycanew, Wexford (Order 2)



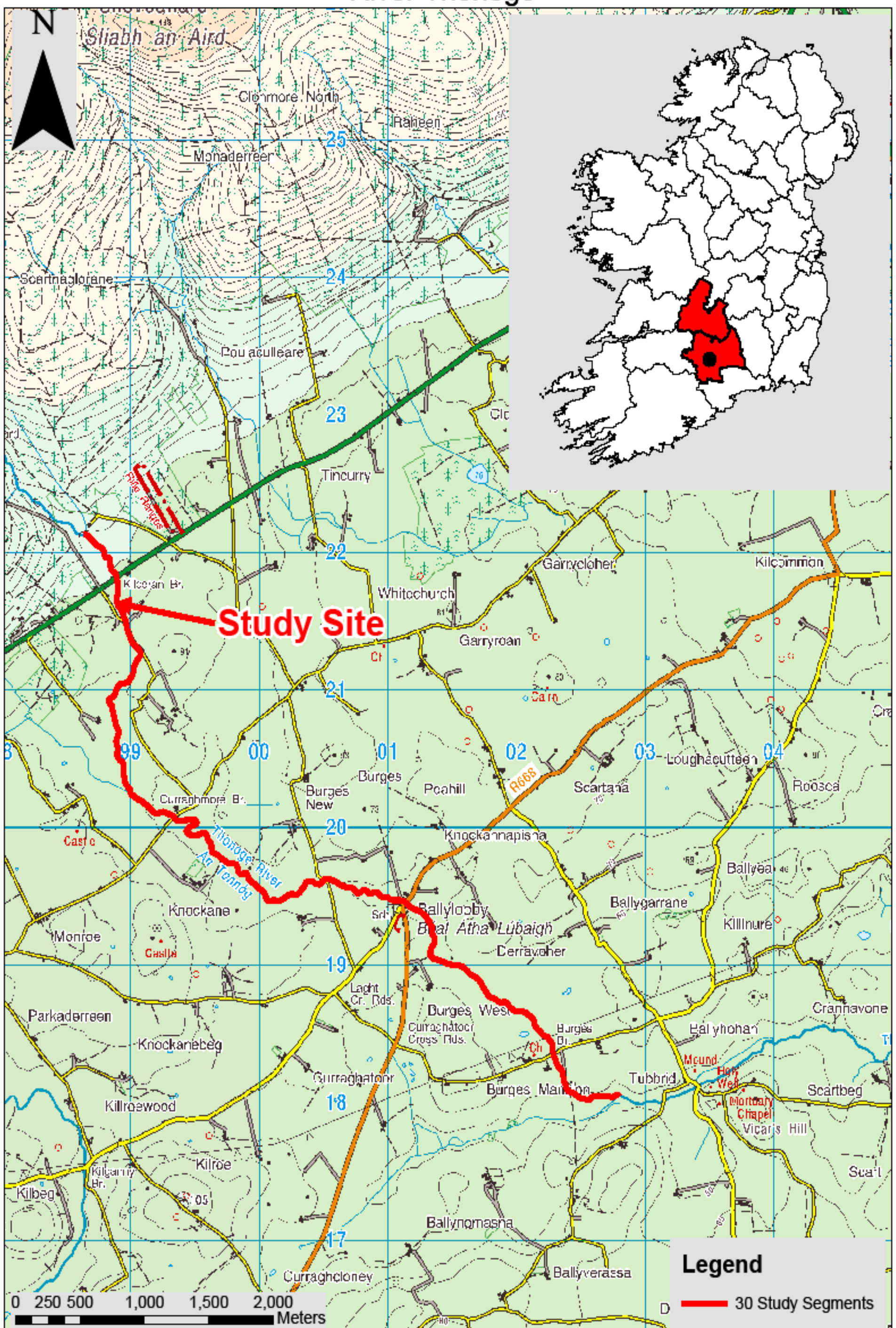
Note: River Segment highlighted in Red

Segment 4 - Trim, Meath (Order 2)



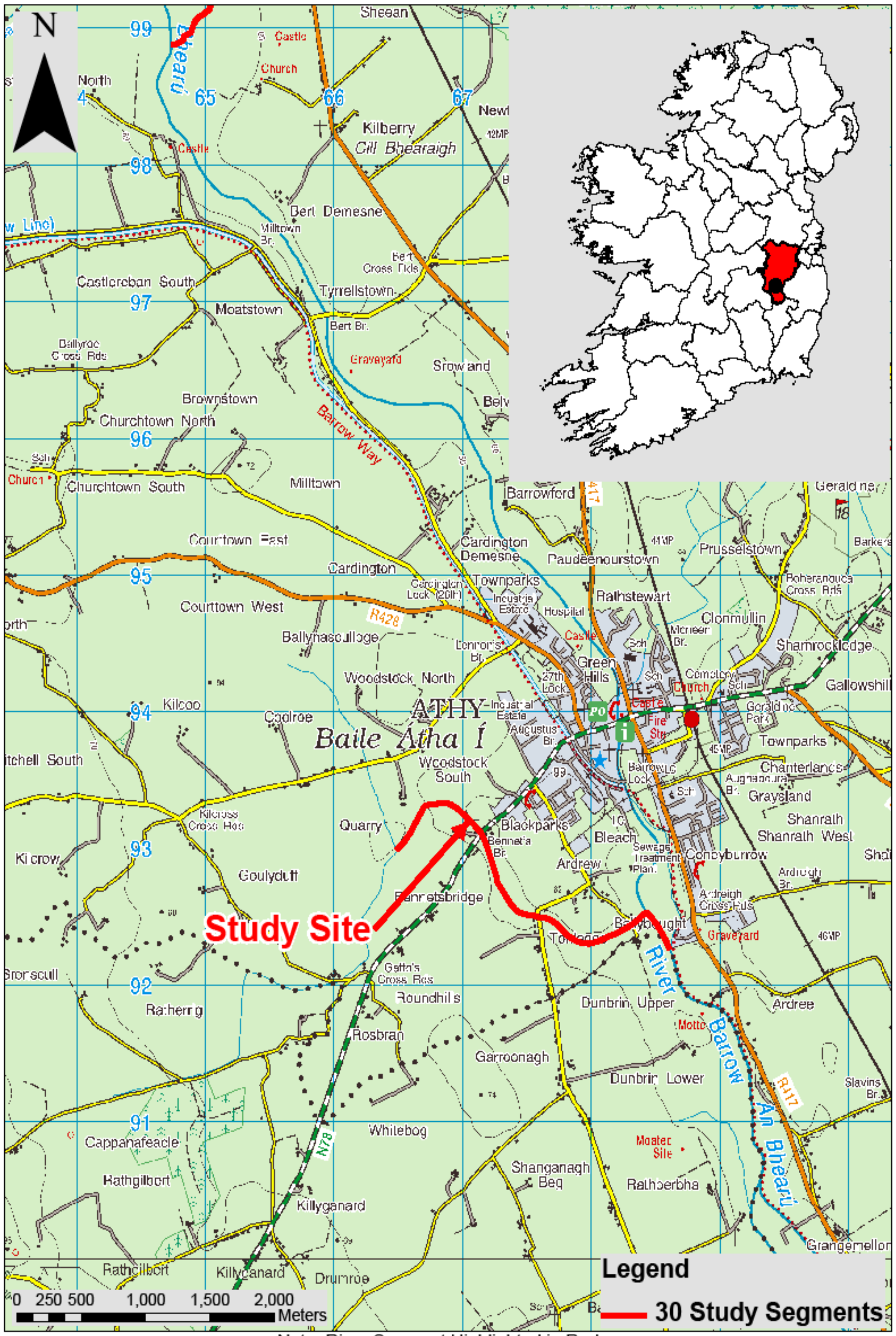
Note: River Segment Highlighted in Red

Segment 6 - Caher, Tipperary (Order 3)
River Thonoge



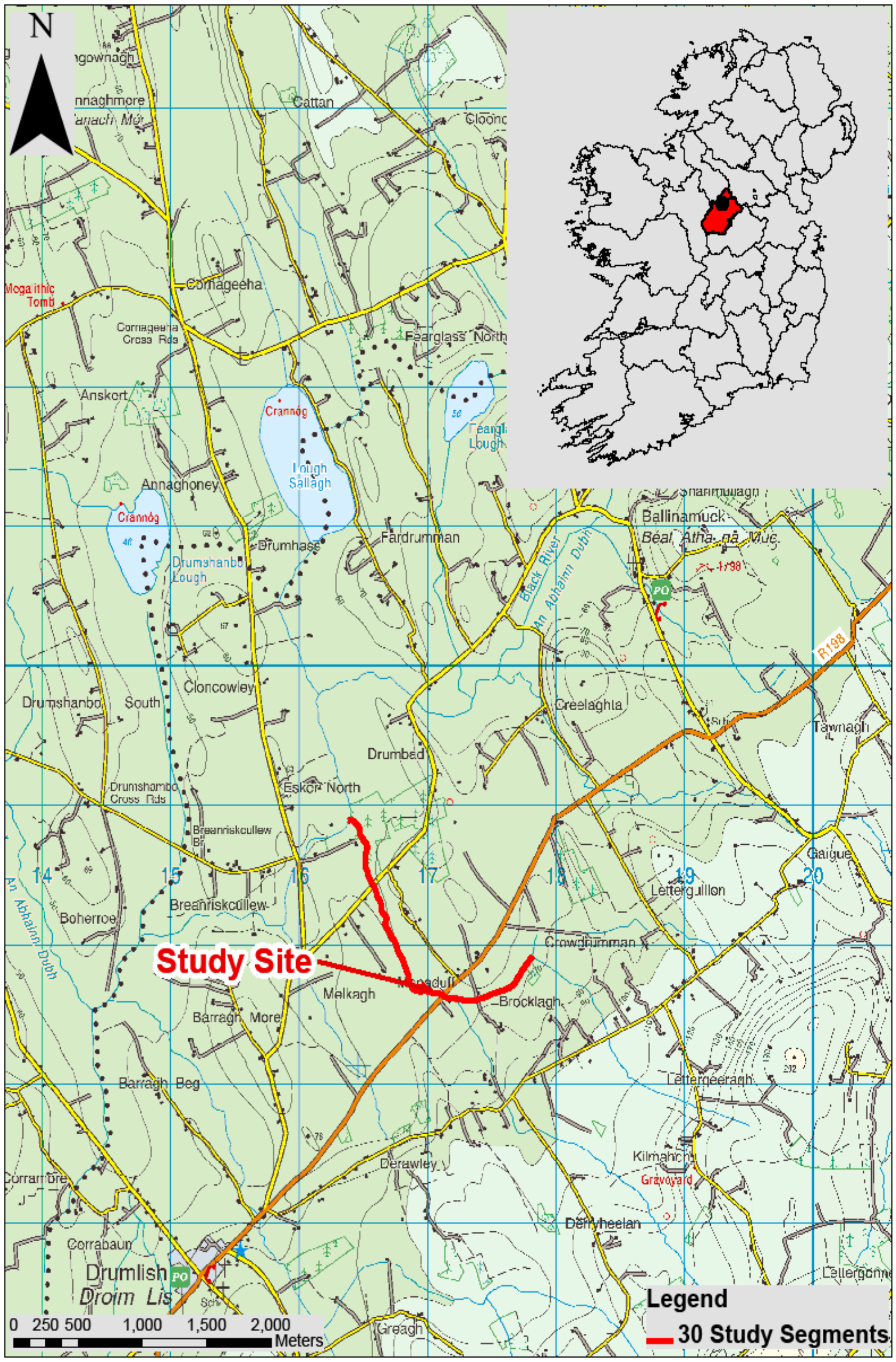
Note: River Segment highlighted in red

Segment 7 - Athy, Kildare (Order 2)

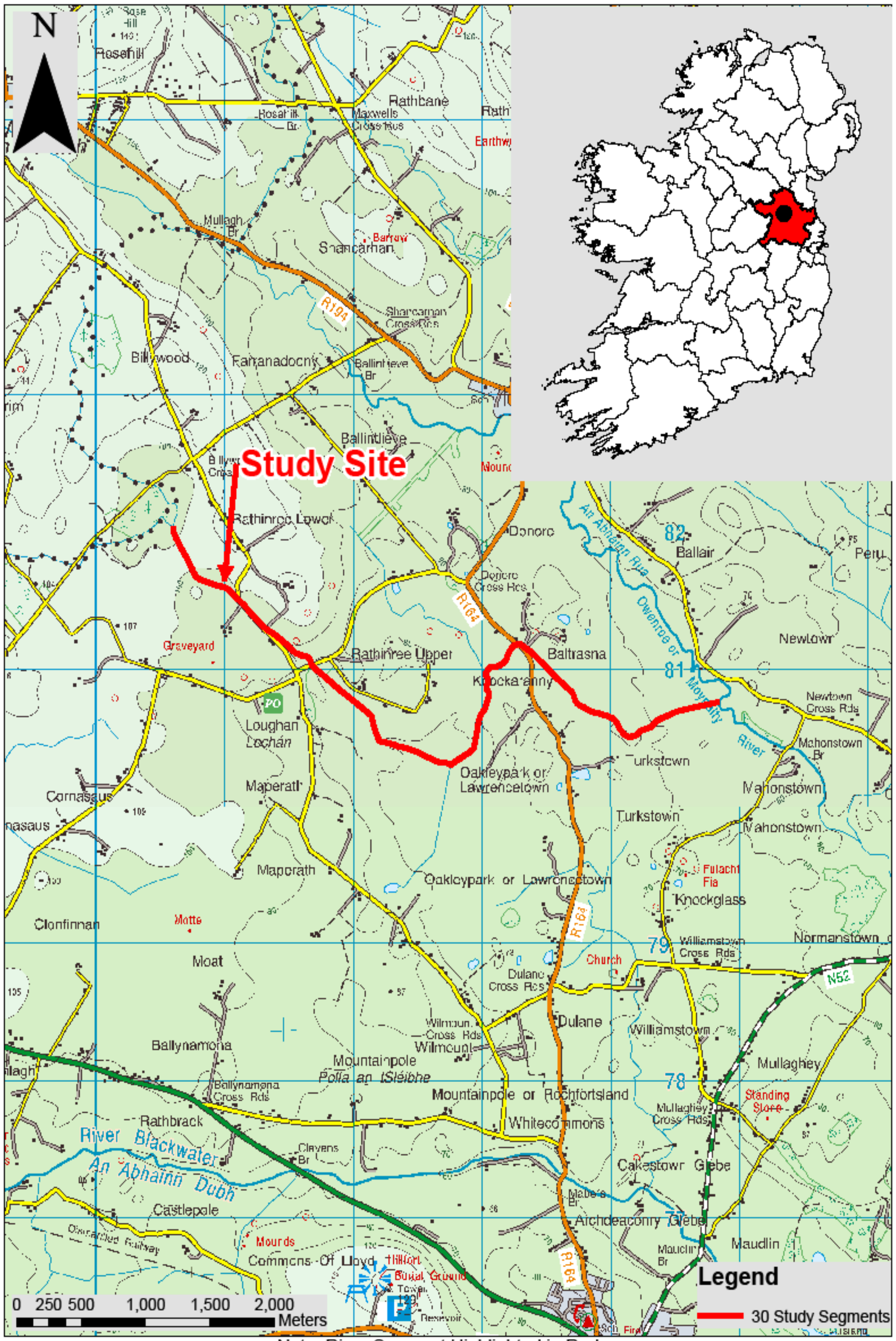


Note: River Segment Highlighted in Red

Segment 8- Monaduff, Longford (Order 2)

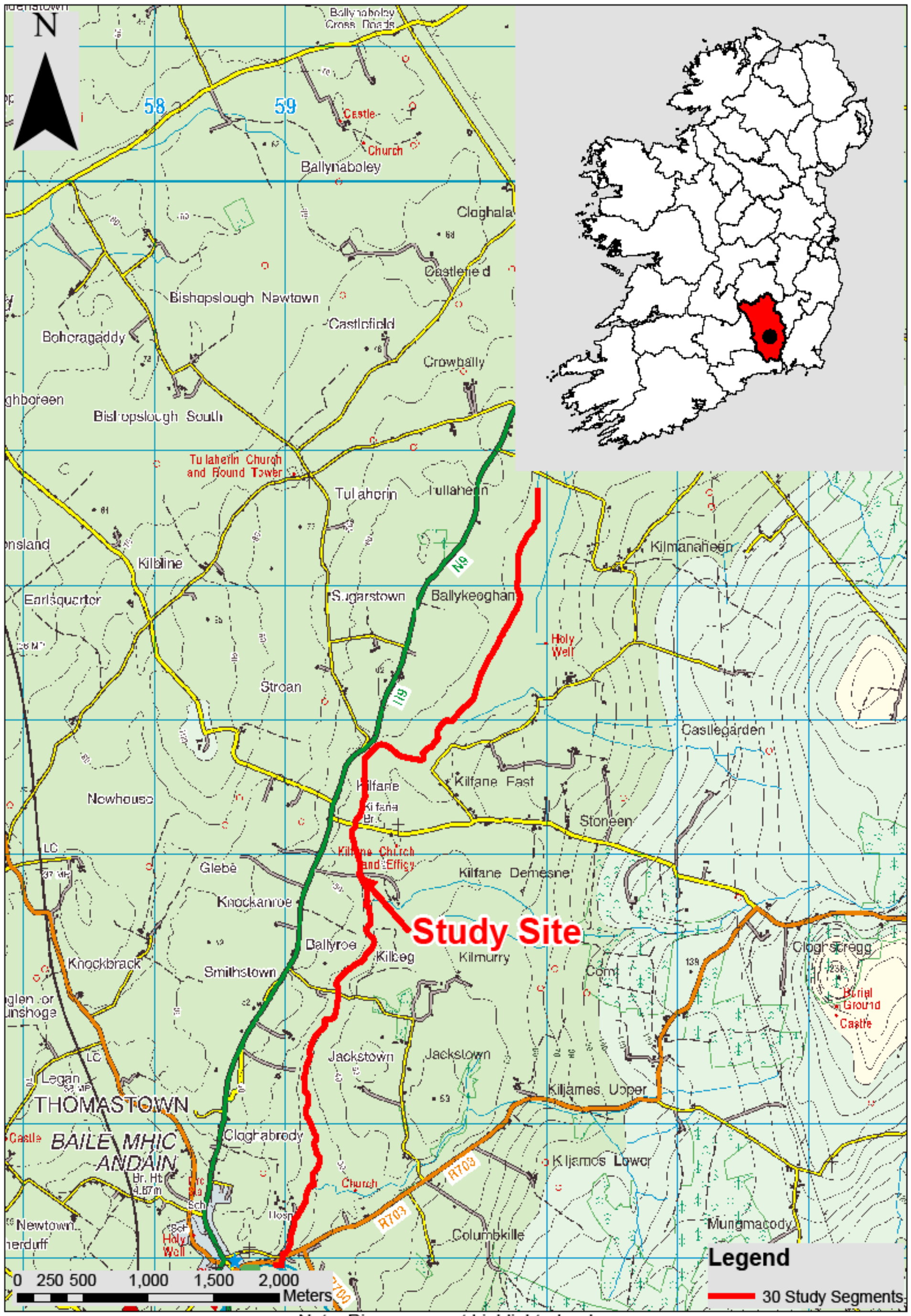


Segment 10 - Moynalty, Meath (Order 2)



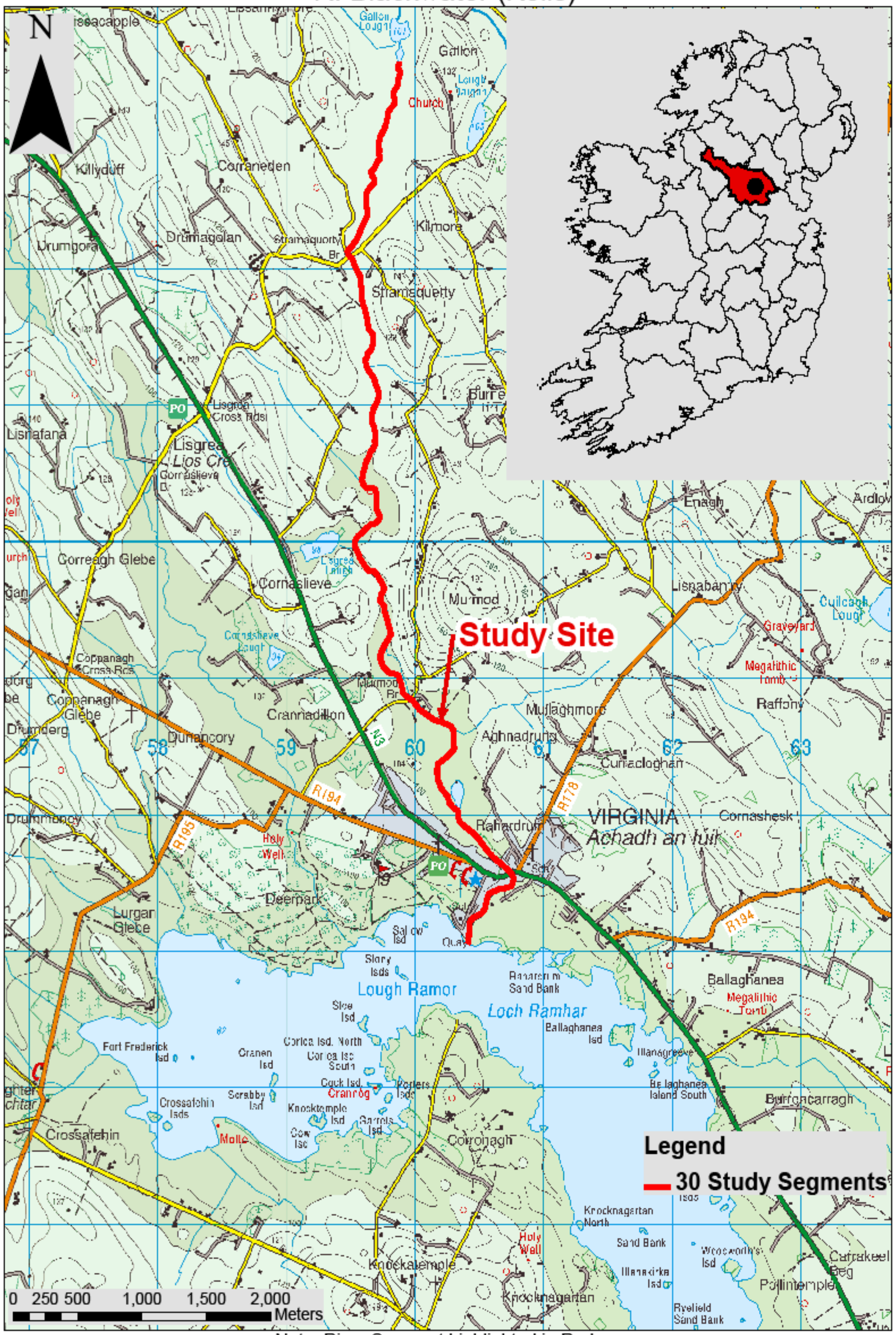
Note: River Segment Highlighted in Red

Segment 11 - Thomastown, Kilkenny (Order 2-3)



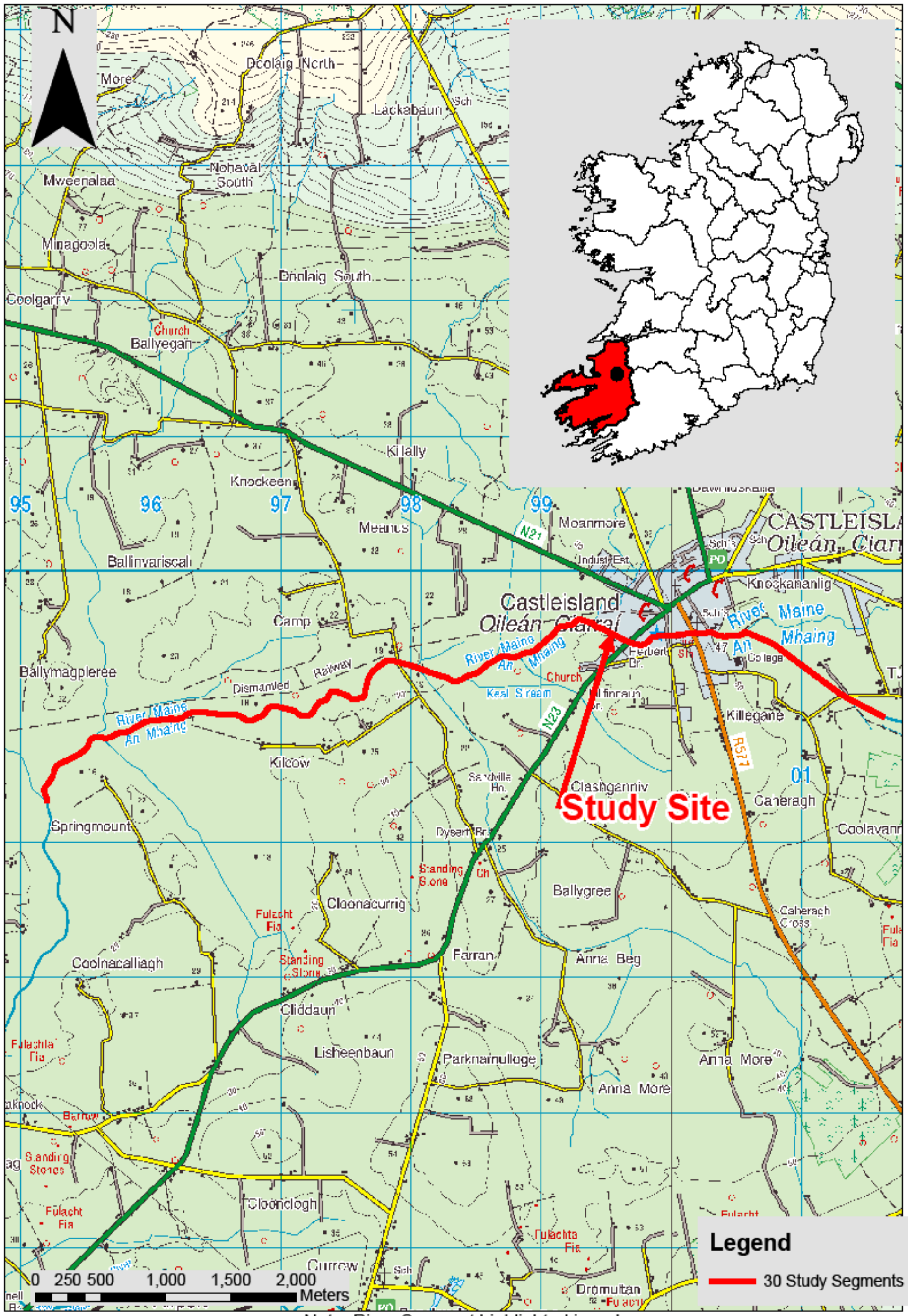
Note: River segment highlighted red

Segment 12 - Virginia, Cavan (Order 4)
R. Blackwater (Kells)



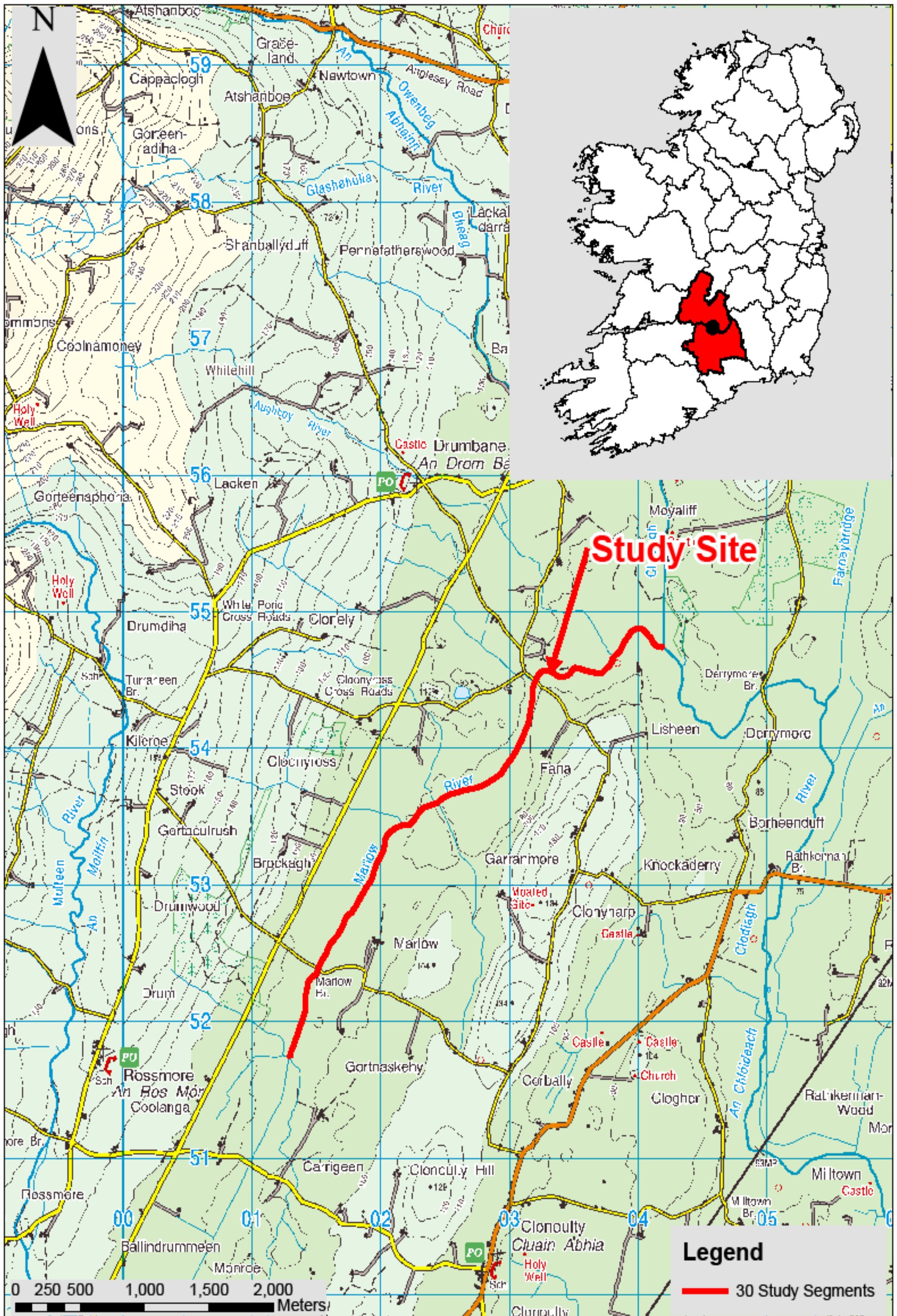
Note: River Segment highlighted in Red

Segment 14 - Castleisland, Kerry (Order 3-4)
River Maine



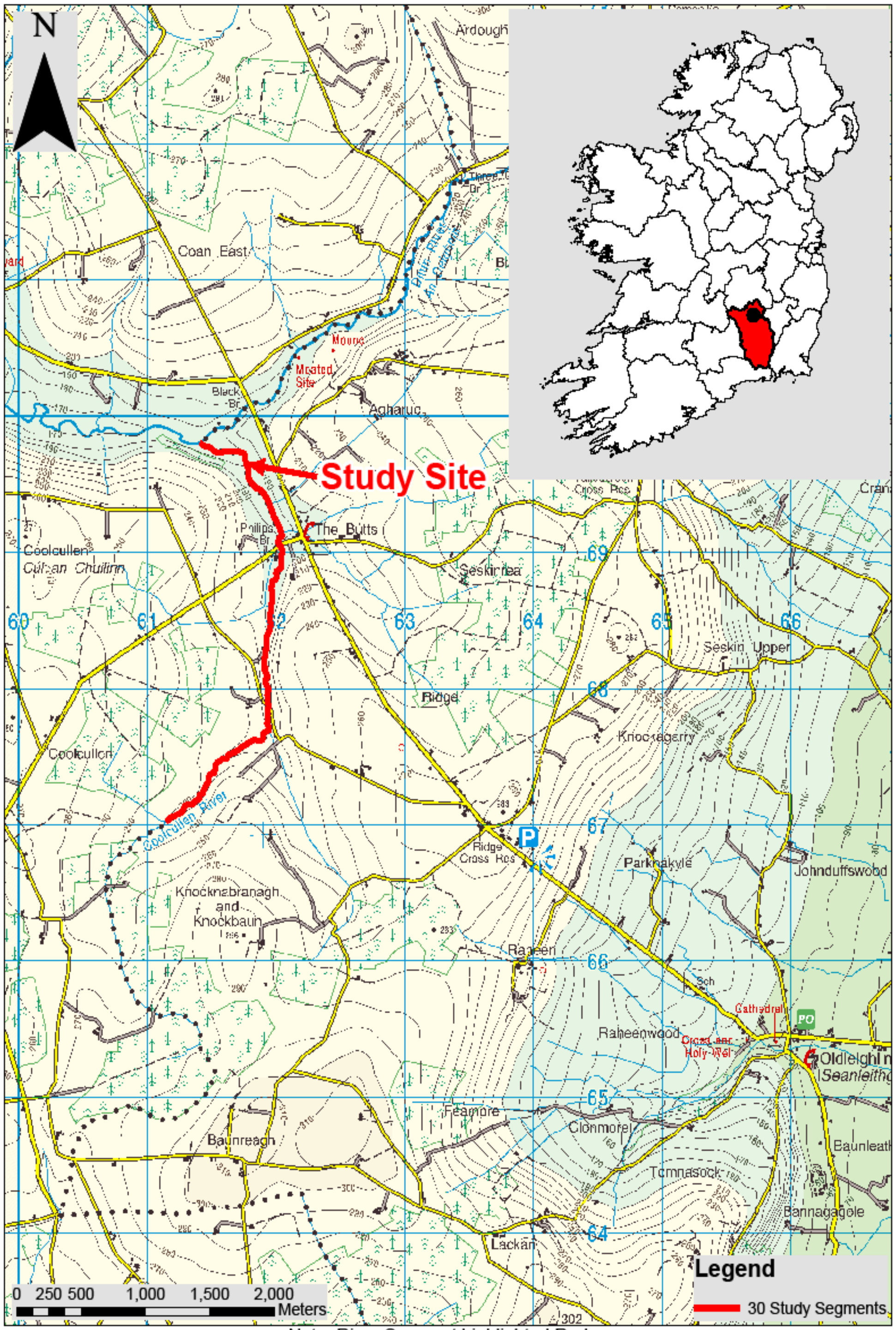
Note: River Segment highlighted in red

Segment 15 - Drumbane, Tipperary (Order 3-4)
River Marlow



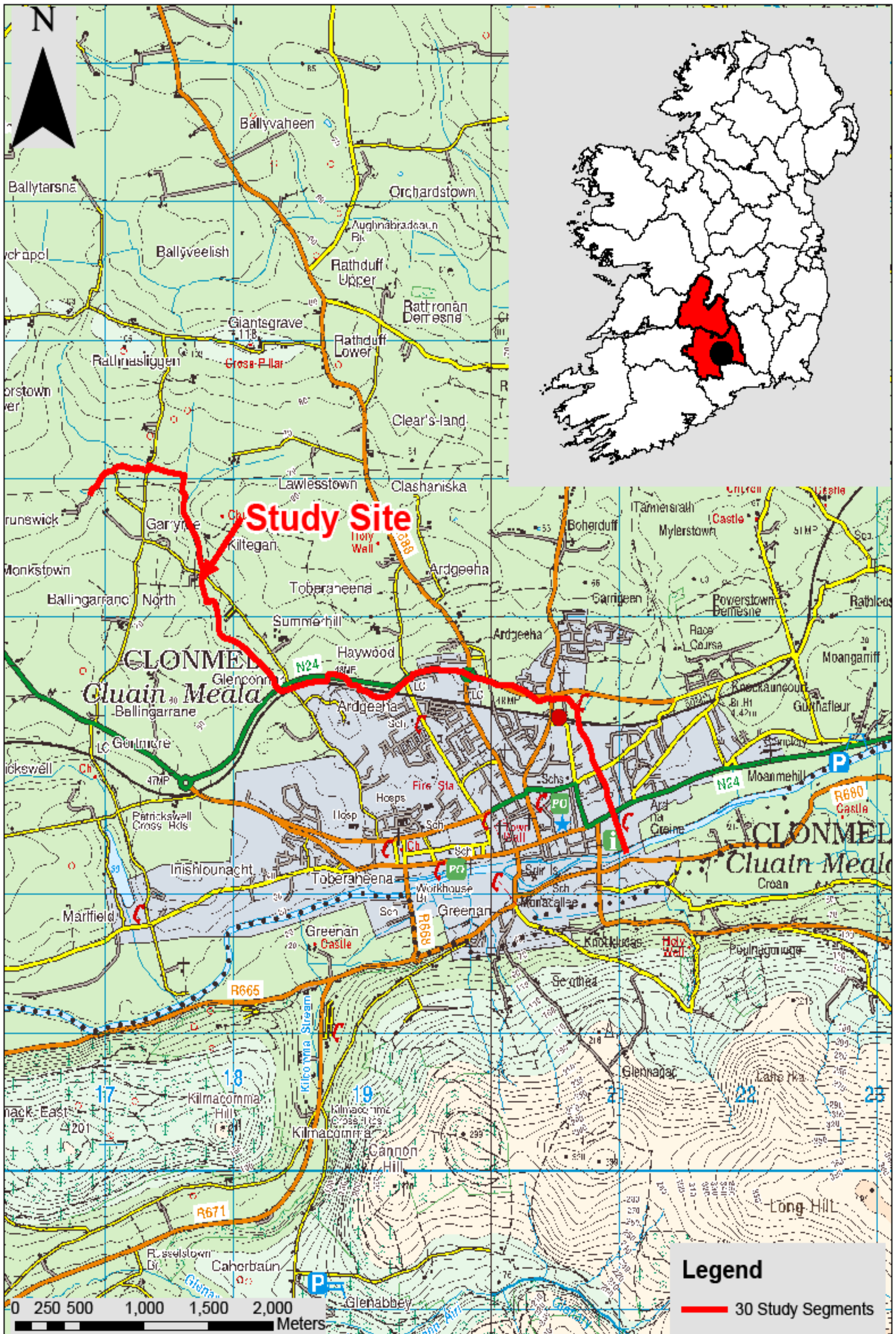
Note: River Segment highlighted red

Segment 16 - Coan, Kilkenny (Order 2-3)



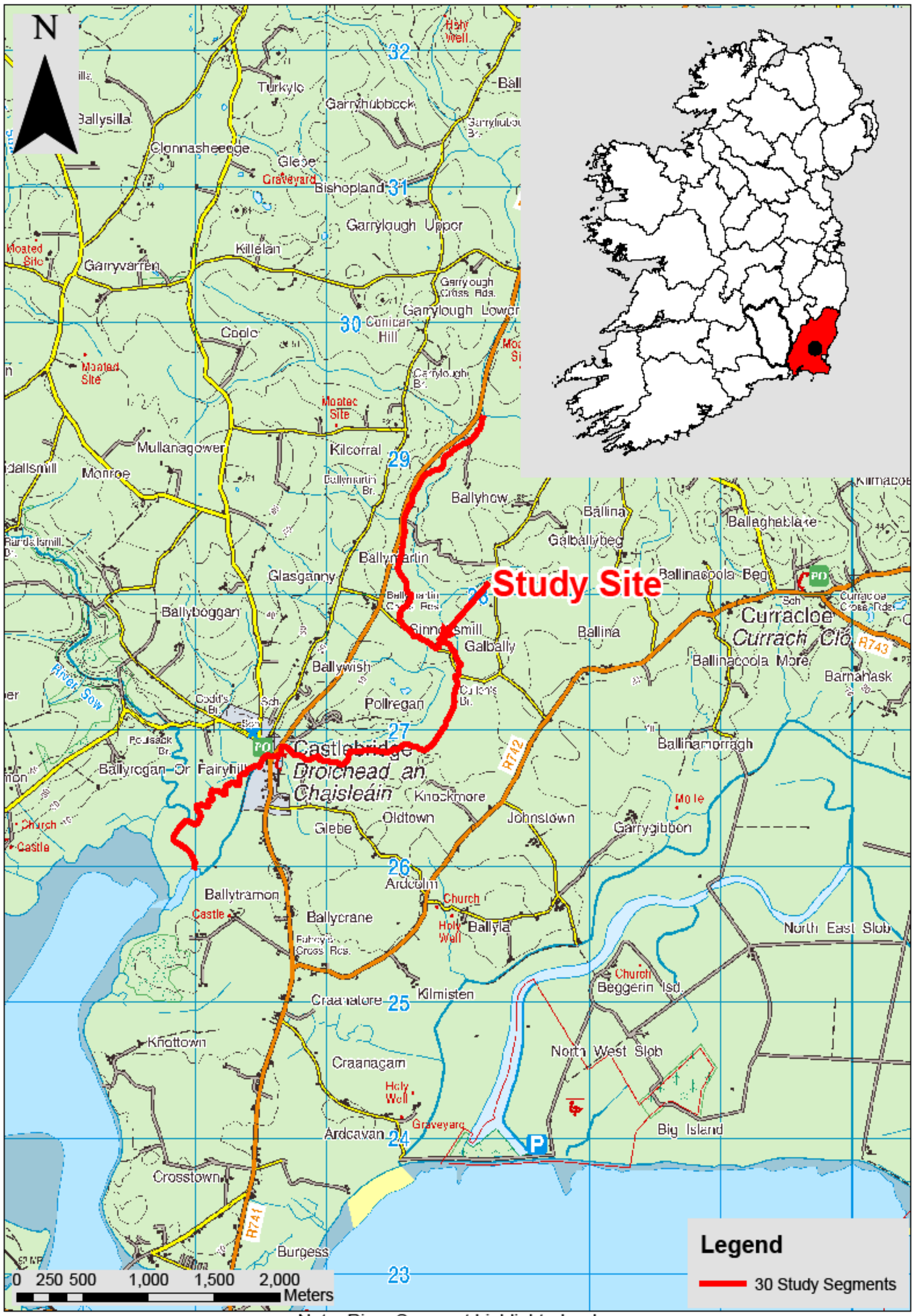
Note: River Segment highlighted Red

Segment 19 - Clonmel, Tipperary (Order 2)



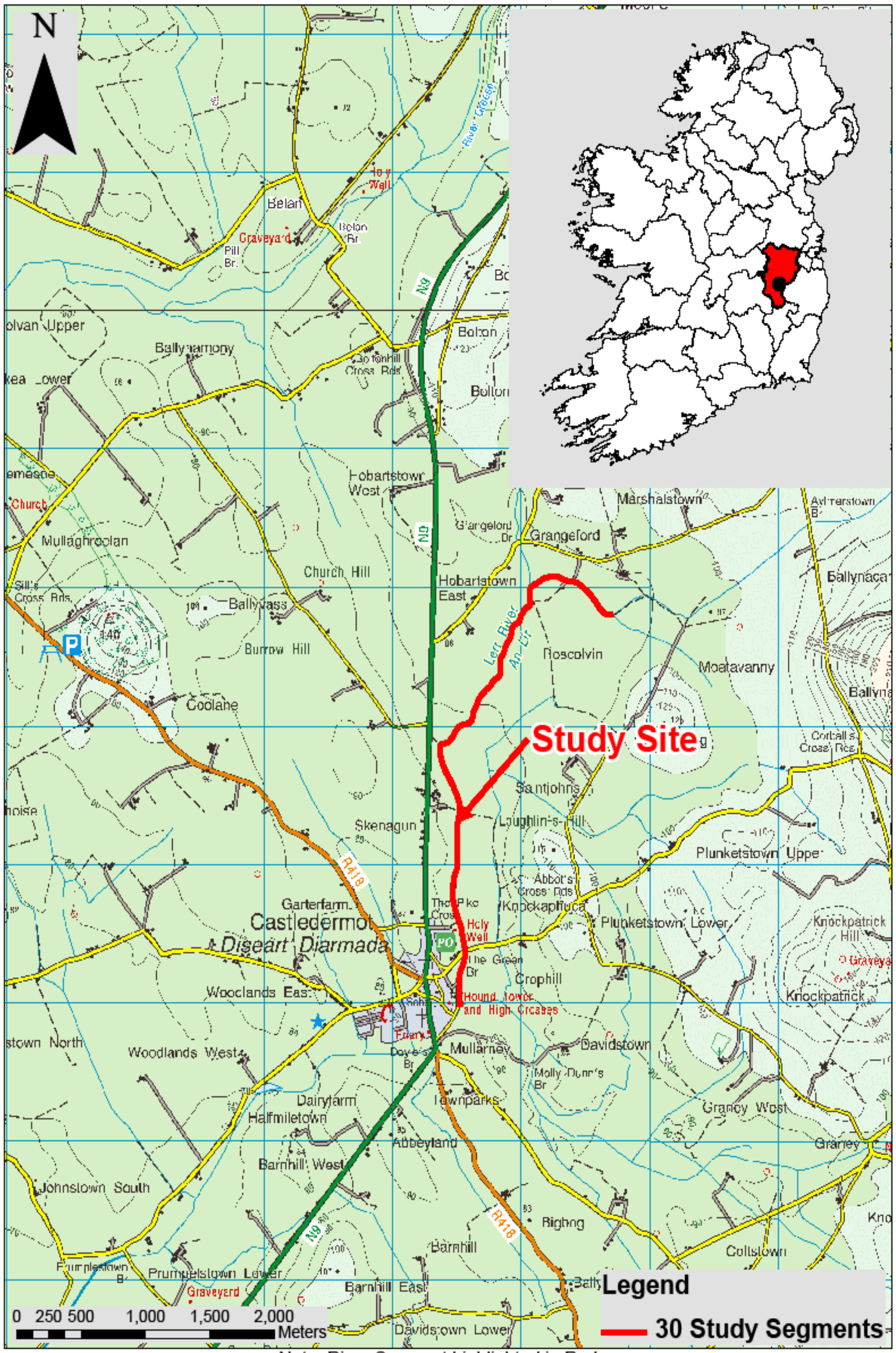
Note: River Segment highlighted red

Segment 20 - Castlebridge, Wexford (Order 4)
River Sow



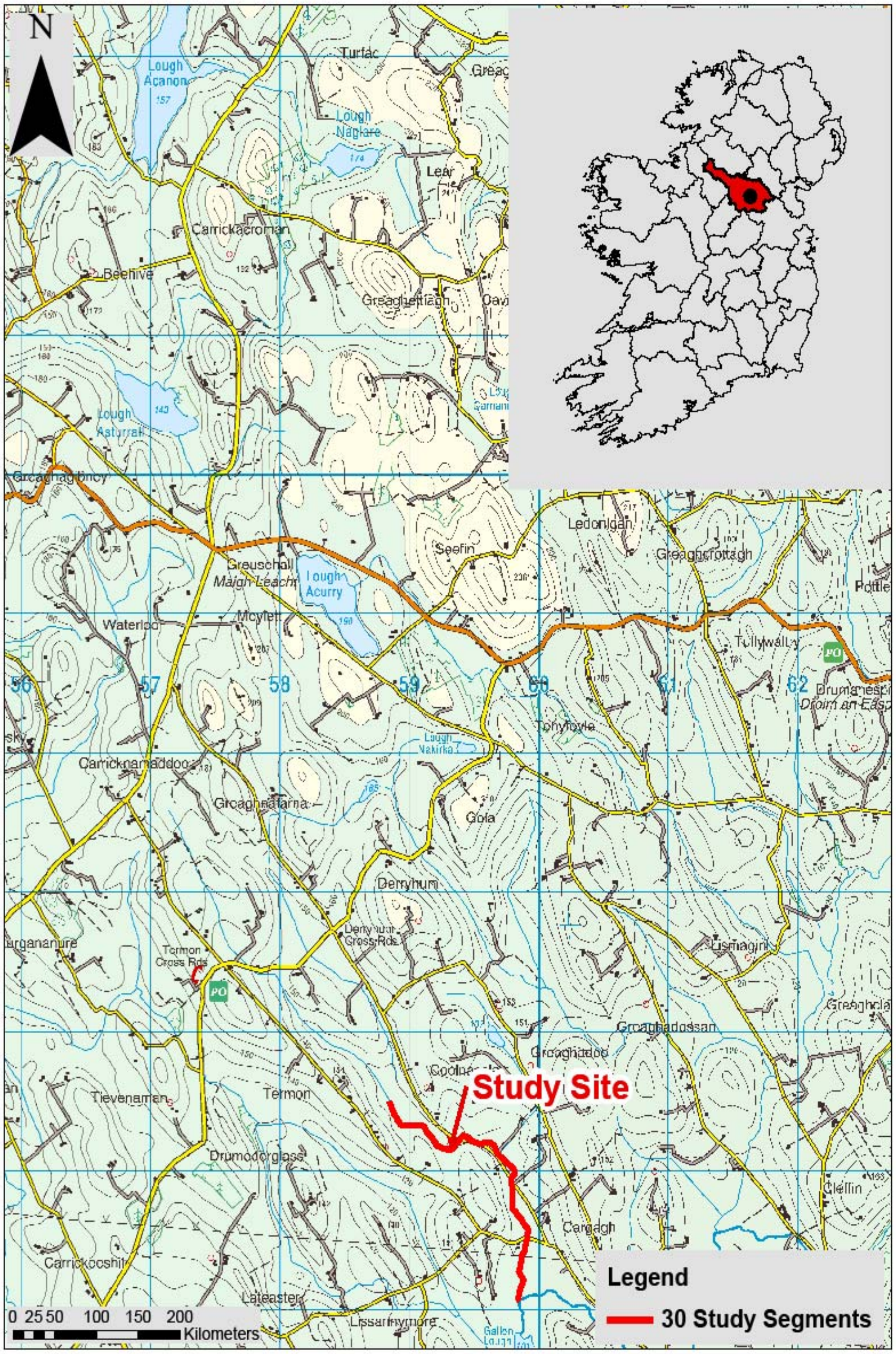
Note: River Segment highlighted red

Segment 23 - Castledermot, Kildare (Order 2-3)
River Lerr



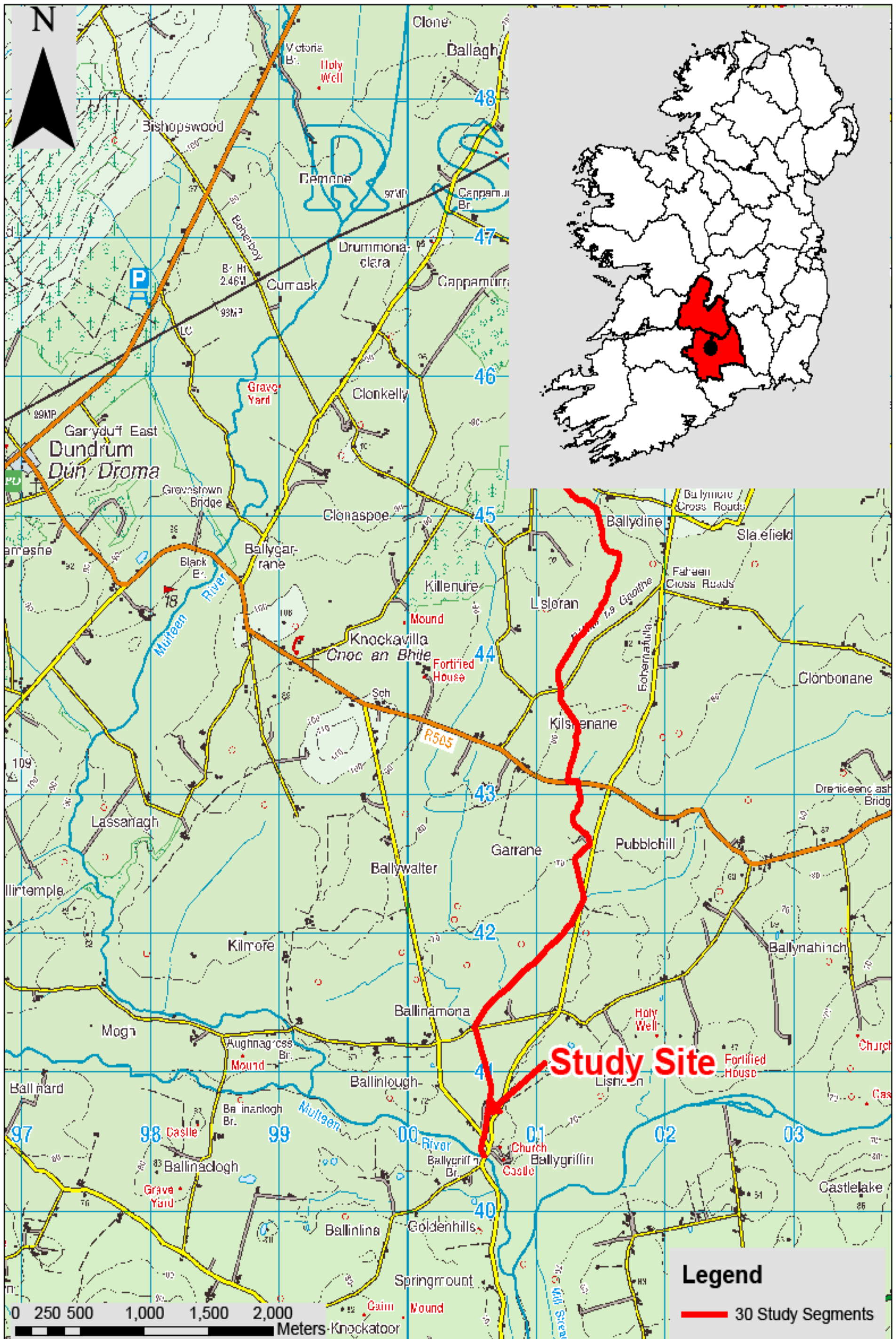
Note: River Segment highlighted in Red

Segment 24 - Killinkere, Cavan (Order 2)



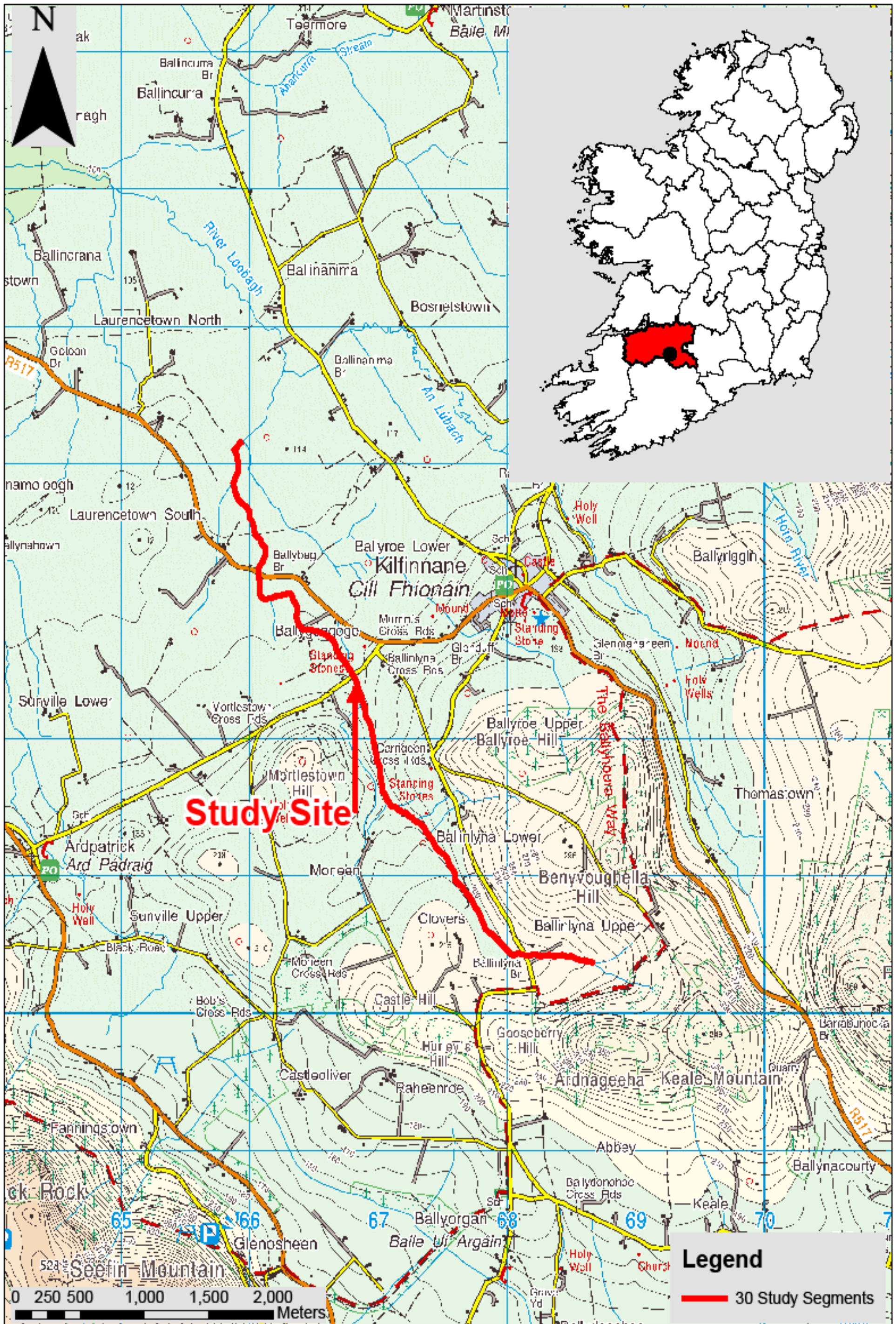
Note: River Segment highlighted in Red

Segment 25 - Ballygriffine, Tipperary (Order 2-3)



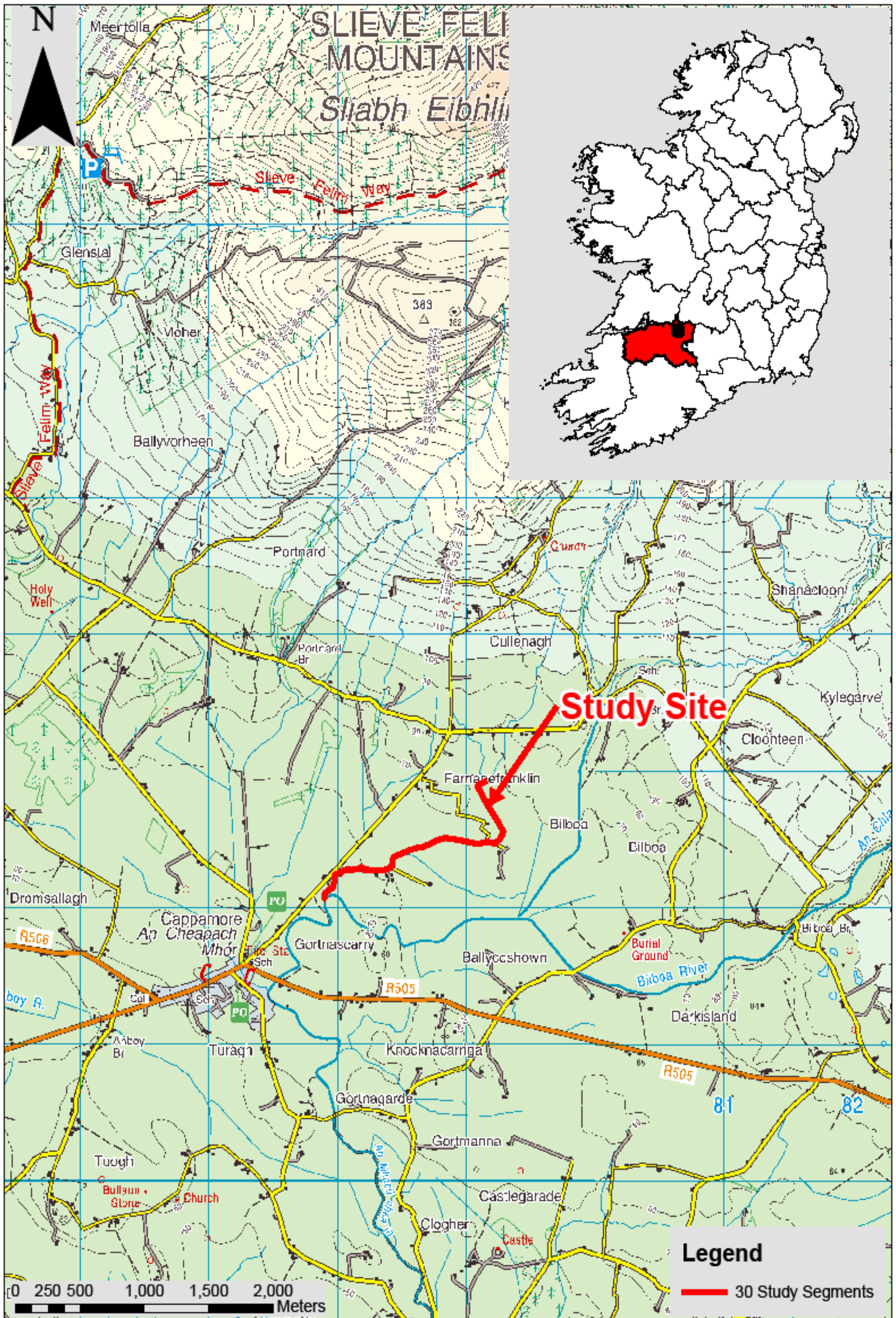
Note: River Segment highlighted in red

Segment 28 - Kilfinnane, Limerick (Order 2)



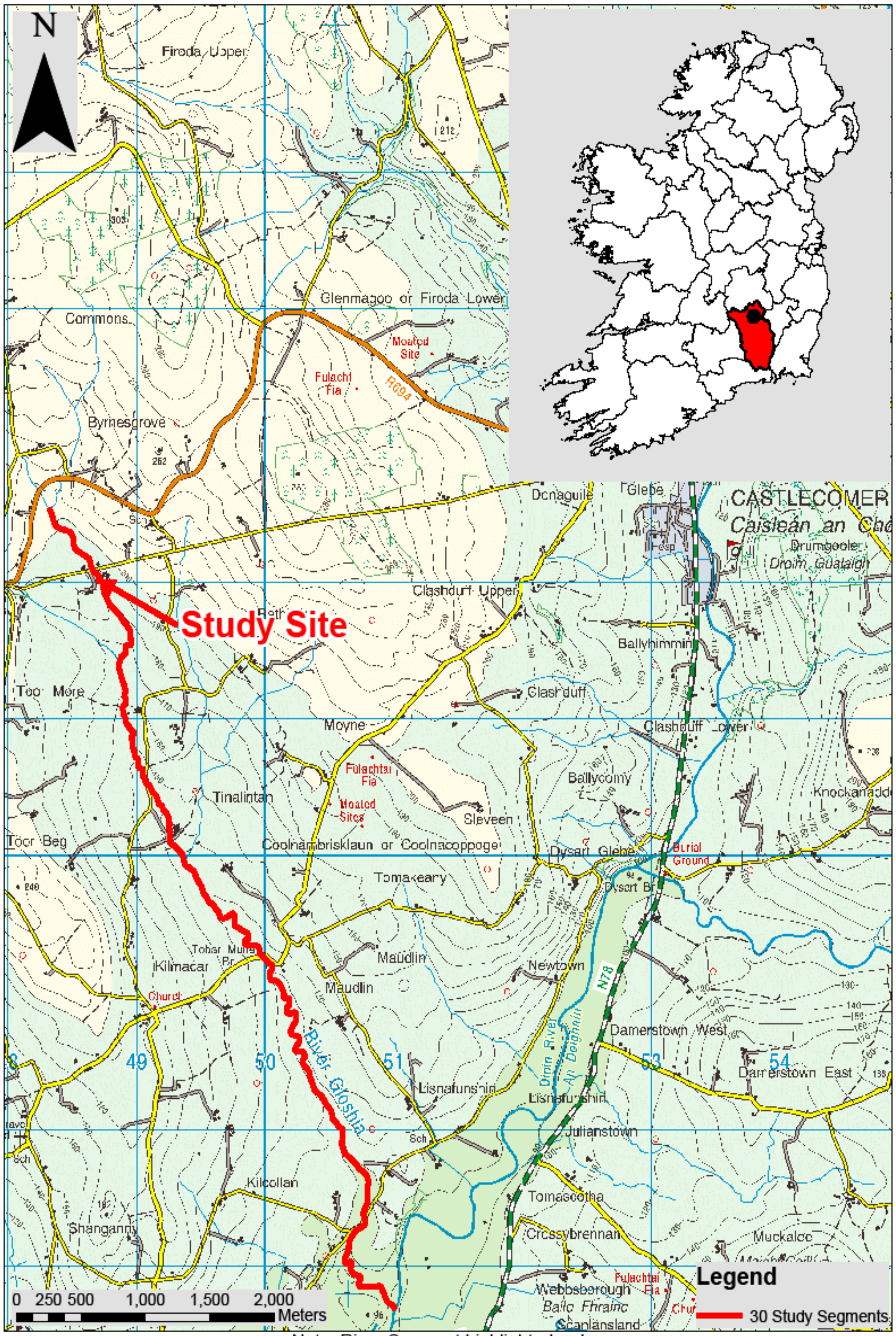
Note: River Segment highlighted in red

Segment 29 - Cappamore, Limerick (Order 2-3)



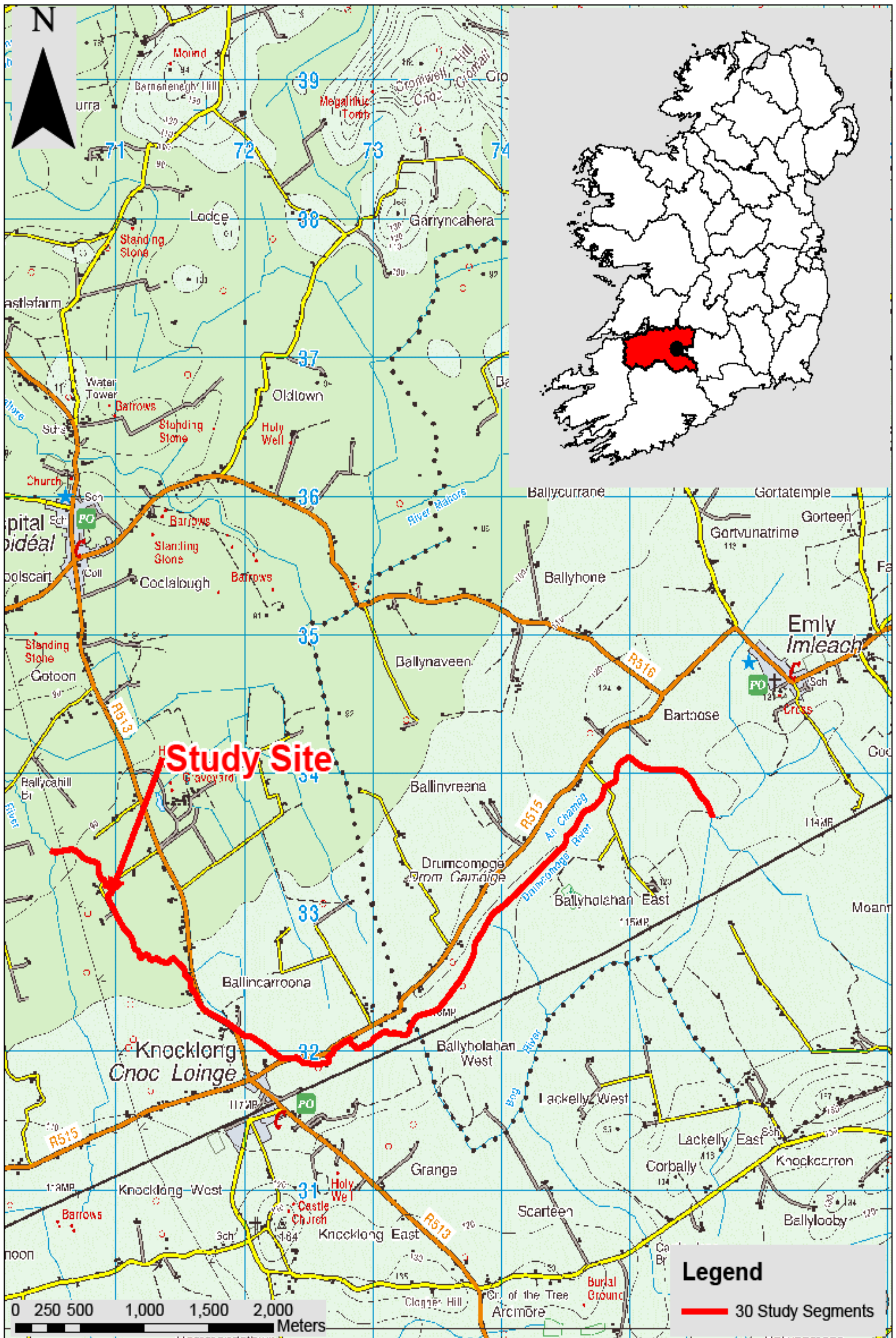
Note: River Segments highlighted in red

Segment 30 - Castlecomer, Kilkenny (Order 2-3)



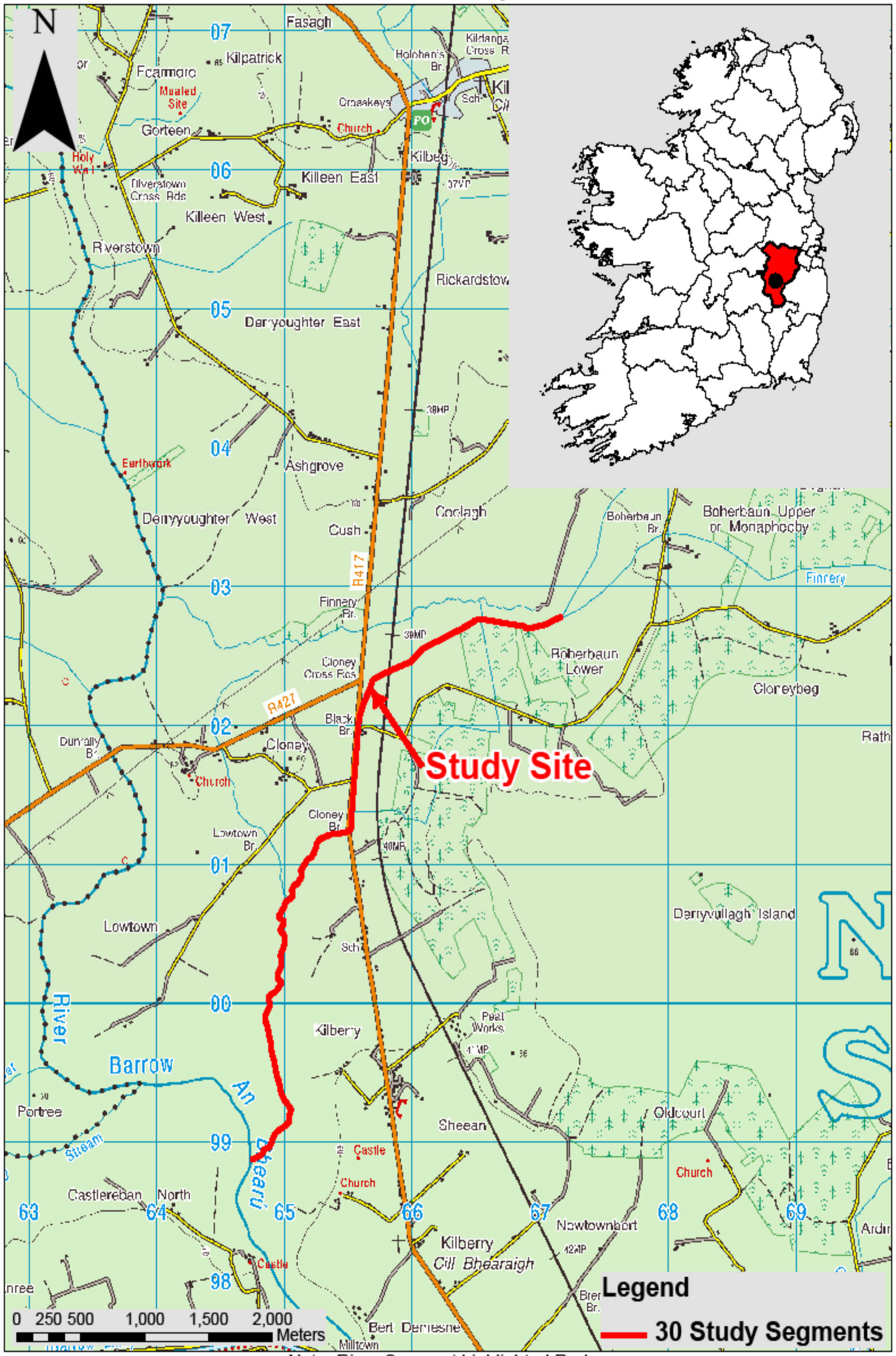
Note: River Segment highlighted red

Segment 31 - Knocklong, Limerick (Order 3-4)
River Camoge



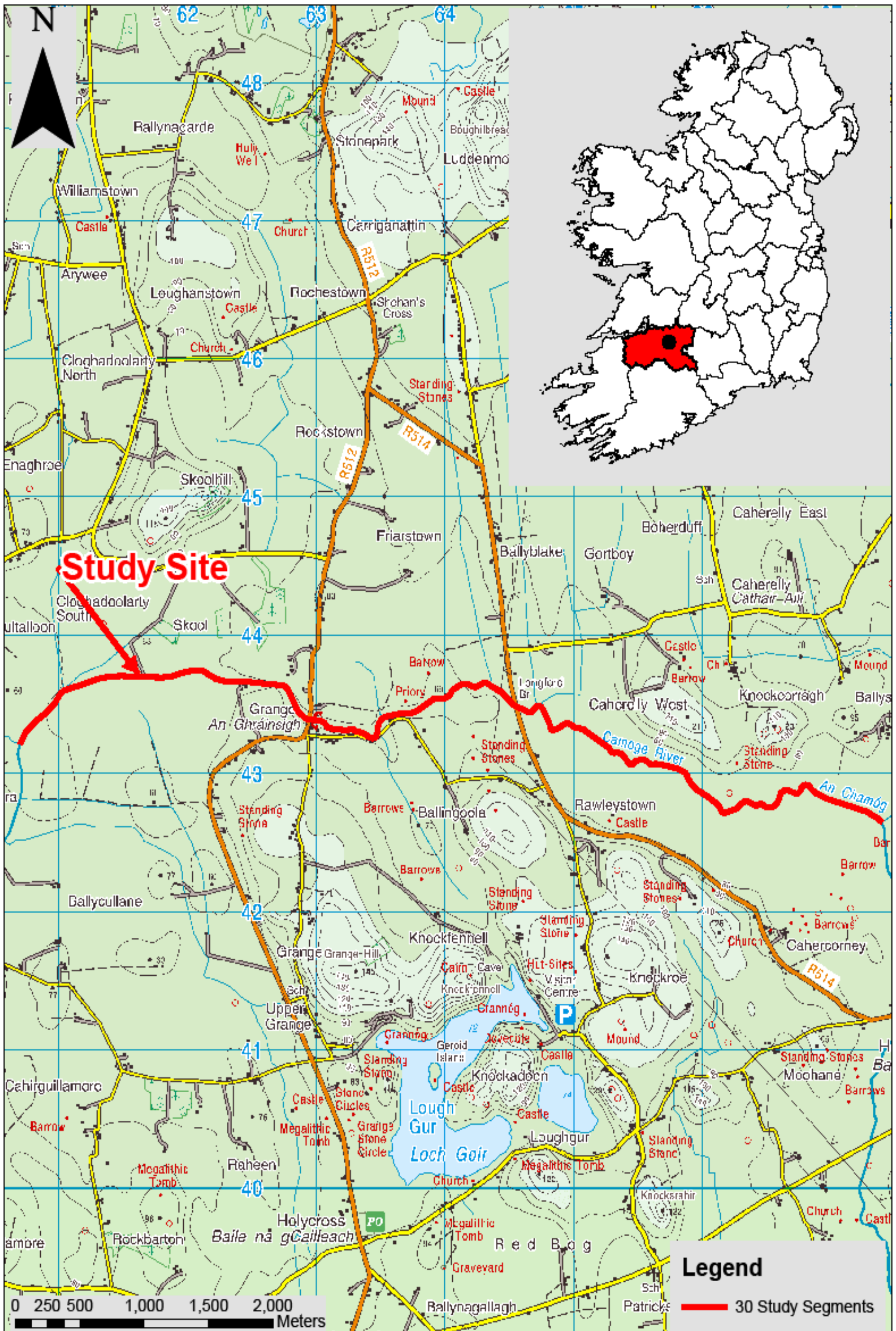
Note: River Segment highlighted in red

Segment 35 - Kilberry, Kildare (Order 3)
River Tully



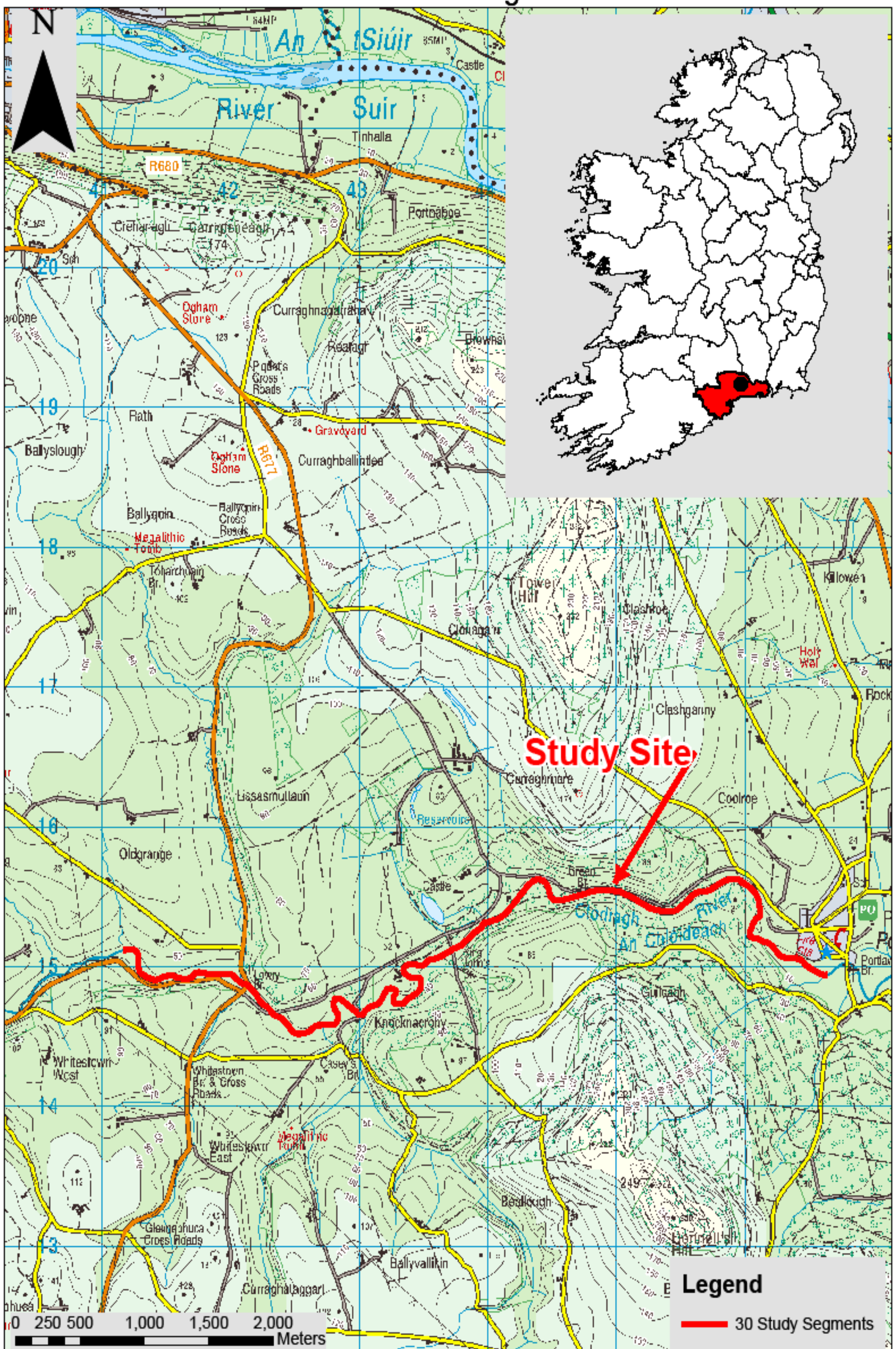
Note: River Segment highlighted Red

Segment 36 - Grange, Limerick (Order 5)
River Camoge



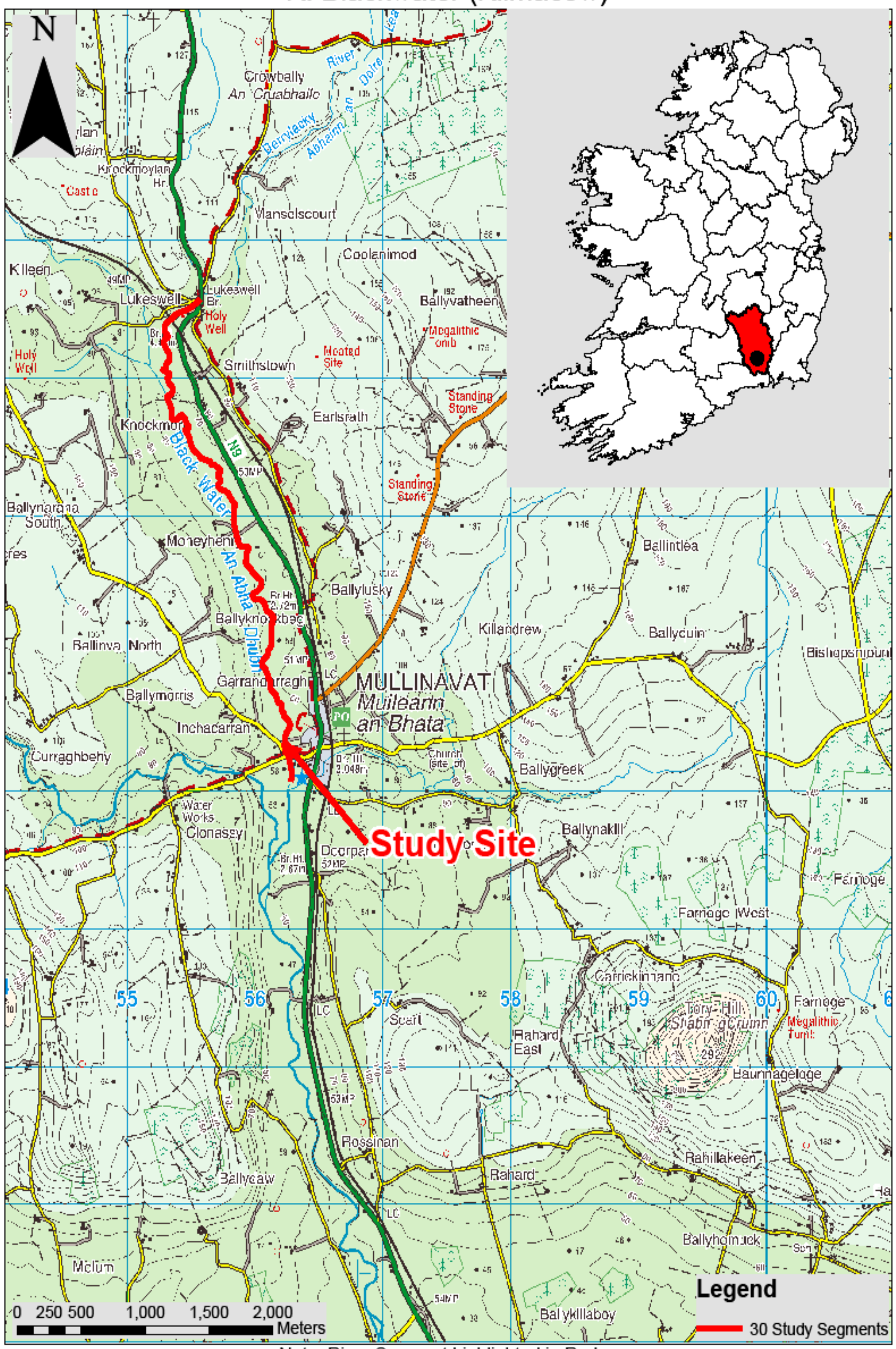
Note: River Segment highlighted red

Segment 43 - Portlaw, Waterford (Order 5)
River Clodiagh



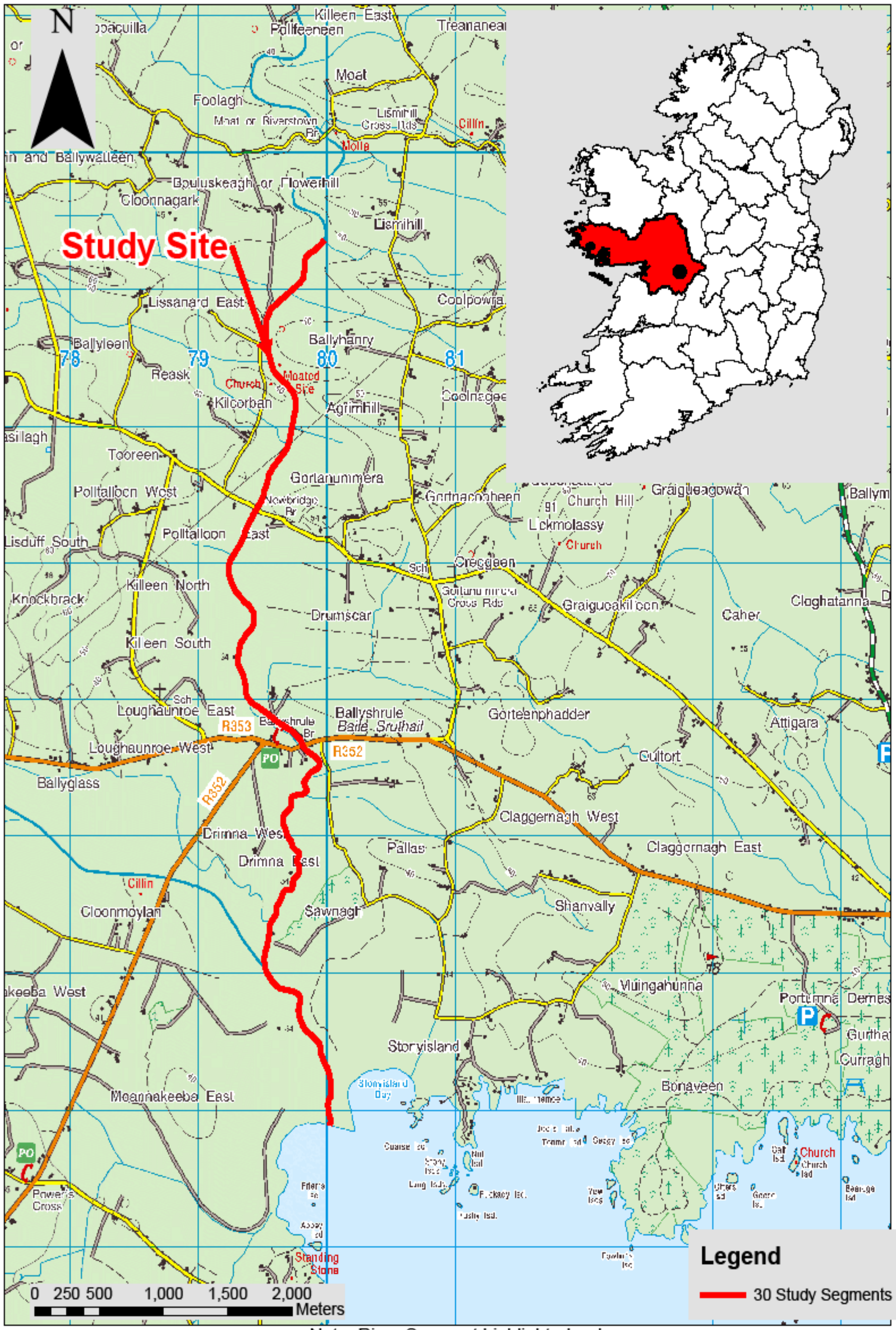
Note: River Segment highlighted red

Segment 48 - Mullinavat, Kilkenny (Order 3)
R. Blackwater (Kilmacow)



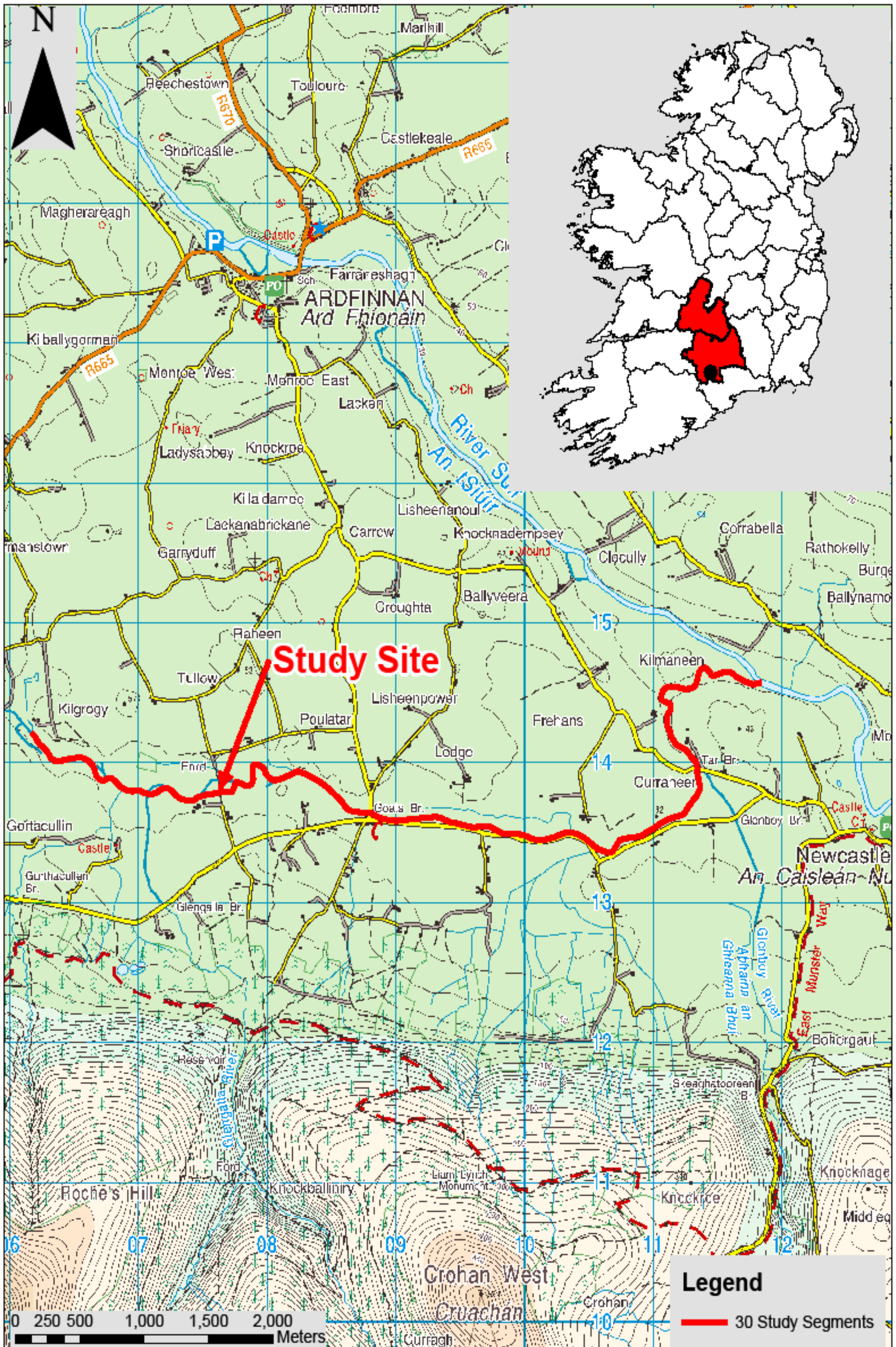
Note: River Segment highlighted in Red

Segment 90 - Ballyshrule, Galway (Order 5)
River Kilcrow



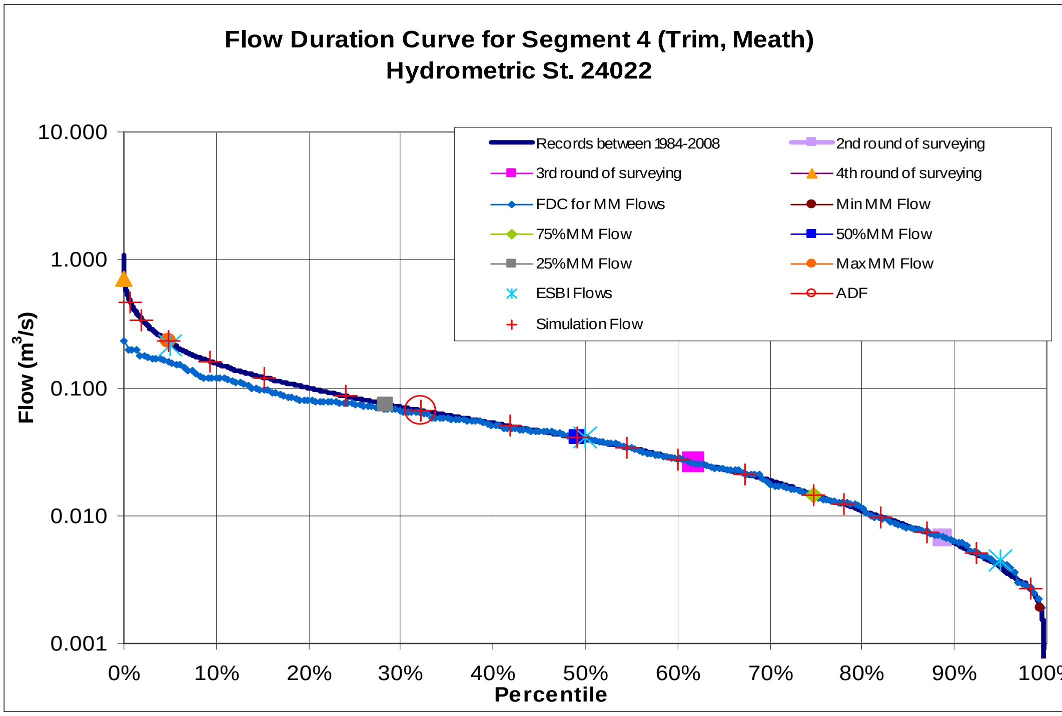
Note: River Segment highlighted red

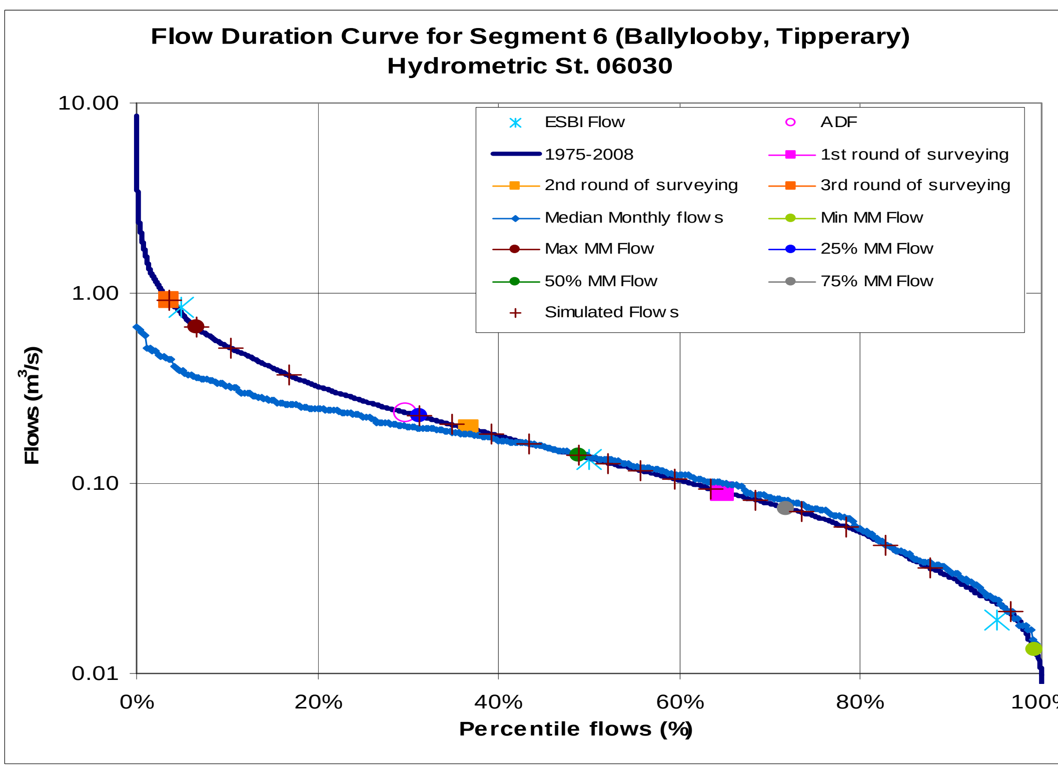
Segment 92 - Newcastle, Tipperary (Order 5)
River Tar

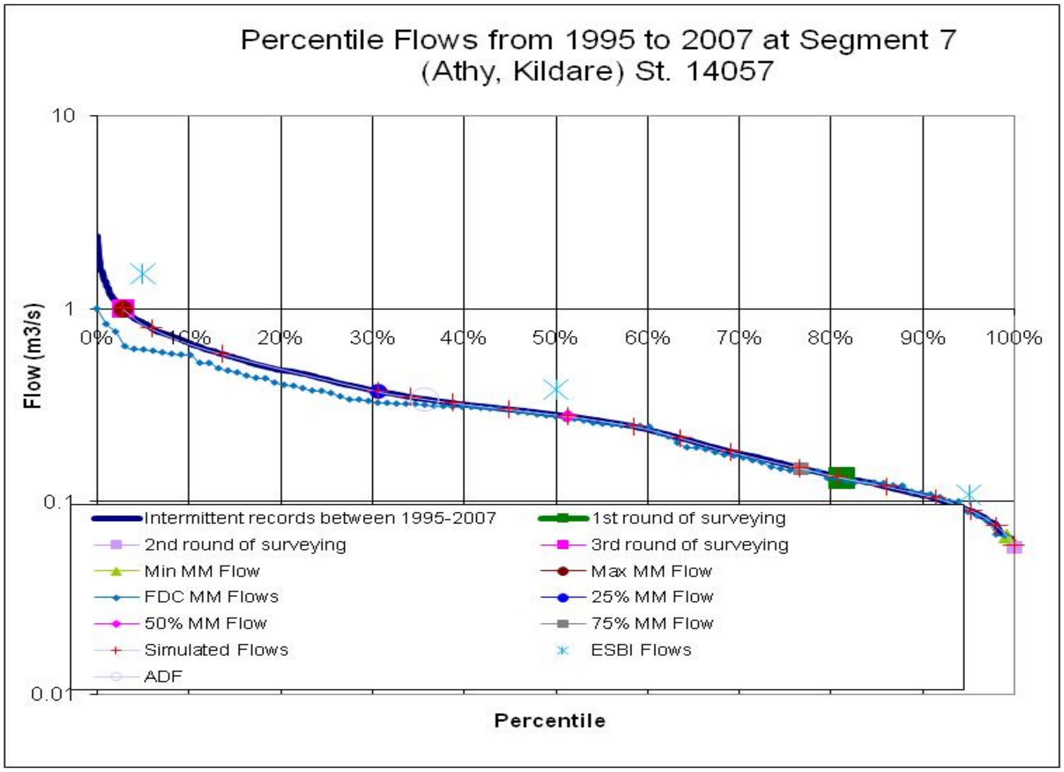


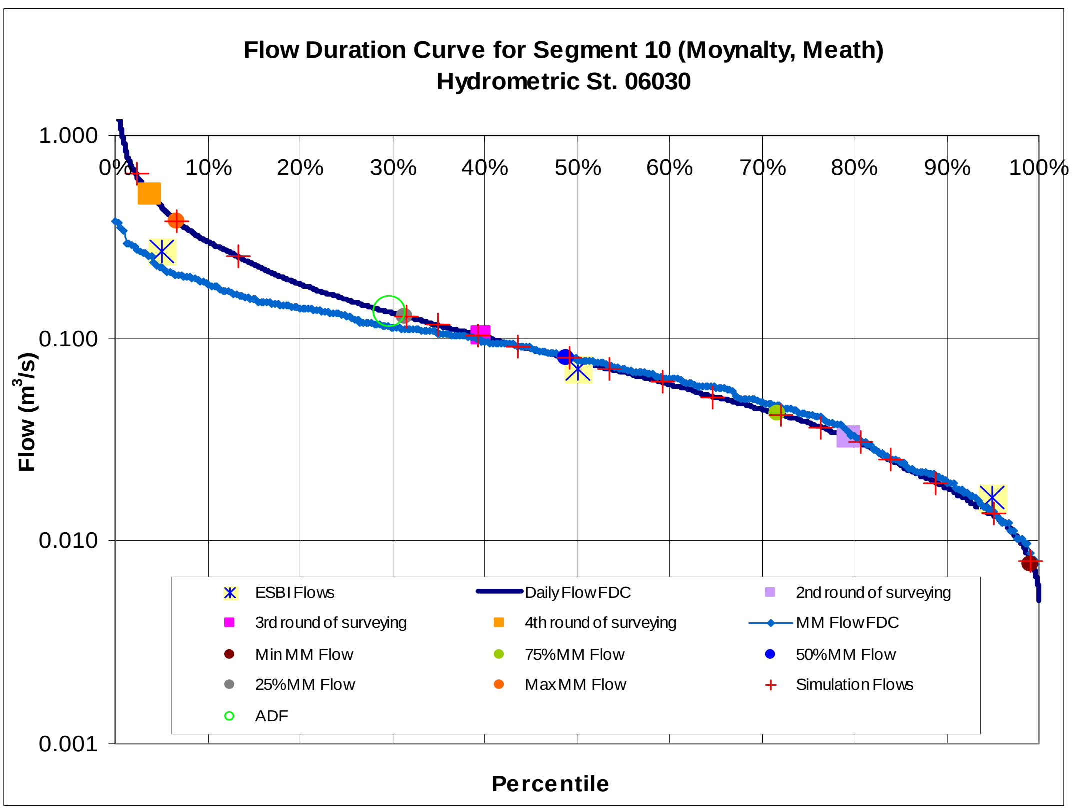
Note: River Segment highlighted in red

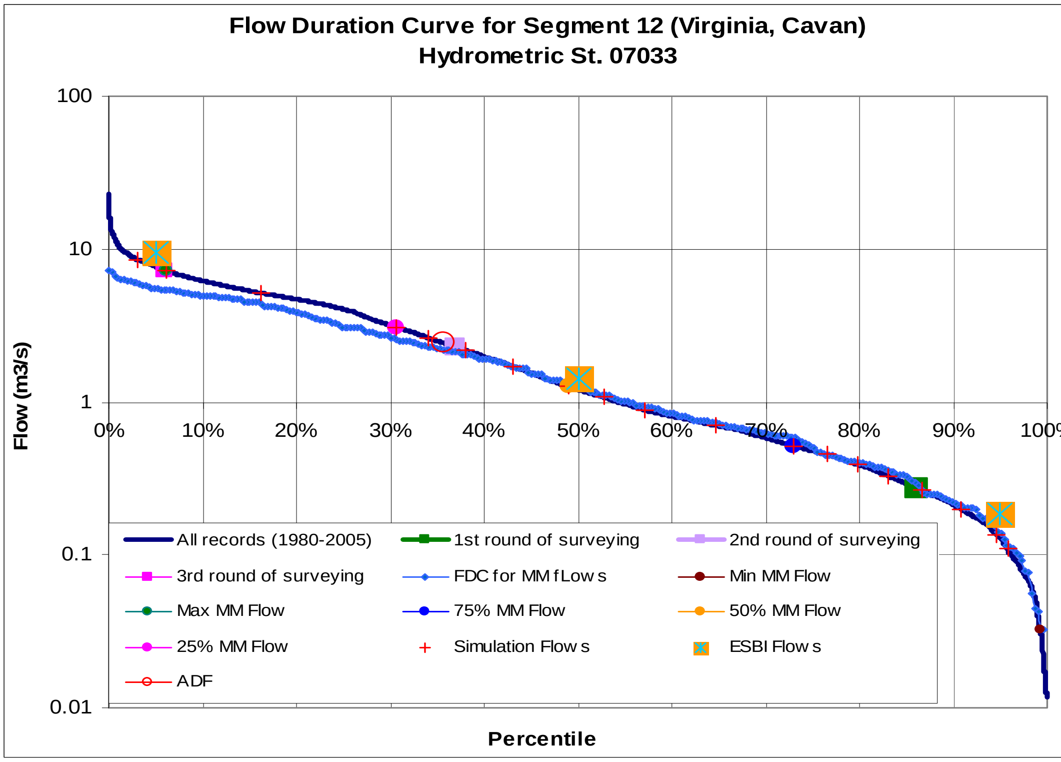
Appendix B – Flow Duration Curves

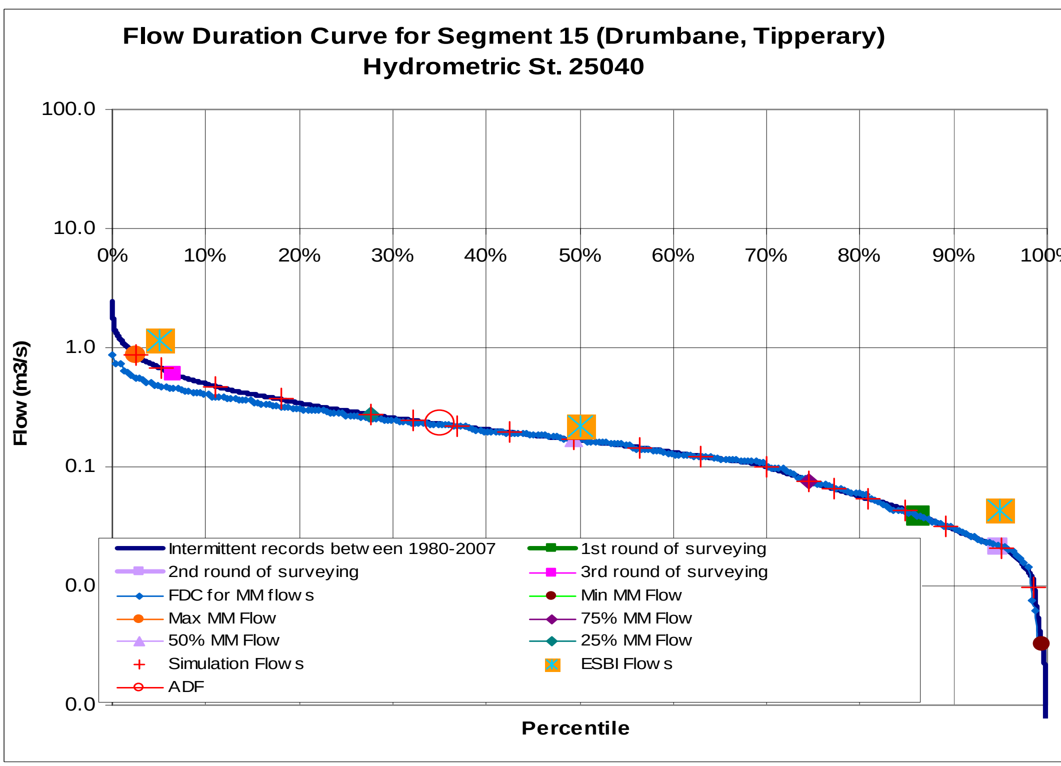

Flow Duration Curve for Segment 4 (Trim, Meath)
Hydrometric St. 24022
Flow (m3/s)
10.000
1.000
0.100
0.010
0.001
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile
Records between 1984-2008
2nd round of surveying
3rd round of surveying
4th round of surveying
FDC for MM Flows
Min MM Flow
75%MM Flow
50%MM Flow
25%MM Flow
Max MM Flow
ESBI Flows
ADF
Simulation Flow

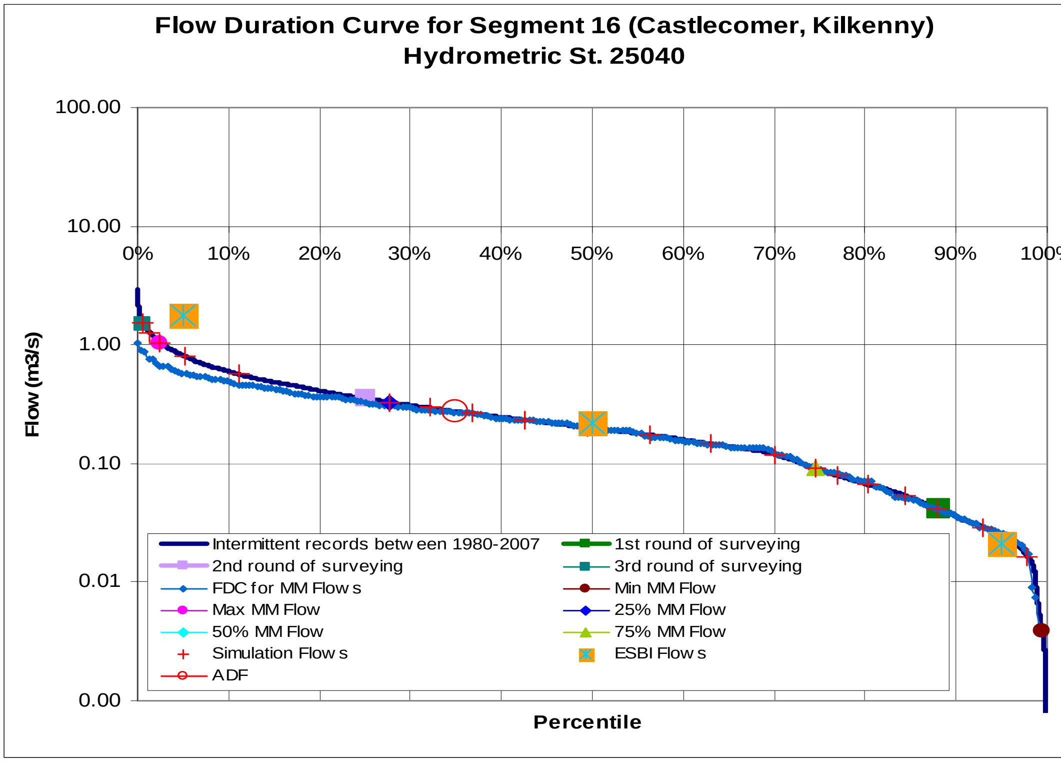

Flow Duration Curve for Segment 6 (Ballylooby, Tipperary)
Hydrometric St. 06030
Flows (m3/s)
10.00
1.00
0.10
0.01
0%
20%
40%
60%
80%
100%
Percentile flows (%)
ESBI Flow
ADF
1975-2008
1st round of surveying
2nd round of surveying
3rd round of surveying
Median Monthly flow s
Min MM Flow
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulated Flow s

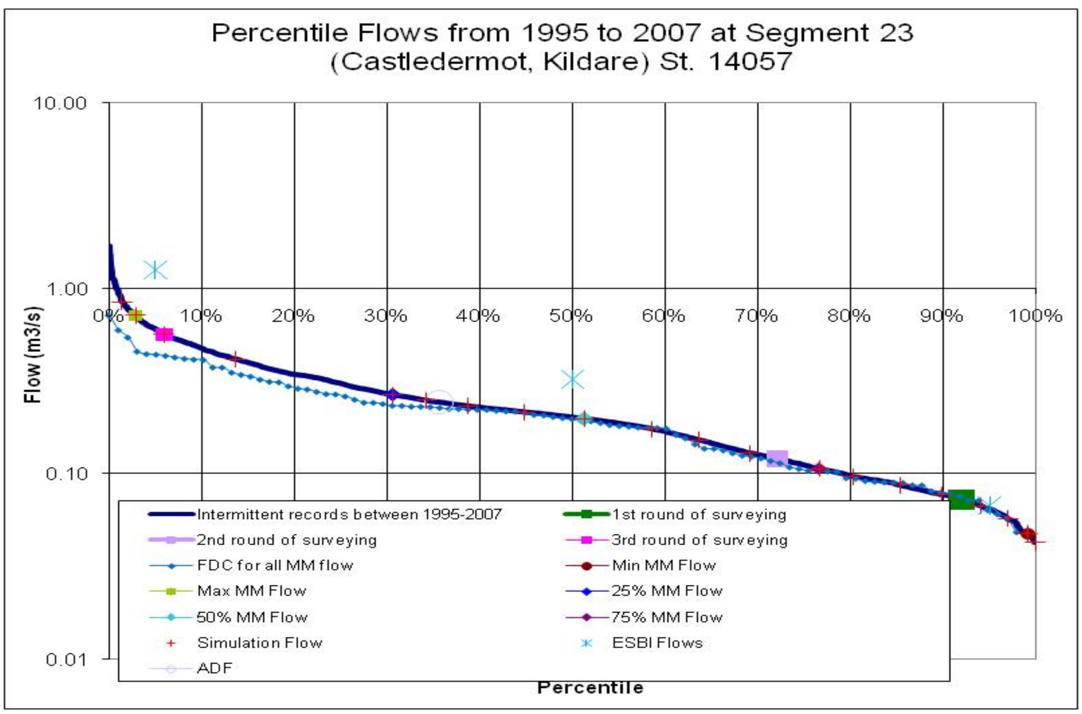

Percentile Flows from 1995 to 2007 at Segment 7
(Athy, Kildare) St. 14057
Flow (m3/s)
10
1
0.1
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile
Intermittent records between 1995-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
Min MM Flow
Max MM Flow
FDC MM Flows
25% MM Flow
50% MM Flow
75% MM Flow
Simulated Flows
ESBI Flows
ADF

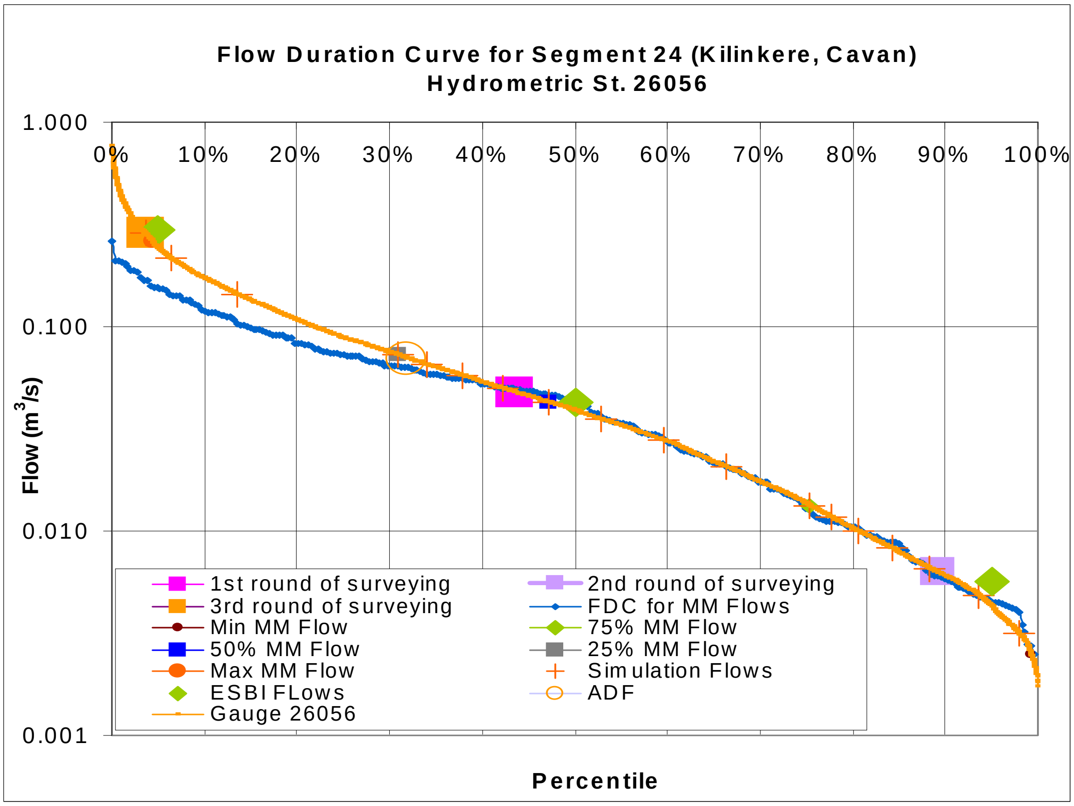

Flow Duration Curve for Segment 10 (Moynalty, Meath)
Hydrometric St. 06030
Flow (m3/s)
1.000
0.100
0.010
0.001
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile
ESBI Flows
Daily Flow FDC
2nd round of surveying
3rd round of surveying
4th round of surveying
MM Flow FDC
Min MM Flow
75%MM Flow
50%MM Flow
25%MM Flow
Max MM Flow
Simulation Flows
ADF

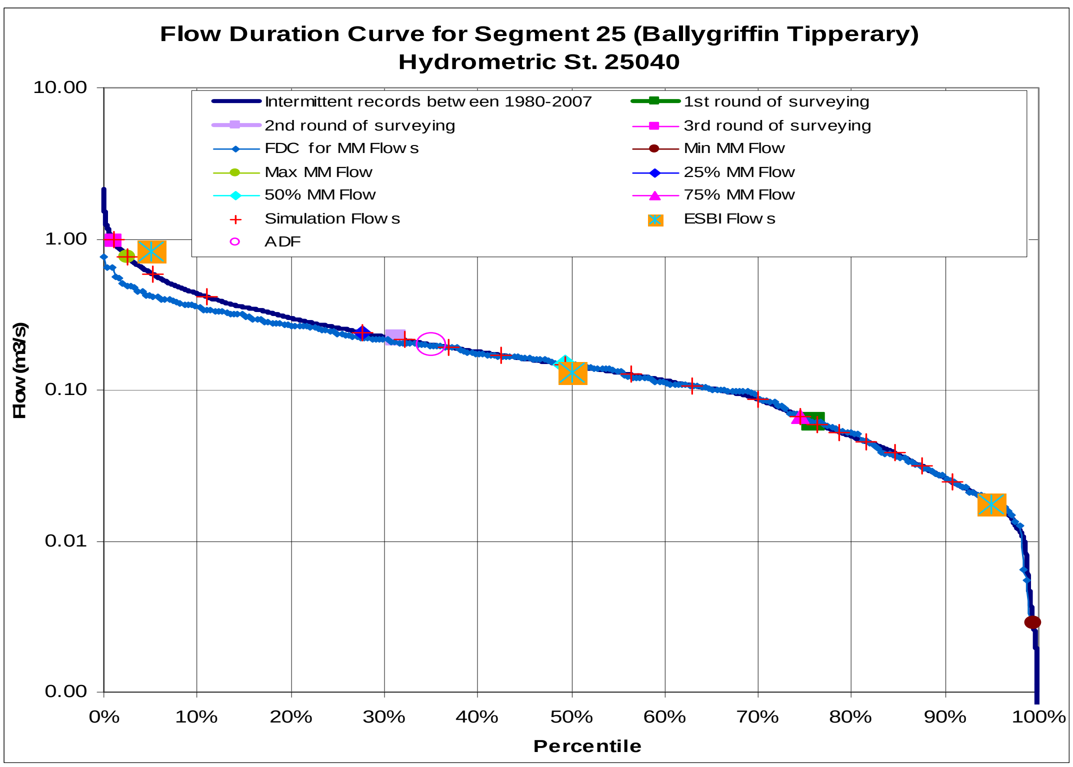

Flow Duration Curve for Segment 12 (Virginia, Cavan)
Hydrometric St. 07033
Flow (m3/s)
100
10
1
0.1
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
All records (1980-2005)
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM fLow s
Min MM Flow
Max MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Simulation Flow s
ESBI Flow s
ADF
Percentile

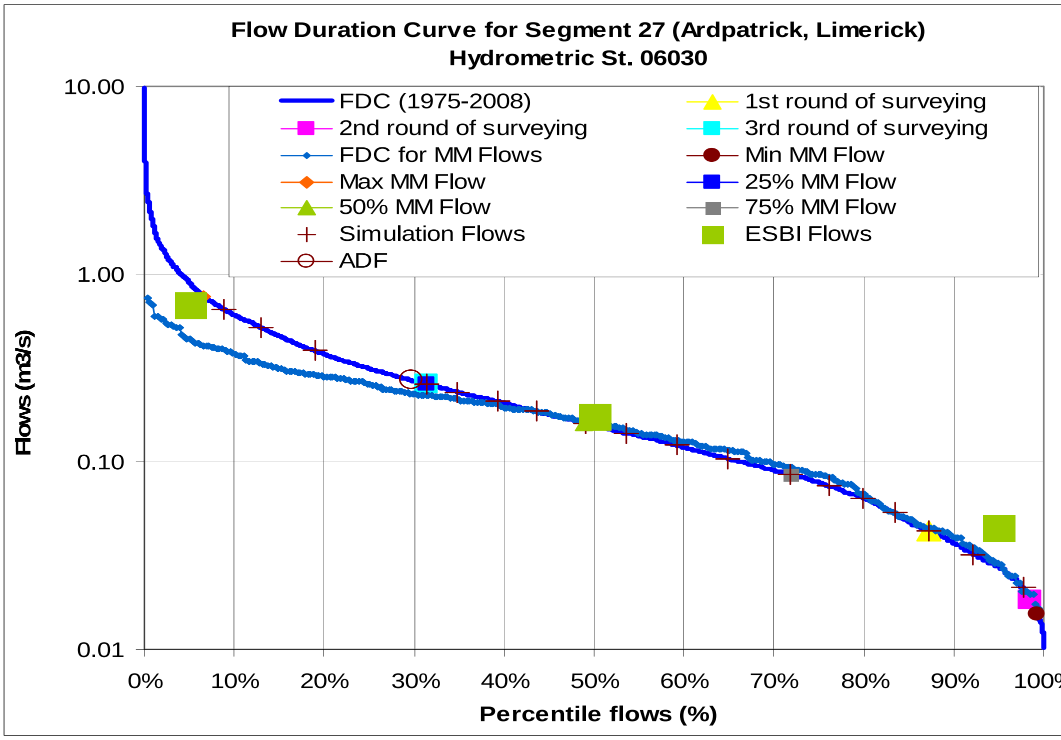

Flow Duration Curve for Segment 15 (Drumbane, Tipperary)
Hydrometric St. 25040
Flow (m3/s)
100.0
10.0
1.0
0.1
0.0
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Intermittent records betw een 1980-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM flow s
Min MM Flow
Max MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Simulation Flow s
ESBI Flow s
ADF
Percentile

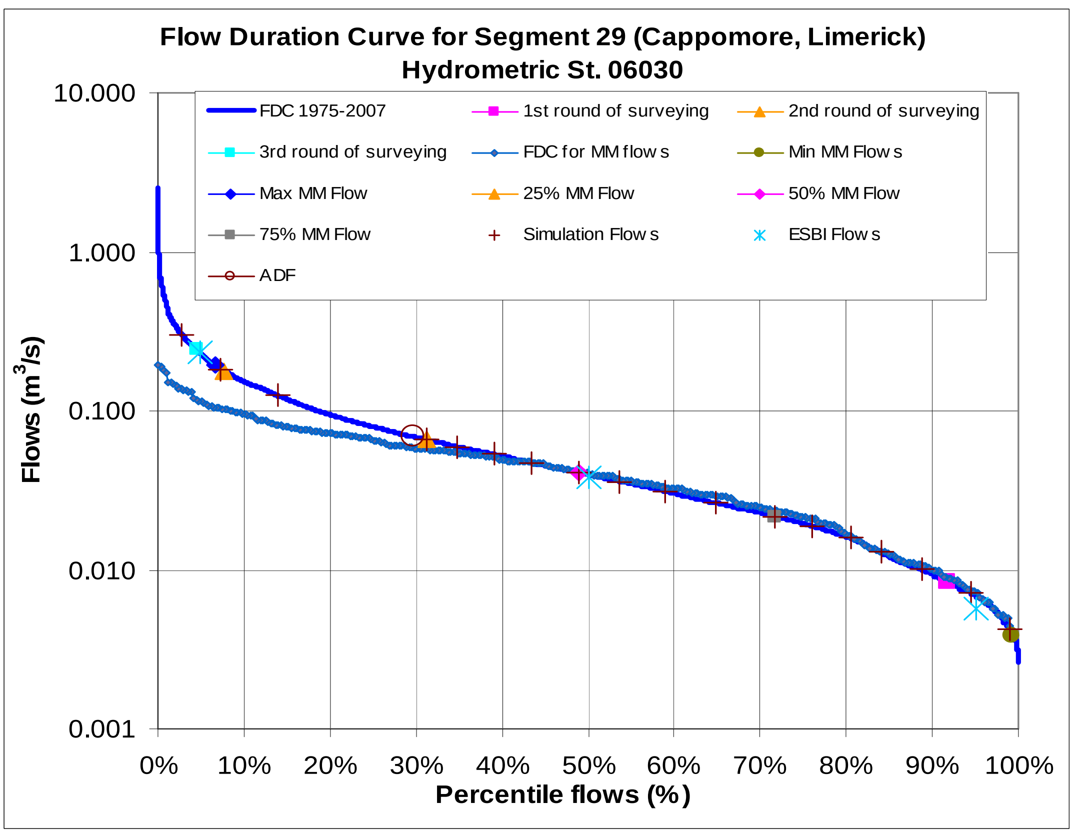

Flow Duration Curve for Segment 16 (Castlecomer, Kilkenny)
Hydrometric St. 25040
Flow (m3/s)
100.00
10.00
1.00
0.10
0.01
0.00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Intermittent records betw een 1980-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flow s
Min MM Flow
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulation Flow s
ESBI Flow s
ADF
Percentile

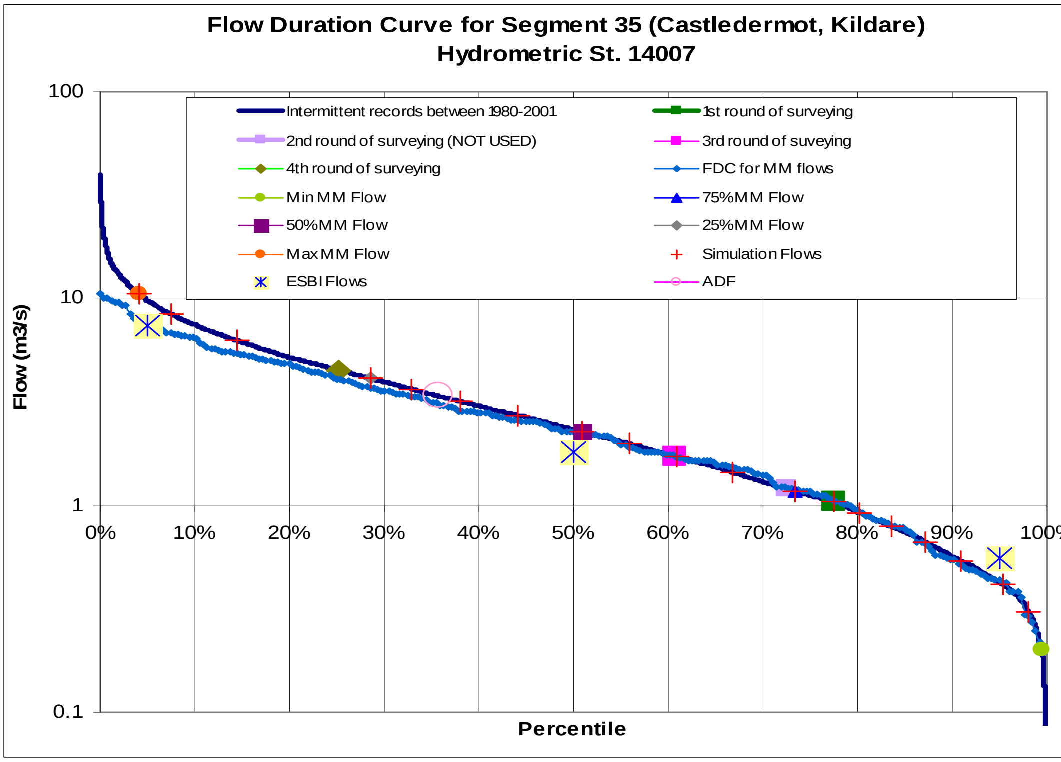

Percentile Flows from 1995 to 2007 at Segment 23
(Castledermot, Kildare) St. 14057
Flow (m3/s)
10.00
1.00
0.10
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Intermittent records between 1995-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for all MM flow
Min MM Flow
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulation Flow
ESBI Flows
ADF
Percentile

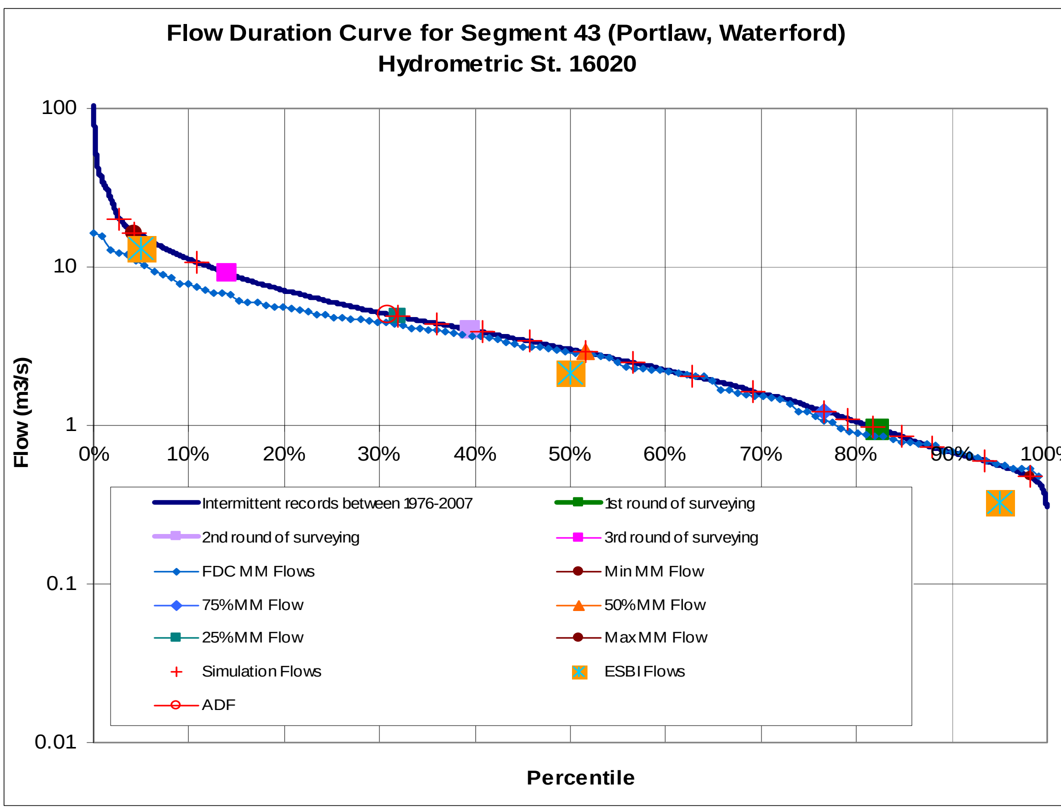

Flow Duration Curve for Segment 24 (Kilinkere, Cavan)
Hydrometric St. 26056
Flow (m3/s)
1.000
0.100
0.010
0.001
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flows
Min MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Max MM Flow
Simulation Flows
ESBI FLows
ADF
Gauge 26056
Percentile

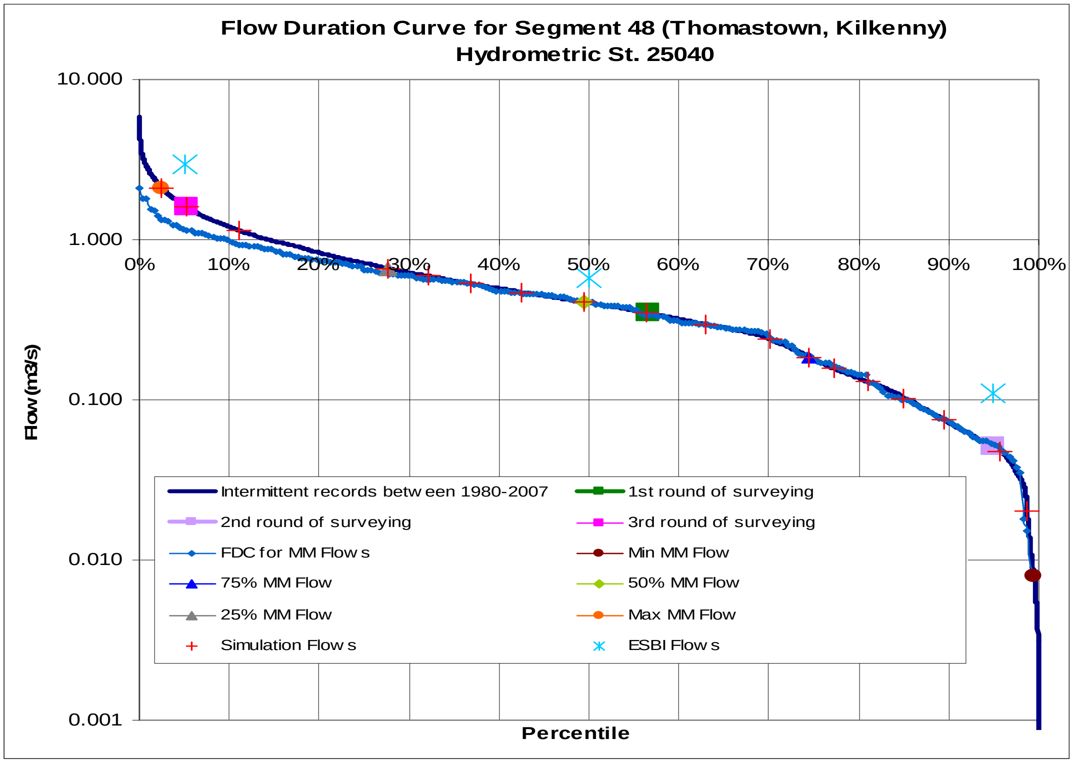

Flow Duration Curve for Segment 25 (Ballygriffin Tipperary)
Hydrometric St. 25040
Flow (m3/s)
10.00
1.00
0.10
0.01
0.00
Intermittent records between 1980-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flows
Min MM Flow
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulation Flows
ESBI Flows
ADF
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile

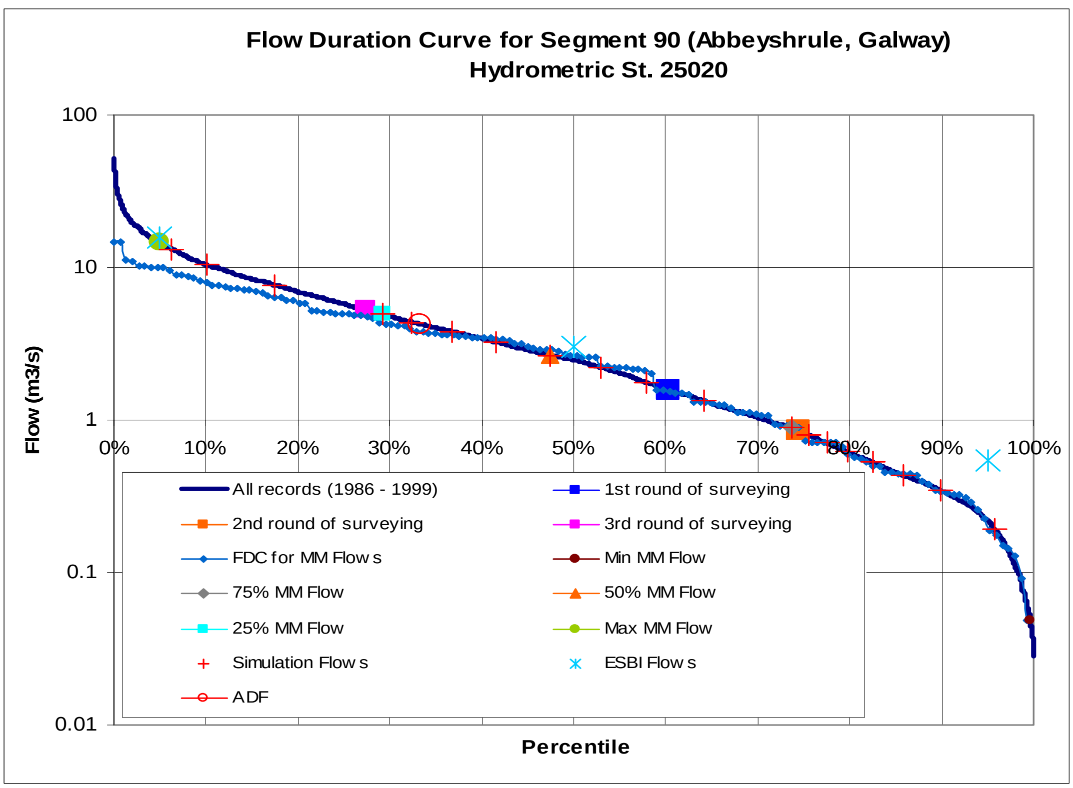

Flow Duration Curve for Segment 27 (Ardpatrick, Limerick)
Hydrometric St. 06030
FDC (1975-2008)
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flows
Min MM Flow
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulation Flows
ESBI Flows
ADF
Flows (m3/s)
10.00
1.00
0.10
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile flows (%)

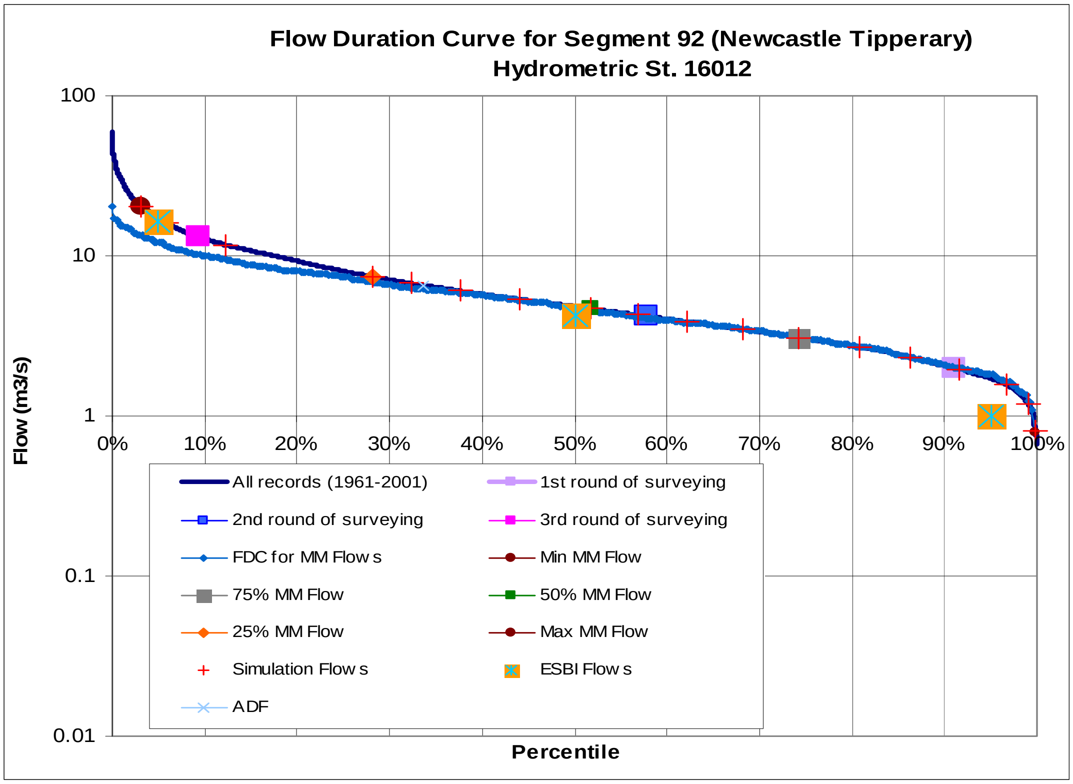

Flow Duration Curve for Segment 29 (Cappomore, Limerick)
Hydrometric St. 06030
FDC 1975-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM flows
Min MM Flows
Max MM Flow
25% MM Flow
50% MM Flow
75% MM Flow
Simulation Flows
ESBI Flows
ADF
Flows (m3/s)
10.000
1.000
0.100
0.010
0.001
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile flows (%)


Flow Duration Curve for Segment 35 (Castledermot, Kildare)
Hydrometric St. 14007
Flow (m3/s)
Percentile
Intermittent records between 1980-2001
1st round of surveying
2nd round of surveying (NOT USED)
3rd round of surveying
4th round of surveying
FDC for MM flows
Min MM Flow
75%MM Flow
50%MM Flow
25%MM Flow
Max MM Flow
Simulation Flows
ESBI Flows
ADF
100
10
1
0.1
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

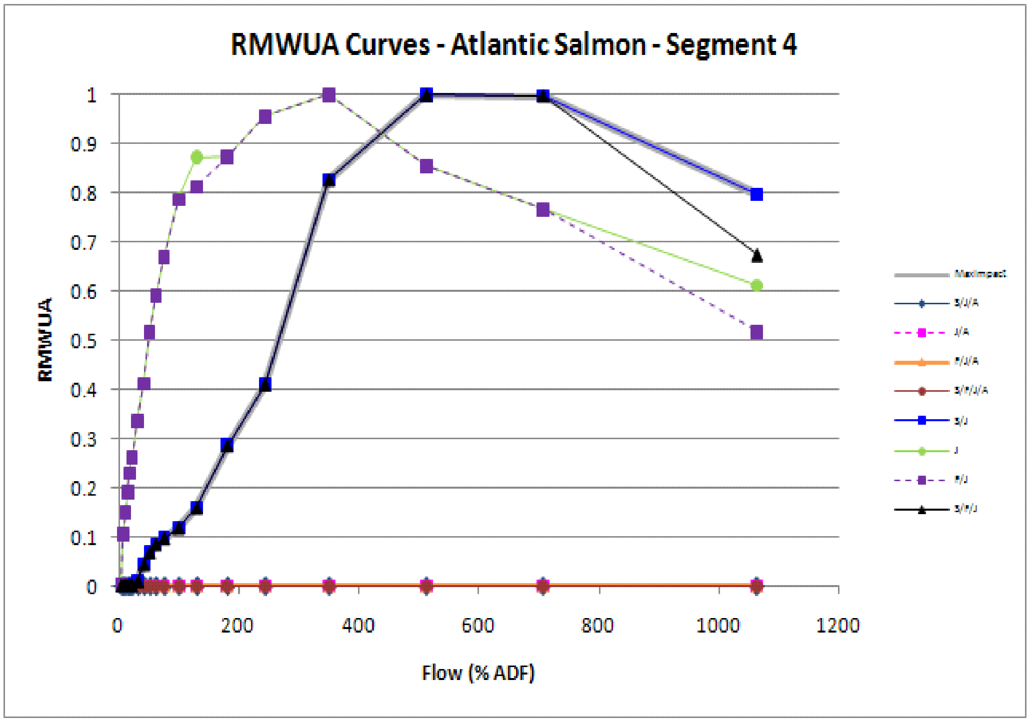

Flow Duration Curve for Segment 43 (Portlaw, Waterford)
Hydrometric St. 16020
Flow (m3/s)
Percentile
Intermittent records between 1976-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC MM Flows
Min MM Flow
75%MM Flow
50%MM Flow
25%MM Flow
Max MM Flow
Simulation Flows
ESBI Flows
ADF
100
10
1
0.1
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Flow Duration Curve for Segment 48 (Thomastown, Kilkenny)
Hydrometric St. 25040
10.000
1.000
0.100
0.010
0.001
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Flow (m3/s)
Percentile
Intermittent records betw een 1980-2007
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flow s
Min MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Max MM Flow
Simulation Flow s
ESBI Flow s

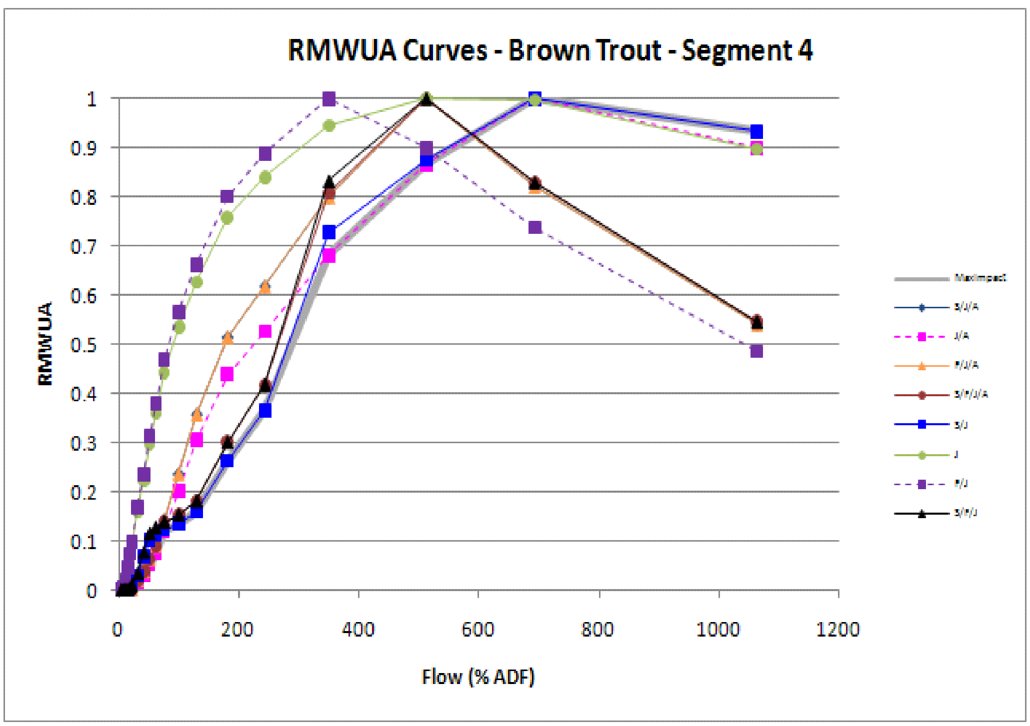

Flow Duration Curve for Segment 90 (Abbeyshrule, Galway)
Hydrometric St. 25020
100
10
1
0.1
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Flow (m3/s)
Percentile
All records (1986 - 1999)
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flow s
Min MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Max MM Flow
Simulation Flow s
ESBI Flow s
ADF


Flow Duration Curve for Segment 92 (Newcastle Tipperary)
Hydrometric St. 16012
Flow (m3/s)
100
10
1
0.1
0.01
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile
All records (1961-2001)
1st round of surveying
2nd round of surveying
3rd round of surveying
FDC for MM Flows
Min MM Flow
75% MM Flow
50% MM Flow
25% MM Flow
Max MM Flow
Simulation Flows
ESBI Flows
ADF

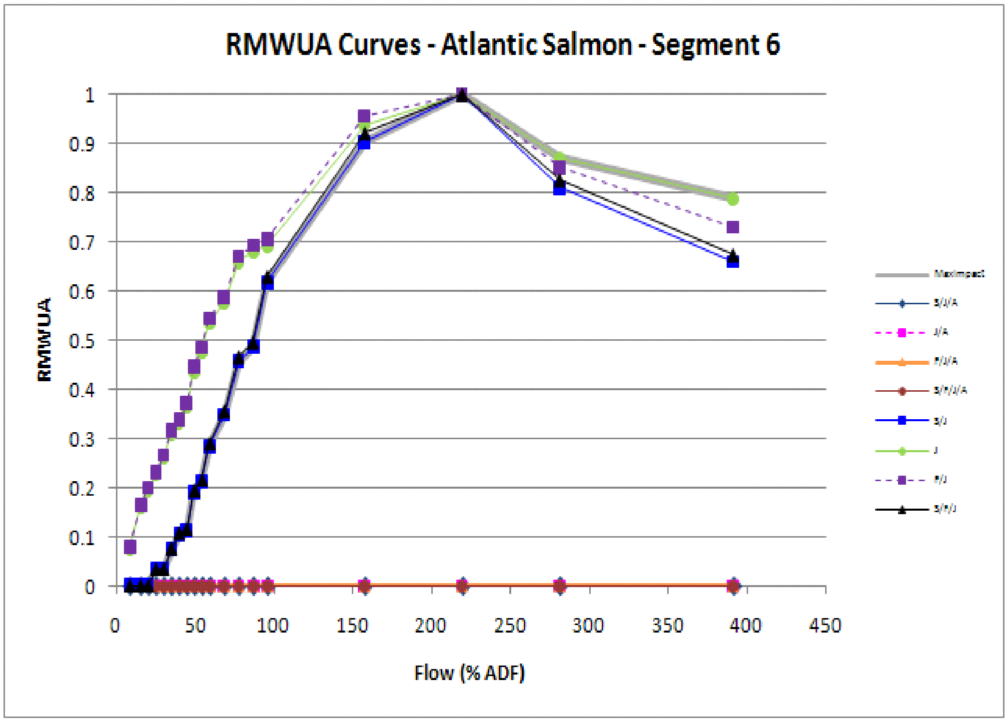
Appendix C – Max Impact RMWAU Curves

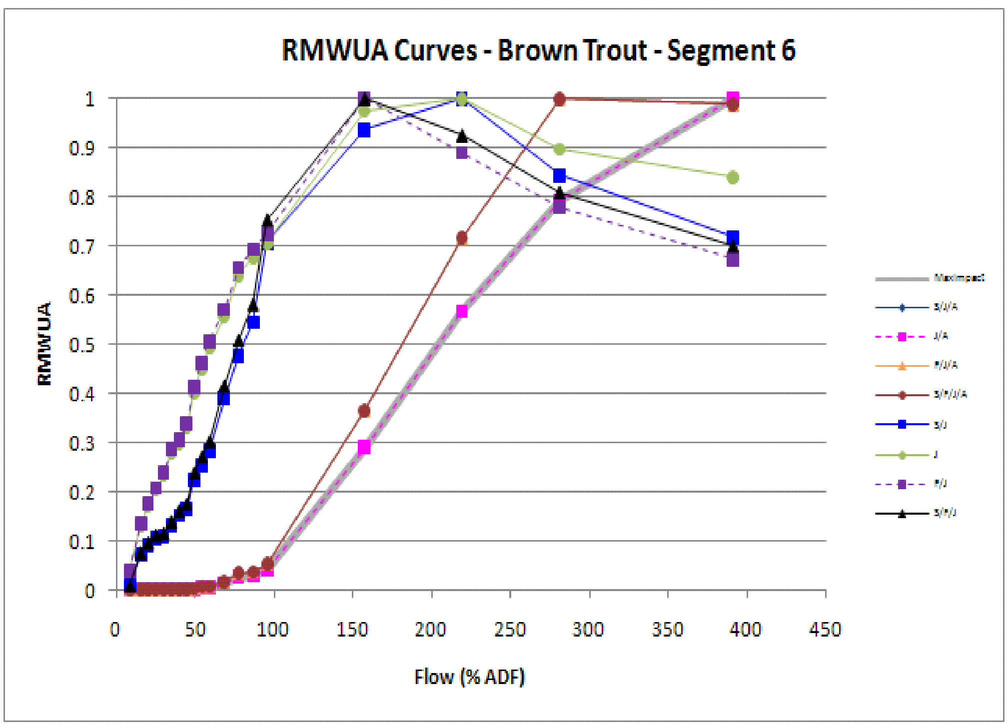


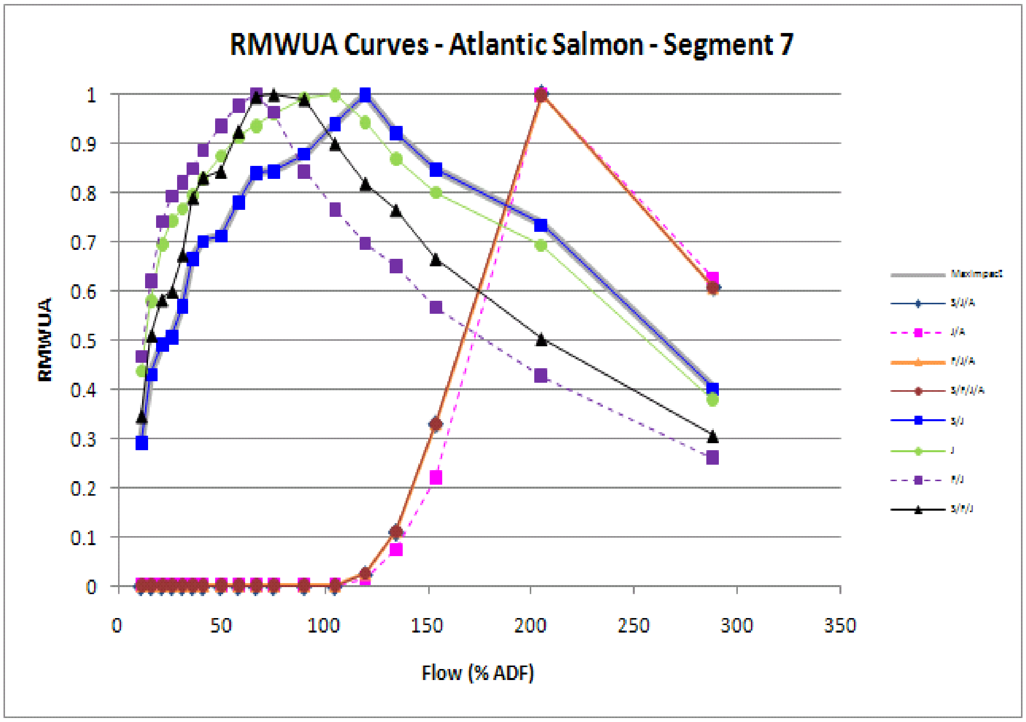
RMWUA Curves - Atlantic Salmon - Segment 4
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

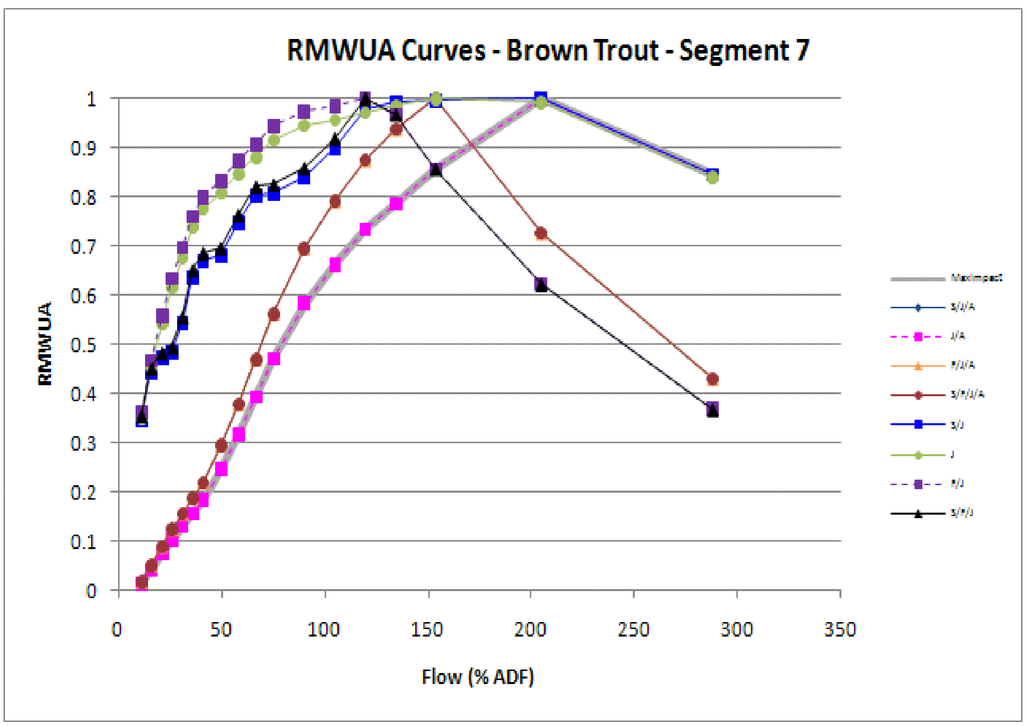


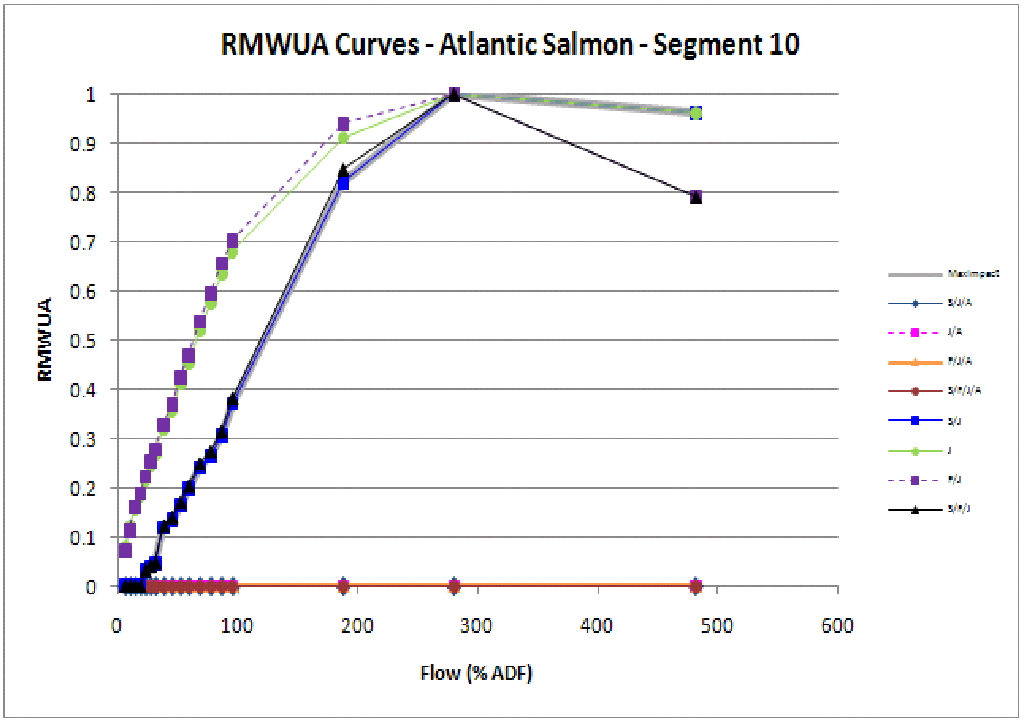
RMWUA Curves - Brown Trout - Segment 4
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

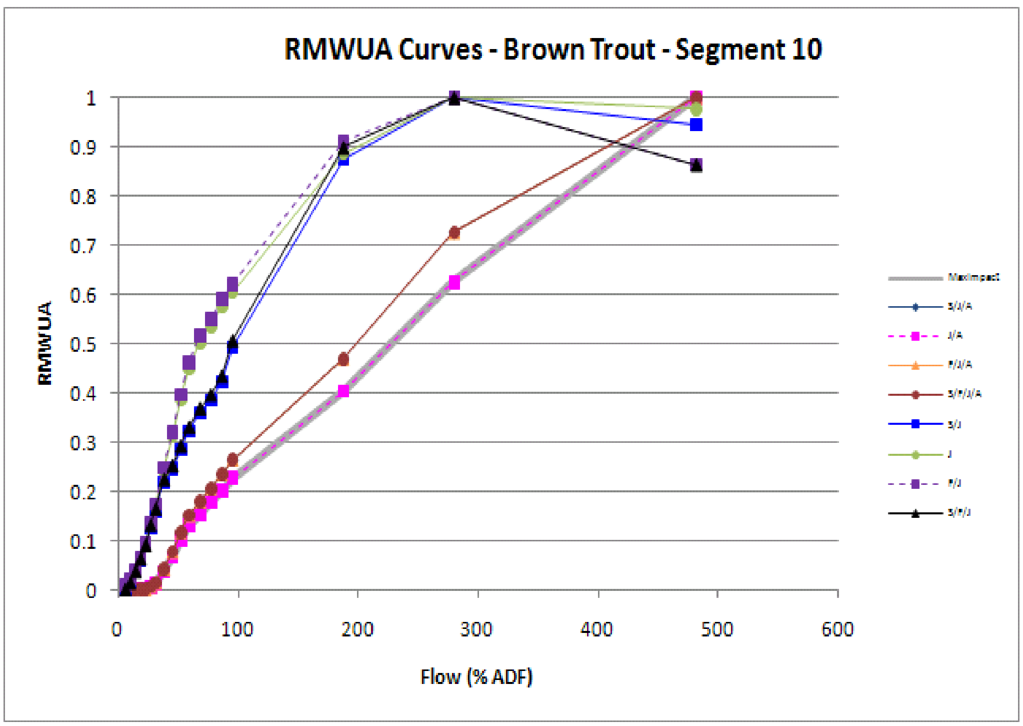

RMWUA Curves - Atlantic Salmon - Segment 6
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

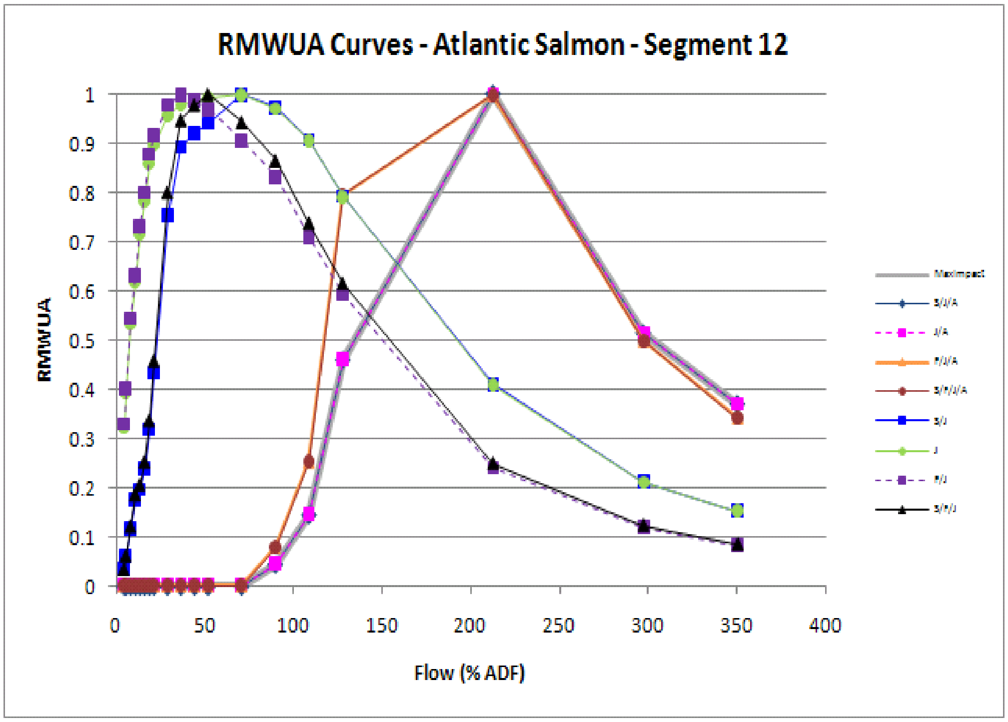

RMWUA Curves - Brown Trout - Segment 6
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

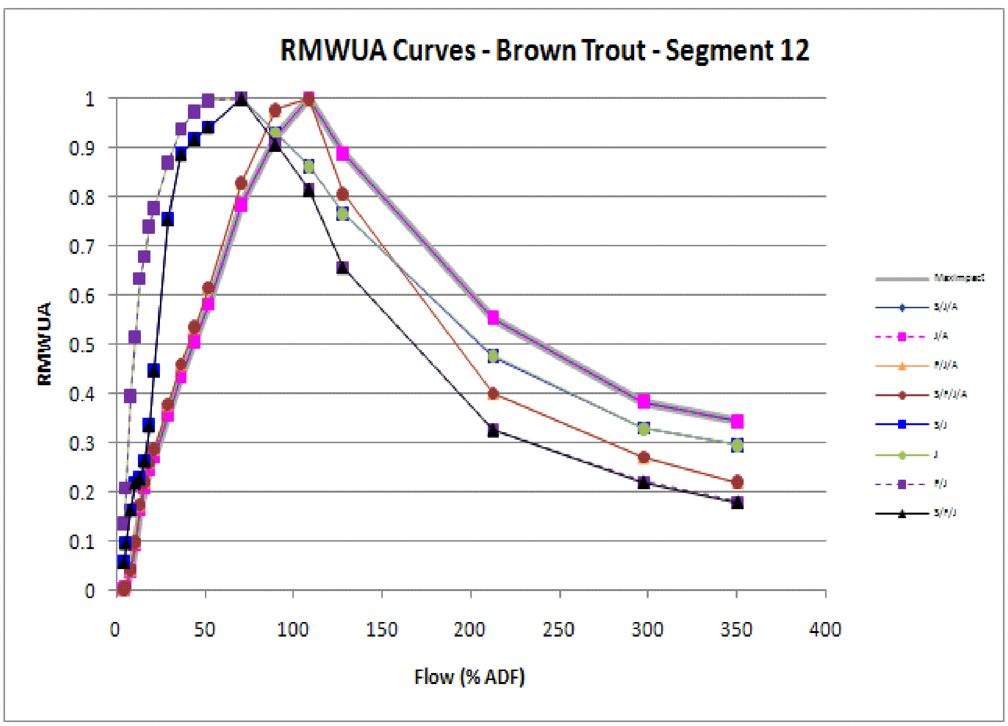

RMWUA Curves - Atlantic Salmon - Segment 7
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

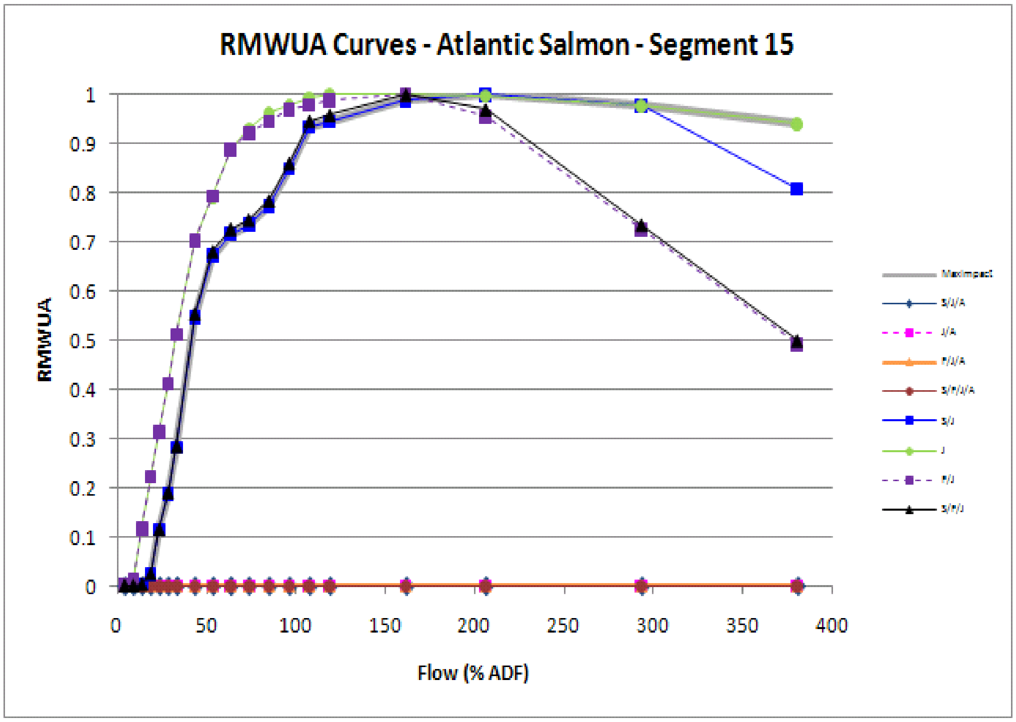

RMWUA Curves - Brown Trout - Segment 7
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

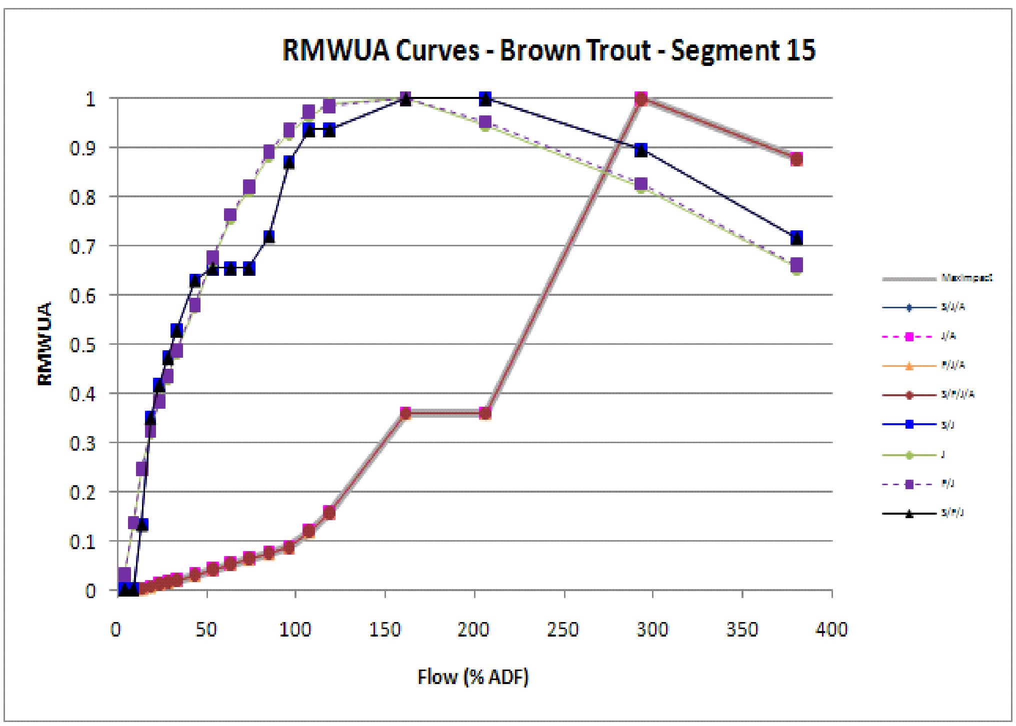

RMWUA Curves - Atlantic Salmon - Segment 10
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

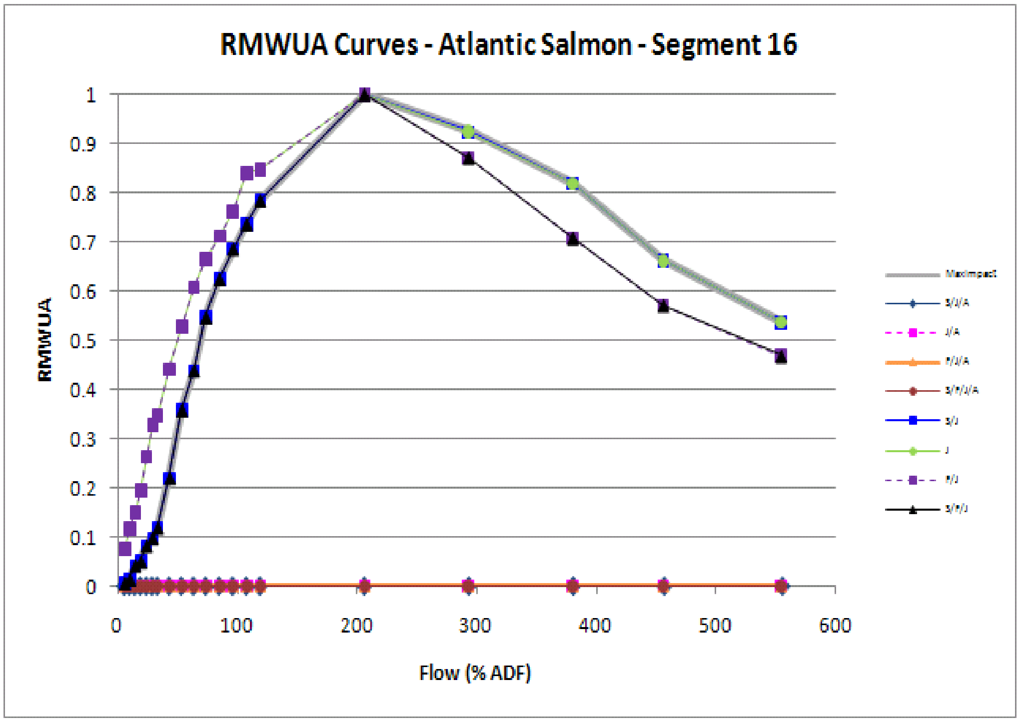

RMWUA Curves - Brown Trout - Segment 10
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

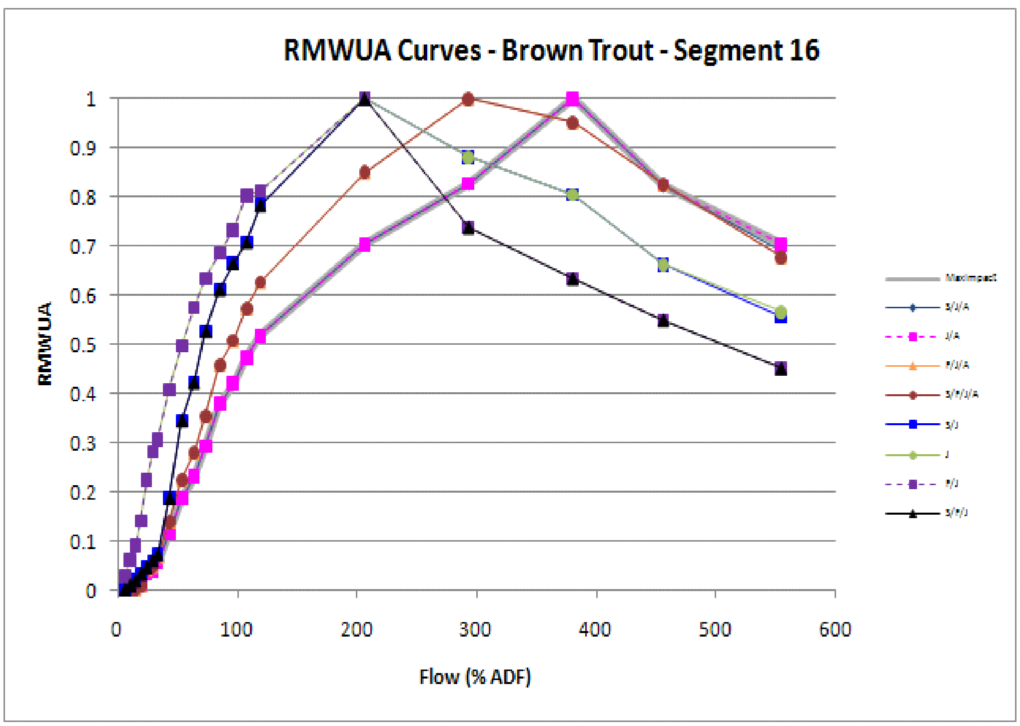

RMWUA Curves - Atlantic Salmon - Segment 12
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

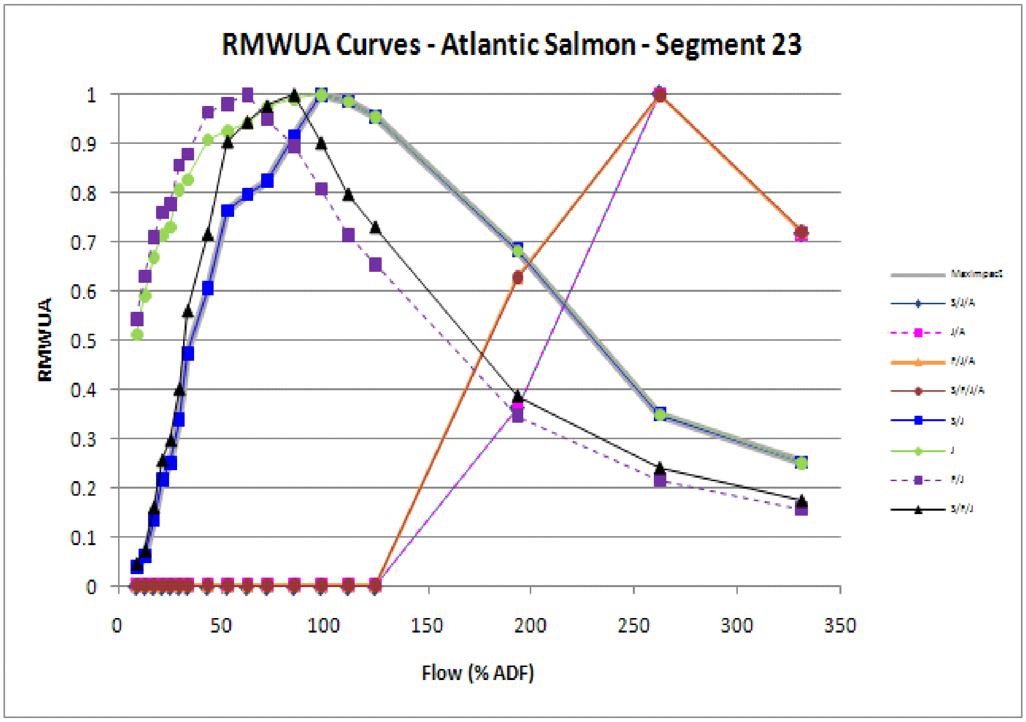

RMWUA Curves - Brown Trout - Segment 12
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

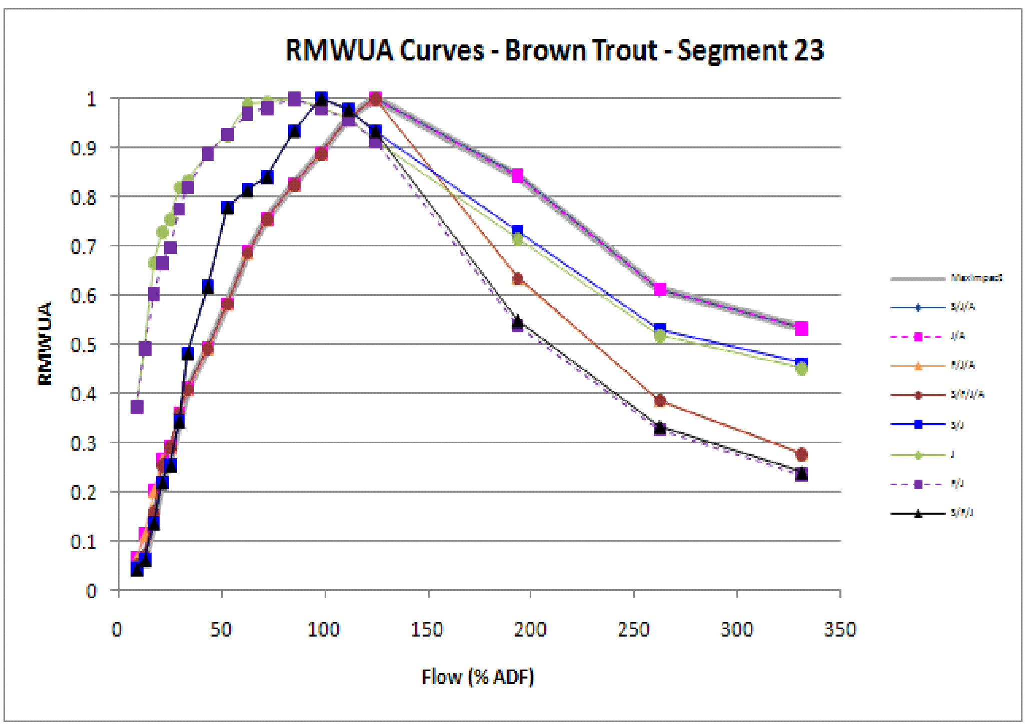

RMWUA Curves - Atlantic Salmon - Segment 15
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
Flow (% ADF)
MaxImpact
S/J/A
J/A
P/J/A
S/P/J/A
S/J
J
P/J
S/P/J

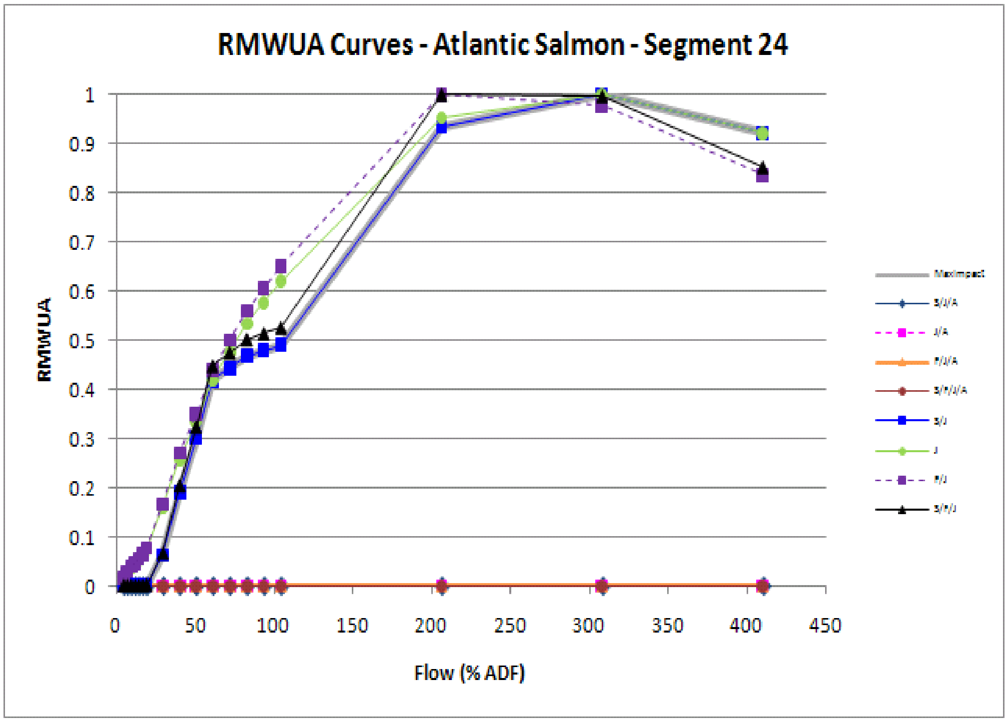

RMWUA Curves - Brown Trout - Segment 15
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
Flow (% ADF)
MaxImpact
S/J/A
J/A
P/J/A
S/P/J/A
S/J
J
P/J
S/P/J

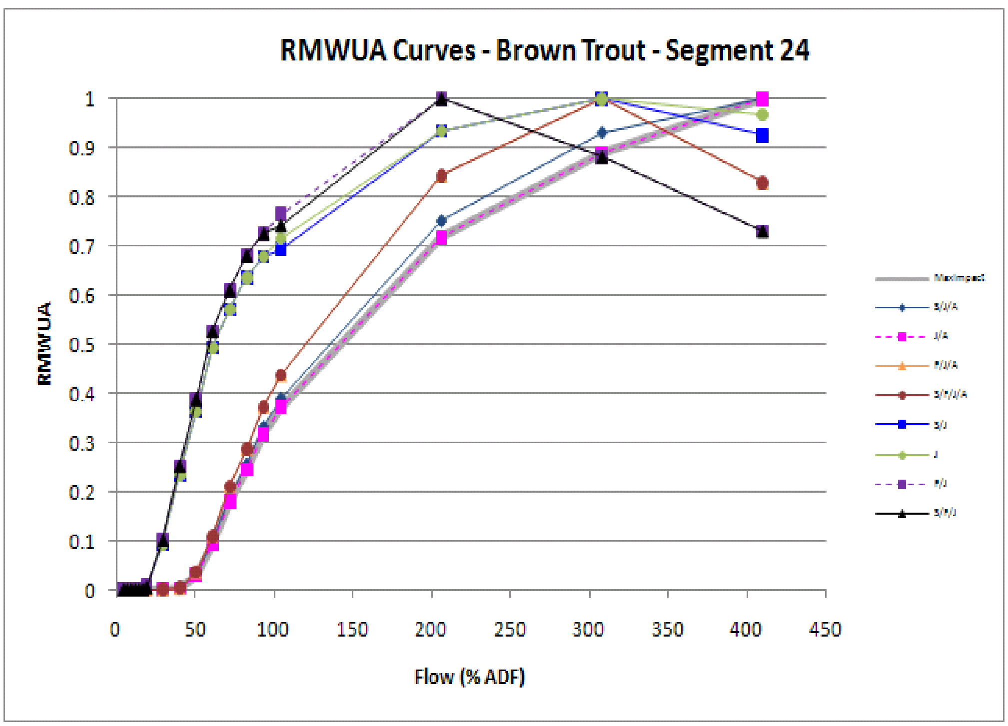

RMWUA Curves - Atlantic Salmon - Segment 16
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

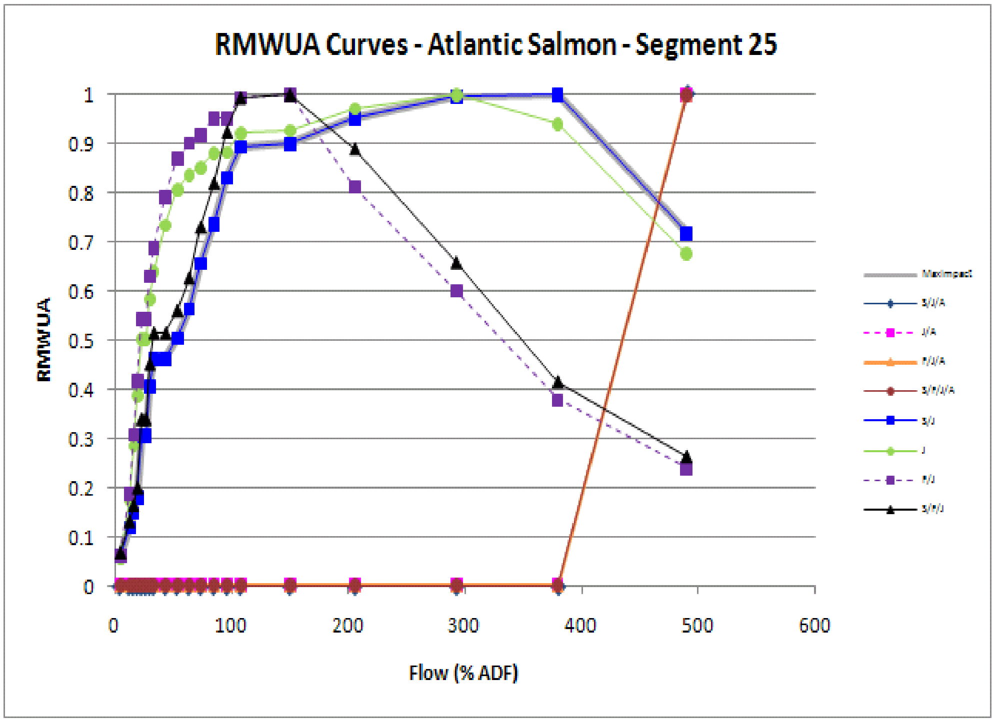

RMWUA Curves - Brown Trout - Segment 16
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

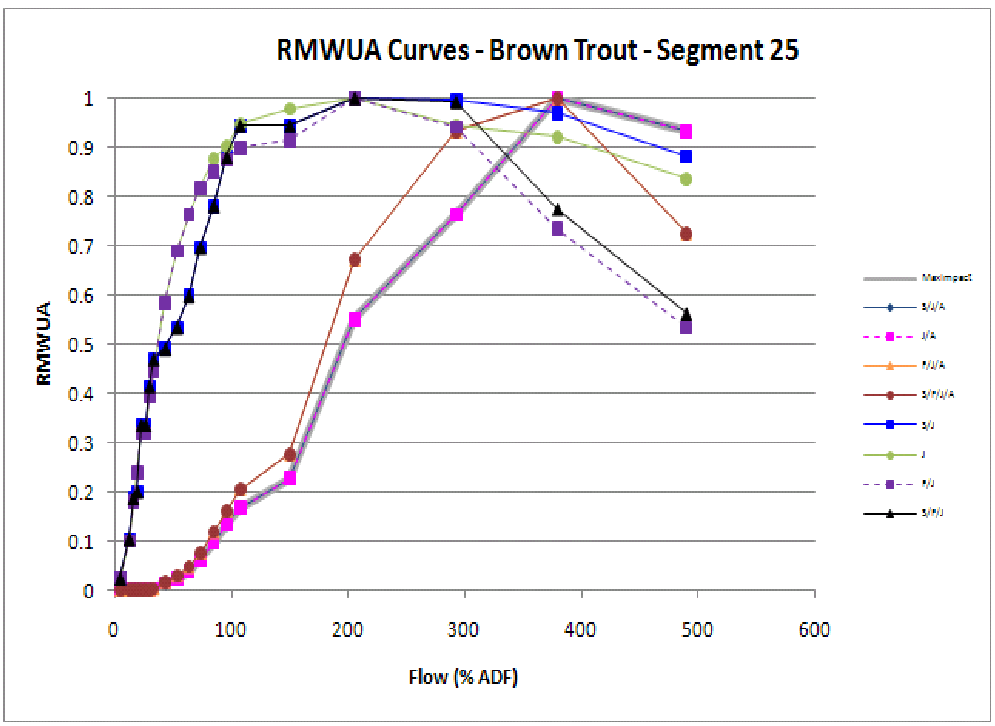

RMWUA Curves - Atlantic Salmon - Segment 23
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

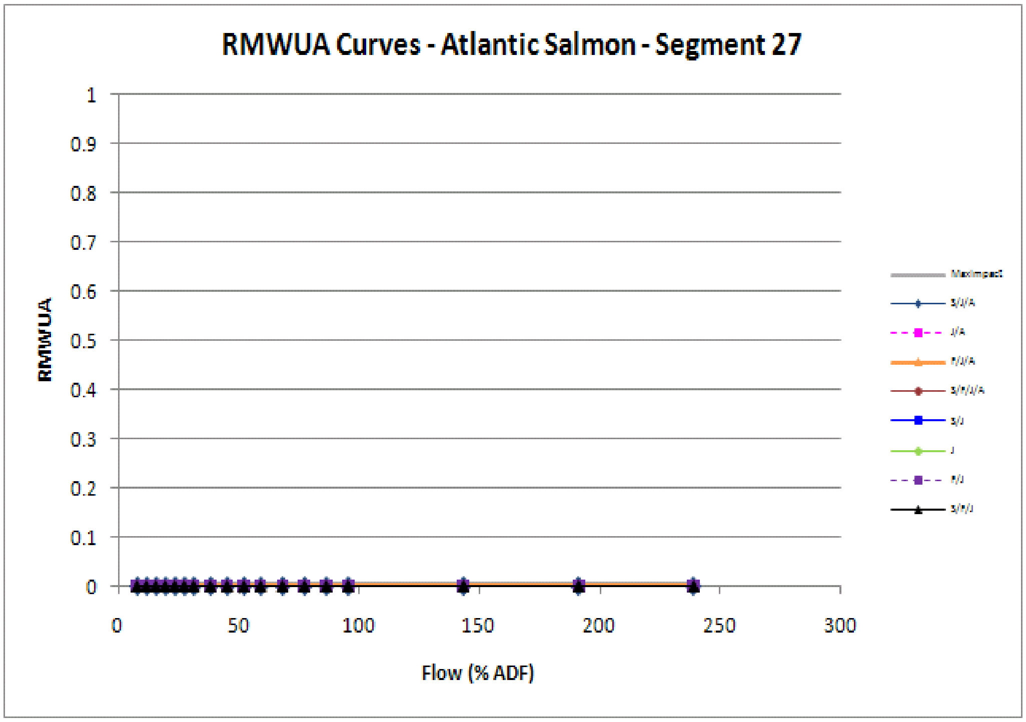

RMWUA Curves - Brown Trout - Segment 23
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

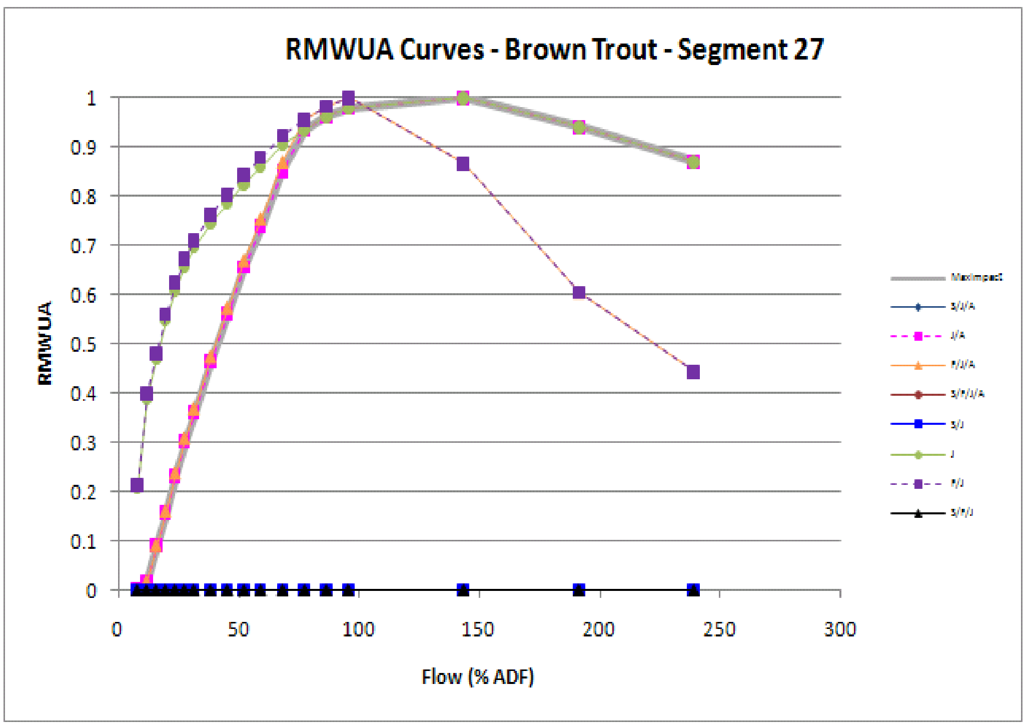

RMWUA Curves - Atlantic Salmon - Segment 24
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

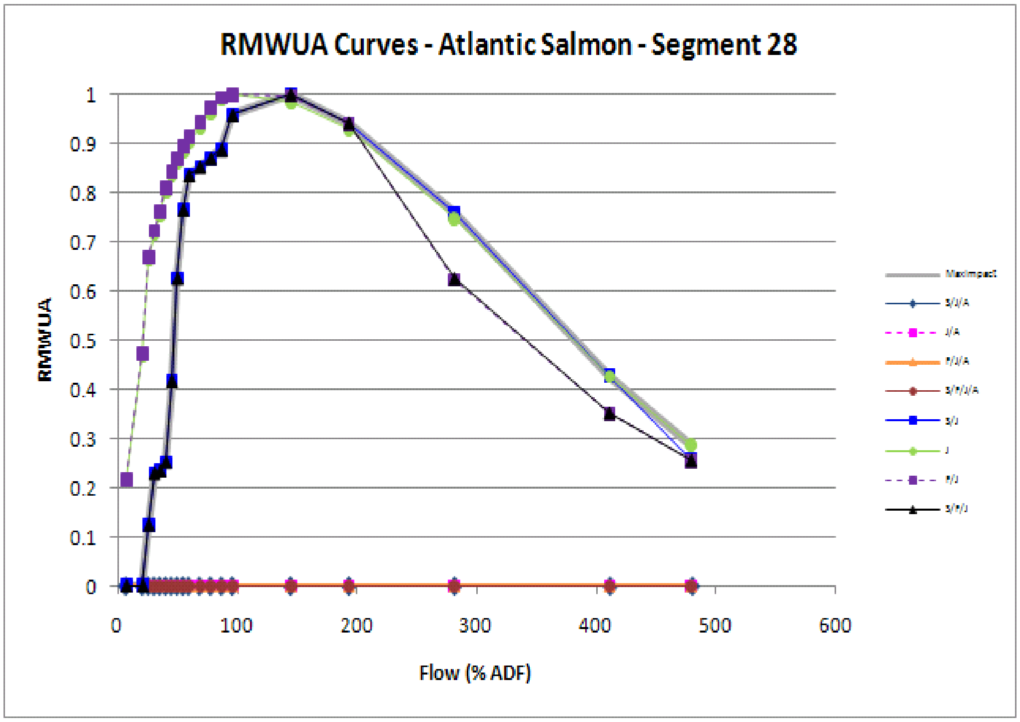

RMWUA Curves - Brown Trout - Segment 24
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

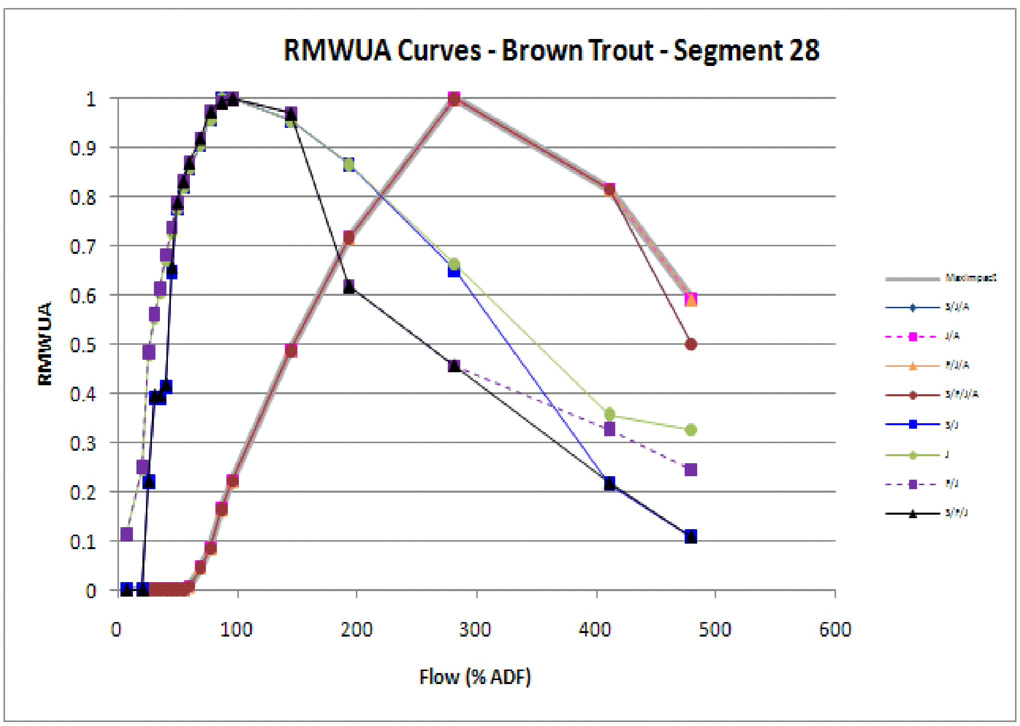

RMWUA Curves - Atlantic Salmon - Segment 25
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

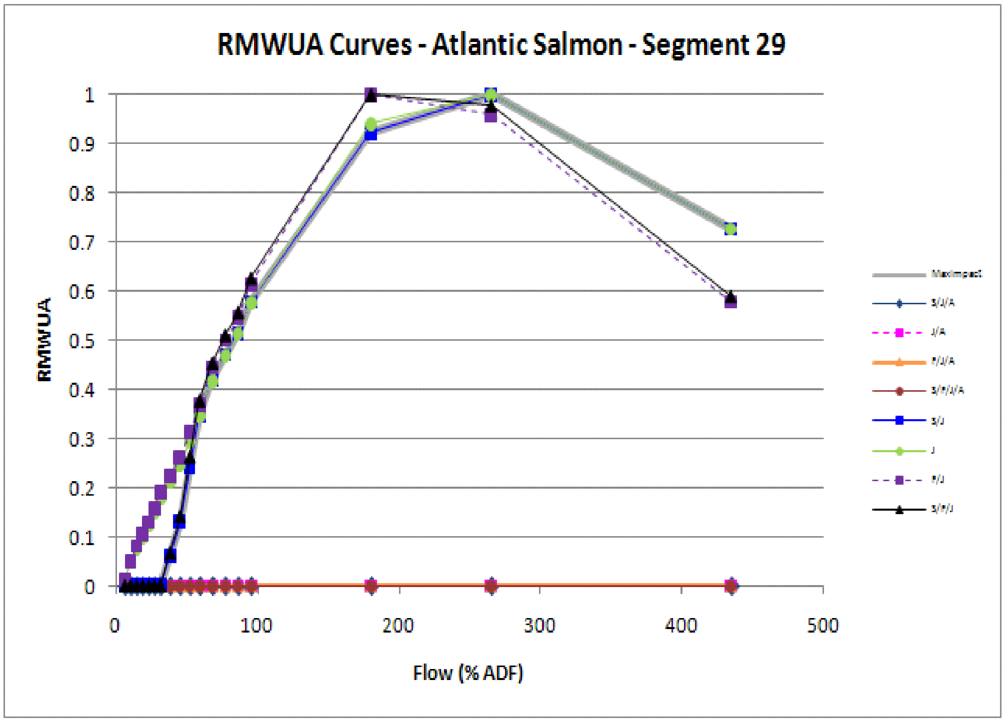

RMWUA Curves - Brown Trout - Segment 25
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

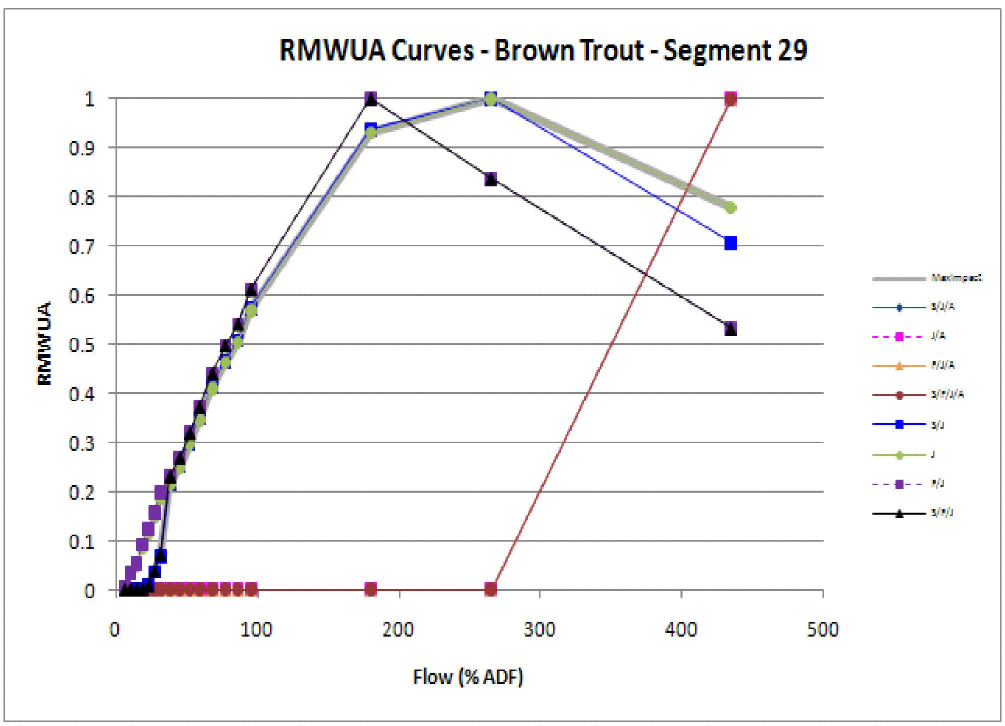

RMWUA Curves - Atlantic Salmon - Segment 27
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

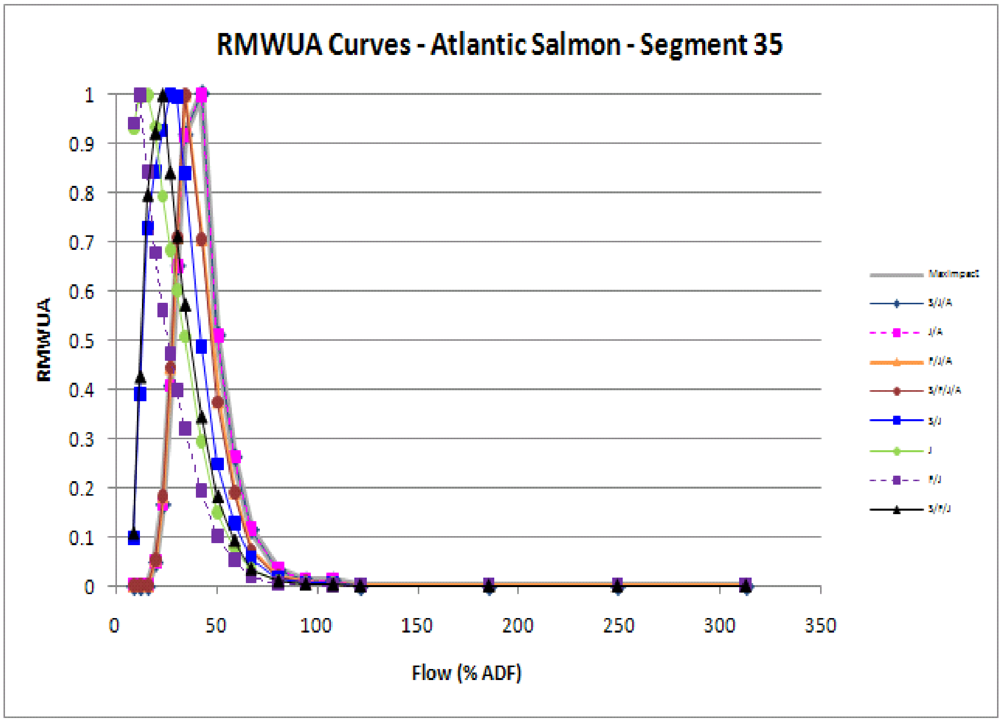

RMWUA Curves - Brown Trout - Segment 27
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

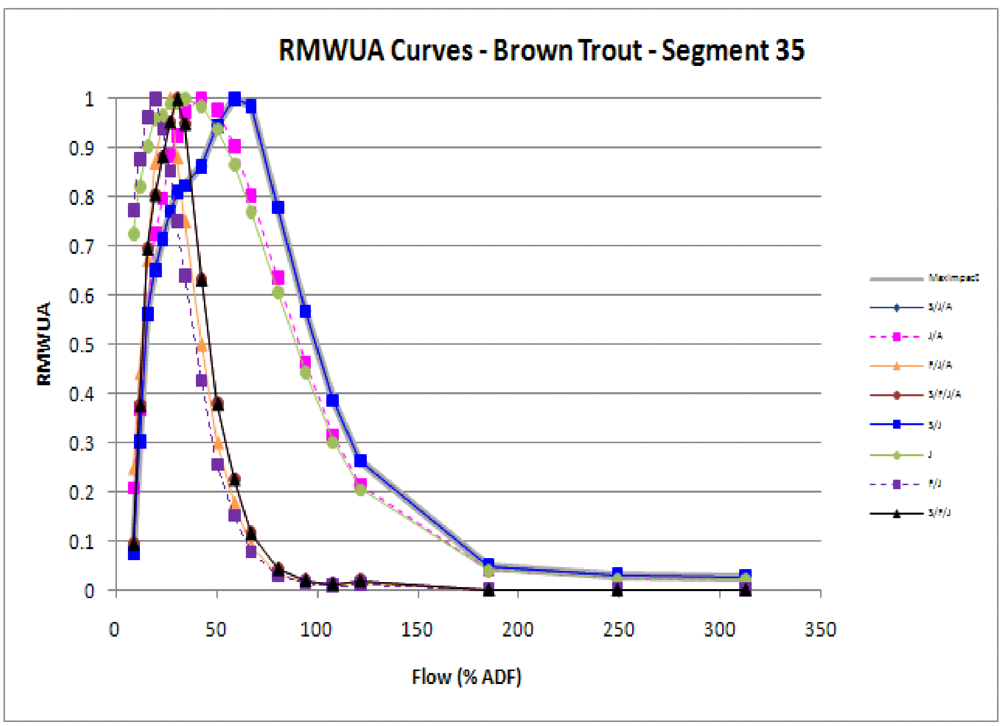

RMWUA Curves - Atlantic Salmon - Segment 28
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

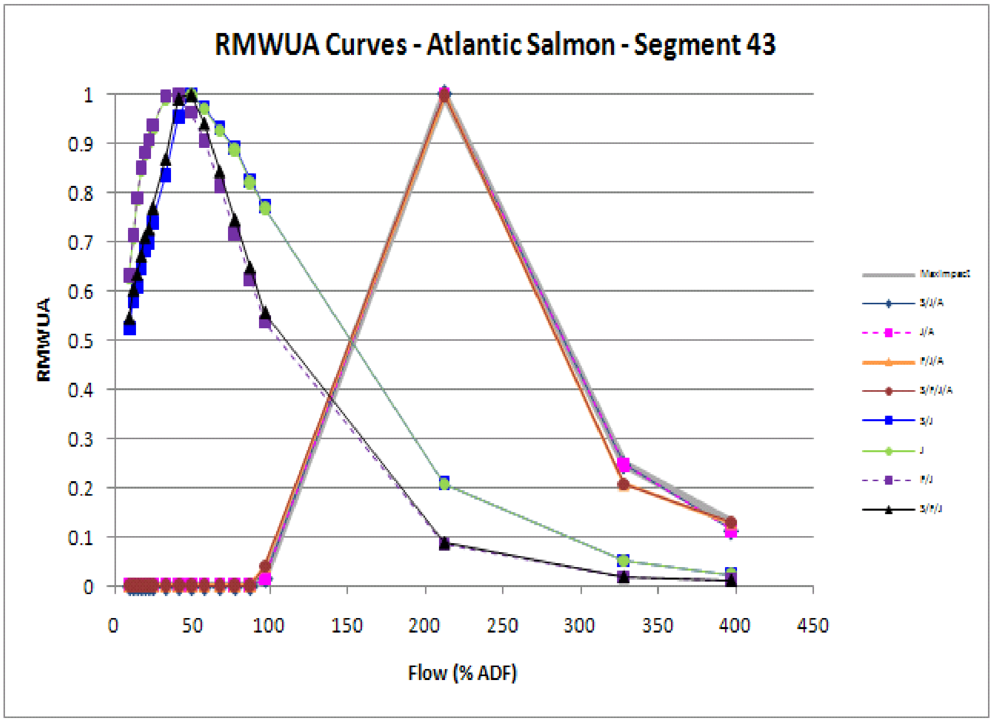

RMWUA Curves - Brown Trout - Segment 28
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

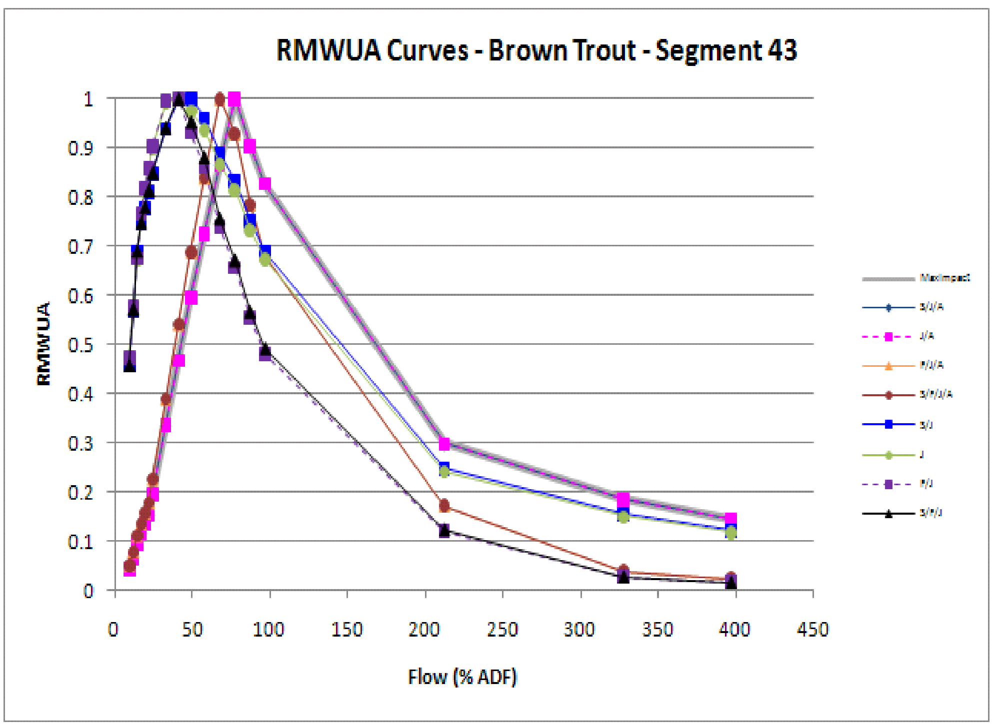

RMWUA Curves - Atlantic Salmon - Segment 29
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

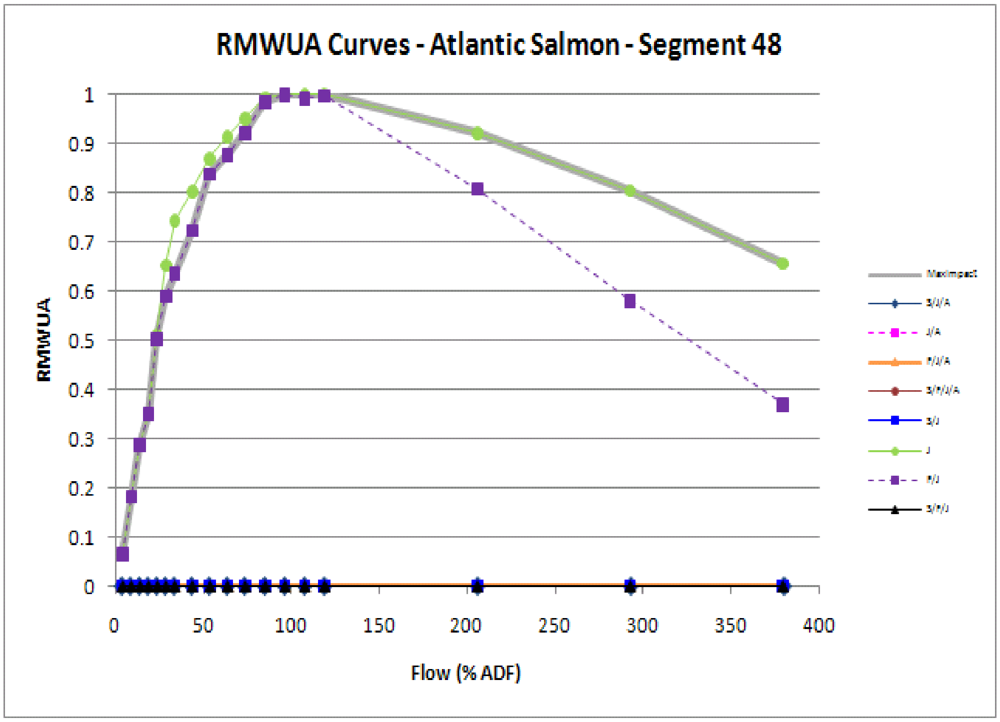

RMWUA Curves - Brown Trout - Segment 29
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

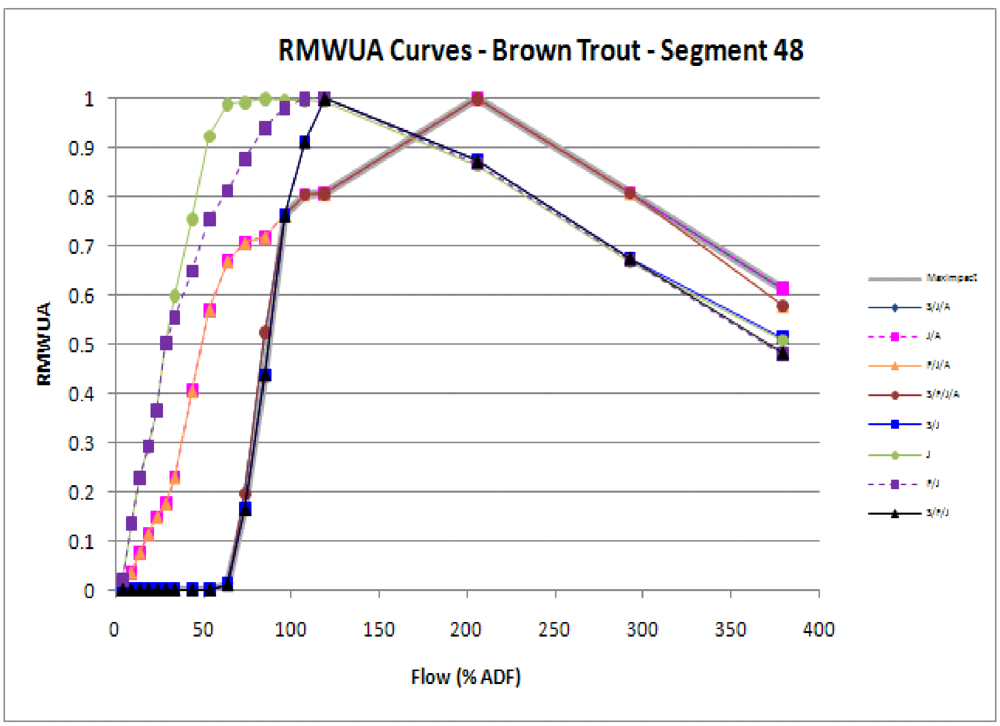

RMWUA Curves - Atlantic Salmon - Segment 35
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

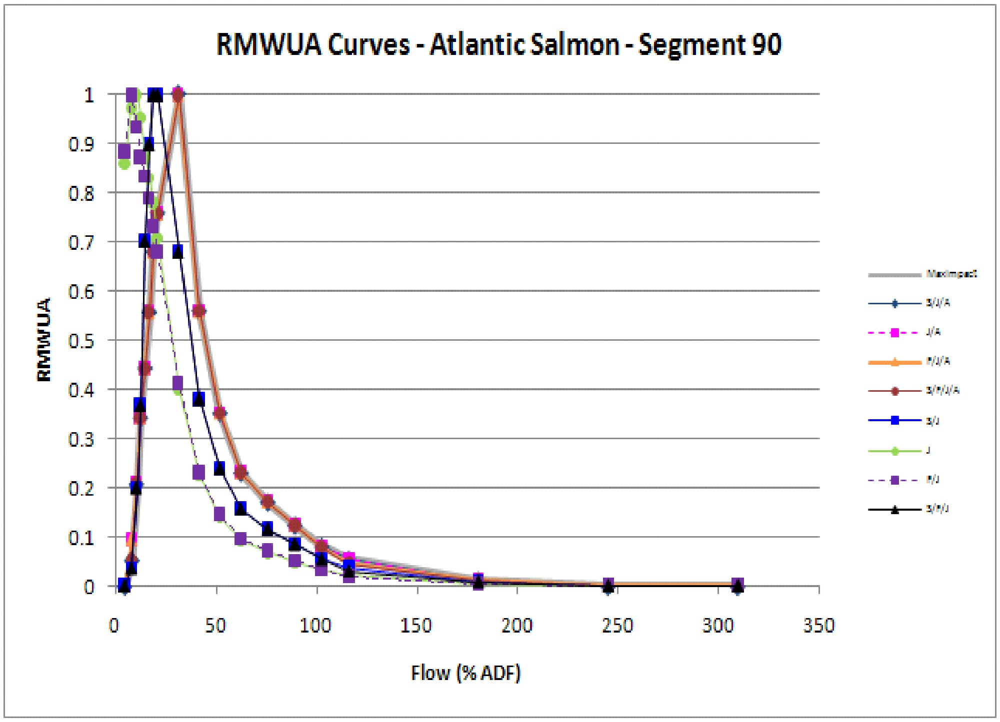

RMWUA Curves - Brown Trout - Segment 35
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

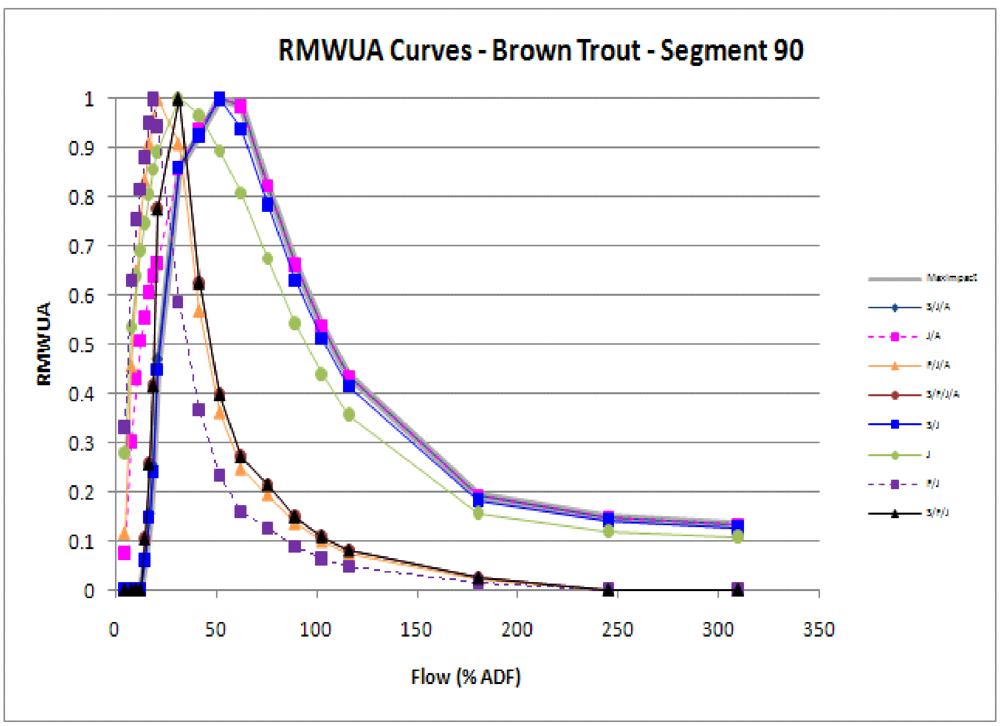

RMWUA Curves - Atlantic Salmon - Segment 43
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

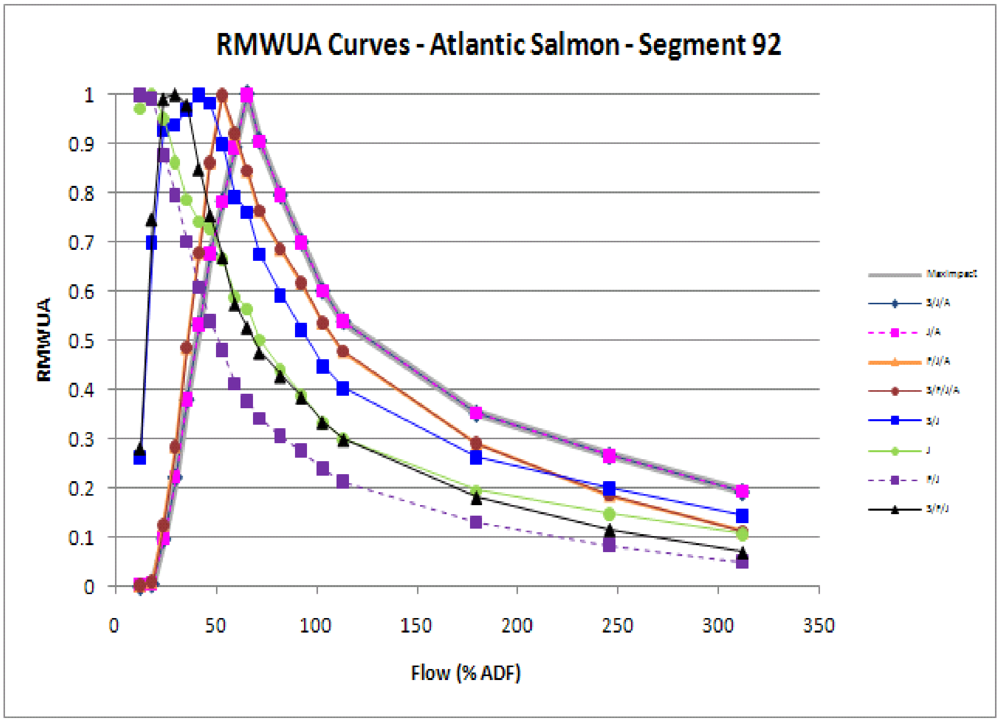

RMWUA Curves - Brown Trout - Segment 43
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

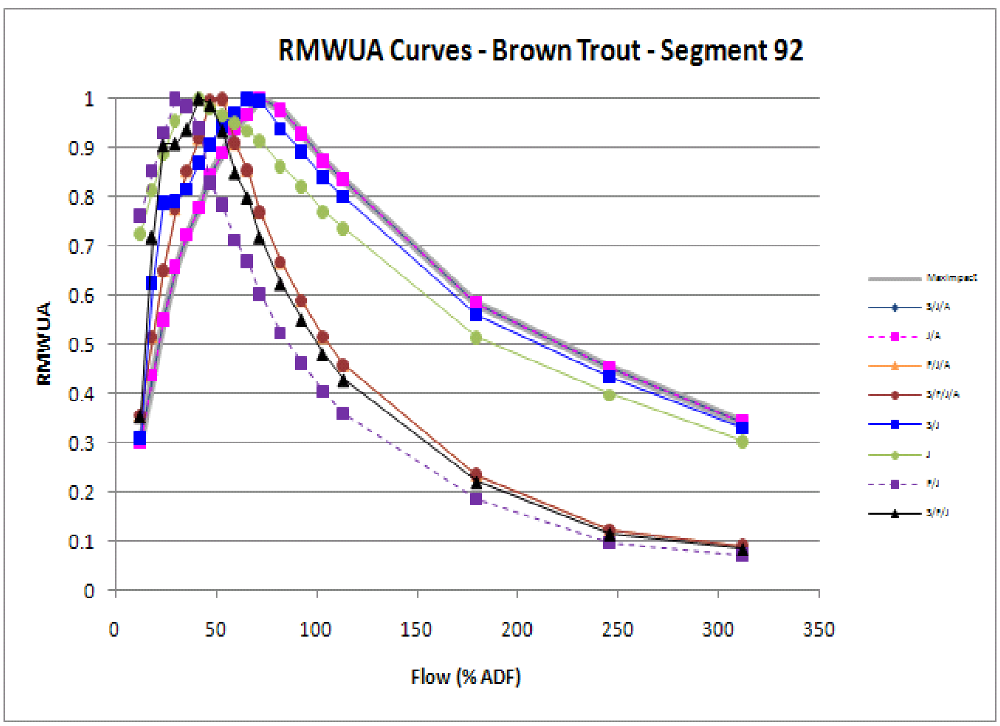

RMWUA Curves - Atlantic Salmon - Segment 48
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
Flow (% ADF)


RMWUA Curves - Brown Trout - Segment 48
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
Flow (% ADF)


RMWUA Curves - Atlantic Salmon - Segment 90
RMWUA
Flow (% ADF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J


RMWUA Curves - Brown Trout - Segment 90
RMWUA
Flow (% ADF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

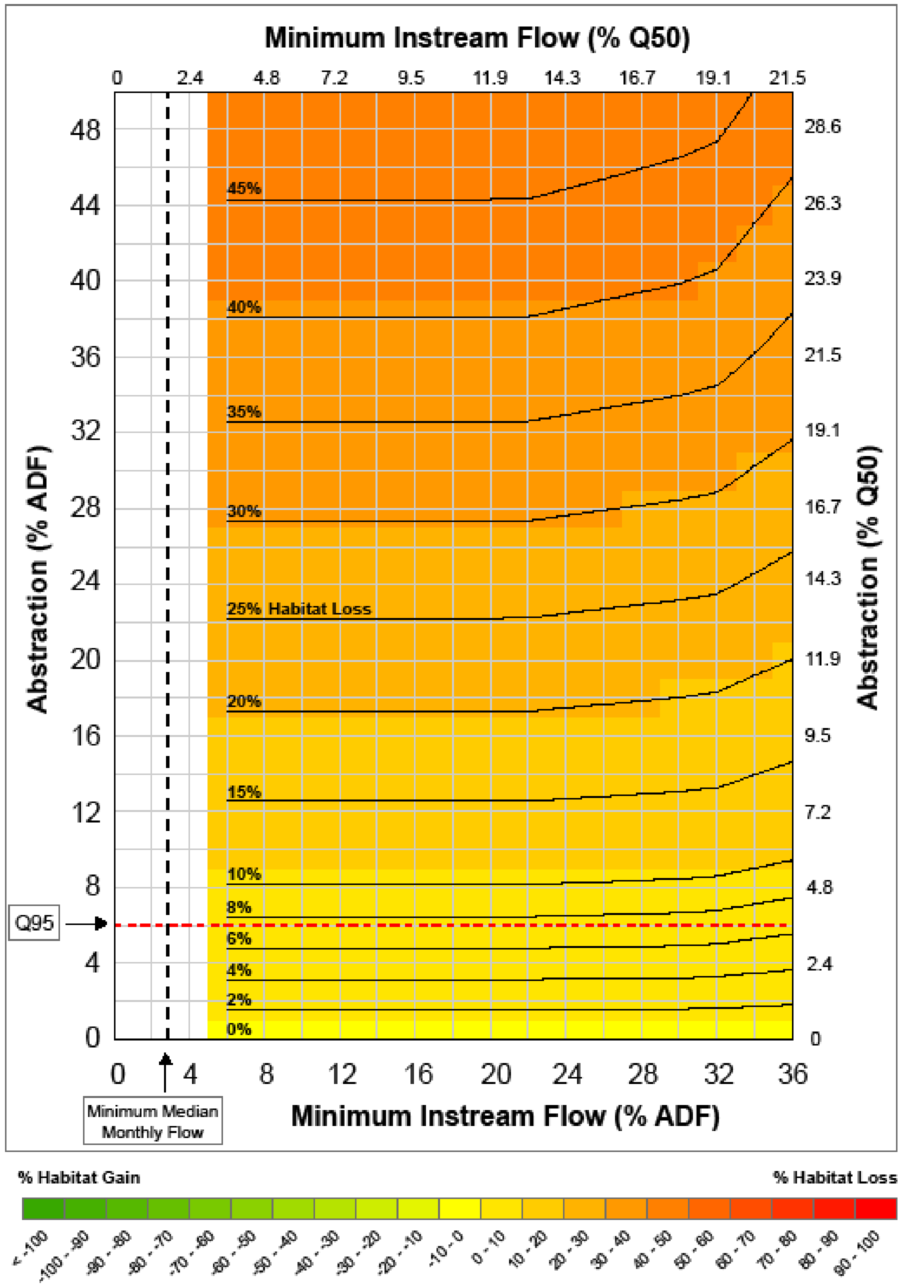

RMWUA Curves - Atlantic Salmon - Segment 92
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

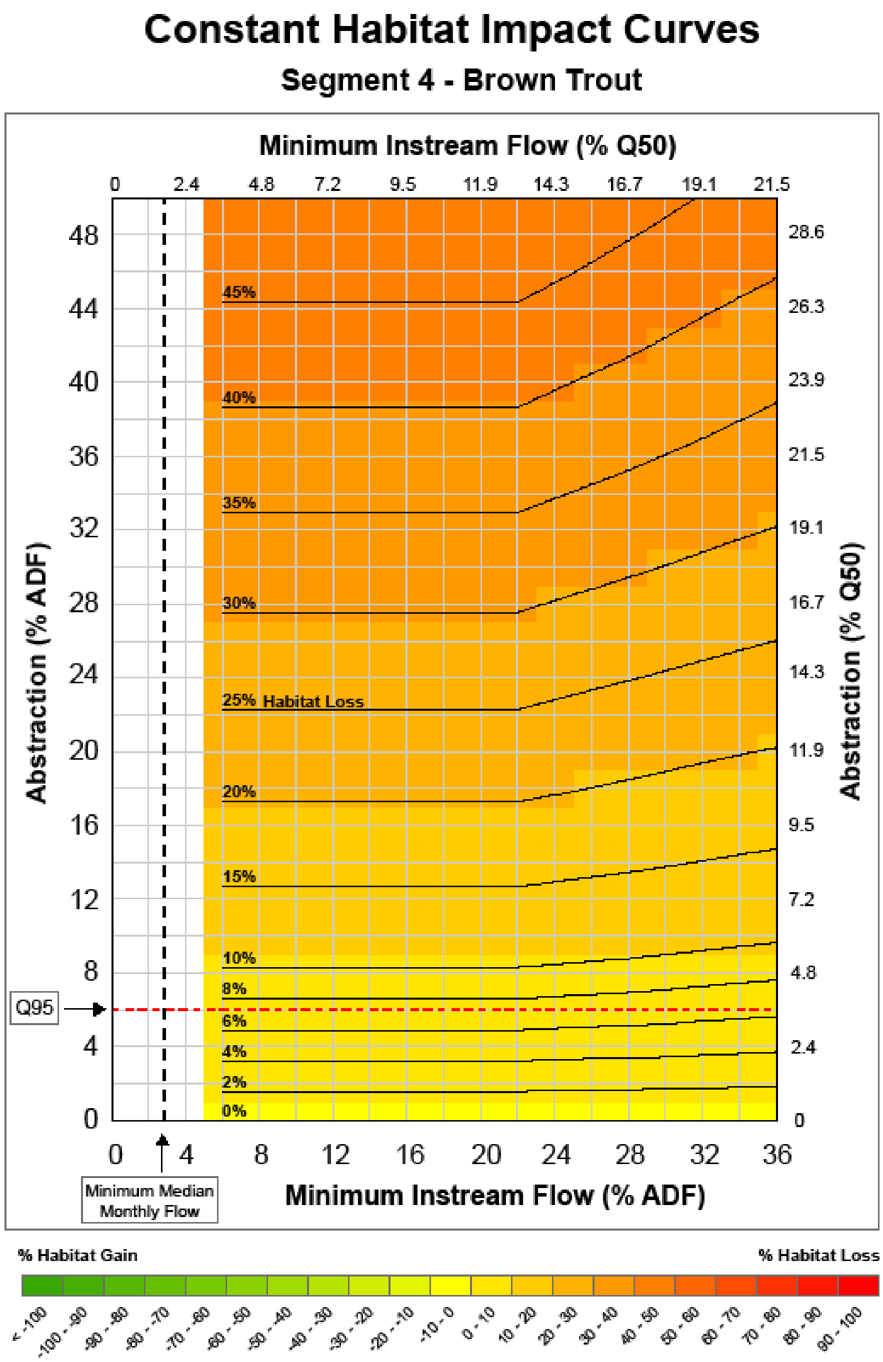

RMWUA Curves - Brown Trout - Segment 92
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

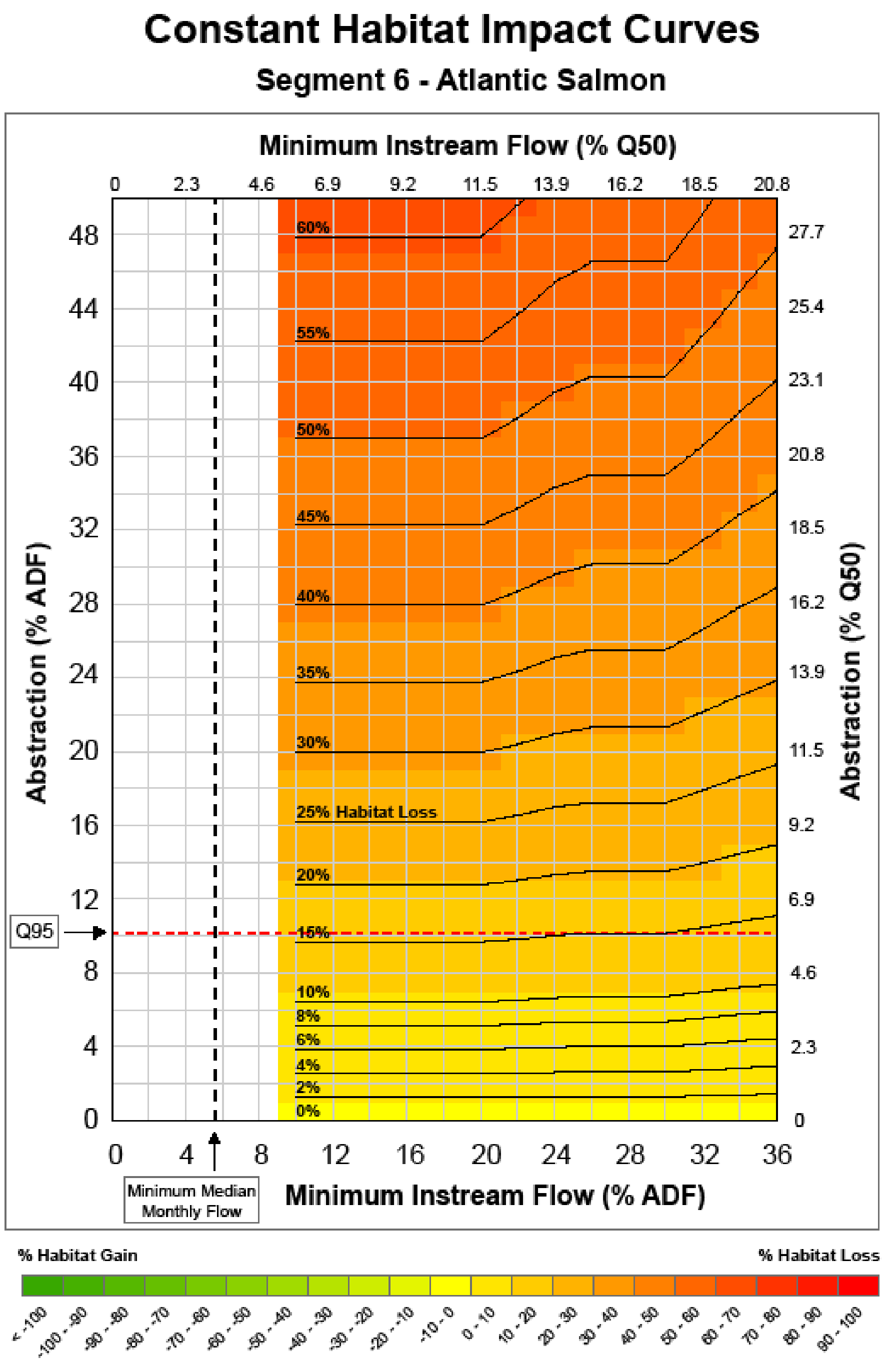
Appendix D – Constant Habitat Impact Curves

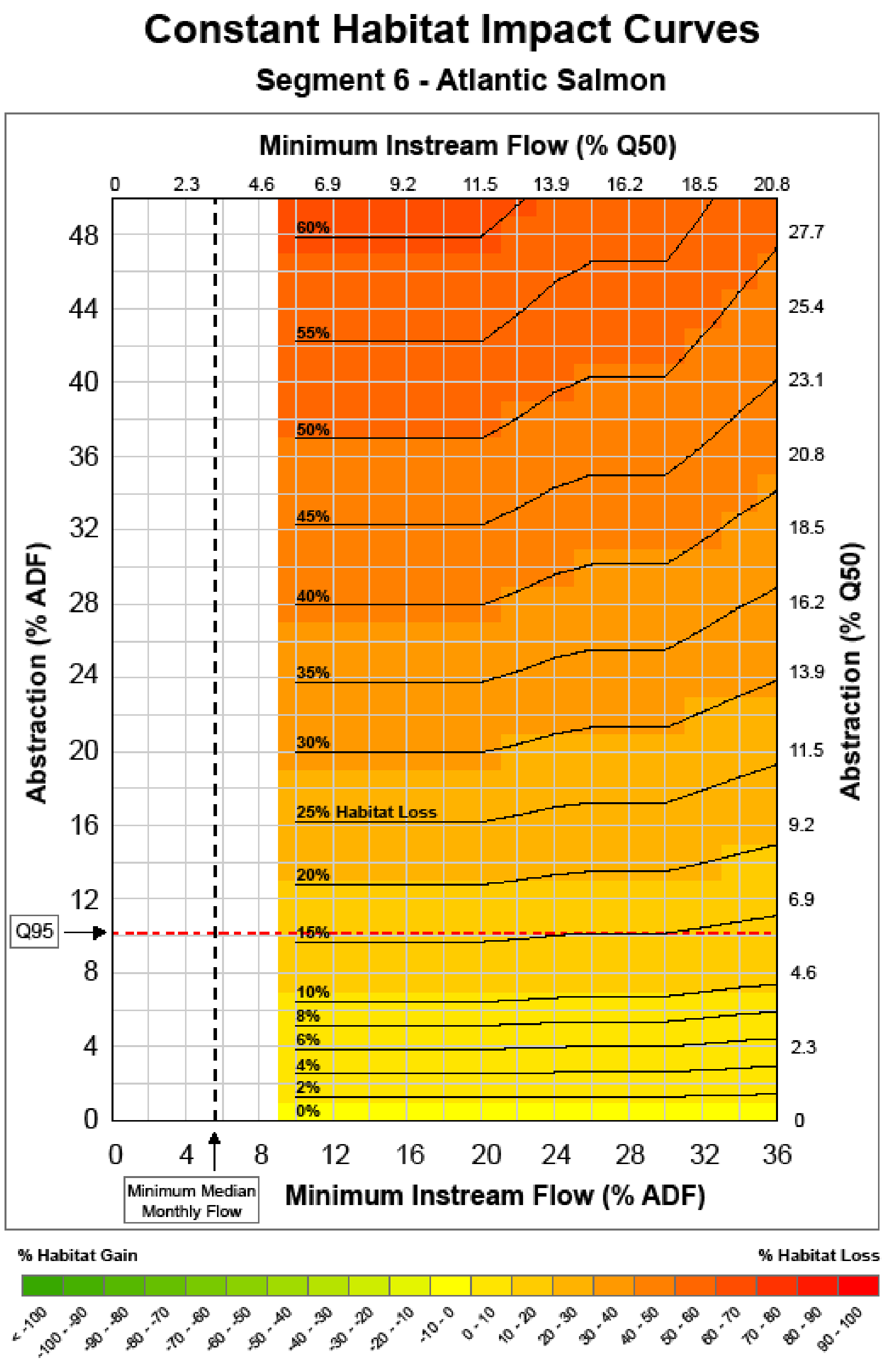
Constant Habitat Impact Curves

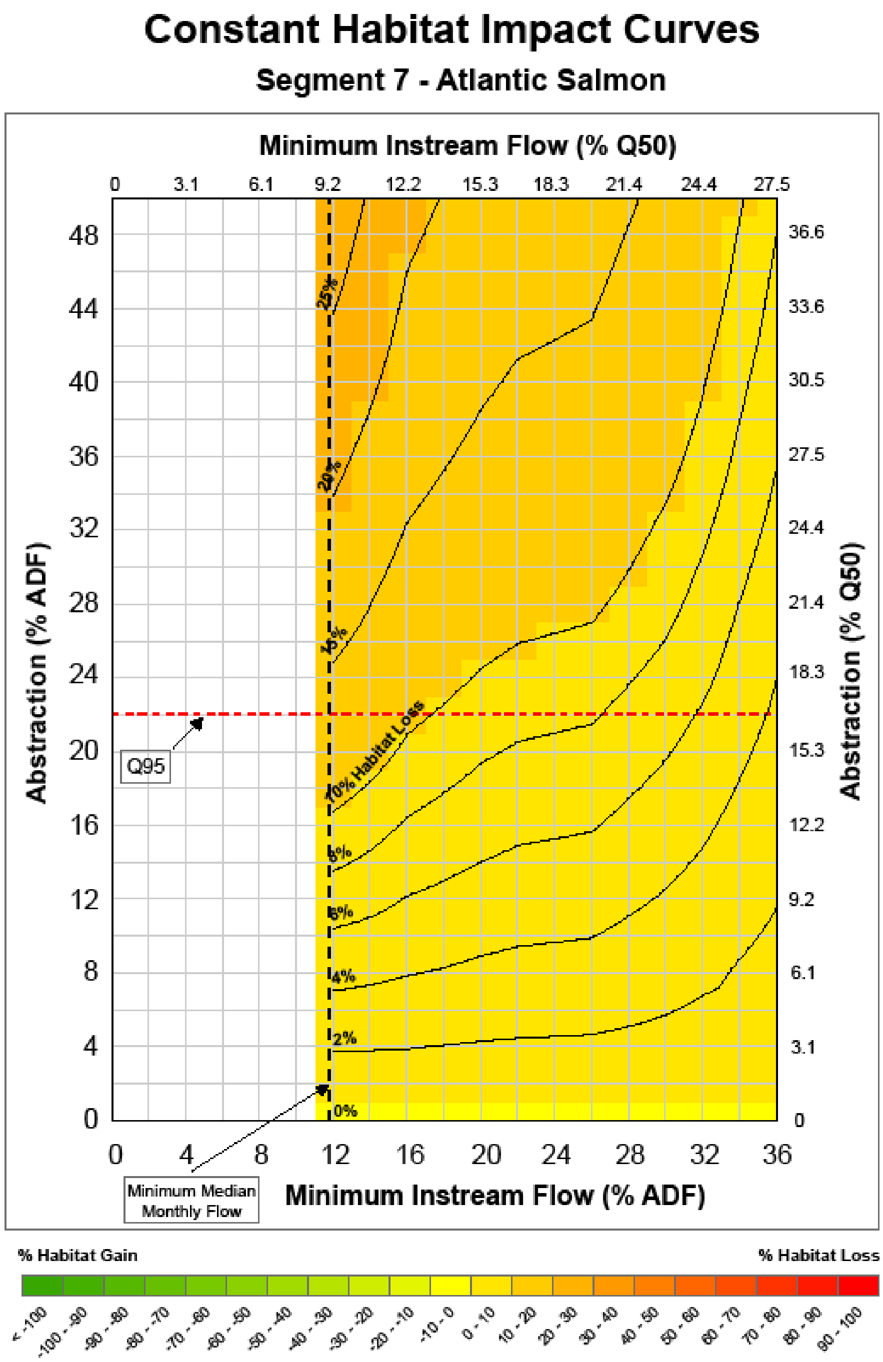
Segment 4 - Atlantic Salmon




Constant Habitat Impact Curves
Segment 4 - Brown Trout
Minimum Instream Flow (% Q50)
0
2.4
4.8
7.2
9.5
11.9
14.3
16.7
19.1
21.5
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
28.6
26.3
23.9
21.5
19.1
16.7
14.3
11.9
9.5
7.2
4.8
2.4
0
45%
40%
35%
30%
25% Habitat Loss
20%
15%
10%
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
0
4
8
12
16
20
24
28
32
36
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

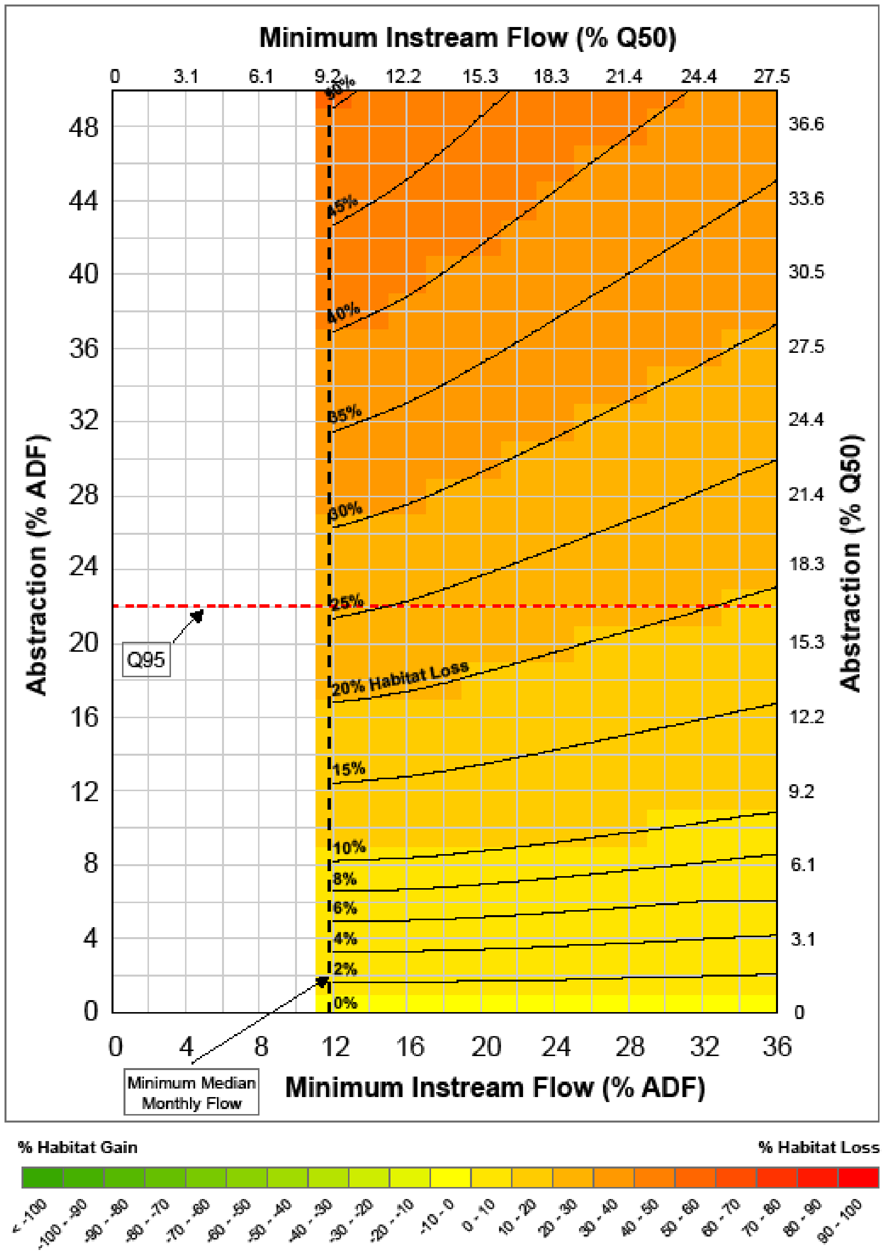

Constant Habitat Impact Curves
Segment 6 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0 2.3 4.6 6.9 9.2 11.5 13.9 16.2 18.5 20.8
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
27.7 25.4 23.1 20.8 18.5 16.2 13.9 11.5 9.2 6.9 4.6 2.3 0
60%
55%
50%
45%
40%
35%
30%
25% Habitat Loss
20%
15%
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100 -100 - -90 -90 - -80 -80 - -70 -70 - -60 -60 - -50 -50 - -40 -40 - -30 -30 - -20 -20 - -10 -10 - 0 0 - 10 10 - 20 20 - 30 30 - 40 40 - 50 50 - 60 60 - 70 70 - 80 80 - 90 90 - 100

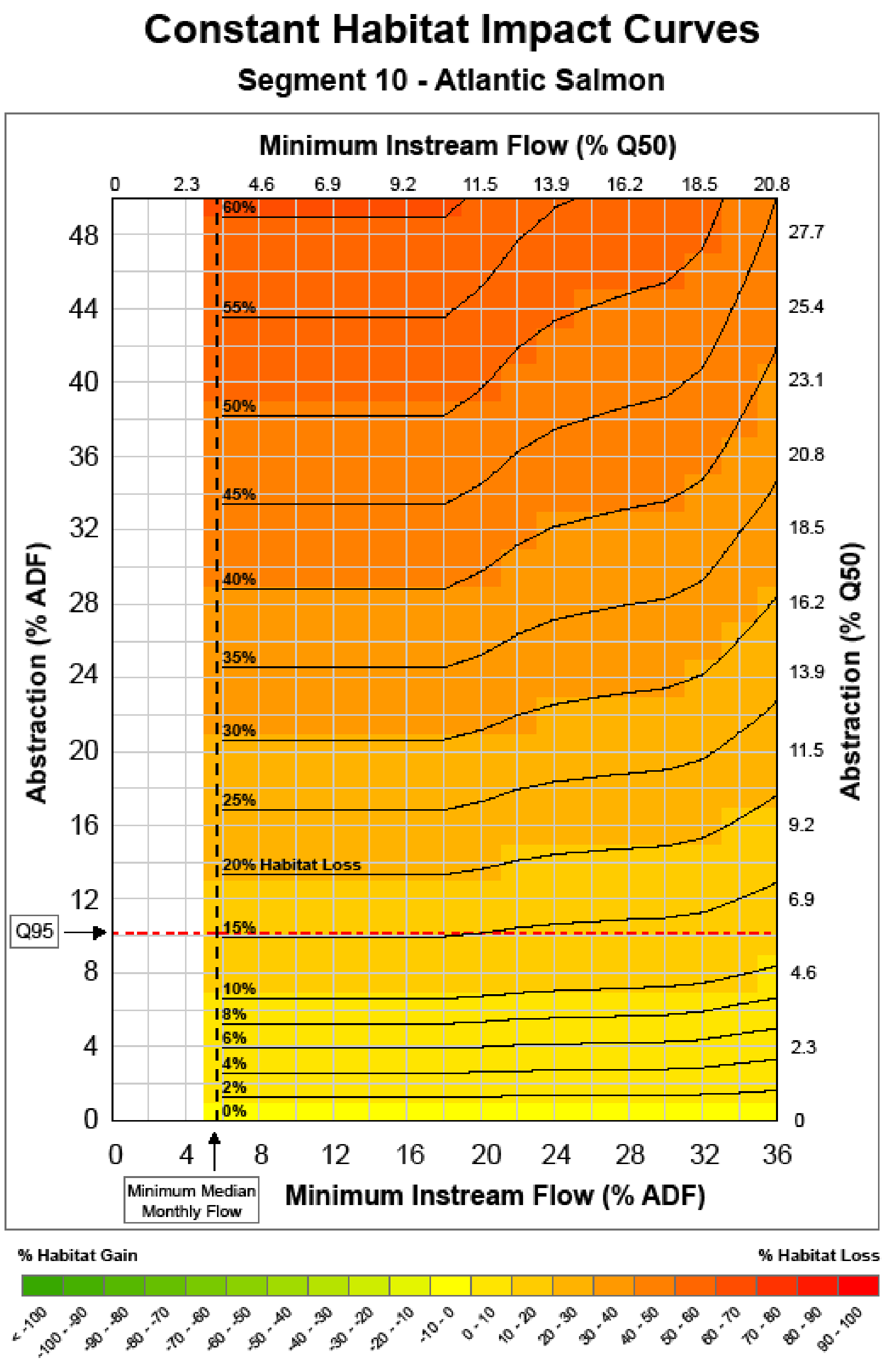

Constant Habitat Impact Curves
Segment 6 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
0
60%
55%
50%
45%
40%
35%
30%
25% Habitat Loss
20%
15%
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 7 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
3.1
6.1
9.2
12.2
15.3
18.3
21.4
24.4
27.5
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
36.6
33.6
30.5
27.5
24.4
21.4
18.3
15.3
12.2
9.2
6.1
3.1
0
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
0
4
8
12
16
20
24
28
32
36
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

Constant Habitat Impact Curves

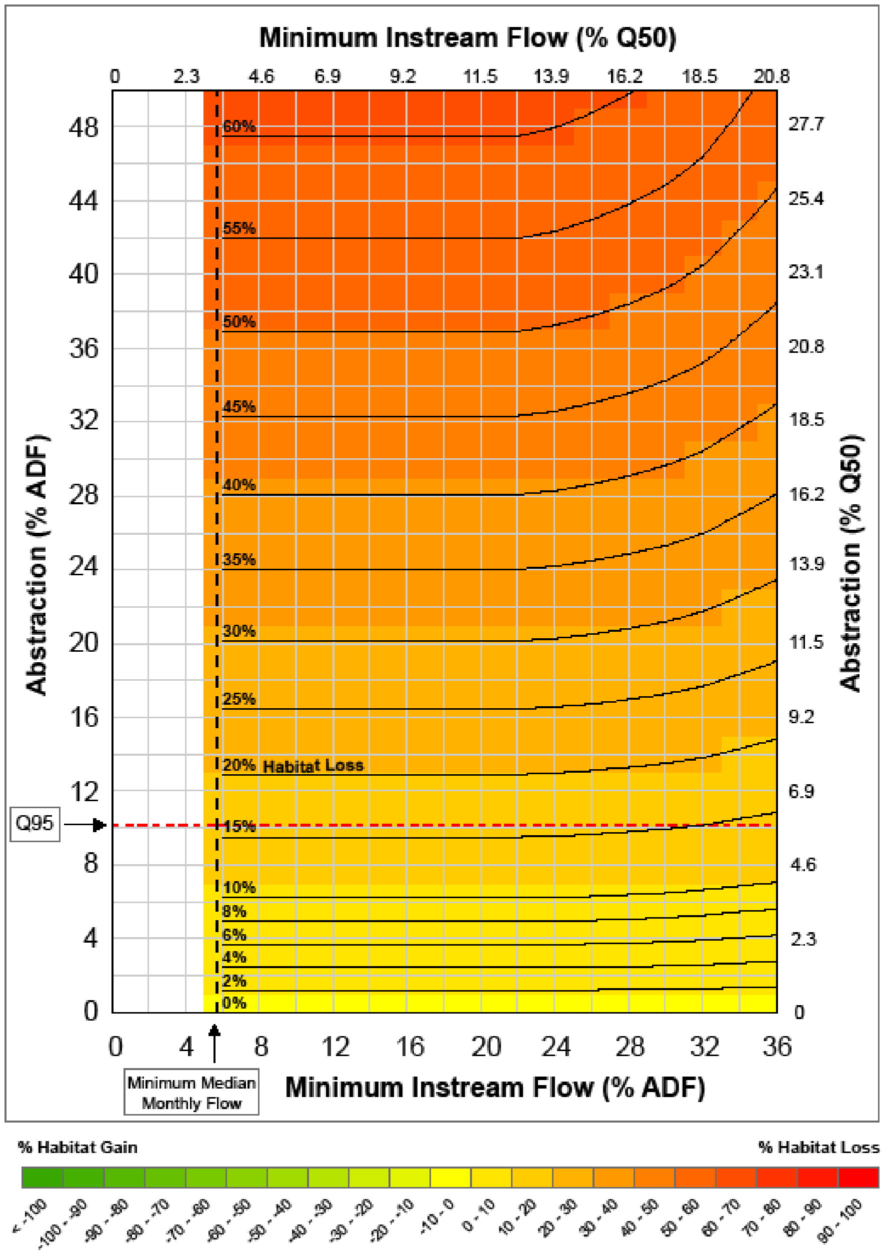
Segment 7 - Brown Trout




Constant Habitat Impact Curves
Segment 10 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
Abstraction (% Q50)
60%
55%
50%
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss

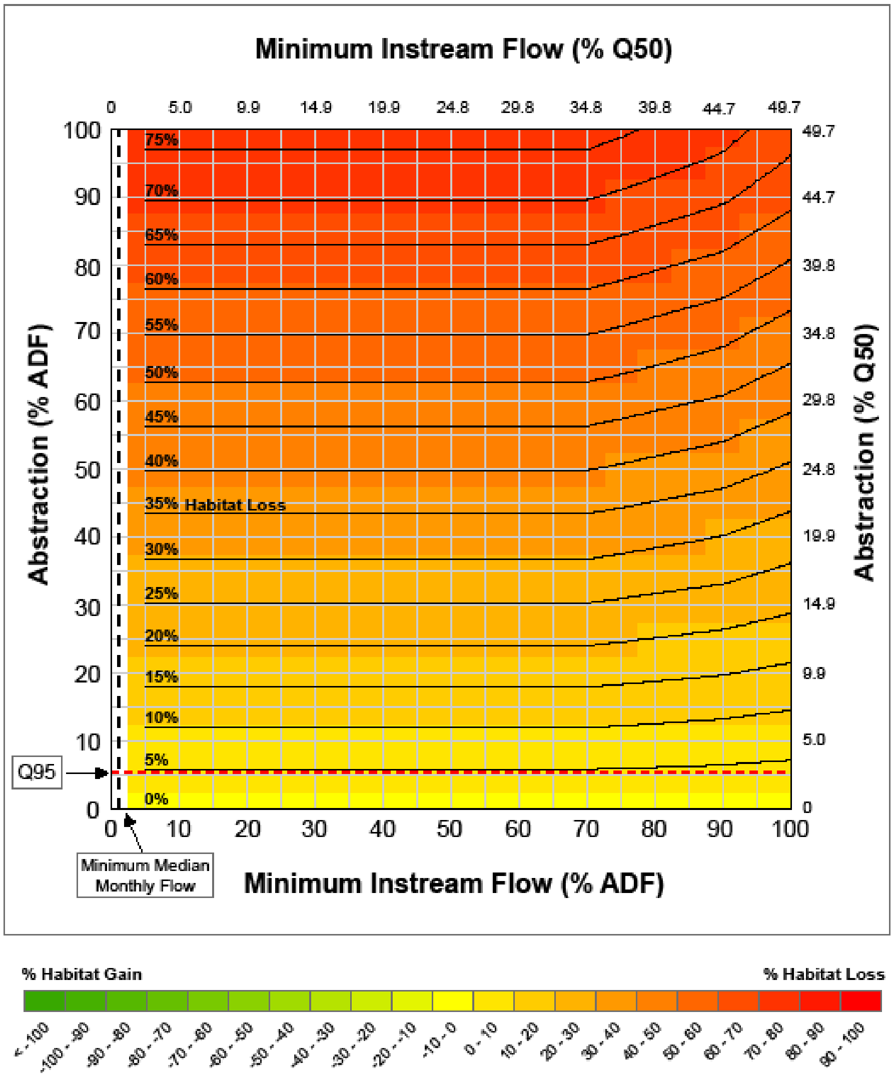
Constant Habitat Impact Curves

Segment 10 - Brown Trout

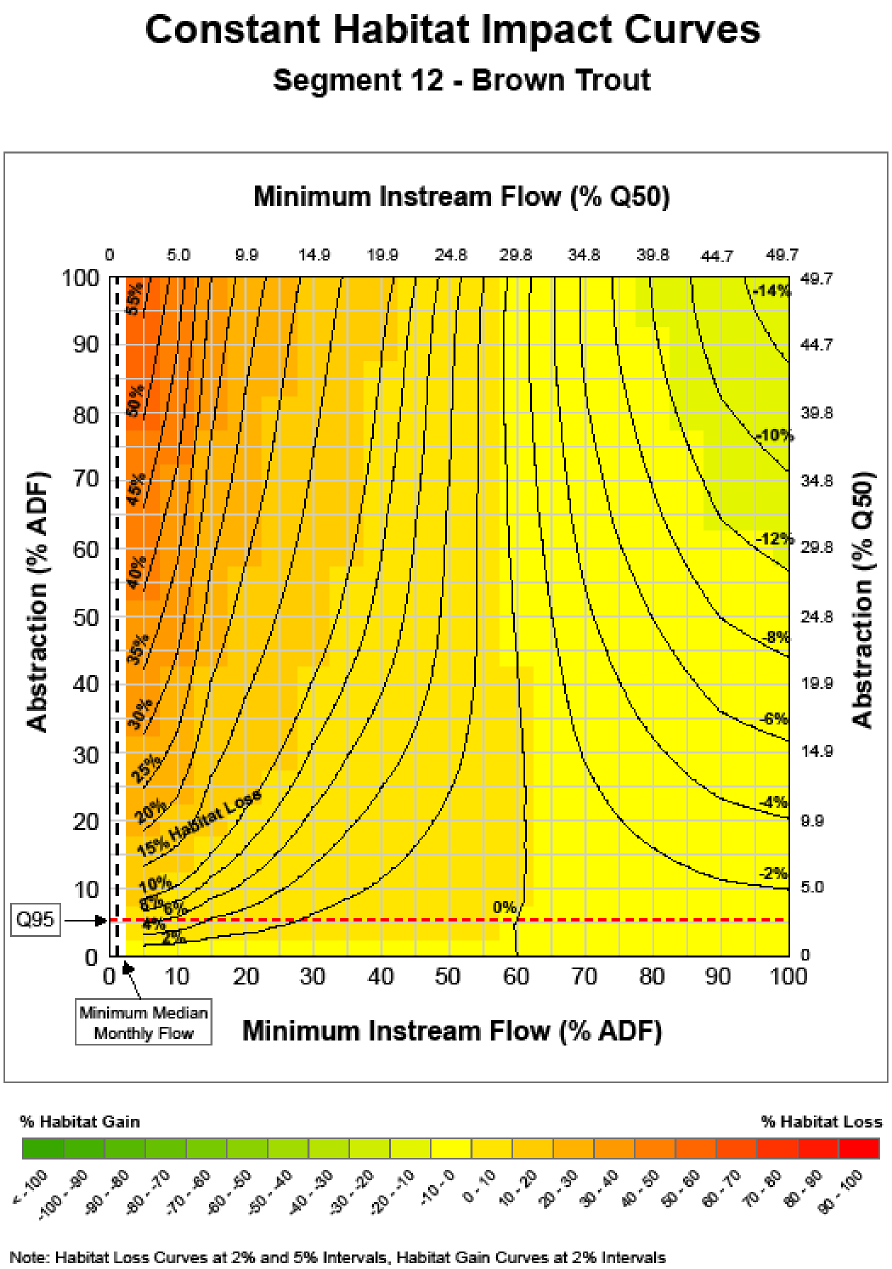


Constant Habitat Impact Curves

Segment 12 - Atlantic Salmon

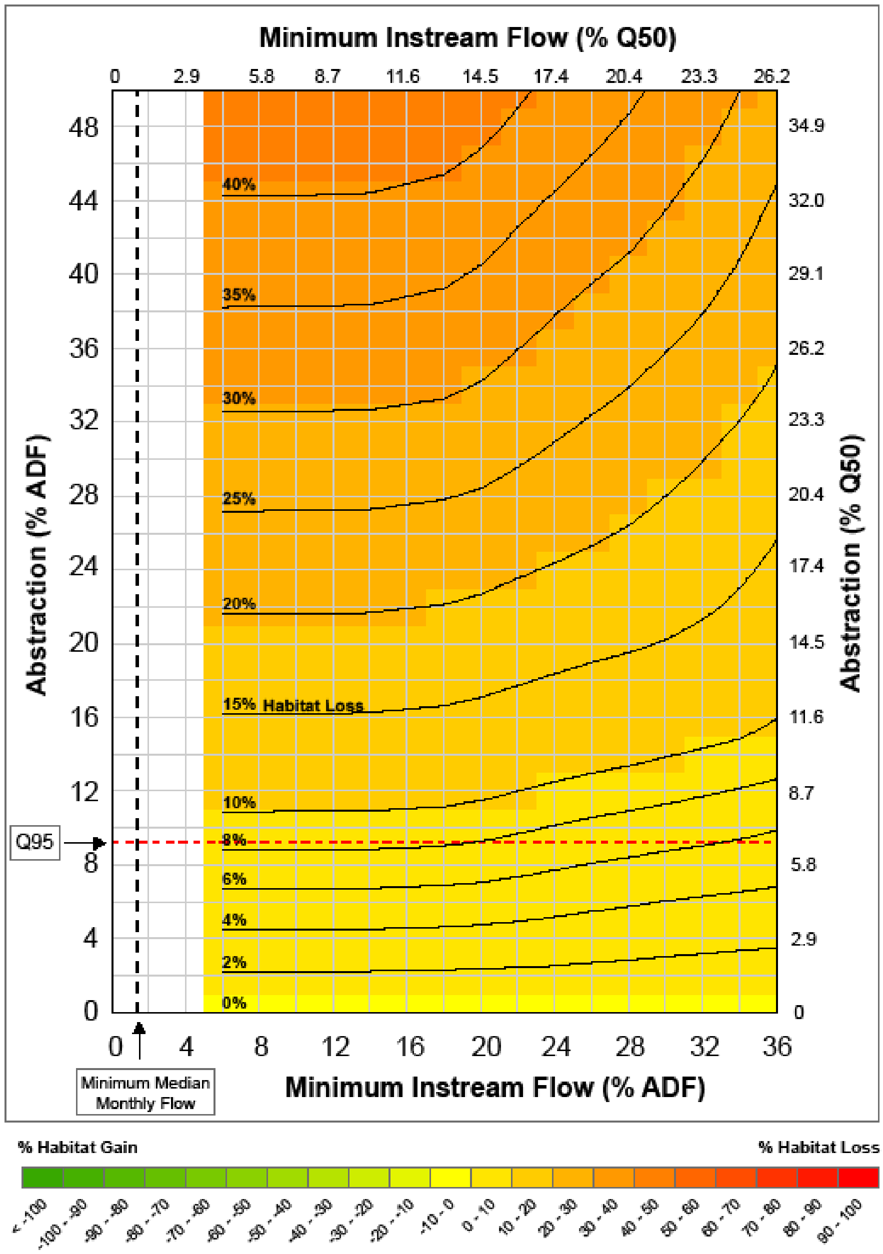


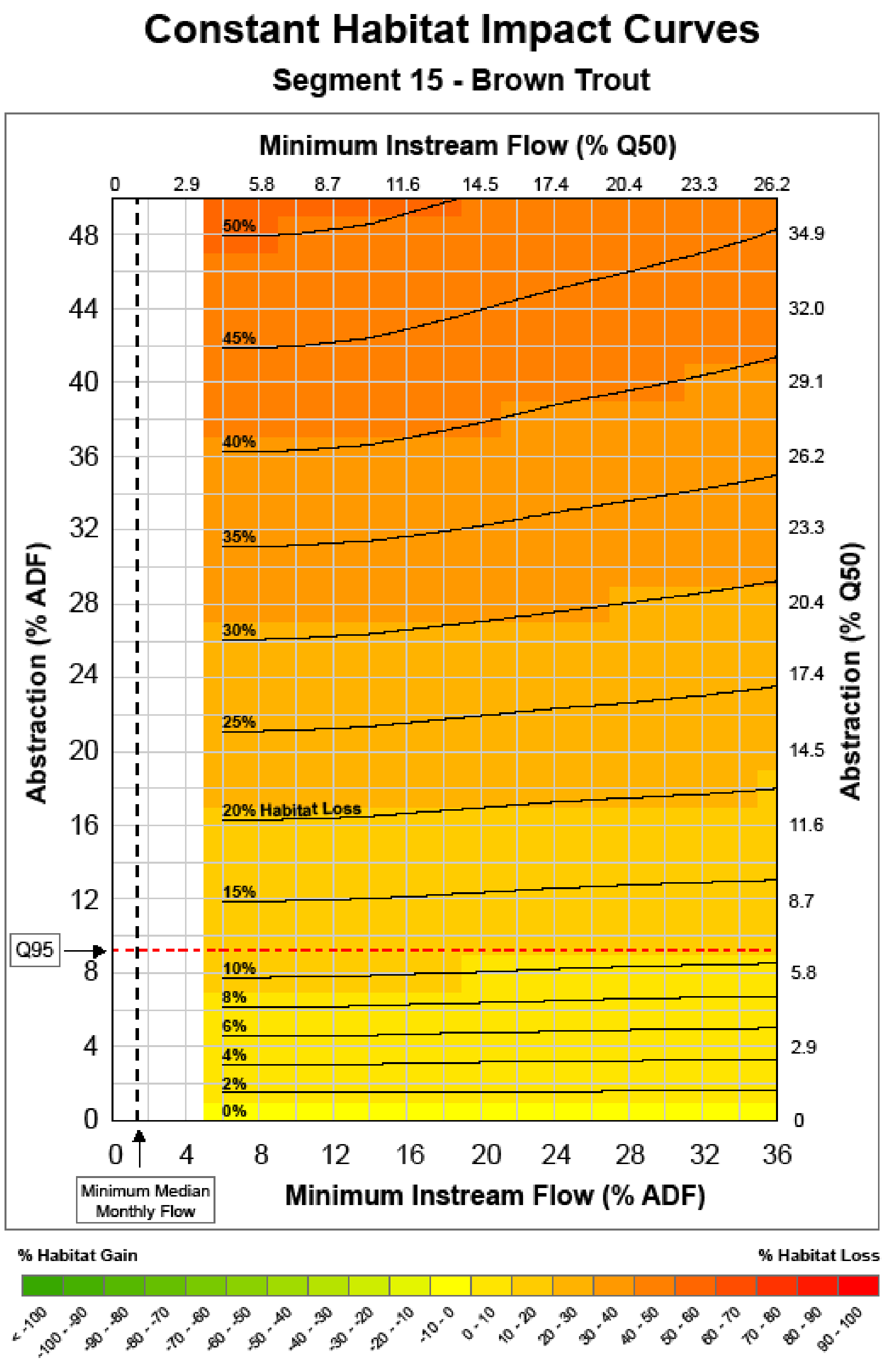
Note: Habitat Loss Curves at 5% Intervals

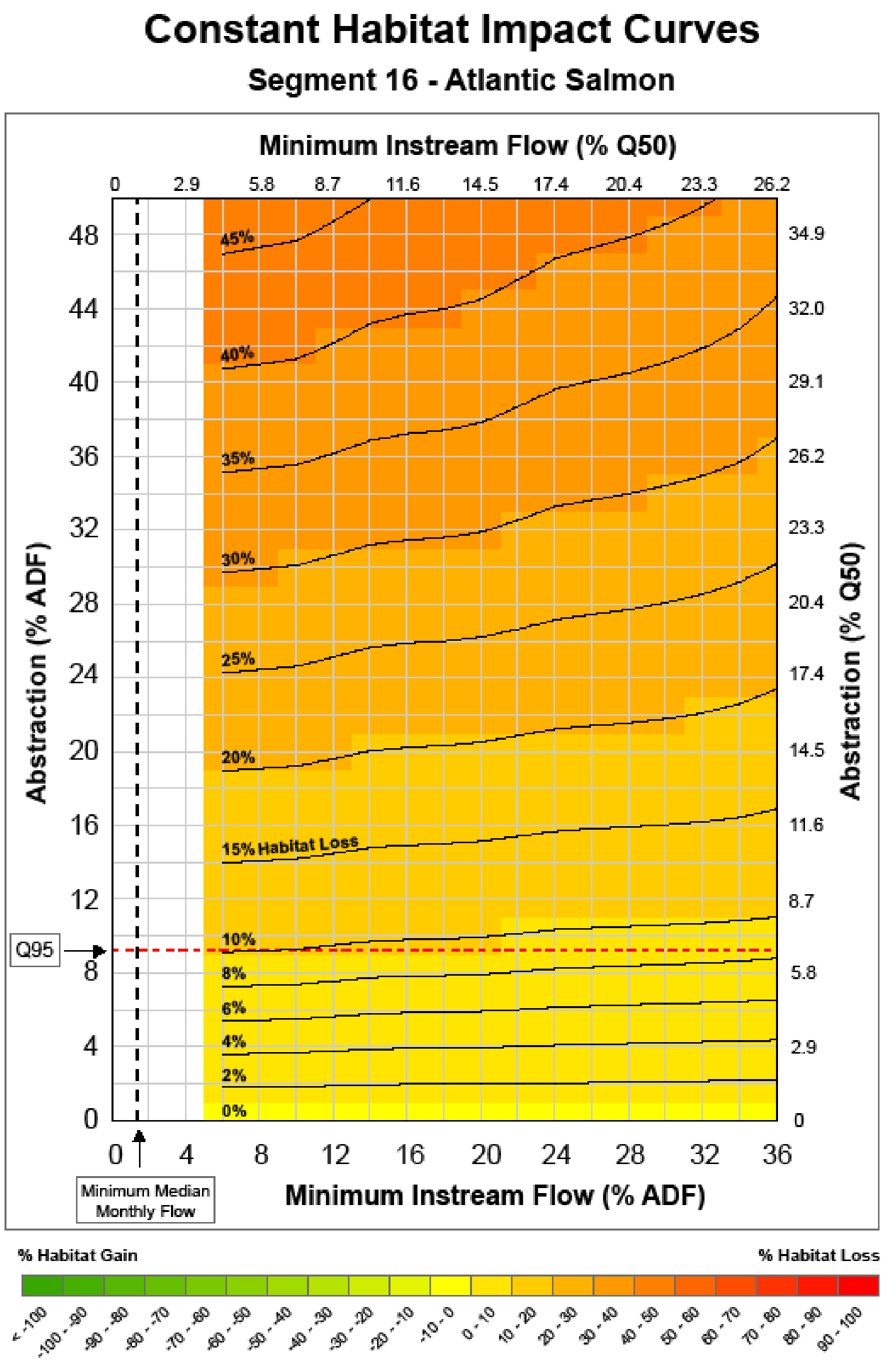

Constant Habitat Impact Curves
Segment 12 - Brown Trout
Minimum Instream Flow (% Q50)
0
5.0
9.9
14.9
19.9
24.8
29.8
34.8
39.8
44.7
49.7
Abstraction (% ADF)
Abstraction (% Q50)
55%
50%
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
-2%
-4%
-6%
-8%
-10%
-12%
-14%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
Note: Habitat Loss Curves at 2% and 5% Intervals, Habitat Gain Curves at 2% Intervals

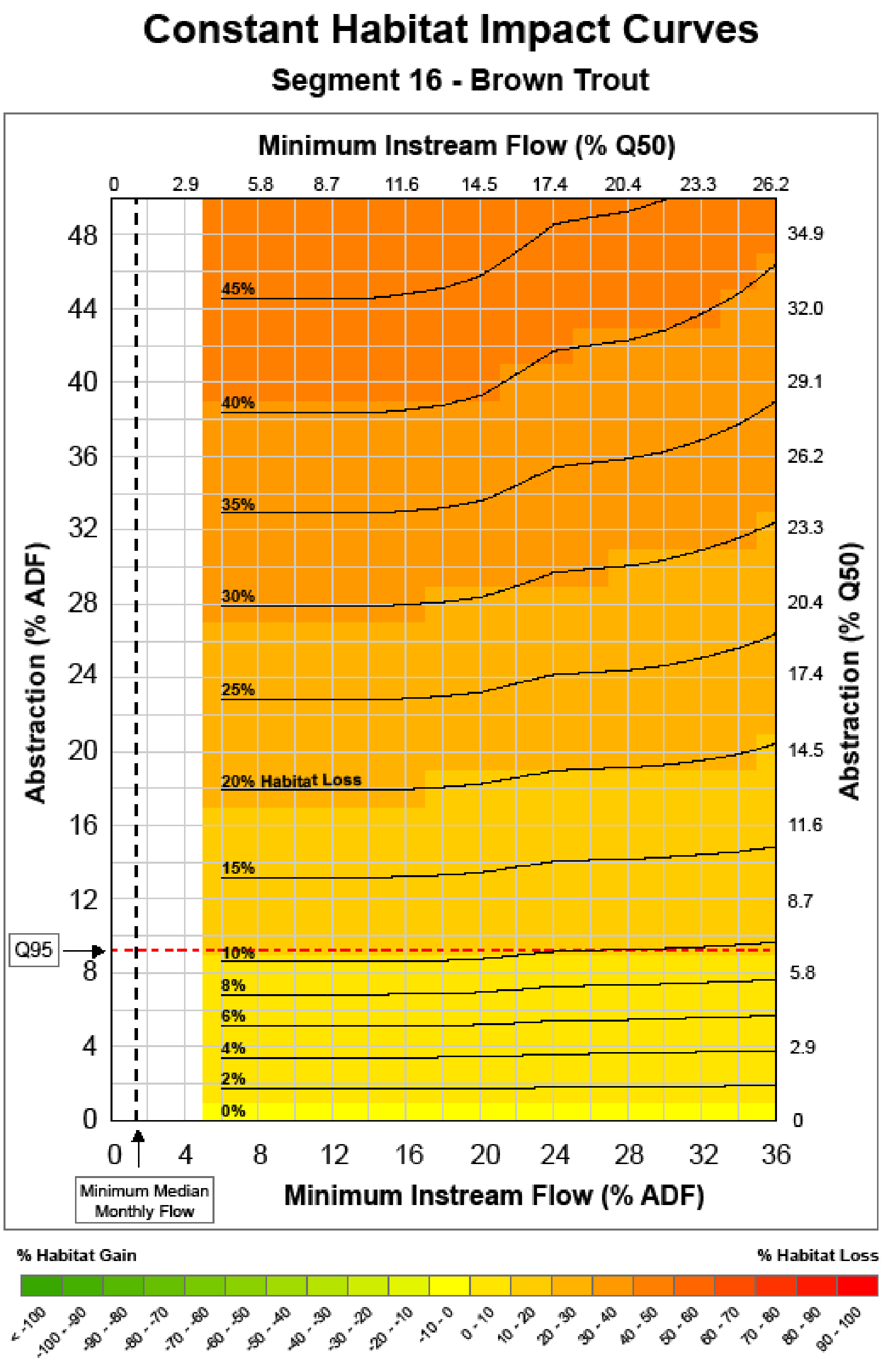
Constant Habitat Impact Curves

Segment 15 - Atlantic Salmon



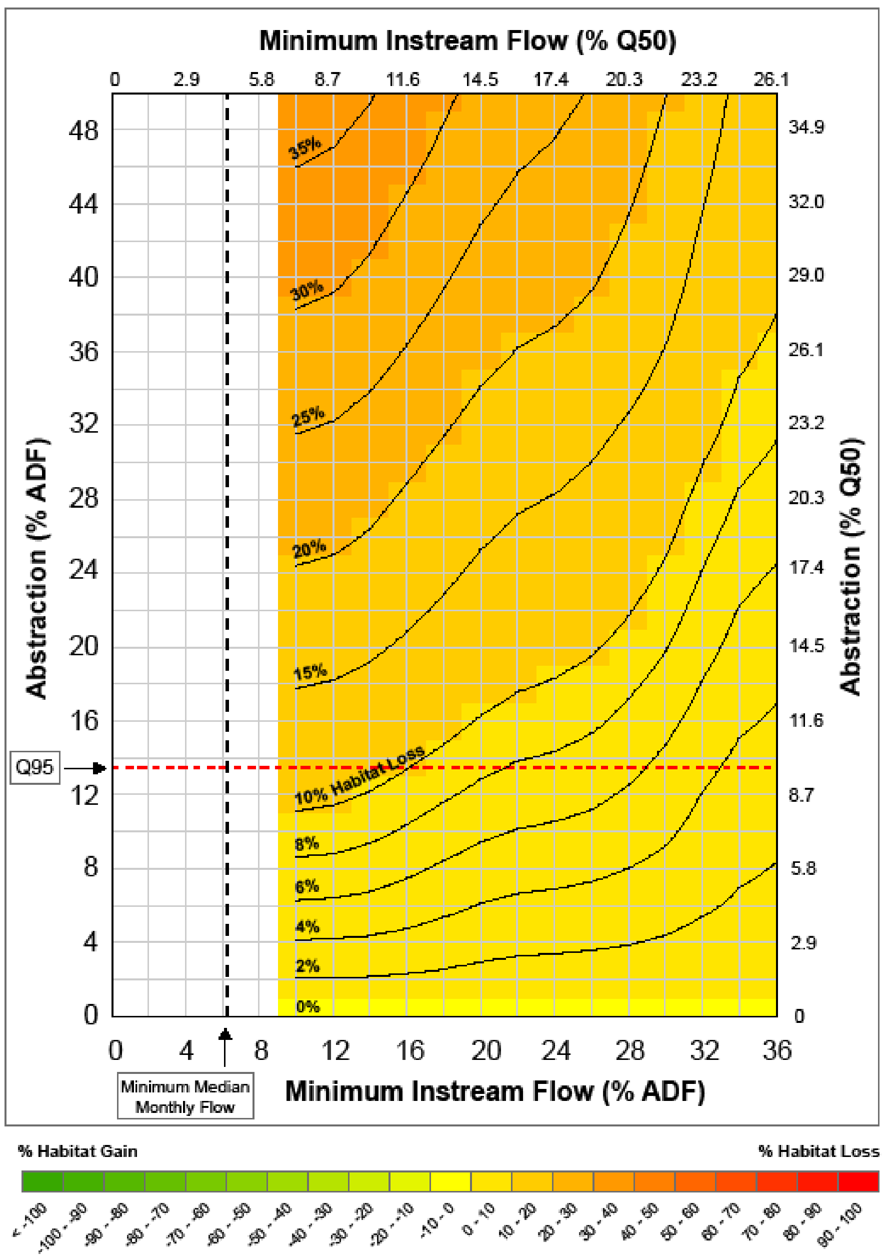

Constant Habitat Impact Curves
Segment 15 - Brown Trout
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.1
26.2
23.3
20.4
17.4
14.5
11.6
8.7
5.8
2.9
0
50%
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

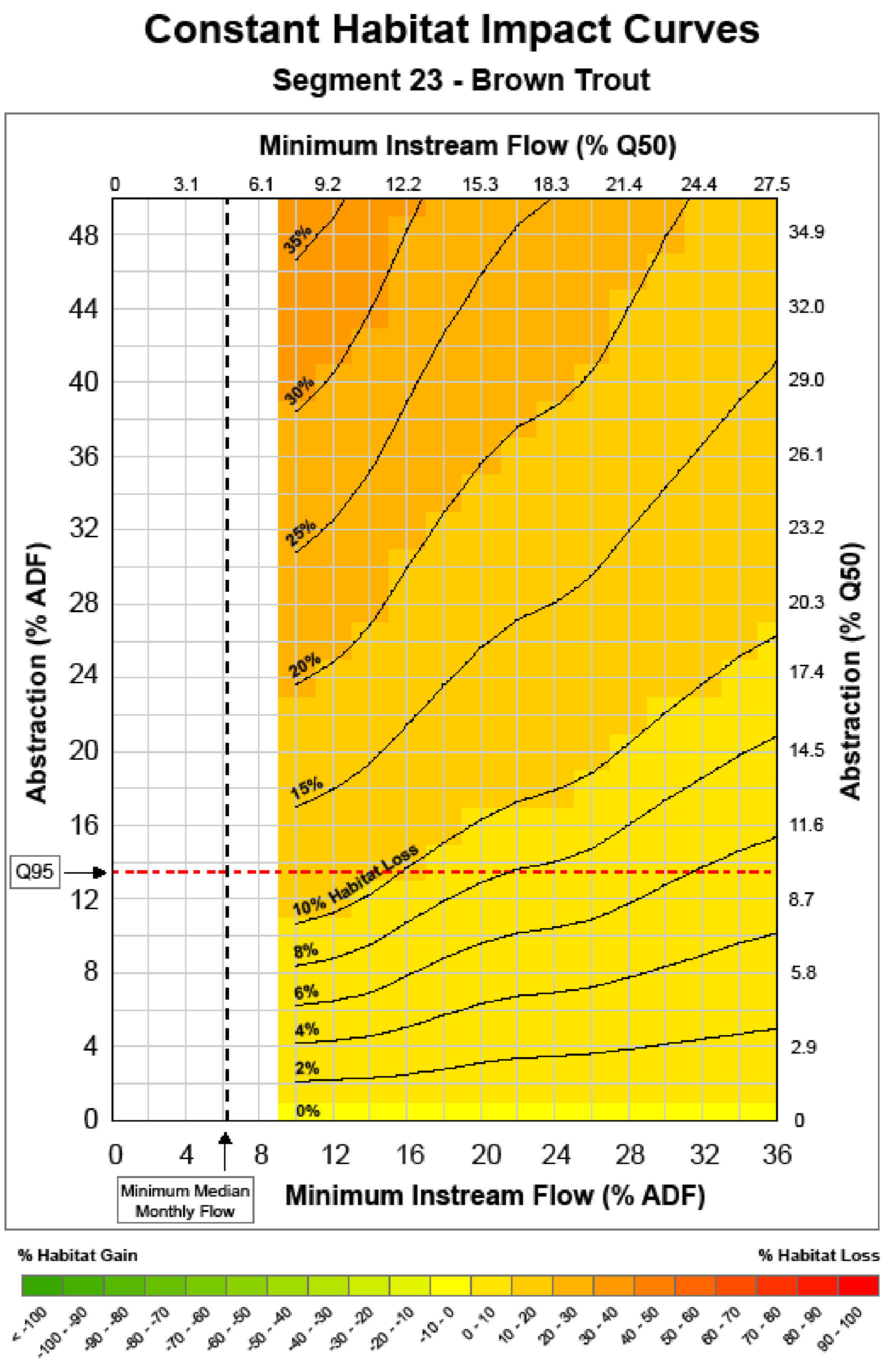

Constant Habitat Impact Curves
Segment 16 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
Abstraction (% Q50)
48
44
40
36
32
28
24
20
16
12
8
4
0
34.9
32.0
29.1
26.2
23.3
20.4
17.4
14.5
11.6
8.7
5.8
2.9
0
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
4
8
12
16
20
24
28
32
36
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

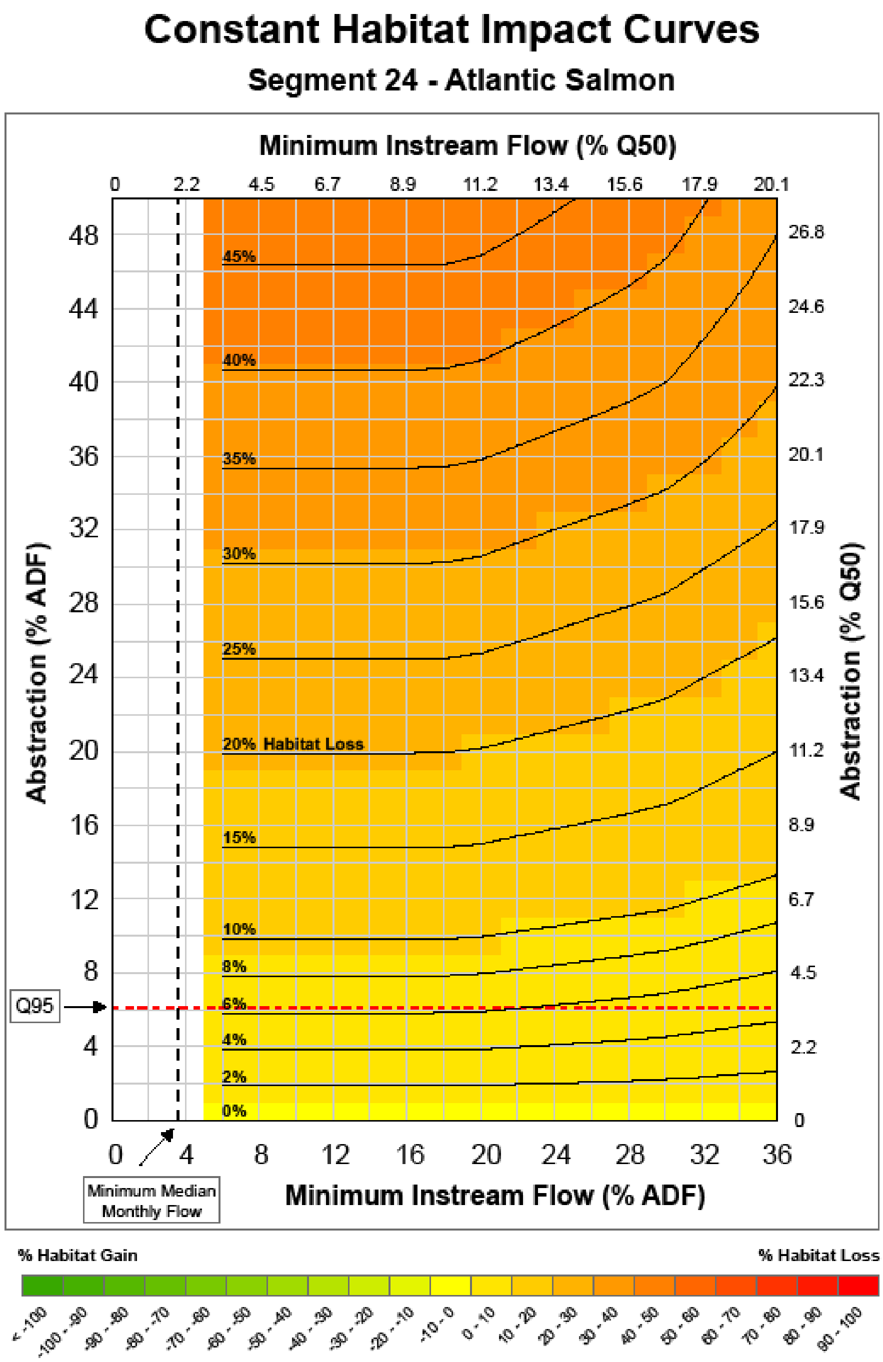

Constant Habitat Impact Curves
Segment 16 - Brown Trout
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.1
26.2
23.3
20.4
17.4
14.5
11.6
8.7
5.8
2.9
0
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

Constant Habitat Impact Curves

Segment 23 - Atlantic Salmon

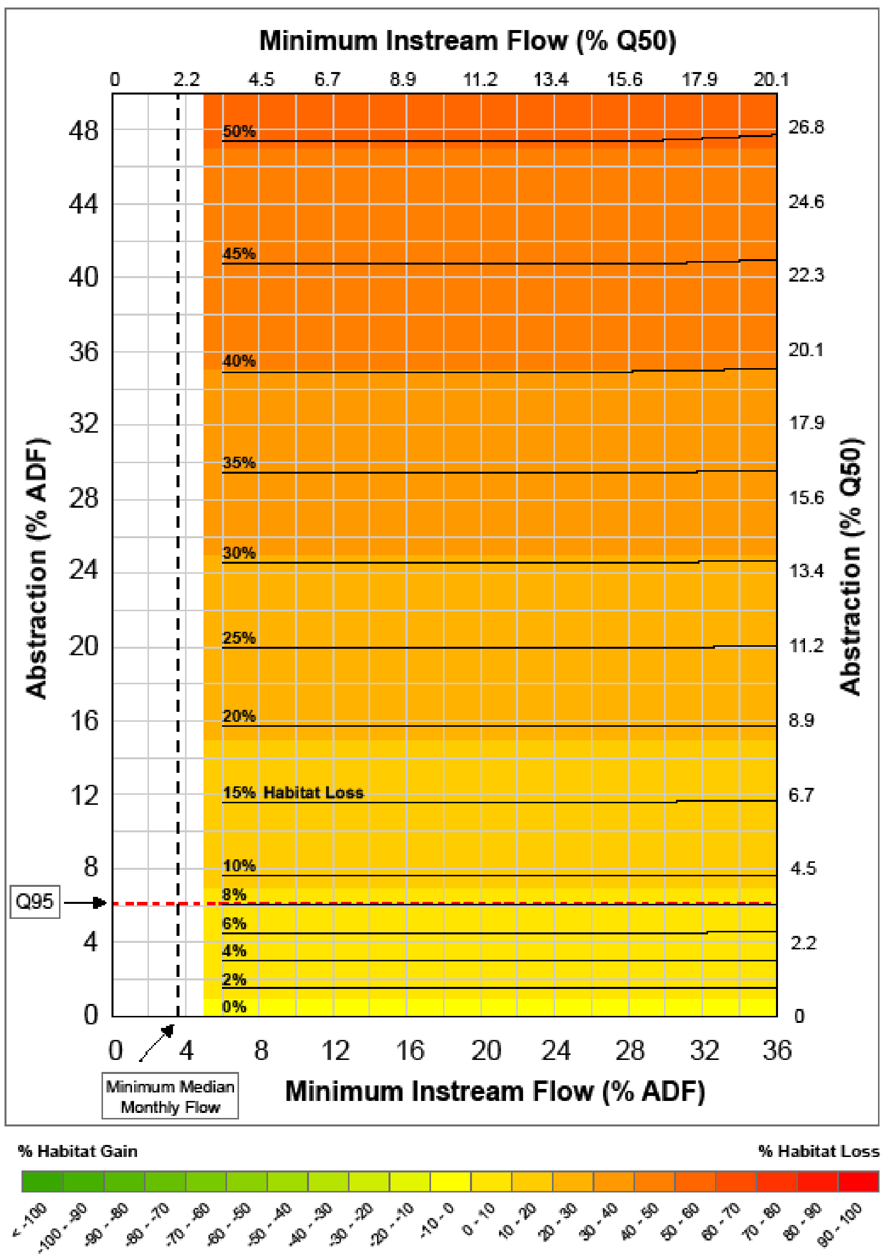


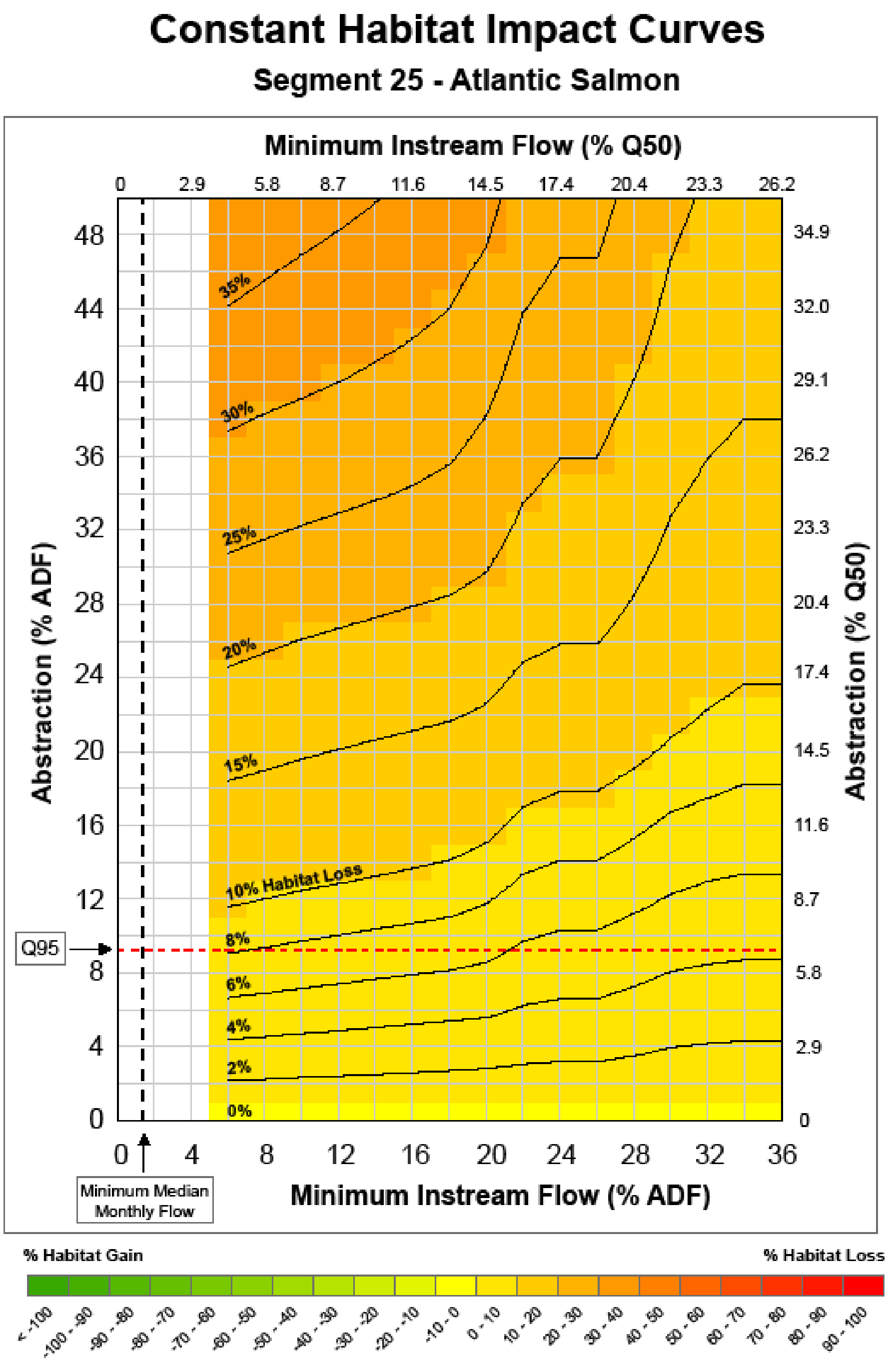

Constant Habitat Impact Curves
Segment 23 - Brown Trout
Minimum Instream Flow (% Q50)
0
3.1
6.1
9.2
12.2
15.3
18.3
21.4
24.4
27.5
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.0
26.1
23.2
20.3
17.4
14.5
11.6
8.7
5.8
2.9
0
35%
30%
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

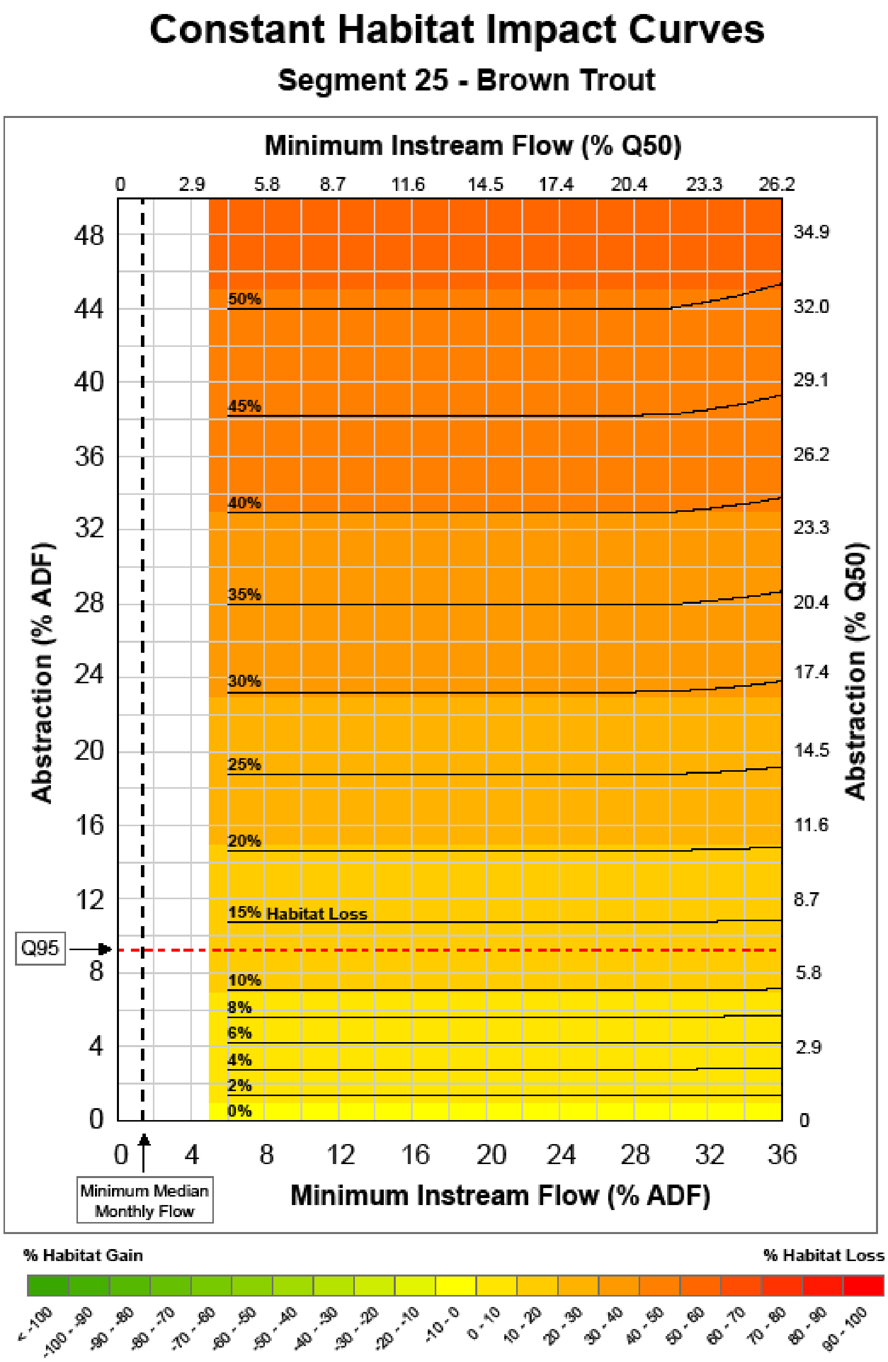

Constant Habitat Impact Curves
Segment 24 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0 2.2 4.5 6.7 8.9 11.2 13.4 15.6 17.9 20.1
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
26.8 24.6 22.3 20.1 17.9 15.6 13.4 11.2 8.9 6.7 4.5 2.2 0
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

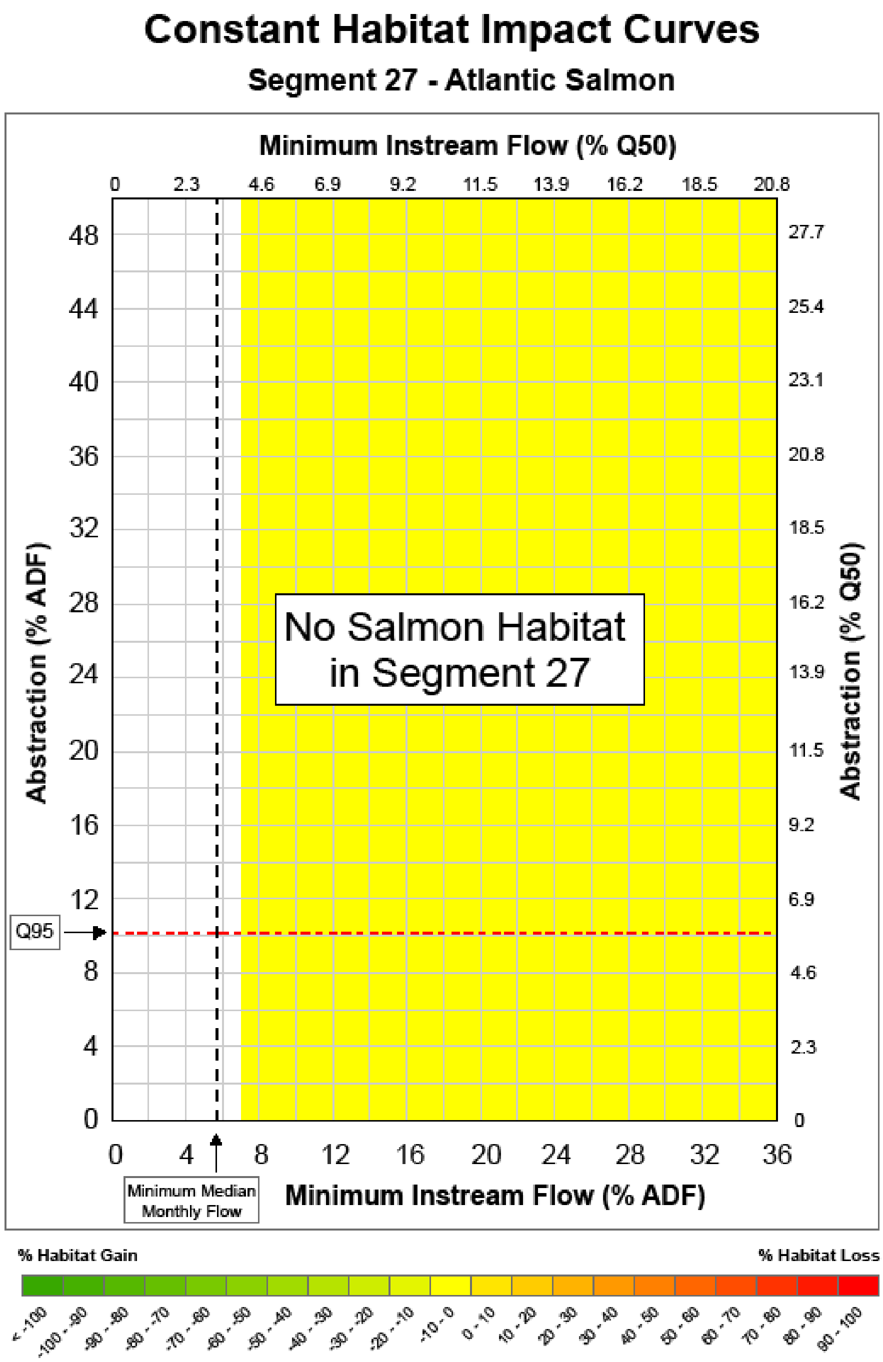
Constant Habitat Impact Curves

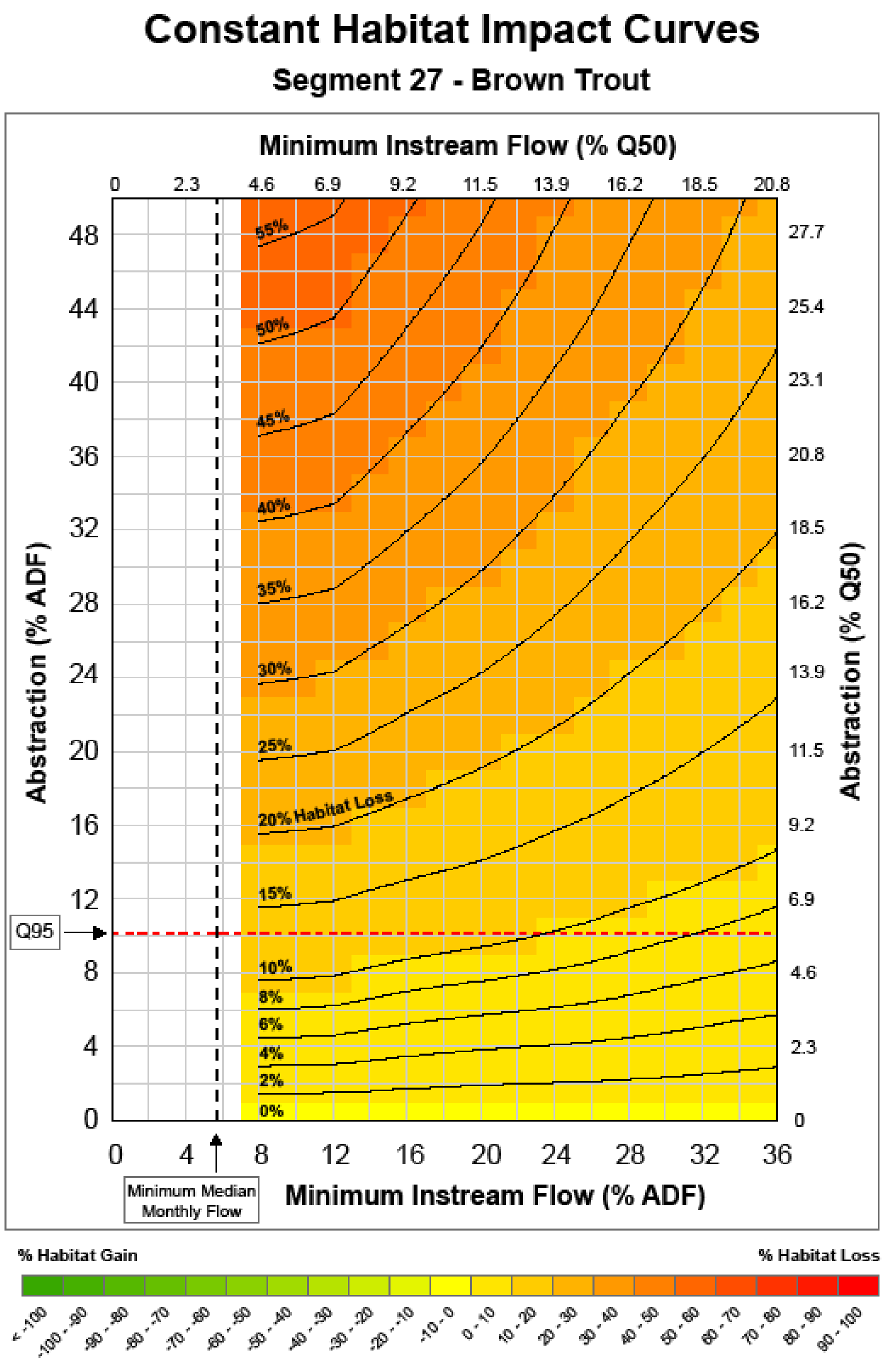
Segment 24 - Brown Trout

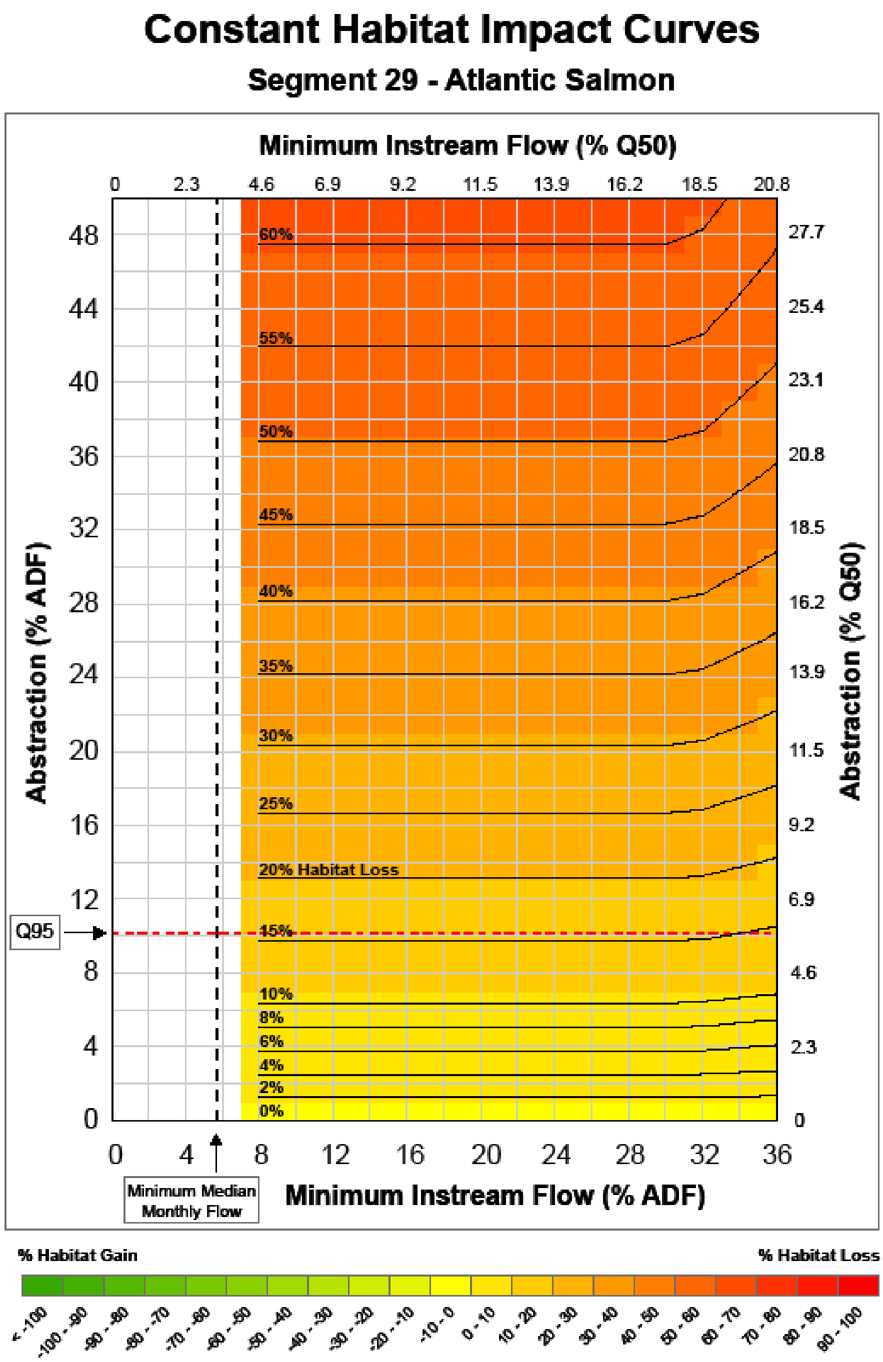


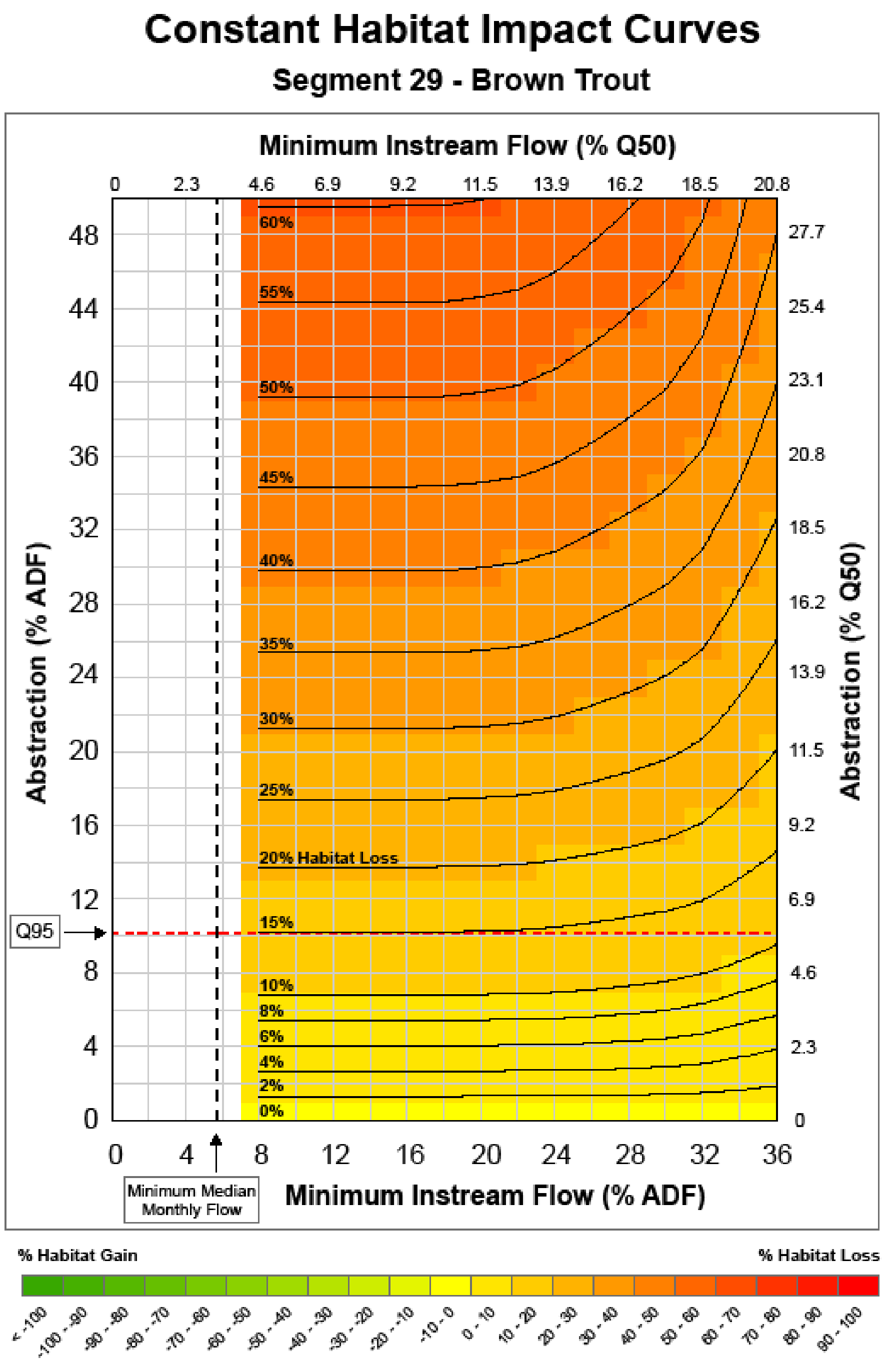

Constant Habitat Impact Curves
Segment 25 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
Abstraction (% Q50)
35%
30%
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss

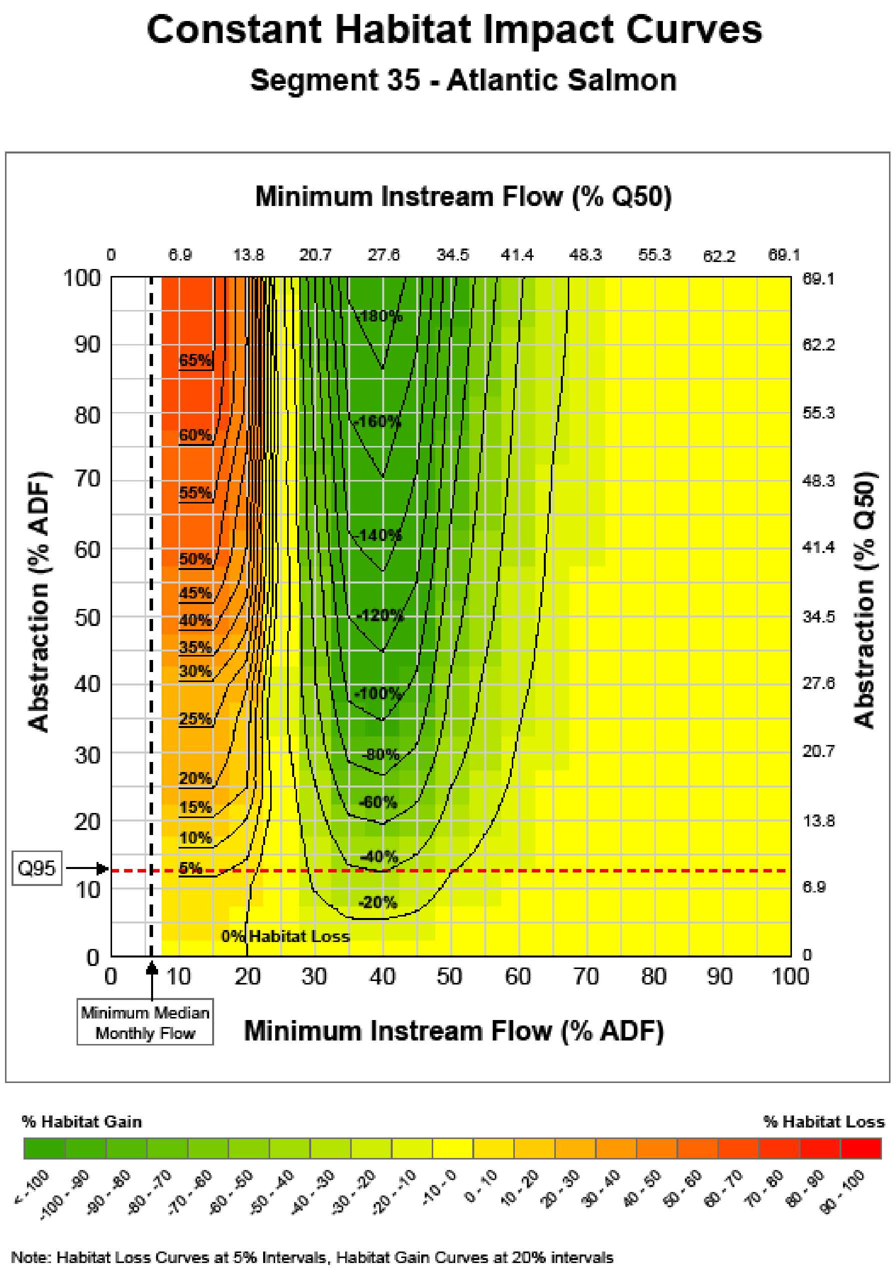

Constant Habitat Impact Curves
Segment 25 - Brown Trout
Minimum Instream Flow (% Q50)
0 2.9 5.8 8.7 11.6 14.5 17.4 20.4 23.3 26.2
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
34.9 32.0 29.1 26.2 23.3 20.4 17.4 14.5 11.6 8.7 5.8 2.9 0
50%
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 27 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
0
No Salmon Habitat in Segment 27
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 27 - Brown Trout
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
Abstraction (% Q50)
55%
50%
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss

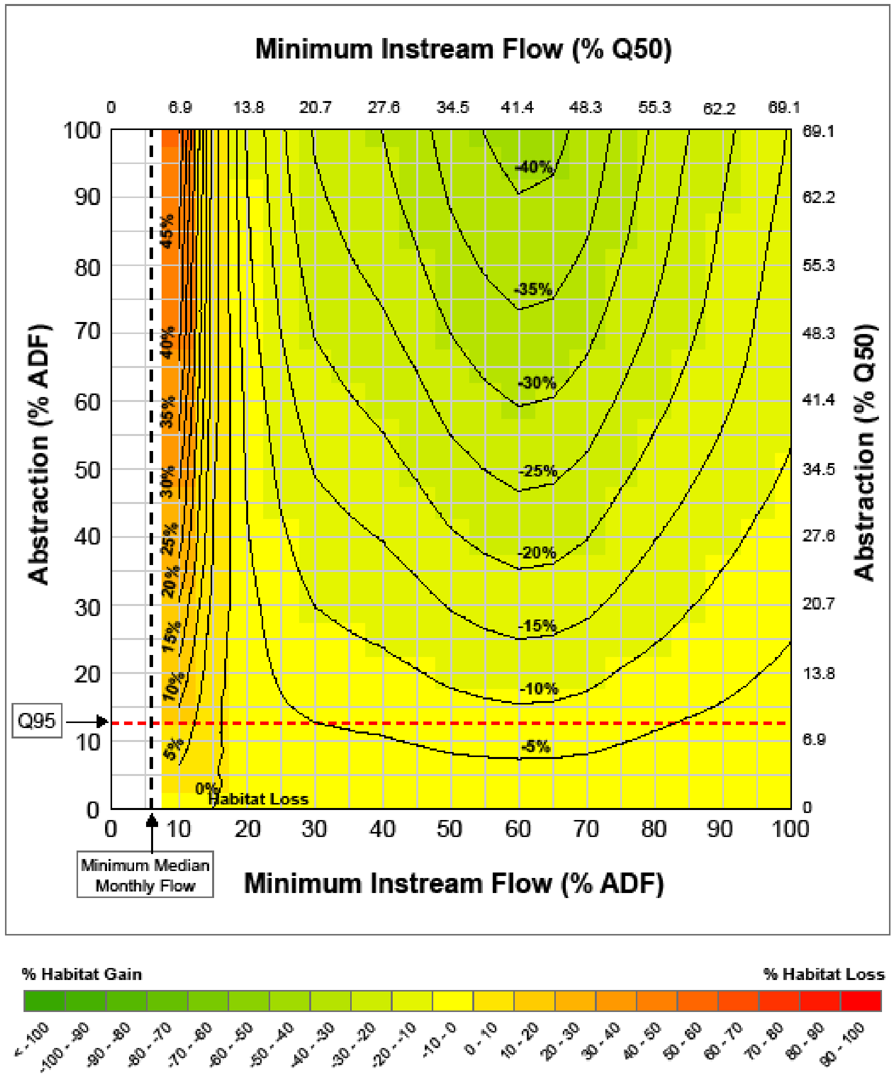

Constant Habitat Impact Curves
Segment 29 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
0
60%
55%
50%
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 29 - Brown Trout
Minimum Instream Flow (% Q50)
0 2.3 4.6 6.9 9.2 11.5 13.9 16.2 18.5 20.8
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
27.7 25.4 23.1 20.8 18.5 16.2 13.9 11.5 9.2 6.9 4.6 2.3 0
60%
55%
50%
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

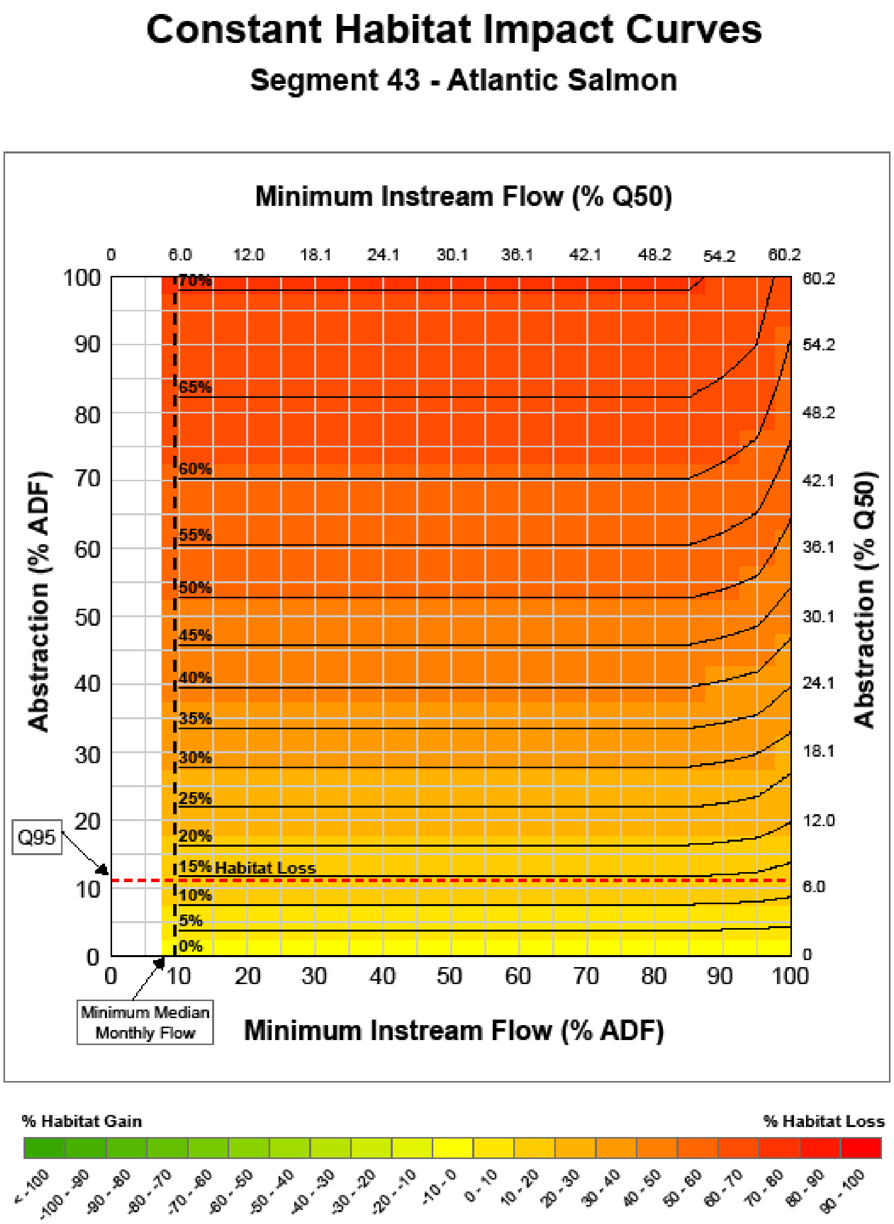

Constant Habitat Impact Curves
Segment 35 - Atlantic Salmon
Minimum Instream Flow (% Q50)
Minimum Instream Flow (% ADF)
Abstraction (% ADF)
Abstraction (% Q50)
Q95
Minimum Median Monthly Flow
0% Habitat Loss
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
-20%
-40%
-60%
-80%
-100%
-120%
-140%
-160%
-180%
% Habitat Gain
% Habitat Loss
Note: Habitat Loss Curves at 5% Intervals, Habitat Gain Curves at 20% intervals

Constant Habitat Impact Curves

Segment 35 - Brown Trout



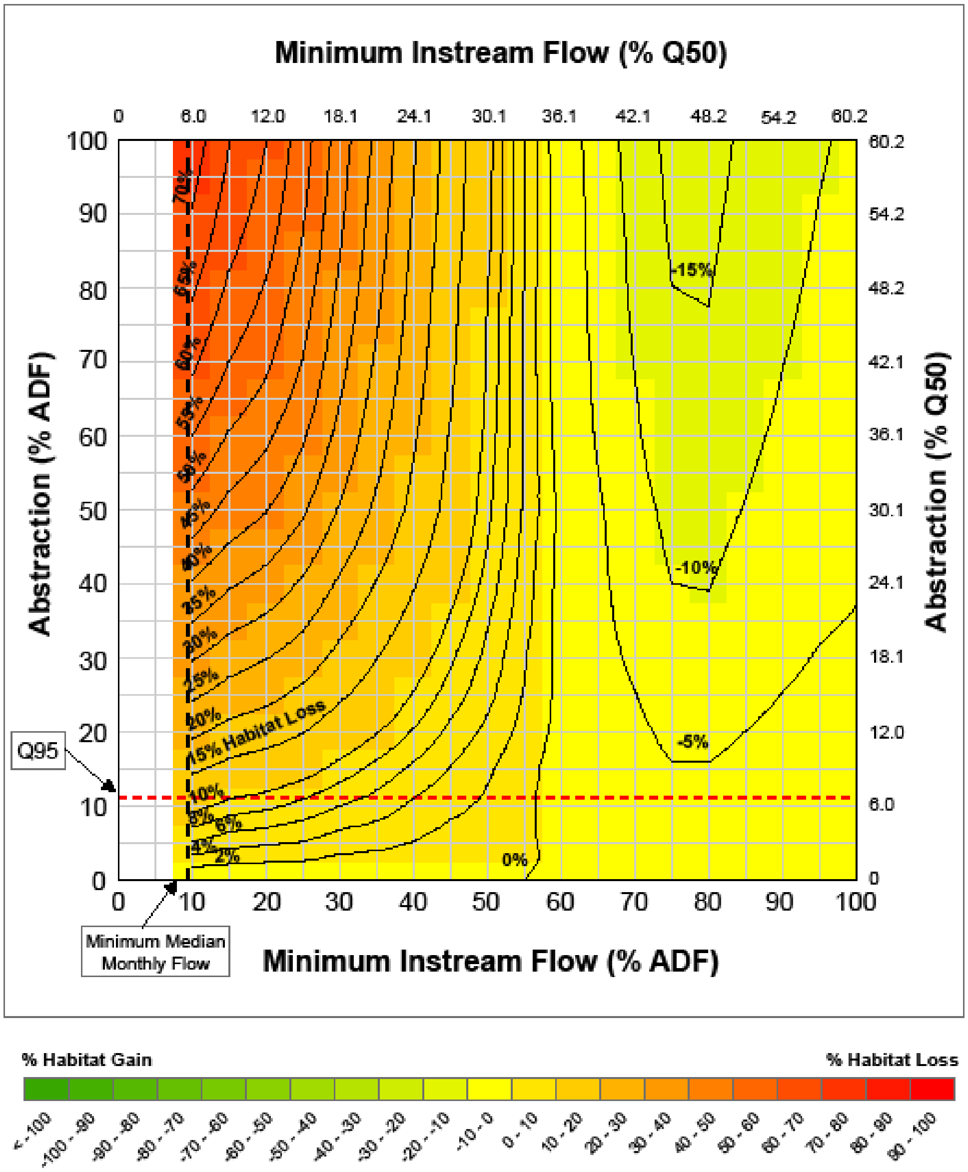
Note: Habitat Loss Curves at 5% Intervals, Habitat Gain Curves at 5% Intervals



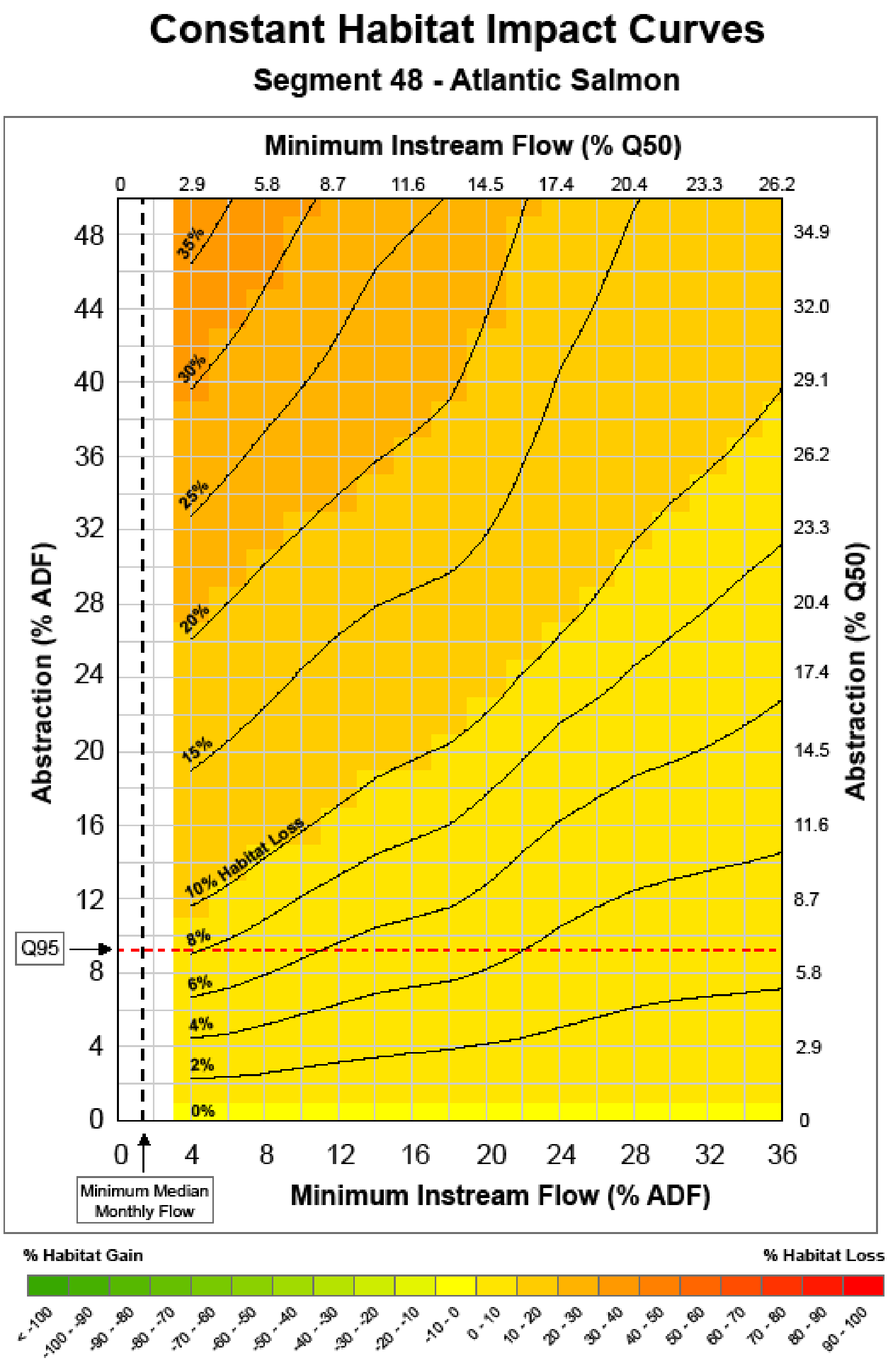
Note: Habitat Loss Curves at 5% Intervals

Constant Habitat Impact Curves

Segment 43 - Brown Trout

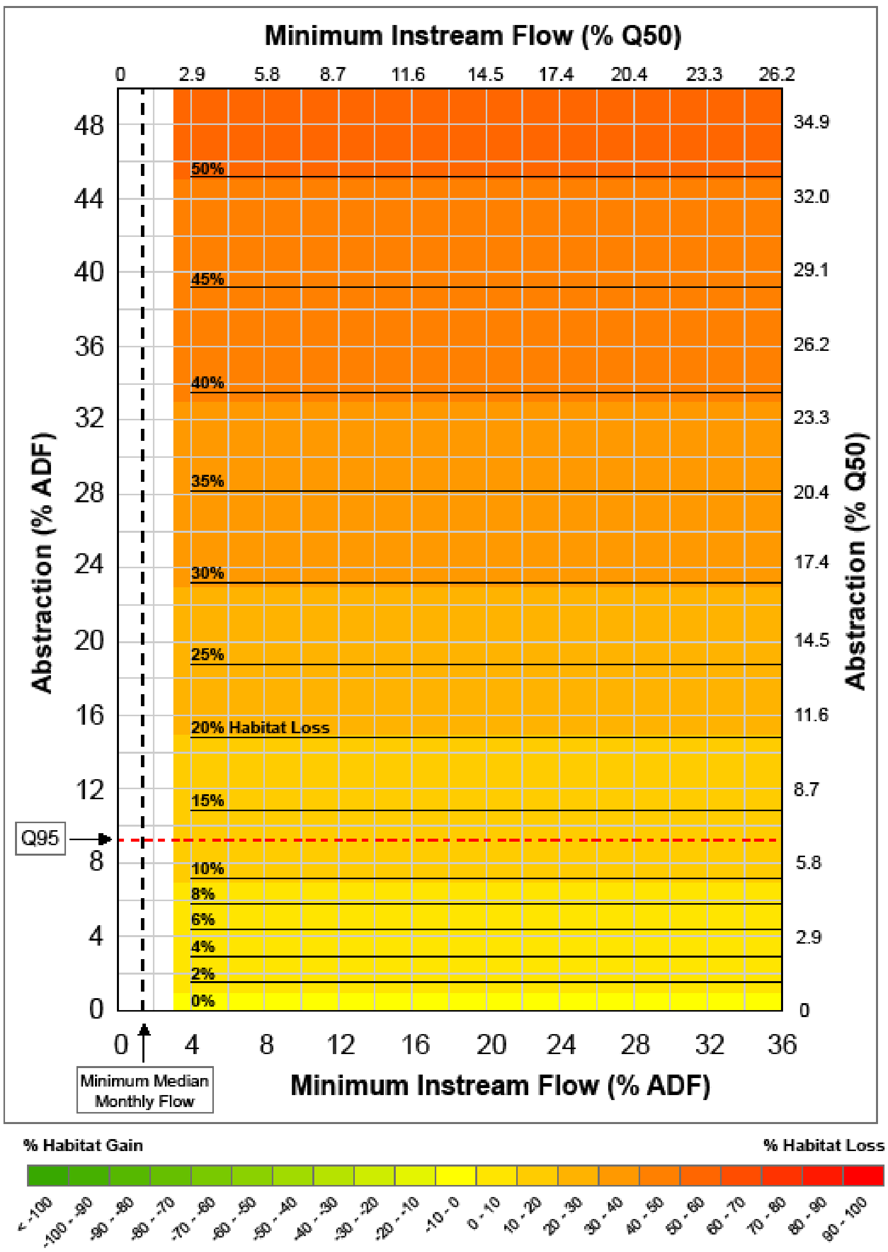


Note: Habitat Loss Curves at 2% and 5% Intervals, Habitat Gain Curves at 5% Intervals


Constant Habitat Impact Curves
Segment 48 - Atlantic Salmon
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
Abstraction (% Q50)
35%
30%
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

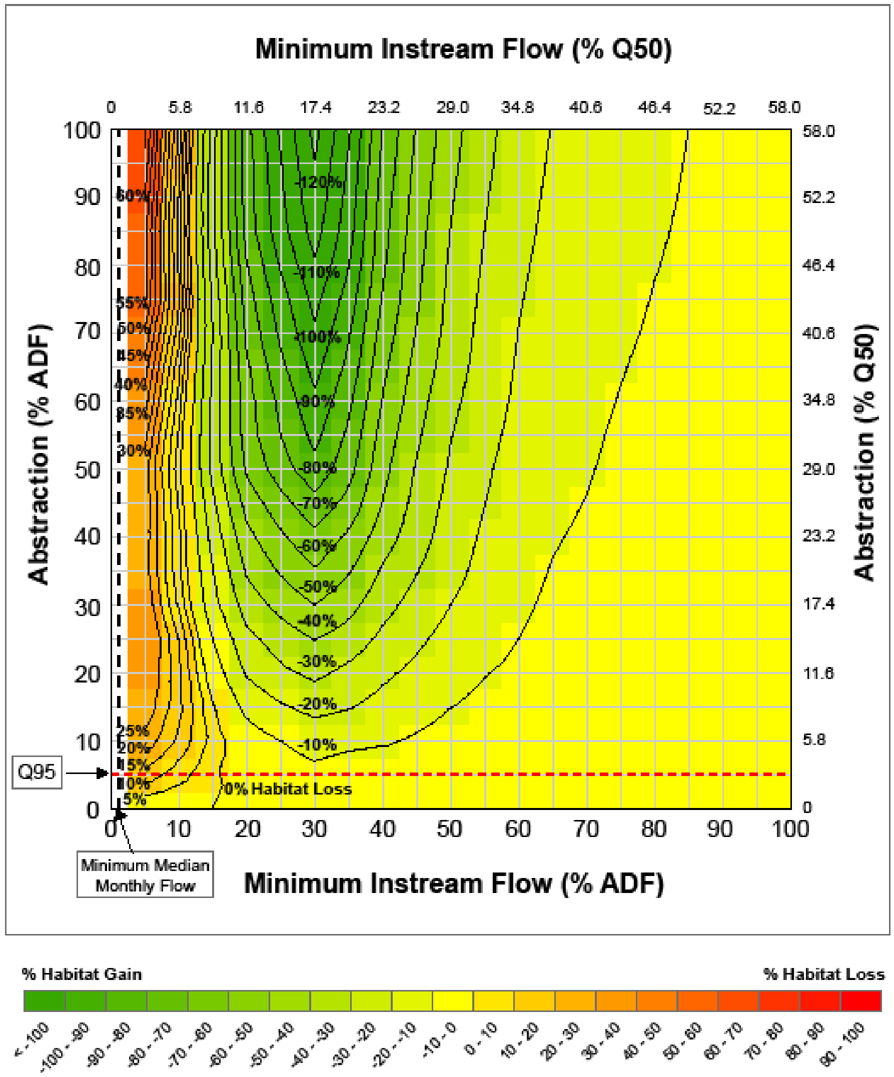
Constant Habitat Impact Curves

Segment 48 - Brown Trout



Constant Habitat Impact Curves

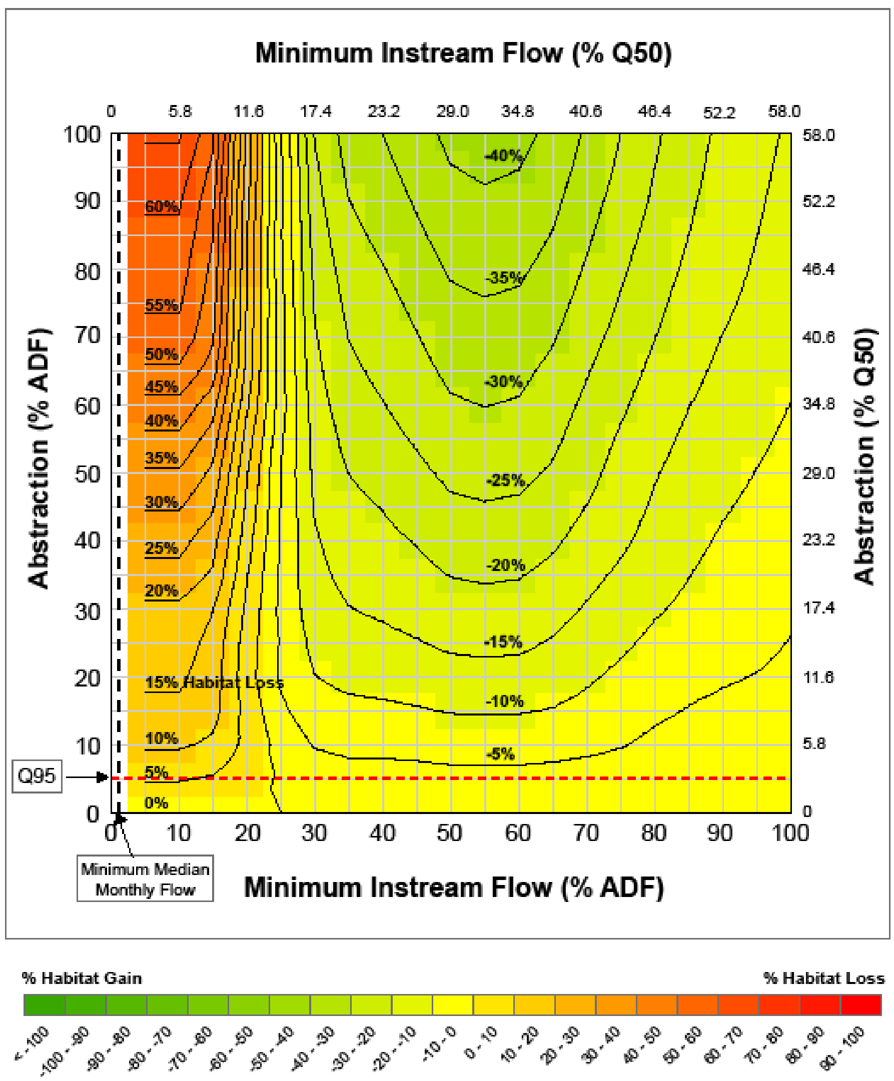
Segment 90 - Atlantic Salmon



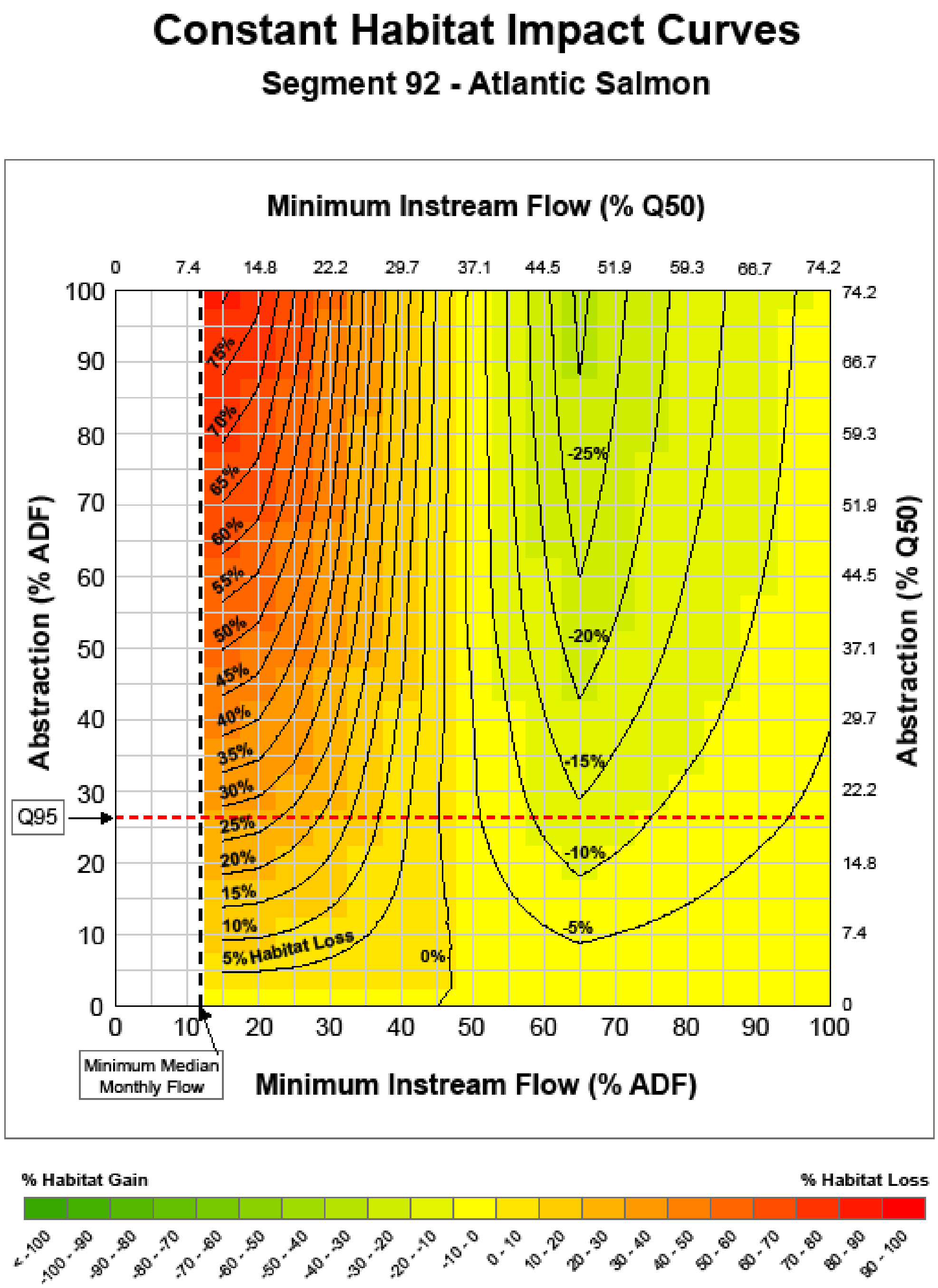
Note: Habitat Loss Curves at 5% Intervals, Habitat Gain Curves at 10% Intervals

Constant Habitat Impact Curves

Segment 90 - Brown Trout



Note: Habitat Loss Curves at 5% Intervals, Habitat Gain Curves at 5% Intervals



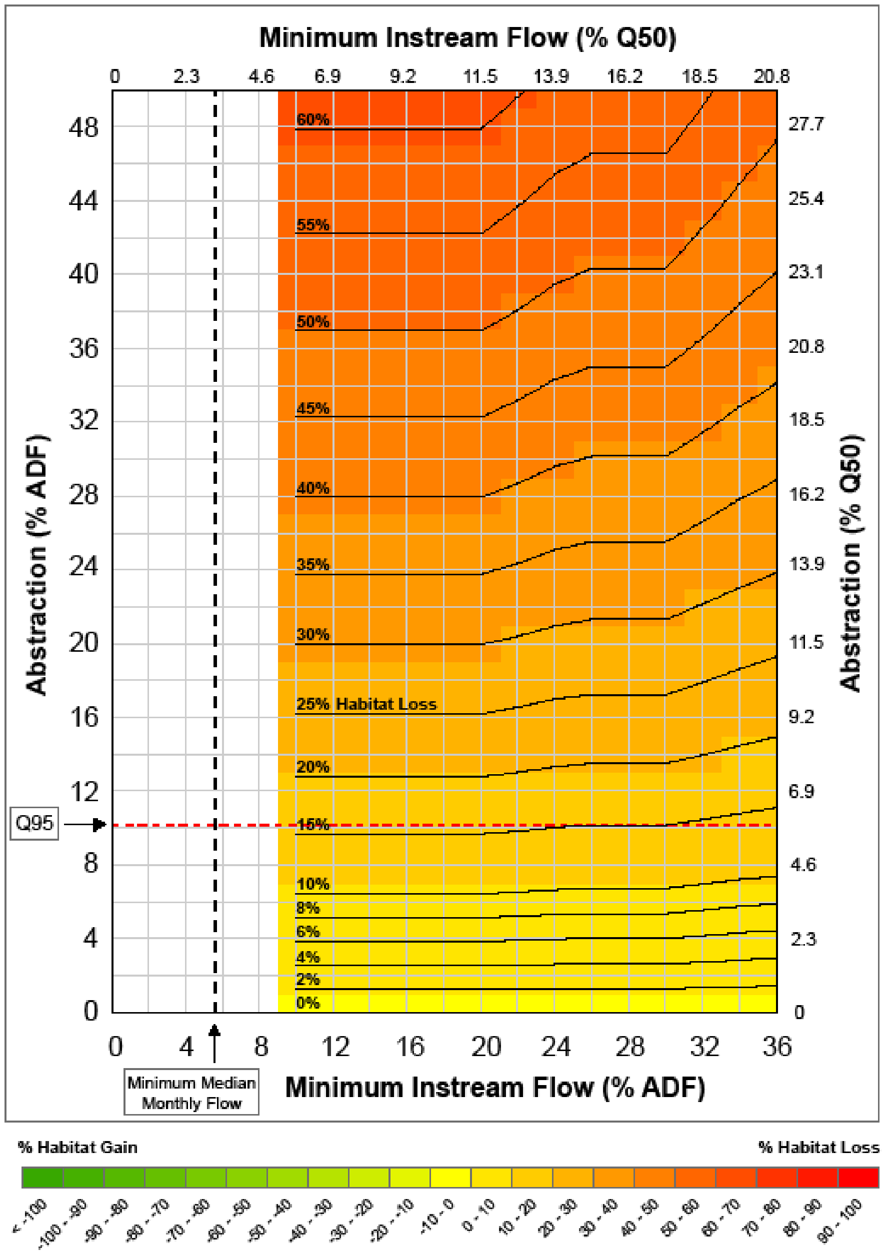
Note: Habitat Loss Curves at 5% Intervals, Habitat Gain Curves at 5% Intervals

Constant Habitat Impact Curves

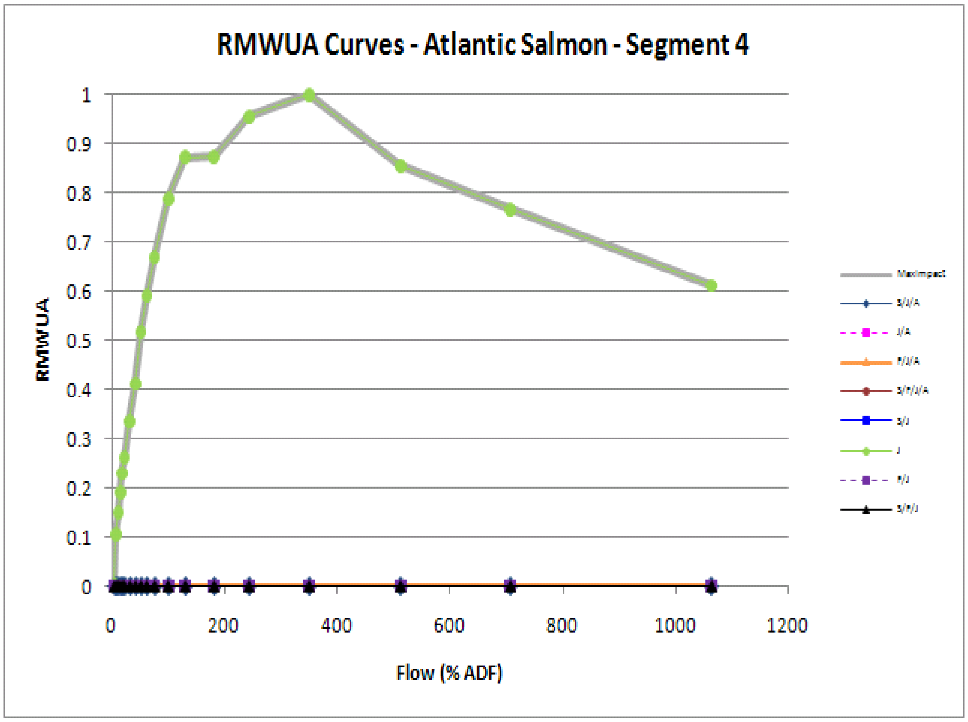
Segment 92 - Brown Trout

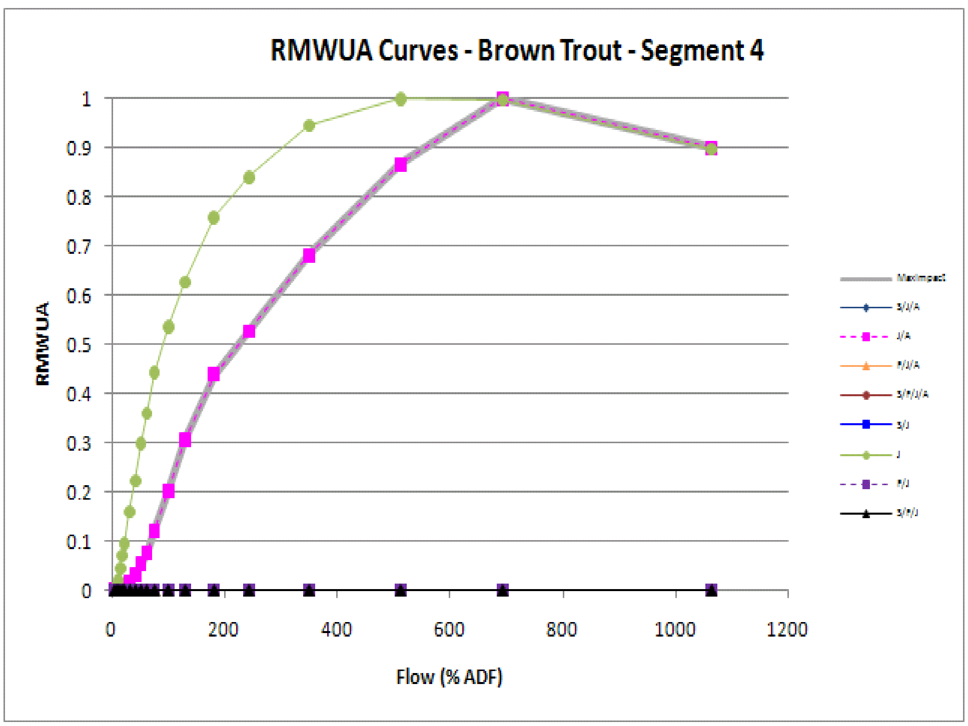
Constant Habitat Impact Curves

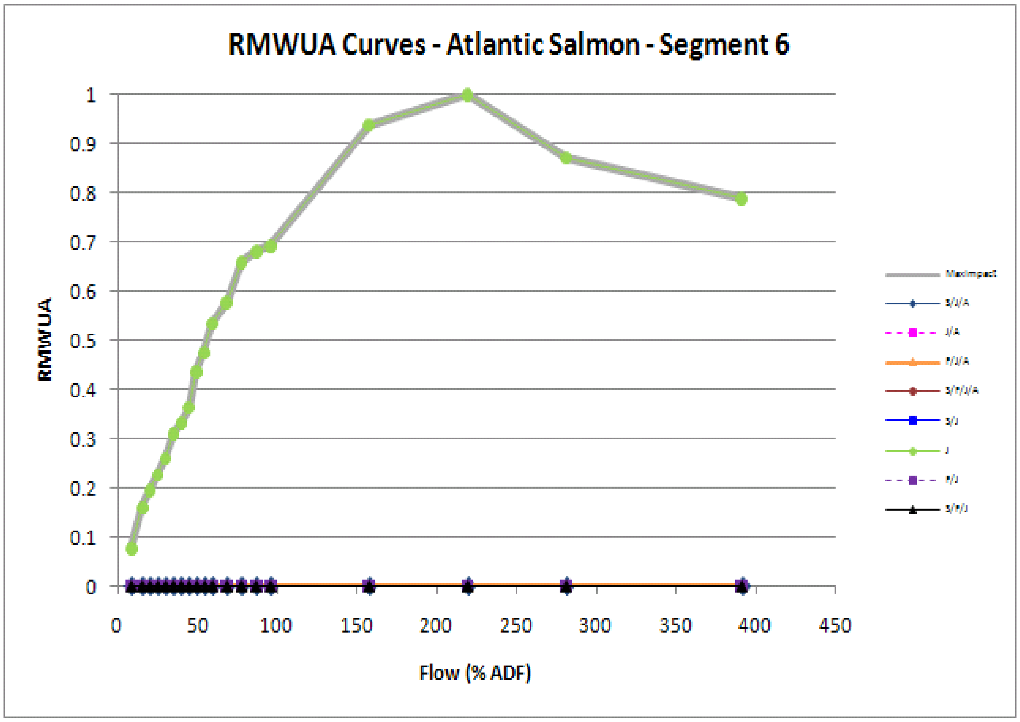
Segment 6 - Atlantic Salmon

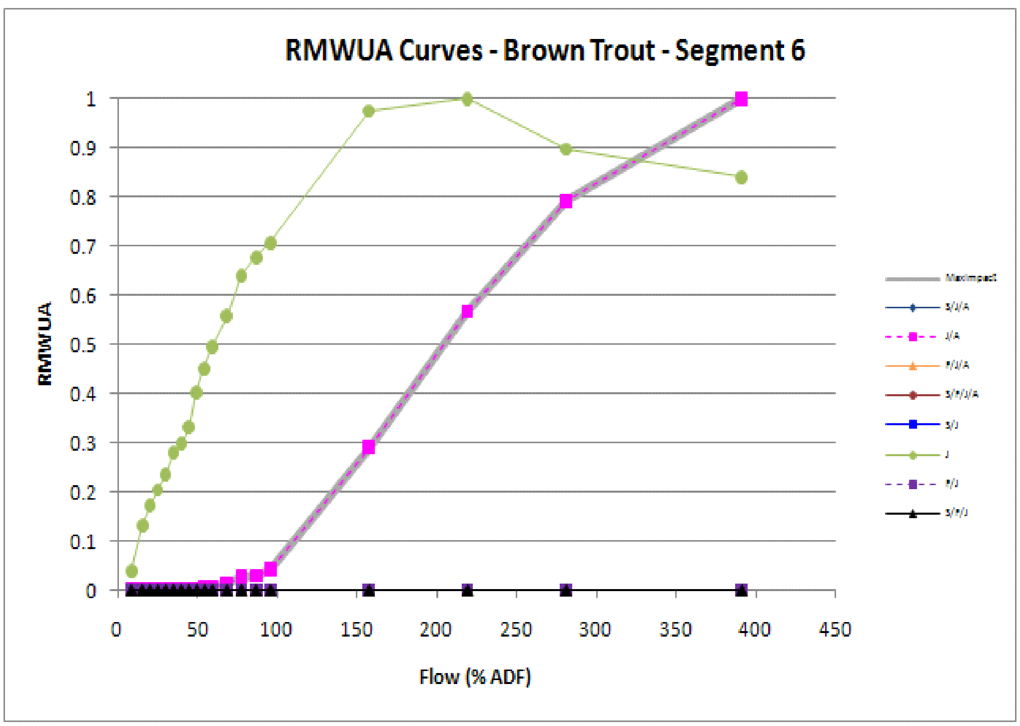


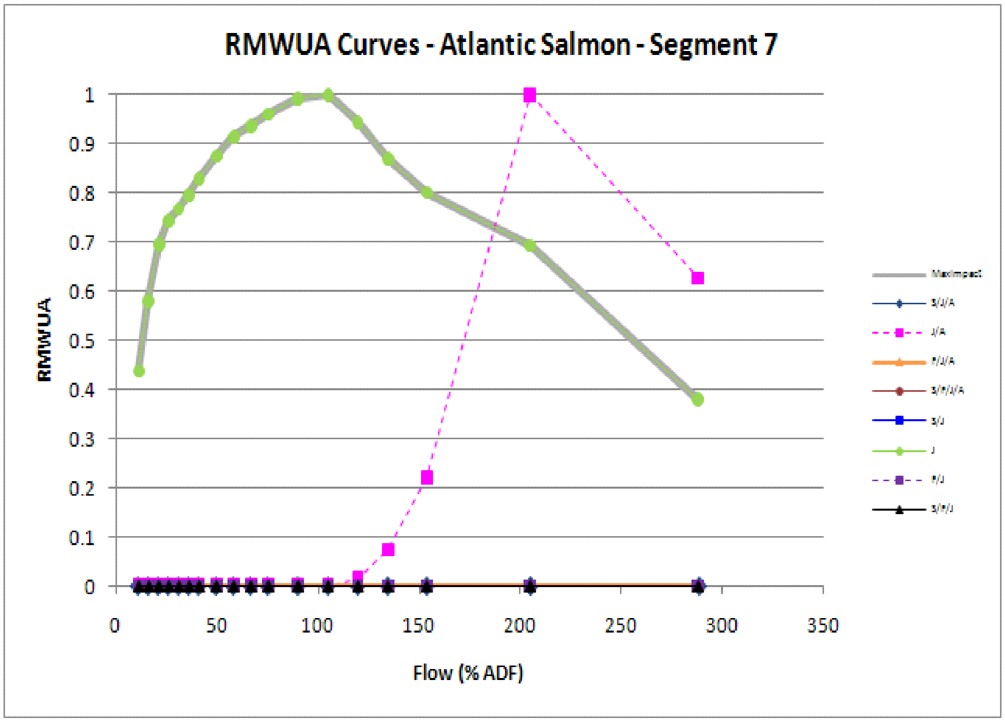
Appendix E – Max Impact RMWUA Curves for Juvenile and Adults

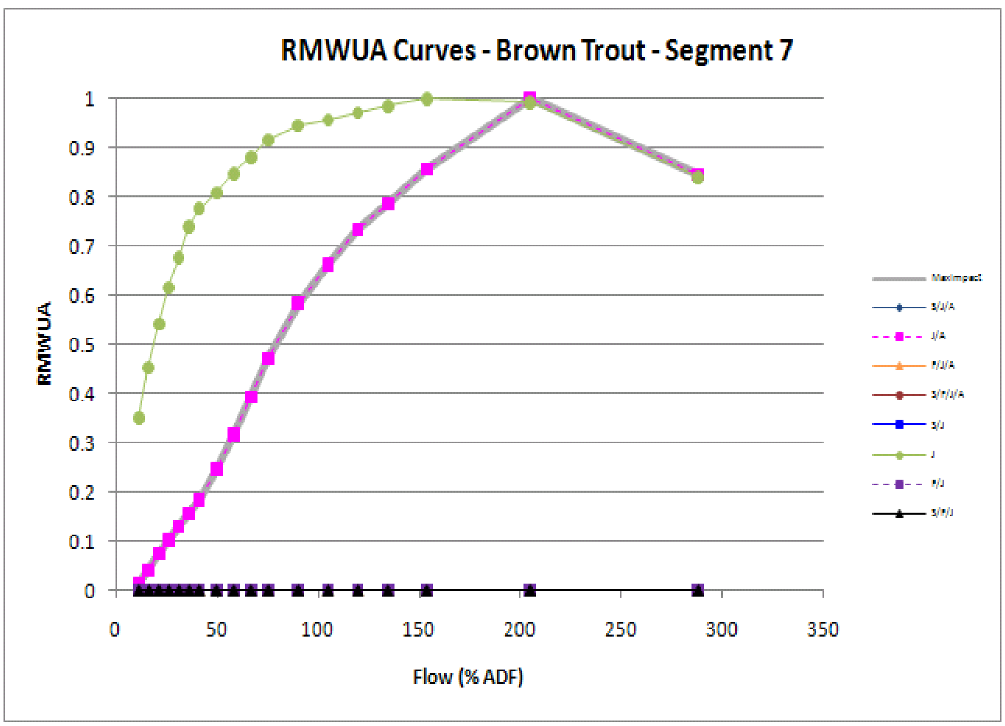

RMWUA Curves - Atlantic Salmon - Segment 4
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

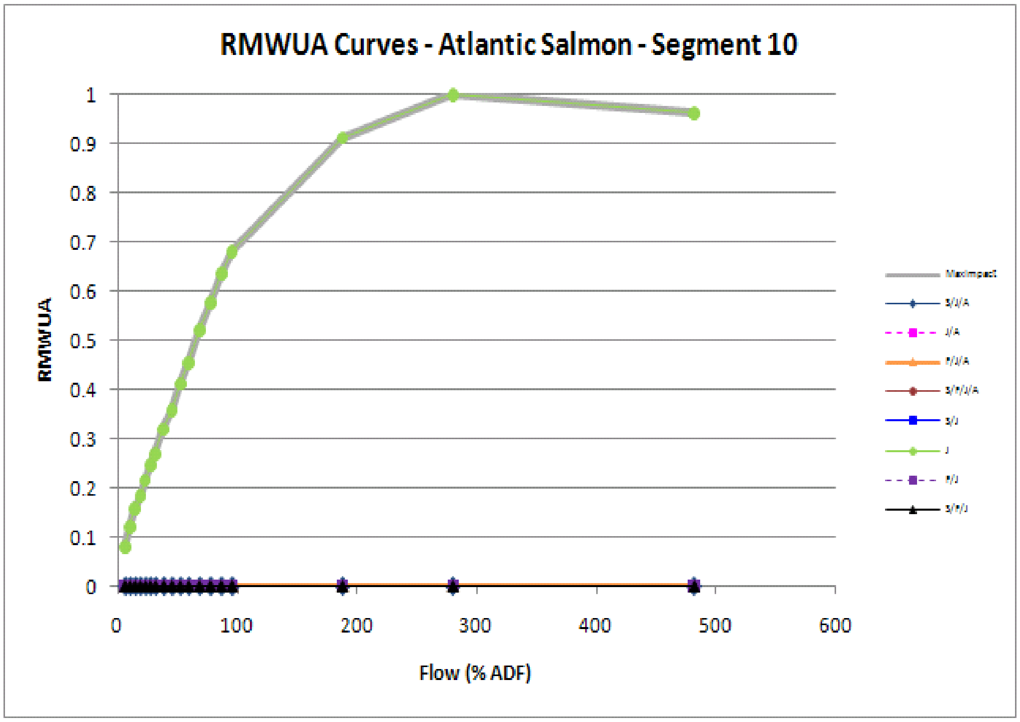

RMWUA Curves - Brown Trout - Segment 4
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

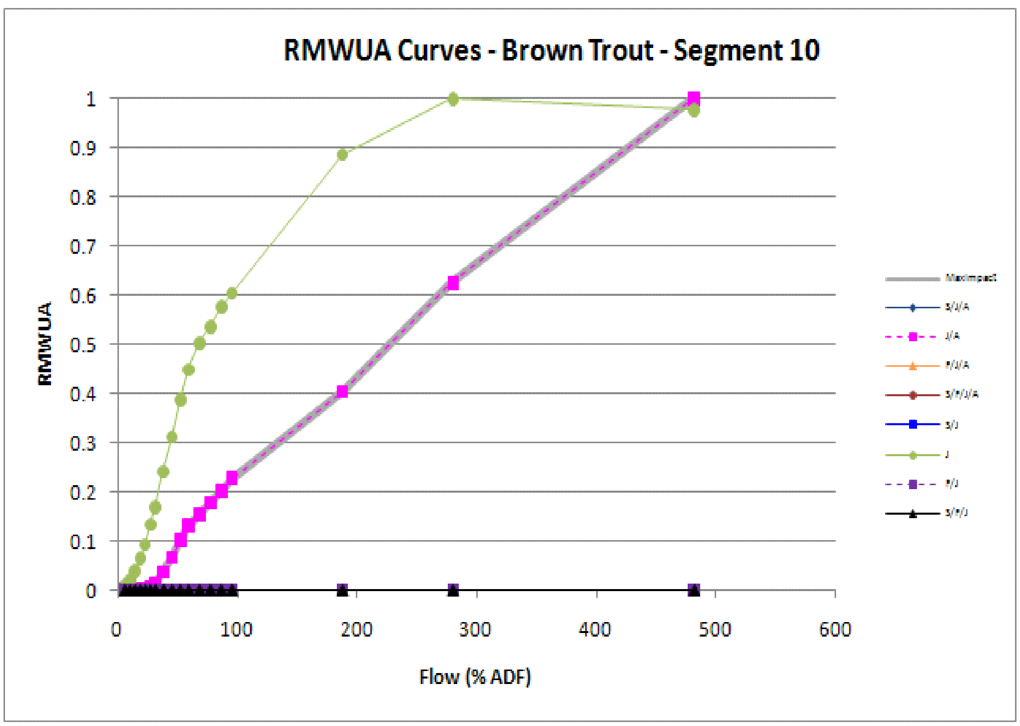

RMWUA Curves - Atlantic Salmon - Segment 6
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

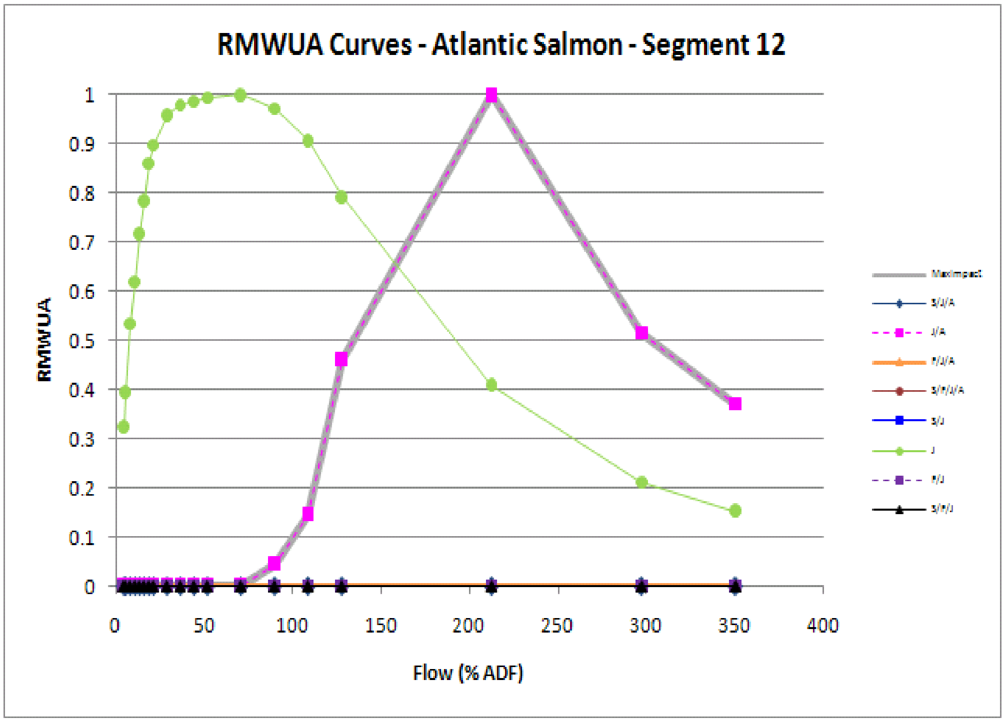

RMWUA Curves - Brown Trout - Segment 6
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

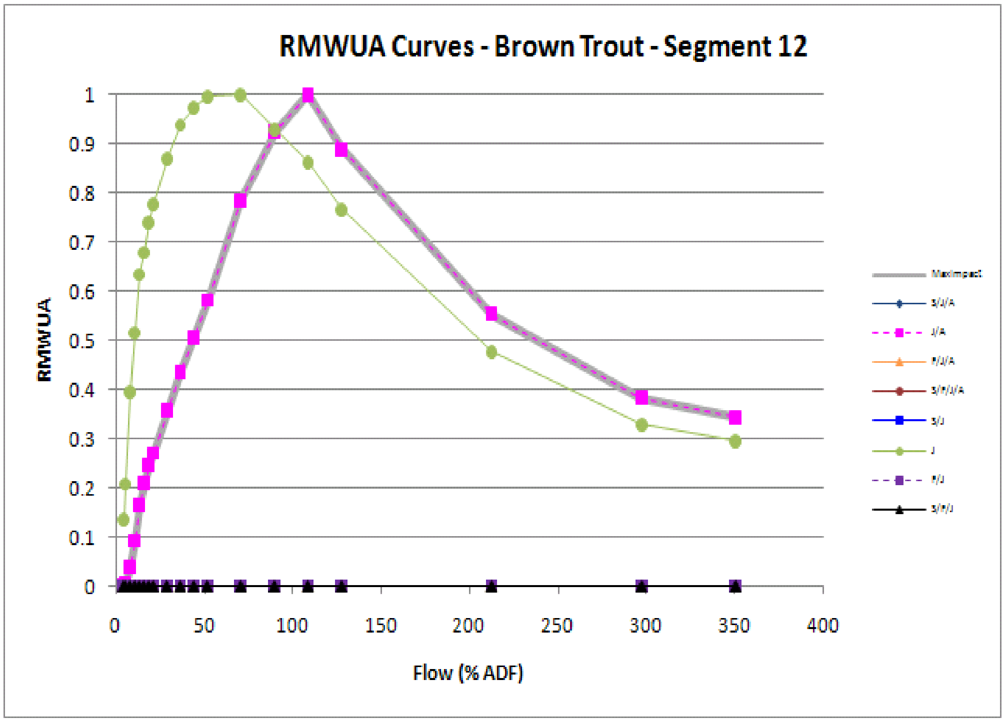

RMWUA Curves - Atlantic Salmon - Segment 7
RMWUA
Flow (% ADF)
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

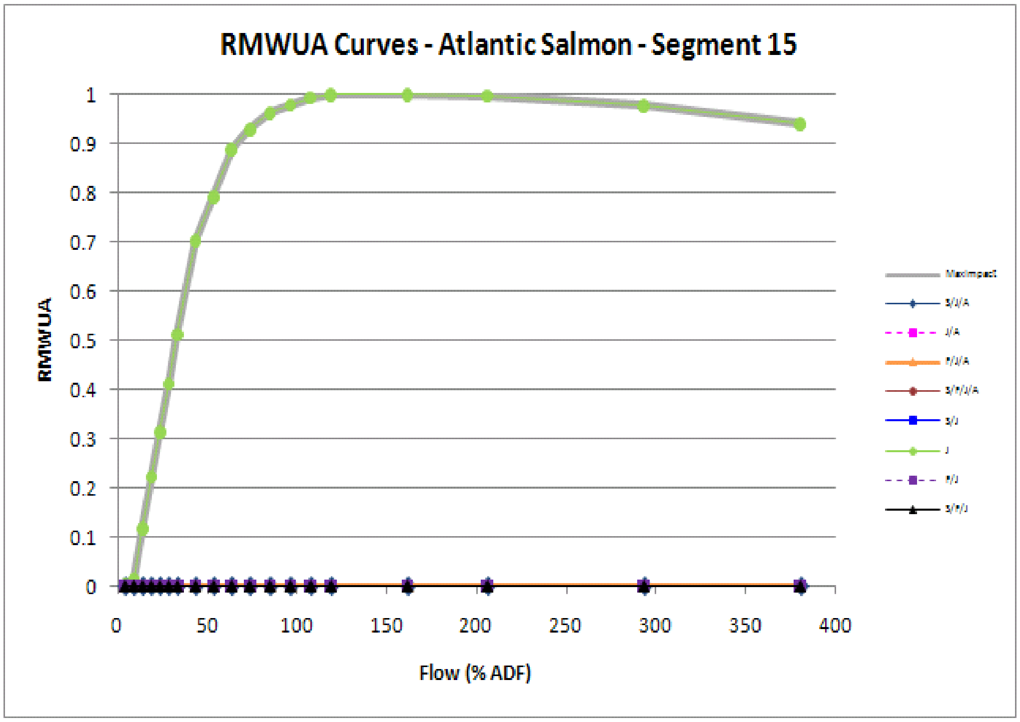

RMWUA Curves - Brown Trout - Segment 7
RMWUA
Flow (% ADF)
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

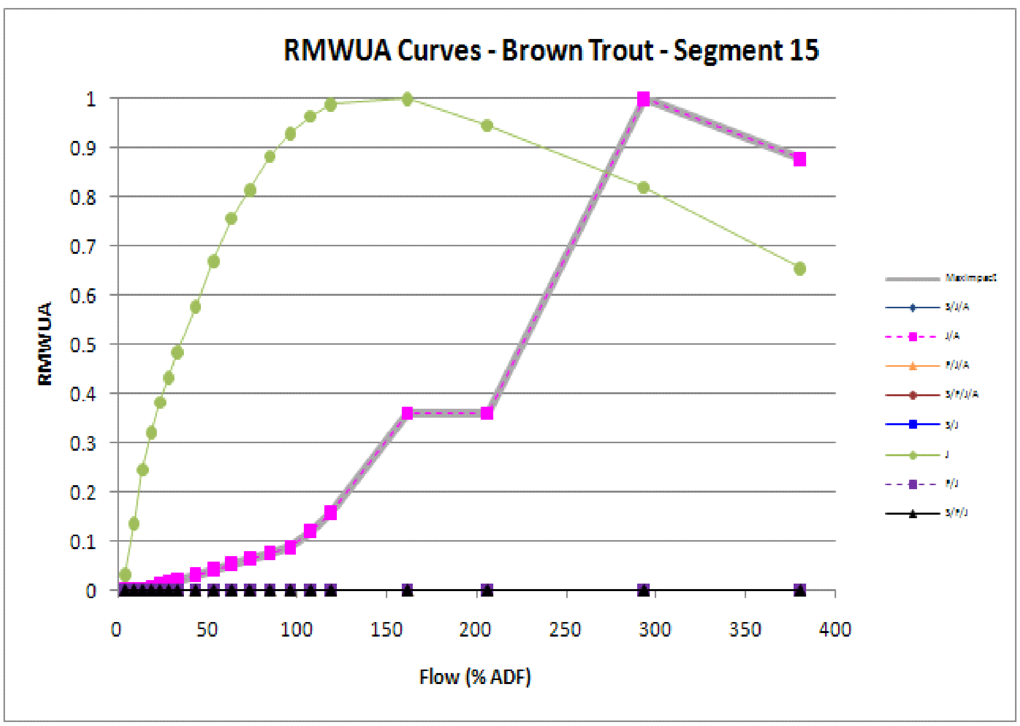

RMWUA Curves - Atlantic Salmon - Segment 10
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

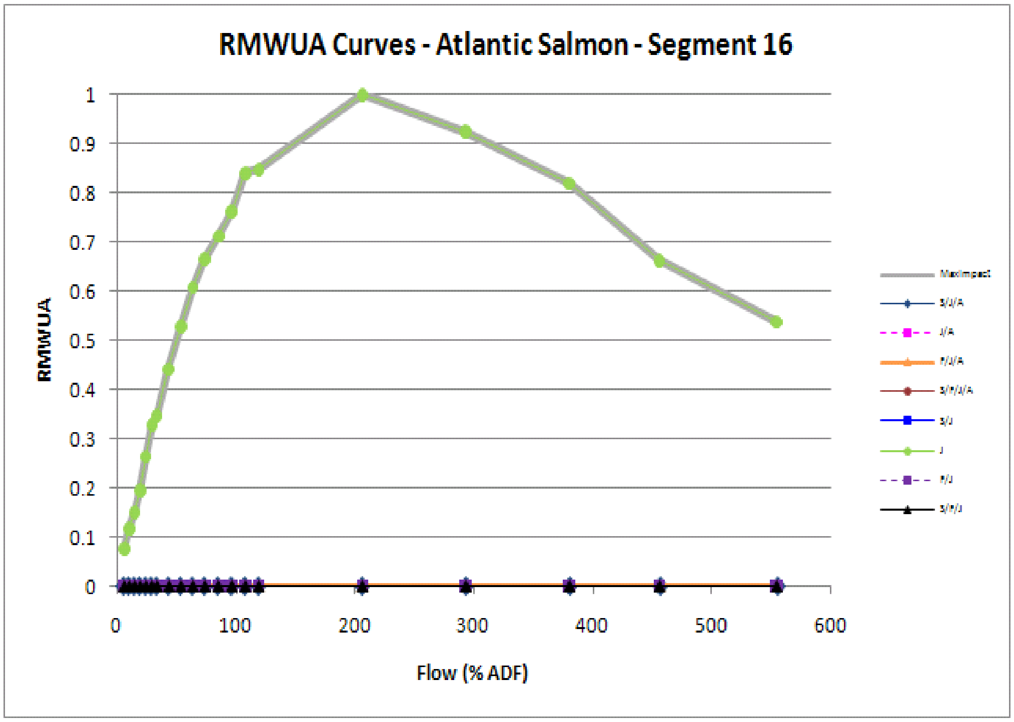

RMWUA Curves - Brown Trout - Segment 10
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

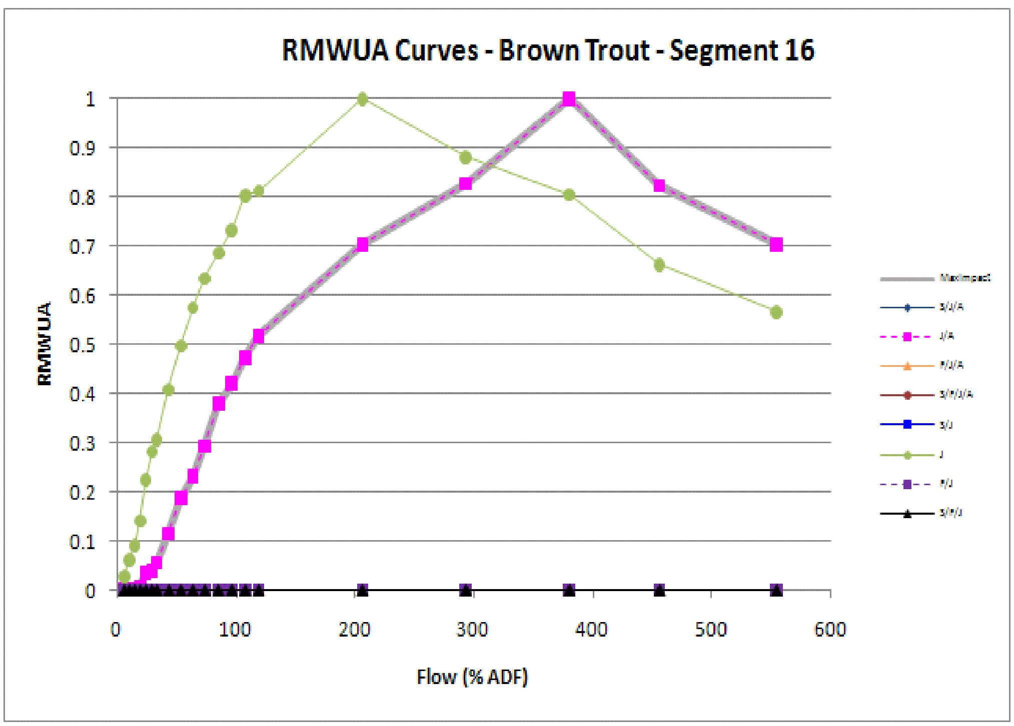

RMWUA Curves - Atlantic Salmon - Segment 12
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

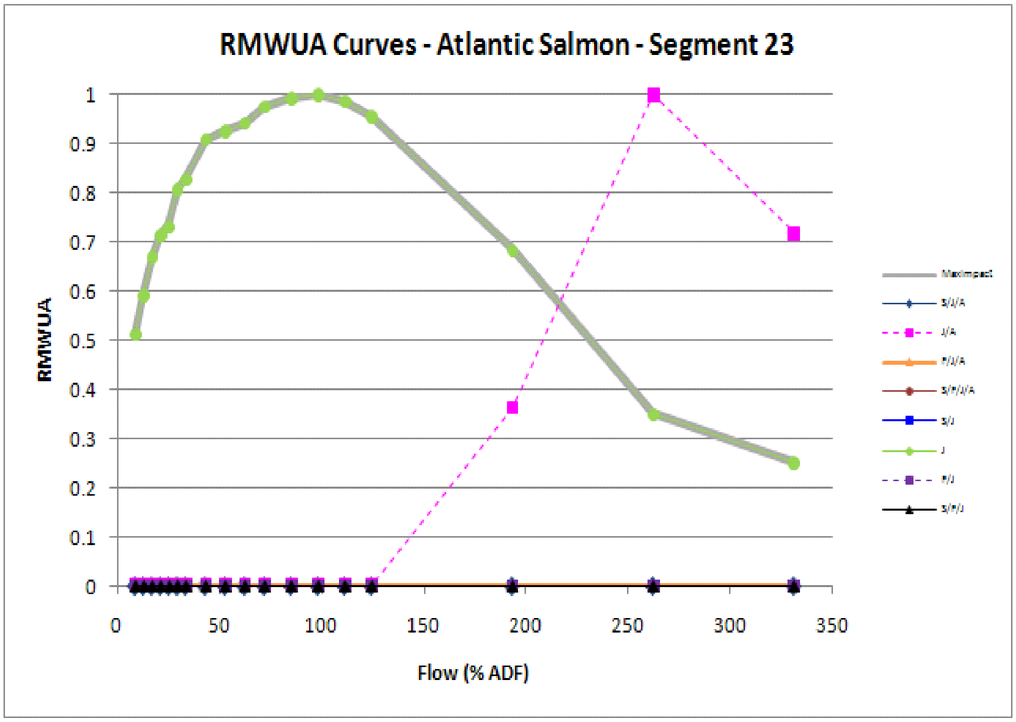

RMWUA Curves - Brown Trout - Segment 12
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

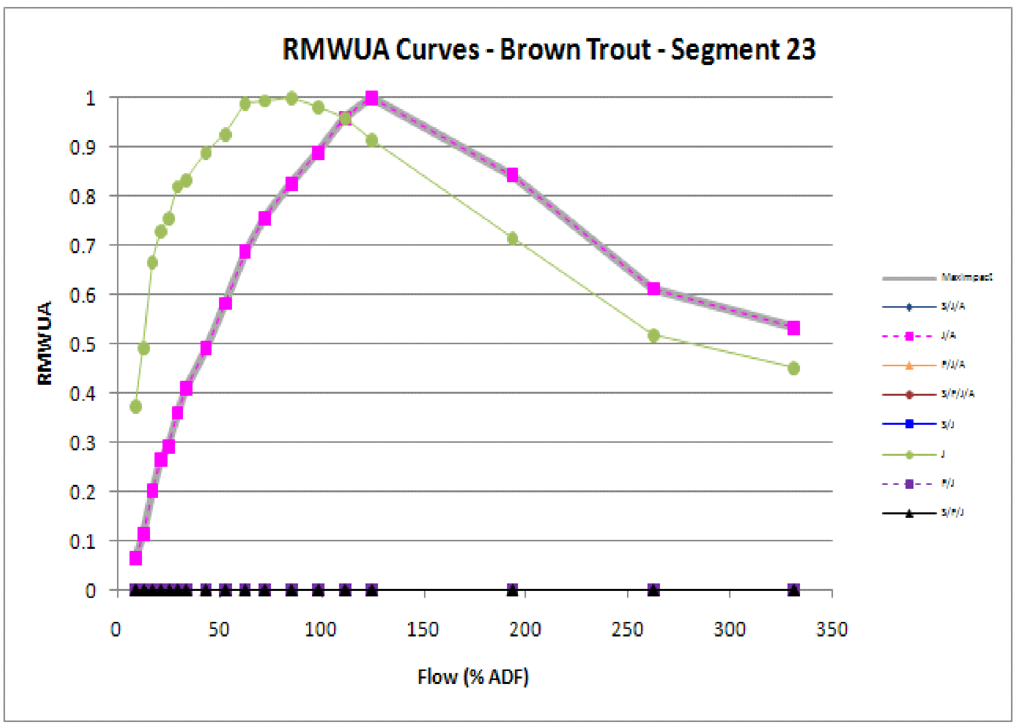

RMWUA Curves - Atlantic Salmon - Segment 15
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

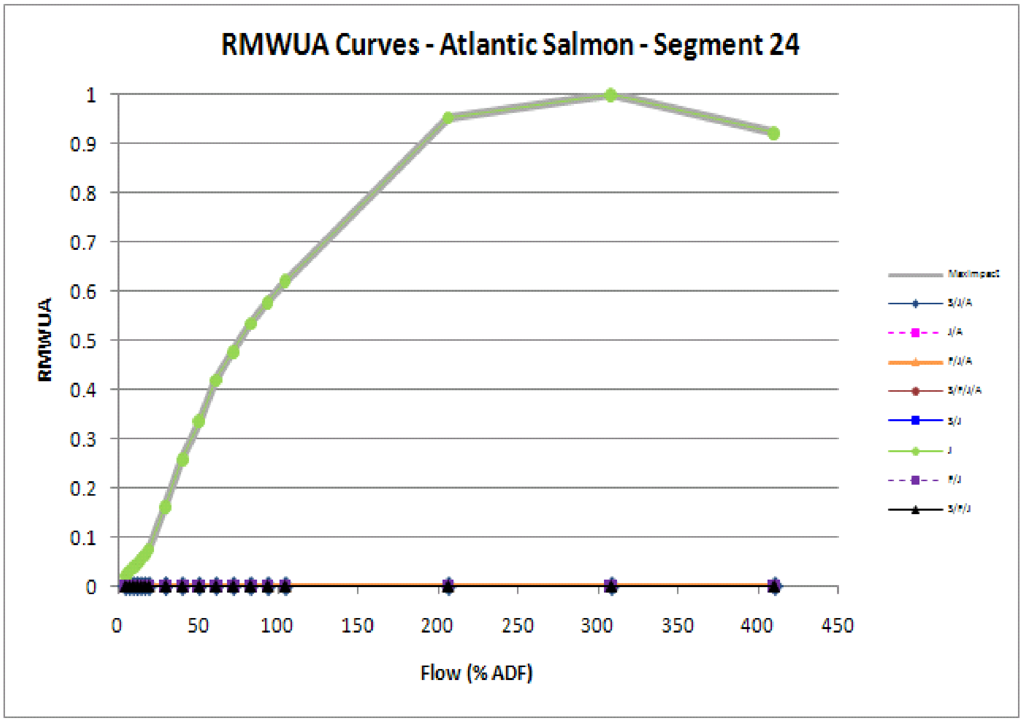

RMWUA Curves - Brown Trout - Segment 15
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

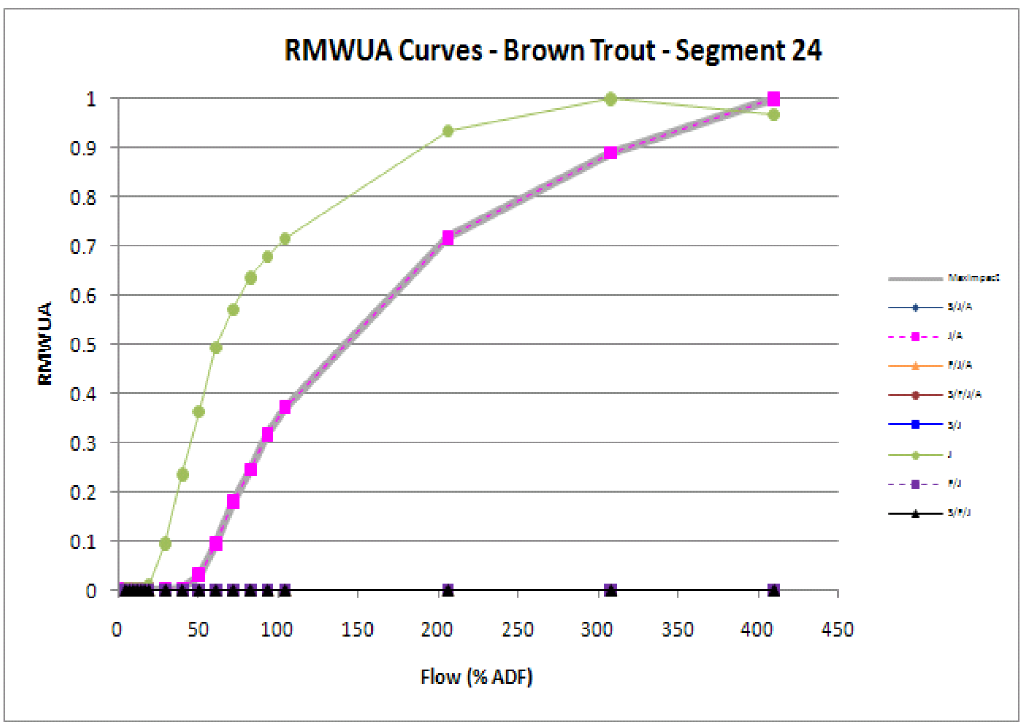

RMWUA Curves - Atlantic Salmon - Segment 16
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

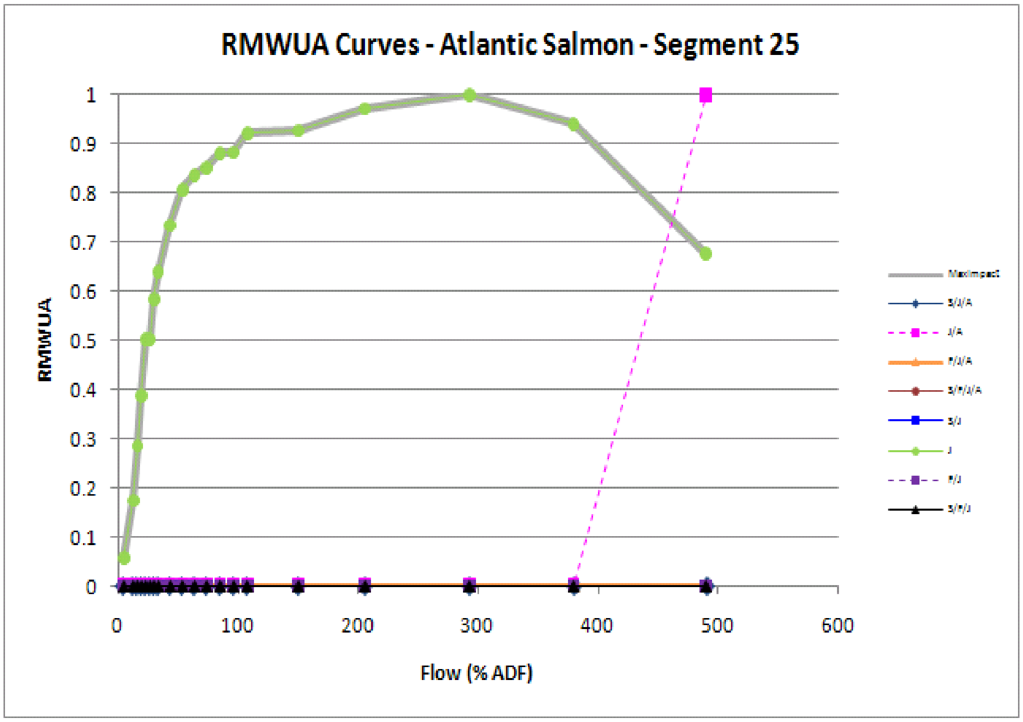

RMWUA Curves - Brown Trout - Segment 16
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

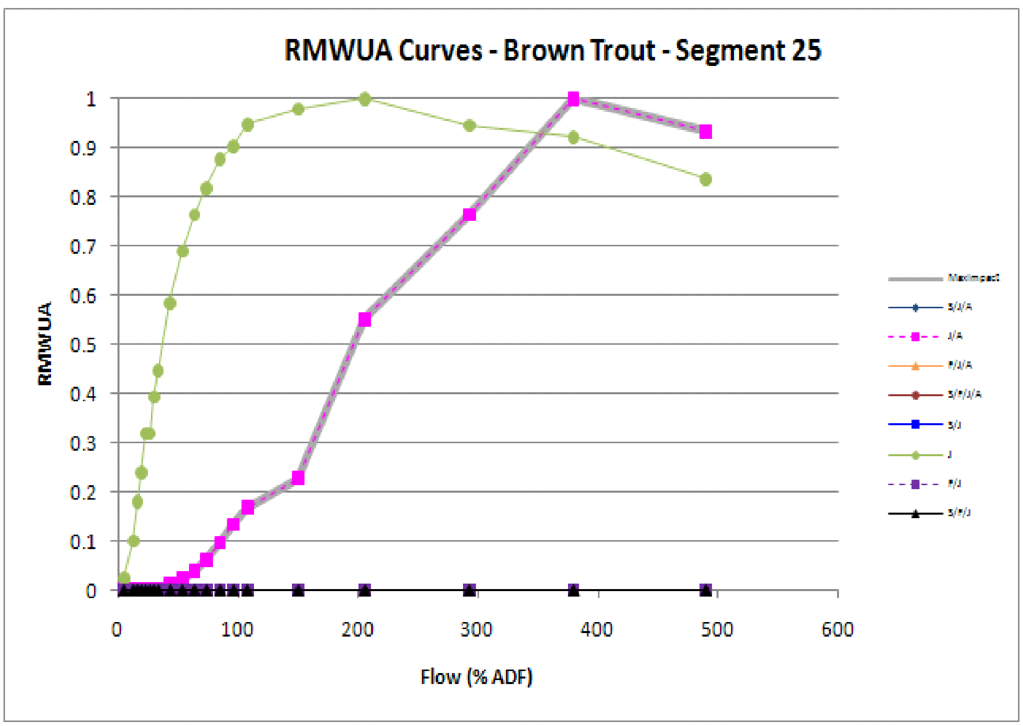

RMWUA Curves - Atlantic Salmon - Segment 23
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

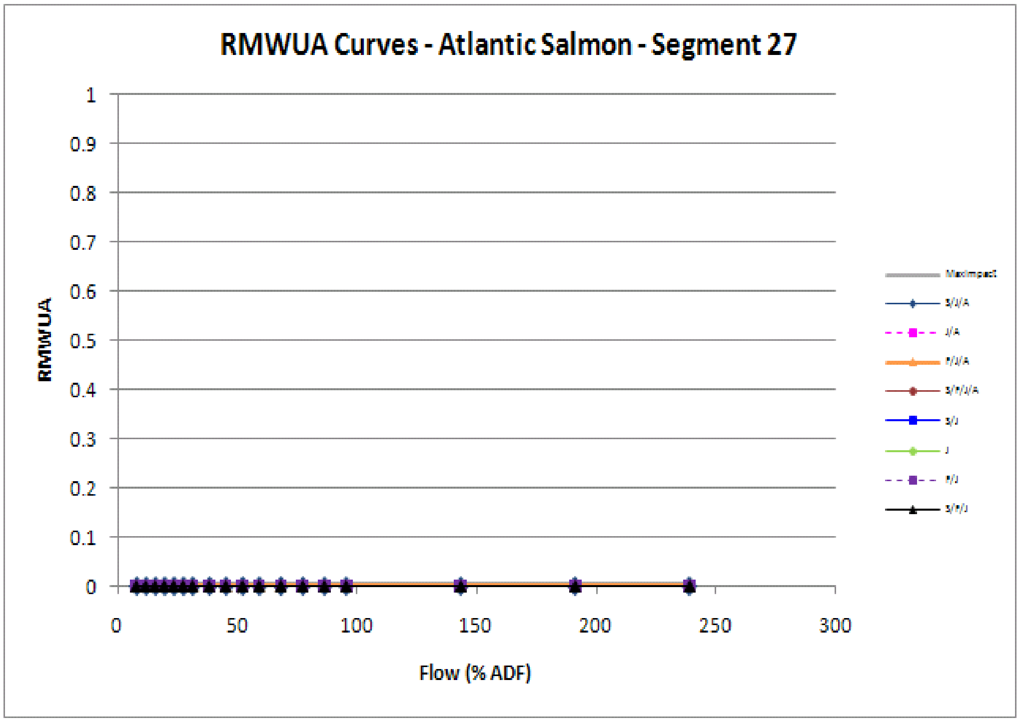

RMWUA Curves - Brown Trout - Segment 23
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

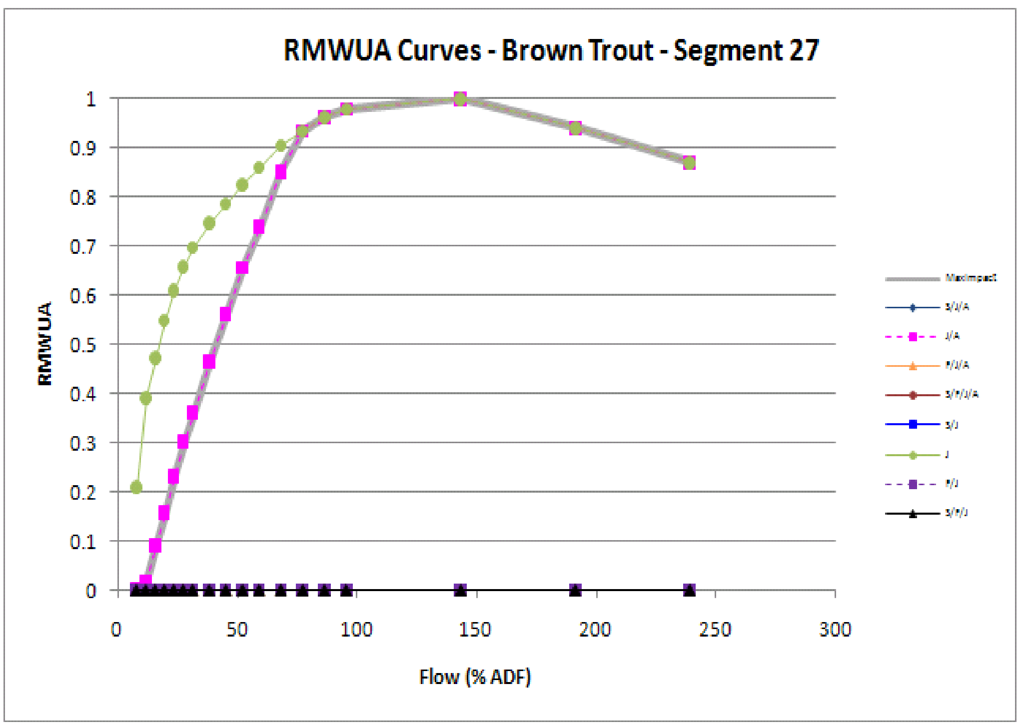

RMWUA Curves - Atlantic Salmon - Segment 24
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

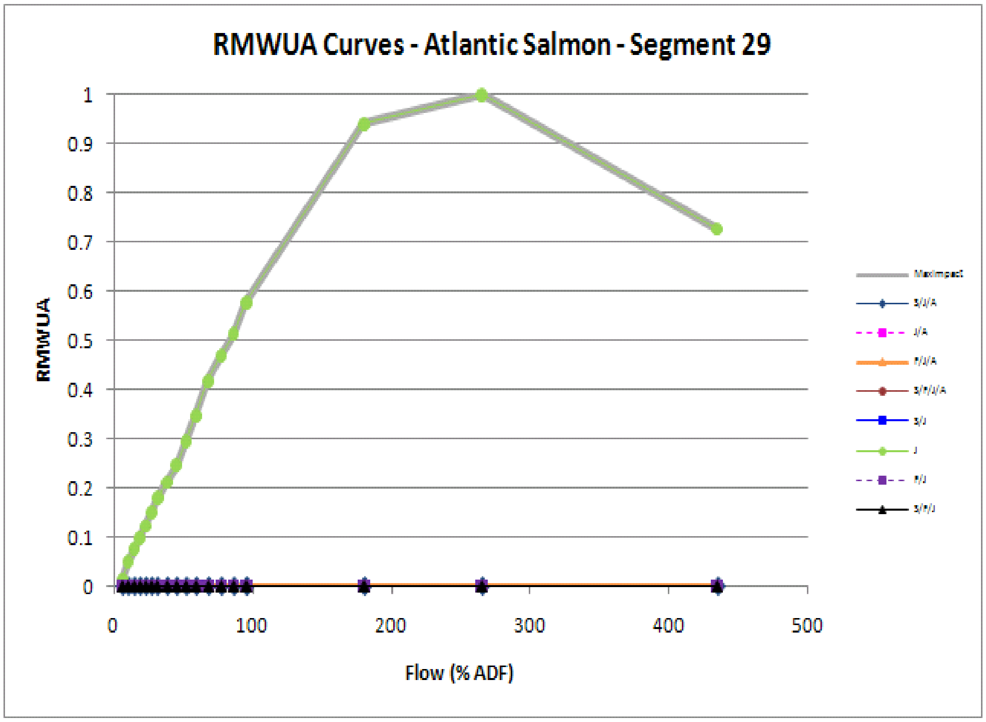

RMWUA Curves - Brown Trout - Segment 24
RMWUA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

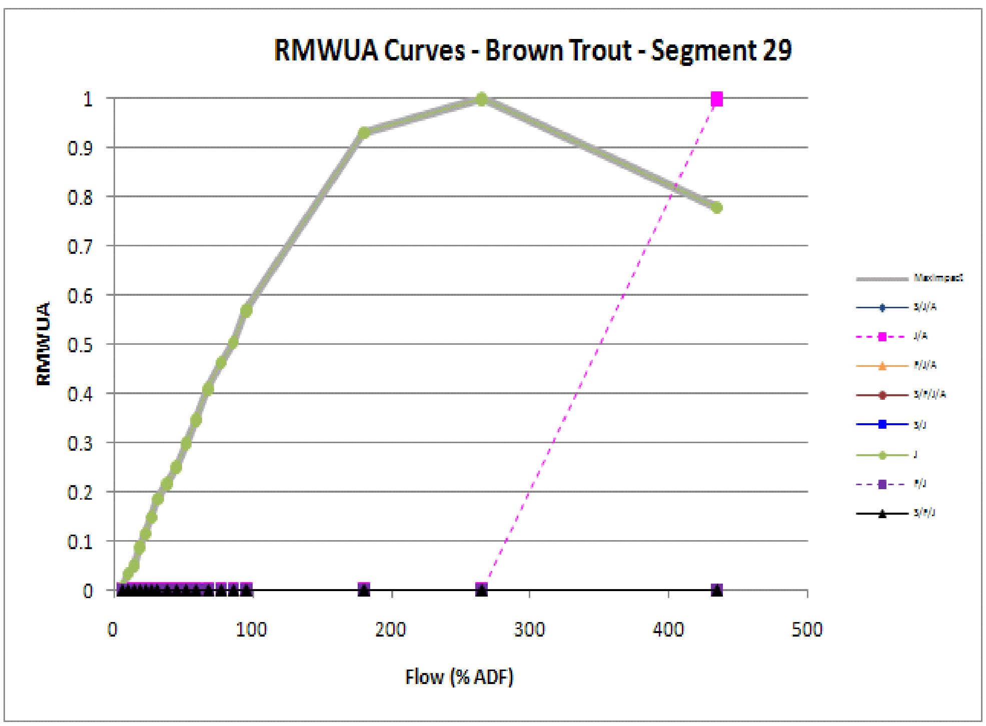

RMWUA Curves - Atlantic Salmon - Segment 25
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

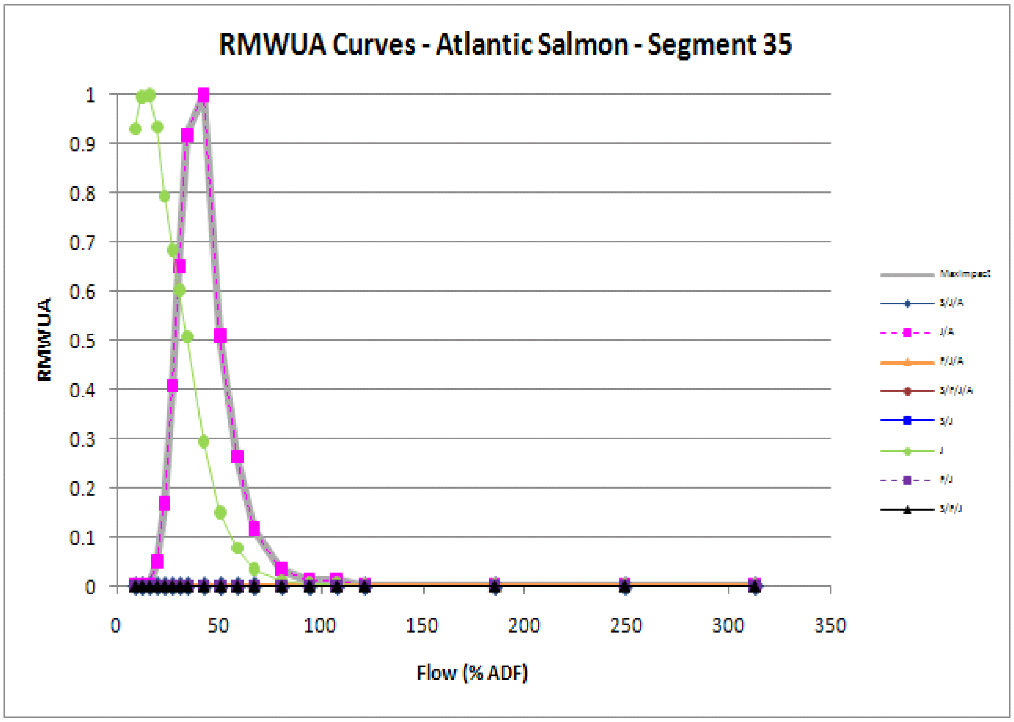

RMWUA Curves - Brown Trout - Segment 25
RMWUA
Flow (% ADF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

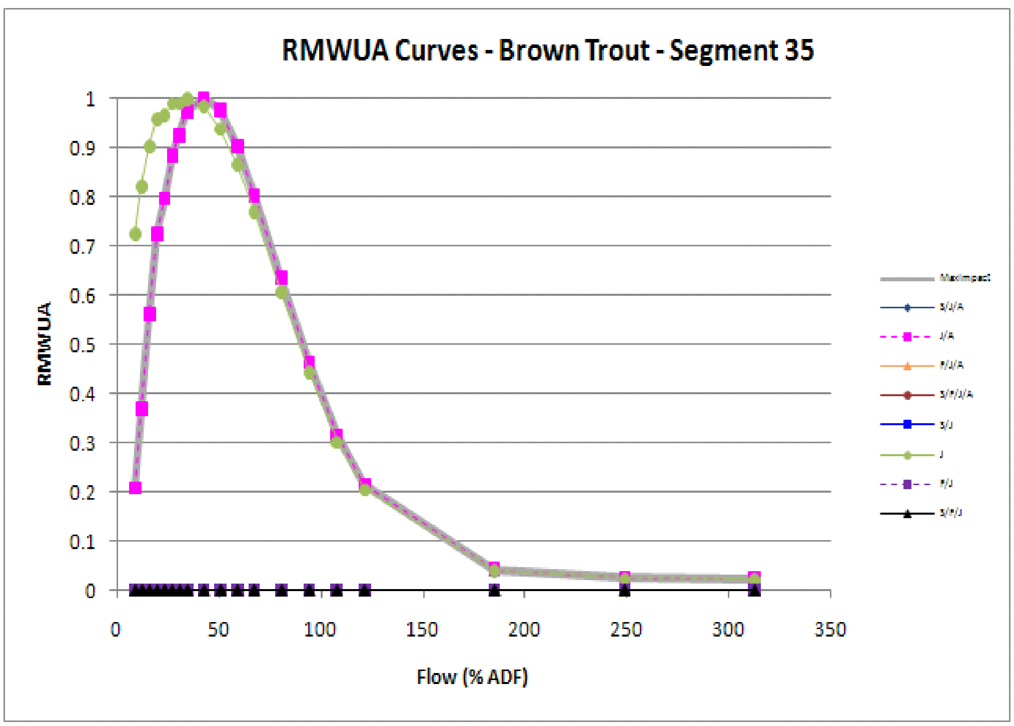

RMWUA Curves - Atlantic Salmon - Segment 27
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
Flow (% ADF)

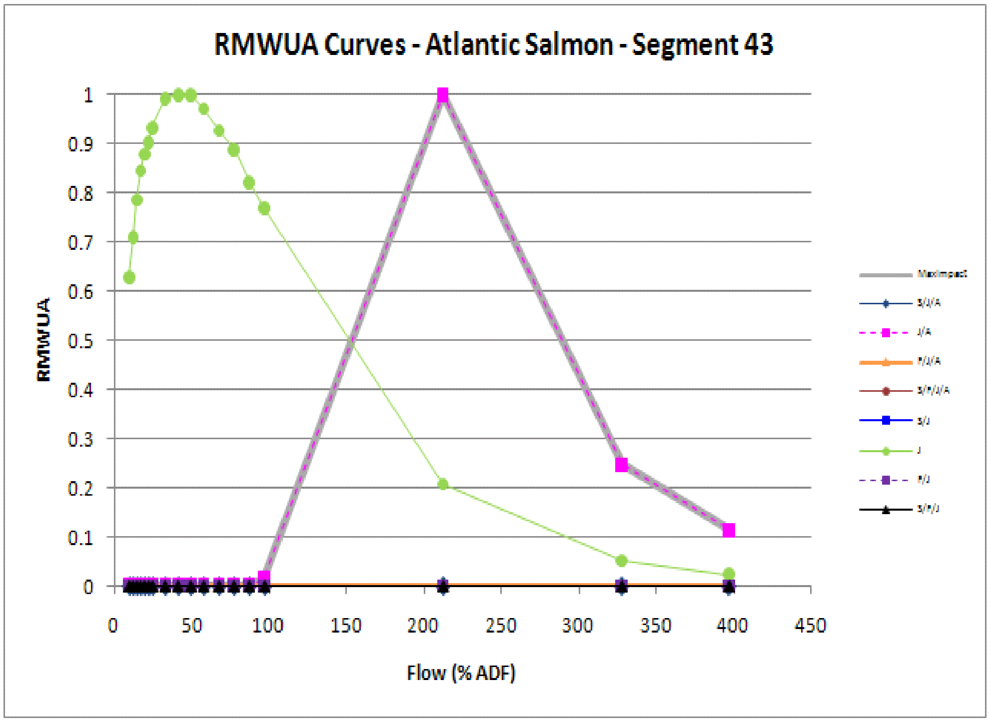

RMWUA Curves - Brown Trout - Segment 27
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
Flow (% ADF)

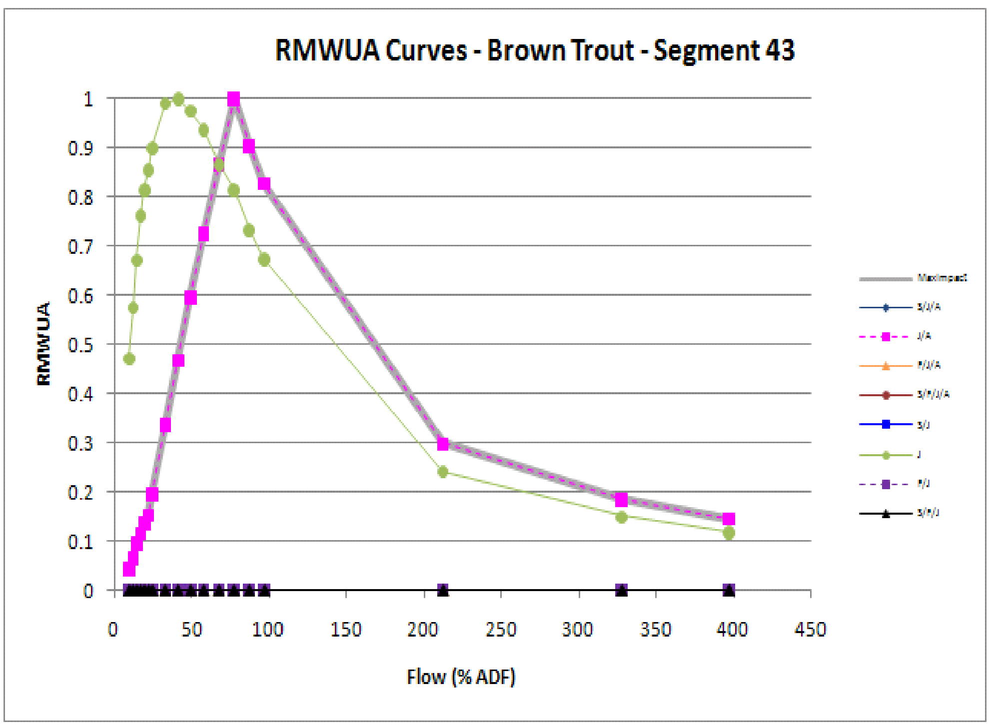

RMWUA Curves - Atlantic Salmon - Segment 29
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

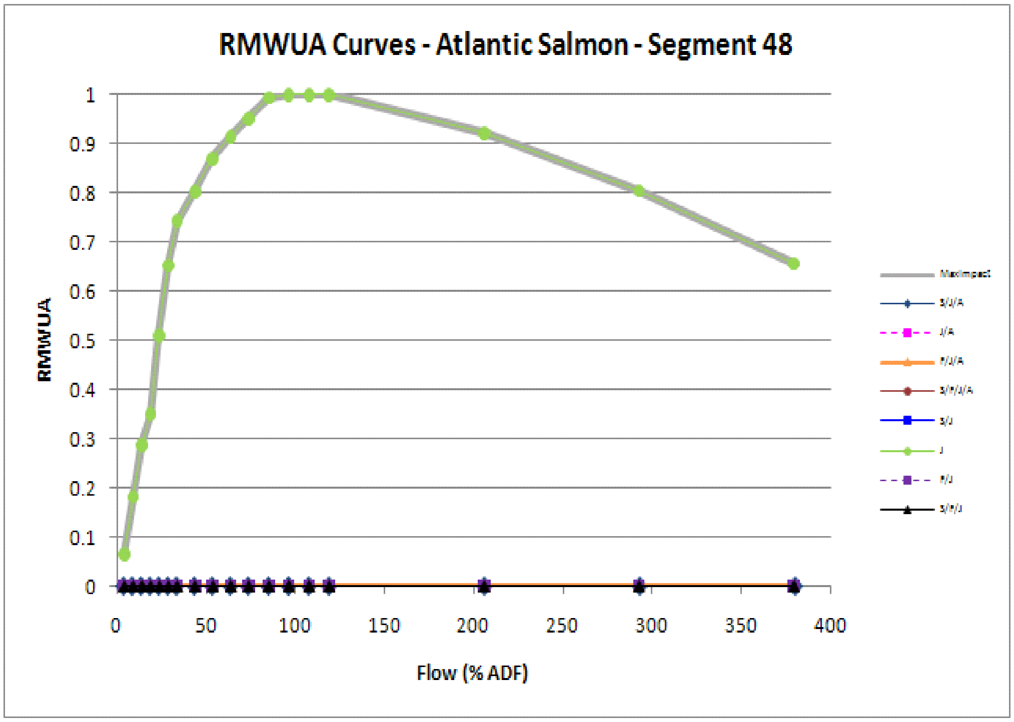

RMWUA Curves - Brown Trout - Segment 29
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

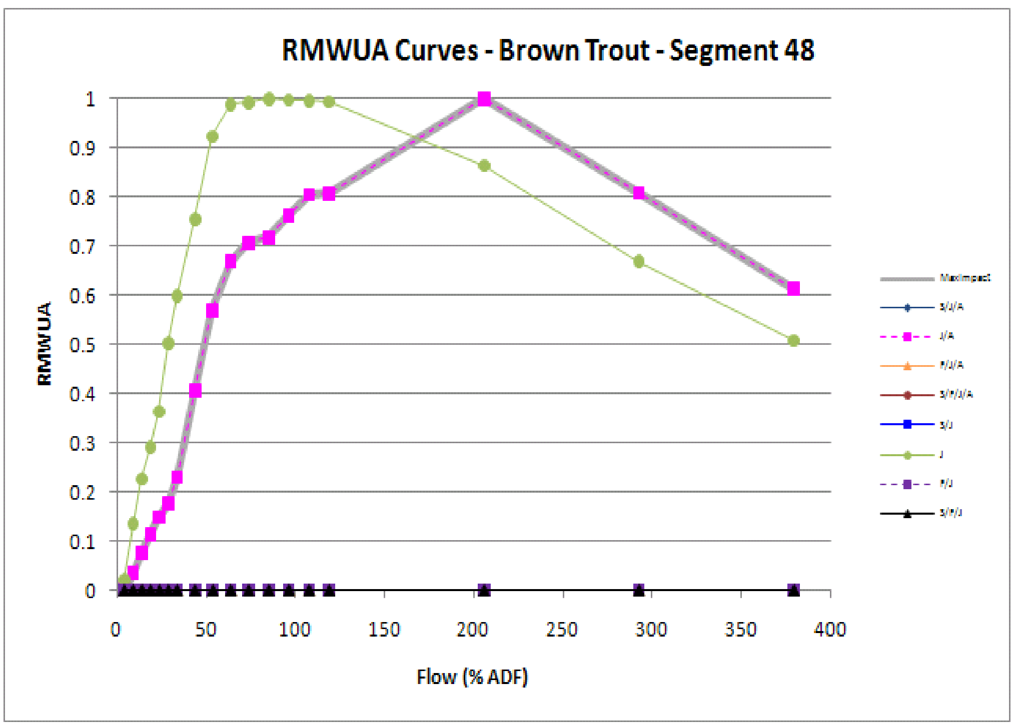

RMWUA Curves - Atlantic Salmon - Segment 35
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

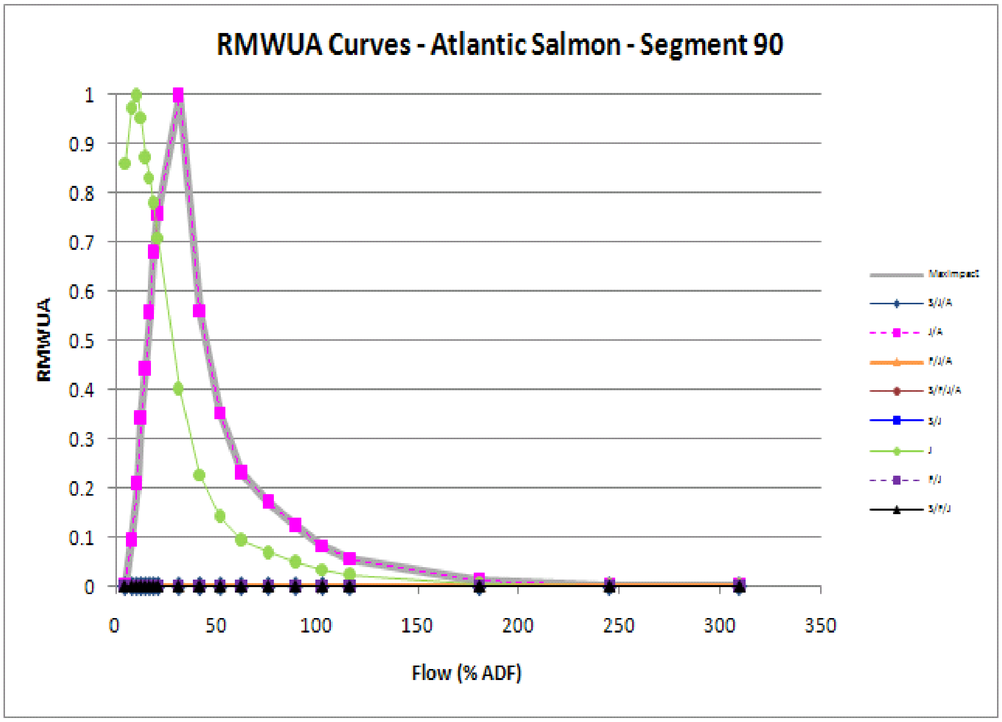

RMWUA Curves - Brown Trout - Segment 35
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

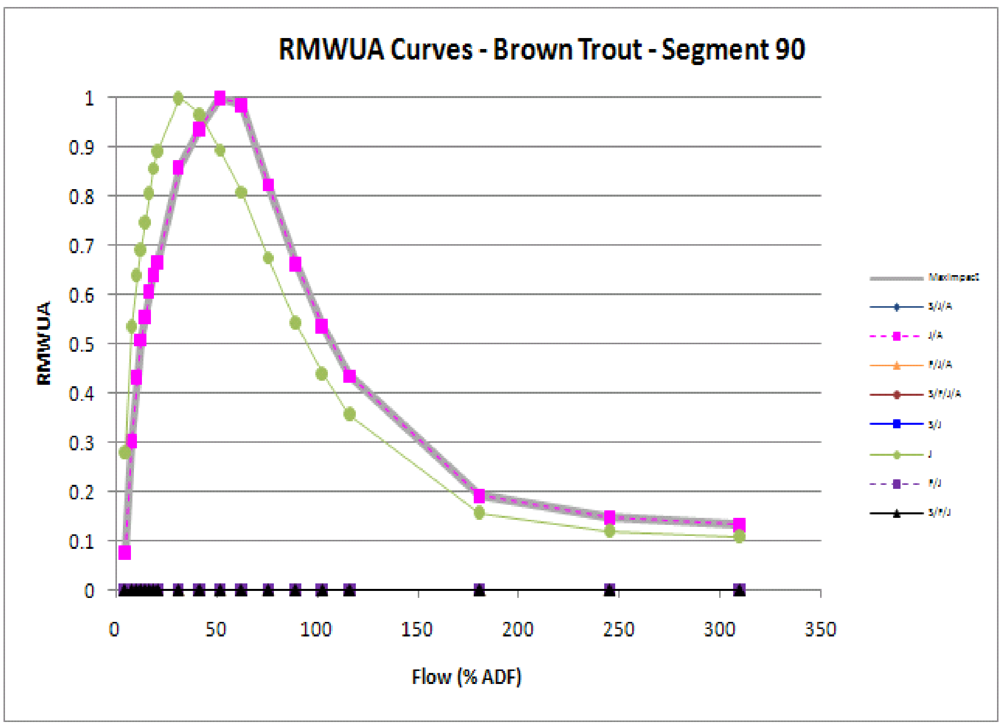

RMWUA Curves - Atlantic Salmon - Segment 43
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

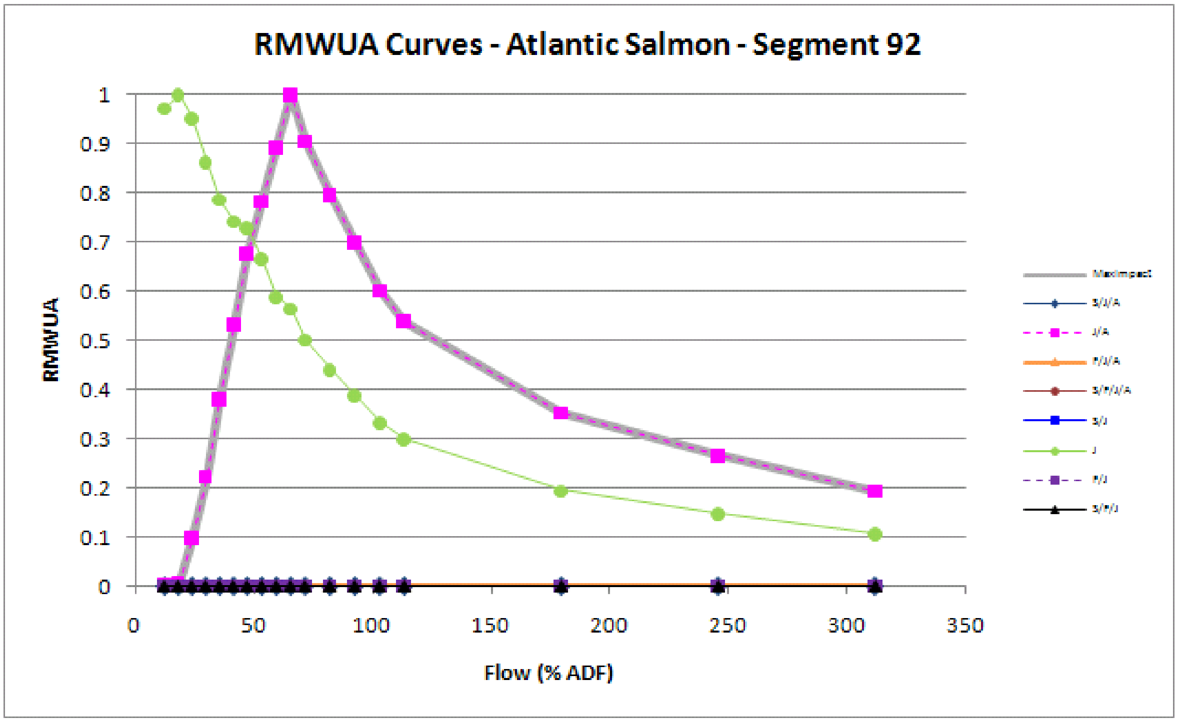

RMWUA Curves - Brown Trout - Segment 43
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
450
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

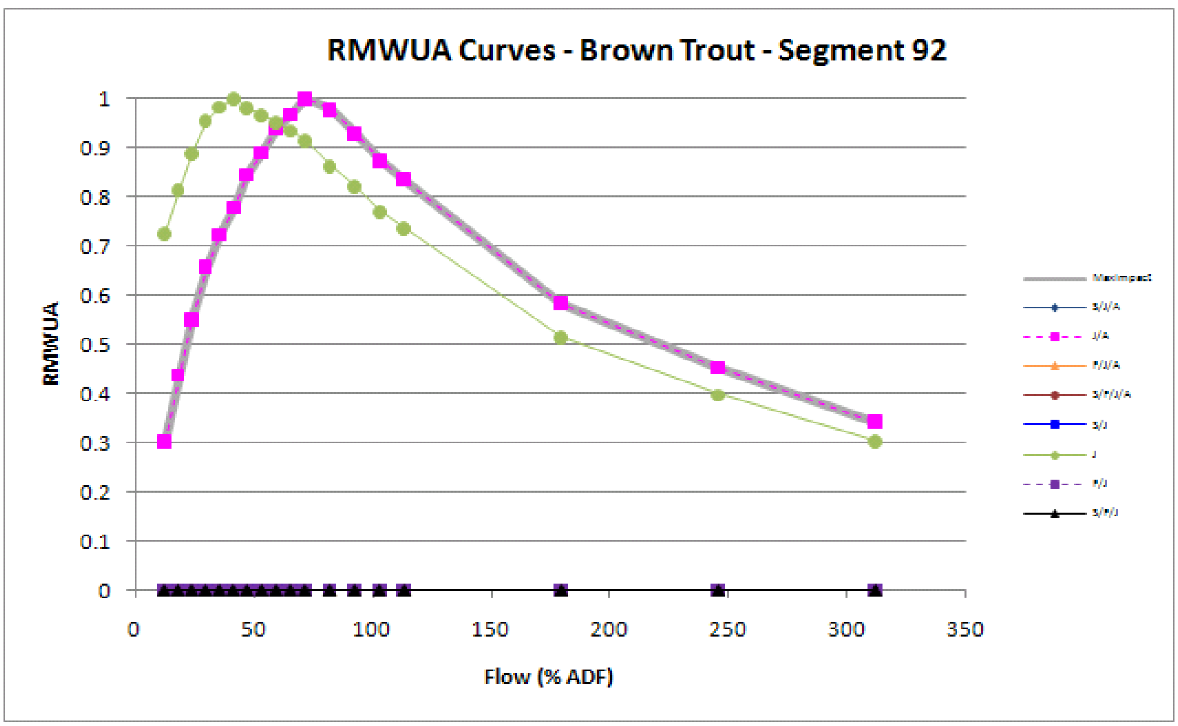

RMWUA Curves - Atlantic Salmon - Segment 48
RMWUA
Flow (% ADF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J


RMWUA Curves - Brown Trout - Segment 48
RMWUA
Flow (% ADF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

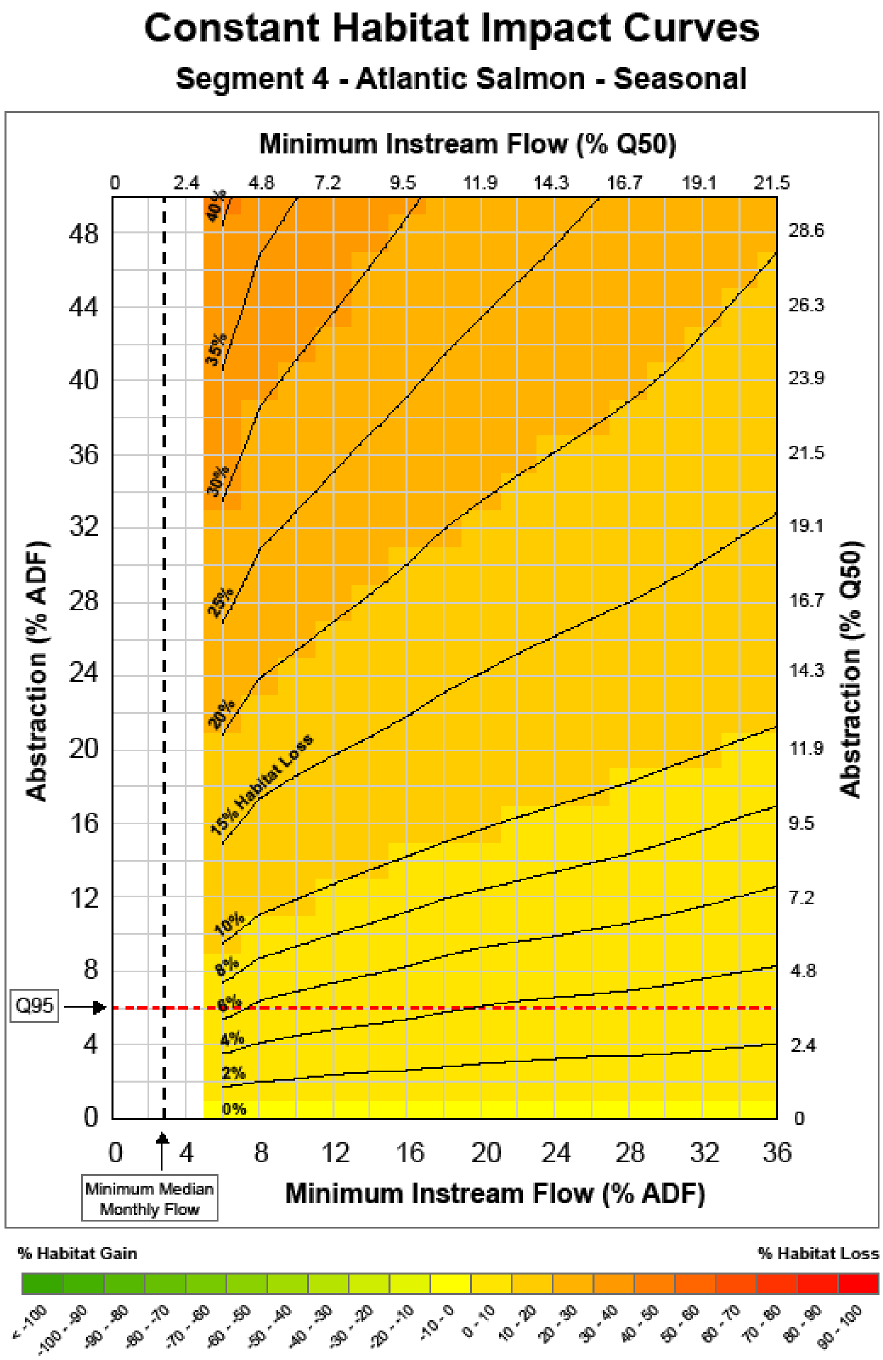

RMWUA Curves - Atlantic Salmon - Segment 90
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

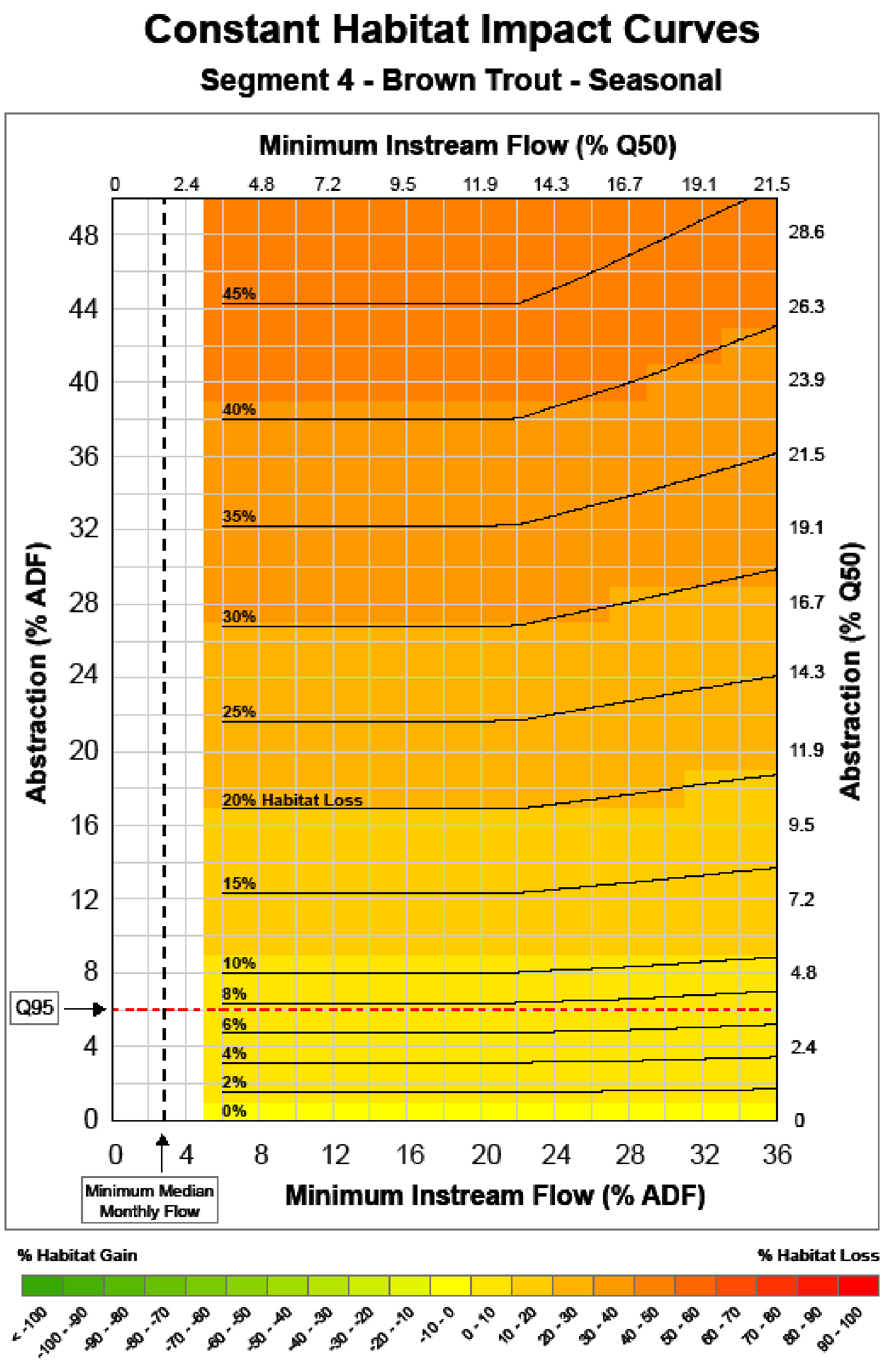

RMWUA Curves - Brown Trout - Segment 90
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)
MaxImpact
S/J/A
J/A
F/J/A
S/F/J/A
S/J
J
F/J
S/F/J

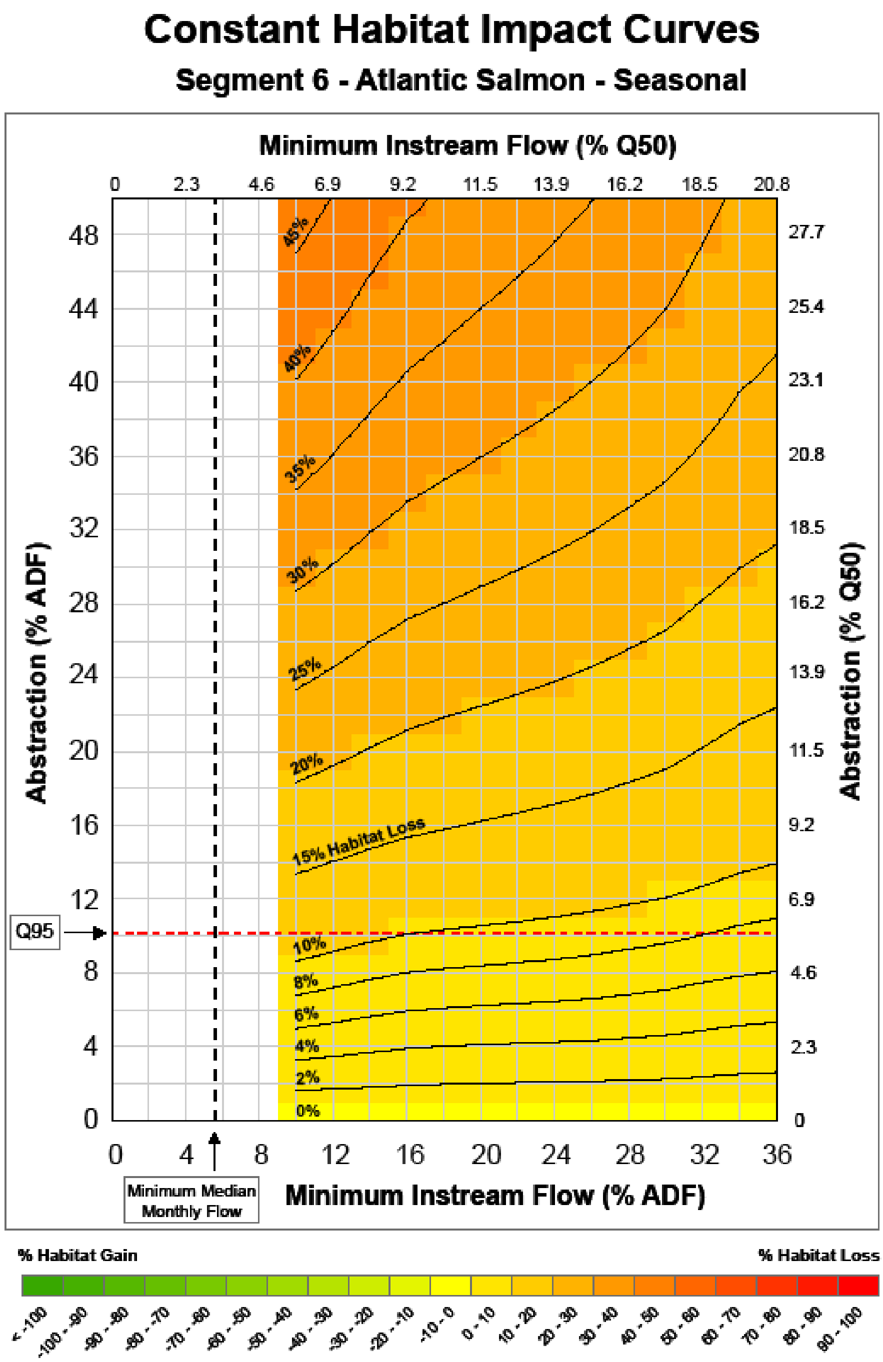

RMWUA Curves - Atlantic Salmon - Segment 92
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)

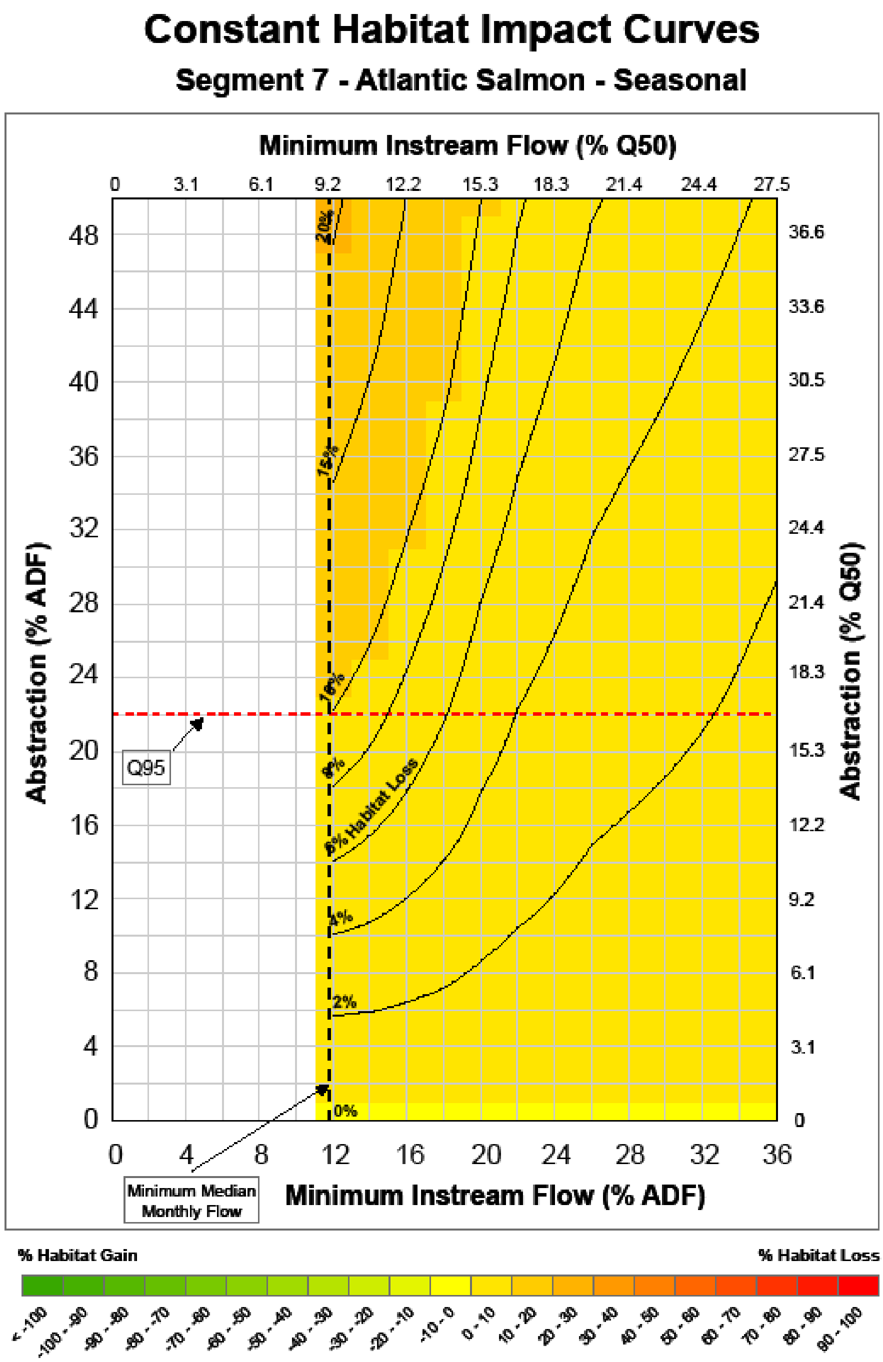

RMWUA Curves - Brown Trout - Segment 92
RMWUA
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Flow (% ADF)

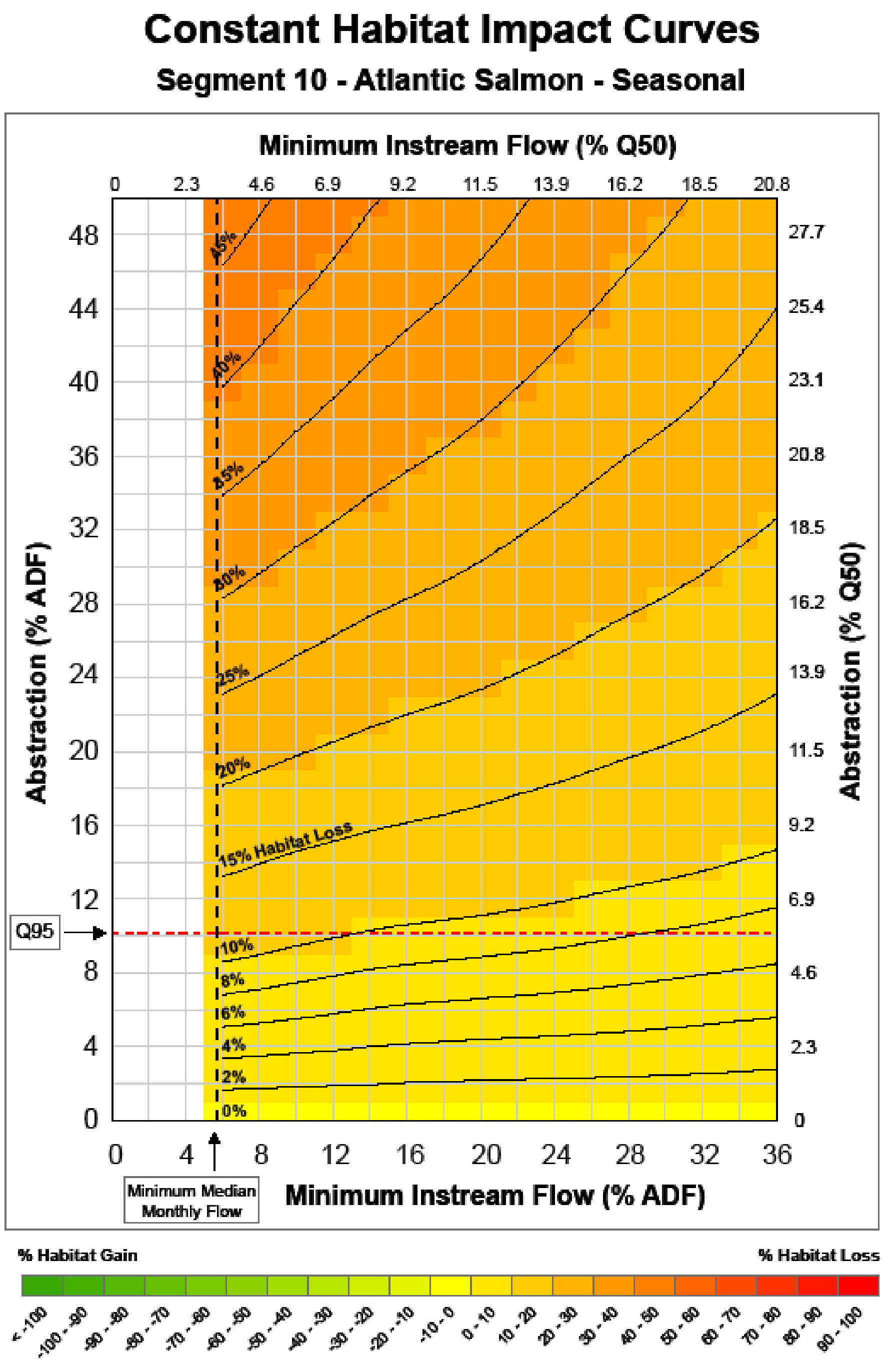
Appendix F – Seasonal Constant Habitat Impact Curve


Constant Habitat Impact Curves
Segment 4 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0 2.4 4.8 7.2 9.5 11.9 14.3 16.7 19.1 21.5
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
28.6 26.3 23.9 21.5 19.1 16.7 14.3 11.9 9.5 7.2 4.8 2.4 0
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 4 - Brown Trout - Seasonal
Minimum Instream Flow (% Q50)
0
2.4
4.8
7.2
9.5
11.9
14.3
16.7
19.1
21.5
Abstraction (% ADF)
Abstraction (% Q50)
45%
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss

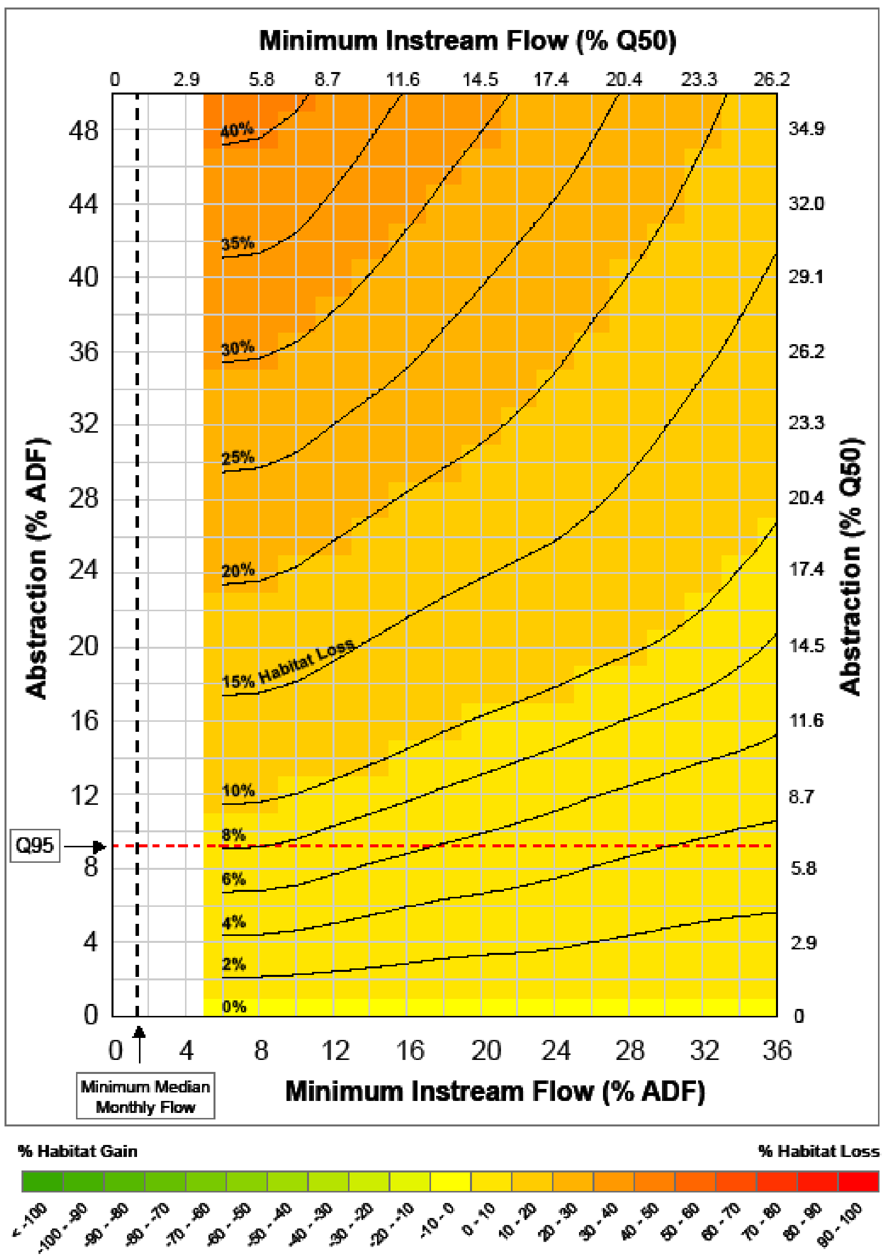

Constant Habitat Impact Curves
Segment 6 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
0
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

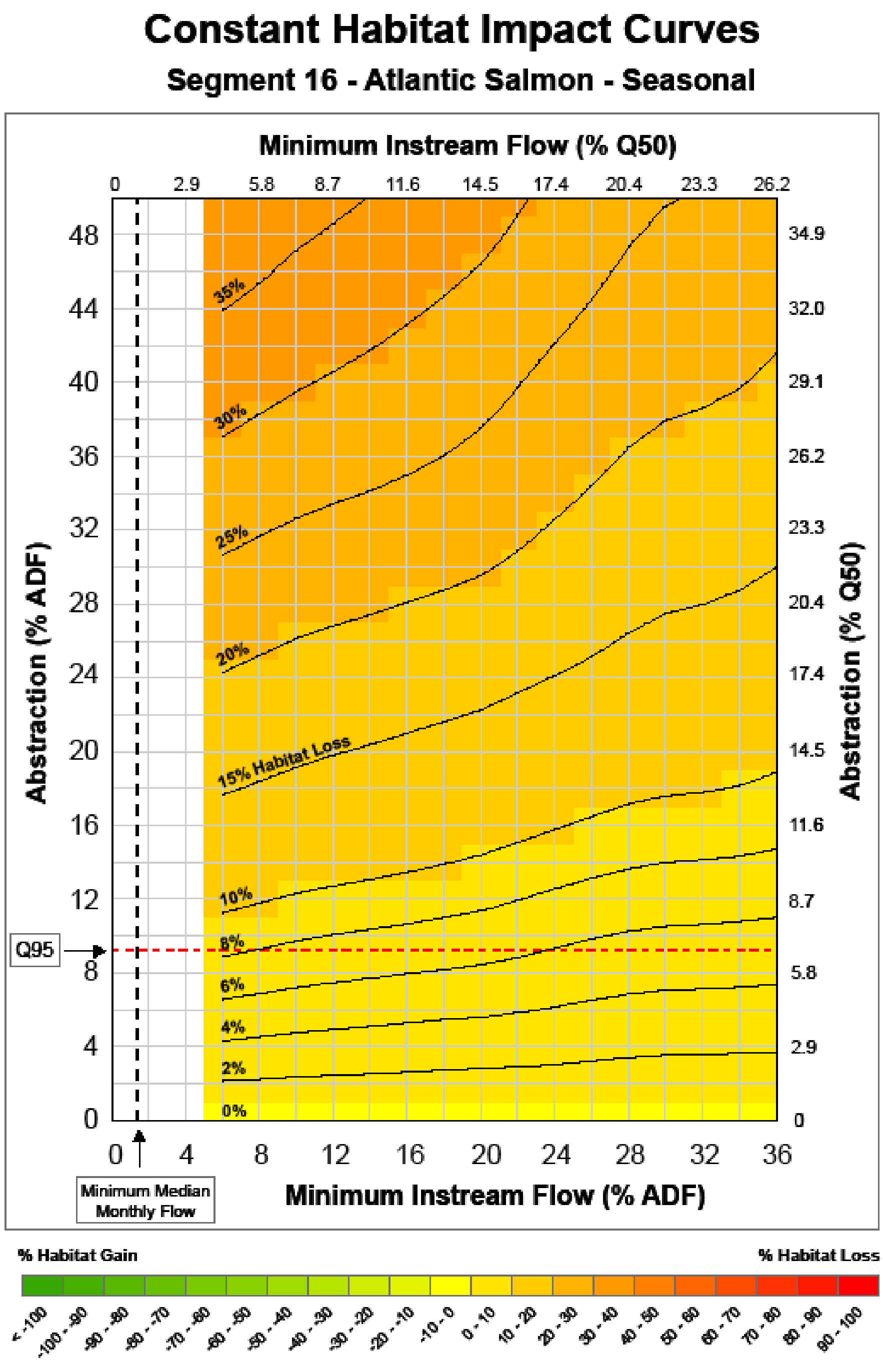

Constant Habitat Impact Curves
Segment 7 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
Abstraction (% ADF)
Abstraction (% Q50)
Minimum Instream Flow (% ADF)
Q95
Minimum Median Monthly Flow
20%
15%
10%
8%
6% Habitat Loss
4%
2%
0%
% Habitat Gain
% Habitat Loss

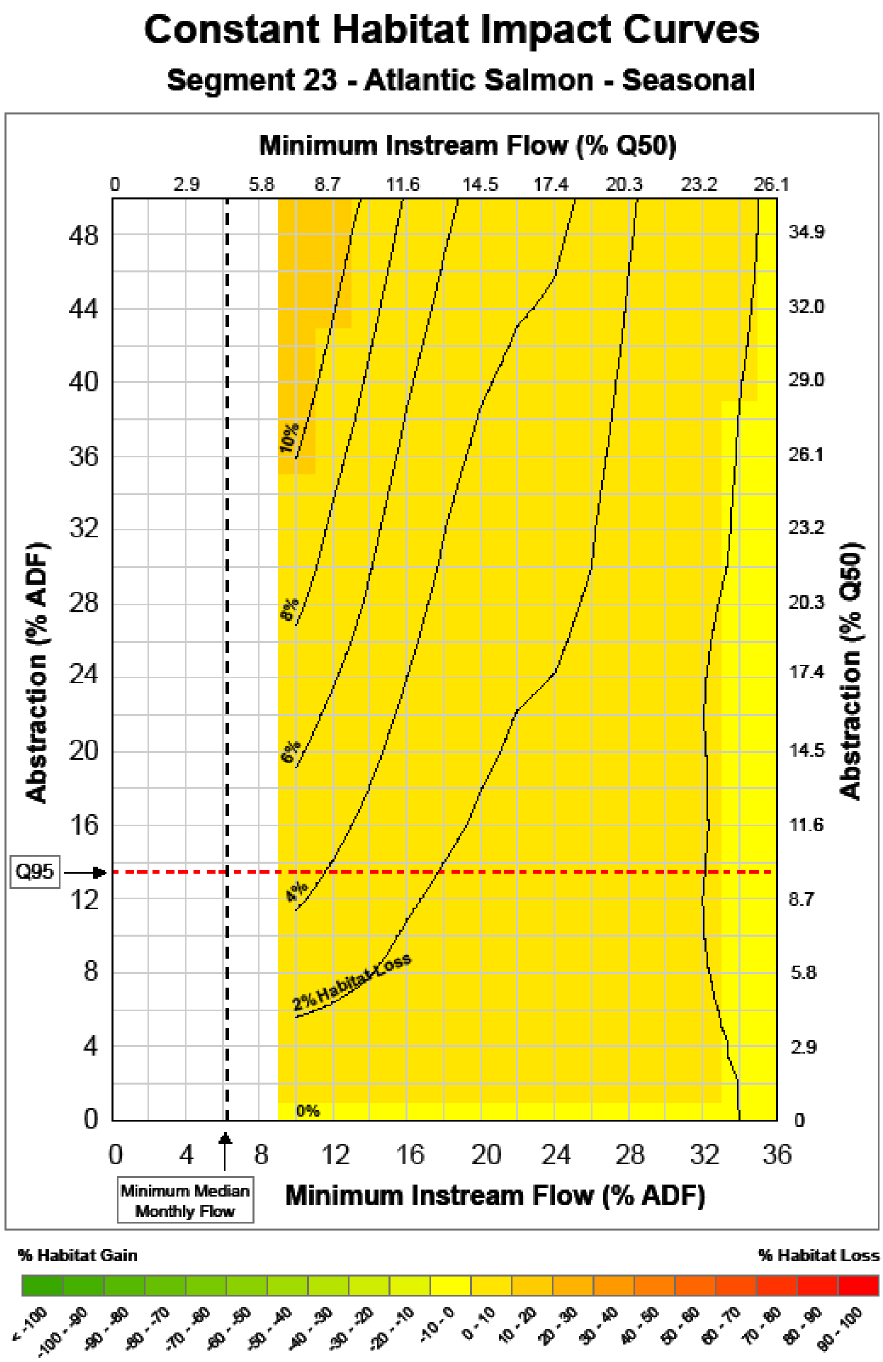

Constant Habitat Impact Curves
Segment 10 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0 2.3 4.6 6.9 9.2 11.5 13.9 16.2 18.5 20.8
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
27.7 25.4 23.1 20.8 18.5 16.2 13.9 11.5 9.2 6.9 4.6 2.3 0
Q95
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

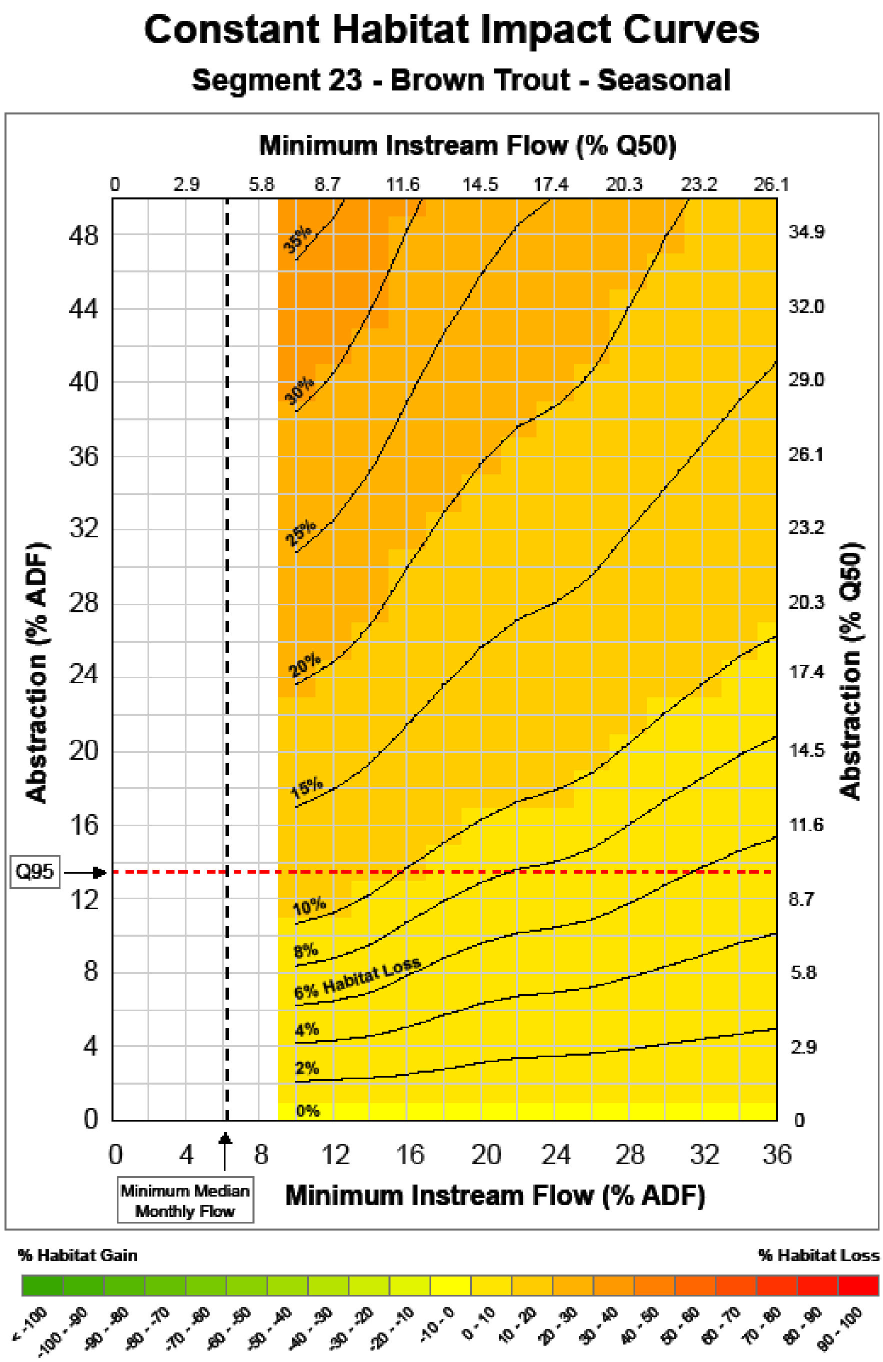
Constant Habitat Impact Curves

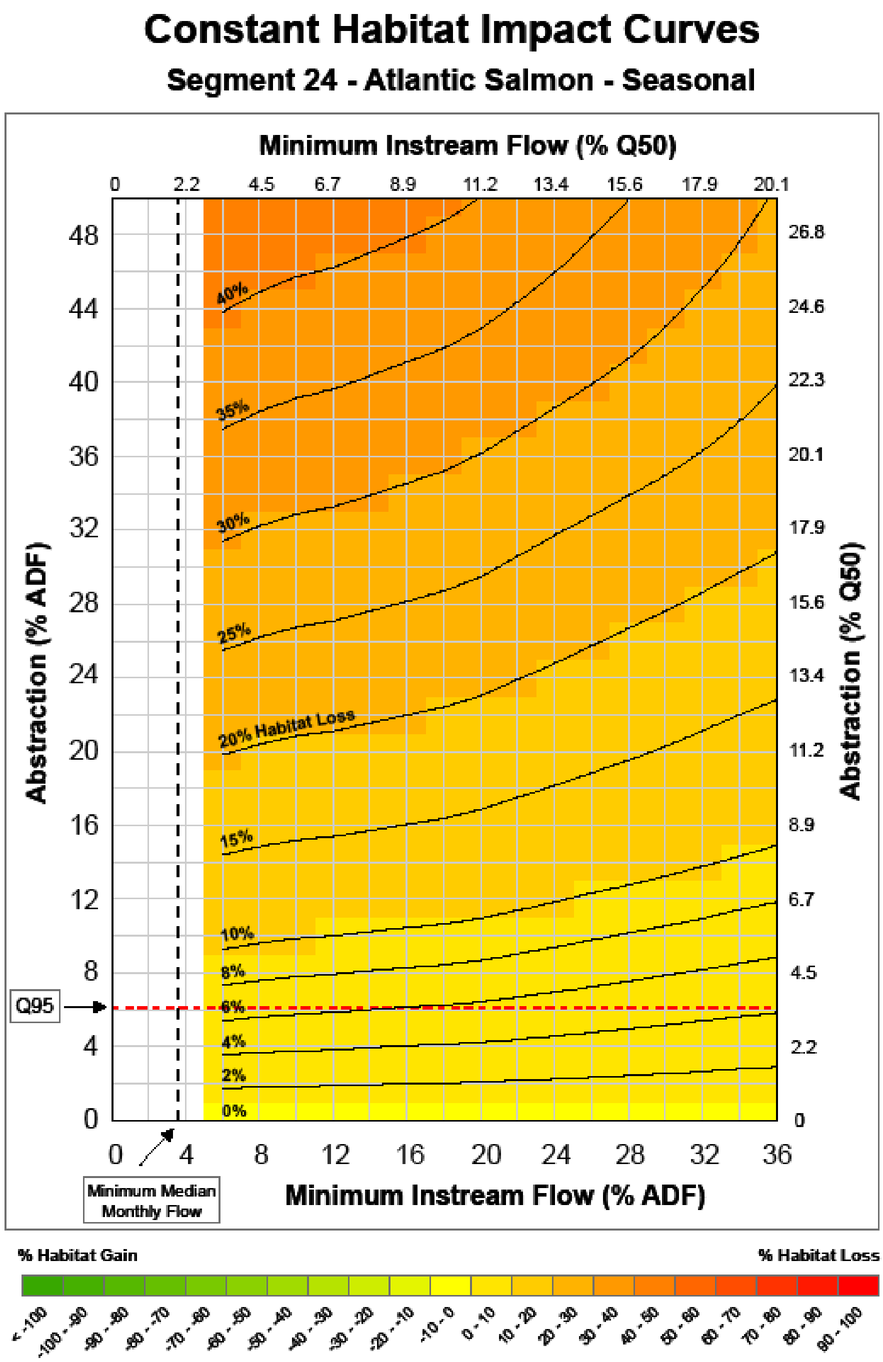
Segment 15 - Atlantic Salmon - Seasonal

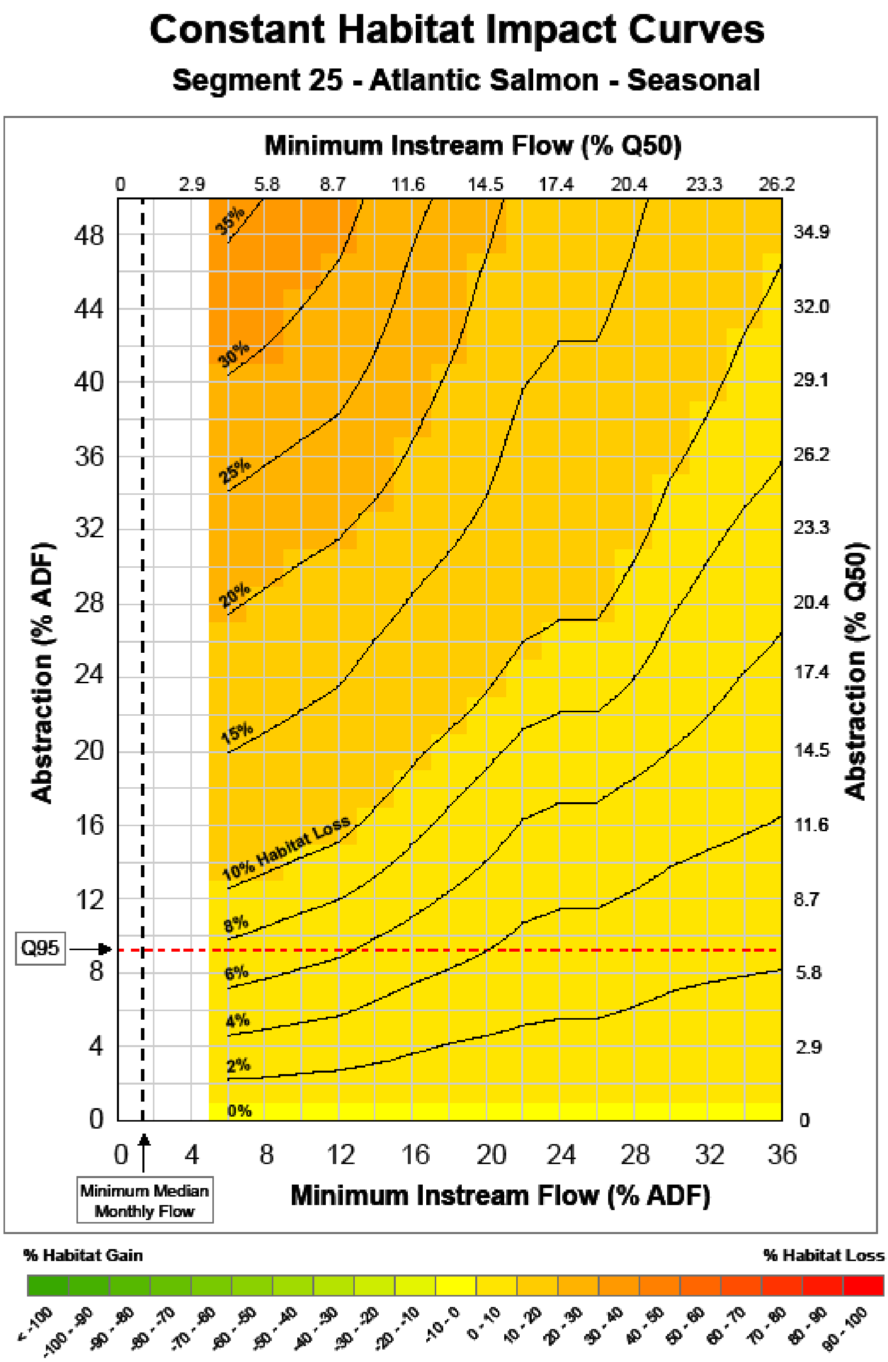


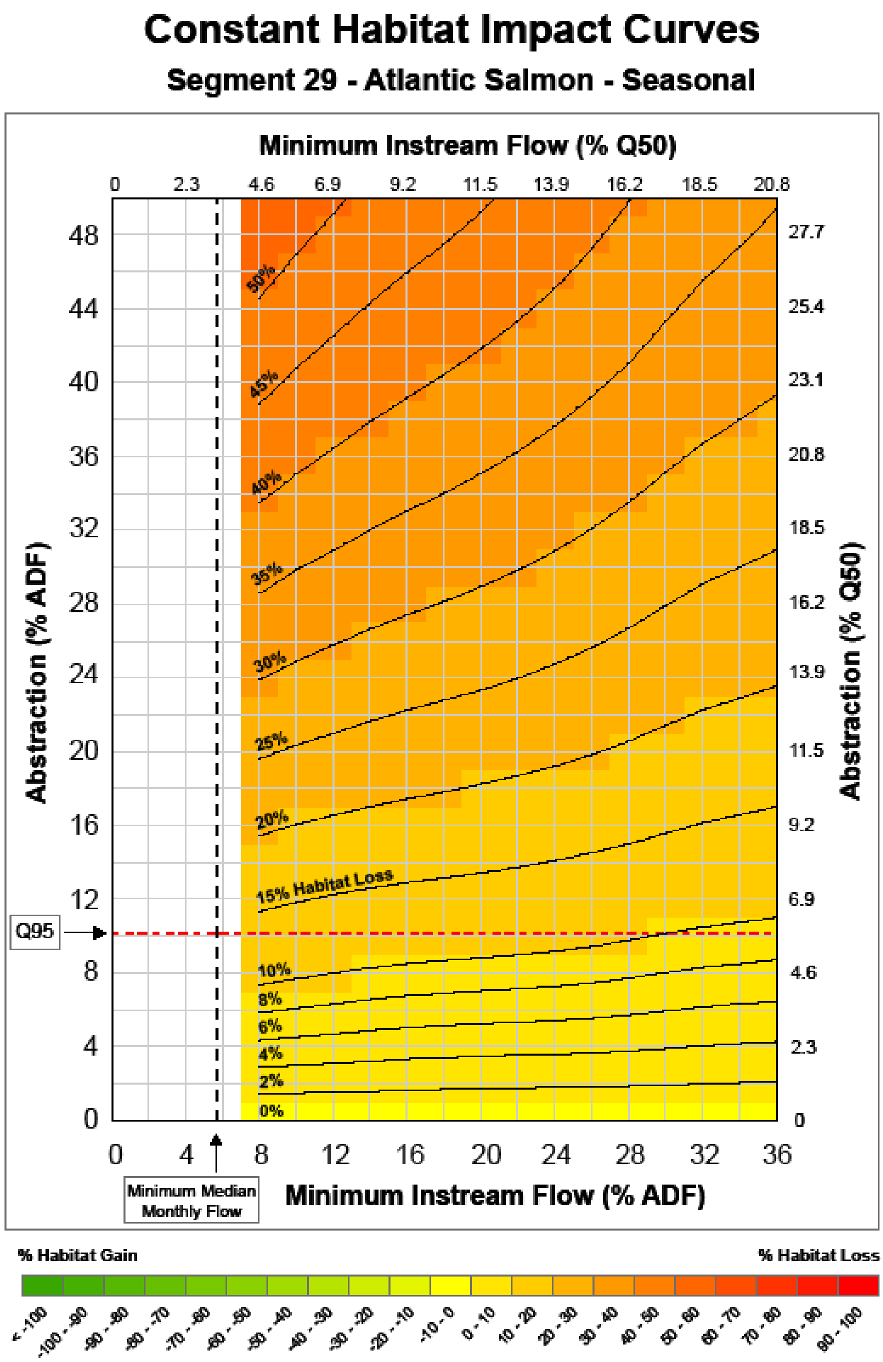

Constant Habitat Impact Curves
Segment 16 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0 2.9 5.8 8.7 11.6 14.5 17.4 20.4 23.3 26.2
Abstraction (% ADF)
48 44 40 36 32 28 24 20 16 12 8 4 0
Abstraction (% Q50)
34.9 32.0 29.1 26.2 23.3 20.4 17.4 14.5 11.6 8.7 5.8 2.9 0
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0 4 8 12 16 20 24 28 32 36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 23 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.3
23.2
26.1
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.0
26.1
23.2
20.3
17.4
14.5
11.6
8.7
5.8
2.9
0
10%
8%
6%
4%
2% Habitat Loss
0%
Q95
Minimum Median Monthly Flow
0
4
8
12
16
20
24
28
32
36
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 23 - Brown Trout - Seasonal
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.3
23.2
26.1
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.0
26.1
23.2
20.3
17.4
14.5
11.6
8.7
5.8
2.9
0
35%
30%
25%
20%
15%
10%
8%
6% Habitat Loss
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

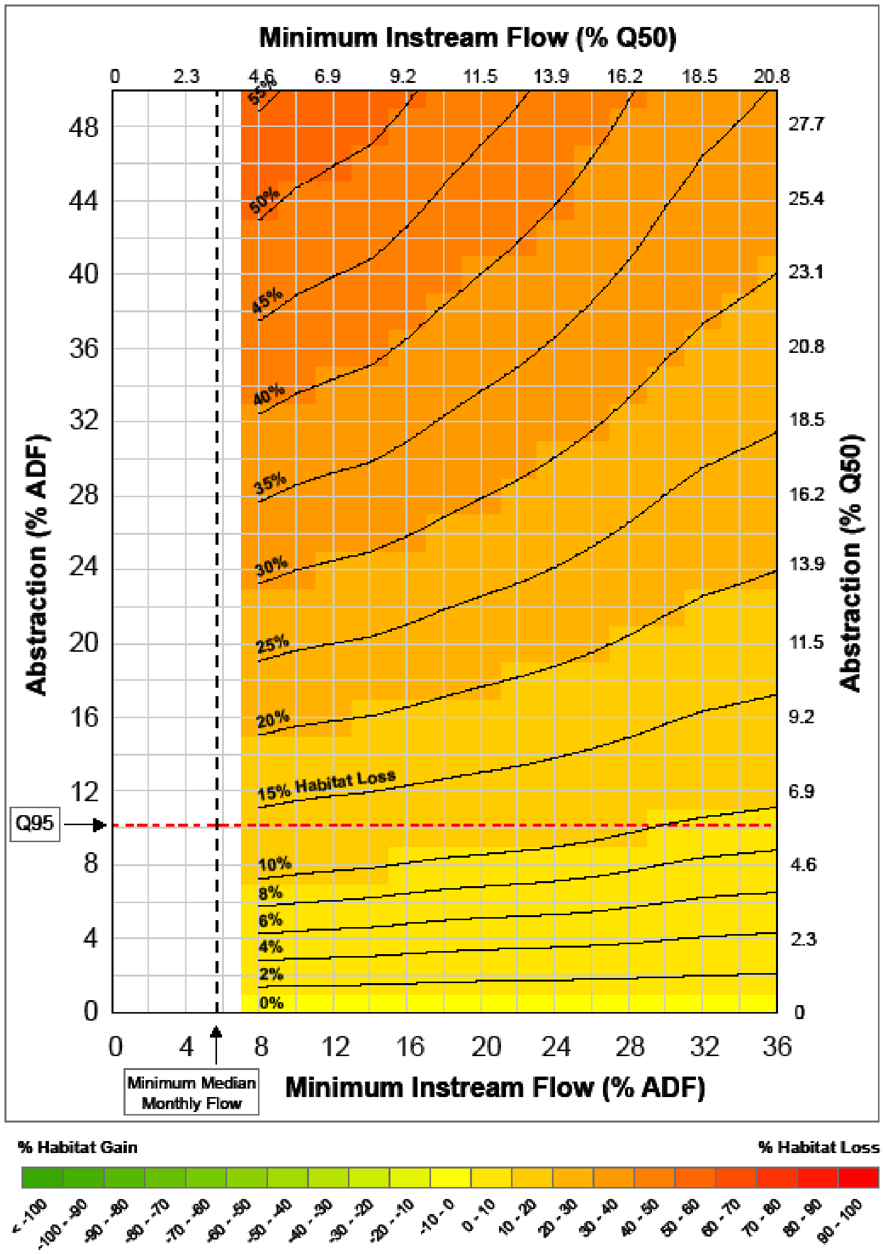

Constant Habitat Impact Curves
Segment 24 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.2
4.5
6.7
8.9
11.2
13.4
15.6
17.9
20.1
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
26.8
24.6
22.3
20.1
17.9
15.6
13.4
11.2
8.9
6.7
4.5
2.2
0
40%
35%
30%
25%
20% Habitat Loss
15%
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

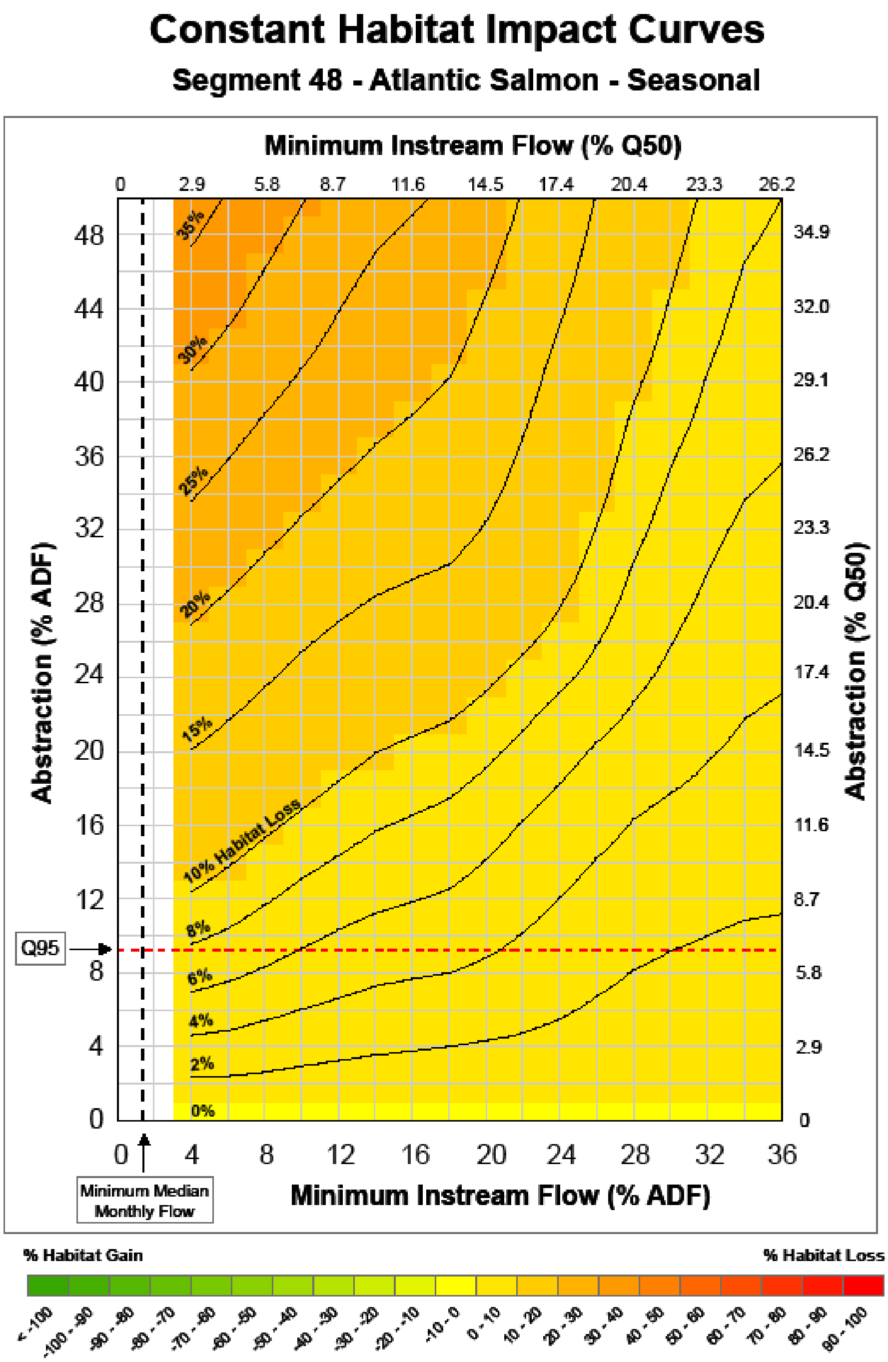

Constant Habitat Impact Curves
Segment 25 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
Abstraction (% Q50)
35%
30%
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss

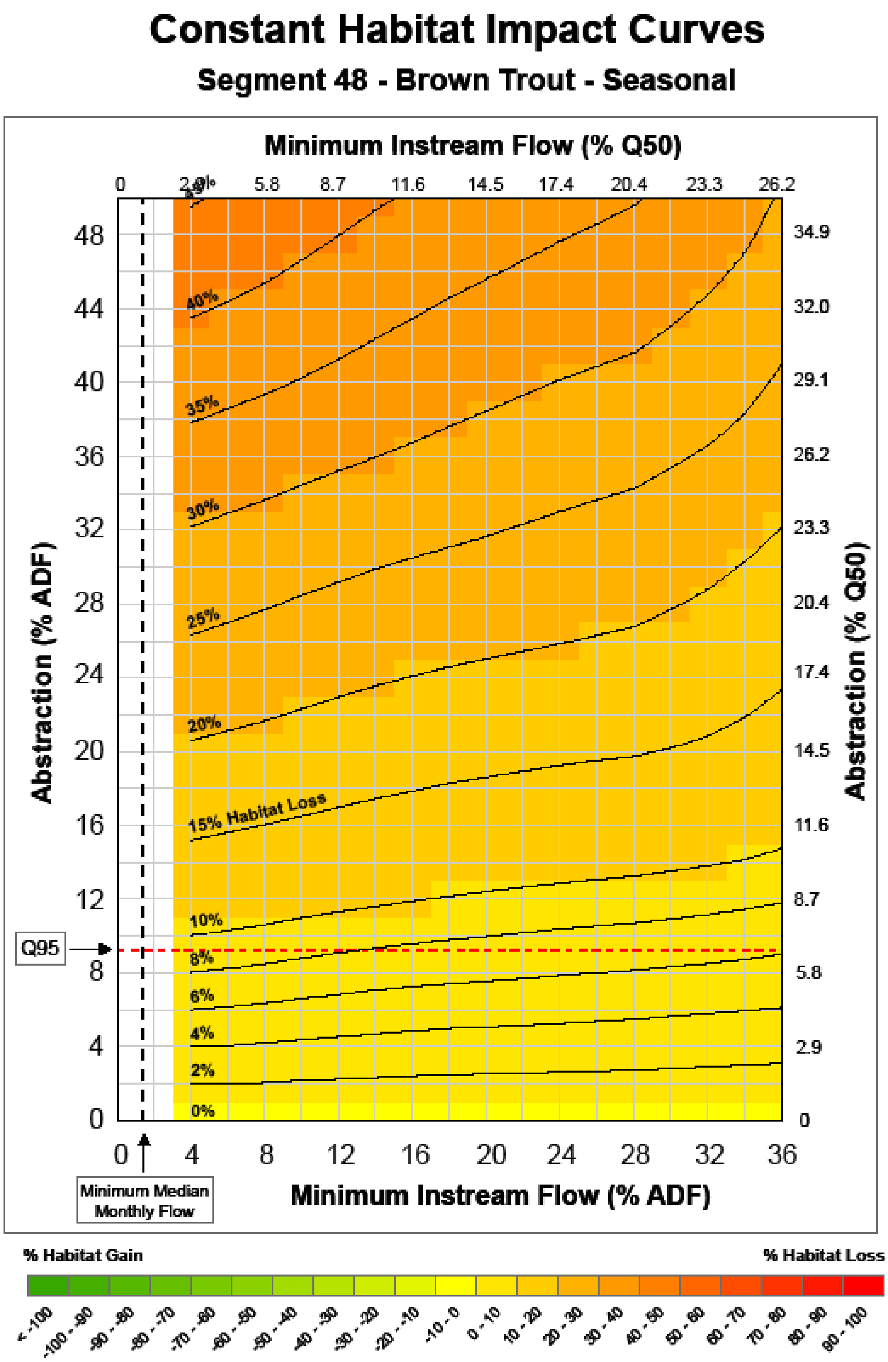

Constant Habitat Impact Curves
Segment 29 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.3
4.6
6.9
9.2
11.5
13.9
16.2
18.5
20.8
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
0
50%
45%
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

Constant Habitat Impact Curves

Segment 29 - Brown Trout - Seasonal




Constant Habitat Impact Curves
Segment 48 - Atlantic Salmon - Seasonal
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.1
26.2
23.3
20.4
17.4
14.5
11.6
8.7
5.8
2.9
0
35%
30%
25%
20%
15%
10% Habitat Loss
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100


Constant Habitat Impact Curves
Segment 48 - Brown Trout - Seasonal
Minimum Instream Flow (% Q50)
0
2.9
5.8
8.7
11.6
14.5
17.4
20.4
23.3
26.2
Abstraction (% ADF)
48
44
40
36
32
28
24
20
16
12
8
4
0
Abstraction (% Q50)
34.9
32.0
29.1
26.2
23.3
20.4
17.4
14.5
11.6
8.7
5.8
2.9
0
40%
35%
30%
25%
20%
15% Habitat Loss
10%
8%
6%
4%
2%
0%
Q95
0
4
8
12
16
20
24
28
32
36
Minimum Median Monthly Flow
Minimum Instream Flow (% ADF)
% Habitat Gain
% Habitat Loss
< -100
-100 - -90
-90 - -80
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
-20 - -10
-10 - 0
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100