Chapter 4
Linking Stream Health with Hydrologic Measures

4.1 Introduction

Over time, unmitigated development can cause serious damage to receiving stream health. Many studies have found a strong linkage between hydrologic variability and stream biota health (a detailed review is given in Table 2.1). Increases in runoff from storm events translate into a greater volume of water received by the stream in a shorter period of time. For example, only one storm with a return period greater than 25 years occurred in the baseline scenario, while six storms with a return period greater than this discharge occurred in the most developed scenario. The elevated flowrate and associated elevated velocity can stress (to different extents) fish, macroinvertebrates, and flora (Poff and Ward 1989). In such conditions, fish require additional energy for movement, macroinvertebrates exhibit an increase in drift, and flora can be flattened or torn from their roots (Poff et al. 1997). The increased flowrate also brings an increase in stream power that can more easily erode stream banks. This erosion can cause the destruction of stream habitats as a naturally complex stream bottom is slowly "bowled out" into a uniform parabolic channel with little longitudinal or cross sectional habitat diversity (Booth 1990). Cover, an essential habitat component for fish, such as large woody debris is washed downstream by the larger events. Although the occasional bankfull flow experienced by a stream has been theorized to act as a beneficial "reset" for ecological processes and the Flood Pulse Concept (Junk, et al. 1989) refers to the beneficial aspects of having floodplain-channel nutrient exchange, the increased frequency of high flow events will eventually outweigh the positive aspects. The channel geometry and associated stream characteristics will slowly change as the channel erodes and widens to accommodate the larger storms. Additionally, lower baseflows caused by reduced groundwater infiltration will produce more extreme low flow events. The lower water level may cause an increase in predation and competition as less habitat is available to the stream biota. Increases in extreme high flow and low flow events and the general increase in variability of the stream will favor generalists or tolerant species that are able to survive or thrive in a wider range of habitat conditions while reducing intolerant fish species that are more sensitive to habitat requirements. Although the Intermediate Disturbance Theory (Connel 1978) suggests an initial increase in species richness as a result of some fish benefiting from the new flow regime, the natural species richness of the stream will eventually suffer as the stream environment becomes increasingly harsh and less hospitable to its natural inhabitants (Poff et al. 1997).

Therefore, building on these ideas, this study will analyze the link between hydrologic variability and the impacts on stream health. A procedure for linking hydrologic variability and stream habitat and overall health will be produced.

4.2 Methods

4.2.1 Flow Variability Metrics

Although many statistical metrics and groupings of metrics have been suggested in the literature as ecologically important, four major types of flow variability statistics are most prevalent:

A. High Flow

High flow statistics deal with the larger magnitude storm events typically associated with developed areas. Floods of ecological and stream health significance are typically those exceeding the bankfull flow as this flow is designated as the channel forming flow. Bankfull flow for streams typically occurs at flows with an average return period of around 1.67 years (Dunne and Leopold 1978, Poff and Allan 1995, Poff et al.1996, and Poff 1996). The 1.67 year return period flood will mark the beginning of out-of-bank flows and also the beginning of flood stage. Therefore the storm with a magnitude corresponding to this frequency will be used as the threshold for floods in this analysis. The number of flood events, the length of flood duration and the magnitude of the flood three times the median flow are used as high flow variables.

B. Low Flow

Low flow statistics are used to analyze the small instream flows associated with droughts. Much of the available research has focused on zero flows as a primary measure of low flow events (Poff and Ward 1989, Poff 1996). However, since fish and other stream biota experience high levels of stress well before zero streamflow is reached, the author used the low flows of 1 day duration and a return period of 2 years as an index of drier low flow periods that occur on a fairly regular basis. The number of low flow events and the length of low flow duration are used as low flow variables.

C. Overall Flow Variability

Overall flow variability statistics attempt to quantify the trend of all measured flows in a channel. Because these statistics measure how far the data points are spread apart or lumped together the emphasis is on the typical flow patterns rather than the extreme events. The coefficient of variation of flow and the range of flows between the 90th and 10th percentile flowrate are used as overall flow variability variables.

D. Predictability and Seasonality

Predictability and seasonality statistics measure flow data behavior and timing. These statistics attempt to determine if there is a typical pattern to the flow pattern or if the variability of the flow regime is temporally random. Because the same rainfall hyetograph is used throughout this study, predictability and seasonality are not expected to vary or produce any significant differences, regardless of landuse. Therefore, this group of statistics is not considered in this study.

Individual statistics for high flow, low flow, and overall flow variability were selected based upon strength of ecological linkage and literature support. Table 4.1 presents the variables chosen to represent these groupings. The number of floods and number of low flow events are a count of the number of times a flood or low flow exceeds predefined threshold levels. The flood duration and low flow duration is also a count of the length of time that these events occur throughout the year. The flood duration variable used the same algorithm as discussed in chapter 3 (section 3.5) for separation of storm events. A new algorithm was developed to separate events for the low flow duration variable. Low flow events were considered independent only if streamflow remained above the maximum low flow threshold value for 24 consecutive hours. As with the flood duration variable, values outside the threshold limits for the low flow variable that were determined to be part of the same event were included in the duration of the event and hence used in calculating the total duration of low flow and flood duration. The FRE3 variable (Clausen and Biggs 1997) is the magnitude of the flood event that is three times the median flow. The coefficient of variation of all hourly flows is determined by dividing the standard deviation of all flows by the average flow. The 90-10 Range is a measure of the difference between the 90th percentile flow and the 10th percentile flow. The high and low flow variables all use the baseline condition as a means of comparison. Therefore the median value for the FRE3 and the threshold values for the floods and low flow events are from the baseline residential development condition.

Table 4.1 Flow variability statistics and groupings

Statistical Group	**Variables**		
High Flow	Number of Flood Events	Flood Duration	FRE3*
Low Flow	Number of Low Flow Events	Low Flow Duration	
Overall Variability	Coefficient of Variation	90-10 Range**	

*The FRE3 is the magnitude of the flood event three times the median flow

**The 90-10 Range is the range of flow values between the 90th and 10th percentile flow values

The 43 year, hourly channel discharges resulting from residential development scenarios with low, medium (cluster pattern), medium (conventional pattern), and high density patterns were again utilized. The relative impact of residential development on the stream health was gauged by the deviation of the variables from the “natural” baseline condition. Since the Back Creek watershed currently contains very little development

(1% imperviousness), it is assumed that the baseline stream condition is minimally impacted and relatively healthy. The degree of deviation was determined by creating a scale of variable values beginning with the value closest to the natural flow regime represented by the baseline condition and ending with the greatest deviation from the natural flow regime, the high density without restrictions full build out scenario. The high density no restriction full build out scenario represents the worst possible scenario with the greatest possible amount of impervious area, hydrologic impact, and, presumably, the greatest stream health impact. Once a value was determined for each variable at both the baseline condition and the high density without restrictions full build out scenario condition, each variable range was evenly divided into three sections (Table 4.2). These variable ranges were then assigned an index of 1, 3, or 5 representing the perceived relative impact on stream health (1 representing little or no impact, 3 representing moderate impact, and 5 representing a large impact).

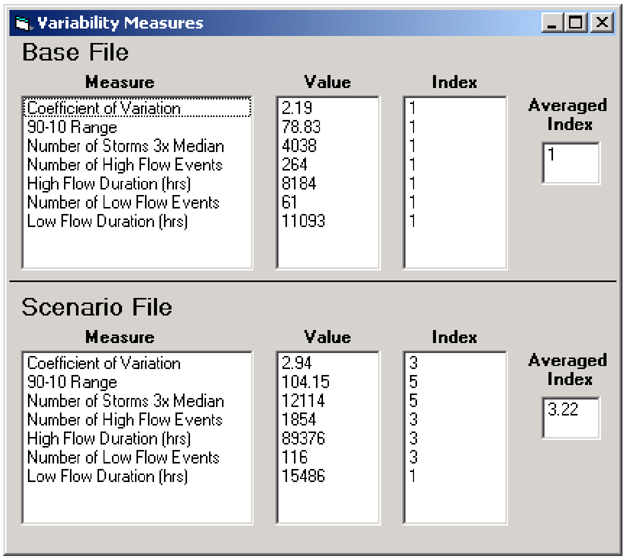
Table 4.2. Flow variables and index ranges of perceived stream health impact

Statistical Group	Variable	Low* Value	High** Value	Index 1 Range	Index 3 Range	Index 5 Range
Overall Variability	Coefficient of Variation	2.195	3.708	2.195-2.70	2.71-3.20	3.21-3.708
	90-10 Range	78.83	114.77	78.83-90.81	90.81-102.79	102.79-114.77
High Flow	FRE3	4038	13026	4038-7034	7035-10030	10031-13026
	High Flow Events	264	4146	264-1558	1559-2852	2853-4146
	High Flow Duration	7668	206352	7668-73895	73896-140124	140125-206352
Low Flow	Low Flow Events	61	188	61-103	104-145	146-188
	Low Flow Duration	11093	24336	11093-15507	15508-19921	19922-24336

*baseline condition **high density full build out without restrictions

The indices for each variable were calculated for all 8 scenarios. The indices were first averaged within the respective statistical group for each scenario and the three statistical group indices were finally averaged to obtain the overall scenario index. Intermediate index averages for each statistical group served to demonstrate the magnitude of stream health impact predicted by each group and to ensure that each statistical group was given equal weighting in the overall scenario index.

Variable values and indices were calculated within an expanded version of the stand-alone Visual Basic Post Processor program discussed in chapter 3. Figure 4.1, for example, compares the baseline condition to the high density development with restrictions scenario. The change in the values of the individual measures and the corresponding index along with the averaged index (1 for the baseline and 3.22 for the scenario in this case) can be visually inspected in this output format.



Base File

Measure	Value	Index
Coefficient of Variation	2.19	1
90-10 Range	78.83	1
Number of Storms 3x Median	4038	1
Number of High Flow Events	264	1
High Flow Duration (hrs)	8184	1
Number of Low Flow Events	61	1
Low Flow Duration (hrs)	11093	1

Averaged Index: 1

Scenario File

Measure	Value	Index
Coefficient of Variation	2.94	3
90-10 Range	104.15	5
Number of Storms 3x Median	12114	5
Number of High Flow Events	1854	3
High Flow Duration (hrs)	89376	3
Number of Low Flow Events	116	3
Low Flow Duration (hrs)	15486	1

Averaged Index: 3.22

Figure 4.1 Sample graphical output from the Post Processor program showing flow variability for the high density with restrictions full build out scenario

4.2.2 Habitat Suitability Parameters

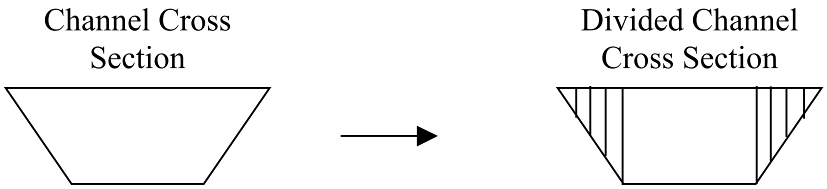
Habitat suitability indices are dimensionless numbers that indicate the appropriateness of a habitat component for a species on a scale of zero to one, with one representing the best habitat range. These indices are typically compiled from a collection of data relating species observations and habitat conditions during the observation (Vadas 1994). Many observations are compiled to minimize the effects of outliers. Typically, velocity, depth, and substrate indices are collected for fish species, as these are perceived to influence the suitability of stream locations for fish species.

This study focuses on the two variables, velocity and depth, that are directly related to flow variability. These can be calculated directly from channel discharge and geometry and are understood to profoundly influence fish habitat preference (Jowett and Duncan 1990). Because HSI's are derived from observations and the accuracy of the indices can be considered coarse, a more generalized approach is taken in this study. Velocity and depth ranges compiled from the averages of observed habitat ranges in relevant literature (Vadas, 1994) are used as the acceptable range of habitat measures for the species evaluated. The inner 50% of these ranges are then designated as the optimum habitat range. The inherent assumption in this process is that the averages of observed habitat ranges in different streams represent an acceptable habitat range in a particular stream and that the optimum habitat level lies in the center of these acceptable habitat ranges.

Computation of Velocity and Depth Parameters

Additionally, the velocity and depth for the habitat ranges are measured from the water column at the point of each fish observation. Because HSPF is a one-dimensional hydrologic model, only average discharge for a given stream location could be immediately produced from the model. Using routing curves and channel geometry at these points, average velocities and a water surface elevation were easily calculated (See Lohani, et al 2002 for complete discussion). Conveyance ratios were employed to disaggregate the velocity and represent the cross section channel habitat heterogeneity. A stepwise procedure for this process is given in Figure 4.2. Using this procedure, the simulated flows by the HSPF model were used to create the acceptable and optimum velocity and depth ranges for fish species across the transect and assumed to be representative of the reach.

Step 1. Divide channel into main channel and side banks. Divide channel side banks into 4 sections of equal width.



Step 2. Calculate the conveyance and conveyance ratio of each slice.

$$K_m = \frac{1.49}{n} * A_m * R_m^{2/3}, \quad K_{Ratio} = \frac{K_m}{\sum_{m=1}^{m=9} K_m}$$

Where:

K_m= conveyance for mth slice, ft^3/s
n = Manning's roughness coefficient
A_m= area of mth slice, ft^2
R_m= hydraulic radius of mth slice, ft
$K_{Ratio,m}$ =ratio of mth slice conveyance to total

Step 3. Calculate the velocity of each slice.

$$v_m = \frac{K_{Ratio}, m * Q}{A_m}$$

Where:

v_m= velocity in mth slice
Q = channel discharge at cross section

Figure 4.2. General steps in velocity disaggregation method used in the Post Processor program

Selection of Fish Species

In order to model the impacts of the hydrologic variability on the fish community, representative adult fish species native to Back Creek were chosen from three habitat guilds (Table 4.3). Central stonerollers (*Campostoma anolmalum*) represent fish species that prefer run habitats, while smallmouth bass (*Micropterus dolomieu*) represent slow pool species, and fantail darters (*Etheostoma flabellare*) represent the fast riffle fish species in Back Creek.

Table 4.3. Habitat guild representative species and habitat ranges from Vadas (1994).

Species	**Acceptable Velocity Range**		**Acceptable Depth Range**		**Optimal Velocity Range (mid 50%)***		**Optimum Depth Range (mid 50%)***	
	ft/s		**ft**		**ft/s**		**Ft**	
Smallmouth bass	0.00	1.64	0.49	5.25	0.41	1.23	1.68	4.06
Central stoneroller	0.16	2.30	0.33	2.46	0.70	1.76	0.86	1.93
Fantail darter	0.49	2.13	0.33	0.82	0.90	1.72	0.45	0.70

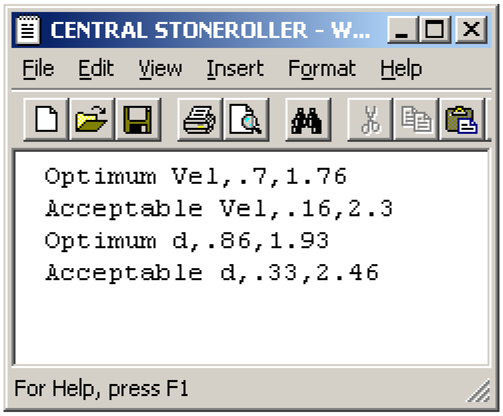
*Optimal ranges used the central 50% of the acceptable ranges

Evaluation of Hydrologic Impacts on Habitat

Four sets of calculations were performed to evaluate the velocity and depth habitat that Back Creek provides for the three fish species.

1. The percentage of total time that the optimum and acceptable velocity, depth, and both velocity and depth were available at the representative cross section of each reach.
2. The percentage of total time that the above parameters were available anywhere in the stream (as represented by the 10 cross sections).
3. The percentage of the total area that supported the above parameters each hour and the amount of time that percentage of area was available for the representative cross section of each reach.
4. The percentage of the total area that supported the above parameters each hour along the entire stream and the amount of time that percentage of area was available.

All habitat suitability analysis was performed using an expanded version of the stand alone Visual Basic HSPF Post Processor described in chapter 3. The Post Processor input was expanded to allow user selection of habitat range data for species (the HSI file) and geometric channel data for each cross section (the FTABLES file). All channel geometry data was either taken directly from data used by HSPF for routing or data that was collected in the field in order to calculate required HSPF inputs (Lohani, et al. 2002). Each scenario run consisted of a basefile representing the unaltered watershed, a scenario file representing the watershed changes from each residential development scenario, an HSI file for a selected fish species (Figure 4.3), and the FTABLES file. The numbers reported in Figure 4.3 are for the central stoneroller species and are obtained from Table 4.3. The output capabilities of the HSPF Post Processor were also expanded to include graphical representations of the area providing acceptable and optimum habitat criteria to each species for the baseline and scenario conditions (Figure 4.4). These graphs quickly summarize the changes in the available are for species habitat variables throughout the channel. An additional comma separated value file was also provided to document and summarize the variability and habitat suitability data. In total, nine channel slices per cross section, ten cross sections per run, three runs per scenario (three fish species), and eight scenarios with 43 years of hourly discharge data along with the baseline data used for comparison in each run amounted to over 1.6 billion habitat data units analyzed.



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Optimum Vel,.7,1.76
Acceptable Vel,.16,2.3
Optimum d,.86,1.93
Acceptable d,.33,2.46
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Figure 4.3. Sample HSI input file for the central stoneroller

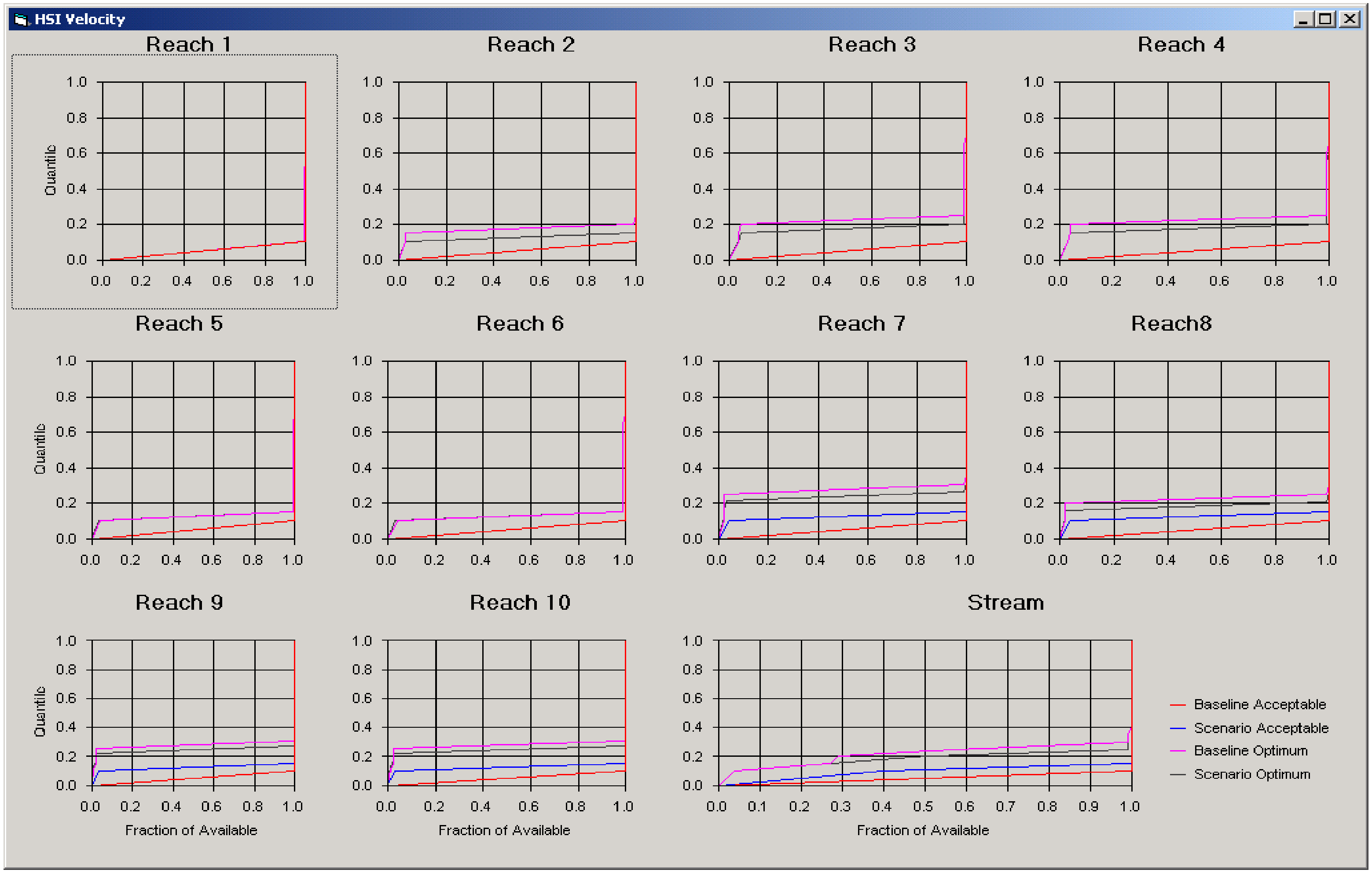


Figure 4.4 Sample graphical area-velocity output for the high density without restrictions full build out scenario from the Post Processor program. The amount of area available (Fraction of Available) and the amount of time each area is available (1 – Quantile) are shown for each reach and for the entire stream.

4.3 Results and Discussion

Flow Variability Metrics

The statistical categories and the measures within each category have varying sensitivities to the resultant flow variability from residential development patterns. The output from HSPF for the base condition and the eight residential development scenarios at the outlet of the Back Creek watershed was classified using the flow variability indices given in Table 4.2. A summary of the output for each scenario is given in Tables 4.4, 4.5, and 4.6. For example, for the high density with restrictions scenario, the coefficient of variation under the overall variability group was observed as 2.94. Therefore, as per the criteria adapted in Table 4.2, it falls under the Index 3 range as shown in Table 4.5. The impervious area land use for each scenario is provided in Table 4.6 as a means of quantifying the amount of watershed development for each scenario. For example, for the high density with restrictions scenario, the coefficient of variation and the 90-10 range have been assigned index 3 and 5, respectively. These indices are then averaged to obtain the overall variability index of 4.00 as shown in Table 4.6.

The high flow statistical category index appears to be the most sensitive to hydrologic change for the lower development densities. This is indicated by the consistently higher variability index for the four development scenarios with the least amount of development (see Table 4.6). For example, for the low density with restrictions type development, the high flow index is observed as 1.67 while overall variability and low flow indices were observed as 1.00. The heightened sensitivity indicates that land use changes in Back Creek under relatively low density development can cause floods or high flow extreme events that are more detrimental to the stream health than the changes in low flow extreme events and the overall change in the flow regime. The index value for this statistical category is greatly elevated by the FRE3 variable as the high flow duration and number of high flow events variable indices are consistently lower and, therefore, less sensitive to hydrologic change. The difference in these indices can be attributed to the definition of a high flow event used by these variables. The high flow duration and number of high flow events variables identify a high flow event as a discharge greater than or equal to bankfull (estimated by the flood

Table 4.4 Flow variability measures for the base condition and eight scenarios near the outlet of Back Creek

Scenario	Overall Variability		High Flow			Low Flow	
	Coefficient of Variation	90-10 Range (cfs)	FRE3 (cfs)	Number of High Flow Events	High Flow Duration (hrs)	Number of Low Flow Events	Low Flow Duration (hrs)
Base	2.19	78.83	4038	264	7668	61	11093
Low Density with Restrictions	2.34	88.04	8532	432	16878	77	11248
Low Density No Restrictions	2.54	94.99	10512	792	33096	90	12314
Medium Density Cluster with Restrictions	2.57	96.17	10740	840	36024	90	12538
Medium Density Conventional with Restrictions	2.75	100.59	11484	1320	61800	109	13864
High Density with Restrictions	2.94	104.15	12114	1854	89376	116	15468
Medium Density Cluster No Restrictions	3.03	105.24	12216	1992	95658	123	16215
Medium Density Conventional No Restrictions	3.38	110.36	12678	2994	146610	148	19730
High Density No Restrictions	3.71	114.77	13026	4146	206352	188	24336

Table 4.5 Flow variability indices* for the base condition and eight scenarios near the outlet of Back Creek

Scenario	Overall Variability		High Flow			Low Flow	
	Coefficient of Variation	90-10 Range	FRE3	Number of High Flow Events	High Flow Duration	Number of Low Flow	Low Flow Duration
Base	1	1	1	1	1	1	1
Low Density with Restrictions	1	1	3	1	1	1	1
Low Density No Restrictions	1	3	5	1	1	1	1
Medium Density Cluster with Restrictions	1	3	5	1	1	1	1
Medium Density Conventional with Restrictions	3	3	5	1	1	3	1
High Density with Restrictions	3	5	5	3	3	3	1
Medium Density Cluster No Restrictions	3	5	5	3	3	3	3
Medium Density Conventional No Restrictions	5	5	5	5	5	5	3
High Density No Restrictions	5	5	5	5	5	5	5

*Each index represents the following: (1) very little or no impact, (3) moderate impact, and (5) a large impact on stream health from flow variability

Table 4.6 Flow variability indices by statistical group and impervious land use percent for the base condition and eight scenarios

Scenario	% Impervious	Overall Variability Index	High Flow Index	Low Flow Index	Averaged Index
Base	1%	1.00	1.00	1.00	1.00
Low Density with Restrictions	6%	1.00	1.67	1.00	1.22
Low Density No Restrictions	10%	2.00	2.33	1.00	1.78
Medium Density Cluster with Restrictions	11%	2.00	2.33	1.00	1.78
Medium Density Conventional with Restrictions	15%	3.00	2.33	2.00	2.44
High Density with Restrictions	19%	4.00	3.67	2.00	3.22
Medium Density Cluster No Restrictions	20%	4.00	3.67	3.00	3.56
Medium Density Conventional No Restrictions	26%	5.00	5.00	4.00	4.67
High Density No Restrictions	34%	5.00	5.00	5.00	5.00

with a 1.67 year average return period), a much larger storm than the flood with a discharge of three times the median used by the FRE3 variable. This further division of the high flow statistical category underscores the impact of land use change on the number of smaller storms in Back Creek. Because smaller storms occur at a much greater frequency than larger storms, it seems logical that there would be a larger number of storms over the 43-year simulation period that could be raised above the FRE3 threshold with relatively little change in land use.

The low flow statistical category index lags behind the other two categories in sensitivity to residential development with the lowest index for all eight scenarios. This indicates that the reduction in stream discharge during low flow events impact the stream health less than the other two categories. However, it is important to note that these statistics are all relative to the baseline condition and the high density full build out without restriction scenario. Because Back Creek is a runoff driven headwater stream with a relatively low average flowrate at the baseline condition, the low flow events may be the more stressful to stream biota and merit a greater weighting in the averaged index (biological processes other than physical habitat may also contribute).

Finally, the overall variability index falls between the other two category indices in the four lower development scenarios and is the greatest index in the highest development scenarios. This indicates that the overall instability of the discharge within the channel increases in sensitivity with greater development and eventually becomes the most decisive factor in the stream health. And yet, paradoxically, it is known that constant flows (e.g. below dams) can be equally limiting. This is reasonable, as many stream biota are known to rebound quickly from disturbances, but have less persistence as stressors such as flow variability persist. The constant change in streamflow would not allow enough time for stream biota to adapt to the new condition or recover from the previous stress (Reice 1985).

The increase in average index, an indication of the overall stream health based upon the ecologically relevant hydrologic variables, follows the impervious land use percent closely (See Figure 4.5). This trend agrees with the studies by numerous authors (see Chapter 2) relating impervious fraction directly with biological indicators and multi metric indices that exclude hydrologic and hydraulic modeling. However, the approach

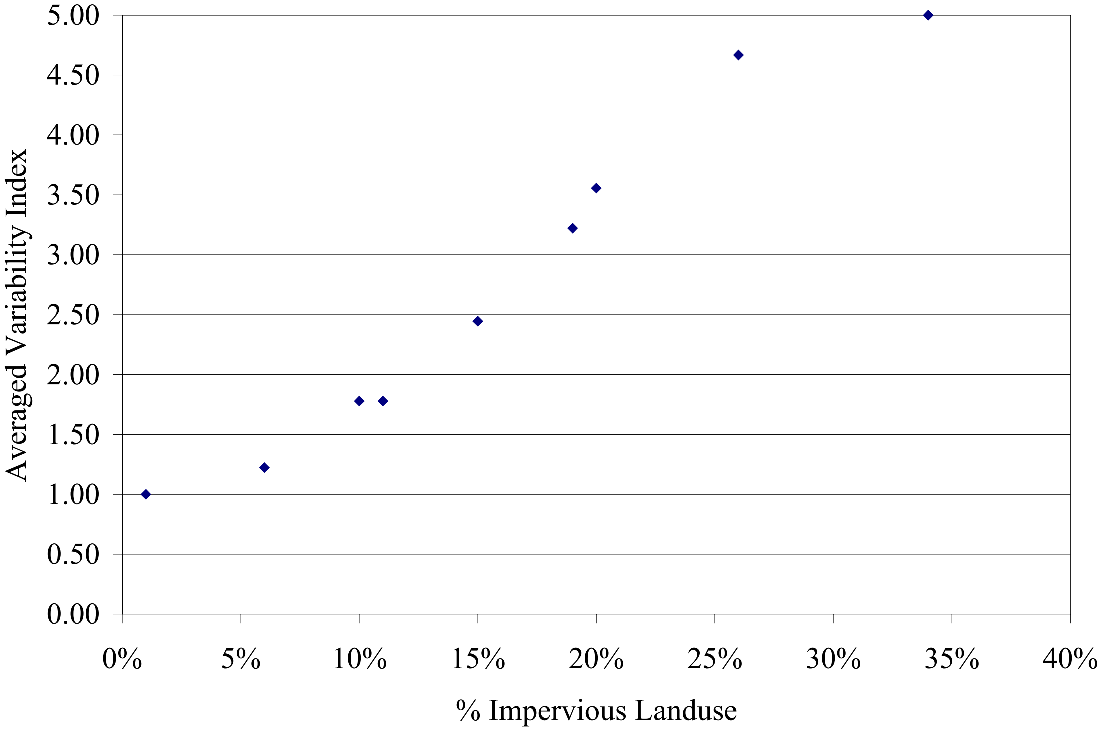


Figure 4.5 Comparison of Averaged Variability Index with % Imperviousness

described in this study assumes that the direct link between hydrology and stream health is constant. The studies relating impervious fraction to stream health require the user to assume that the hydrologic and hydraulic processes of a watershed are based purely on the amount of impervious land use cover and no other physical characteristic of the watershed. Time of concentration, infiltration, overland runoff, flow attenuation and other hydrologic processes are ignored. Further, in some cases, these studies assume the transferability of land use and stream health correlations. Unless very similar watersheds are used, transferability of such indirect relationships is questionable. Therefore, use of a direct relationship model as described here is suggested.

Habitat Suitability Parameters

As previously mentioned, the results for the habitat suitability parameters are presented in four parts:

- Fraction of total time velocity, depth, and both velocity and depth within the optimum and acceptable limits of species are available at each cross section

- Fraction of total time velocity, depth, and both velocity and depth within the optimum and acceptable limits of species are available throughout the entire stream
- The amount of time fractions of total area with velocity, depth, and both velocity and depth within the optimum and acceptable limits of species are available at each cross section
- The amount of time fractions of total area with velocity, depth, and both velocity and depth within the optimum and acceptable limits of species are available throughout the entire stream

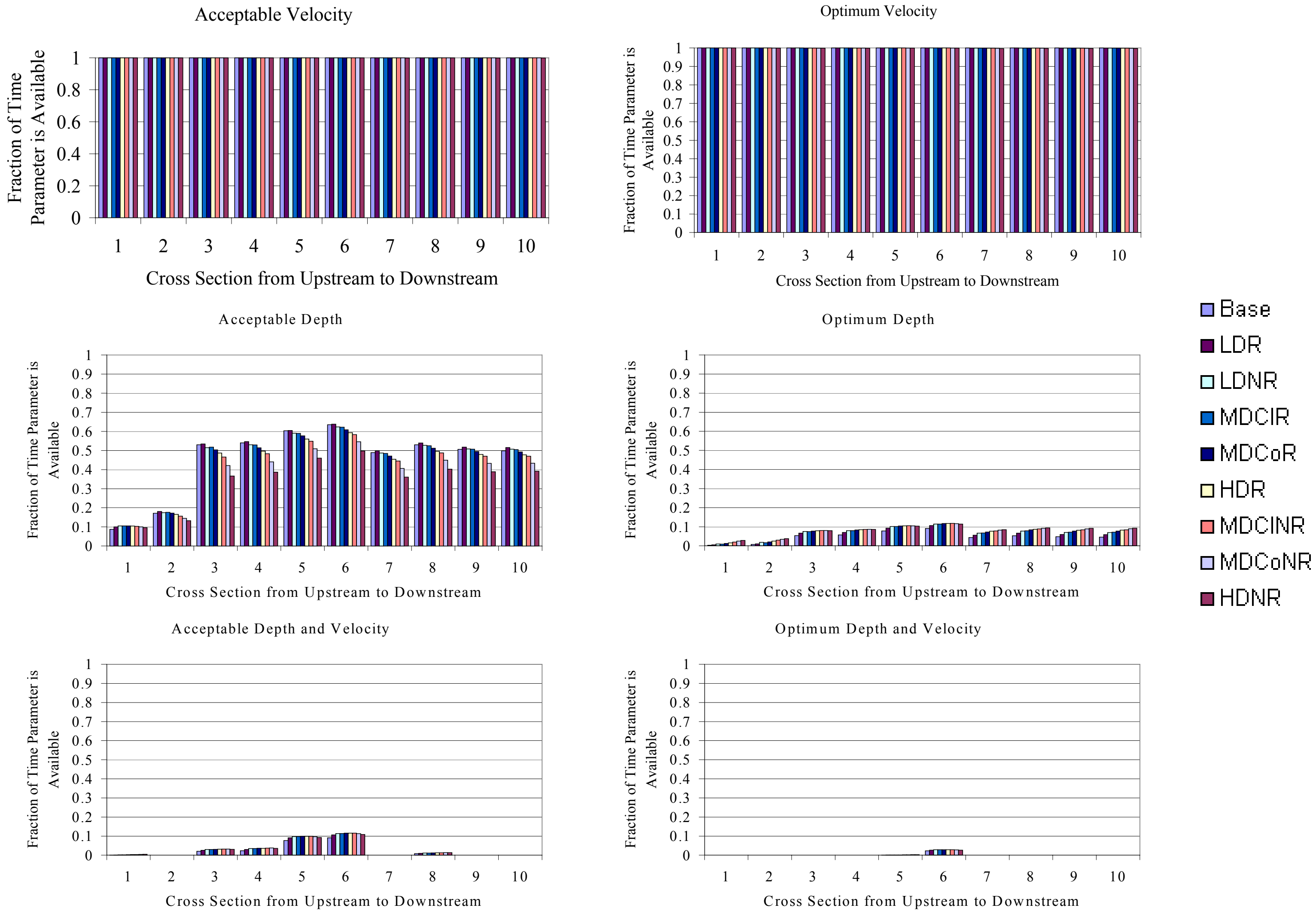
To conserve space, a system of acronyms and abbreviations was developed for each of the scenarios as listed in Table 4.7. These acronyms and abbreviations will be used to refer to the scenarios from this point forward.

Table 4.7 Acronyms and abbreviations for the scenarios used in this chapter

Full Build Out Scenario	Acronym/ Abbreviation
Baseline	Base
Low density with restrictions	LDR
Low density without restrictions	LDNR
Medium density (cluster) with restrictions	MDClR
Medium density (cluster) without restrictions	MDClNR
Medium density (conventional) with restrictions	MDCoR
Medium density (conventional) without restrictions	MDCoNR
High density with restrictions	HDR
High density without restrictions	HDNR

First, the fraction of the total time that the velocity, depth, and both the velocity and depth at each reach cross section are within the optimum and acceptable limits for the central stoneroller, fantail darter, and smallmouth bass fish species are presented in Figures 4.6, 4.7, and 4.8, respectively. Here total time means the simulation period of 43 years. These graphs show the fraction of time that the relevant habitat suitability parameter is within the optimum or acceptable species limits in at least one part of the channel. For example, for the high density without restrictions development pattern, there is acceptable velocity habitat for the central stoneroller in Reach 3 approximately half of the total simulation time. It may be noted that channel cross sections are divided into 9 pieces for computation of these variables. Therefore, the area of water (in a two dimensional, cross section view) that supports the optimum or acceptable species requirements can range from one small increment of the channel bank to the entire channel cross section.

It is evident from the three figures that there are significant differences in the amount of time that habitat suitability parameters are available for the three fish species, supporting the designation of these species as representative of habitat guilds. While the optimum and acceptable velocities for all three species are shown to be abundant for all scenarios, the availability of optimum and acceptable depths for the fish species range from almost non-existent (in the case of the optimum depth for smallmouth bass) to fairly abundant (in the case of the acceptable depth for the central stoneroller and fantail darter). The availability of locations within the channel supporting both the velocity and depth reveals the overall ability of Back Creek to support the fish species habitat specifications from a hydrologic perspective.



Acceptable Velocity

Optimum Velocity

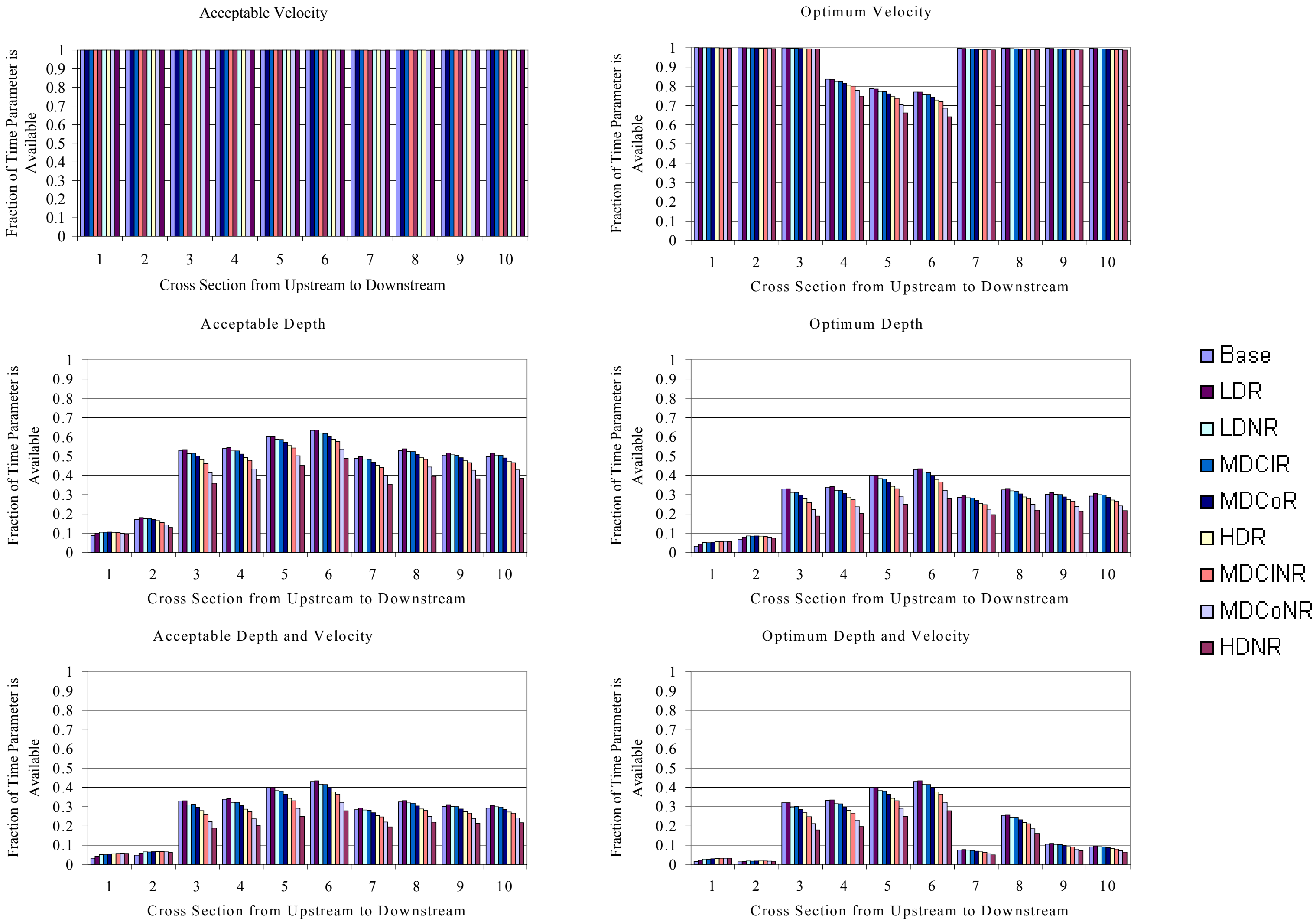
Acceptable Depth

Optimum Depth

Acceptable Depth and Velocity

Optimum Depth and Velocity

Figure 4.6 Central stoneroller plots showing amount of time habitat parameters are present at channel cross sections


Acceptable Velocity

Optimum Velocity

Acceptable Depth

Optimum Depth

Acceptable Depth and Velocity

Optimum Depth and Velocity

Figure 4.7 Fantail darter plots showing amount of time habitat parameters are present at channel cross sections

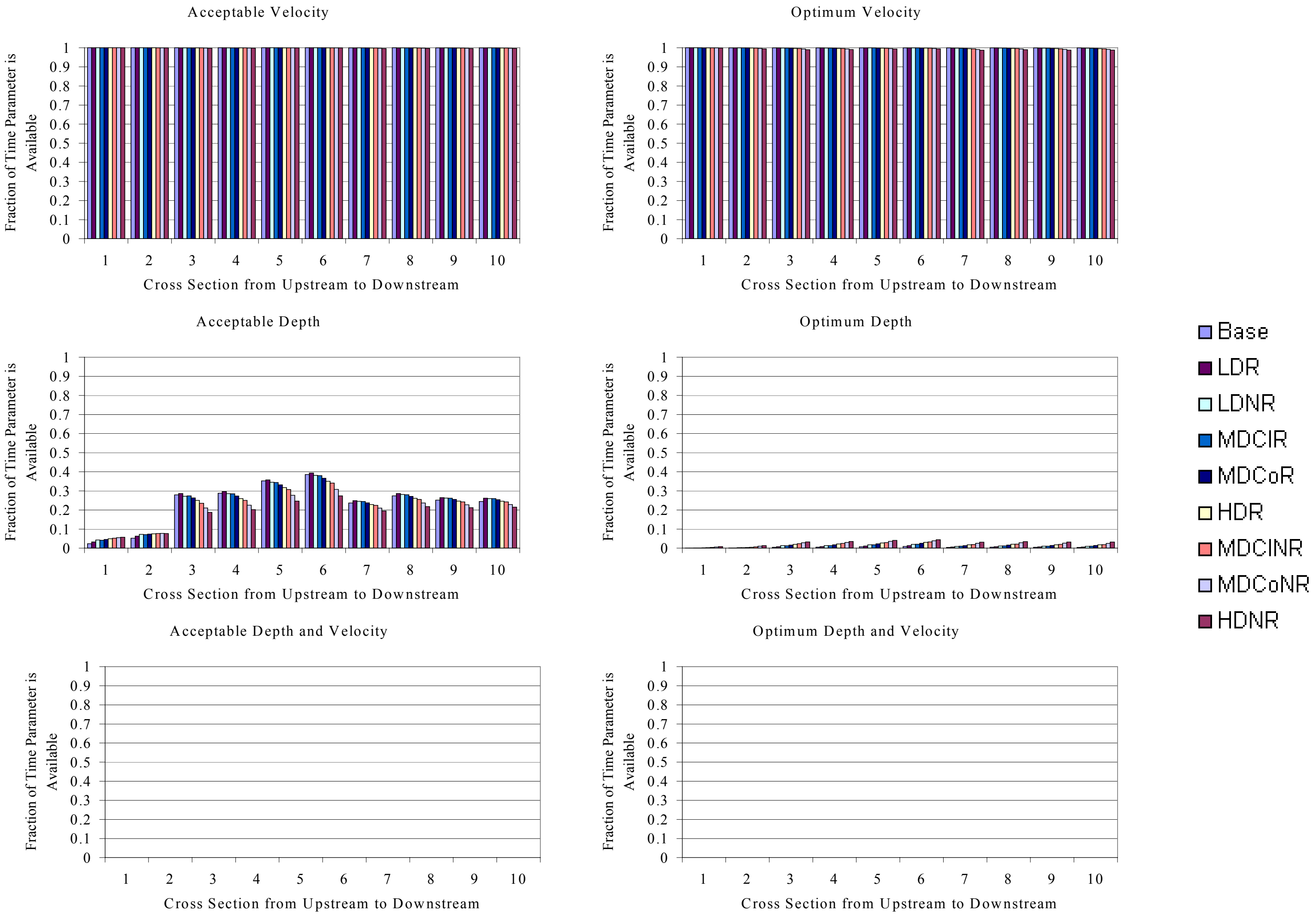


Figure 4.8 Smallmouth bass plots showing amount of time habitat parameters are present at channel cross sections

From the overall characteristics of these graphs, the channel appears to favor the fantail darter (Figure 4.6), as habitat that fit the specifications of this species are available for a greater period of time than the those of the other two species. The habitat specifications of the stoneroller (Figure 4.5) are also supported to a lesser extent, while the habitat specifications of the smallmouth bass (Figure 4.7) are not supported at any reach. These results are supported by the occurrence of these species in Stancil's (2000) fish sampling results from Back Creek during 1998 and 1999 shown in Table 4.8. The infrequent occurrence of smallmouth bass in the fish sampling tend to confirm the model results, although it must be understood that the cross sections used in the model are merely representative of the reach geometry and may not characterize all habitat within the reach. Longitudinal variations in the fraction of time that habitat values are within species suitability ranges result from changes in the channel geometry, hydrology, and hydraulics. These variations underscore the importance of accurately representing the channel by using an appropriate number of channel cross sections taken from representative areas. The differences between the amount of time habitat is supported at the optimum and acceptable levels for most of the habitat variables is also apparent from the plots.

Table 4.8 Selected fish species and occurrence from fish sampling of Back Creek in 1998 and 1999 by Stancil (2000).

Fish Species	Occurrence
smallmouth bass	9
central stoneroller	299
fantail darter	1297

The scenario data trends presented in Figures 4.6, 4.7, and 4.8 are best understood when analyzed with the optimum and acceptable velocity and depth ranges presented in Table 4.3 and the Log Pearson Type 3 density curves presented in Figure 3.11. While it is natural to associate floods and high flows with increasing development, it is important to remember that development actually decreases the baseflow of a channel by reducing infiltration and hence reducing the groundwater recharge. The reduction in the most frequently observed discharges with increasing development is depicted in Figure 3.11. However, an increase in the frequency of high flows during the heavier storm events with an increase in development is also evident in Figure 3.11. Therefore, lower velocities and depths should dominate the flow regime of developed watersheds while elevated velocities and depths should be observed during the less frequent, larger storm events created by the increased overland flow and decrease in time of concentration. The ranges of suitable velocities and depths for the fish species and the association with the hydrologic characteristics of Back Creek can also help explain the scenario data trends. Because Back Creek is a small headwater stream, the discharges and hence the velocities and depths of the stream are relatively small and typically on the lower end of habitat suitability ranges for fish species.

Analysis of Velocity Related Impacts

The fraction of time that optimum and acceptable velocities for the habitat of the three species is at or near 100% for the velocity variable (with the notable exception of reaches 4, 5, and 6 of the optimum velocity plot for the fantail darter). A decrease in the amount of time that velocity is optimal for fantail darter relative to the amount of time velocity is acceptable likely is due to the jump in the lower range constraint for velocity between acceptable and optimal velocity. This reduction in the amount of time that optimum velocities are supported from the amount of time acceptable velocities are supported is not evident in the other two species because the lower constraint on optimal velocity is less than that of the fantail darter.

Analysis of Depth Related Impacts

The fraction of time that optimum and acceptable depths are supported by Back Creek for the scenarios is the constraining variable for the amount of time that the overall habitat can be supported for these fish species. The fraction of time that acceptable depths for the central stoneroller are available decrease significantly with development in all reaches, except the uppermost reach where development has very little impact on the fraction of time acceptable depth habitat is available. In this upper reach, relatively little depth habitat is available in the baseline condition and in this region the development scenarios do not have a significant impact on depth habitat availability. The lack of impact from the development scenarios is generated by the combination of the reduced baseflow depths and the increase in the storm flow depths. The amount of time baseflow and smaller storm depths that support stream depth habitat for the central stoneroller in the downstream reaches dominate the timeseries. However, the relatively smaller amount of time that the increase in moderate to large storms producing acceptable depths becomes significant in the upper reach. Because these two conditions produce opposite trends for the development scenarios (baseflow and smaller storms producing a downward trend in available acceptable depth habitat and moderate to large storms producing an upward trend in available acceptable depth habitat), the result in this case is a masking of both trends. The increase in the lower constraint of the habitat depth from acceptable to optimum depth for the central stoneroller results in less time supporting available optimum depth habitat and a greater significance of the increase in moderate to large storms. This process results in a trend showing an increase in the fraction of time with available optimum depth habitat with increasing development.

Analysis of Both Depth and Velocity Related Impacts

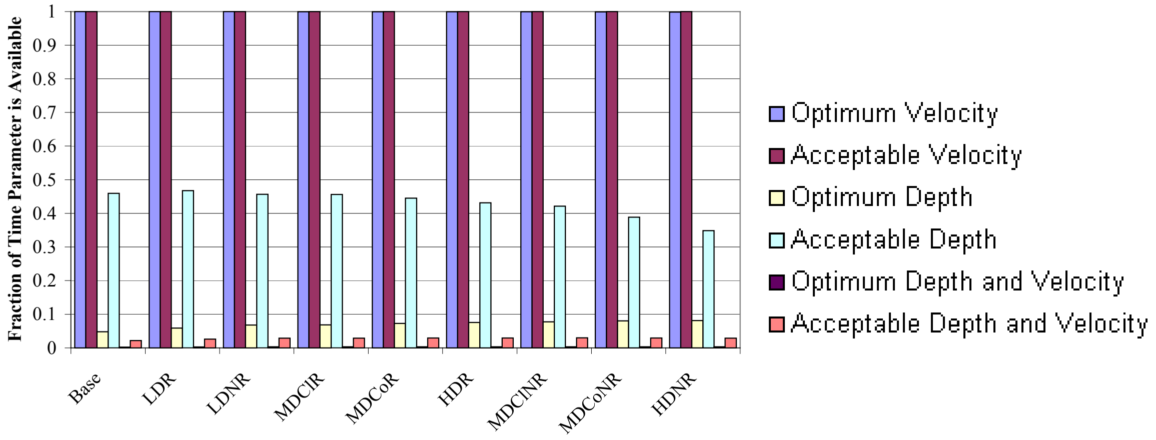
The increase in development causes a considerable reduction in the fraction of time that both the acceptable and optimum depth habitat are available at the same location for fantail darter species, with the exception of the upper two reaches. Because the optimum habitat depth range for the fantail darter is lower than that of the other two species, the baseflow and smaller storm flows are the dominant contributor to the amount of time that optimum habitat depth is available. However, there still is a significant decrease between the amount of time that acceptable and optimum habitat are available for each reach because of the increase of the lower habitat depth constraint.

With the highest habitat depth ranges, the amount of time the depth habitat of the smallmouth bass is supported is the lowest of the three fish species. The amount of acceptable habitat depth for the smallmouth bass follows a similar trend to that of the other two species. The relatively high lower constraint of the optimum depth habitat triggers the very low fraction of time that the optimum depth habitat can be supported. Additionally, moderate to large storm flow depths provide the greater depths needed to support the optimum depth habitat causing the increase in the fraction of time optimum depth habitat is available with increasing development.

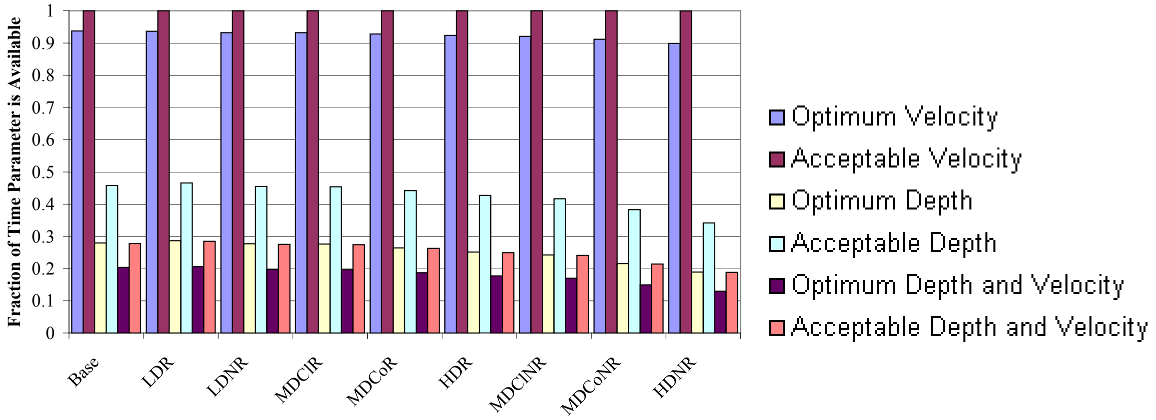
The fraction of time that velocity and depths are available for species in the same location show a distinct trend for each species with an increase in development. The amount of time that habitat is available for the central stoneroller is largely unaffected by the increase in development, while the amount of time habitat is available for the fantail darter decreases with increased development, and no habitat is available for the smallmouth bass.

Figure 4.9 summarizes the data by plotting the total amount of time that the different habitat suitability parameters are available at any point within the stream. This summary of data assumes that the fish have the ability to sense the stress of being in an area outside the species suitability range and the ability to search and fin areas with better suitability. This assumption seems valid as long as there is enough suitable habitat in the stream such that a fish could be reasonably expected to be able to find the more suitable habitat. This figure underscores the overall trends presented above. The sensitivity of the fantail darter habitat availability to increases in development and the relative insensitivity of the central stoneroller habitat availability to increases in development are evident. Finally, the slight increase between the baseline condition and the lower development patterns before the downward trend in the fraction of time that depth habitat is available may indicate some support for the Intermediate Disturbance Theory.

Central stoneroller



Fantail darter



Smallmouth bass

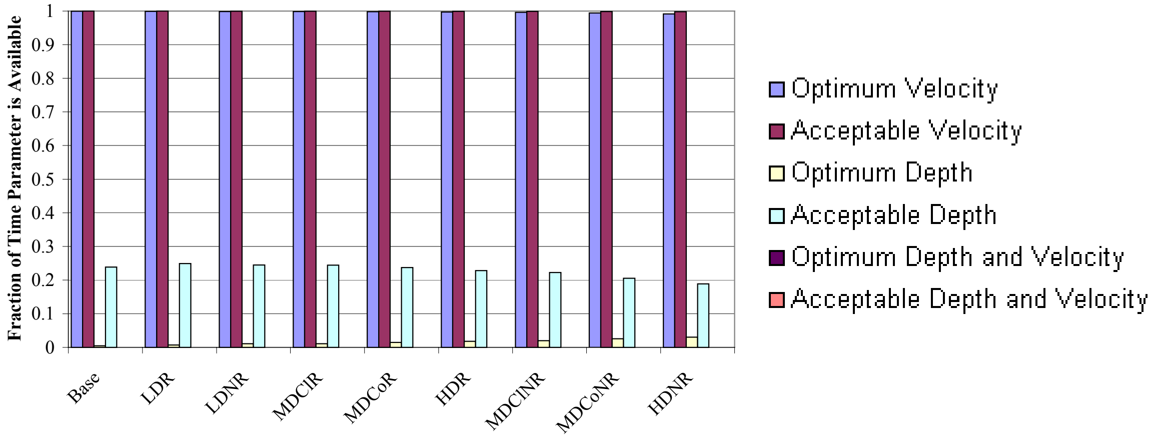


Figure 4.9 Plots showing amount of time habitat parameters are present within the channel

Although the fraction of the total time that habitat variables are available for fish species is helpful in developing trends, a higher level of data resolution can be attained by determining how much and how often the reach and channel can support habitat variable ranges. Because the data encompasses all hourly channel discharge data, the quantile can be used to represent the fraction of time that each fraction of the total area is available as shown in Figure 4.10. Therefore, subtracting the quantile value of the fractional area available from one produces the fraction of total time that the fractional area available to habitat variables occurs. Further analysis of the data yielded Figures 4.11, 4.12, and 4.13 where the fraction of area available for optimum and acceptable velocity, depth, and both depth and velocity are plotted against the fraction of area available quantile[1]. For example, for the high density without restrictions scenario, the fractional area of 0.5 corresponds to a quantile value of about 0.72 for acceptable depth habitat. This means that during 28% of the total simulation time (43 years), half of the total channel area supports acceptable depths for the fantail darter for this scenario.

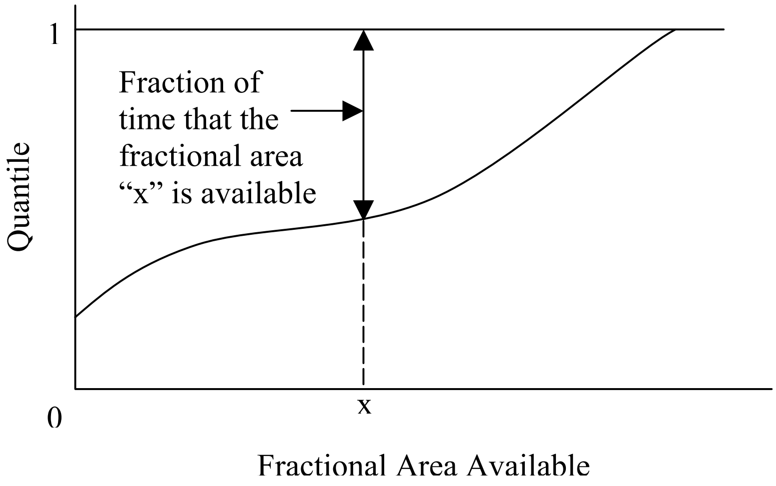


Figure 4.10 Method for arriving at the fraction of time that the fractional area occurs

These figures show similar trends to that of Figures 4.6 through 4.9 in the amount of time that some area is available in the channel to support fish species habitat variables.

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[1] Data and plots for each reach are included in Appendix G.

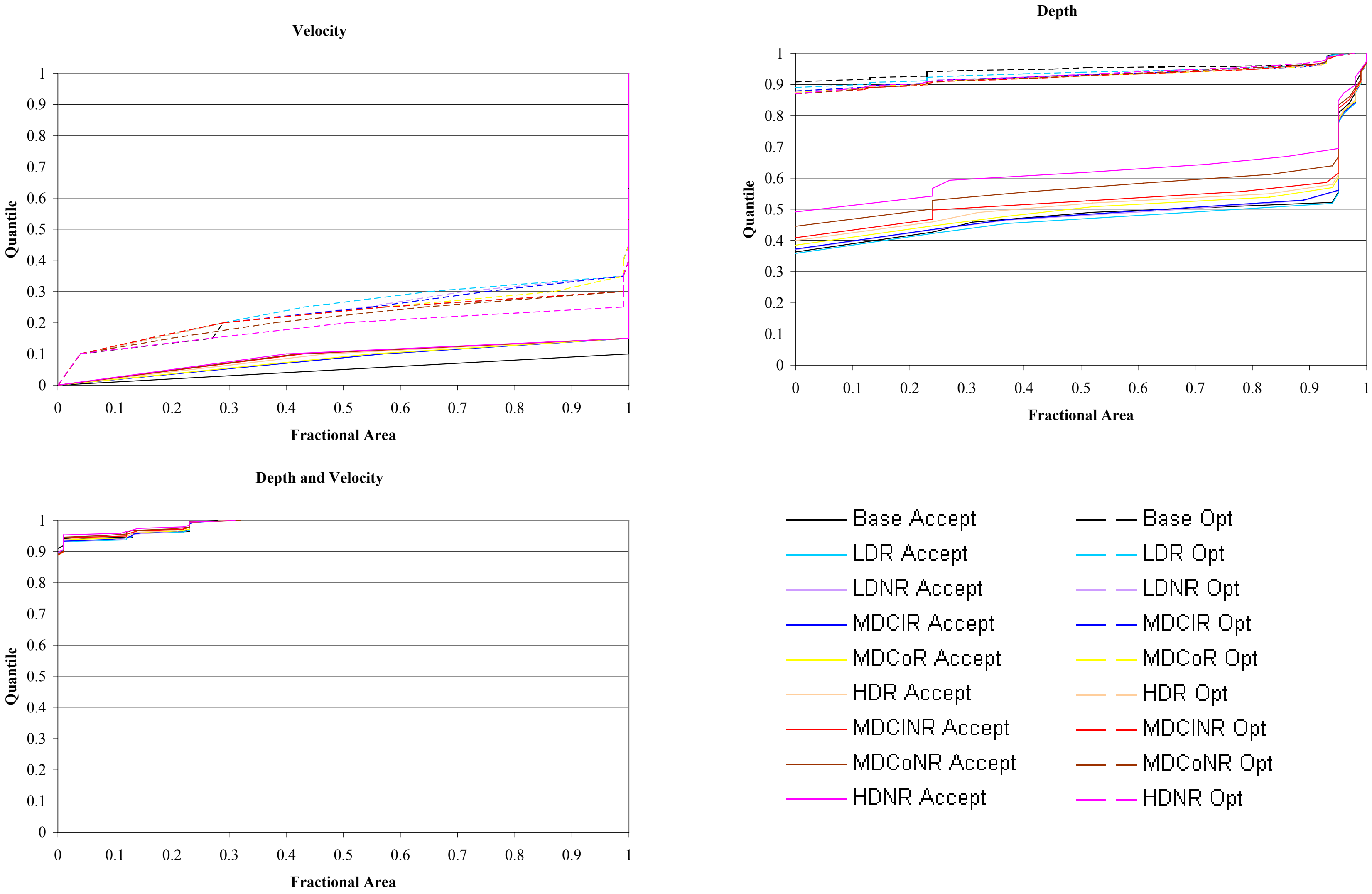

Figure 4.11 Central stoneroller plots showing amount of time and area that habitat parameters are present within the channel

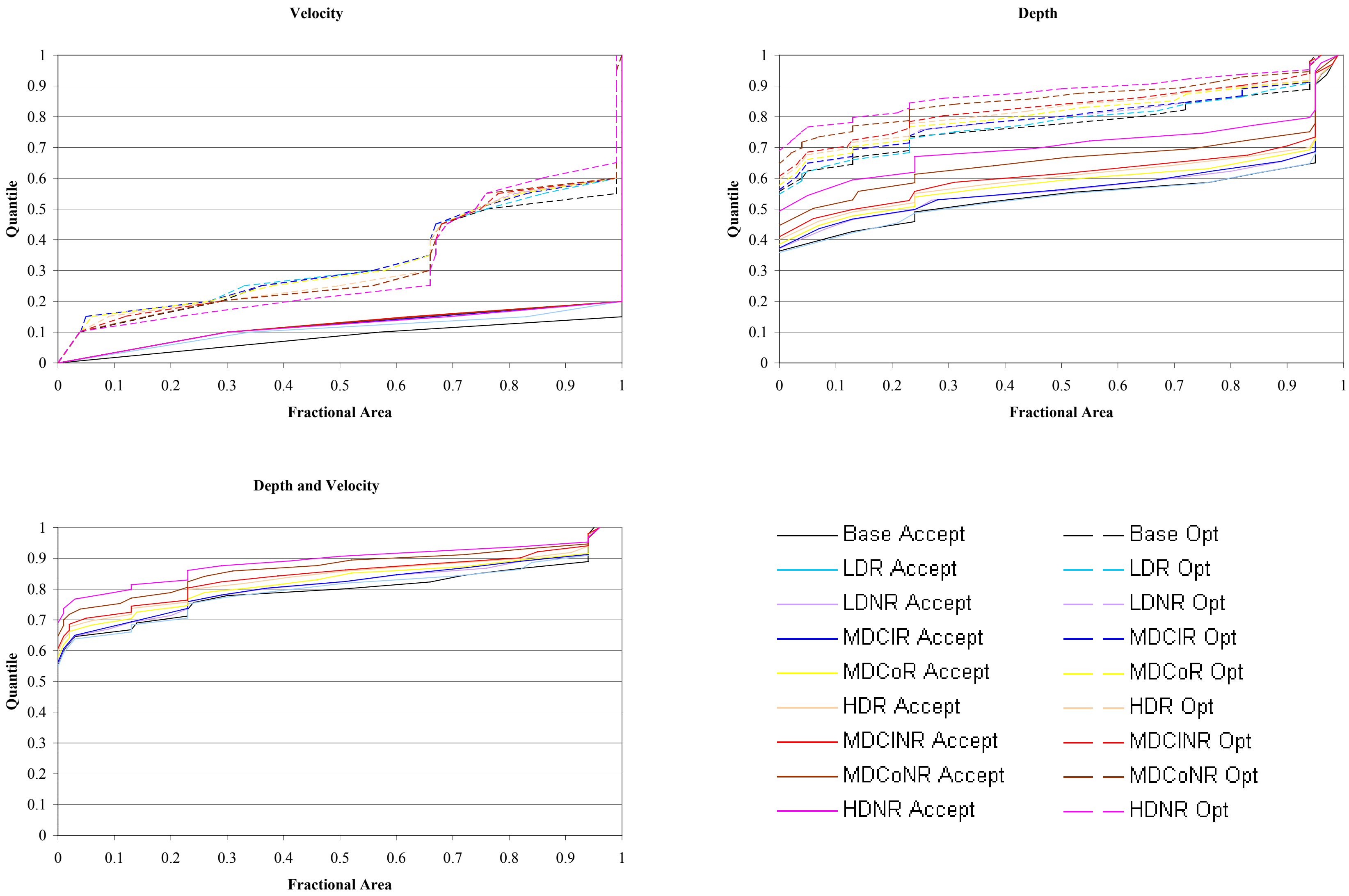

Figure 4.12 Fantail darter plots showing amount of time and area that habitat parameters are present within the channel

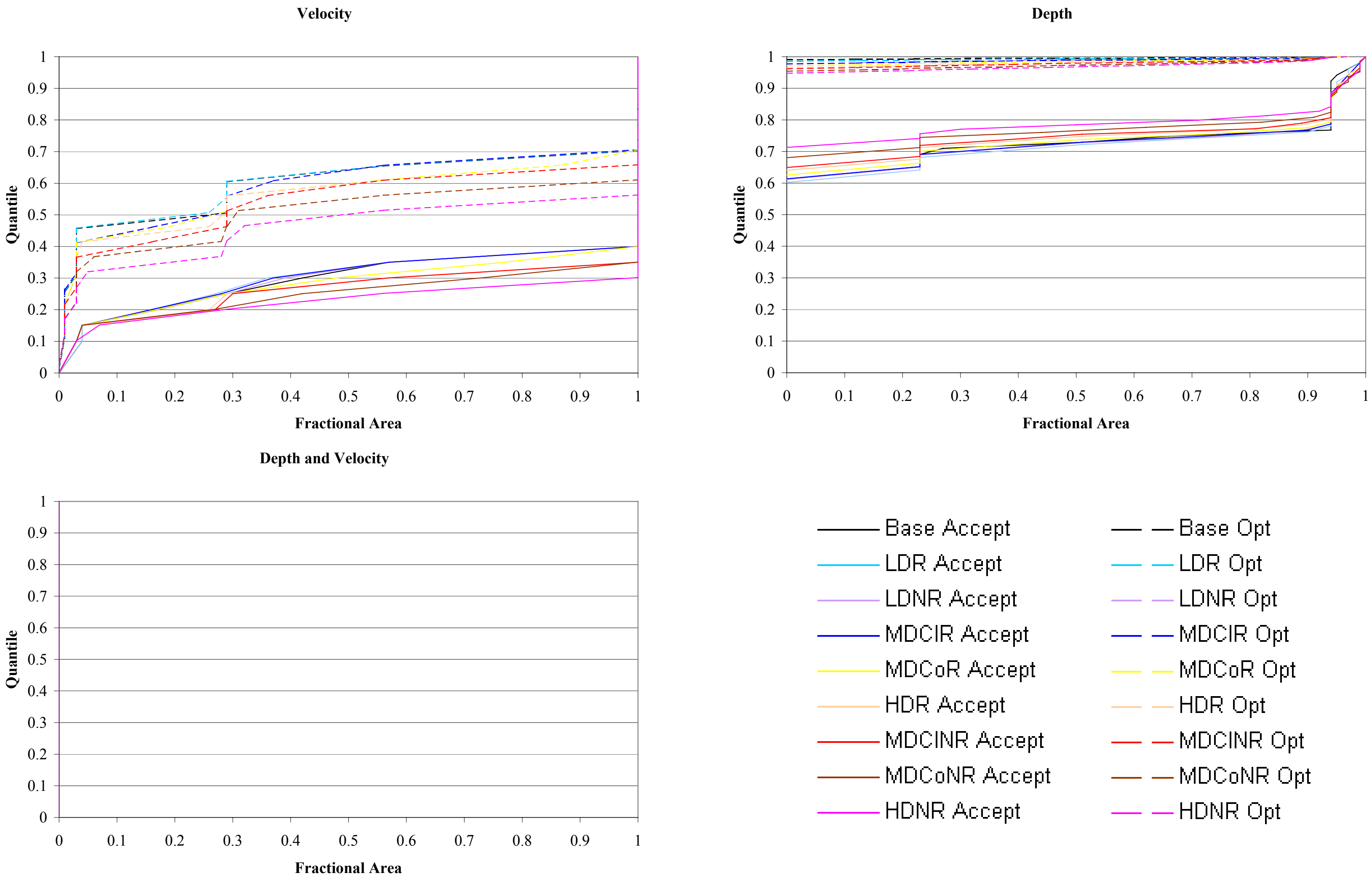

Figure 4.13 Smallmouth bass plots showing amount of time and area that habitat parameters are present within the channel

Notable deviations in the data include the amount of velocity available for each species and the available optimum depth and velocity variable for the central stoneroller. First, the trends for the amount of time that velocity habitat is available for the fish species were obscured by the large amount of time that relatively small portions of the channel contained appropriate velocity habitat. However, even with the additional data resolution, trends in the amount of time when velocity habitat is available with the amount of development are not clear for the central stoneroller and fantail darter. The optimum and acceptable velocity habitat for the smallmouth bass species, on the other hand, shows a clear increase with increasing development. The lack of a clear trend between available velocity habitat and development for the central stoneroller and fantail darter results from the previously discussed relationship between stream channel velocity and development. The trend showing an increase in available velocity habitat for the small mouth bass with an increase in development also results from the previously discussed relationship. Because the acceptable and optimum velocities for the smallmouth bass are significantly lower than those of the other two species, increased development and the associated lower velocities for baseflow and smaller storms would increase the amount of velocity habitat available for the species. The elevated velocity habitat range for the other two species shows signs of both the reduction in velocities during baseflow and small storms and the elevation in velocity of larger storms, making a trend in the velocity habitat with development impossible to discern. It is noteworthy that the obscured trend in velocity habitat with development is negated by the opposite trend in depth habitat with development. Second, the small amount of time that optimum depth and velocity habitat for the central stoneroller (detected in Figure 4.6) represented an area so small that the fraction of total channel area represented was practically zero.

These figures show that the amount of area that supports each of the species habitat variables can vary widely. However, each development scenario produces about the same characteristic curve for each habitat variable, indicating that the relative range of habitat variable availability is relatively unaffected by the increase in development in Back Creek.

4.4 Summary and Conclusions

Two general methods for analyzing the impacts of hydrologic change from residential development scenarios on stream health were employed in this chapter. First, the impact of the flow variability was analyzed using streamflow based statistical metrics developed from the literature review. Ranges were developed for the selected flow variables based upon the baseline flow regime (considered to be healthy and relatively unimpacted by development) and the maximum development scenario. The selected variable ranges were divided into three equal sections representing the relative stages of impact that flow variability would represent. The indices developed from the flow variability showed an increase in negative impact on stream health that closely followed the amount of development in each scenario.

Second, fish species representing different habitat guilds were selected to determine the impact that hydrologic changes caused by development would have on hydrological habitat variables. The amount of time and area that velocity, depth, and both velocity and depth in the channel supported the optimum and acceptable ranges of each of the species was determined. The results from this analysis showed variations in the response of fish species habitat availability response. The two major processes governing this response were: (1) a decrease in velocity and depth in the channel during baseflow and smaller storm events in response to the decrease in groundwater recharge from development; and (2) an increase in velocity and depth in the channel during larger storms in response to the increase in surface runoff and the decrease in time of concentration from development. Depth habitat was found to be the constraining variable for the fish species, as a greater amount of velocity habitat was available. Overall, the velocity and depth habitat available for fantail darter species (representative of the riffle guild) was reduced with an increase in development, while the habitat available for the central stoneroller (representative of the run guild) was slightly reduced, and the habitat available for the smallmouth bass (representative of the pool guild) remained near zero. These results indicate that with increasing development, Back Creek would remain a riffle species dominated creek with a moderate amount of run species. However, there would also be a greatly reduced amount of habitat available to riffle species and pool species.