

**An Evaluation of Changes in Woundfin (*Plagopterus argentissimus*) Populations
in the Virgin River, Utah, Arizona, and Nevada, 1976-1999**

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INTRODUCTION

The impetus for this study came from several state and federal biologists who have worked on the Virgin River and were concerned about what has happened to the native fish fauna in the last 20 years. A number of stations on the Virgin River in Utah, Arizona, and Nevada have been sampled for fish by the Virgin River Fishes Recovery Team (originally the Woundfin Recovery Team) since 1976. This monitoring effort has generally been conducted in the spring, typically during April or May, and again in the fall, typically during September. These data, along with other collection information from various research efforts and other monitoring studies, have been combined into a centralized database by Dr. Thom Hardy of Utah State University. Although the database has been available to essentially anyone, and Dr. Hardy has been more than accommodating in assisting those persons that may want to use the database, very few biologists other than Dr. Hardy have actually tried to use the database. Reasons for this include being insufficiently versed in computer software to attempt such a venture, lack of funds, and finding the database was too difficult to use because of its size and complexity.

During the last 30 years several of the native fish species in the Virgin River have gone from being fairly abundant to being very rare. The woundfin (*Plagopterus argentissimus*), listed as Endangered under the Endangered Species Act of 1973, went from being very abundant in over 100 miles of the river to being common in only about 30 miles of the river. Also, the Virgin River chub (*Gila seminuda*) was listed as Endangered because of perceived reductions in its population size, and the Virgin spinedace (*Lepidomeda mollispinis*) was proposed for listing as a Threatened species as a result of habitat loss and fragmentation. Because of these concerns, many of the biologists working with Virgin River fishes had the impression that the Virgin River database held the answers as to why the native fish populations had declined, if only they could access it. Hence, BIO-WEST, Inc. (BIO-WEST) proposed a study to use the database to answer questions about why the native fishes had declined. The U.S. Fish and Wildlife Service (USFWS) agreed to fund the project with financial assistance from the Southern Nevada Water Authority.

Initially, a copy of the database was obtained, along with instructions from Dr. Hardy's staff on how the database was setup, and initial explorations of the information contained in it were begun. During this time Dr. Hardy and his staff continued to update and make the database more user friendly, which helped the effort tremendously. In addition, information on historic flows in the Virgin River was gathered, since flow changes were thought to be a potential cause of some of the fish declines. Other interested biologists were asked for a list of questions they would like to see addressed by this study. Mr. Jim Heinrich of the Nevada Department of Fish and Game provided a number of questions, including the following:

1. Why did woundfin numbers decline so precipitously at most monitoring stations in the last 20 years?
2. What has been the effect of prolonged drought on the native fishes?

3. What was the effect of Quail Creek Reservoir (completed in early 1985) on the rare fishes?
4. What was the effect of the Quail Creek Dam (in 1989) break on the rare fishes?
5. What are the factors that caused the increase in red shiner (*Cyprinella lutrensis*) in the Virgin River?
6. What was the effect of the first (1988) chemical treatment in the Utah section on downstream fish populations?

These questions tend to bracket the general concerns for the Virgin River fishes. The primary concern is what has caused the recent declines in the native fish community, human-induced or natural factors? In addition, there is a concern over the best way to present catch data found in the database so actual population changes are reflected.

BACKGROUND

Several authors have used the data collected on the Virgin River to describe the changes in fish populations that have occurred and have made hypotheses on the causative mechanisms for these changes. This section briefly summarizes some of the recent papers in this regard, including how the authors used the database, how they expressed fish catch data, and what conclusions they drew. This information is provided to point out what has been done in the past with the database and to provide comparisons for analyses that are performed as part of this study.

Dr. James Deacon of the University of Nevada-Las Vegas (UNLV) and his students have conducted many studies on the Virgin River. Deacon and Hardy (1984) compared spring flow size to reproductive success of woundfin as measured by mean size of the fish in the fall. They concluded that very low (less than 130 cubic feet per second [cfs]), and very high (greater than 1,000 cfs), spring flows resulted in reduced reproductive success, whereas intermediate spring flows resulted in the best recruitment. They used data only from fall samples, and also segregated "disturbed habitats" (primarily areas heavily influenced by upstream irrigation withdrawals) from undisturbed habitats. They assumed that young woundfin found in a location were spawned and reared in that location, and that size of young woundfin in the fall was relatively similar year to year.

Deacon (1988) addressed the effect of Quail Creek Dam and Reservoir on woundfin populations in the Utah portion of the Virgin River. He concluded that changes in flow caused by Quail Creek Dam, and changes in water quality caused by sinkholes that developed near the Quail Creek Dam Diversion, reduced woundfin populations in the Utah portions of the river. He also suggested that red shiner abundance at Beaver Dam Wash may have been related to upstream movement and subsequent abundance of the species in upstream locations. In addition, he noted that flash floods were common most years except during 1984-1986, and that these low-flow conditions may have helped red shiner become very abundant at Beaver Dam Wash and upstream into Utah. The analysis Deacon (1988) used expressed fish density as the mean number of fish per seine unit in

fall samples, and a “seine unit” was defined as the multiple seine hauls at one location during one sampling. The number of seine hauls varied from three to ten or occasionally more.

Gregory and Deacon (1994) used the database developed by Dr. Hardy to analyze changes in the Virgin River fish fauna. Mean number of fish per seine unit from fall samples was again used as the primary method for showing fish density. Gregory and Deacon (1994) concluded that Quail Creek Reservoir diversions and operation, the invasion of red shiner because of high natural (1983) and human-induced (sewer outflow) summer flows, and a 1988 fish poisoning operation to eradicate red shiner in Utah all negatively impacted native fish populations in the Utah and Arizona sections of the river. Non-native fishes have been able to recover from these perturbations, but native fishes have not, according to their analysis.

Lentsch and Bradwich (No Date) utilized the Virgin River database to compare fish density with flow to address the question of when and how red shiner became so abundant at Beaver Dam Wash and upstream locations in the mid-to-late 1980s. They used a different estimator of fish density, mean number of fish per seine haul. They concluded that the reason red shiner abundance increased dramatically at Beaver Dam Wash in 1985 and subsequent years was the lack of flash flooding in the river at flows above 2,000 cfs (as measured at the Littlefield U.S. Geological Survey [USGS] gage) during 1995 and 1996. Two sequential years without such flooding events had not occurred since the 1930s.

Dr. Hardy has conducted numerous studies that have included analyses using the Virgin River database that he created. Hardy et al. (1989) analyzed monthly Virgin River collections from July 1984 to August 1987 made by Mr. Terry Hickman, a private consultant who was under contract to the Washington County Water Conservancy. The Hickman collections were part of the mitigation package for Quail Creek Reservoir. This intensive data collection set provided an opportunity to statistically test several assumptions regarding sampling in the Virgin River. Hardy et al. (1989) concluded that sampling riffles and pools for woundfin added to the variability within and between stations, because woundfin were seldom found in those habitats. They also concluded that samples during high-flow periods (greater than 100 cfs) also resulted in higher sampling variability than sampling during lower flow periods. The data indicated that sample sizes (seine units) of 25 or more were needed to distinguish changes in population density.

In looking at individual station collection information, Hardy et al. (1989) concluded that effects of altered flows from Pah Tempe Hot Springs, apparently a result of sinkholes in the river near the Quail Creek Reservoir withdrawal structure, were very evident at the Ash Creek sampling site but not as evident at sites further downstream. Woundfin numbers dropped dramatically in 1985 but rebounded by 1987. The authors also compared flow and reproductive success as measured by the number of young-of-the-year (YOY) woundfin but found no statistical correlation. They did determine that overwinter mortality was about 30 percent, regardless of flow level during the winter.

In addition to the above data analysis, Hardy et al. (1989) also developed suitability index curves from the data collected by Hickman and used Instream Flow Incremental Methodology (IFIM) techniques to predict impacts of Quail Creek Reservoir and the proposed North Creek Reservoir.

Hardy (1991) presented data from monthly collections in 1990 and 1991, and made comparisons with data from earlier years that were contained in the database. Mean number of fish per seine unit was used in these comparisons. The conclusion from the study was that in 1990 and 1991 woundfin populations in particular and native fish populations overall had declined in the Virgin River. It also indicated that size of woundfin in the fall may not be a good representation of reproductive success as used earlier by Deacon and Hardy (1984). This conclusion was based on tracing size classes of woundfin and noting relatively little growth in some years.

Hardy (1994) evaluated flow options within the Utah section of the river. Pre-Quail Creek Reservoir flows were compared with the present flow pattern, which included a year-round 86 cfs minimum flow below the Quail Creek outflow, and with a proposed scenario that included changing the winter release from Quail Creek Reservoir to 50 cfs. The 50 cfs scenario has been proposed by the Washington County Water Conservancy District and would include a 5 cfs minimum flow in the summer below Washington Fields Diversion, an area which is presently dewatered during most summers. PHABSIM analyses using suitability curves developed in Hardy et al. (1989) showed that woundfin habitat would not be substantially reduced by a change from 86 to 50 cfs in the winter and that the 5 cfs minimum flow below the Washington Fields Diversion resulted in substantially increased woundfin habitat. Habitat for larger species, such as Virgin River chub and flannelmouth sucker (*Catostomus latipinnis*), that prefer deeper habitats would decrease with the 50 cfs winter flow.

Hardy et al. (1995) continued analyzing proposed flow changes (Hardy 1994) associated with water development on the Virgin River, as well as responding to criticism of the effect of Quail Creek Reservoir on native fish populations. A more-intensive analysis of flows in various sections of the river before and after the construction of Quail Creek Reservoir were developed from a hydrology model developed by the Utah Division of Water Resources was provided. Future scenarios with proposed projects in place were also provided. The conclusion of the hydrology analysis was that neither the existing Quail Creek Project nor future proposed water development projects would effect higher flows thought to be important for fish habitat maintenance as well as riparian maintenance. They utilized multispectral videography of the river to measure habitat changes at various flows as a check for the PHABSIM analyses run as run by Hardy (1994). Both methods showed similar results within the flow ranges studied and suggested that neither Quail Creek Reservoir nor future proposed projects would negatively affect woundfin and other native fish habitat.

Hardy et al. (1995) also compared woundfin catch at monitoring stations immediately above and below Quail Creek with mean annual flow to address the concern about potential affects of Quail Creek Reservoir on native fishes. Woundfin catch rates were calculated as the average catch per unit effort for the first seine pass only during fall monitoring. The authors concluded that woundfin populations at the four sites closely tracked the strength of the flow year: During drought years the populations were low, and during average and above average years populations were larger. In

addition, populations above and below the Quail Creek inflow were not different except in 1985 when Pah Tempe Hot Springs increased dramatically in flow because of upstream sink holes. Woundfin abundance at the Near Ash Creek site, the closest site downstream of Pah Tempe Hot Springs, dropped dramatically because of the change in water quality from the increased spring flow but rebounded as flows returned to normal in 1986. This report was a reply to criticism (Deacon 1988, Gregory and Deacon 1994) on the effects that Quail Creek Reservoir had on native fish populations.

BIO-WEST initiated this study early in 1995 and began investigating the information contained in the database that Dr. Hardy had developed. As mentioned earlier, one of the questions considered involved the effect of Quail Creek Reservoir on native fishes. As described above, some of the researchers working on the Virgin River had different opinions about the causes of native fish declines and the role of Quail Creek Reservoir in particular. The addition of another research study added to the concern that duplication of efforts was not warranted.

In an effort to get the various researchers together and seek ways to work on problems as a group rather than individually, a researchers' workshop was proposed. Dr. Deacon arranged the meeting for July 10-12, 1995, at UNLV and developed a proposed agenda. The researchers that attended included Dr. Deacon, Dr. Hardy, and his co-worker Mr. Craig Addley, Dr. Paul Holden of BIO-WEST, Drs. W.L. Minckley, Paul Marsh, and Mike Douglas of Arizona State University, and Mr. Jim Heinrich from the Nevada Division of Wildlife. Other attendees included USFWS personnel from the Reno, Las Vegas, and Salt Lake City offices; as well as a representative from American Rivers, an environmental group concerned about river ecosystems. Mr. Addley brought the database on a computer and was prepared to work with it at the meeting.

Dr. Deacon intended to use the database information at the meeting to look at the various questions about changes in the native fish populations to develop a consensus on the reasons for the changes. But the meeting became a lively discussion of the database itself and how consistent and reliable the data contained within it really were. It was clear that the researchers that had been monitoring the river for many years (Deacon, Holden, and Hardy) and were familiar with the information in the database were ready to use the data to draw conclusions. Those researchers less familiar with the data (Minckley, Marsh, and Douglas) were much more questioning of its validity. In addition, the group also discussed how best to report the data (i.e., number of fish per seine unit, number per first pass seine haul, number per 100 square meters, or a population calculation based on depletion sampling). Another line of discussion involved how much variation was introduced into the sampling data as a result of using different seine sizes, different crews, different times of the day, different river flows, etc. Again this discussion raised concerns about how the database was used and stimulated discussion on experiments that could be conducted to answer some of these questions.

Although the meeting failed to fulfill its primary objective of analyzing data to determine why the native fish fauna changed, it did highlight the need to determine if the data were reliable and could be used in the fashion that Deacon, Hardy, and others had been using it over the past 10 years. The meeting provided a type of peer review of the past analyses and raised some basic questions about the long-term monitoring that made up the bulk of the database. The meeting resulted in a decision

to determine a baseline of fish abundance at each station over the time period of the monitoring activities that was statistically valid. It was also concluded that, because of the type of monitoring that had been conducted (seining of primarily sandy run habitats), the database would likely not be very useful for species (other than woundfin and red shiner) that preferred other habitat types. To that end the meeting refocused the effort of this study to first determine the reliability of the data and how best to present the fish abundance information.

A draft report was completed in 1996 using the database, which included data through 1993 (Holden and Zucker 1996). The U.S. Bureau of Reclamation provided additional funding in 1999 to update the analyses in the 1996 report with data through 1999, as well as add some new analyses that might illuminate the factors contributing to the declines of native fishes in the Virgin River. This final report, therefore, has been updated to include the fish collection and hydrology data collected from 1994 through 1999.

RESULTS AND DISCUSSION

Initial Database Analyses

Prior to the Las Vegas workshop in July 1995, BIO-WEST's efforts on this project involved obtaining an updated version of the Virgin River database, becoming familiar with the database, and initiating analyses. This occurred during a time when Dr. Hardy and his staff were making the database easier to use, which aided BIO-WEST's efforts considerably but also took additional time as the database was improved. In addition to learning about the database and how to access information, seining information from woundfin monitoring in 1976 that was not in the original version of the database was entered into the version used in this study.

For this final report the database was again obtained from Dr. Hardy, and it included data through 1999. The database had been changed considerably in the intervening years and now is in a Microsoft Access format. However, BIO-WEST had to create its own file to account for samples with no woundfin and samples with no fish. Samples with no woundfin had been accounted for in the prior report (Holden and Zucker 1996), but the preconstructed queries within the database queries did not return samples where no fish were caught. A more-detailed description of how the BIO-WEST data file was created is included in Appendix A.

Statistical Reliability Testing

Introduction

The Virgin River database consists of data collected by different investigators using different protocols and recording different information from different areas along the Virgin River (Figure 1). In the absence of a clearly defined, carefully followed sampling protocol, the reliability of the data collected and the comparability across years is not definitively known. For some samples, especially in the earlier years sampled, accurate information on the number of passes taken and/or how many fish were caught in each pass is not available (although the total number of fish caught is usually recorded). Some samples consist of only a single pass. Passes were not always taken until depletion. Precise, rigorous population estimates cannot be performed on many of the

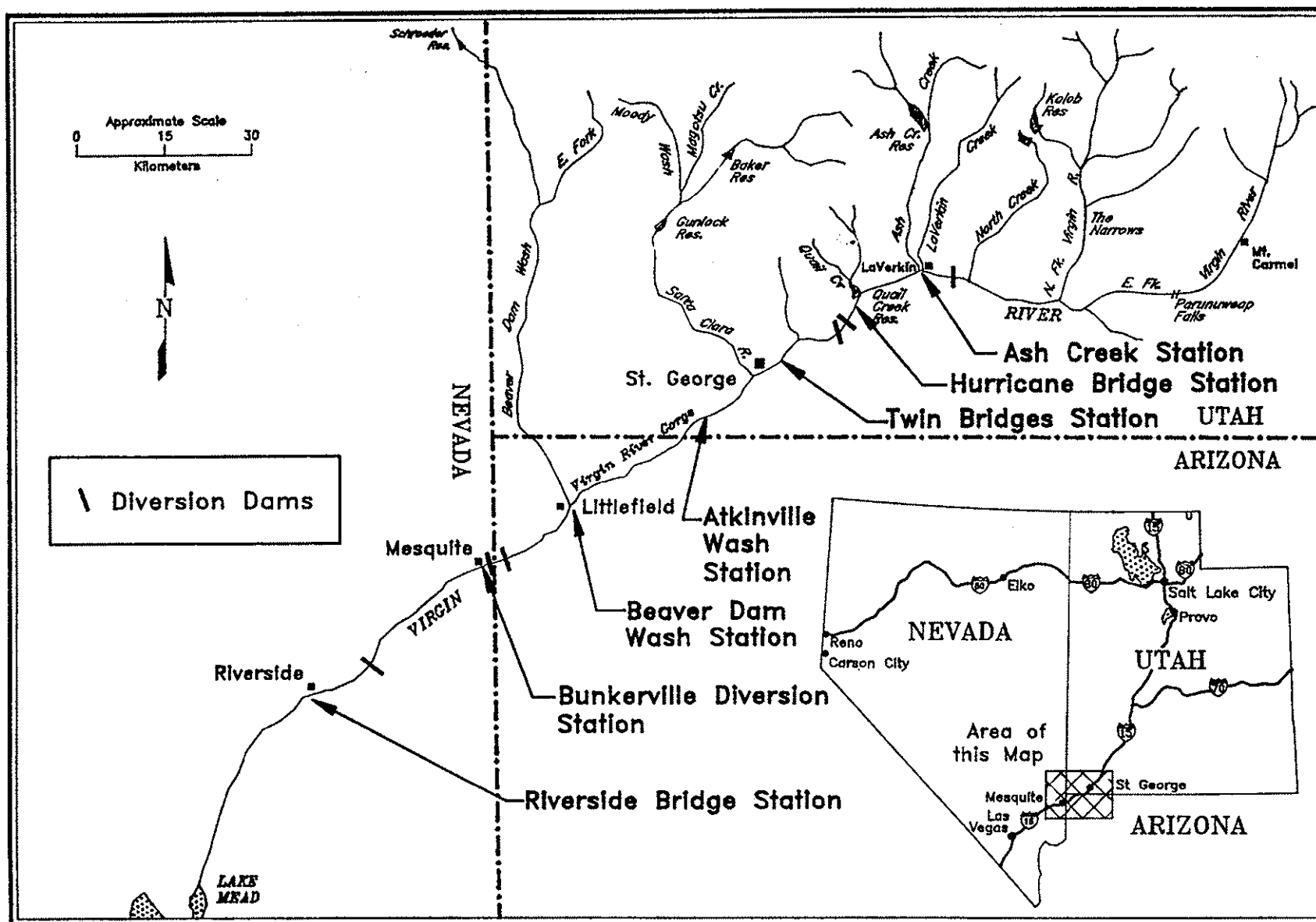


Figure 1. Map of the Virgin River.

samples because of lack of data or protocol inconsistencies. To be able to use most of the available information, a more-general estimate of woundfin abundance must be used. Two potentially useful measures are the number of woundfin caught in the first seine pass and the total number of woundfin caught in all passes ("seine unit").

Measures of woundfin per unit area are likely to be poor indicators of how many fish are in the river because of subjectivity in microsites sampled and a lack of reliable information on area sampled. Seining samples were generally taken from the habitats most likely to contain woundfin, runs with a sand substrate. Area of available habitat similar to that sampled was not recorded. The number of samples taken and the total area sampled at a given station, on a given day, varied widely. If woundfin are concentrated in certain microsites, then the number caught per unit area may depend on how much of that microsite was sampled. Extrapolation to estimate the woundfin population at a station based on density estimates and total area would be inappropriate and unreliable. The number of woundfin caught regardless of area sampled is probably a better estimate of local woundfin abundance, since the sampling was focused on those microsites most likely to hold fish. For these reasons, we chose to use the number of woundfin caught in total, rather than adding an areal quantifier to the catch-per-unit-effort (CPUE) statistic.

In order to investigate the usefulness of first pass and seine unit data, and to facilitate subsequent analyses, a new dataset was established. Appendix A explains how the dataset was established. This dataset essentially included all of the pertinent data on fish catch that was needed for the statistical analyses. In developing the new dataset, inappropriate and erroneous data had to be excluded. Samples where only a single pass was taken or pass information was missing were excluded from first pass vs. seine unit comparisons, but were included for all other analyses. Samples in which no woundfin were caught were included with a 0 rather than not being listed for that species, and samples where no fish were caught had to be added with 0s for all species in question. Only data collected by seining were included. Seasons were assigned according to the following: fall, 8/15-11/15; winter, 11/15-2/15; spring, 2/15-5/15; and summer 5/15-8/15. We took the natural logarithms (ℓ_n) of (number of woundfin + 1) for first pass data and seine unit data. One was added to all values because $\ell_n(0)$ is undefined. In the results and discussions that follow, whenever we refer to $\ell_n(\text{woundfin})$ it is implied that it is $\ell_n(\text{woundfin}+1)$. The ℓ_n -transformed data was much closer to a normal distribution than the untransformed data, making it more appropriate for most analyses. Additionally, rare extreme values (potential outliers) do not influence the means of natural logarithms as much as they do the raw means. Data from the following four stations were used in these analyses: near Ash Creek (River Mile 94.75-95.32), near Hurricane Bridge (RM 84.19-89.19), near Twin Bridges (RM 71.52), and near Beaver Dam Wash (RM 34.95). These stations were selected because they represent four of the most-commonly sampled stations since the 1970s, and they represent four rather distinct areas in relation to woundfin habitat and woundfin populations.

First Pass Vs. Seine Unit

We compared numbers of woundfin caught in the first seine pass to numbers of woundfin caught in all passes at a particular sampling site (seine unit). We wanted to determine whether there were differences between the two measures and their reliability. We used two primary approaches to compare the two measures. First, the seine unit data was regressed on the first pass data to test the strength of the relationship between them. Second, variability within stations and seasons was compared using seine unit and first pass data.

For each station and season, the natural logarithm of the number of woundfin caught per seine unit (+1) was regressed on the natural logarithm of the number of woundfin caught in the first pass (+1). As shown in Table 1, in all 16 cases (four stations and four seasons) the two variables were highly correlated, with a mean R^2 value of 0.919 (range of 0.851 to 0.976, see Table 1). The relationship between ℓ_n (first pass) and ℓ_n (seine unit) was very consistent across stations and seasons. The slopes (x-coefficients) were all close to one (mean: 1.126, range: 1.061 to 1.181, Table 1), suggesting that the differences between first pass and seine unit data do not change much as the number of fish caught increases. The high correlation and consistency of the relationship across

Table 1. Results of regressions of (woundfin caught per seine unit) on (woundfin caught in the first pass) for each station in each season.

STATION	SEASON	Y-INTERCEPT	REGRESSION SLOPE ^a	R-SQUARE
Ash Creek	Fall	0.131	1.093	0.851
Ash Creek	Spring	0.055	1.149	0.918
Ash Creek	Summer	0.096	1.181	0.889
Ash Creek	Winter	0.044	1.146	0.976
Beaver Dam Wash	Fall	0.097	1.170	0.912
Beaver Dam Wash	Spring	0.092	1.154	0.921
Beaver Dam Wash	Summer	0.117	1.164	0.888
Beaver Dam Wash	Winter	0.186	1.173	0.921
Hurricane Bridge	Fall	0.279	1.059	0.908
Hurricane Bridge	Spring	0.230	1.074	0.922
Hurricane Bridge	Summer	0.213	1.092	0.930
Hurricane Bridge	Winter	0.159	1.074	0.939
Twin Bridges	Fall	0.095	1.112	0.924
Twin Bridges	Spring	0.187	1.113	0.905
Twin Bridges	Summer	0.065	1.149	0.954
Twin Bridges	Winter	0.095	1.114	0.956

^aAll regression slopes were statistically significant ($p < 0.001$).

seasons and stations suggest that woundfin caught in the first pass is a reliable predictor of woundfin caught per seine unit.

The variability in woundfin per seine unit was compared with the variability in woundfin in the first pass using the untransformed data. The overall (combining all stations, seasons, and years) coefficient of variation (CV) for the number of woundfin caught in the first pass is 285.4, and for the number of woundfin caught in all passes (seine unit) is 252.8. Standard deviations (STD) and CVs for each station and season were computed to compare the variability in number of woundfin in first pass and seine unit (Table 2). Standard deviations were consistently and significantly higher for the seine unit data ($p = 0.001$, paired t-test), but, as this is at least partly a function of the higher means of the seine unit data, CVs are better measures of variability. Coefficients of variation of the first pass were significantly greater than those of the seine unit ($p = 0.022$, paired t-test). Although statistically significant, the difference in CVs was small (mean difference was 22.012 or 8.2%). There is slightly less variability in the seine unit data than in the first pass data.

In conclusion, first pass data are reliable predictors of seine unit data and are not much more variable than seine unit data. Under different sampling conditions, in different habitats, or for other species, first pass data and seine unit data may not be as interchangeable, but for this data set, first pass data are essentially as useful as seine unit data. Since variability is not reduced much by additional passes, little statistical power is gained by taking multiple passes.

We chose to use seine unit data for most of our subsequent analyses, primarily for consistency with previous analyses of other researchers using seine unit as the measure of woundfin abundance. Additionally, the slightly lower variability in seine unit data resulted in slightly greater power to detect differences and relationships in the data.

Season

Data were not collected during all seasons in all years. In most years, there was a spring sampling trip and a fall sampling trip. Samples were also collected frequently during the summer and occasionally during the winter. We performed an ANOVA to determine differences in woundfin abundance and discharge on the day sampled between seasons within a station, and between stations within a season. We used Tukey's Honestly Significant Difference test to compare all possible differences between means. Since spring and fall were sampled most consistently, and could provide information about different aspects of woundfin population dynamics, we wanted to compare these two seasons in more detail. Paired t-tests of Coefficients of Variation were used to test whether spring woundfin data were any more or less variable than fall woundfin data.

Table 2. Coefficient of variation (CV), standard deviation (SD), mean, and number of observations (N) of woundfin per seine unit and woundfin in first pass for each station in each season.

Station	Season	Variable	N	Mean	SD	CV
Ash Creek	Fall	First Pass	280	3.046429	15.67643	514.5839
		Seine Unit	280	4.739286	17.70487	373.5767
Ash Creek	Spring	First Pass	220	1.181818	2.559544	216.5768
		Seine Unit	220	1.831818	3.707808	202.4114
Ash Creek	Summer	First Pass	237	1.978903	5.451207	275.4661
		Seine Unit	237	3.708861	9.97856	269.0465
Ash Creek	Winter	First Pass	105	4.809524	11.05849	229.9291
		Seine Unit	105	7.419048	15.457	208.3421
Beaver Dam Wash	Fall	First Pass	216	3.731481	10.85645	290.942
		Seine Unit	216	7.12037	19.22073	269.9401
Beaver Dam Wash	Spring	First Pass	181	3.160221	8.237568	260.6643
		Seine Unit	181	5.486188	13.03994	237.6868
Beaver Dam Wash	Summer	First Pass	151	3.350993	10.44043	311.5623
		Seine Unit	151	6.649007	20.29358	305.2122
Beaver Dam Wash	Winter	First Pass	14	10.57143	20.44021	193.3533
		Seine Unit	14	26.28571	50.91536	193.6997
Hurricane Bridge	Fall	First Pass	644	12.44099	29.78233	239.3887
		Seine Unit	644	19.74845	39.4013	199.5159
Hurricane Bridge	Spring	First Pass	397	6.876574	17.30745	251.6871
		Seine Unit	397	10.56927	21.73935	205.6845
Hurricane Bridge	Summer	First Pass	518	8.42471	19.16207	227.4508
		Seine Unit	518	14.06757	31.23538	222.0383
Hurricane Bridge	Winter	First Pass	238	6.37395	8.47974	133.0374
		Seine Unit	238	9.411765	12.28282	130.505
Twin Bridges	Fall	First Pass	351	5.102564	13.3046	260.7434
		Seine Unit	351	8.387464	20.56872	245.2317
Twin Bridges	Spring	First Pass	220	2.922727	6.427568	219.9168
		Seine Unit	220	5.563636	11.85878	213.148
Twin Bridges	Summer	First Pass	204	6.254902	19.20678	307.0676
		Seine Unit	204	11.46569	35.37183	308.5016
Twin Bridges	Winter	First Pass	105	5.780952	11.68084	202.0573
		Seine Unit	105	8.895238	17.58601	197.7014

The number of woundfin caught per seine unit differed by season at all stations (Figure 2; p values ranged from 0.001 to 0.041). At Hurricane Bridge there were more woundfin per seine unit in fall samples than in spring samples ($p = 0.01$), but fall and spring did not significantly differ at the other three stations. It would be ecologically reasonable to expect more woundfin in the fall because YOY woundfin would be present in fall samples, whereas spring samples would consist mostly of mature fish, but Hurricane Bridge was the only station that supported this expectation.

At all stations discharge on the day sampled significantly differed between seasons ($p < 0.001$). The order, from lowest to highest discharge, was summer, fall, winter, and spring at all four stations (Figure 3). At all four stations, discharge from spring samples was significantly greater than discharge from fall samples ($p < 0.001$).

Variability in woundfin abundance did not differ between spring and fall samples. The mean (of the four stations) CV in woundfin per seine unit was actually greater in the fall samples than in the spring samples (272.1 in the fall and 214.7 in the spring). However, a paired t-test showed that this difference was not statistically significant ($p = 0.283$).

For subsequent analyses of changes in woundfin abundances, we chose to use spring and fall samples. Spring and fall were the seasons most consistently sampled; not as many years had summer and/or winter samples. Spring data are likely to be at least close to as reliable as fall data, since they are no more variable. However, a paired t-test shows that the overall mean number of woundfin caught per seine unit in the spring (1.011) is significantly different ($p < 0.001$) from that in the fall (1.204), but the magnitude of this difference is small. Therefore, we decided that the inclusion of spring data, as well as fall data, in the analyses provided more information about woundfin population dynamics.

Water Temperature

In 1996 most samples (2,219 out of 2,983) did not have a water temperature recorded, so a regression equation was developed to predict water temperature based on day of the year and time of day. Discharge and river mile were also investigated as possible explanatory variables, but water temperature did not significantly depend on either of these variables, so they were not included. Both a sine function and a linear standardization of the date were tried, with the linear standardization giving the better fit. The equation used was:

$$22.61 - 0.122 * \text{standardized date (days away from August 1)} + 0.475 * \text{hour.}$$

The R^2 value was 0.782. We used this equation to predict temperature for any record in the 2000 version of the database that had no temperature measurements.

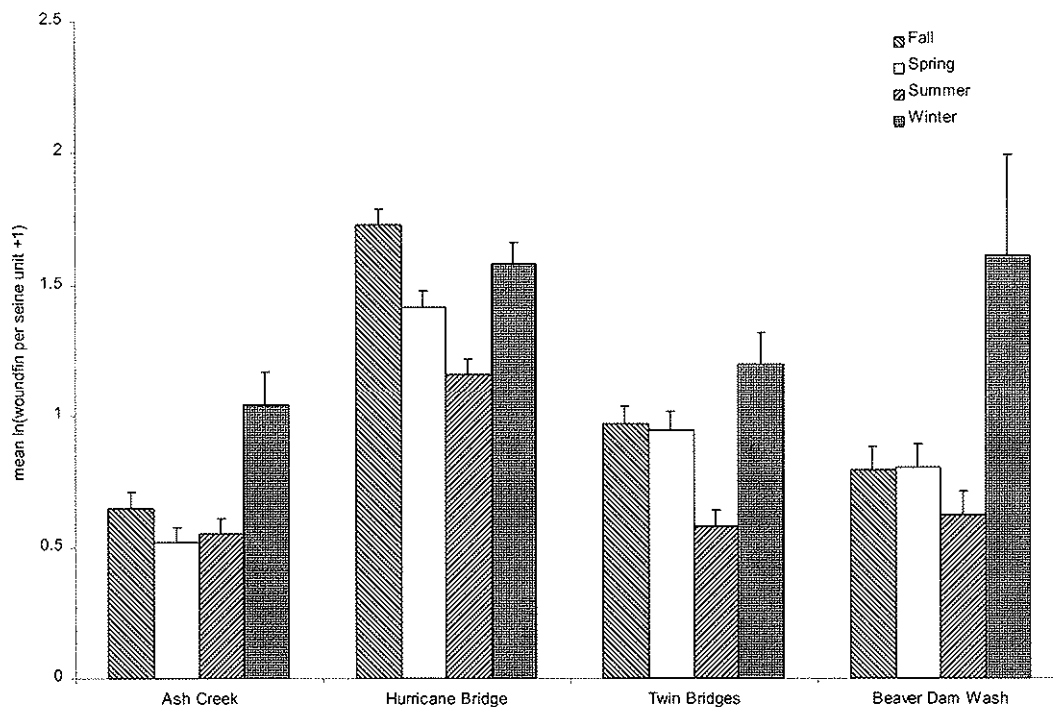


Figure 2. Mean woundfin abundance $\ell_n(\text{woundfin per seine unit} + 1)$ by season at each station. Bars represent one standard error.

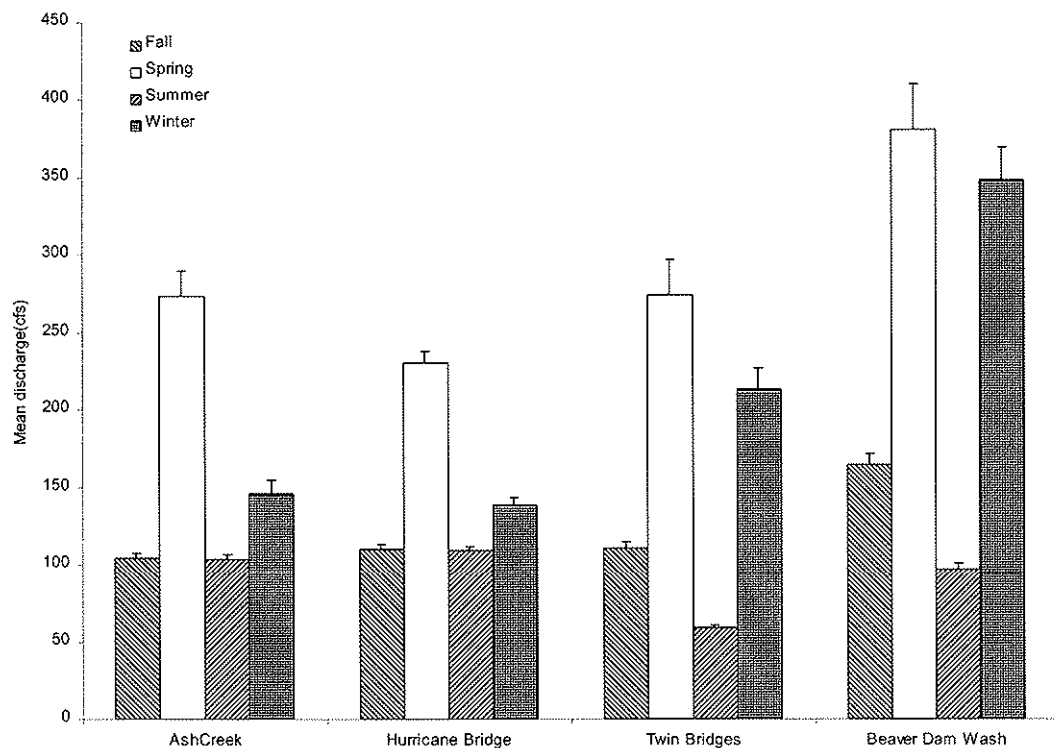


Figure 3. Mean discharge, in cubic feet per second (cfs), on the days woundfin were sampled, by season at each station. Bars represent one standard error.

The relationship between water temperature and woundfin per seine unit was examined using linear regression. There were weak significant positive relationships at all stations and seasons except for Beaver Dam Wash in winter, which had no significant relationship (p ranged from 0.001-0.047). Only Hurricane Bridge in winter ($R^2=0.16$) and Twin Bridges in winter ($R^2=0.10$) had R^2 values over 0.10. Most of the other combinations of stations and seasons R^2 values were 0.05 or lower. By itself, water temperature explains very little of the variation in woundfin abundance. When interpreting these results however, it must be kept in mind that the majority of the values of water temperature are estimates based on time of day and day of the year.

Habitat

We investigated differences between habitat types in woundfin abundances and in variability of woundfin abundances. At each station, ANOVAs were performed to test whether habitat types differed in ℓ_n (woundfin per seine unit). ANOVAs were also performed in each season at each station. Since there were several uncommon habitat types that may have been inflating the variability, we also performed the aforementioned analyses using only samples from the primary habitat types, riffles, runs, and pools. (These habitats accounted for 4,387 of the 4,847 samples.) ANOVAs testing differences between habitat types for each station in each season were also performed excluding samples in which no woundfin were caught. Variability in woundfin per seine unit was compared using data from all habitat types, riffles, runs, and pools, and runs only. We also compared variability in woundfin per seine unit within each habitat type.

There were significant differences between habitats in ℓ_n (woundfin per seine unit) at Ash Creek, Hurricane Bridge, and Twin Bridges (all p -values < 0.001, Figure 4), but habitats did not significantly differ in woundfin abundance at Beaver Dam Wash ($p = 0.49$, Figure 4). When the data were broken into seasons, the results were not as clear. Only at Hurricane Bridge were there differences between habitats in all seasons. In fall habitats differed only at Hurricane Bridge. Conversely, in the spring, habitats differed at all stations, except for Beaver Dam Wash. In winter all stations showed significant differences between habitats.

Using only data collected at riffles, runs, and pools ($N = 4387$) produced similar results. At Ash Creek and Hurricane Bridge there were significant differences between habitats in ℓ_n (woundfin per seine unit, $p < .0001$ at both stations, Figure 5), but habitats did not differ in woundfin per seine unit at Beaver Dam Wash ($p = 0.365$) or Twin Bridges ($p = 0.100$, Figure 5). Tukey pairwise multiple comparisons (Zar 1984) were performed to compare differences between individual habitat types using a 0.05 significance level. At both Ash Creek and Hurricane Bridge, runs had significantly more woundfin than riffles. At Ash Creek pools had significantly fewer woundfin than runs and did not differ from riffles, whereas at Hurricane Bridge pools did not significantly differ from runs and had more woundfin than riffles. There were no consistent patterns among seasons.

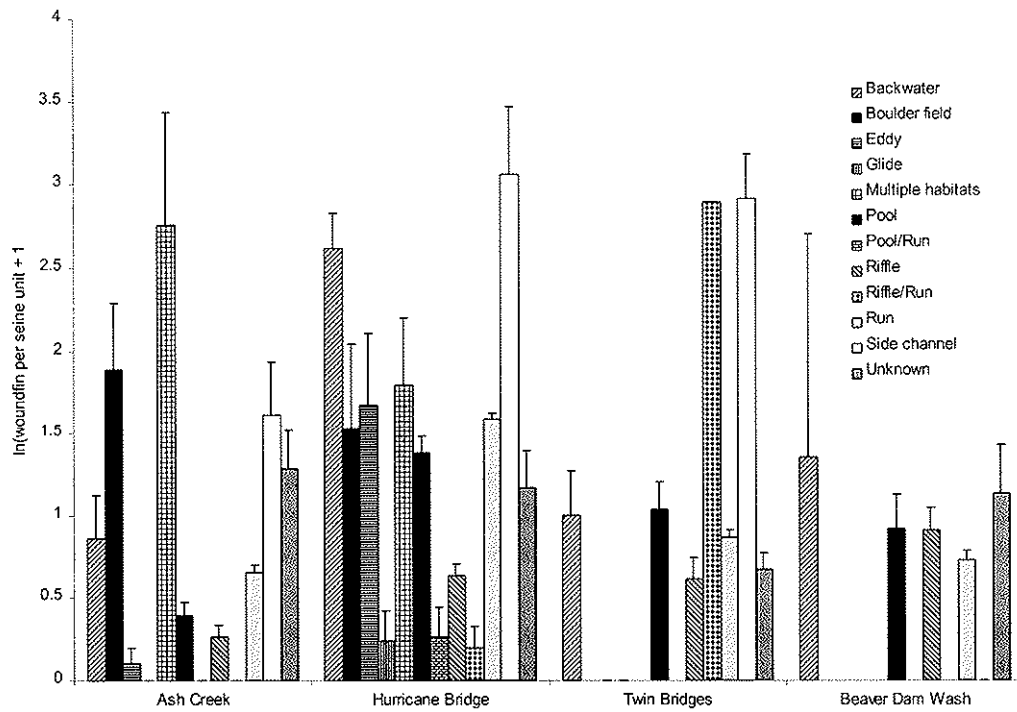


Figure 4. Mean woundfin abundance $\ell_n(\text{woundfin per seine unit} + 1)$ by habitat type at each station. Not all habitats were sampled at all stations.

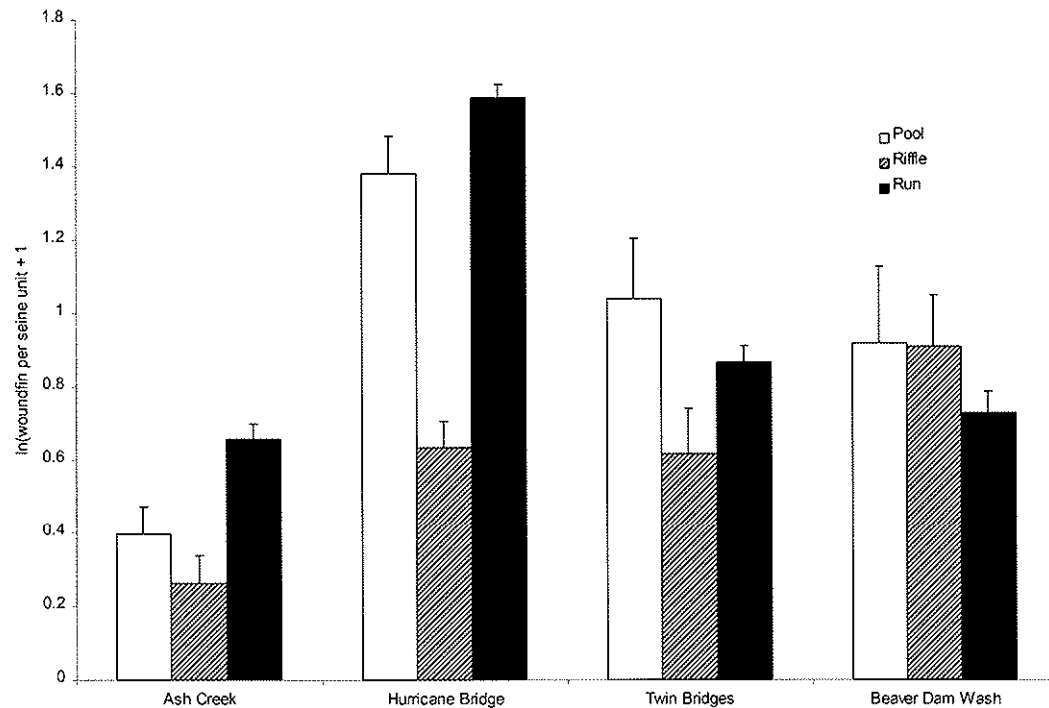


Figure 5. Mean woundfin abundance $\ell_n(\text{woundfin per seine unit} + 1)$ by habitat type at each station, using only data from pools, riffles, and runs. Bars represent one standard error.

Variability in the number of woundfin per seine unit using data from all habitats was compared to the variability using data from runs only and from runs, riffles, and pools. Hardy et al. (1989) suggested that including other habitat types increased variability. Combining all stations and seasons, the CV was 129.81 using data from all habitats, 129.5 from runs, riffles, and pools, and 123.8 from runs only. The reduction in CV by excluding all habitats other than runs is slight (less than 5%). Table 3 gives the CVs by station using all habitats, riffles, runs and pools, and runs only. The mean (of the four stations) reduction in CV by excluding data from habitats other than runs was 3.86 or 2.62%.

Table 3. Coefficient of variation (CV), standard deviation (SD), mean, and number of observations (N) of ℓ_n (woundfin per seine unit +1) for each station in each season using data from all habitats, from pools, riffles, and runs, and from runs only.

STATION	DATA SET	N	Mean	SD	CV
Ash Creek	all habitats	1,011	0.627535	1.072846	170.9621
	riffles, runs, and pools	857	0.587747	1.018896	173.3563
	runs only	650	0.664547	1.072553	161.3961
Beaver Dam Wash	all habitats	634	0.785032	1.339391	170.6163
	riffles, runs, and pools	570	0.781351	1.308594	167.4784
	runs only	446	0.744753	1.306713	175.4558
Hurricane Bridge	all habitats	2,083	1.459486	1.466665	100.4919
	riffles, runs, and pools	1,931	1.475637	1.467945	99.47874
	runs only	1,514	1.602394	1.474667	92.02902
Twin Bridges	all habitats	1,119	0.866276	1.267433	146.3083
	riffles, runs, and pools	958	0.865313	1.269501	146.7100
	runs only	798	0.873623	1.258534	144.0591

Variability of runs was compared with other habitats using CVs of the number of woundfin caught per seine unit (combining stations and seasons). Coefficients of variation from different habitats varied from 58.7 to 383.9, but much of the variation in CVs was in unusual habitats that were not sampled very often (Table 4). The primary habitat types had the following CVs: pool - 137.97, riffle - 174.9, and run - 123.8. The overall CV for runs was lower than for pools (10.2%) and substantially lower than for riffles (29.2%). However, since variability is inversely related to sample size, the much greater number of runs sampled (3,468, compared with 460 riffles and 459 pools) may partly explain the lower CV in runs.

Table 4. Coefficient of variation (CV), standard deviation (SD), mean, and number of observations (N) of ℓ_n (woundfin per seine unit +1) for each habitat type.

Habitat	N	Mean	SD	CV
Run	3,468	1.125941	1.39372	123.7826
Riffle	460	0.598699	1.047334	174.935
Pool	459	1.016545	1.402533	137.9706
Backwater	67	1.560392	1.462908	93.75256
Eddy	29	0.842761	1.401828	166.3376
Side channel	43	2.387907	1.402159	58.71917
Glide	27	0.12597	0.483592	383.8939
Multiple habitats	5	1.82	1.255129	68.96316
Boulder fields	12	1.794167	1.112331	61.9971
Pool/run	20	0.103972	0.339199	326.2403
Riffle/run	12	0.356127	0.841475	236.2855
Unknown	234	0.952178	1.390253	146.0077
Other	11	0	0	NA ^a

^aNA = not applicable.

In summary, data from runs are less variable (in number of woundfin per seine unit) than data from all habitats, but including data from other habitats does not substantially affect the overall variability. The greater sample size (4,847 vs. 3,468) using data from all habitats may have partially offset the effects of adding more variability. Since variability does not change much by including other habitats, our analyses of the dataset includes data from all habitats.

Discharge

We investigated the relationship between woundfin per seine unit and discharge using two approaches. First, we examined the relationship between woundfin per seine unit and discharge on the day of the sample. Then we compared yearly mean, maximum, and minimum discharges to yearly mean woundfin per seine unit. We used discharge measurements from the USGS gage at Littlefield, Arizona (Gage#09415000) because it had the longest and most-consistent period of record of all the potential gages.

When all samples of ℓ_n (woundfin per seine unit) were regressed on ℓ_n (discharge on day of sampling) at each station in each season, there was a consistent pattern of more woundfin caught at higher discharges during spring and summer. With the exception of Twin Bridges in the spring and Ash Creek in the summer, regressions at each station in spring and summer of ℓ_n (woundfin) on $\ell_n(Q)$ were highly significant (all p-values were < 0.01). However, $\ell_n(Q)$ explained only a small amount of the variation in ℓ_n (woundfin). In the fall, both Ash Creek and Hurricane Bridge showed a significant positive relationship between woundfin and discharge ($p = 0.010$). However, virtually none of the variability in woundfin abundance appeared to be explained by these relationships ($R^2 = 0.026$ and 0.016 , respectively). Winter samples produced mixed results. At Ash Creek and

Hurricane Bridge, there were significant relationships ($p = 0.005$, $R^2 = 0.124$ and 0.035 , respectively), but there was no relationship at either Twin Bridges or Beaver Dam Wash in winter.

Using data from the Littlefield gage, we found no consistent, significant relationship between yearly mean woundfin abundance and yearly mean discharge, yearly maximum discharge, or yearly minimum discharge for all statistics as a whole. However, at Hurricane Bridge yearly mean woundfin abundance was significantly positively related to yearly minimum and yearly mean discharge ($p < 0.05$). When we regressed mean woundfin abundance at Hurricane Bridge against both yearly minimum and yearly mean discharge, it explained over 25% of the variation in woundfin abundance ($R^2 = 0.285$), the least-disturbed woundfin population. The relationship between discharge and woundfin abundance may be temporally offset. We did not compare woundfin abundances to any precedent discharges, but Hardy et al. (1989) did and found no significant relationships for the times he examined.

Since woundfin abundance at Hurricane Bridge seemed related to certain discharge parameters, we decided to examine the effects of discharge on woundfin abundance more closely. We obtained flow records from USGS gage 09408150 (Virgin River near Hurricane, Utah) and gage 09431200 (Virgin River near Bloomington, Utah) in addition to the records we already had for gage 09415000 (Virgin River near Littlefield, Arizona). The flow records for the Hurricane (1968-88 and 1990-99) and Bloomington (1978-1999) gages were not nearly as extensive as the Littlefield gage (1930-1999). However, data from the Hurricane gage were much more likely to be representative of the flow conditions at the Hurricane Bridge station and possibly the Ash Creek station, and data from the Bloomington gage more-closely approximated flow conditions at the Twin Bridges station. We calculated 50% exceedence flow, summer 50% exceedence flow, peak flow, spring peak flow, and spring 7 day maximum flow for at each gage for the years 1976-1999. We substituted flow data from Hurricane gage for the Twin Bridges station in 1976-77.

We used a backwards stepwise regression in SYSTAT to build a regression model for woundfin abundance at each of the stations using the five discharge variables mentioned above. When performing multiple linear regression in SYSTAT eigenvalues for the x matrix, condition indices, and variance proportions are provided with the analysis, so that redundancy and collinearity of the x variables can be judged easily. As one would expect, the three peak variables were fairly collinear, as were the two 50% exceedence variables. Therefore, we tried to use only one variable from each of these sets.

When we regressed fall woundfin abundance at Ash Creek against the five flow variables generated from the Hurricane gage, we generated a regression model containing peak daily discharge and 50% exceedence flow ($R^2 = 0.207$, $p = 0.038$). Spring woundfin abundance at Ash Creek was best explained by a regression model including peak daily discharge and summer 50% exceedence flow from the Hurricane gage ($R^2 = 0.415$, $p = 0.002$). In both cases, peak daily discharge was the most significant variable.

Fall woundfin abundance at Hurricane Bridge was best explained by a regression model containing peak daily discharge and the spring 7-day maximum discharge as measured at the Hurricane gage ($R^2 = 0.435$, $p = 0.004$). The 7-day spring maximum was slightly more significant to the model. Although these two variables showed some evidence of collinearity, removal of either variable substantially lowered the correlation coefficient. Spring woundfin abundance at Hurricane Bridge was explained using a model containing peak daily discharge and 50% exceedence flow from the Hurricane gage ($R^2 = 0.454$, $p = 0.002$). The 50% exceedence flow was the most-significant variable.

When we regressed fall woundfin abundance at Twin Bridges against the five flow variables generated from the Bloomington gage flow data, we created a regression model containing only the 50% exceedence flow ($R^2 = 0.43$, $p = 0.001$). Spring woundfin abundance at Twin Bridges was best explained by summer 50% exceedence flow, 50% exceedence flow, and spring 7-day maximum flow ($R^2 = 0.495$, $p = 0.001$). Summer 50% exceedence flow was the most-significant variable. Summer 50% exceedence flow and 50% exceedence flow did not exhibit a high degree of collinearity, and removing either from the model substantially reduced the correlation coefficient.

Finally, we regressed fall and spring woundfin abundance at Beaver Dam Wash against the five-flow variable generated from the Littlefield gage. We found that both fall and spring woundfin abundance were best explained by spring peak daily discharge and summer 50% exceedence flow. However, the regression model was only significant for the spring ($R^2 = 0.255$, $p = 0.018$).

The models produced for the Hurricane Bridge and Twin Bridges stations explained over 40% of the variability in both spring and fall woundfin abundance. The models at the other two stations did not do quite as well. We saw that both peak flows and average (base) flows seemed to be important in explaining variability in woundfin abundance.

Summary

In summary, a large number of statistical analyses were performed on the woundfin data to determine what factors may explain the variability in the data. We concluded that first pass and seine unit data are very similar and could be used interchangeably. We also concluded that relationships between woundfin abundance (seine unit) and season, water temperature, and habitat occur, but that these factors do not explain most of the variability that occurs from year to year in the data. We did find a relatively large amount of variability in woundfin abundance was accounted for by certain discharge parameters. Therefore, we thought we should further investigate the influence of different levels of flow on woundfin abundance, after we examined any trends apparent in the data.

Ecological Analyses

The next step in our analyses of this dataset was to investigate differences in woundfin abundances between years and explore potential causal mechanisms. Our basic dataset used woundfin per seine unit from all habitat types at the four primary stations (Ash Creek, Hurricane Bridge, Twin Bridges, and Beaver Dam Wash) in spring and fall. In order to make the data set more complete, we utilized data from close sites and dates to supplement missing collections. At Ash Creek, we substituted June collections for missing spring collections in 1976, 1977, 1982, 1993 (July), and 1998. Additionally, the fall collections from 1980-1982 and the 1981 spring collection came from river mile 95.96 (above LaVerkin Creek). At Hurricane Bridge we used a July collection in 1993 and a June collection in 1998 to substitute for missing spring collections, and a November 1999 collection was substituted for a missing fall collection. We utilized June collections in 1976, 1977, 1992, and a 1998 July collection in exchange for missing spring collections in those years at Twin Bridges. We also used data collected at river mile 74.37 (above Johnson Diversion) in fall 1988, river mile 69.11 (I-15 Bridge) in fall 1991, and river mile 72.33 (Twin Bridges at return ditch) in spring 1993 to represent Twin Bridges. Finally, we used June collections from 1976 and 1977, and July collections from 1993, 1997, and 1998 at Beaver Dam Wash to substitute for missing spring collections in these years. We believe that these substitutions helped create a more-complete dataset without adding undue variation.

Differences Between Years in Woundfin Abundance

Woundfin abundances significantly differed between years at all stations (Table 5). Post-hoc pairwise comparisons (Tukey tests) between individual years were performed, but they were not very useful because they were unable to clearly separate groups of high years from low years. This was at least partly because of the high number of pairwise comparisons between years (up to 24 years or 276 pairwise comparisons). Cluster analysis was useful to group years into high, moderate, and low woundfin abundances, but it does not incorporate the variability within years, and cannot reliably test the significance of between-year differences. Figures 6 and 7 give woundfin abundances and cluster assignments for the primary four stations for spring and fall. (Figures 8 through 10 provide woundfin abundances and cluster assignments for other stations.) Overall ANOVAs testing whether or not number of woundfin depends on year were highly significant at all stations in both spring and fall (Table 5). Differences between years appear to be statistically meaningful, and due to more than just random sampling variation.

Based on the above described analyses, Figures 6-10 provide a baseline of how woundfin populations have changed over the past 20 years. We feel this baseline can be used for additional analyses. Although some statistically significant differences may be found within one of the clusters between years, our analyses indicate the differences between clusters are strong and provide the best way to compare years.

Table 5. Results of ANOVAs testing overall differences in ℓ_n (woundfin in first pass + 1) and ℓ_n (woundfin per seine unit + 1) between years at each station in each season.

STATION	SEASON	VARIABLE	N	F-VALUE	P-VALUE
Ash Creek	Fall	ℓ_n (first pass)	329	8.432	< 0.001
Ash Creek	Fall	ℓ_n (seine unit)	329	9.506	< 0.001
Ash Creek	Spring	ℓ_n (first pass)	276	17.061	< 0.001
Ash Creek	Spring	ℓ_n (seine unit)	276	20.007	< 0.001
Beaver Dam Wash	Fall	ℓ_n (first pass)	230	16.085	< 0.001
Beaver Dam Wash	Fall	ℓ_n (seine unit)	230	19.135	< 0.001
Beaver Dam Wash	Spring	ℓ_n (first pass)	234	11.013	< 0.001
Beaver Dam Wash	Spring	ℓ_n (seine unit)	234	12.414	< 0.001
Hurricane Bridge	Fall	ℓ_n (first pass)	714	22.216	< 0.001
Hurricane Bridge	Fall	ℓ_n (seine unit)	714	22.879	< 0.001
Hurricane Bridge	Spring	ℓ_n (first pass)	507	19.432	< 0.001
Hurricane Bridge	Spring	ℓ_n (seine unit)	507	24.114	< 0.001
Twin Bridges	Fall	ℓ_n (first pass)	392	22.683	< 0.001
Twin Bridges	Fall	ℓ_n (seine unit)	392	23.812	< 0.001
Twin Bridges	Spring	ℓ_n (first pass)	282	16.710	< 0.001
Twin Bridges	Spring	ℓ_n (seine unit)	282	18.618	< 0.001

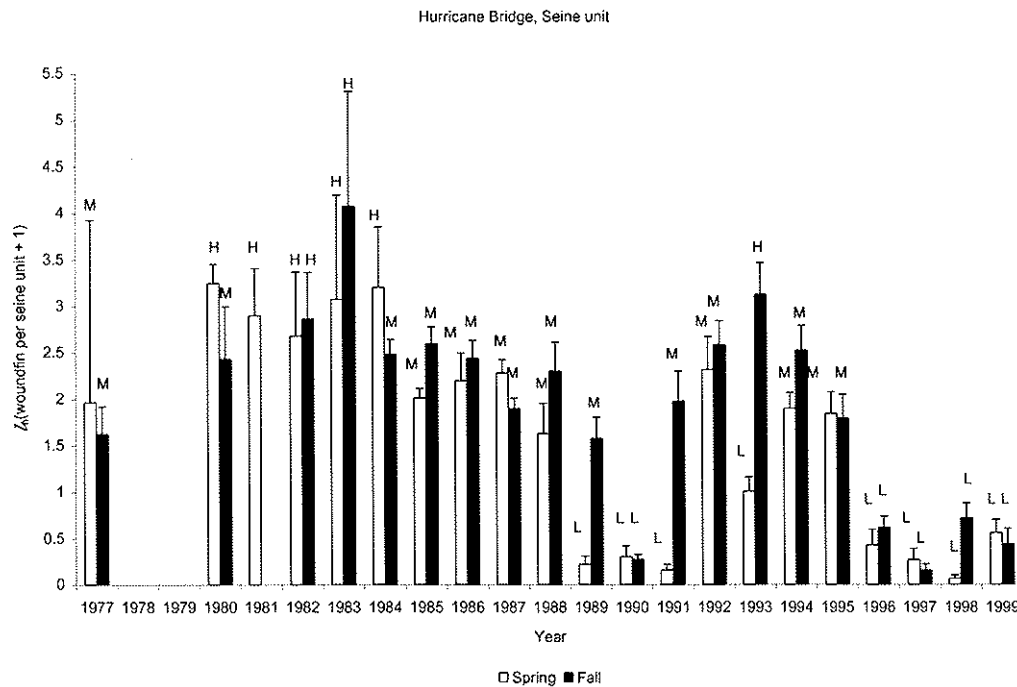
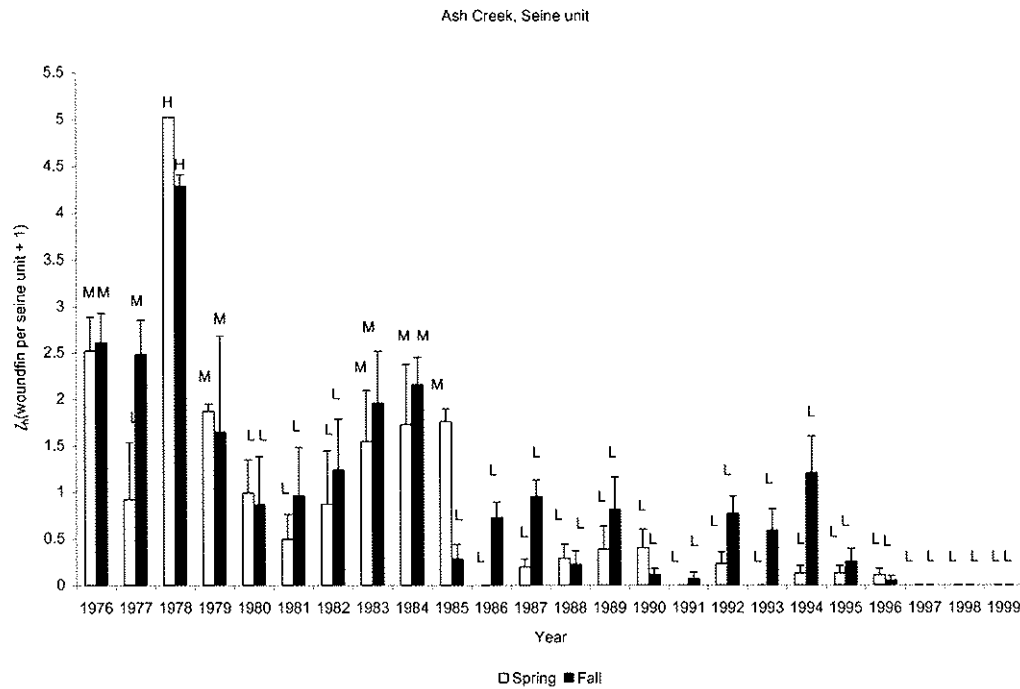


Figure 6a and b. Mean woundfin abundance λ_n (woundfin per seine unit +1) by year at (a) Ash Creek and (b) Hurricane Bridge. Labels above bars represent cluster assignments (H=high, M=moderate, L=low). Bars represent standard error.

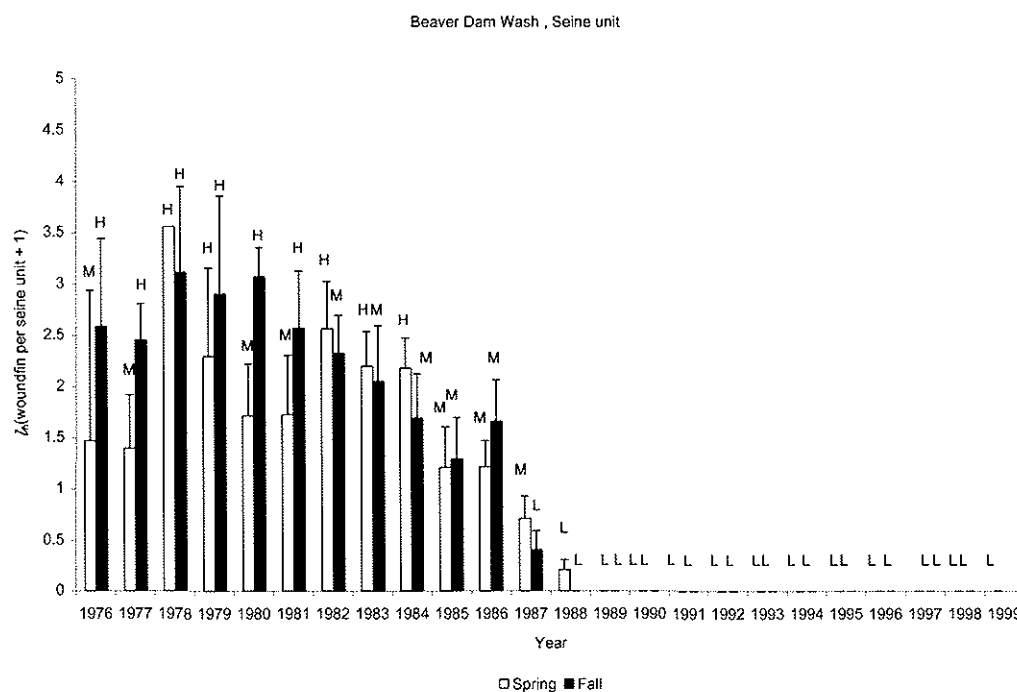
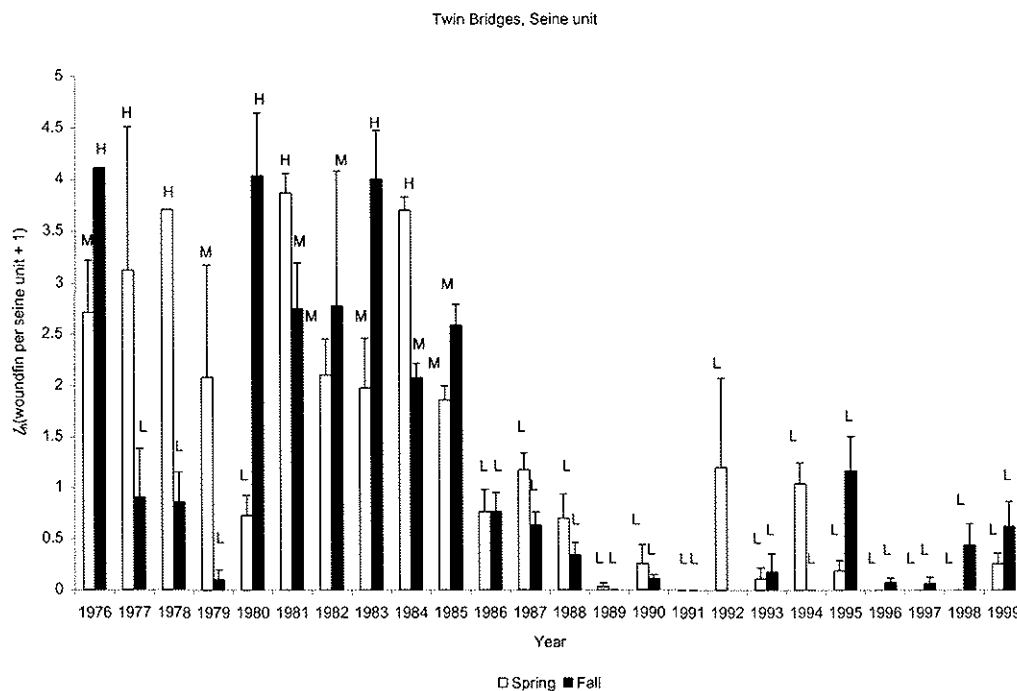


Figure 7a and b. Mean $\ell_n(\text{woundfin per seine unit} + 1)$ by year at (a) Twin Bridges and (b) Beaver Dam Wash. Labels above bars represent cluster assignments (H=high, M=moderate, L=low). Bars represent standard error.

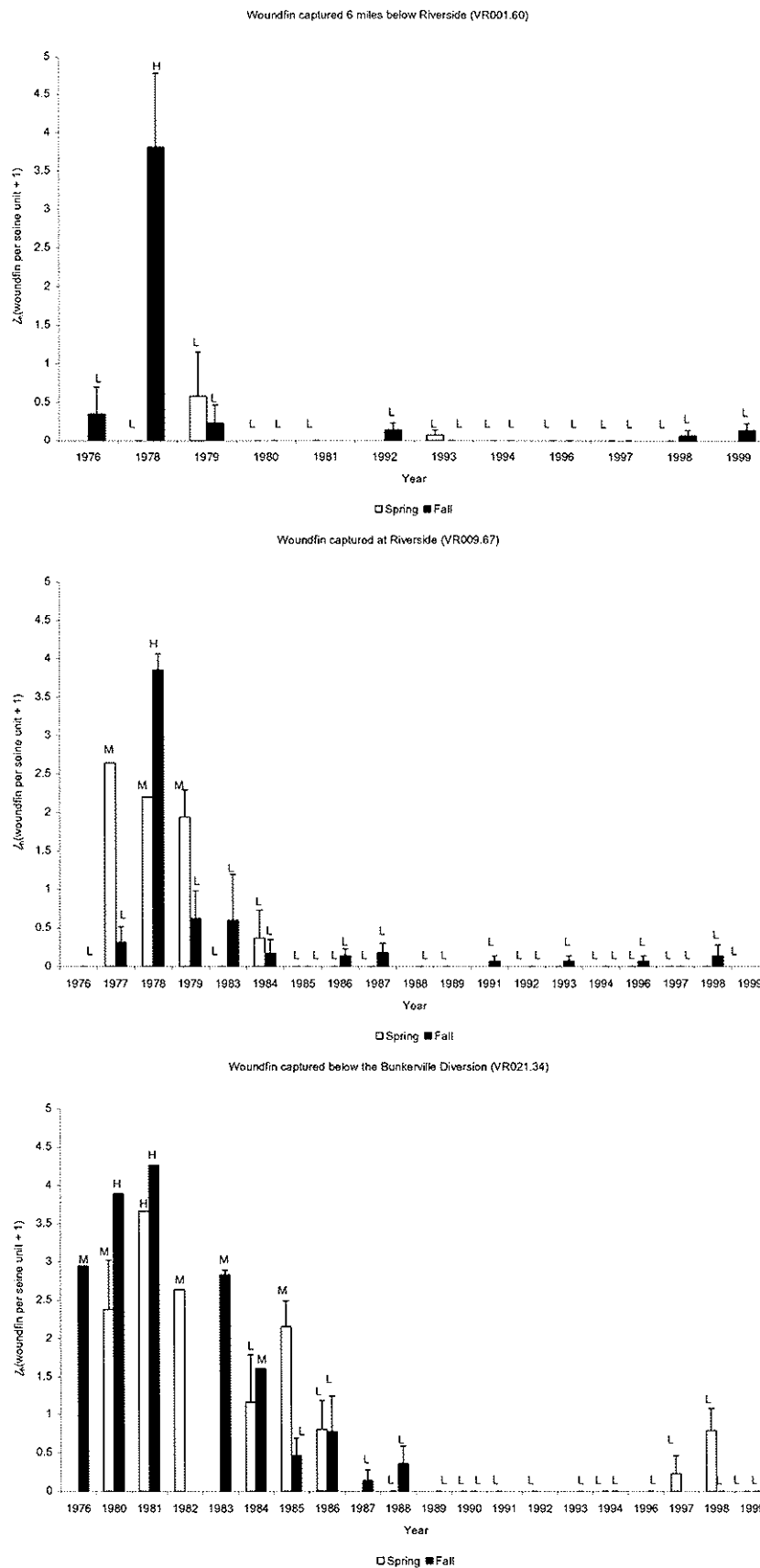
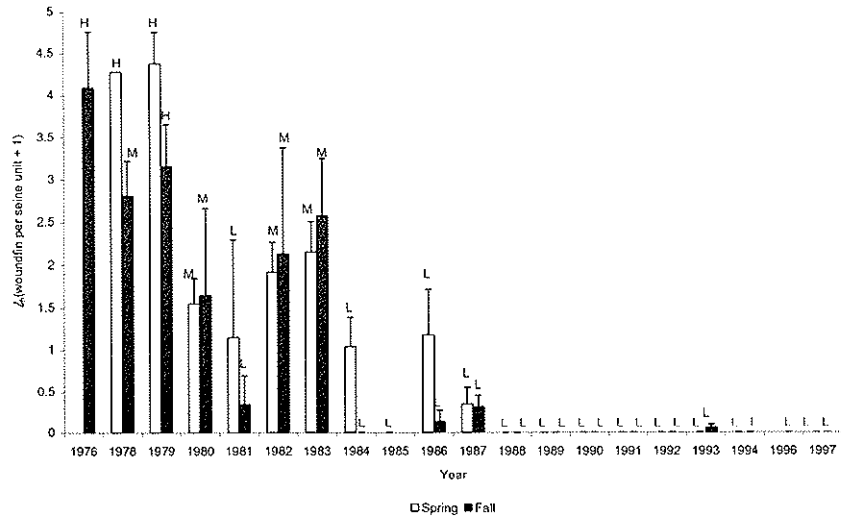
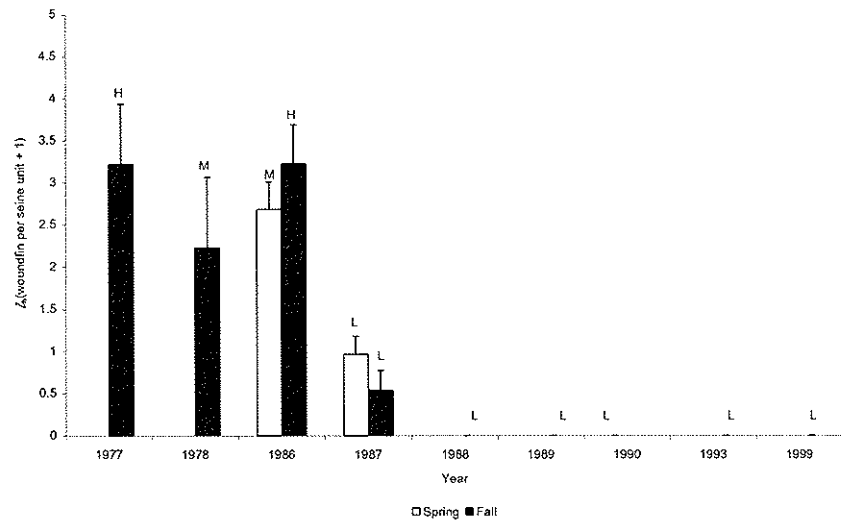


Figure 8. Mean $\ell_n(\text{woundfin per seine unit} + 1)$ by year at other stations from River Mile (RM) 1.60 to 21.34. Labels above bars represent cluster assignments (H=high, M=moderate, L=low). Bars represent standard error.



Woundfin captured at Big Bend (VR026.77 - VR033.52)



Woundfin captured at Cedar Pockets (VR047.05)

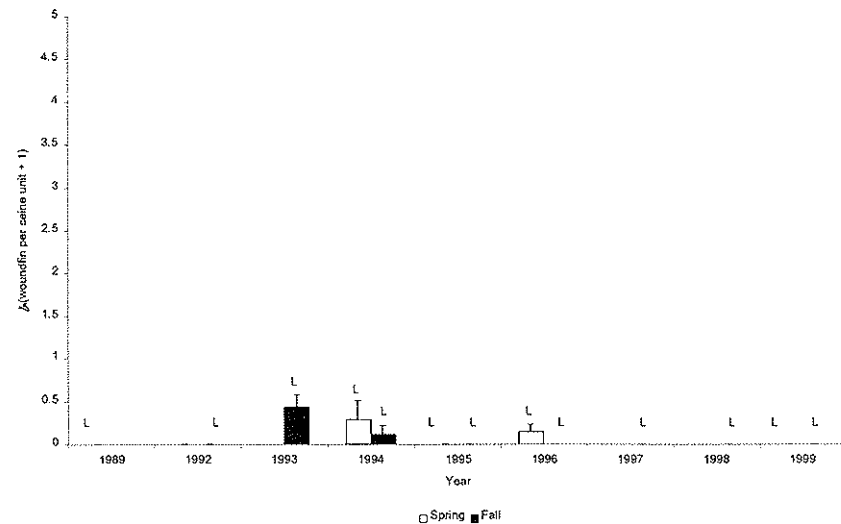


Figure 9. Mean $\ell_n(\text{woundfin per seine unit} + 1)$ by year at other stations from River Mile (RM) 21.36 to 47.05. Labels above bars represent cluster assignments (H=high, M=moderate, L=low). Bars represent standard error.

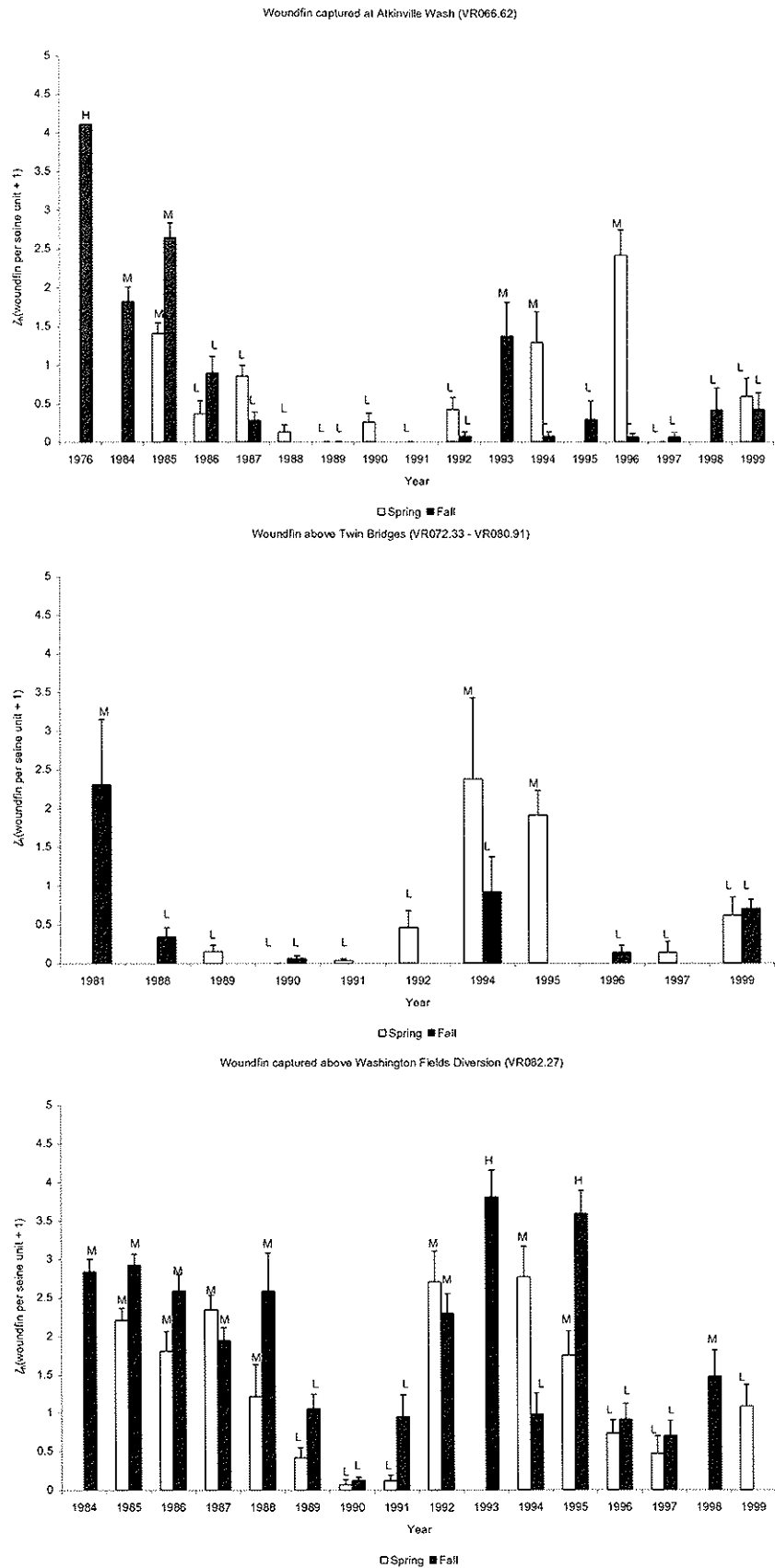


Figure 10. Mean $\bar{\ell}_n$ (woundfin per seine unit +1) by year at other stations from River Mile (RM) 66.62 to 82.27. Labels above bars represent cluster assignments (H=high, M=moderate, L=low). Bars represent standard error.

Trends over the 20-Year Period of Record

The relationship between year and woundfin abundance was further investigated by regressing woundfin per seine unit (in fall and spring) on year at each station. At all stations, we found highly significant, negative relationships between woundfin abundance and year in both fall and spring samples (Figures 11 - 14, $p \leq 0.011$). At Ash Creek and Beaver Dam Wash, there has been a clear decrease in woundfin populations between 1976 and 1999. The regression with year accounted for greater than 47% of the variability in woundfin numbers per seine unit at Ash Creek and greater than 69% of the variability at Beaver Dam Wash. At these stations, there has been a clear decrease in woundfin populations between 1976 and 1999. Red shiner became extremely abundant around Beaver Dam Wash in about 1986-1987, and they have replaced many of the woundfin in that part of the river, which at least partially accounts for the decline over time at this station. Since red shiner are not present at Ash Creek, the decline at this station decline is as not readily explainable. Hardy et al. (1995) showed that increases in the flow of Pah Tempe Hot Springs in 1985 decreased woundfin numbers in that year and 1986 but indicated they rebounded after that time. Figure 6a shows this decline in late 1985 and 1986 but that the population never really rebounded. Another potential explanation is drought, since a drought period occurred in the late 1980s to early 1990s. The effects of Quail Creek Reservoir may also explain the decline in woundfin at Ash Creek. This area of the river is affected by the depletions of Quail Creek, and no minimum flows are available for this reach. The conclusion is that woundfin numbers are clearly lower now than they were in the past at Ash Creek.

At Hurricane Bridge and Twin Bridges, the trends are not quite as strong, especially in the fall. At both stations less than 36% of the fall variability in woundfin numbers was explained by year. Over 62% of the variability in spring woundfin abundance was explained by year at Twin Bridges, and over 53% of the variability in woundfin abundance was accounted for by year at Hurricane Bridge. Hurricane Bridge represents a portion of the Virgin River that is thought by most experts to be the "best" remaining woundfin habitat in the river system and an area that has always been a stronghold for this species. It has been affected by Quail Creek Reservoir depletions but has a minimum flow (86 cfs) that is required by the USFWS. Additionally, red shiner have not invaded this area. At Hurricane Bridge, poor overwinter survival but continued strong recruitment might explain the apparent discrepancy between low woundfin abundances in the spring samples and high woundfin abundances in the fall samples from 1989-1991. Relatively strong years from 1992 - 1995 also prevented a strong linear trend in the Hurricane Bridge data.

At Twin Bridges, fall woundfin abundances were as low during the later years as they were in the spring samples, but there were also some low fall samples in the late 1970s that prevented a significant linear decline over time. A negative relationship would be expected at Twin Bridges, since red shiner became abundant at this site in 1985 and are thought to replace woundfin in such circumstances (Deacon 1988, Gregory and Deacon 1994). Additionally, poisonings to remove red shiner impacted this section of the river in 1988. The Twin Bridges station is not far downstream of Hurricane Bridge and probably receives some woundfin via drift from this productive section of the river. We regressed fall and spring woundfin abundances at Twin Bridges against fall and spring woundfin abundances at Hurricane Bridge to attempt to determine if woundfin abundance at Twin Bridges is partially determined by woundfin abundance at Hurricane Bridge. We found there was a significant positive relationship between spring woundfin abundance at Twin Bridges

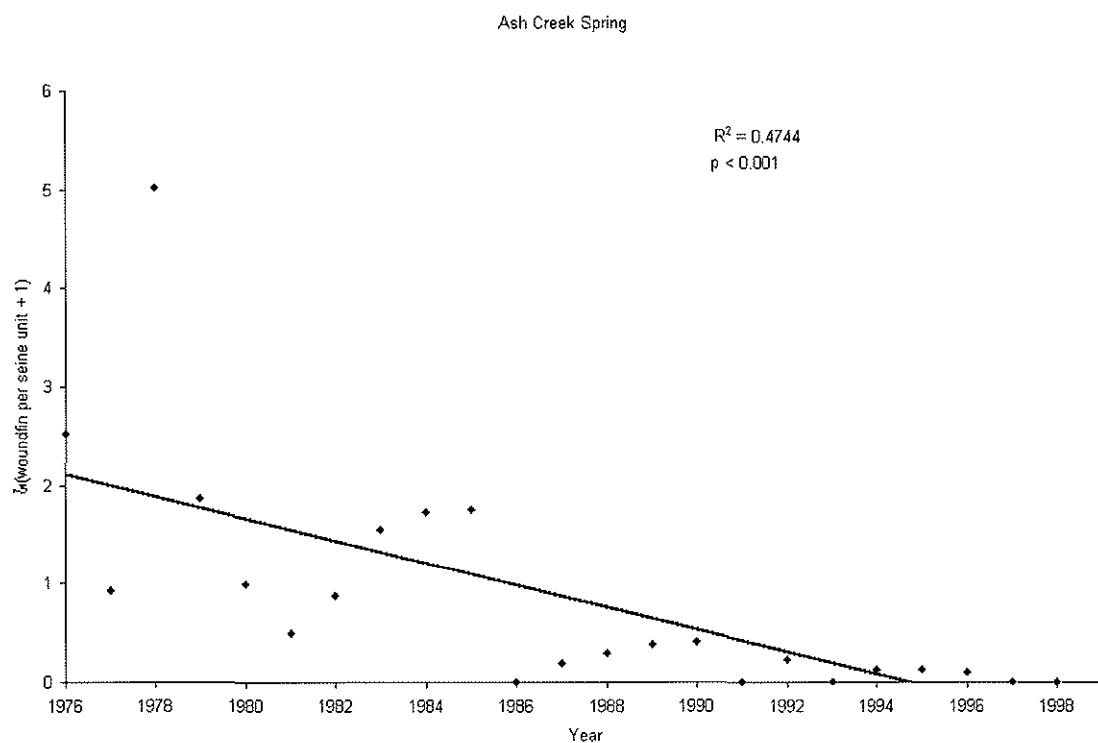
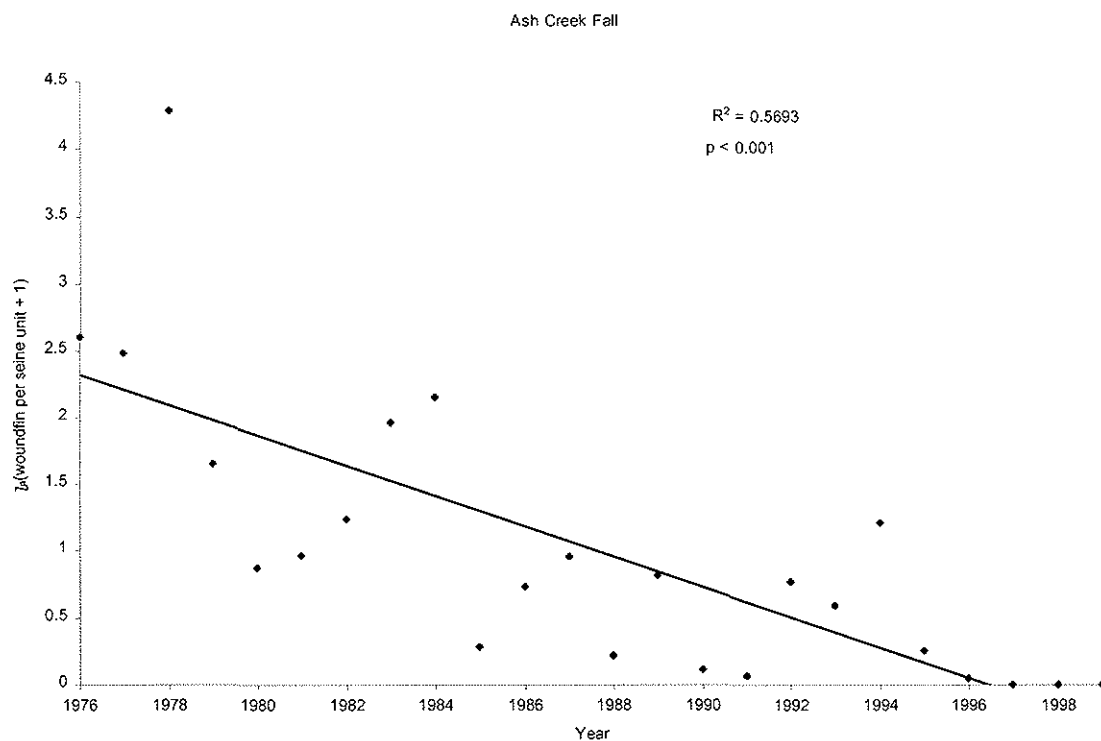


Figure 11. Regression of $\ell_n(\text{woundfin per seine unit} + 1)$ by year at Ash Creek in fall and spring.

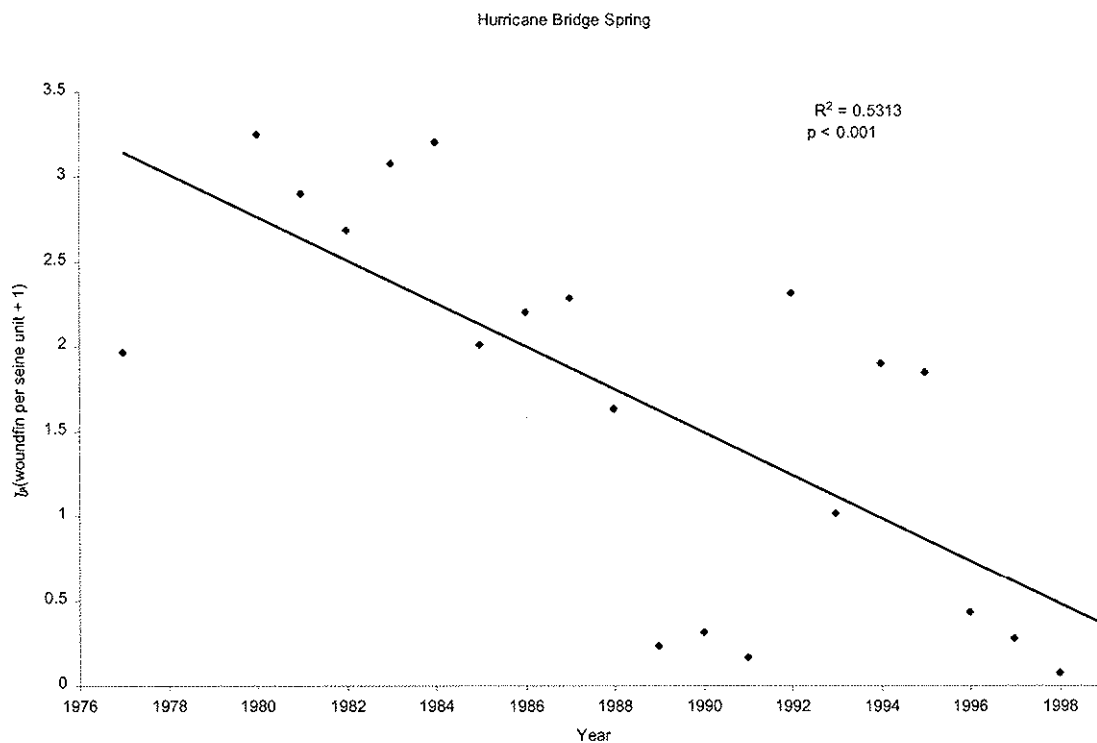
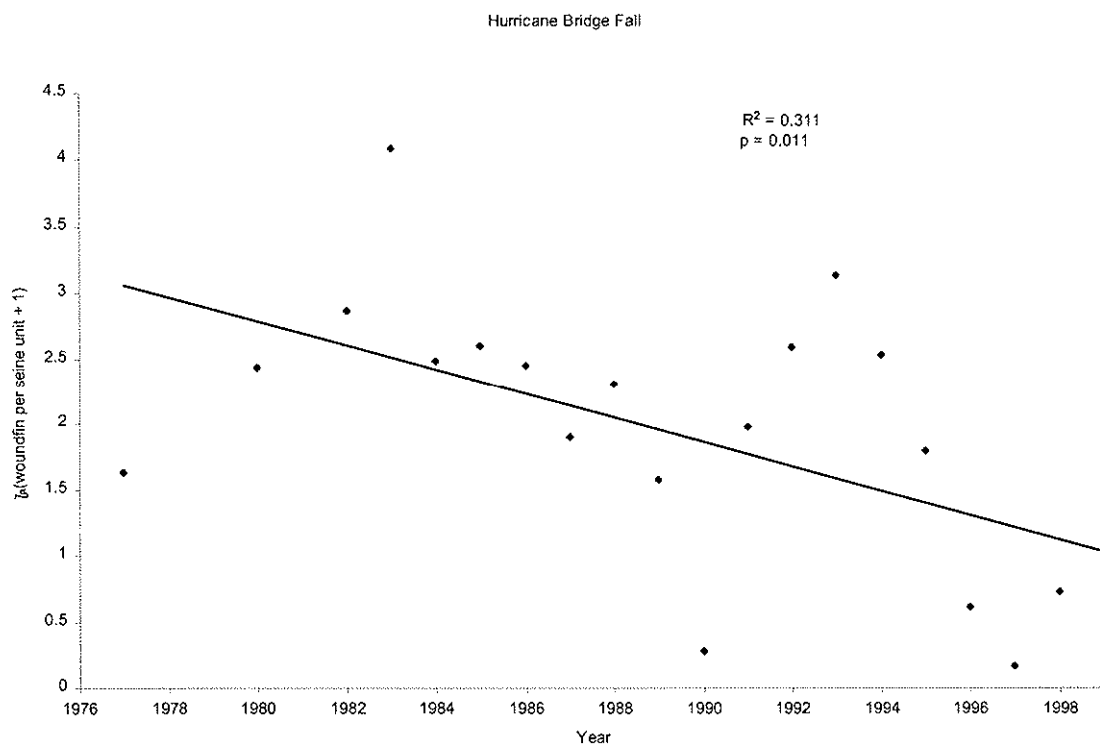


Figure 12. Regression of $\ln(\text{woundfin per seine unit} + 1)$ by year at Hurricane Bridge in fall and spring.

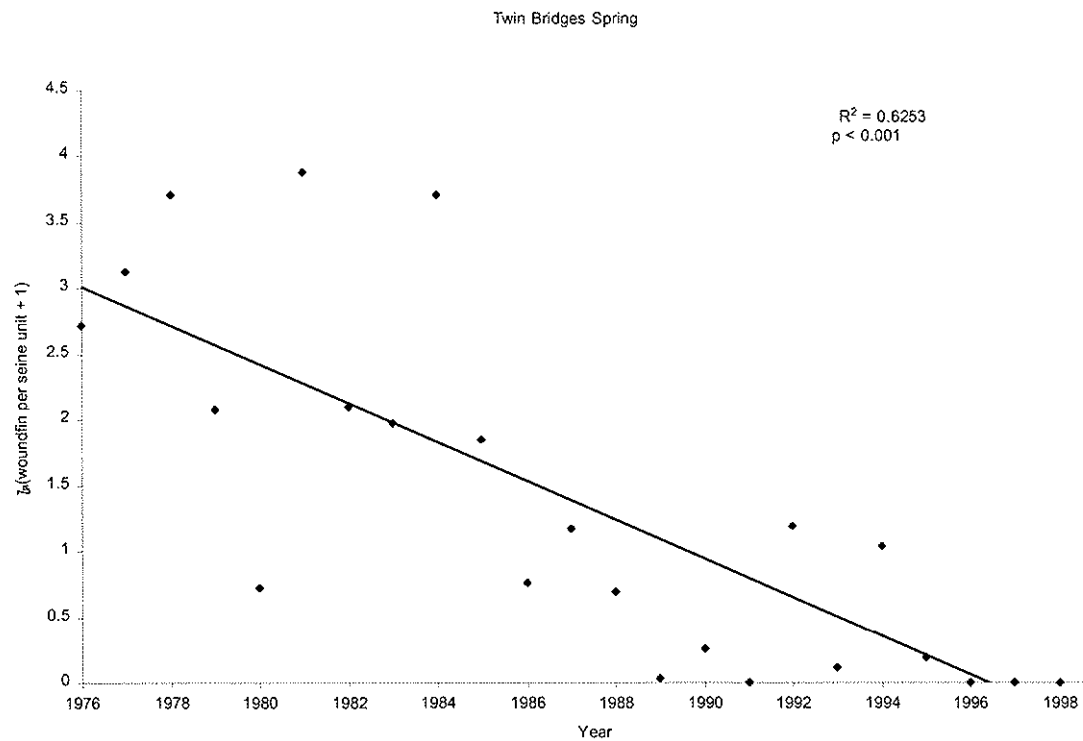
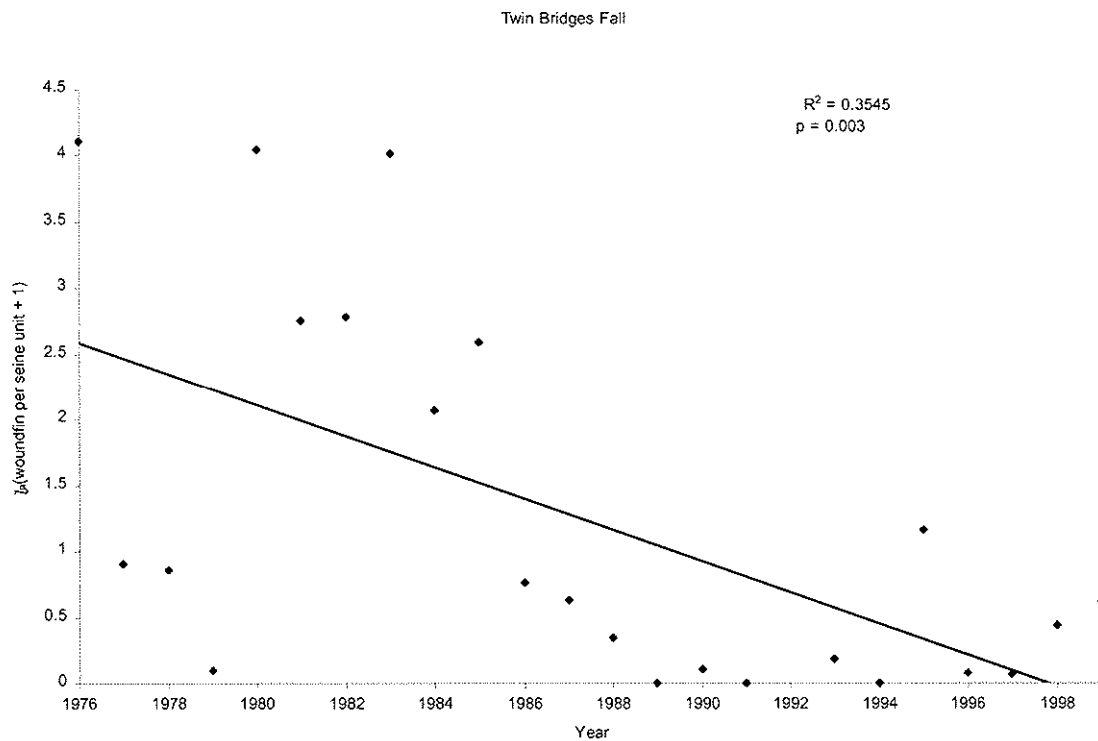


Figure 13. Regression of $\ln(\text{woundfin per seine unit} + 1)$ by year at Twin Bridges in fall and spring.

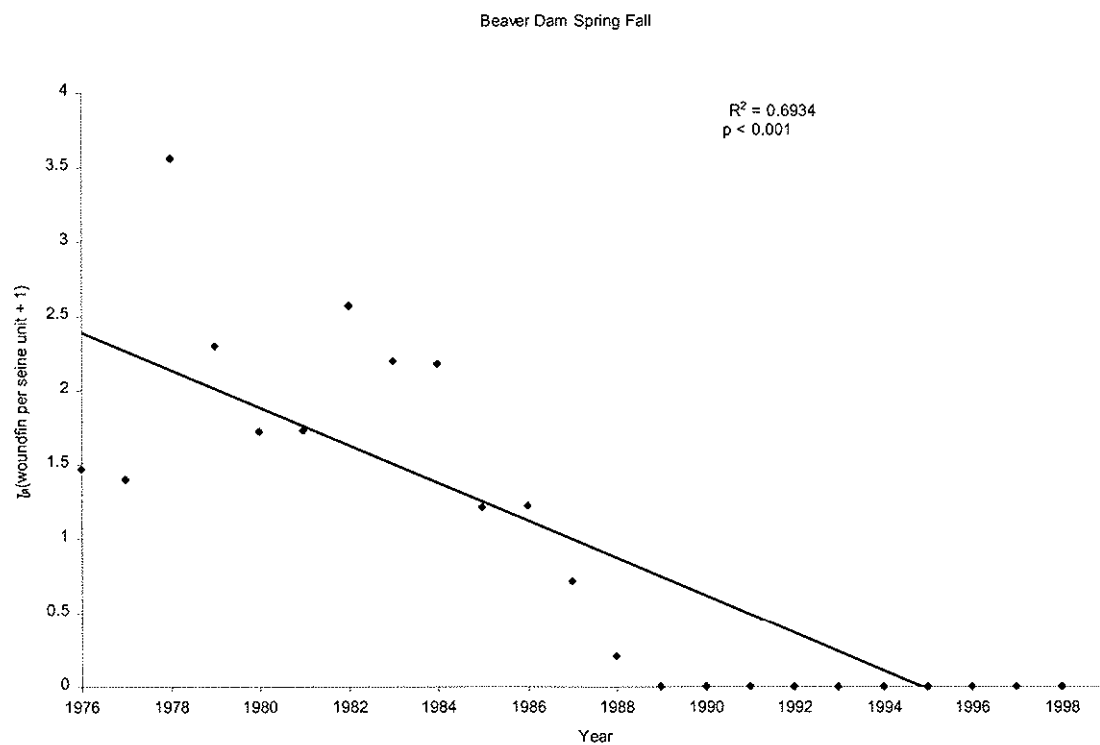
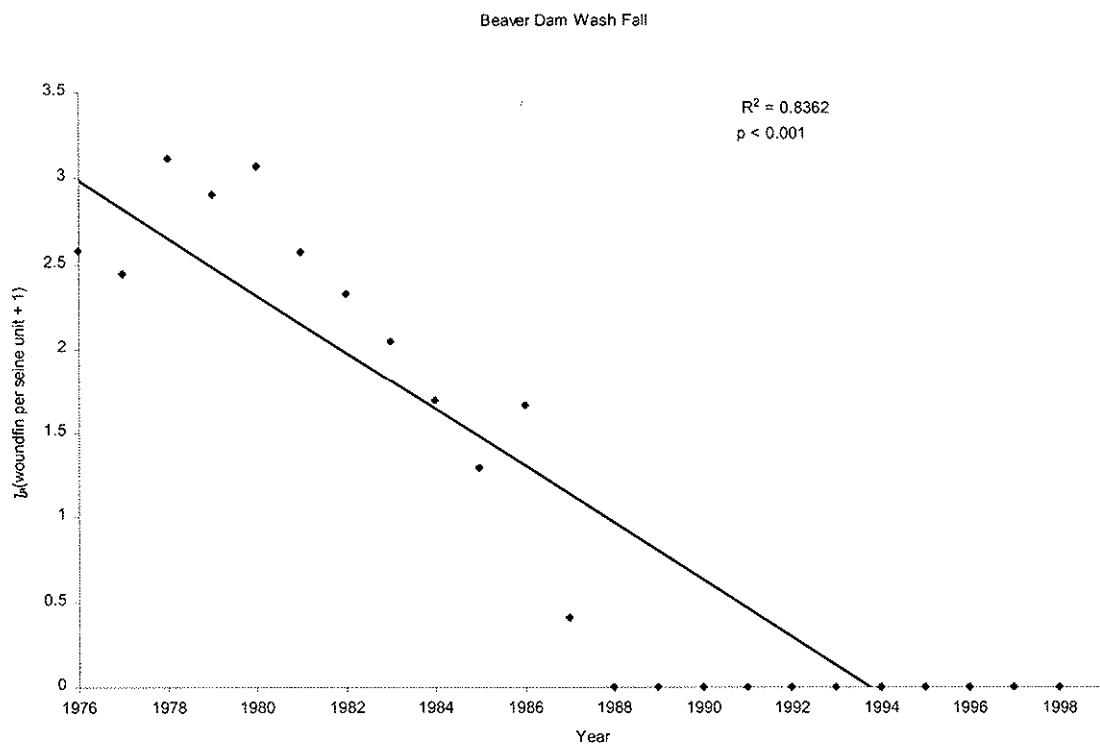


Figure 14. Regression of $\ln(\text{woundfin per seine unit} + 1)$ by year at Beaver Dam Wash in fall and spring.

and spring woundfin abundance at Hurricane Bridge ($R^2 = 0.364$; $p = 0.004$) but not between the fall abundances at the two locations ($R^2 = 0.194$; $p = 0.059$). We also compared spring abundance at Hurricane Bridge with fall abundance at Twin Bridges to determine if there was a lag effect of drift time. We found that spring abundance at Hurricane Bridge had a significant positive relationship with fall abundance at Twin Bridges ($R^2 = 0.344$; $p = 0.007$). Although these positive relationships existed, the amount of variability explained by these relationships was less than the amount explained by the relationship of woundfin abundance to year at Twin Bridges. Additionally, we found significant positive relationships when we regressed woundfin abundance in fall and spring at Hurricane Bridge against woundfin abundance in fall and spring at Ash Creek ($p \leq 0.011$, $R^2 = 0.308$ and 0.397 , respectively). We also found a significant positive relationship when we regressed spring woundfin abundance at Twin Bridges against spring woundfin abundance at Ash Creek ($p < 0.001$, $R^2 = 0.493$). Therefore, it is difficult to decipher whether the stations are influencing each other through drift or if the same climactic and anthropogenic factors are having similar impacts on woundfin populations at all stations. In recent poisoning operations below Washington Fields Diversion, it has been shown (USFWS 1995, Comella and Fridell 1998) that woundfin repopulate the poisoned reach from above the diversion, so downstream drift to Twin Bridges does occur. However, the importance of drift on the size of the woundfin population at Twin Bridges in relation to other variables is unclear.

Year Class Strength

In addition to woundfin abundance, we also attempted to look at recruitment success through year class strength. In order to do this, we looked at size of woundfin in fall samples. By examining histograms of summer and fall samples at each station, we determined (similarly to Deacon and Hardy, 1980 and Deacon and Hardy, 1984) that a good average break point between juveniles and adults in fall samples seemed to be around 55 millimeters (mm) for the upper river. Therefore, we considered any woundfin caught in fall samples at Ash Creek, Hurricane Bridge, and Twin Bridges that was 55 mm or less to be a juvenile spawned that year. In examining histogram from the Beaver Dam Wash area, we saw that it might be more appropriate to use 60 mm as the break point between juvenile and adult woundfin at stations in the lower river.

We used the average length of woundfin in fall samples and the percent of juvenile woundfin in fall samples at each of the four stations as measures of recruitment success in an attempt to determine patterns in year class strength at our 4 stations over the period of record. We performed an ANOVA to determine if either average woundfin length or the percent of juveniles in fall samples differs between years. We found that both average fall length and percent of juveniles in the fall significantly differed between years at all stations (Figures 15-18; $p < 0.001$). We regressed both average woundfin length in the fall and percent of juvenile woundfin in the fall against year to determine if there was a significant trend in year class strength from 1977 to 1999 at any station. None of the regressions were significant, indicating that there was not a trend toward diminishing year class strength over time at any of the four stations. Whatever factors are causing a decline in woundfin populations seem to be impacting both adult and juvenile fish.

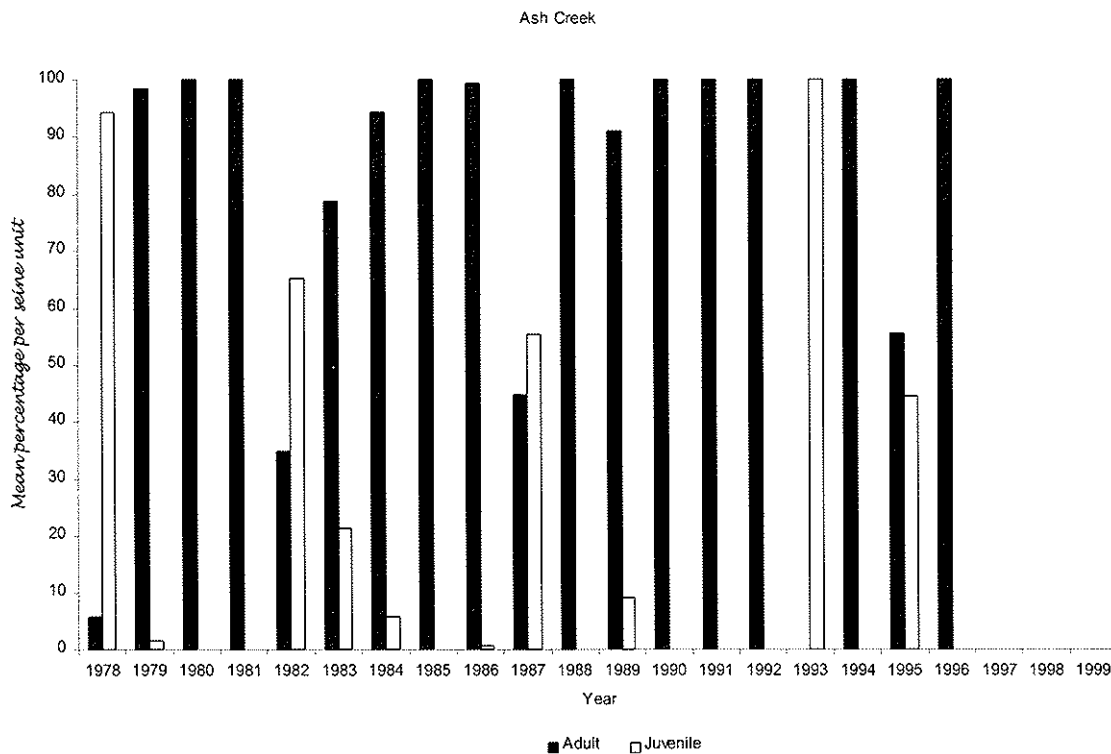
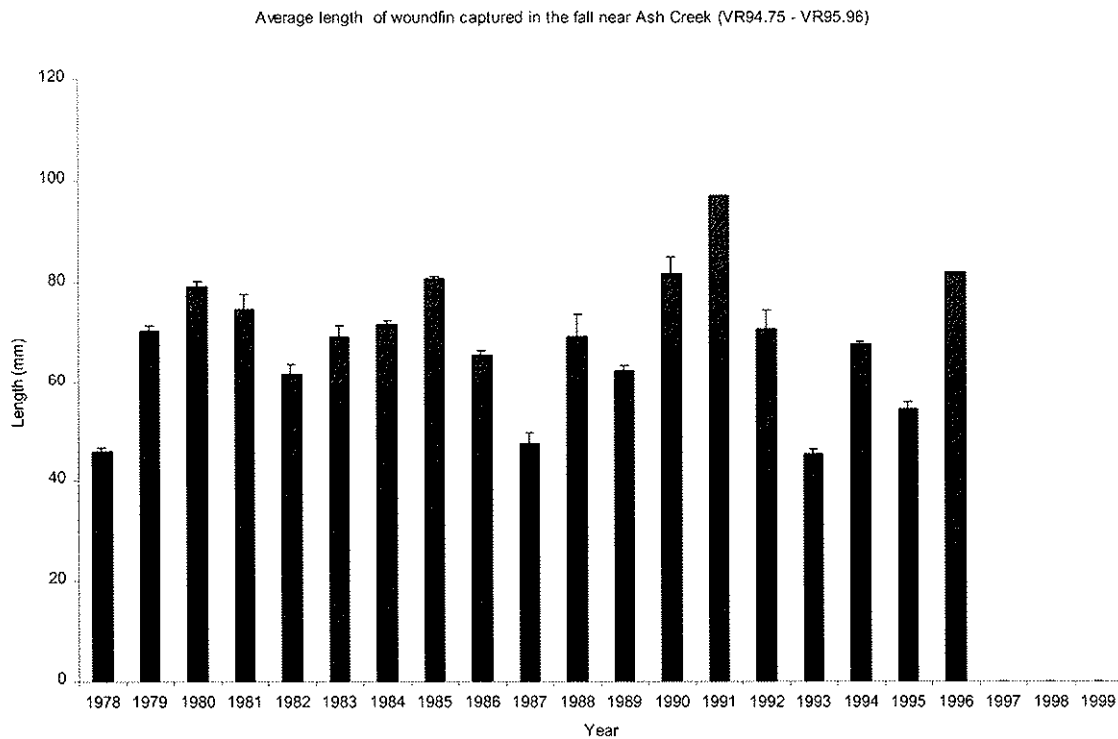


Figure 15a and b. Mean (a) length of woundfin captured in the fall and (b) percent juvenile woundfin in the fall by year at Ash Creek. Bars represent standard error.

Figure 16a Average length of woundfin captured in the fall at Hurricane Bridge (VR84.19 - VR89.19)

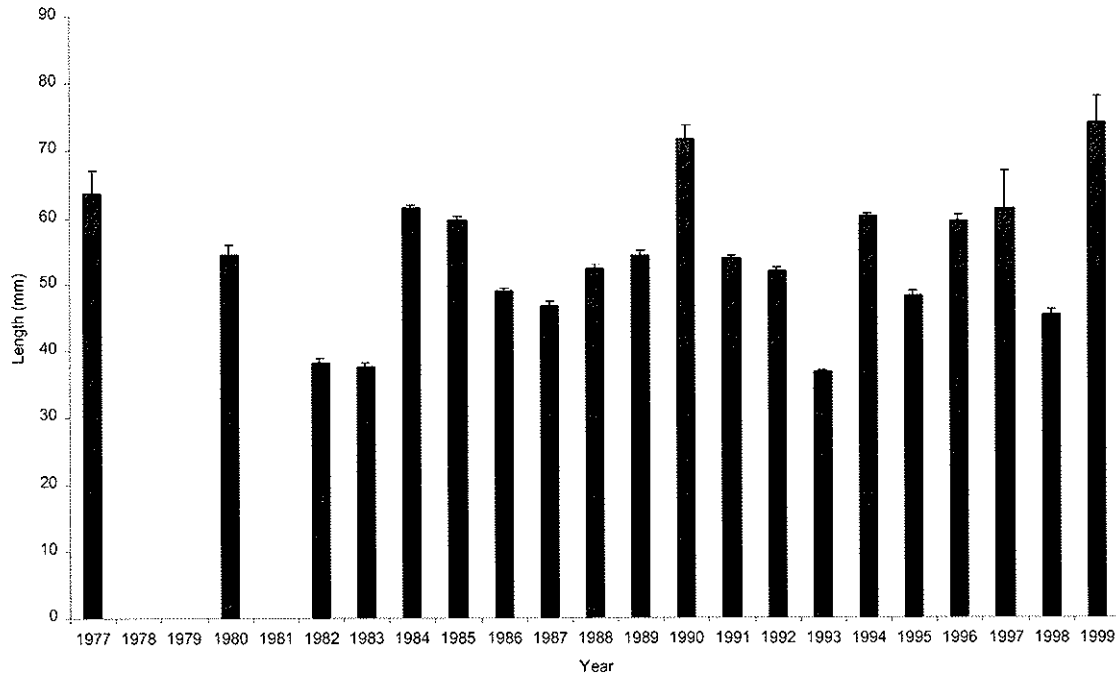


Figure 16b Hurricane Bridge

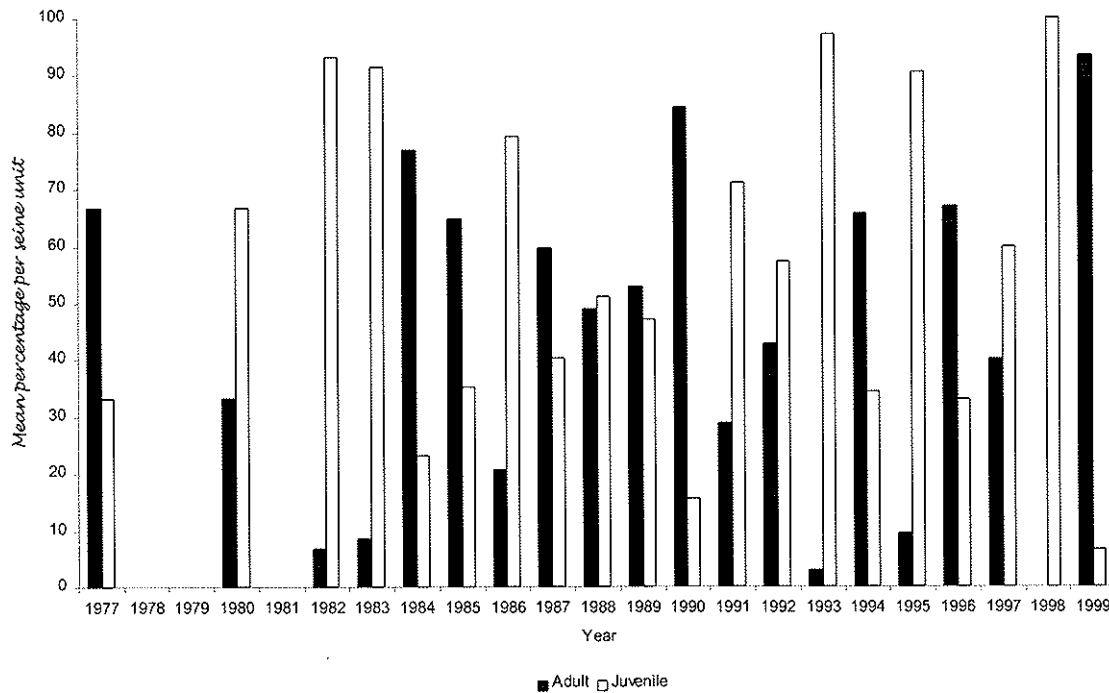


Figure 16a and b. Mean (a) length of woundfin captured in the fall and (b) percent juvenile woundfin in the fall by year at Hurricane Bridge. Bars represent standard error.

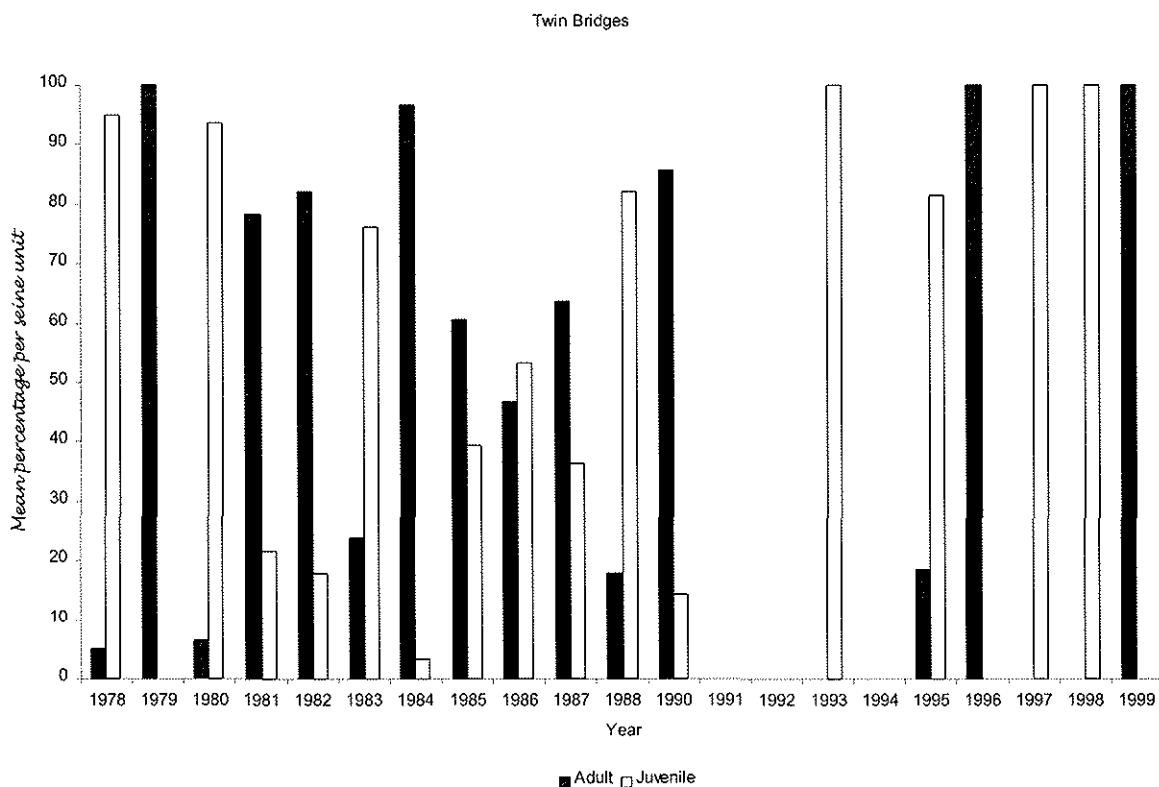
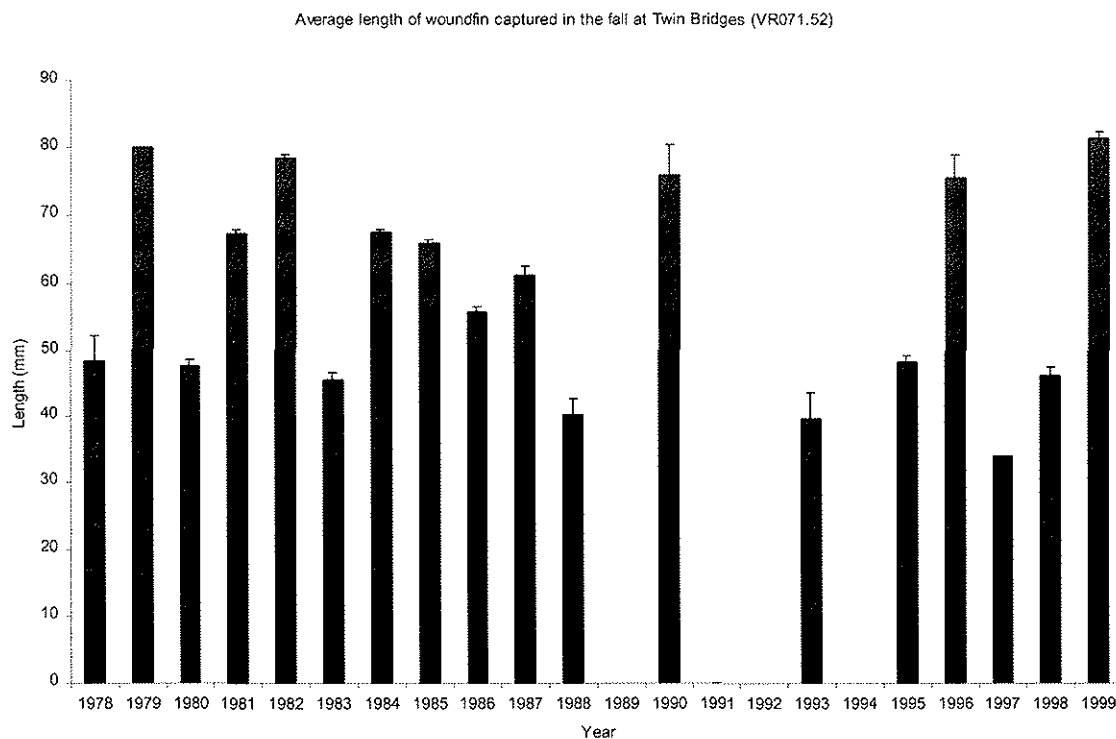


Figure 17a and b. Mean (a) length of woundfin captured in the fall and (b) percent juvenile woundfin in the fall by year at Twin Bridges. Bars represent standard error.

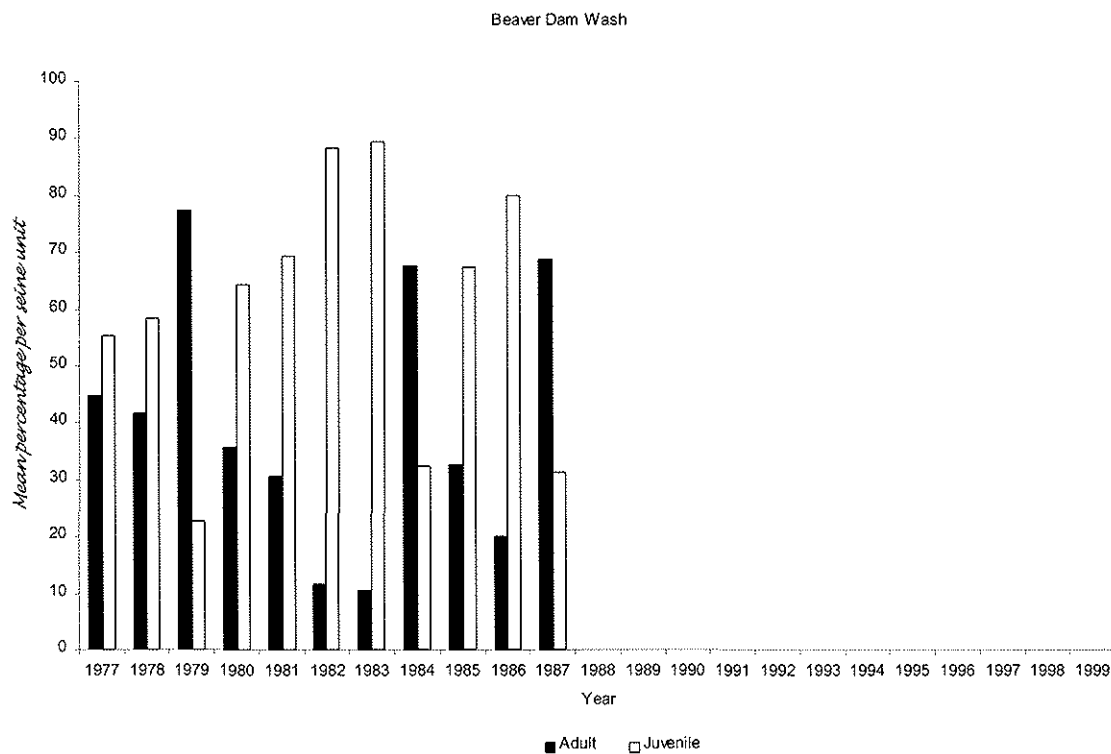
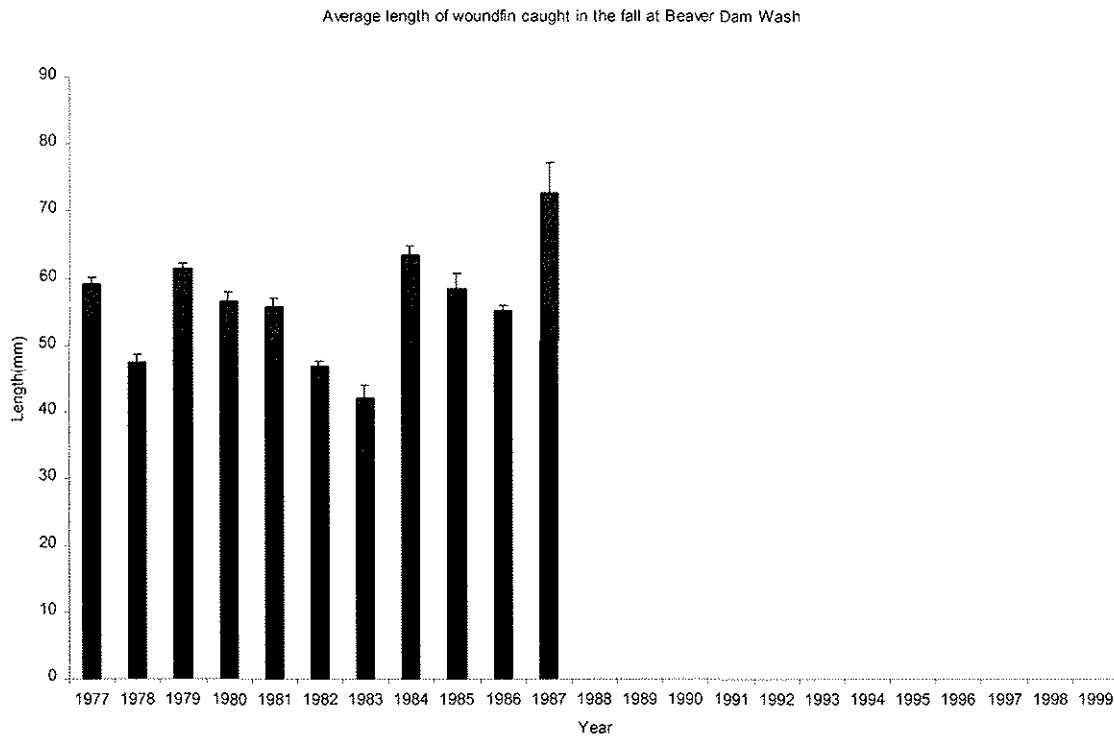


Figure 18a and b. Mean (a) length of woundfin captured in the fall and (b) percent juvenile woundfin in the fall by year at Beaver Dam Wash. Bars represent standard error.

Comparisons of ANOVA Results Using Different Datasets

We wanted to test whether the choices we made about what data to use affected the results of overall ANOVAs of whether woundfin abundance depended on year. Our primary dataset for most of our analyses uses ℓ_n (woundfin per seine unit) at the four primary stations in spring and fall and from all habitat types. Against this dataset, we tested using ℓ_n (first pass data) instead of ℓ_n (seine unit data), using just ℓ_n (woundfin from runs) instead of from all habitats, and using data excluding the data added from other seasons and stations to make the dataset more complete.

We compared the cluster groupings and the results of ANOVAs testing differences in woundfin abundance between years using first pass data and seine unit data. Results of overall ANOVAs of whether or not the number of woundfin depends on the year (at each station in each season) were similar for first pass and seine unit data as shown in Table 5. F-values were highly correlated ($R^2 = 0.968$), demonstrating that differences between stations and seasons in ANOVA results were consistent for the two measures of woundfin abundance. A paired t-test, however, showed that the F-values from seine unit data were significantly greater than those from first pass data ($p = .003$), but the magnitude of this difference was small (mean of 2.107, or 11.9%). Differences between years were slightly more significant using seine unit data than using first pass data, suggesting that (for this data set) seine unit data has slightly more power to resolve differences between years. Cluster assignments using first pass data were similar to those using seine unit data. Only 19 out of 183 observations (not all stations were sampled in all seasons all years) were assigned to different clusters, depending on whether first pass or seine unit data were used.

Results of ANOVAs testing differences between years in ℓ_n (woundfin per seine unit) at each station in fall and spring using only data from runs were compared with ANOVA results using data from all habitat types. Data from all habitats had a higher mean F-value than data using only runs, but a paired t-test showed that difference as not significant ($p = 0.08$). Differences between years may be easier to discover when using the data from all habitats.

To examine the influence of the data we added from close sites and other seasons, ANOVAs were performed using data excluding these close site data. Differences between years in woundfin per seine unit were tested at each station in spring and fall. Results were similar to those with the data included. F-values did not differ ($p = 0.730$, paired t-test). Significant information about overall differences in woundfin between years was not lost by including the data from close sites and other seasons.

Relationship of Trends in Woundfin Abundance to Other Variables

Discharge

There were significant differences between years in mean discharge on the days fish were sampled at each station ($p < 0.001$). We attempted to perform analyses of covariance (ANCOVAs) for each station to try to clarify the interrelationships between year, woundfin abundance, and discharge. However, when we tested for homogeneity of slopes between year and discharge, we found that there was a significant interaction between year and mean discharge in relation to woundfin abundance. Therefore, it was inappropriate to proceed with the analysis of covariance. We

regressed mean discharge on the day of sampling against years for all four stations and found no significant relationships.

Effects of Drought

Hardy et al. (1995) suggested that woundfin abundance varies with the strength of the water year and that abundance is reduced in drought years. In order to test the effects of drought, we first had to determine which years were “drought” years. Drought years cannot be determined from simply looking at peak flows. Hydrologic conditions during the rest of the year may be at least as ecologically important as the high flow events. Flow duration curves were constructed for each year from 1970 to 1999 using mean daily discharges from the Littlefield gage (Appendix B). For each year, we determined the discharge level that was exceeded on 50% of the days (50% exceedence level). Essentially, this value represents the median discharge. We also determined the 25% and 75% exceedence levels. The exceedence levels are measures of how much water is in the river for a given proportion of the year, and they provide an indication of base flows. These exceedence levels are plotted by year in Figure 19. Figure 20 shows peak daily discharges by year. In order to combine the peak discharges with the different exceedence discharges to differentiate drought years from non-drought years, we performed a K-means cluster analysis using annual peak daily discharges and 25%, 50%, and 75% exceedence discharges. Since the peak and 25% exceedence flows generally had much higher means and standard deviations than the 50% and 75% exceedence flows, we used the data standardization option in SYSTAT to place all the flow data on a common scale.

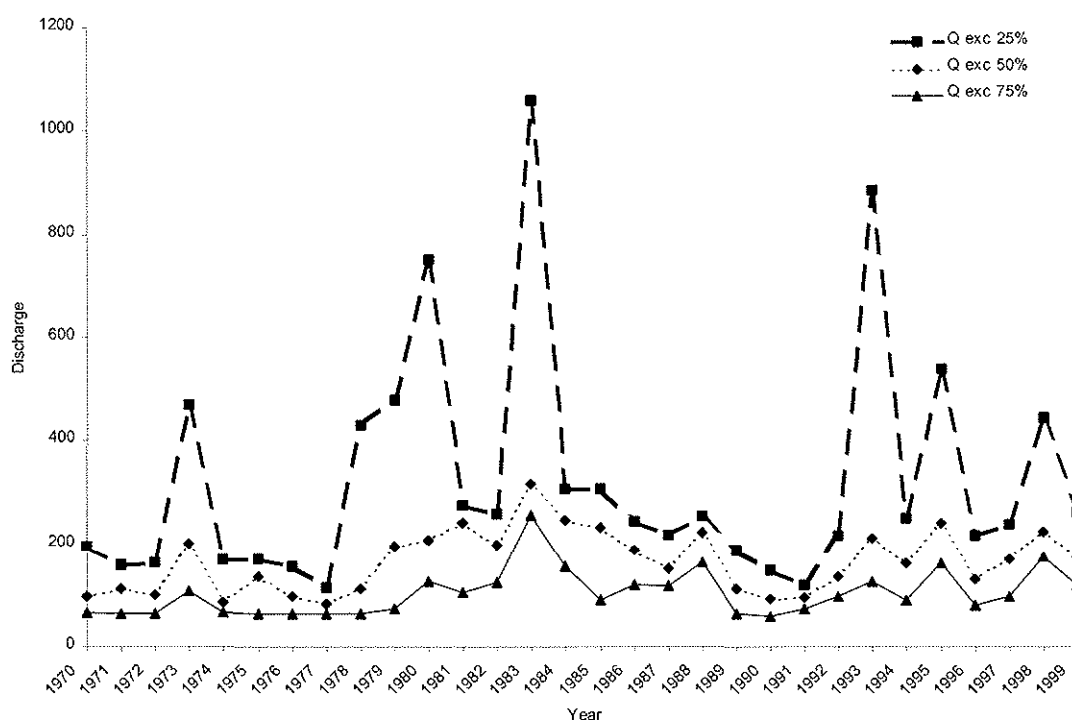


Figure 19. Discharges (cfs) that were exceeded 20%, 50%, and 80% of the days in each year (flow excellencies).

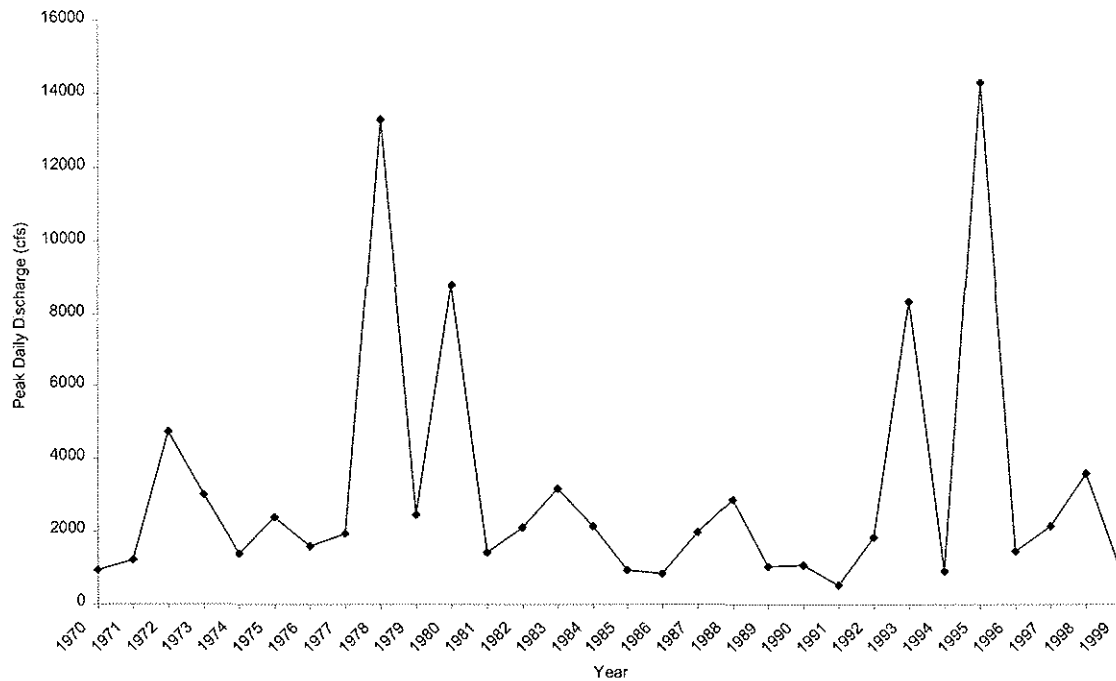


Figure 20. Peak daily discharge (cfs) by year at Littlefield, Arizona.

In the drought analyses that follow, we excluded the very high peak discharge associated with the breaching of the Quail Creek dam in January 1989 since this was not a natural event and the ecological effects were probably different from those of natural high flows. We did perform the following analyses including this high flow but chose not to include the results in this discussion.

The cluster analysis was fairly effective in grouping years into five clusters based on discharge characteristics. All four discharge measures were important in grouping the years into clusters. (All four significantly differed between clusters.) Figure 21 gives a graphical representation of the different clusters based on just peak daily discharge and the 50% exceedence level. Cluster 1 can be described as having very high peak flows and contains data from 1978 and 1995. Cluster 2 has high peak flows and high base flows, and contains data from 1980 and 1993. Cluster 3 has low peak flows and very high base flows, and contains data from 1983 only. Most of the years between 1970 and 1999 fall into one of the last two clusters, both of which have low peak flows. Cluster 4 has low-to-moderate peak flows and moderate-to-high base flows, and contains data from 1979, 1981-82, 1984-86, 1988, 1994, and 1997-1999. Cluster 5 has low-to-moderate peak flows and low-to-moderate base flows and includes data from the remaining years. A visual examination of the clusters shows a few discrepancies. In Cluster 1 the extremely high peak flows of 1978 and 1995 caused them to be clustered, despite the fact that a large difference in 50% exceedence flows exists. In Cluster 5, 1973 has a higher peak daily discharge and 50% exceedence discharge than five of the years in Cluster 4 and appears to belong in that cluster. Also in Cluster 5, 1972 has a much higher peak discharge than the rest of the years in that cluster, but its low 50% exceedence discharge caused it to be grouped here. Including 25% and 75% exceedence levels changed the

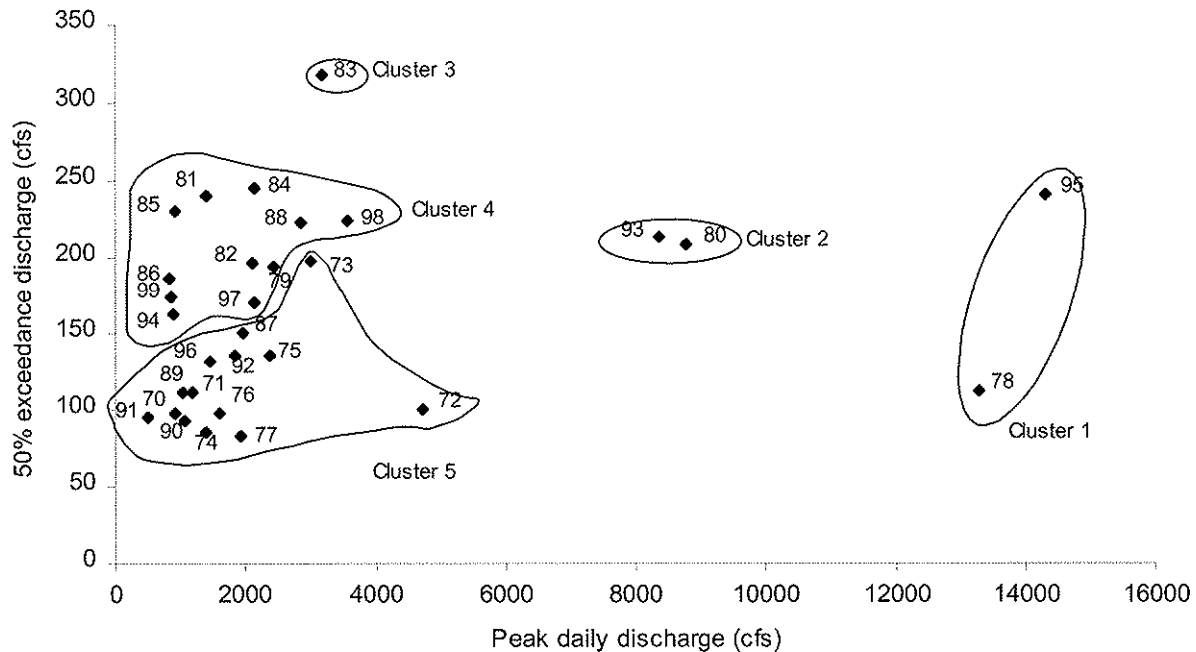


Figure 21. Scatterplot of years by peak daily discharge and 50 percent exceedance level and cluster groupings. Years within the same circles belong to the same cluster.

groupings because 1973 had a much higher 25% exceedance discharge than all other years, causing it to be grouped by itself and causing 1978, 1980, 1993, and 1995 to become one cluster. This leaves us with the problem of deciding which years actually qualify as drought years.

To determine which years were actually drought years, we ran K-means cluster analyses on two more data sets. The harshest effects of drought are usually felt during the summer. Therefore, a drought year should really be a year that has low spring runoff leading to low summer base flows. Following this logic, we clustered peak daily discharge during the spring runoff period (April, May, and June) with the summer low-flow period (June, July, and August) 50% exceedance discharge. The results of this analysis can be seen in Figure 22. The cluster analysis effectively separated the data into six groups. Cluster 1, which can be described as having very high spring peak flows and low summer base flows, contained data from 1973 and 1978. Cluster 2 can be described as having very high spring peak flow and very high summer base flow, and contains data from 1983 only. Cluster 3 has high spring peak flows and low-to-moderate summer base flows. This cluster contains data from 1979-1981 and 1993. Cluster 4 has high spring peak flows and high summer base flows, and contains data from 1988, 1995, and 1998. Cluster 5 has low-to-moderate spring peak flows and moderate summer base flows. Cluster 5 contains data from 1982, 1984-1987, 1992, and 1999. Cluster 6 has low spring peak flows and low summer base flows, and contains data from the remainder of the years.

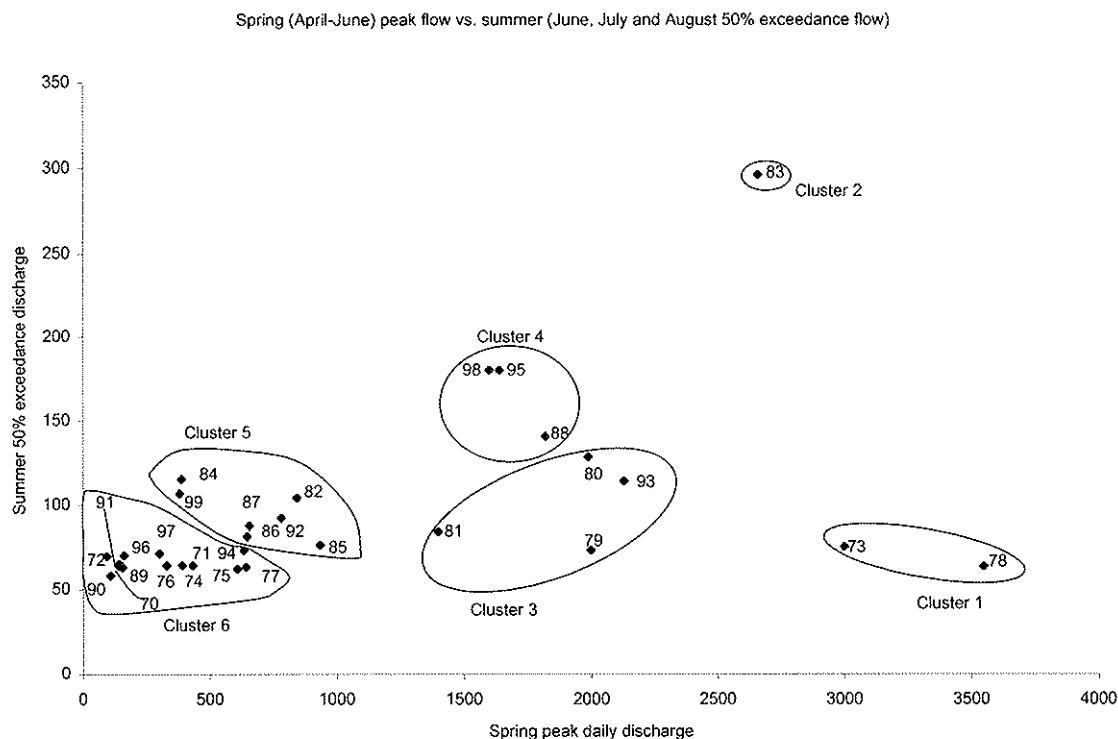


Figure 22. Scatterplot of years by peak daily discharge in spring (April-June) and summer (June-August) 50 percent exceedance level and cluster groupings. Years within the same circles belong to the same cluster.

In the preceding analysis, 1973, 1978, 1979, and 1981 had moderate-to-high spring peak flows but low summer base flows. We wouldn't expect this if the peak flows were associated with spring runoff. To reduce the impact of 1-day storm events influencing spring peak flows, we ran a final cluster analysis using the 7-day maximum peak daily discharge from April to June of each year, with the 50% exceedance flows for June to August of each year. The results of this analysis can be seen in Figure 23. Once again, the data were effectively grouped into six clusters. Cluster 1 had a very high spring runoff event and low summer base flow. Cluster 1 contained data from 1973 only. Cluster 2 had a very high spring runoff event and very high summer base flow, and contained data from 1983 only. Cluster 3 had high spring runoff events and low-to-moderate summer base flows, and contained data from 1978-80 and 1993. Cluster 4 had a high spring runoff events and high summer base flows, and contained data from 1988, 1995, and 1998. Cluster 5 had a low-to-moderate spring runoff event, and moderate summer base flows. Cluster 5 contained data from 1972, 1981-82, 1984-87, 1992, and 1999. Cluster 6 had low summer base flows and a low spring runoff event. The years in Cluster 6 had a 7-day spring maximum of under 500 cfs and median summer flow of under 75 cfs. Additionally, all the years in this cluster fell in the low peak/low base flow clusters in the other two analyses except 1994 and 1997, which fell in the low end of the low peak flow/moderate base flow cluster in the annual peak daily discharge versus annual 50%

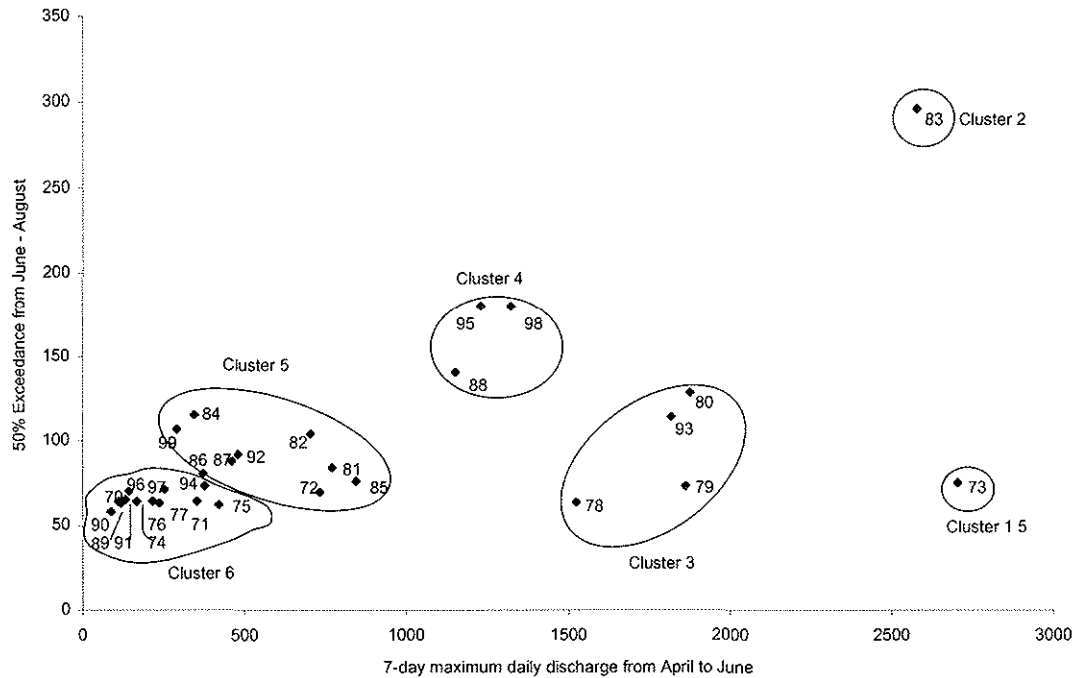


Figure 23. Scatterplot of years by peak 7-day average discharge in spring (April-June) and summer (June-August) 50% exceedence level and cluster groupings. Years within the same circles belong to the same cluster.

exceedence discharge analysis. We feel that the following years best represent the true drought years: 1970-71, 1974-77, 1989-91, 1994, and 1996-97.

The effects of drought on woundfin abundance in the fall at each station were investigated using both t-tests with separate variances and Bonferroni adjusted probabilities and one-way ANOVAs with several specific contrasts. We used a t-test to compare drought years with non-drought years. During the years woundfin were sampled, there were essentially three drought periods, one in 1976 and 1977 (which actually started in 1974), another from 1989-1991, and the most recent from 1994-1997. At each station, we used ANOVA to compare woundfin per seine unit in the early drought years (1976-1977) with the mid and late drought years (1989-1992) and the early, mid, and late drought years with non-drought years. We used a t-test to compare woundfin abundance in years that had high peak flows (1978-1980, 1988, 1993, 1995, and 1998) with years that did not have high peak flows.

Drought years had significantly less woundfin than non-drought years at all stations (Figure 24a, $p \leq 0.013$). The mid drought years had significantly less woundfin than non-drought years (Figure 24b, $p \leq 0.004$). The late drought years had significantly less woundfin than non-drought years at

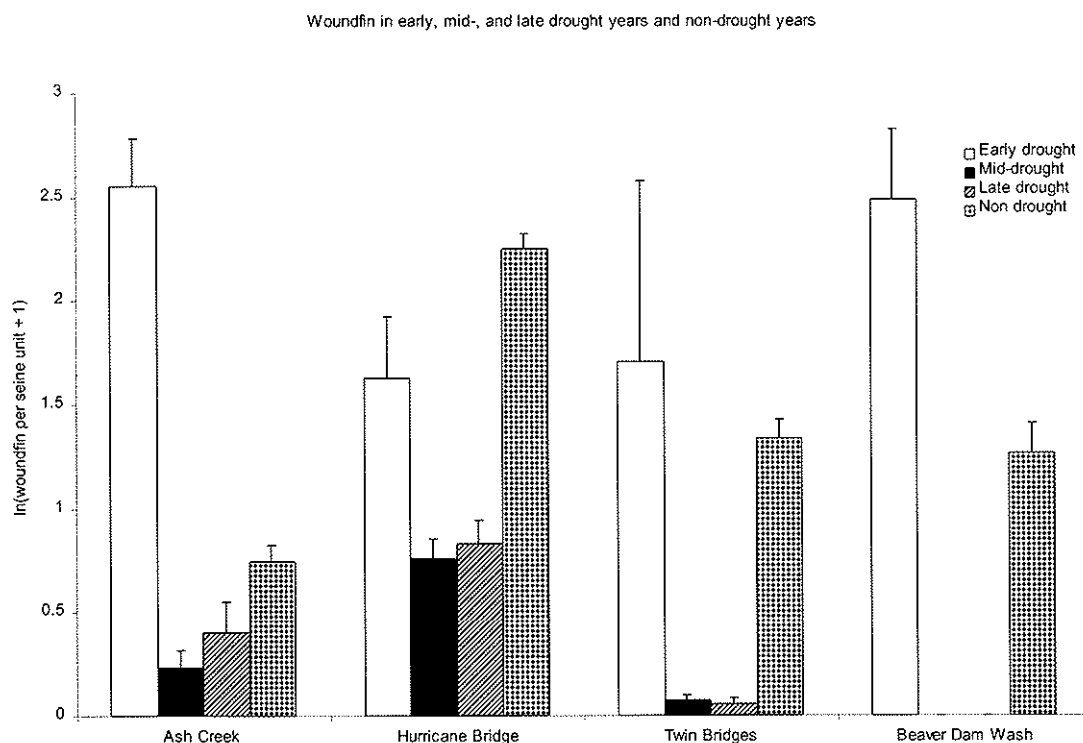
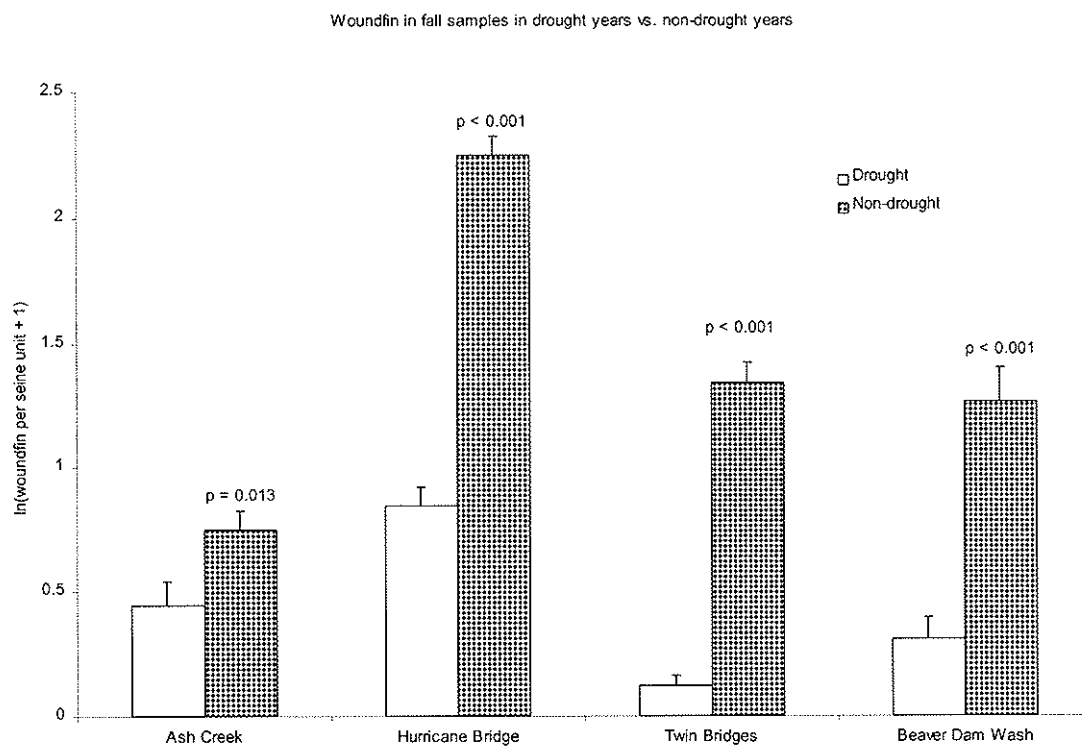


Figure 24a and b. Contrasts of differences in $\ell_n(\text{woundfin per seine unit} + 1)$ at each station between (a) drought years and non-drought years, (b) early drought years, mid drought years, late drought years, and non-drought years. P-values from ANOVA contrasts are given for each station.

all stations (Figure 24b, $p < 0.001$), except at Ash Creek, where we saw no significant difference. Results for the early drought years versus non-drought years varied by station (Figure 24b). At Ash Creek and Beaver Dam Wash, early drought years had significantly higher numbers of woundfin than non-drought years ($p \leq 0.001$), whereas no significant differences were found at Hurricane Bridge and Twin Bridges. Beaver Dam Wash and Ash Creek are the two stations that underwent the most dramatic declines in woundfin numbers in the late 80s and 1990s, which would explain why the non-drought years would have significantly lower numbers of woundfin than the early drought years. Within the drought years, the early drought years had significantly higher numbers of woundfin than the mid and late drought years at all stations except Hurricane Bridge (Figure 24b, $p \leq 0.04$). Finally, Hurricane Bridge was the only station showing a significantly higher number of woundfin during years with high spring runoff (Figure 25, $p = 0.011$). The differences at the rest of the stations were not significant.

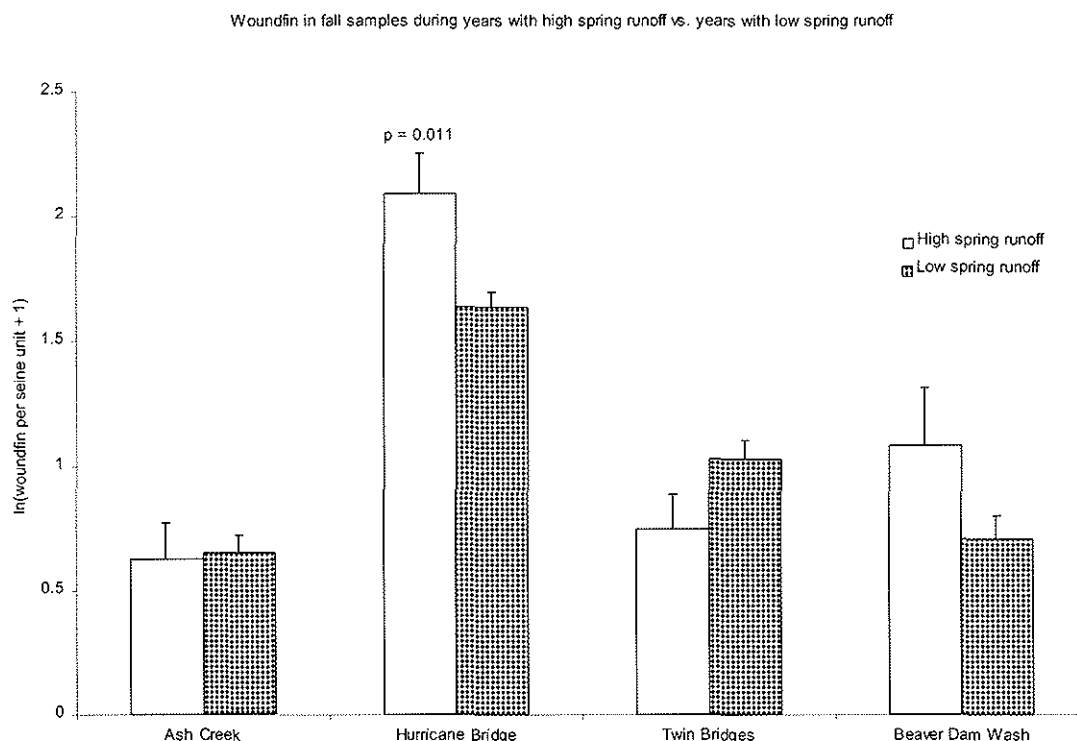


Figure 25. Contrast of differences in $\ln(\text{woundfin per seine unit} + 1)$ between years with a high peak daily discharge and years without a high peak daily discharge by station.

Since it appeared that woundfin abundance was impacted by yearly and long-term fluctuations in flow, we also wanted to examine how drought might impact year class strength. To do this, we used a t-test with separate variances and Bonferroni adjusted probabilities to compare the average length of woundfin in the fall (Figure 26) and percentage of juveniles present in the fall (Figure 27) during drought years and non-drought years. At Hurricane Bridge and Beaver Dam Wash, we saw significantly smaller mean length for fall woundfin in non-drought years ($p < 0.001$). The same trend was also present at Twin Bridges, but it was not significant ($p = 0.079$). Ash Creek and Hurricane Bridge had a significantly higher mean percentage of juvenile woundfin in fall samples in non-drought years ($p \leq 0.024$). Twin Bridges and Beaver Dam Wash also had a higher mean percentage of juveniles in the fall of non-drought years, but the difference was not significant.

At the Hurricane Bridge station, we see significant differences between drought and non-drought years for every comparison, except for the early drought years versus non-drought years. These results suggest that Hurricane Bridge represents the “expected” results of drought, reduced abundance. We see a similar trend at Twin Bridges, but some of the differences are not significant. Therefore, while it appears drought had some impact on Twin Bridges, it also appears that other factors may be at work. A confounding factor at this station is the presence of red shiner during the late drought years, so that the cumulative effect of both drought and red shiner were worse than the effect of either singularly. Since this area is immediately below the Hurricane Bridge region, which seems to be very productive for woundfin, downstream drift during high flows may also explain some of the trends noted.

At Beaver Dam Wash and Ash Creek, the results of our analyses are a bit more mixed. At Beaver Dam Wash the effects of drought are more difficult to assess because woundfin were locally extirpated by fall 1988. Therefore, we only have data from the early drought years, which had significantly higher numbers of woundfin than the non-drought years. The analysis comparing drought vs. non-drought years at Beaver Dam Wash is skewed because woundfin had been extirpated by the mid and late drought years. Therefore, we cannot attribute the loss of the woundfin population at Beaver Dam Wash to drought alone. Drought seems to have been one factor in the decline of woundfin at Ash Creek, since drought years had significantly higher woundfin numbers overall, but the early drought years had significantly higher numbers of woundfin than non-drought years, and the late drought years have numbers similar to the non-drought years. The impacts from water withdrawal for Quail Creek Reservoir, along with the increase in flow of Pah Tempe Hot Springs in 1985, may have acted in conjunction with the mid drought years to negatively impact the woundfin population at Ash Creek.

There appears to be one general pattern in the drought contrasts at Hurricane Bridge and a different general pattern at the other three stations. Hurricane Bridge is the station with the most-stable, “healthy” woundfin population. Hurricane Bridge was the only station where non-drought years had higher mean ℓ_n (woundfin per seine unit) than the early drought years, although that difference was not significant. Additionally, Hurricane Bridge was the only station where the presence or absence of a high spring peak flow significantly affected woundfin abundances. Hurricane Bridge and Beaver Dam Wash both have relatively stable flow in normal years, while Ash Creek is now impacted by withdrawals for Quail Creek and Twin Bridges is impacted by irrigation withdrawals. In summary, drought may have some influence on woundfin abundances at all stations, but it

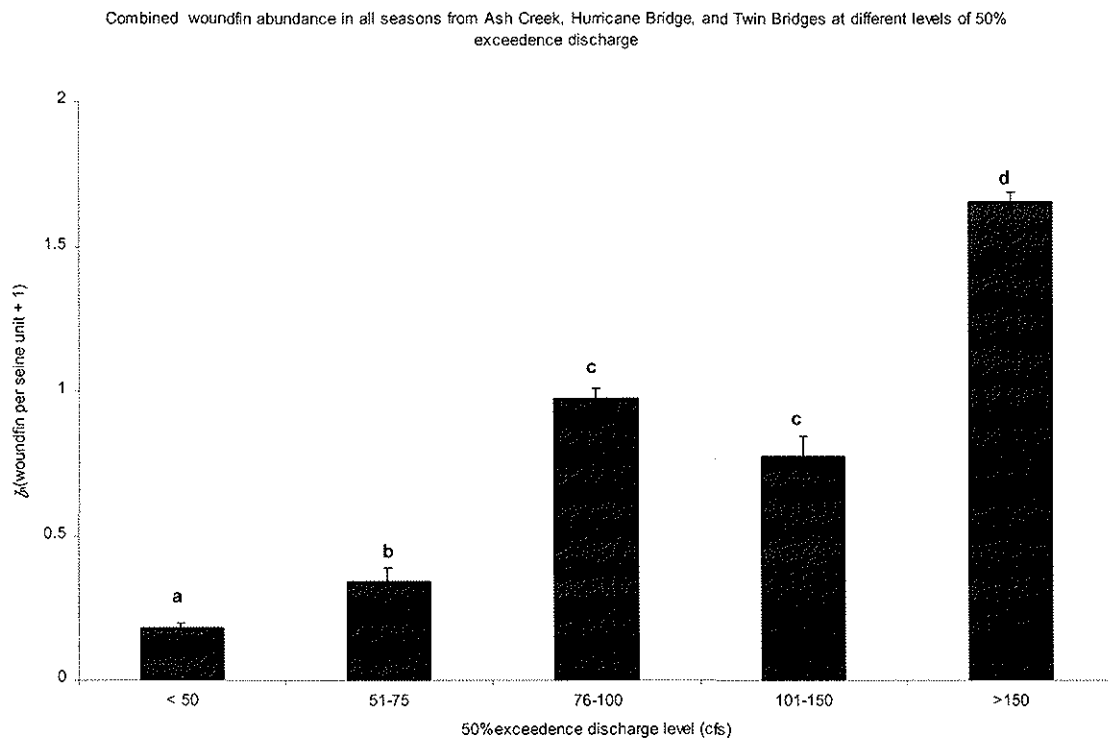
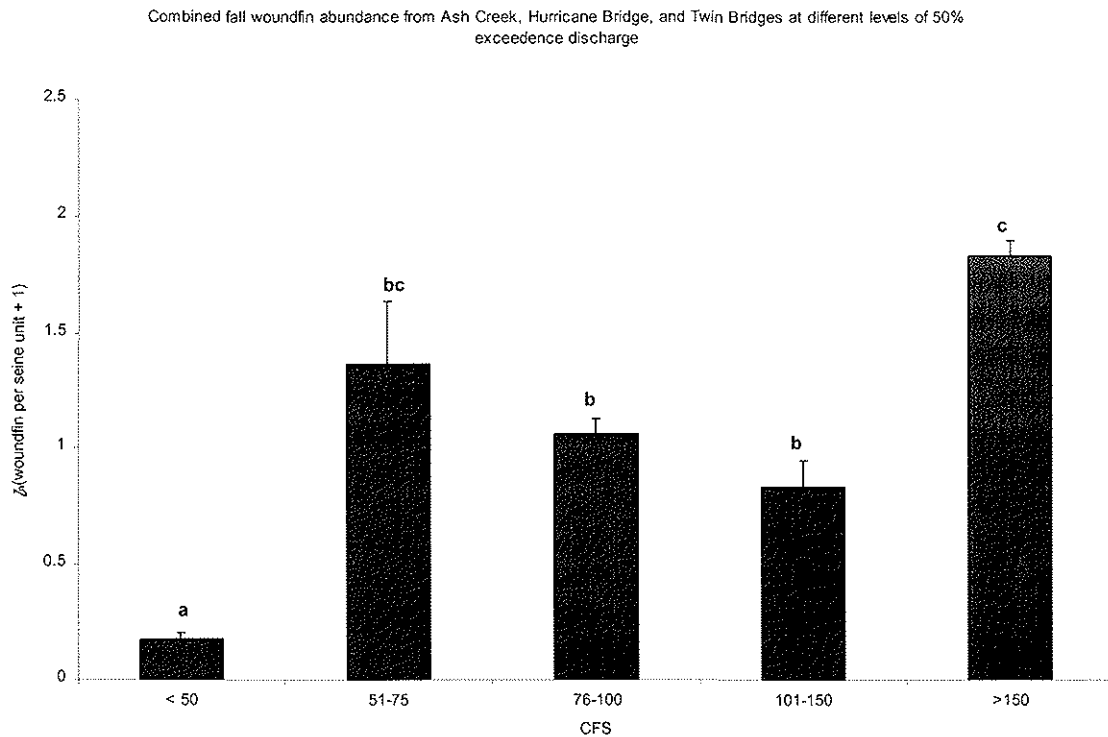


Figure 26a and b. Combined mean $\ell_n(\text{woundfin per seine unit} + 1)$ by yearly 50% exceedence level (a) in the fall at Ash Creek, Hurricane Bridge, and Twin Bridges (b) in all seasons at Ash Creek, Hurricane Bridge, and Twin Bridges. Letter represent significant differences ($p < 0.05$).

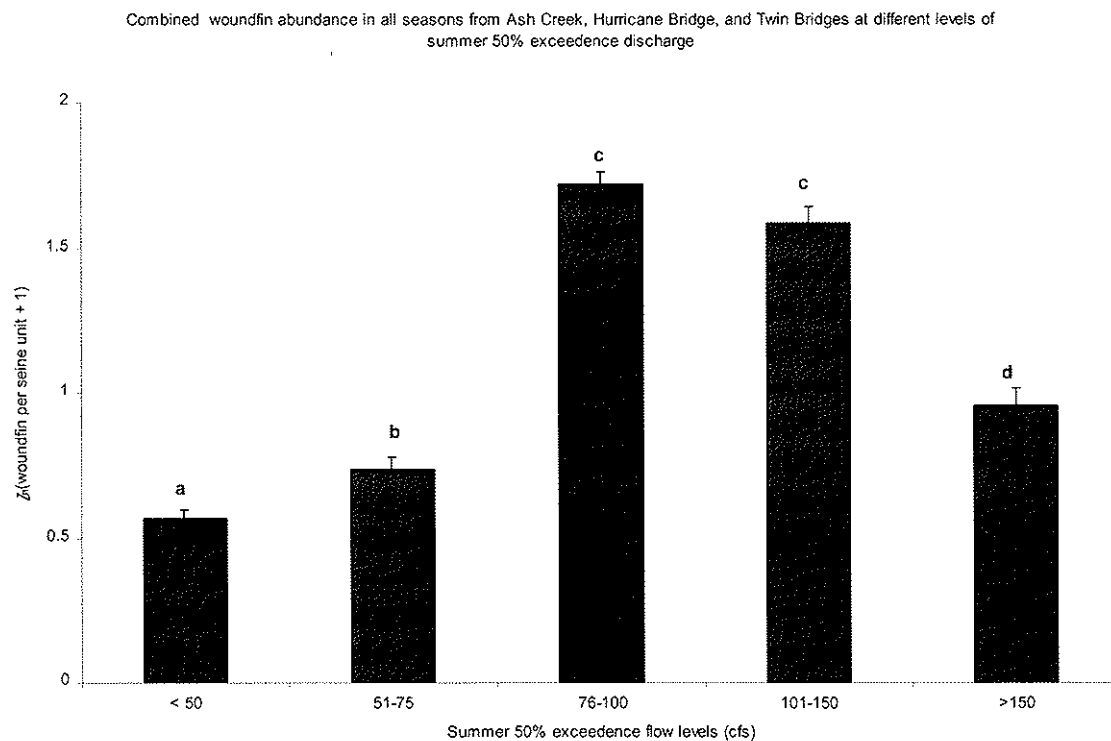
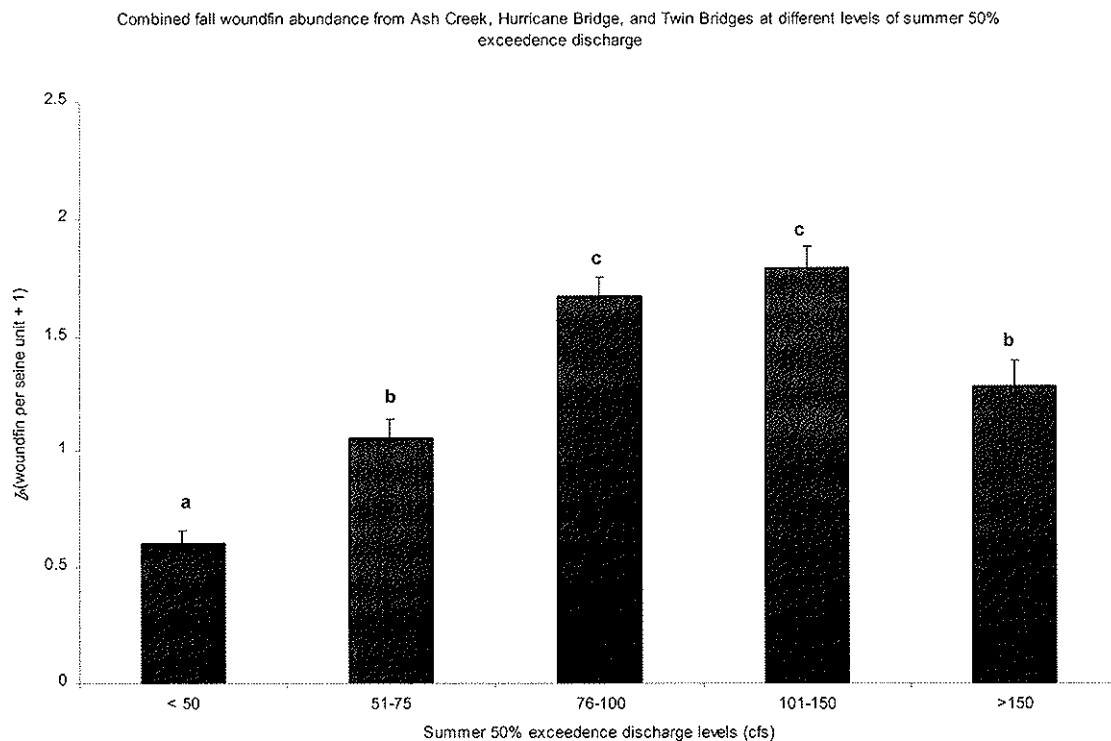


Figure 27a and b. Combined mean $\ln(\text{woundfin per seine unit} + 1)$ by summer 50% exceedence level (a) in the fall at Ash Creek, Hurricane Bridge, and Twin Bridges (b) in all seasons at Ash Creek, Hurricane Bridge, and Twin Bridges. Letter represent significant differences ($p < 0.05$).

definitely has a negative impact at Hurricane Bridge. Other factors, either in conjunction with or independent of drought, are most likely responsible for the dramatic declines in woundfin at stations other than Hurricane Bridge.

Additional Flow Analyses

Results of earlier discharge analyses, in conjunction with the results of the drought analyses, seemed to show that low flows may have played an important role in the declines in woundfin abundance. Therefore, we decided to examine woundfin abundance under different flow levels from 1976-1999. We separated years into five categories using their 50% exceedence discharge. We used flow records from the Hurricane gage for the Ash Creek and Hurricane Bridge stations, the Bloomington gage for the Twin Bridges station, and the Littlefield gage for Beaver Dam Wash. The five categories we used were 50% exceedence flow: ≤ 50 cfs, 51-75 cfs, 76-100 cfs, 101-150 cfs, and > 150 cfs. We used ANOVA with a Tukey Honestly Significant difference multiple comparison test to compare fall woundfin abundance between the five categories of 50% exceedence flow. We chose fall woundfin abundance since recruitment for the year would be included in this measure. We compared data from all stations combined and each station individually. We only used years up through 1988 at Beaver Dam Wash, since no woundfin were found at this station after that time.

We found that when all four stations were combined, years where the 50% exceedence flows were above 150 cfs had significantly higher fall mean woundfin abundance than all other flow levels, except 51-75 cfs ($p < 0.001$). Additionally, years where the 50% exceedence flows were below 50 cfs had the lowest woundfin abundances ($p \leq 0.001$). However, when we looked at the data by station we found no significant differences between flow levels at Beaver Dam Wash ($p = 0.076$), and that only three of the five 50% exceedence levels were present at the Littlefield gage from 1976-1989. We also had found that our five flow variables explained very little variation in woundfin abundance at Beaver Dam Wash in our stepwise regression models. Therefore, we decided to eliminate Beaver Dam Wash samples from the analysis. When we repeated the same analysis on the fall data from Ash Creek, Hurricane Bridge, and Twin Bridges, we found the exact same results (Figure 26, $p < 0.001$). When we included data from all seasons at these three locations in this analysis, we found that while flows greater than 150cfs still had the highest mean woundfin abundance (Figure 26, $p < 0.001$), 50% exceedence flows between 76 and 150 cfs had significantly higher mean woundfin abundance than flows below 75 cfs ($p \leq 0.001$).

Since our drought analyses indicated that summer low flows may have an impact on woundfin survival and recruitment, we repeated this analysis using summer 50% exceedence flows and the fall woundfin abundance data from Ash Creek, Hurricane Bridge, and Twin Bridges. We found that years with a summer 50% exceedence flow between 75-150 cfs had significantly higher fall woundfin abundance than all other summer 50% exceedence flow levels (Figure 27, $p \leq 0.036$), and that years with summer 50% exceedence flow less than 50 cfs had the lowest woundfin abundance ($p < 0.001$). Including data from all seasons, we found similar results except that summer 50% exceedence flows between 51-75 cfs had significantly lower mean woundfin abundance than summer 50 % exceedence flows above 150 cfs (Figure 27, $p = 0.030$).

After running the above analyses, we wanted to get a clearer picture of what flow levels produced higher woundfin abundances. We decided to combine 50% exceedence flow or summer 50% exceedence flow levels into flow levels below and above 75 cfs and below and above 100 cfs. We then used a t-test with separate variances and Bonferroni adjusted probabilities to compare fall woundfin abundance at 50% exceedence or summer 50% exceedence levels at or below 75 cfs with those above 75 cfs. We repeated this analysis on fall woundfin abundance in years with 50% exceedence or summer 50% exceedence levels at or below 100 cfs with those years above 100 cfs (Figure 28). We found that years with a 50% exceedence discharge above 75 cfs had significantly higher fall woundfin abundance than years with a 50% exceedence discharge at or below 75 cfs ($p < 0.001$). When we increased the level of 50% exceedence discharge to below and above 100 cfs, we found that the years with 50% exceedence flows above 100 cfs had significantly higher fall woundfin abundance than years with 50% exceedence flows at or below 100 cfs ($p < 0.001$). The same results were true when we used summer 50% exceedence flows ($p < 0.001$).

These results strongly suggest that flows of less than 100 cfs are not good for woundfin in all reaches of the Virgin River and that flows less than 50 cfs are especially poor. We do not know if flows below 100 cfs or 50 cfs lead to declining populations, but the suggestion from this analysis is that low flows (i.e., < 100 cfs) may not be the type of flows that would lead to recovery of an endangered species.

Red Shiner, Speckled Dace, and Virgin Spinedace

We also investigated the dynamics of red shiner and speckled dace (*Rhinichthys osculus*) during this time period because we felt these two species are also sampled fairly well by the woundfin monitoring techniques. Some of the other native species, such as Virgin River chub, desert sucker (*Pantosteus clarki*), and flannelmouth sucker are not as likely to be adequately sampled with the monitoring techniques. Additionally, we took a cursory look at Virgin spinedace population dynamics, since this is a species of concern that may be sampled adequately by seining techniques. ANOVAs were performed to test differences between years and differences between seasons sampled. Analyses on red shiner were not done at Hurricane Bridge or Ash Creek because no red shiner were present. Figure 29 gives mean spring and fall speckled dace abundance by year for Ash Creek and Hurricane Bridge. Note that Virgin spinedace abundance at Ash Creek has recovered in recent years, in contrast with the woundfin population (Figure 6a). Figures 30 and 31 give yearly mean speckled dace and red shiner per seine unit in spring and fall for Twin Bridges and Beaver Dam Wash. Since red shiner reputedly first made it above the Virgin Gorge in the mid 1980s, we compared red shiner and speckled dace abundances from 1976 to 1985 with abundances from 1985 to 1999 using a two sample t-test with separate variances and Bonferroni adjusted probabilities.

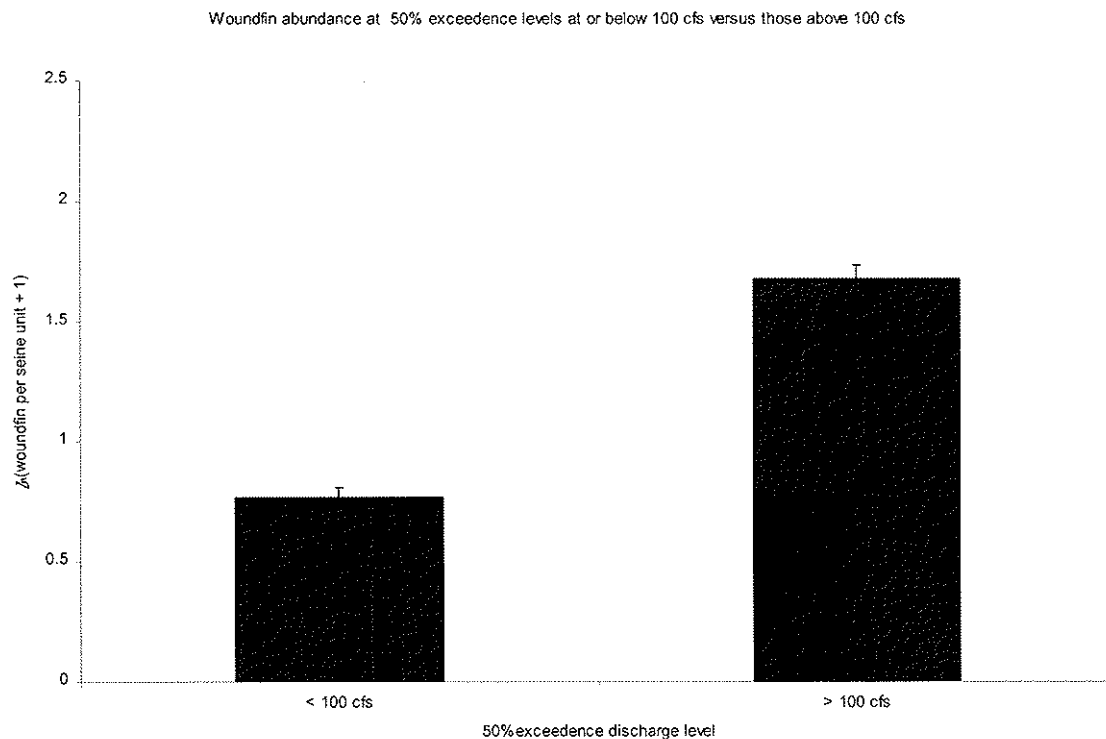
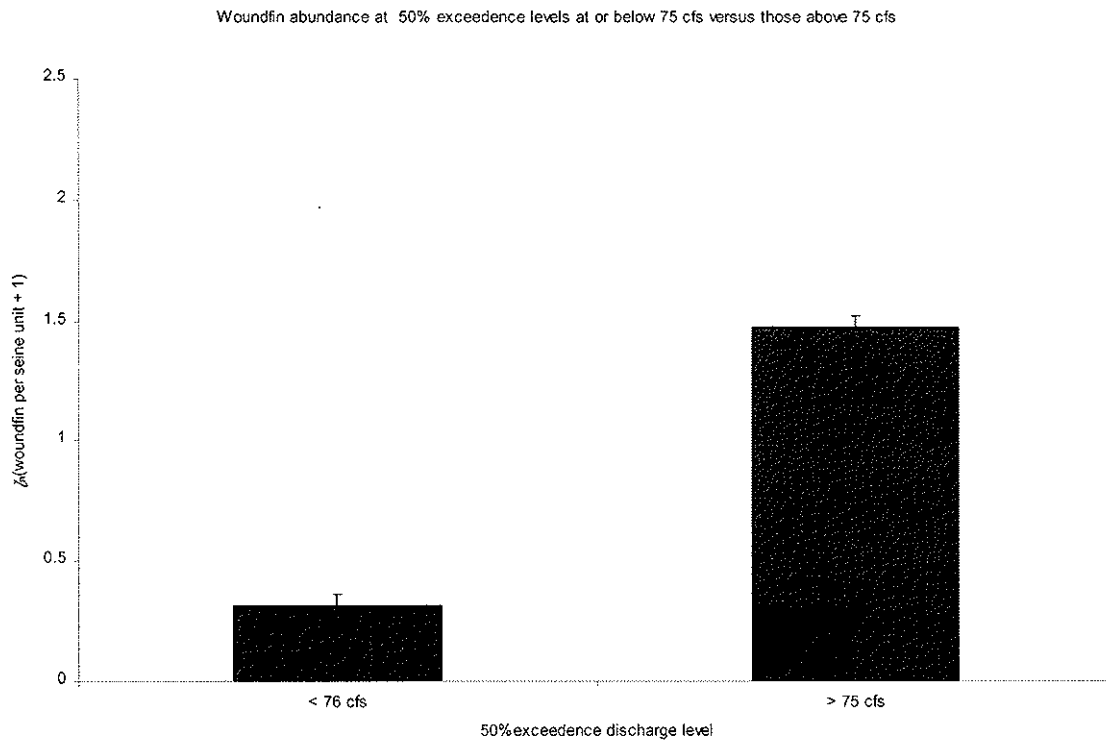


Figure 28a and b. Combined mean $\ell_n(\text{woundfin per seine unit} + 1)$ in the fall at Ash Creek, Hurricane Bridge, and Twin Bridges at (a) 50% exceedence levels below and above 75 cfs and (b) 50% exceedence levels below and above 100 cfs.

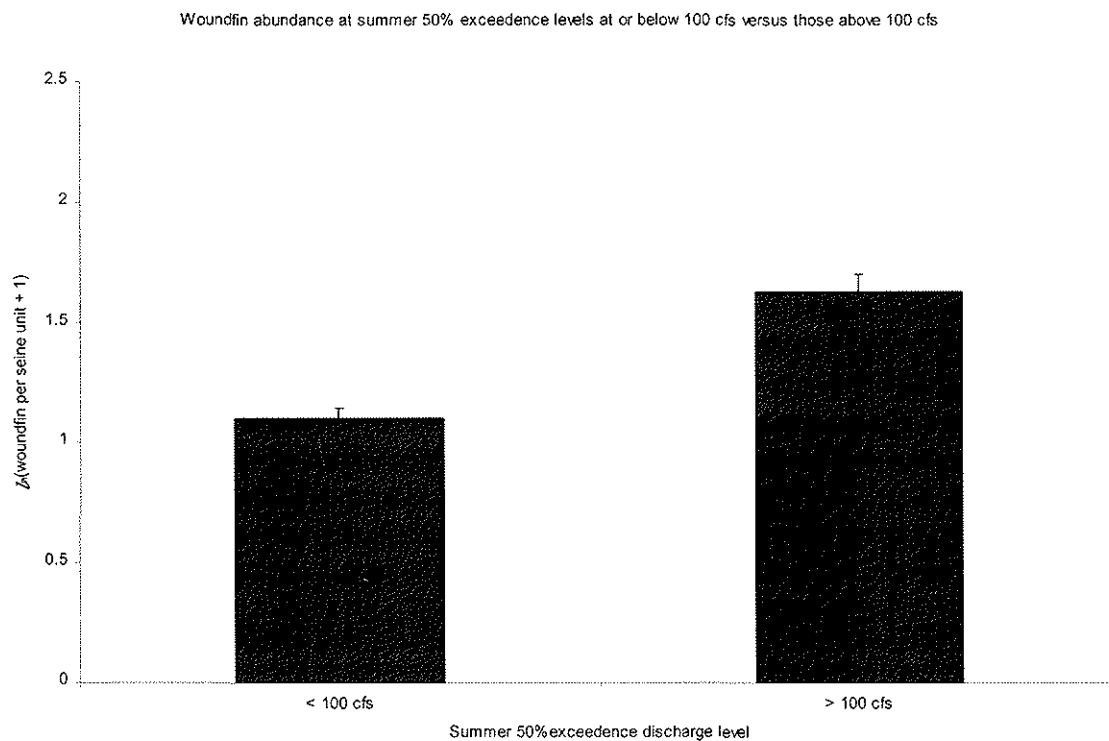
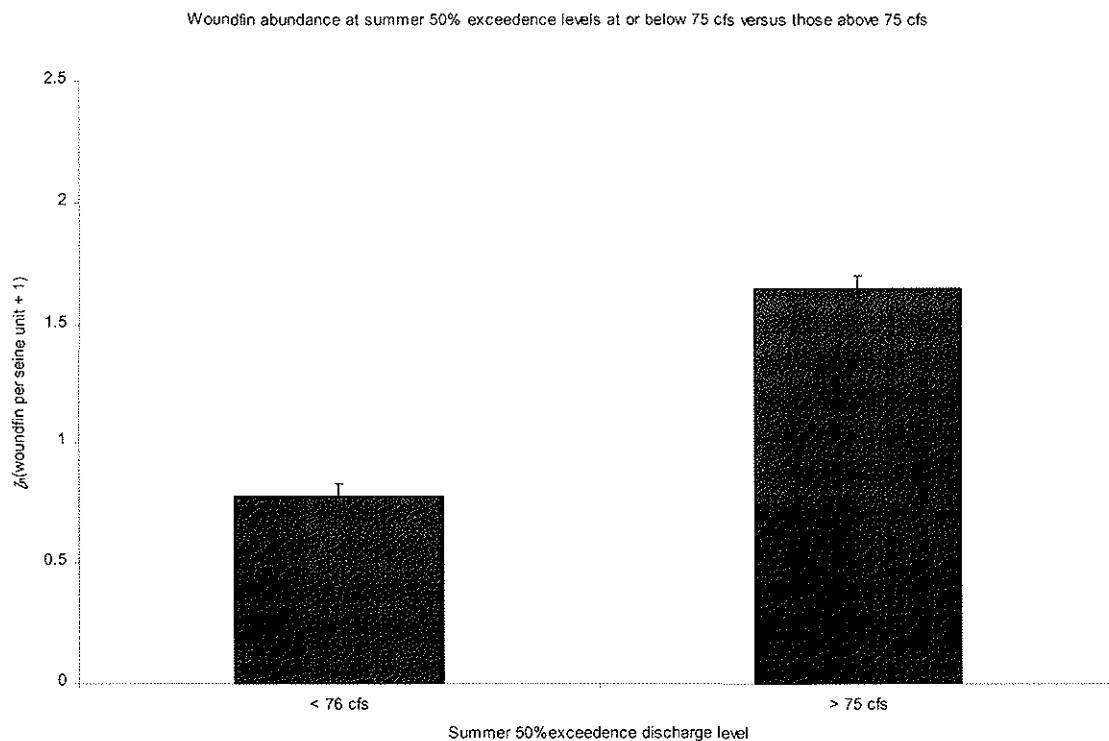


Figure 28c and d. Combined mean $l_n(\text{woundfin per seine unit} + 1)$ in the fall at Ash Creek, Hurricane Bridge, and Twin Bridges at (c) summer 50% exceedence levels below and above 75 cfs and (d) summer 50% exceedence levels below and above 100 cfs.

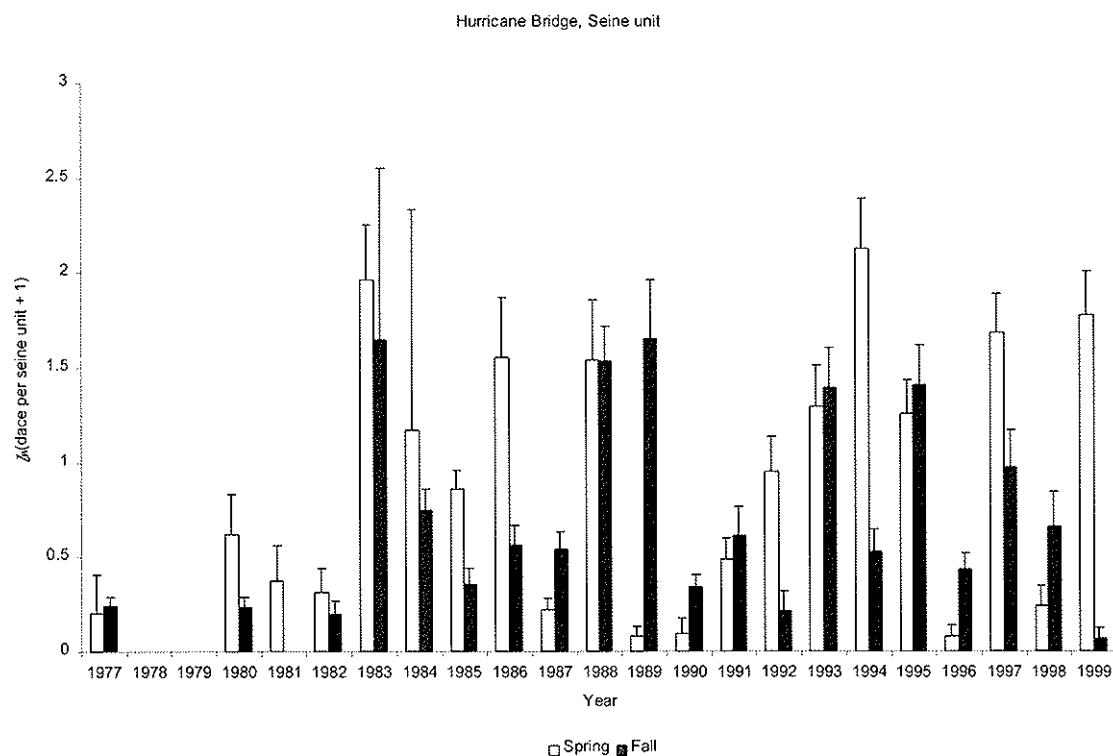
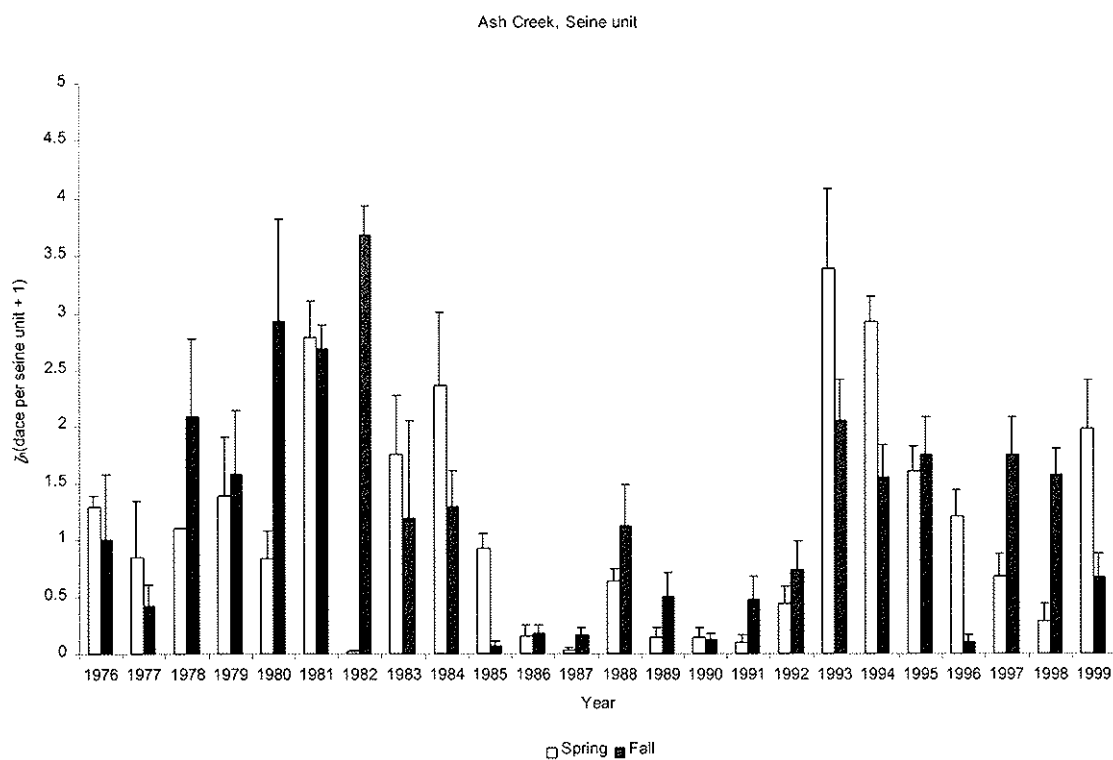


Figure 29a and b. Mean $\ell_n(\text{dace per seine unit} + 1)$ by year at Ash Creek and Hurricane Bridge. (0 = sampled and no fish caught. Blank space = no data).

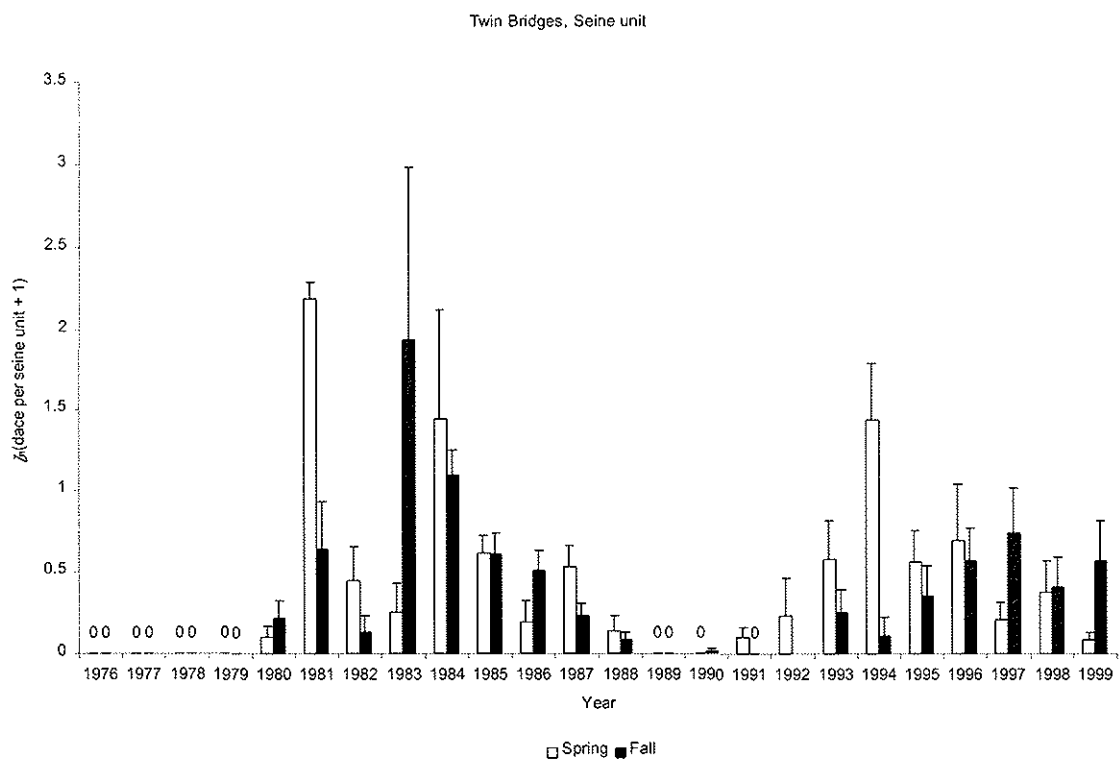


Figure 30bTwin Bridges, Seine unit

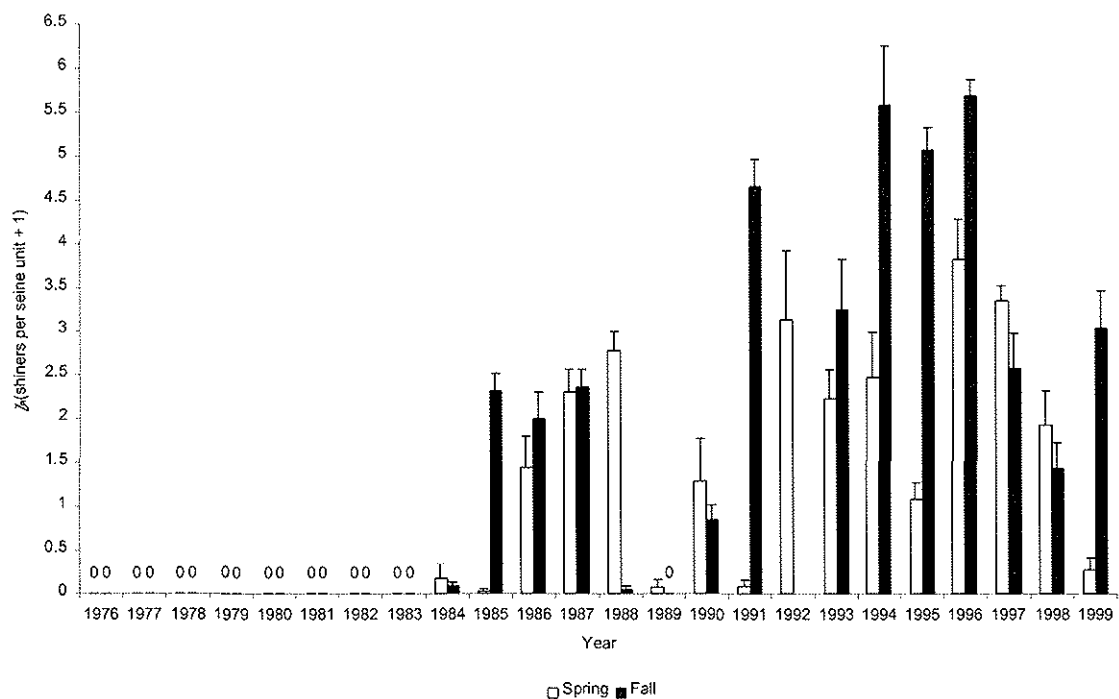


Figure 30a and b. Mean ℓ_n (dace per seine unit +1) and mean ℓ_n (shiner per seine unit +1) by year at Twin Bridges. (0 = sampled and no fish caught. Blank space = no data).

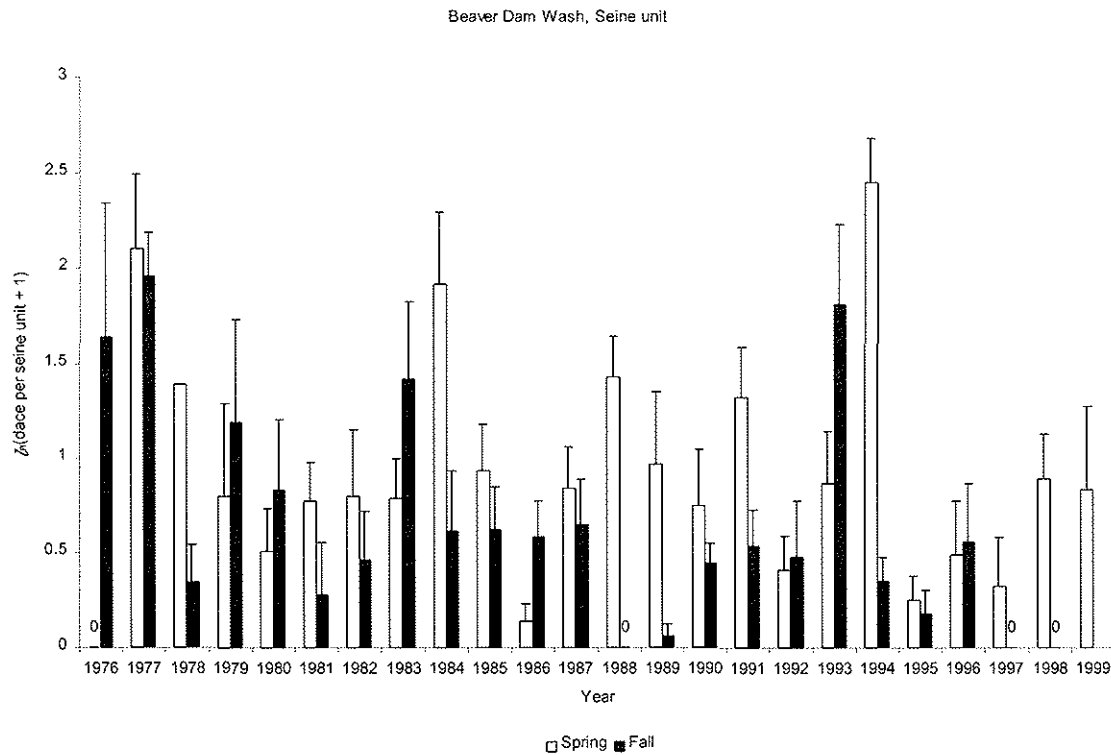


Figure 31b Beaver Dam Wash, Seine unit

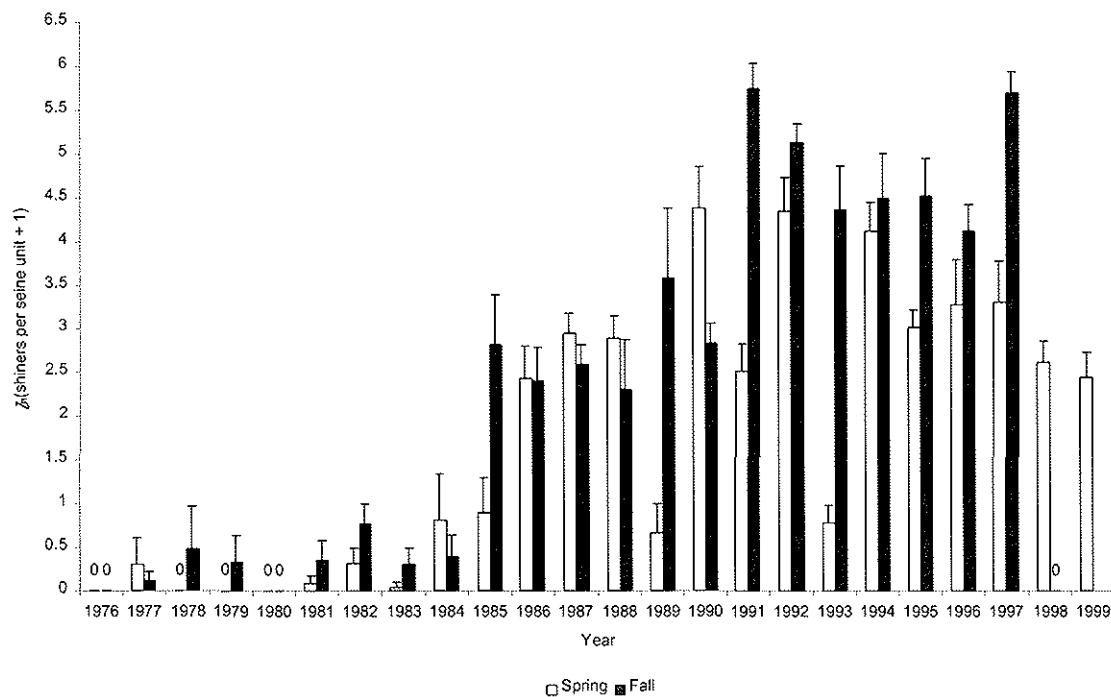


Figure 31a and b. Mean $\ell_n(\text{dace per seine unit} + 1)$ and mean $\ell_n(\text{shiner per seine unit} + 1)$ by year at Beaver Dam Wash. (0 = sampled and no fish caught. Blank space = no data).

At Beaver Dam Wash and Twin Bridges, we found significant differences in ℓ_n (red shiner per seine unit + 1) between years for both spring and fall collections (p values < 0.001 in all cases, Figures 30 and 31). We also found that both stations had a significantly higher red shiner abundance after 1985 than before 1986 in both spring and fall ($p < 0.001$). At all stations in both spring and fall, we found significant differences between years in ℓ_n (dace per seine unit + 1) ($p < 0.001$). However, these differences, unlike those of red shiner and woundfin, do not appear to represent a directional trend (Figures 26 to 28). The comparisons of speckled dace pre-1986 and post-1985 varied by station. At Ash Creek, no significant differences in speckled dace per seine unit were observed in the fall, but in the spring speckled dace abundance was significantly lower after 1985 ($p=0.016$). In the spring at Hurricane Bridge, no significant differences in speckled dace were apparent, but in the fall we saw significantly higher numbers of speckled dace after 1985 ($p = 0.011$). At Twin Bridges, the numbers of speckled dace were significantly lower after 1985 than before 1986 in both spring and fall ($p \leq 0.033$). Finally, at Beaver Dam Wash there were no significant differences in speckled dace abundance in the spring, but there were significantly lower numbers of speckled dace after 1985 in the fall samples ($p < 0.001$). Therefore, while the two upper stations apparently show no change in speckled dace populations after 1985, the two lower stations show some evidence in a decline in speckled dace numbers after 1985.

We found significant differences between seasons in red shiner per seine unit at Beaver Dam Wash and at Twin Bridges ($p < 0.001$). At both stations, the only significant difference between seasons was that fall had the highest mean number of red shiner ($p < 0.001$). At Beaver Dam Wash red shiner per seine unit were lowest in winter, and at Twin Bridges the summer collections had the lowest numbers of red shiner per seine unit. Differences between seasons in speckled dace per seine unit were only significant at Hurricane Bridge ($p < 0.001$), where spring was significantly higher than all other seasons ($p < 0.006$), and fall was higher than summer and winter ($p < 0.02$).

We also looked at the effect of drought on red shiner and speckled dace. We found significantly higher numbers of red shiner in the fall during drought years at both Twin Bridges and Beaver Dam Wash (Figure 32, $p < 0.001$). Speckled dace numbers were generally higher during non-drought years, but only significantly so at Twin Bridges ($p < 0.001$).

Virgin spinedace population dynamics are shown for spring and fall collections at all four stations in Figures 33 and 34. We performed ANOVA to examine Virgin spinedace populations between years at each station with a Tukey Honestly Significant Difference follow up test to compare all possible differences between means. Since Twin Bridges only had very low numbers of Virgin spinedace in 5 of the 23 years sampled at that station, we chose not to analyze this data. We will point out that Virgin spinedace appear to surface at Twin Bridges during or immediately after periods of relatively high numbers at Hurricane Bridge. As with all the other species, Virgin spinedace abundances were significantly different between years in both spring and fall at all stations ($p < 0.001$). We regressed mean spring and fall Virgin spinedace abundance against year at all stations to determine if a long-term trend appeared to be present. We found no significant relationships between mean Virgin spinedace abundance and year at Ash Creek. Virgin spinedace abundance at Hurricane Bridge seemed to increase over time, and this relationship was significant in the spring ($p = 0.034$, $R^2 = 0.215$). Similar to woundfin, we saw a significant decline in mean

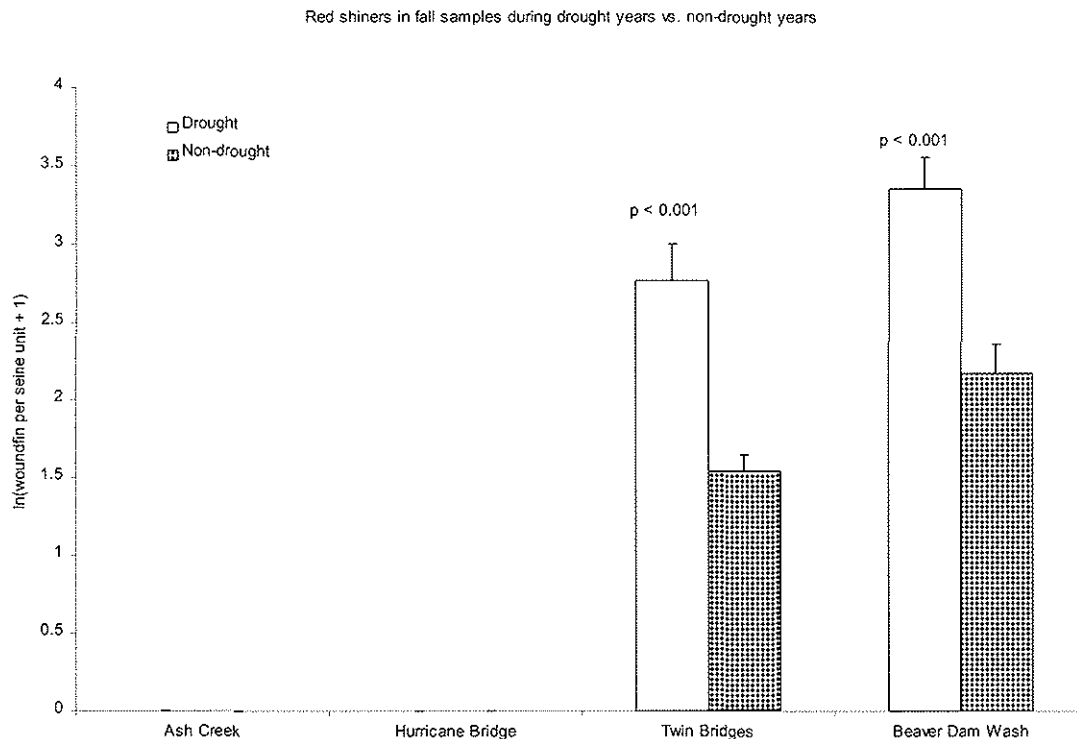


Figure 32. Mean $\ell_n(\text{dace per seine unit} + 1)$ and mean $\ell_n(\text{red shiner per seine unit} + 1)$ by year at Beaver Dam Wash. (0 = sampled and no fish caught. Blank space = no data).

Virgin spinedace abundance over time in the spring and fall at Beaver Dam Wash ($p \leq 0.001$, $R^2 = 0.425$ and 0.499 , respectively).

We used the t-test with separate variances and Bonferroni adjusted probabilities to examine the differences in Virgin spinedace abundance in drought and non-drought years, before 1986 and after 1985, and high versus low runoff years. We found that drought seemed to have a negative impact on fall Virgin spinedace abundance. However, only Ash Creek showed a convincing significantly higher fall Virgin spinedace abundance in non-drought years. Beaver Dam Wash showed significantly higher abundance in non-drought years, but the result was biased by the fact that no Virgin spinedace were captured at this station after 1988. We used ANOVA with a Tukey Honestly Significant difference test to compare mean fall Virgin spinedace abundance in the early, mid, and late drought years with non-drought years at Beaver Dam Wash. When we compared Virgin spinedace abundance in the drought years when fish were present (1976-77) with non-drought years, we found that Virgin spinedace abundance in these early drought years did not significantly differ from Virgin spinedace abundance in non-drought years ($p = 0.075$). We also saw a positive influence of high spring runoff. Mean fall Virgin spinedace abundances at Ash Creek, Hurricane Bridge, and Beaver Dam Wash were significantly higher in years with high spring runoff than in years without high spring runoff.

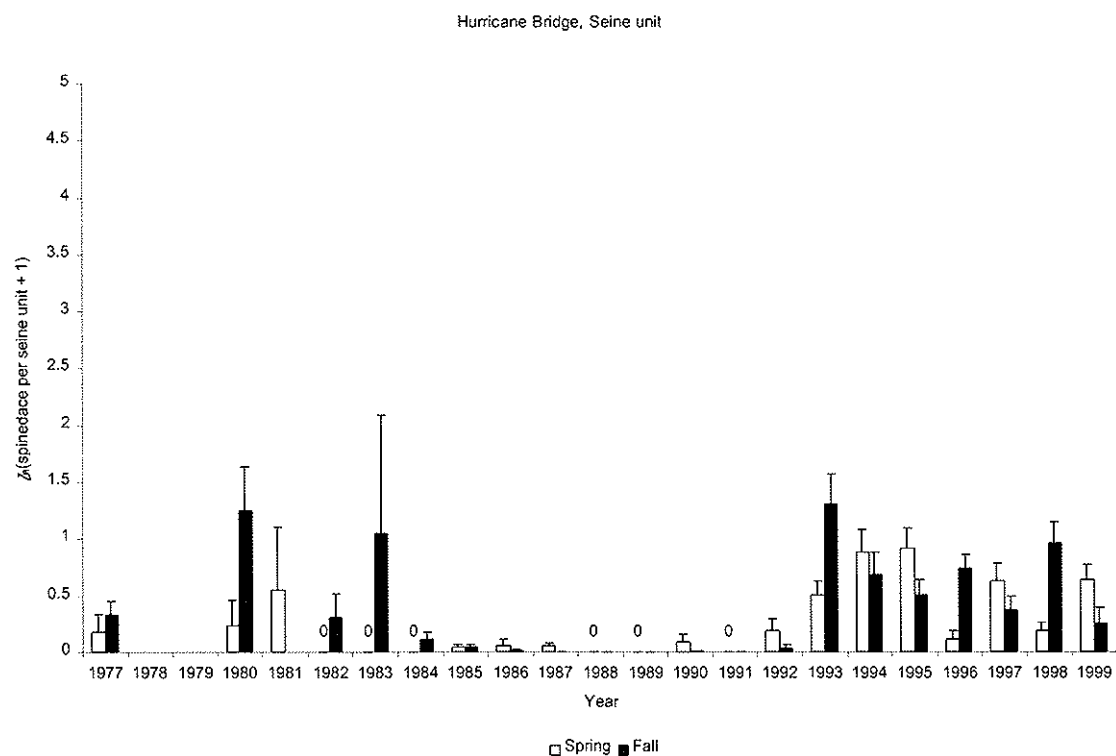
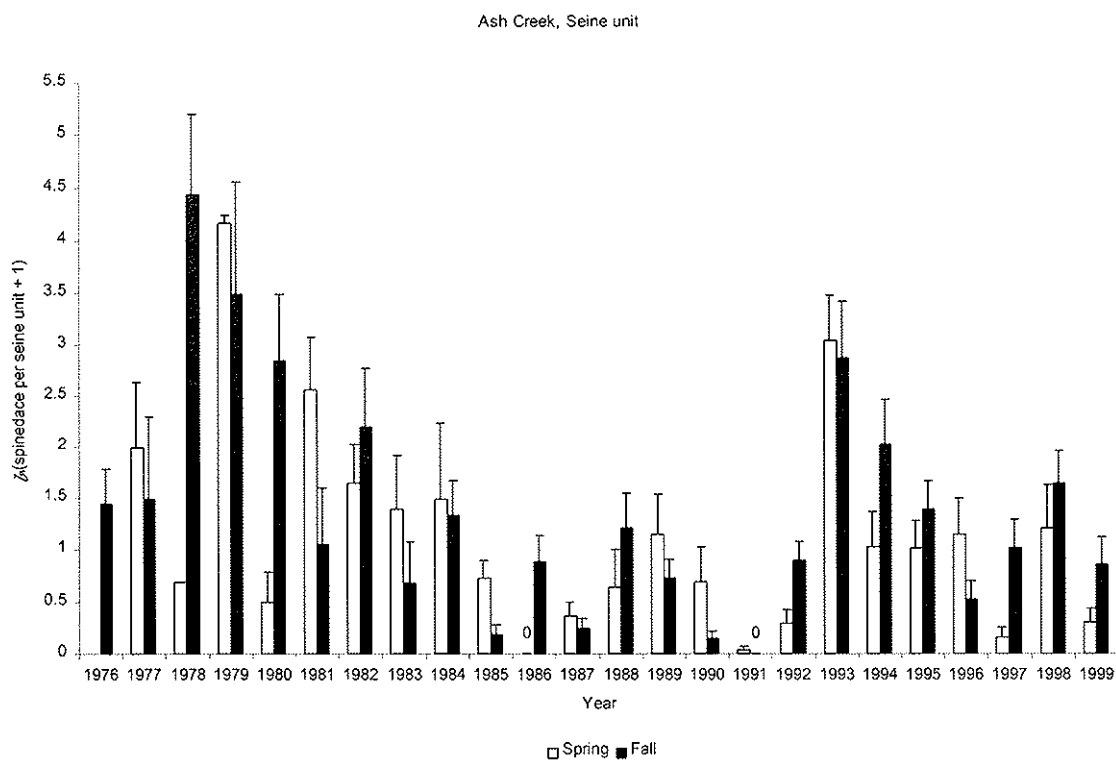


Figure 33a and b. Mean ℓ_n (Virgin spinedace per seine unit +1) by year at (a) Ash Creek and (b) Hurricane Bridge. (0 = sampled and no fish caught. Blank space = no data).

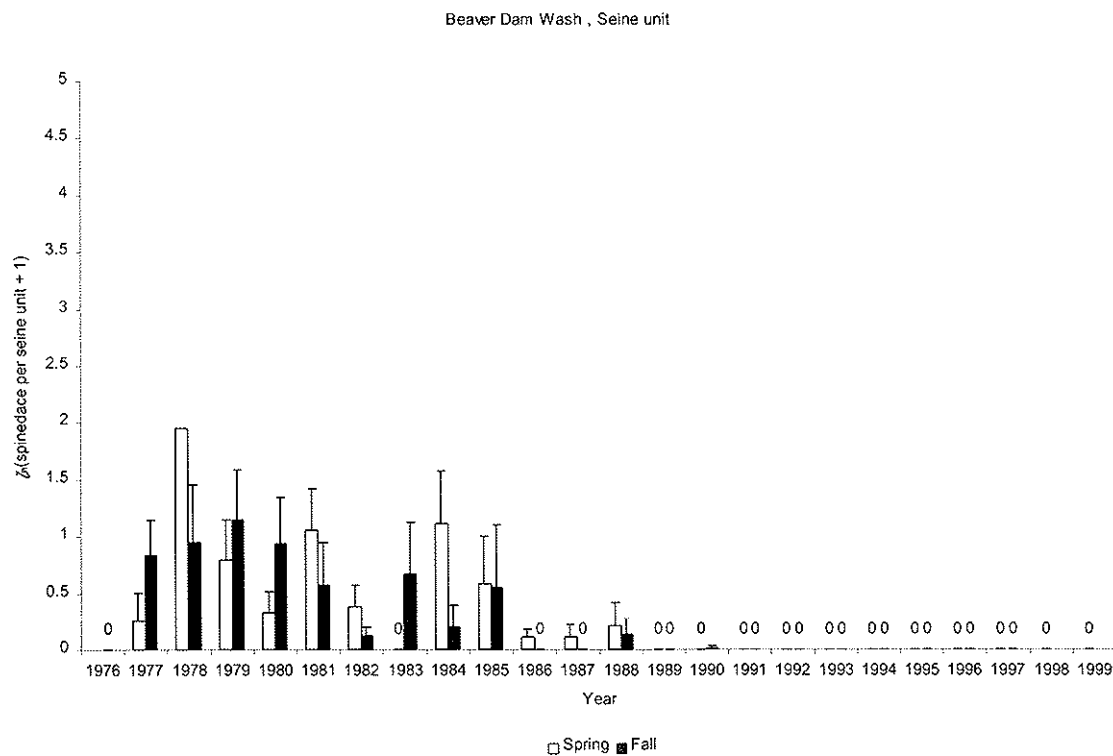
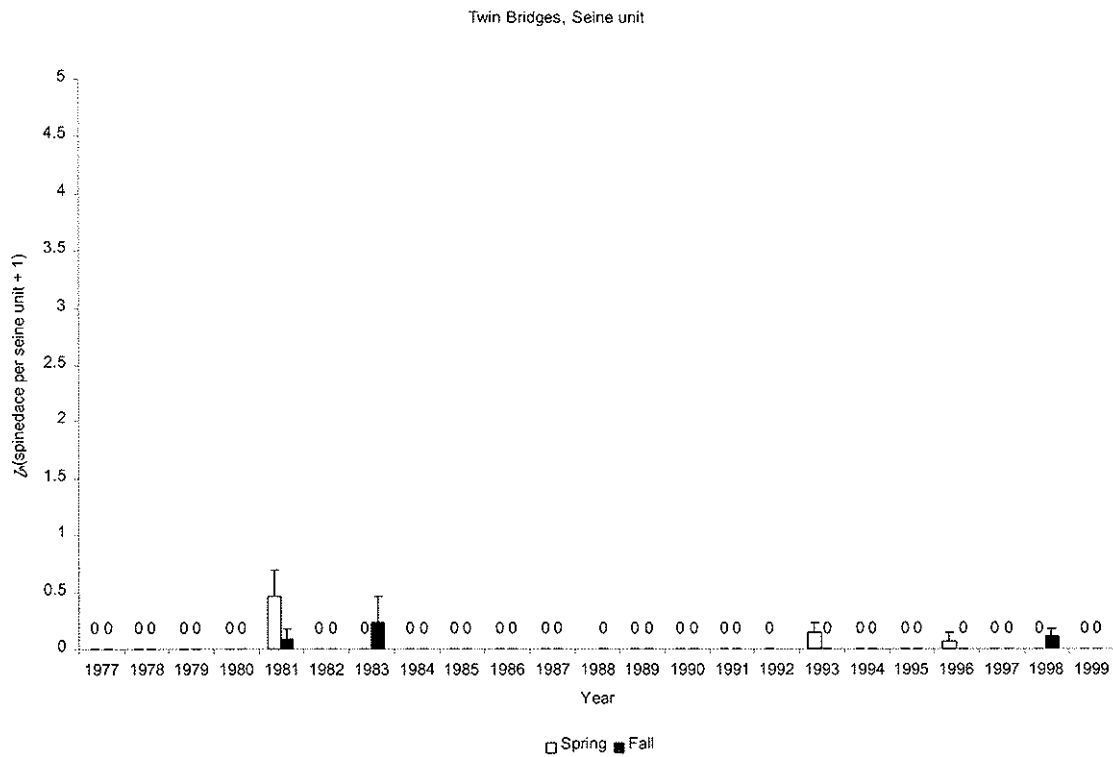


Figure 34a and b. Mean ℓ_n (Virgin spinedace per seine unit +1) by year at (a) Twin Bridges and (b) Beaver Dam Wash. (0 = sampled and no fish caught. Blank space = no data).

We also used a t-test with separate variances and Bonferroni adjusted probabilities to compare mean Virgin spinedace abundance before 1986 and after 1985. We found that, in the spring at Ash Creek and in the fall and spring at Beaver Dam Wash, Virgin spinedace abundance was significantly higher before 1986 ($p \leq 0.009$). Mean Virgin spinedace abundance was higher in the fall at Ash Creek, but the difference was not significant. Conversely, at Hurricane Bridge we found that mean Virgin spinedace abundance in both spring and fall was significantly higher after 1985 ($p \leq 0.01$).

Woundfin/Red Shiner Interactions

Since red shiner are considered to be a major factor in the decline in woundfin in the Virgin River below the Washington Fields Diversion, we wanted to examine the relationship between red shiner abundance and woundfin abundance. As mentioned previously, red shiner numbers didn't really increase significantly at Beaver Dam Wash or above the Virgin River Gorge until after 1985. Therefore, we wanted to compare woundfin abundances at the two stations with red shiner (Twin Bridges and Beaver Dam Wash) before and after 1985. We did this by again using t-tests with separate variances and the Bonferroni adjusted probabilities. We also regressed ℓ_n (woundfin per seine unit) against ℓ_n (shiner per seine unit) to investigate the relationship between red shiner abundance and woundfin abundance.

For spring and fall samples at both stations, we found significantly higher woundfin abundance from 1976-1985 than from 1986-1999 (Figure 35, $p < 0.001$). There was a highly significant, negative relationship between woundfin and red shiner at Beaver Dam Wash for fall samples ($p < 0.001$, $R^2 = 0.643$) and spring samples ($p < 0.001$, $R^2 = 0.578$). At Twin Bridges, the relationships were not as strong, but both spring ($p = 0.011$, $R^2 = 0.27$) and fall ($p = 0.049$, $R^2 = 0.18$) samples at showed significant inverse relationships between woundfin and red shiner. However, the R^2 -values for Twin Bridges were much lower, indicating that far less of the variance in woundfin abundance was explained by red shiner abundance at this station. Additionally, the absence of woundfin at the Beaver Dam Wash Station will continue to inflate the R^2 -value at this station over time.

At Beaver Dam Wash, the precipitous decline in woundfin almost completely coincides with the abrupt increase in red shiner. However, there is some overlap in the timing of the two events (see Figure 31 and Figure 6). Red shiner increased substantially in fall 1985 and remained at about the same abundance level until the early '90s, when they became even more abundant. Woundfin abundance increased slightly from 1985 to 1986, and then dropped in 1987. If the presence of red shiner is the cause of the elimination of woundfin from near Beaver Dam Wash, then it took about a year of high red shiner abundance before the woundfin population collapsed. At the other three stations, other factors may have played a large role in the woundfin declines observed between 1976-1999.

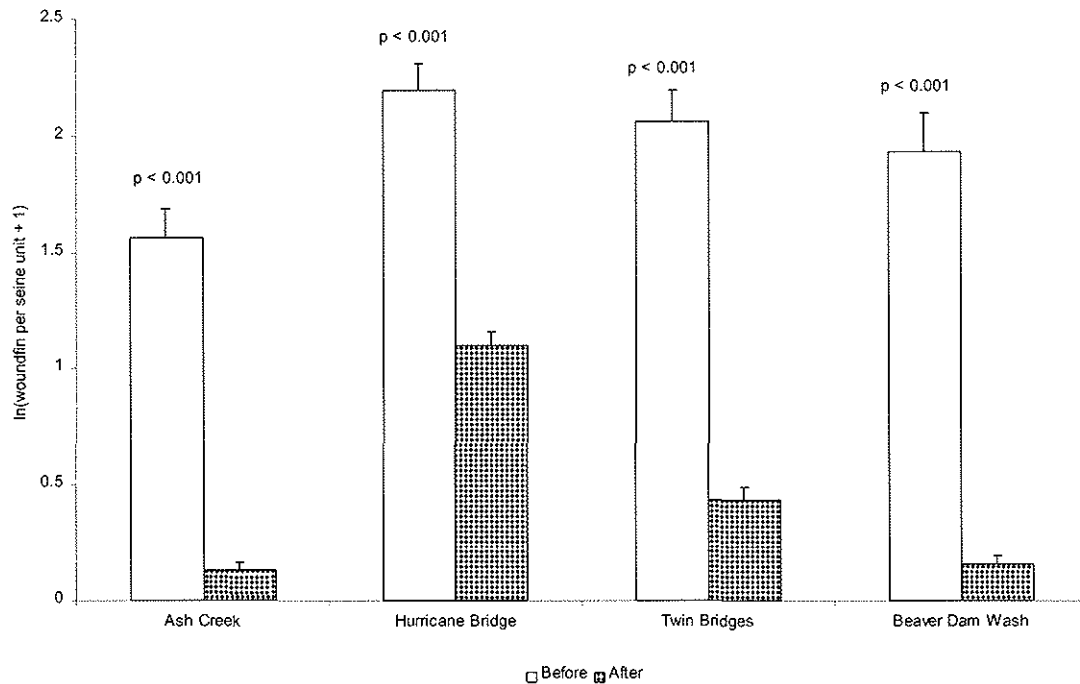
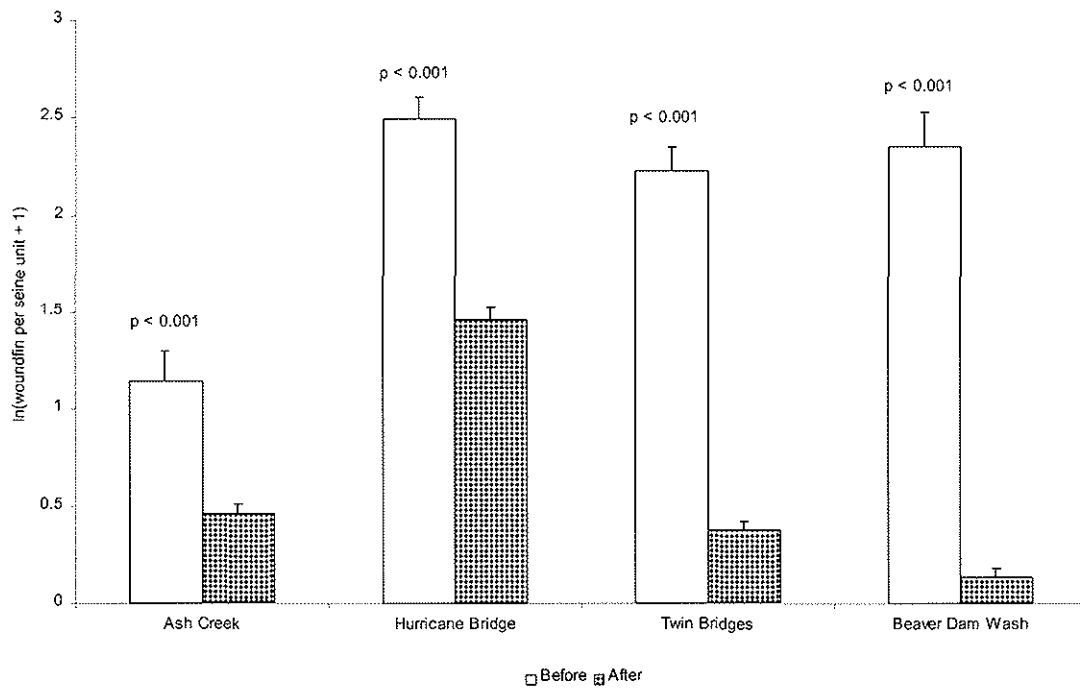


Figure 35a and b. Comparison of mean $\ln(\text{woundfin per seine unit} + 1)$ before 1986 and after 1985 at Ash Creek, Hurricane Bridge, Twin Bridges, and Beaver Dam Wash in (a) fall and (b) spring. Bars represent standard error.

Quail Creek and Other Significant Events

In addition to the biological factors of drought and non-native fish, many anthropogenic factors have most likely contributed to the changes in woundfin abundance over the last 25 years. With the development in the St. George and Mesquite areas, there has almost certainly been a general change in physical habitat and flows caused by human encroachment into riparian zones and increased water consumption. The impact of this trend toward development in the Virgin River Basin is difficult to assess except in general terms. However, a few major human-induced impacts to the system have occurred over the past 20 years. The first of these events was the construction of Quail Creek Reservoir in 1985.

The Quail Creek Reservoir project was completed in 1985. The years after 1985 comprise the time that the Quail Creek Dam has been in operation and separate red shiner presence and absence above the Virgin River Gorge, as well as high numbers of red shiner from low numbers at Beaver Dam Wash. Two of our stations have not been invaded by red shiner and, therefore, can be examined for evidence of changes in woundfin abundance potentially caused by the operation of Quail Creek Dam. Once again, we used a t-test with separate variances and Bonferroni adjusted probabilities to compare woundfin abundance before 1986 with woundfin abundance after 1985 in spring and fall at Ash Creek and Hurricane Bridge. For spring and fall samples, we found significantly higher woundfin abundance per seine unit from 1976-1985 than from 1986-1999 at both stations (Figure 35, $p < 0.001$). Since no red shiner are present at either of these stations, we can clearly say that some other factor has caused a decline in woundfin abundance at these two stations between the late 1970s and early 1980s and the late 1980s and 1990s.

In addition to Quail Creek Dam's daily removal of water from the system, the dike impounding Quail Creek Reservoir burst on January 1, 1989. The resulting peak flows of over 60,000 cfs probably immediately impacted the fish populations in the river, as well as indirectly creating future impacts by altering the physical structure of the river below Quail Creek. All of the stations except Ash Creek would have been affected by this flood. Unfortunately, trying to decipher the effects of the flood is virtually impossible, because several other stressors were at work during this time period. As previous analyses showed, 1989 - 1991 were drought years. Therefore, we would already expect to have depressed woundfin abundance and increased red shiner abundance during this time period, based on what we found in the drought analyses. Additionally, the Virgin River Fishes Recovery Team made three efforts in 1988-89 to remove red shiner from the Washington Fields Diversion to the mouth of the Virgin River Gorge with rotenone. The first of these attempts in early October 1988 was not contained at the mouth of the Gorge, and fish were found dead or distressed as far downstream as Mesquite, Nevada (USFWS 1995). Both the Twin Bridges and Beaver Dam Wash stations would have been effected by this treatment. The remaining treatments in early November 1988 and late August 1989 only impacted the Twin Bridges station.

If we go back to the ANOVAs we performed to look at differences in woundfin, speckled dace, and red shiner abundance between years in the spring and fall at each station, we might be able to examine the combined effects of these events. We used a Tukey Honestly Significant Difference pair wise comparison test to examine the differences between years. At Hurricane Bridge, we saw a significant decrease in woundfin and speckled dace abundance from spring and fall 1988 to spring 1989 (Figure 6, $p \leq 0.002$). However, abundance of both woundfin and speckled dace

rebounded by fall 1989. Therefore, it appears that Hurricane Bridge recovered relatively quickly from the high peak flow caused by the Quail Creek dike failure. The drop in both woundfin and speckled dace abundance in 1990 is more likely a result of the drought period.

At Twin Bridges, we found that woundfin abundances were too low in spring and fall 1988 to show a significant difference between 1988 and 1989, but only one woundfin was caught during spring 1989, and no woundfin were caught during fall 1989. Similarly, we saw very few red shiner and speckled dace in 1989 spring and fall collections (Figure 27). The paucity of fish present at Twin Bridges in 1989 is most likely a result of the rotenone treatments in late 1988 and August 1989. The continued low abundance of woundfin and speckled dace through 1991 is probably the result of drought exacerbating the impacts of rotenone treatments.

Beaver Dam Wash is perhaps the most-difficult station at which to isolate the impacts of any of the above factors. At this station 1988 marked the culmination of a 6- to 7-year downward trend in woundfin abundance. However, the fall collection at Beaver Dam Wash was made after the October 1988 rotenone treatment that would have impacted this reach. Consequently, no woundfin or speckled dace were collected at Beaver Dam Wash in fall 1988 (Figures 7 and 28). Red shiner abundance appeared unchanged. While woundfin abundance had been declining at Beaver Dam Wash since as early as 1981, the combination of increasing numbers of red shiner, the rotenone treatment, and drought may explain the disappearance of woundfin from this station after 1988.

Indicators of Hydrologic Alteration

Both Hurricane Bridge and Ash Creek showed a decline in woundfin abundance after 1985, despite the fact that red shiner, rotenone treatments, and heavy irrigation withdrawals did not effect these areas. The major impacts to these areas are most likely from climatic events such as drought or the new operations of Quail Creek. We attempted to investigate hydrologic changes before and after 1985 using the Indicators of Hydrologic Alteration (IHA) software package (Richter et al. 1996, Richter et al. 1997). This software takes long-term streamflow records and converts them into "ecologically relevant" hydrologic parameters. By specifying a discreet impact period, one can examine the mean and coefficient of variation for these parameters between the two time periods. Differences between the time periods are reflected as the percent difference between the value of the parameter in the pre- and post-impact period. We explored flow data from several of the Virgin River gages with this software to determine if differences in the flow regime pre- and post-Quail Creek Dam operation. Unfortunately, 20-28 years of pre-impact and post-impact data is needed to draw any real conclusions from the IHA results (B. Richter, The Nature Conservancy, personal communication), and our post-impact period was only 15 years long (1985-1999). Some gages did not have 20 years of pre-impact data, either (Hurricane and Bloomington). Therefore, we used this analysis as a cursory examination to see if there was any indication of a change in flow after 1985.

We first ran data from the Hurricane, Bloomington, and Littlefield gages through the software. Tables 6 and 7 show the output from the Hurricane and Littlefield gages. The Bloomington gage data showed the same general trends as Hurricane, so we are not presenting that data. Just looking at the Hurricane Bridge data, we see that the post-1985 flow data have much lower monthly flows, particularly in the spring, where average flows are over 30% lower than pre-1985. The trend toward lower flows is apparent in the second group of parameters as well. They show that the

Table 6. Results of the indicators of hydrological alteration analysis for the Virgin River near Hurricane, Utah (pre-impact 1968-84, post-impact 1985-99).

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre-impact	Post-impact	Deviation Magnitude/%	Pre-impact	Post-impact	Deviation Magnitude/%
Group 1: Monthly Magnitude						
October	119.6	110.6	-9.0/-7.5	.39	.69	.30/78.5
November	153.2	115.2	-38.1/-24.8	.27	.65	.37/137.7
December	193.5	11.5	-81.9/-42.3	.44	.66	.22/48.8
January	211.3	188.6	-22.7/-10.7	.50	.88	.39/77.5
February	269.3	200.1	-69.2/-25.7	.90	.88	-.02/-2.3
March	370.5	256.2	-114.4/-30.9	.82	.98	.16/19.3
April	459.7	305.0	-154.7/-33.7	.79	1.01	.22/27.4
May	580.2	330.9	-249.4/-43.0	.97	1.18	.20/20.9
June	221.0	147.5	-73.5/-33.3	.98	.92	-.06/-6.3
July	121.9	98.6	-23.4/-19.2	.44	.52	.07/16.8
August	133.1	101.8	-31.4/-23.6	.47	.44	-.03/-5.6
September	116.8	130.0	13.1/11.2	.54	.71	.17/32.0
Mean % change			25.5			39.4
Group 2: Magnitude and Duration						
1-day minimum	57.8	44.9	-12.9/-22.3	.36	.46	.10/26.8
3-day minimum	60.0	47.3	-12.7/-21.2	.35	.44	.09/27.1
7-day minimum	63.7	51.2	-12.5/-19.7	.32	.43	.11/33.8
30-day minimum	75.5	62.6	-12.9/-17.1	.35	.40	.05/14.4
90-day minimum	101.5	82.1	-19.4/-19.1	.36	.43	.07/19.2
1-day maximum	2811.4	2307.7	-503.7/-17.9	.90	1.38	.48/52.9
3-day maximum	1672.6	1393.4	-1279.3/-16.7	.82	1.06	.24/29.2
7-day maximum	1185.9	833.6	-352.3/-29.7	.80	.87	.07/8.8
30-day maximum	745.0	479.7	.265.3/-35.6	.77	.85	.08/10.7
90-day maximum	547.7	376.6	.171.1/-31.2	.67	.82	.15/21.9
Mean % change			23.05			24.64

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre- impact	Post- impact	Deviation Magnitude/%	Pre- impact	Post- impact	Deviation Magnitude/%
Group 3: Timing of annual extremes						
Julian date of minimum maximum	241.9	280.7	38.8/21.2	.09	.18	.09/104.8
Julian date of maximum	280.5	88.7	174.2/95.2	.34	.34	0/1.2
Mean % change			58.2			53.0
Group 4: Frequency and and Duration of High and Low Pulses						
Low pulse count	8.1	11.6	3.5/44.0	.60	.65	.04/7.1
High pulse count	4.3	3.1	-1.1/-26.8	.92	.94	.02/1.8
Low pulse duration	10.9	11.7	.8/7.3	.65	1.10	.45/69.9
High pulse duration	4.8	2.7	-2.1/-44.5	1.13	1.38	.25/21.8
Mean % change			30.6			25.2
Group 5: Rate and Frequency of Change in Conditions						
Fall rate	-47.1	-37.9	9.3/-19.7	-.66	-.65	.01/-9
Rise rate	63.2	42.7	-20.6/-32.5	.72	.77	.06/8.1
Number of reversals	132.4	127.1	.36/-5.4	.11	.36	.26/244.4
Mean % change			18.888			84.5

Table 7. Results of the indicators of hydrologic alteration analysis for the Virgin River at Littlefield, Arizona (pre-impact 1930-84, post-impact 1985-99).

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre-impact	Post-impact	Deviation magnitude/%	Pre-impact	Post-impact	Deviation magnitude/%
Group 1: Monthly Magnitude						
October	145.3	145.4	.1/0	.64	.55	-.10/-14.9
November	191	179.3	-11.8/-6.2	.41	.55	.14/33.3
December	232.9	176.7	-56.3/-24.2	.68	.5	-.18/-26.8
January	227.8	263.7	35.9/15.7	.46	.7	.24/51.5
February	320.9	307.1	-13.7/-4.3	1.03	.96	-.07/-7.1
March	356.8	393.8	37.0/10.4	1.00	1.21	.21/21.6
April	424.0	335.2	-88.8/-20.9	.90	.98	.08/9.0
May	442.3	351.2	-91.0/-20.6	1.20	1.24	.04/3.7
June	139.3	150.8	11.5/8.3	1.18	1.10	-.08/-6.6
July	109.6	101.7	-7.9/-7.2	.68	.58	-.10/-14.9
August	189.1	126.7	-62.5/-33.0	.95	.57	-.38/-39.6
September	147.8	172.0	24.2/16.4	.92	.82	-.10/-10.8
Mean % change			13.9			20.0
Group 2: Magnitude and Duration						
1-day minimum	55.9	57.2	1.3/2.3	.14	.32	.18/136.6
3-day minimum	56.9	57.9	1.0/1.8	.14	.32	.19/133.8
7-day minimum	58.1	59.5	1.4/2.4	.14	.34	.19/136.3
30-day minimum	64.2	668.4	4.2/6.5	.20	.39	.19/95.5
90-day minimum	93.0	98.1	5.2/5.6	.45	.49	.04/10.0
1-day maximum	3512.9	3257.1	-255.8/-7.3	1.01	1.23	.22/21.3
3-day maximum	2270.2	1795.7	-474.5/-20.9	1.05	1.07	.01/1.4
7-day maximum	1442.2	1088.1	-354.1/-24.6	.95	1.06	.11/11.9
30-day maximum	750.2	600.7	-149.5/-19.9	.77	.88	.10/13.0
90-day maximum	541.7	519.0	-22.6/-4.2	.69	.81	.12/16.7
Mean % change			9.55			57.64

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre- impact	Post- impact	Deviation magnitude/%	Pre- impact	Post- impact	Deviation magnitude/%
Group 3: Timing of Annual Extremes						
Julian date of minimum	206.5	170.9	35.6/19.4	.13	.15	.02/18.5
Julian date of maximum	187.7	108.9	78.9/43.1	.27	.32	.05/19.7
Group averages			31.3			19.1
Group 4: Frequency and Duration of High and Low Pulses						
Low pulse count	6.5	4.3	-2.2/-34.2	.52	.80	.28/53.6
High pulse count	4.5	3.3	-1.2/-26.2	.67	.89	.22/32.6
Low pulse duration	14.4	8.1	-6.3/-43.7	.61	.80	.20/32.4
High pulse duration	5.0	2.8	-2.1/-42.5	1.97	1.31	-.66/-33.6
Mean % change			36.6			38.1
Group 5: Rate and Frequency of Change in Conditions						
Fall rate	-61.6	-53.4	8.2/-13.3	-.66	-.98	-.31/47.5
Rise rate	88.1	64.4	-23.6/-26.9	.78	1.13	.36/46.3
Number of reversals	120.8	127.7	6.8/5.7	.12	.3	.18/158.5
Group averages			15.3			84.1

minimum flows are lower and that the extended maximum flows are much lower during the post-impact period. However, both the pre- and post-impact data at the Hurricane gage are based on less than 20 years of flow record.

When we ran the analysis on flow data from the Littlefield gage, we saw that many of these differences were dampened by increasing the amount of pre-impact data (1930-1984). However, we still saw lower spring flows, and lower extended high flows (Table 7). Richter et al. (1996) and Alley and Burns (1983) both suggest that a reference site, uninfluenced by the human alteration being examined, can be used as a climatic control. In other words, an upstream gage that is relatively unperturbed should help to distinguish flow alterations that can be attributed to differences in climate versus those most likely caused by the perturbation in question. In our case the Virgin River gage near Virgin, Utah (USGS gage # 09406000) provided a site upstream from Quail Creek Diversion that has little upstream water development (C. Addley, Utah State University, personal communication; USGS website 2001). Table 8 shows the results of the analysis of the Virgin gage for the period extending from 1930-1999. At the Virgin gage both the monthly means in spring and summer, as well as the short-term and extended minimum and maximum flows, were substantially lower after 1985. Overall, these values are perhaps even lower than the data from the Littlefield gage. However, at some point during the mid 1980s the City of St. George began releasing more water from their water treatment plant. This put permanent flow through the Virgin River Gorge and possibly stabilized flow immediately below the gorge. Therefore we also ran the IHA analysis for the Virgin gage for the 1968-1999 time period so that we could compare it to the Hurricane gage (Table 9). Again, we found at least the same amount of deviation between the pre- and post-impact data here as at the Hurricane Bridge gage. Therefore, we can conclude from the IHA analyses that the post-1985 time period appears to have substantially lower spring and summer flows than the pre-1985 period. The extended flow maxima are also much lower after 1985. The two drought periods 1989-1991 and 1994, 1996-97 may have contributed to this finding. The cursory perusal of data from the IHA analysis suggest that the past 15 years have had below average flows throughout the Virgin River basin.

Conclusions

Perhaps it would be best to revisit the primary goal of this study prior to drawing our conclusions. Our objective in statistically analyzing the information in the database was to attempt to identify what factors have contributed to the decline of native fishes (particularly woundfin) in the Virgin River. Additionally, we wanted to address concerns about the best way to present catch data in order to have statistically valid data that would reflect actual populations changes. We believe that using the fish catch data expressed as the $\ell_n(\text{seine unit} + 1)$ will provide relatively reliable and comparable results over aerial measures of CPUE and first pass data. The process of identifying what factors are most important in contributing to the decline of Virgin River fishes is a much more complex issue. We found that all of the factors mentioned in the introduction probably played some role in the decline of woundfin at a minimum of one of our four stations. We also found that each of our four stations had a slightly different set of stressors. Therefore, we will briefly discuss the impacts we felt were important at each station, before drawing overall conclusions.

Table 8. Results of the indicators of hydrologic alteration analysis for the Virgin River at Virgin, Utah (pre-impact 1930-84, post-impact 1985-99).

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre-impact	Post-impact	Deviation Magnitude/%	Pre-impact	Post-impact	Deviation Magnitude/%
Group 1: Monthly Magnitude						
October	137.5	76.6	-60.8/-33.8	.65	.45	-.20/-30.1
November	146.4	97.7	-48.7/-33.3	.50	.60	.10/19.5
December	155.4	127.9	-27.5/-17.7	.53	1.19	.66/123.0
January	164	119.2	-44.8/-27.3	.63	.86	.23/35.9
February	186.5	11.7	-74.8/-40.1	.44	.55	.11/25.6
March	246.1	157.6	-88.4/-35.9	.68	.87	.19/28.6
April	393.4	242.8	-150.7/-38.3	.56	1.27	.70/124.8
May	421.5	303.5	-118.0/-28.0	.78	1.47	.69/88.3
June	148.0	115.1	-32.9/-22.2	.59	.72	.14/23.0
July	125.2	95.5	-29.7/-23.7	.68	.49	-.19/-28.2
August	142.2	107.5	-34.6/-24.3	.57	.57	0/.2
September	149.6	89.7	-59.9/-40.0	.71	.52	-.19/-26.4
Group Averages			31.3			46.1
Group 2: Magnitude and Duration						
1-day minimum	54.3	66.2	11.9/22.0	.34	.30	-.03/-9.6
3-day minimum	57.3	67.3	9.9/17.3	.33	.30	-.02/-6.9
7-day minimum	60.5	69.2	8.7/14.4	.32	.30	-.02/-5.9
30-day minimum	75.00	75.0	.1/.1	.31	.32	.01/2.5
90-day minimum	100.5	82.5	-18.0/-17.9	.39	.36	-.04/-9.0
1-day maximum	2201.1	1572.9	-628.3/-28.5	.85	1.65	.81/95.5
3-day maximum	1218.0	897.6	-320.4/-26.3	.65	1.52	.88/135.6
7-day maximum	841.3	570.1	-271.3/-32.2	.62	1.36	.74/118.0
30-day maximum	547.1	381.9	-165.1/-30.2	.62	1.30	.68/111.2
90-day maximum	379.8	263.4	-116.4/-30.6	.55	1.14	.60/109.1
Group averages			21.94			58.99

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre-impact	Post-impact	Deviation Magnitude/%	Pre-impact	Post-impact	Deviation Magnitude/%
Group 3: Timing of Annual Extremes						
Julian date of minimum	215.7	298.7	83.0/45.4	.14	.19	.05/32.4
Julian date of maximum	195.7	68.1	127.7/69.8	.26	.29	.03/11.7
Group averages			57.6			22.1
Group 4: Frequency and and Duration of High and Low Pulses						
Low pulse count	9.9	5.0	-4.9/-49.6	.55	.81	.26/47.9
High pulse count	5.4	1.9	-3.5/-64.5	.67	1.115	.48/72.3
Low pulse duration	9.4	52.4	43.0/455.5	.60	1.32	.71/118.5
High pulse duration	4.2	1.0	-.2/-4.7	1.00	2.23	1.23/123.3
Group averages			143.6			90.5
Group 5: Rate and Frequency of Change in Conditions						
Fall rate	-55.0	-20.8	34.2/-62.2	-.85	-1.32	-.47/54.7
Rise rate	66.6	33.5	-33.1/-49.6	.92	1.21	.29/31.1
Number of reversals	125.8	59.9	-65.9/-52.4	.20	1.13	.93/459.2
Group averages			54.7			181.7

Table 9. Results of the indicators of hydrologic alteration analysis for the Virgin River at Virgin, Utah (pre-impact 1968-84, post-impact 1985-99).

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre-impact	Post-impact	Deviation Magnitude/%	Pre-impact	Post-impact	Deviation Magnitude/%
Group 1: Monthly Magnitude						
October	201.7	89.5	-112.1/-55.6	.64	.47	-.16/-25.7
November	184.5	104.8	-79.6/-43.2	.61	.47	-.14/-23.3
December	201.1	112.3	-88.8/-47.8	.65	.50	-.15/-23.3
January	232.7	121.4	-111.3/-47.8	.69	.39	-.30/-43.5
February	206.6	197.6	-9.0/-4.3	.41	.60	.19/45.7
March	342.6	225.6	-117.0/-34.1	.70	.59	-.11/-16.2
April	497.2	367.6	-129.6/-26.1	.45	.63	.18/39.5
May	524.2	453.3	-70.9/-13.5	.57	.94	.37/61.6
June	185.6	141.2	-44.4/-23.9	.52	.72	.20/39.5
July	171.0	124.6	-46.4/-27.1	.67	.71	.05/7.3
August	190.3	123.8	-66.6/-35.0	.58	.67	.04/6.2
September	207.1	145.0	-62.0/-30.0	.60	.79	.19/31.8
Mean % change			32.1			30.5
Group 2: Magnitude and Duration						
1-day minimum	60.2	42.6	-17.6/-29.3	.42	.43	.01/1.8
3-day minimum	64.6	46.0	-18.5/-28.7	.40	.43	.03/6.7
7-day minimum	68.9	49.4	-19.5/-28.3	.38	.41	.03/7.3
30-day minimum	91.2	64.0	-27.3/-29.9	.32	.39	.07/22.5
90-day minimum	127.9	86.4	-41.5/-32.5	.42	.42	0.0/-1.0
1-day maximum	3268.9	2132.1	-1136.8/-34.8	.74	.85	.11/14.6
3-day maximum	1737.1	1185.3	-551.8/-31.8	.51	.71	.21/40.5
7-day maximum	1154.8	802.4	-352.4/-30.5	.50	.67	.17/34.9
30-day maximum	690.6	545.9	-144.8/-21.0	.42	.77	.35/83.3
90-day maximum	480.0	379.2	-100.8/-21.0	.43	.64	.21/48.7
Mean % change			28.78			25.43

MEANS (STREAMFLOW IN CFS)			COEFFICIENTS OF VARIATION			
IHA Group	Pre- impact	Post- impact	Deviation Magnitude/%	Pre- impact	Post- impact	Deviation Magnitude/%
Group 3: Timing of Annual Extremes						
Julian date of minimum maximum	206.1	193.7	12.4/6.8	.18	.22	.04/21.1
Julian date of maximum	198.5	153.6	44.9/24.5	.25	.31	.06/22.7
Group averages			15.6			21.9
Group 4: Frequency and Duration of High and Low Pulses						
Low pulse count	9.1	15.7	6.6/72.7	.47	.43	-.04/-8.5
High pulse count	6.9	4.0	-2.9/-41.9	.48	.74	.26/54.2
Low pulse duration	9.9	8.6	-1.3/-13.4	.65	.47	-.19/-28.3
High pulse duration	3.2	2.6	-.6/-19.8	.70	1.05	.35/50.2
Group averages			37.0			35.3
Group 5: Rate and Frequency of Change in Conditions						
Fall rate	-86.3	-56.2	30.1/-34.9	-.72	-.71	.01/-8
Rise rate	105.0	66.2	-38.8/-37.0	.84	.67	-.16/-19.5
Number of reversals	102.0	133.8	31.8/31.2	.17	.17	.17/95.4
Group averages			34.4			38.6

Beaver Dam Wash is the station we used to represent the lower Virgin River. Although woundfin persist in small numbers throughout portions of the lower river (Figures 8 and 9) (Holden and Abate 1999, Holden and Golden 2000), they are essentially extirpated throughout the majority of this section. At Beaver Dam Wash red shiner appear to be the biggest factor in the decline of woundfin. Our regression of woundfin abundance against year showed a precipitous decline in woundfin beginning in the mid 1980s and culminating in 1988, when woundfin disappeared from all Recovery Team monitoring sampling. Simultaneously, red shiner, which were established at Beaver Dam Wash in the early 1970s (Cross 1975), began to flourish by 1986 and 1987. Consequently, we found a fairly strong negative relationship when we regressed woundfin abundance against red shiner abundance at this station. The establishment and growth of a red shiner population at this station is definitely related to the extirpation of woundfin at this station.

Other factors may have played a role in the decline, as well. Woundfin were gone by the mid and late drought years, making it difficult to determine what impacts low flows may have had on the Beaver Dam Wash woundfin population. However, we did see some evidence of drought impacts on woundfin recruitment at Beaver Dam Wash. The October 1988 rotenone treatment may have contributed to the complete eradication of woundfin from this station. The fall 1988 sampling at Beaver Dam Wash occurred after the treatment, and it was the first time that no woundfin were captured. All subsequent sampling efforts have failed to find evidence that woundfin are still present at this site. In short, since woundfin were eliminated by fall 1988, it is difficult to assess the potential impacts of some of the other stressors may have had on woundfin at this station.

The decline and total elimination of woundfin from Beaver Dam Wash is difficult to understand, especially for researchers that sampled the site in the 1970s and early 1980s when woundfin outnumbered red shiner. Holden and Abate (1999) showed that this site is presently a cobble substrate run/riffle habitat, not the sand substrate run habitat more typical of woundfin habitat. Dr. Jim Deacon of the University of Nevada-Las Vegas sampled this station extensively in the 1970s and early 1980s and he recalls the area having extensive sand substrate, as does Dr. Holden of BIO-WEST. We have searched for any information that would describe potential habitat changes at this site, but have found none. We suspect that a major shift in habitat in the Beaver Dam Wash area, resulting in a dominant cobble substrate, likely played a role in the woundfin decline at Beaver Dam Wash, and is also partially responsible for the lack of any rebuilding of the population in recent years. The loss of woundfin populations in the Utah portion of the river also likely contributes to the continuing lack of woundfin at this site, since there are no longer any woundfin moving downstream from strong upstream populations.

Of the three remaining sites, only Twin Bridges has experienced the suite of stressors that affected Beaver Dam Wash. Again we see a general decline in woundfin abundance as evidenced by the significant negative relationship in our regression of woundfin abundance against year. However, the amount of variance explained by year is not quite as strong. The reason for this is, although we saw a sharp decline in woundfin abundance from 1984-1988, woundfin have not completely disappeared from the reach. We did find a significantly lower woundfin abundance after 1985 at Twin Bridges. The sharp decline in woundfin abundance also coincided with the establishment and growth of a red shiner populations at this station. Similar to the results at Beaver Dam Wash, we found a significant negative relationship when we regressed woundfin abundance against red shiner

abundance at Twin Bridges. However, the relationships at Twin Bridges were not nearly as strong as the relationships we found at Beaver Dam Wash. The biggest reason for this is that woundfin persisted in low, but extremely variable numbers from 1989-1999. Since woundfin have persisted in the presence of red shiner at Twin Bridges, we had the opportunity to examine the impact of some of the other factors on woundfin abundance.

We found that woundfin abundance was significantly lower in drought years, especially in the 1989-1991 drought period and the 1994 and 1996-97 drought period. The combined effects drought, the Quail Creek Dike breaching, and the 1988 and 1989 rotenone treatments would explain the extremely low woundfin abundance from 1989-1991. From 1992-1999, woundfin abundances at Twin Bridges were extremely low and variable, but the periods where virtually no woundfin were found all coincide closely with periods of drought. However, the effects of drought may be confounded by the effects of downstream drift. We found a significant positive relationship between mean woundfin abundance at Twin Bridges and mean woundfin abundance at Hurricane Bridge, indicating that drift may account for some of the woundfin abundance at Twin Bridges. In low flow years, dry sections of river in between the two stations may prevent any woundfin from reaching the Twin Bridges station. A combination of factors appear to be involved in the continued low numbers of woundfin at Twin Bridges, although the crucial period of decline still seems tied to the appearance of red shiner.

Red shiner have been contained to below the Washington Fields Diversion, mainly through the poisoning efforts of the Utah Division of Wildlife and others involved with the Virgin River Fishes Recovery Team. Our remaining two stations are above this diversion, and free from red shiner. If red shiner are the sole factor responsible for the decline in woundfin abundance, then we would expect not to see a decline in woundfin over the years at these two stations. We did find significant negative relationships when we regressed woundfin abundance against year at each of these stations. We also found that woundfin abundance after 1985 was significantly lower than before 1986 at both stations, indicating that at some point during the 1980s, a downward trend in woundfin population abundance began at all stations, with or without red shiner.

At Ash Creek, we see a sharp drop in the woundfin abundance from 1985 to 1986, which Hardy et al.(1995) attributed to sinkholes increasing the amount of flow from Pah Tempe Hot Springs, thereby negatively impacting water quality. They also reported that woundfin abundance rebounded by 1986. However, Figure 6 shows that over the long term woundfin abundance has not returned to pre-1985 levels at Ash Creek. Gregory and Deacon (1994) suggested that the lowered woundfin abundance at Ash Creek might be the result of Quail Creek Diversion seriously reducing flows in the stretch from Pah Tempe Hot Springs to Quail Creek and that the flows were too low to dilute the effect of water quality from the hot springs. When we analyzed the data for Ash Creek, we found that drought significantly lowered woundfin abundance and most likely recruitment. Low flows seemed to have a negative impact on woundfin abundance and recruitment at all stations. Figure 6 shows that after the initial dramatic decline of woundfin abundance in 1985, there was a rebound that lasted through 1989. Woundfin abundance then dropped off again in 1990-91. This decline was followed by another period of recovery from 1992-1994. Another sharp decline occurred in 1995-1996. The decline culminated in 1997, when no woundfin were captured at this station. No woundfin were captured at Ash Creek from fall 1996 until April 2000

(Figure 6a). The periods of sharp decline in 1990-91 and 1995-97 both coincide with drought periods. From the data available, we can conclude that the initial combined impact of Quail Creek Diversion operations and the sinkholes at Pah Tempe Hot Springs lowered woundfin abundance. The low flows caused by the operation of Quail Creek Diversion may have kept woundfin abundance at low levels. The diversion-induced low flow levels appear to have exacerbated the already negative influences of drought, thereby not allowing the population to recover and leading to the near extirpation of the species from this section of the river in 1997.

Conversely, the stretch of the river below Quail Creek has a minimum 86 cfs flow (or natural flow) required by the USFWS Biological Opinion for Quail Creek Dam and Reservoir. The Hurricane Bridge station is in this stretch. Hurricane Bridge has had the highest and most-consistent numbers over the past 25 years. However, we still saw a decline over that time period at this station. Major impacts to this population are apparent in spring 1989, 1990-1991, and 1996-1999. Hurricane Bridge is immediately below the outflow of Quail Creek Reservoir; therefore, it probably received the brunt of the high flow caused by the dike failure in January 1989 (66,000 cfs at the Hurricane gage), which would explain the decrease in woundfin abundance from 1988 to spring 1989. Hurricane Bridge was the only station where woundfin abundance showed significant decreases between all of our drought comparisons (except no difference between early drought years and non-drought years). The amount of spring runoff also explained over 40% of the variation in fall woundfin abundance at this station, highlighting the significant effect of flow on woundfin at this station. Drought conditions explain the declines in woundfin abundance in 1990-91 and 1996-97. However, woundfin abundance failed to rebound with flows at this station in 1998 and 1999, raising concerns that the woundfin population at this station may be in peril, as well. If repopulation from upstream sections has helped woundfin populations to rebound in the past, then the crash of the Ash Creek population may be influencing the ability of Hurricane Bridge to rebound after perturbation.

In addition, the recent increase in Virgin spinedace at Hurricane Bridge also suggests that some other factor or factors may be affecting woundfin in this area. Since Virgin spinedace are typically found in cooler tributary streams, where as woundfin are found in the mainstem, this recent increase suggests that the Hurricane Bridge area has become more tributary-like in some factors, such as water quality. This change may be the reason woundfin have not responded to higher flow years in the later 1990s. BIO-WEST conducted a woundfin population estimate for the Hurricane Bridge area in the late 1970s and early 1980s and compared it with 1998 estimates reported under a separate U.S. Bureau of Reclamation contract in December 1998 using the monitoring data. For the early years, the average population estimate was over 13,000 woundfin for the 8-mile reach above Washington Fields Diversion. For 1998 the estimate was just over 1,600 woundfin. These estimates show the magnitude of the woundfin population decline in the Hurricane Bridge area as reflected in Figure 6b.

In conclusion, we have shown that a myriad of factors have been involved in the decline of woundfin in the Virgin River. Red shiner abundance and low flows seem to be the two factors explaining the largest amount of variation in woundfin abundance. In the areas below the Washington Fields Diversion, red shiner have had a detrimental effect on woundfin populations, but it is difficult to isolate which other factors have also been involved in the woundfin decline

because so many stressors have impacted those areas. However, the rotenone treatments, along with flow alterations caused by Quail Creek Dam and irrigation diversions, probably played a role in the decline at these stations, too. The upper two stations provide good evidence that woundfin populations are fairly dependent on certain amounts of flow. With minimum flow differentiating Ash Creek from Hurricane Bridge, it appears that Ash Creek clearly shows the negative impacts that low flows have on woundfin populations. The population crash in 1997 at this station also shows the vulnerability of woundfin populations to perturbations, such as drought, once they have reached a critically low level.

Perhaps Hurricane Bridge provides us with the best information on what disturbances impact woundfin populations; other than the dike breach in 1989, the only clear disturbances at this station have been drought and changes in flow and water quality resulting from the construction of Quail Creek Reservoir. The effects of drought at other stations may be masked by more-obvious confounding factors. Hurricane Bridge showed that low flows negatively impact woundfin survival and recruitment. Our analysis of summer 50% exceedence flows showed that summer flows less than 100 cfs resulted in lower woundfin numbers than flows above 100 cfs. The downward trend in woundfin numbers at Hurricane Bridge may be a reflection of the effect of extended flows below 100 cfs from a combination of drought and the minimum 86 cfs flow below Quail Creek Reservoir. In addition, the inability of the population at Hurricane Bridge to quickly recover after 1996-97 offers some support to the idea that a healthy woundfin population upstream from a particular area may be important in maintaining woundfin abundance after disturbances. The inability to rebound may also show that subtle changes in the river resulting from water development may have greater impacts than anticipated. The data from all the stations show that once woundfin abundance levels reach a certain point, any prolonged disturbance could bring the population to the brink of local extinction. Currently, there are no healthy woundfin populations remaining in the Virgin River or any sections of the river that are unaffected by human-caused disturbances.

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APPENDIX A

MODIFICATION AND SUMMARIZATION OF THE DATASET

APPENDIX A

MODIFICATION AND SUMMARIZATION OF THE DATASET

The goal of this exercise was to reduce and summarize the Virgin River dataset into a more manageable size and structure that could be easily manipulated and subjected to statistical analyses.

Primary steps:

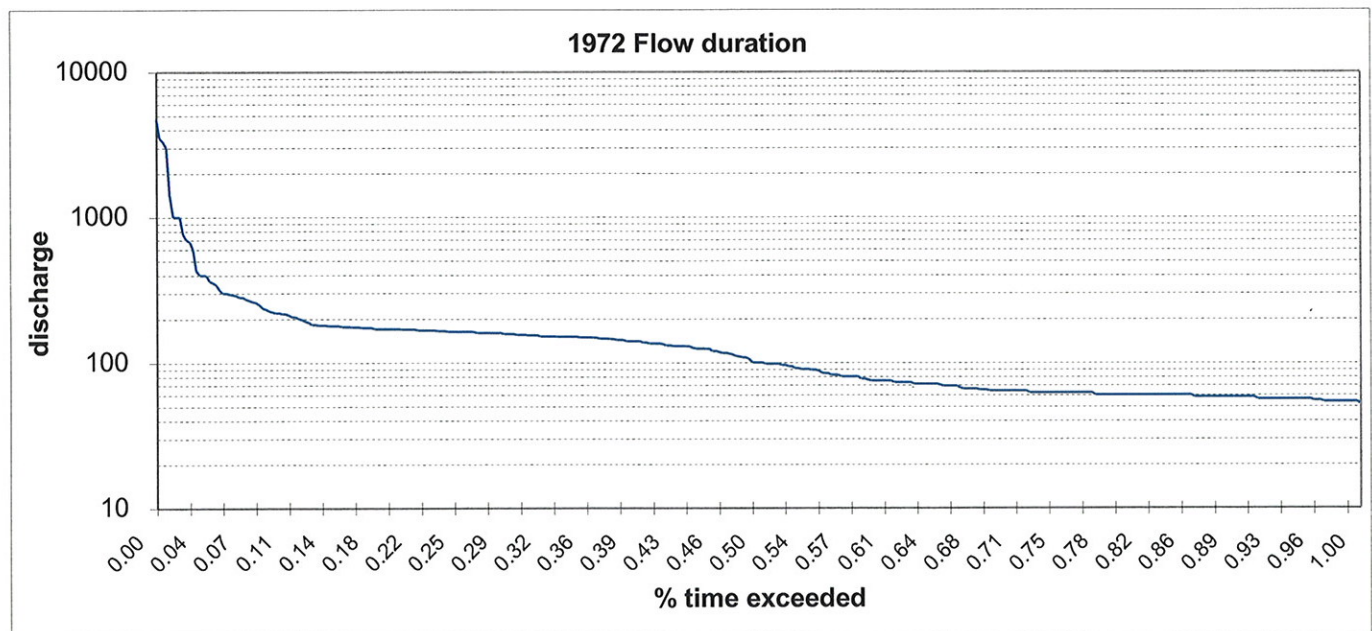
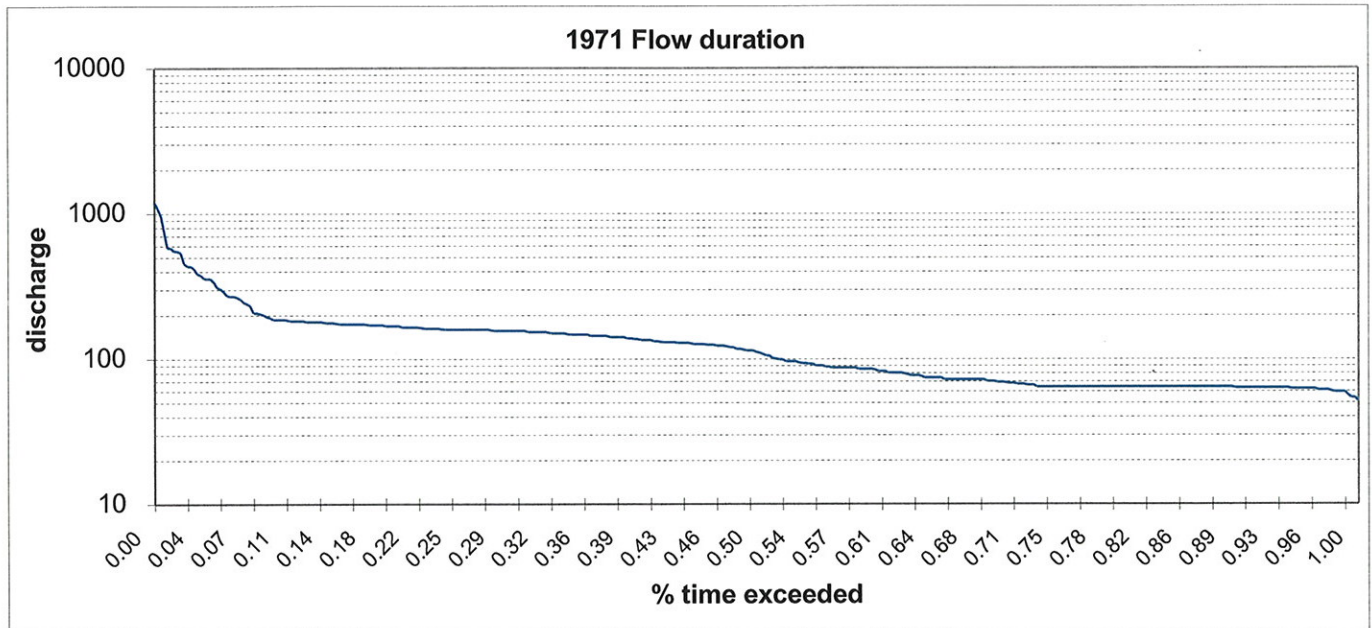
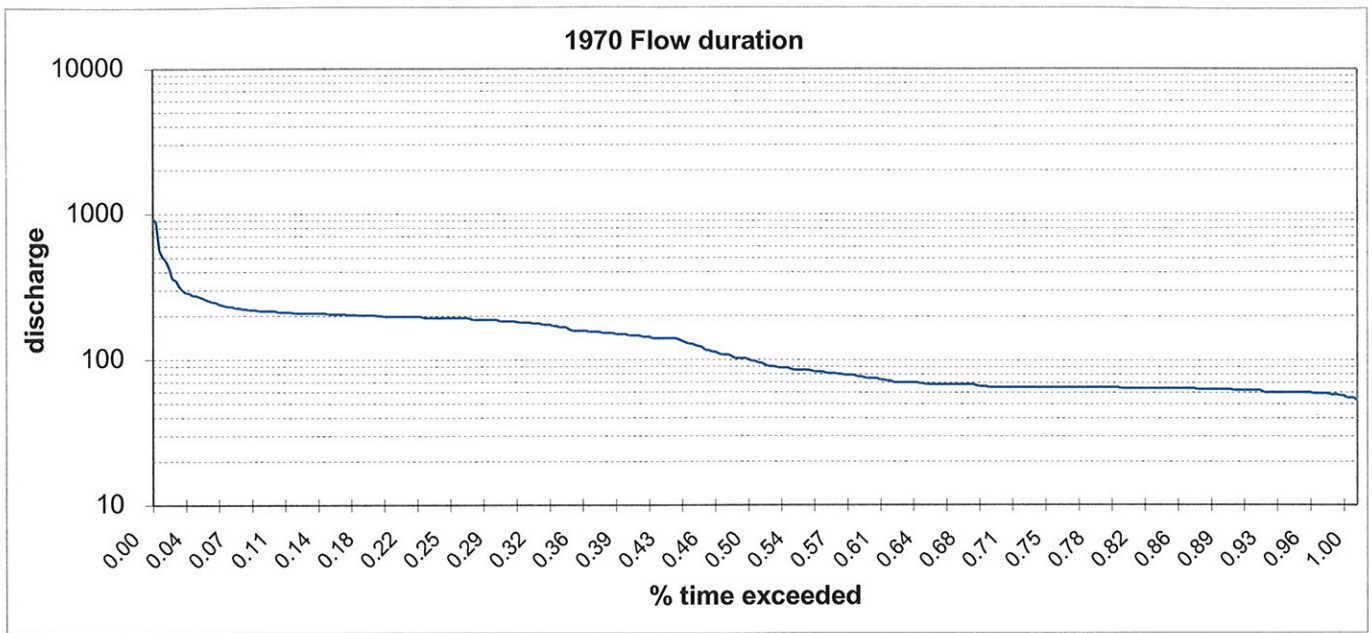
1. We queried all seining data from Ash Creek, Hurricane Bridge, Twin Bridges, and Ash Creek (boundaries defined within the report), using the Report Query (data by individual seining units) option within the database.
2. A record indicating zero woundfin was inserted for each sample in which no woundfin were caught.
3. We queried the master data table for all seining samples taken at the four stations. We then compared these samples with the records we had previously queried and added zeros for samples in which no fish were caught.
4. Woundfin, shiner, and speckled dace were selected. (All other species excluded.)
5. Records for each pass in a sample were reduced to a single record including number of woundfin caught in the first pass, the sum of woundfin, speckled dace, and shiner caught in all passes and the number of passes (as well as data identifying and describing each sample).
6. In order to make the data set more complete, we utilized data from close sites and dates to supplement missing collections. At Ash Creek, we substituted June collections for missing spring collections in 1976, 1977, 1982, 1993 (July), and 1998. Additionally, the fall collections from 1980-1982 and the 1981 spring collection came from river mile 95.96 (above LaVerkin Creek). At Hurricane Bridge we used a July collection in 1993 and a June collection in 1998 to substitute for missing spring collections, as well as a November collection in 1999 to substitute for a missing fall collection. We utilized June collections in 1976, 1977, and 1992, and a July collection in 1998 in exchange for missing spring collections in those years at Twin Bridges. We also used data collected at river mile 74.37 (Above Johnson Diversion) in fall 1988, river mile 69.11 (I-15 Bridge) in fall 1991, and river mile 72.33 (Twin Bridges at return ditch) in spring 1993 to represent Twin Bridges. Finally, we used June collections in 1976, 1977, 1993 (July), 1997, and 1998 at Beaver Dam Wash to substitute for missing spring collections in these years.

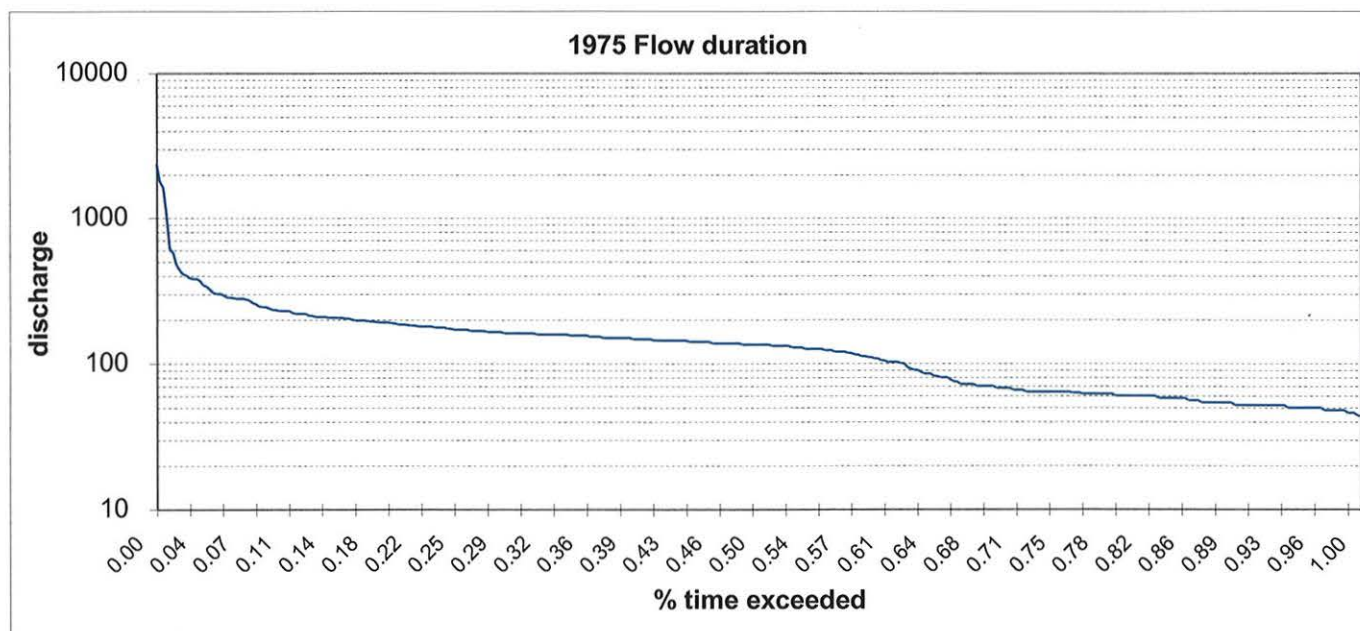
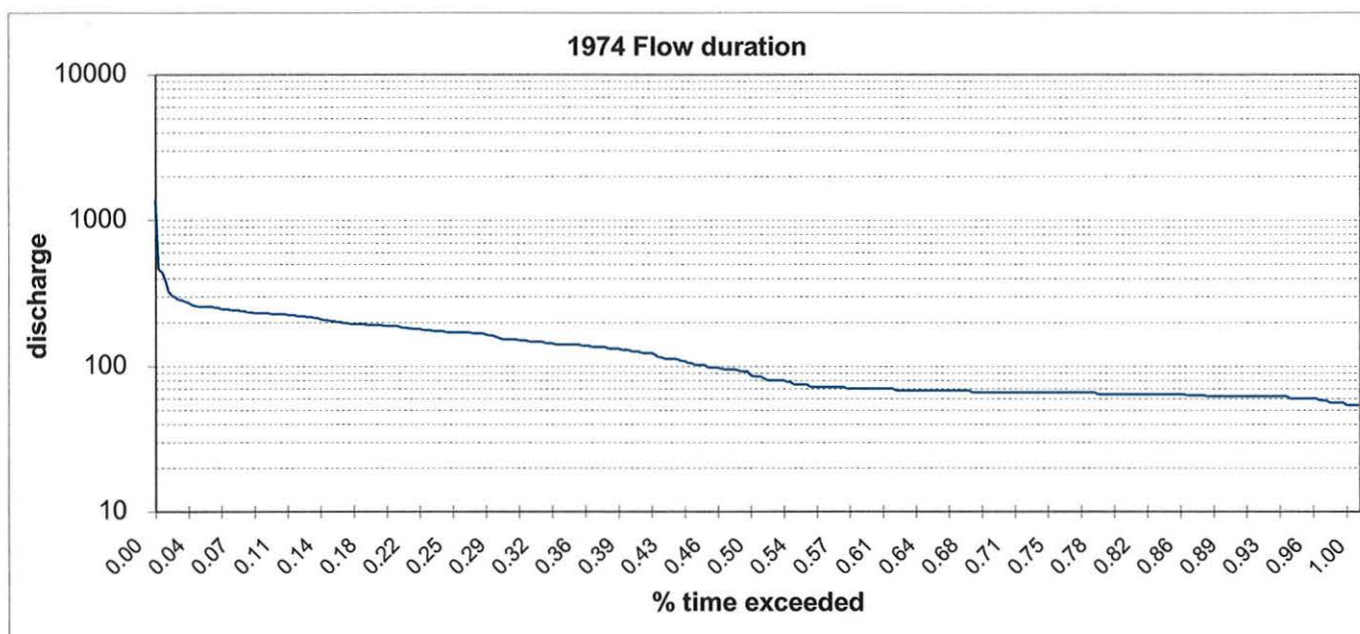
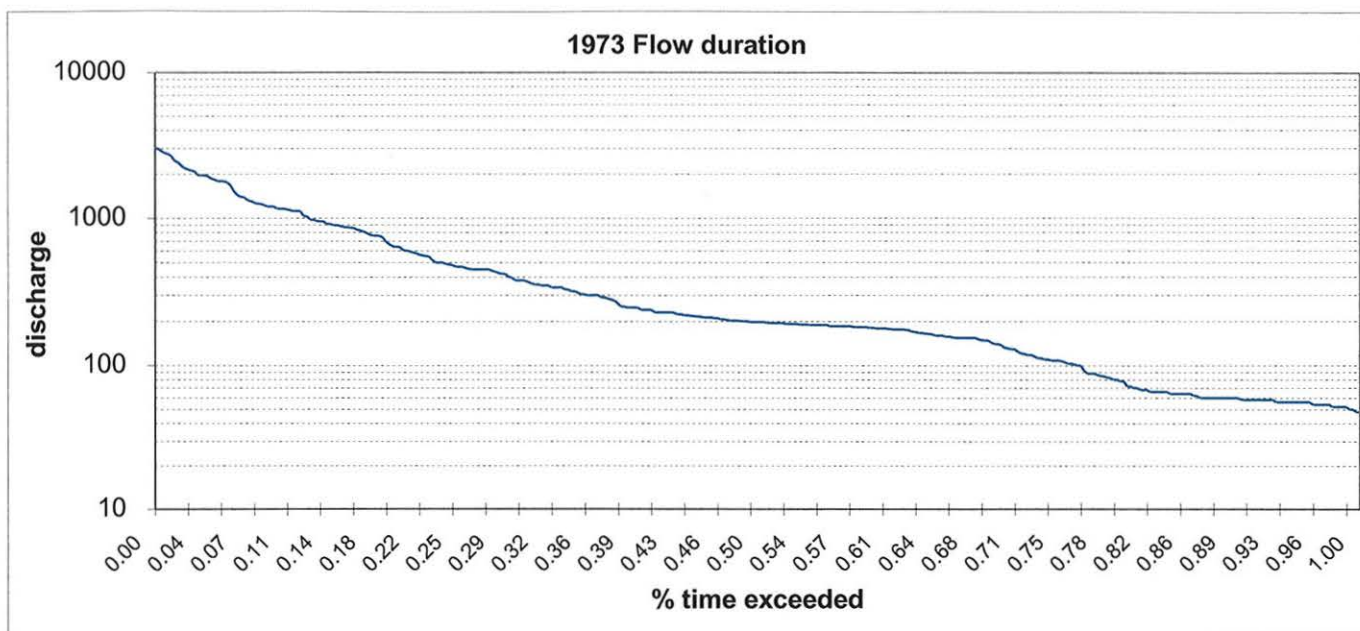
7. All years (1976-1999) and stations were combined into a single file.
8. A column (variable) for season was created using the following categories: Fall, 8/15-11/14; Winter, 11/15-2/14; Spring, 2/15-5/14; Summer, 5/15-8/14.
9. Records in which only one pass was taken were excluded.
10. Woundfin density estimates (number of woundfin per 100 meter²) were examined and subsequently rejected because of high variability (relative to number of fish caught in first pass or in seining unit), unreliable area values, and because the area sampled was often dependent on subjective assessments of habitat availability and likelihood of catching fish, rather than a predetermined, standardized, random sampling strategy.
11. From examination of scatterplots and residual plots, it was determined that the natural logarithms of woundfin numbers caught would be more appropriate for most analyses. Additionally, rare extreme values do not influence the means of natural logarithms as much as they do the raw means.
12. If three or fewer samples were taken in a given year at a given station, those records were excluded from the analyses. The following stations and years were excluded: AC78, AC81, AC83, BDW78, HB83, TB79, and TB81. These were later put back in ALLSUM.xls.
13. Estimates of discharge on the day of sampling were added to the dataset. For the Ash Creek and Hurricane Bridge stations, values from the gage near Hurricane, Utah, were used. For Twin Bridges, flows near Bloomington, Utah, were used. For Beaver Dam Wash, values from Littlefield, Arizona, were used. Several missing values had to be estimated by fitting a regression based on discharge at another station.
14. Missing water temperature values (about 75% of the samples) were estimated using a regression equation based on day of the year and time of day.
15. The number of habitat categories was reduced to be useable in statistical analyses. Adjectives were eliminated (e.g., "slow run" became "run"). Multiple descriptors were reduced to a single descriptor (e.g., "run/pool" became "run," "pool/run" became "pool"). Weird descriptors (e.g., sand, LB) were replaced with "UNK" (unknown).
16. Numbers of red shiner and speckled dace per seine unit (sum of all passes in a sample) were added to the file.
17. Records removed in steps 9 and 12 were restored to the dataset. Statistical results were essentially the same with or without these records, so they were included in the final dataset.

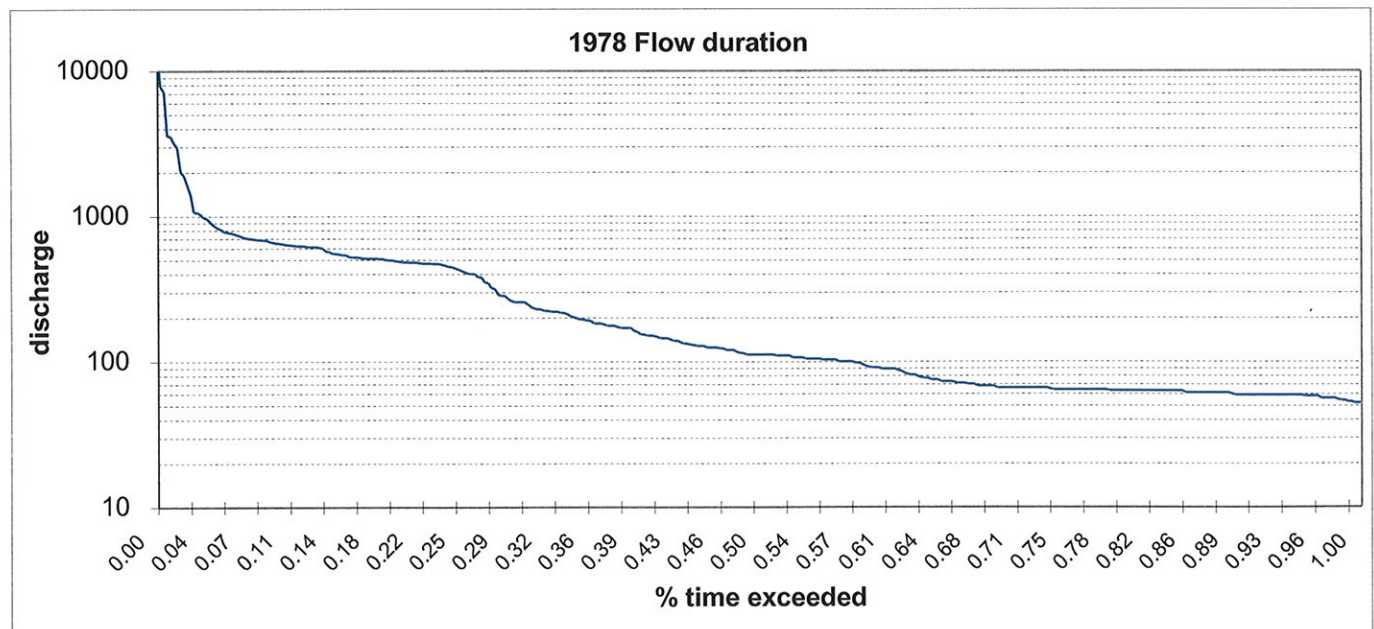
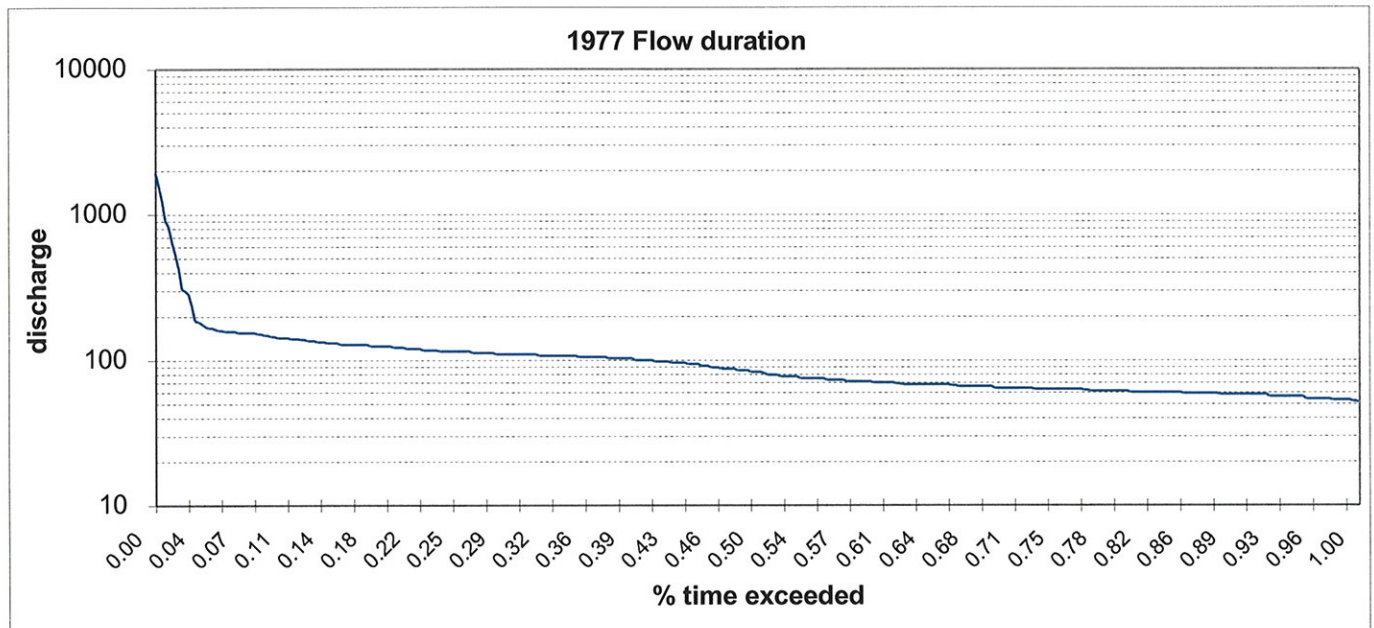
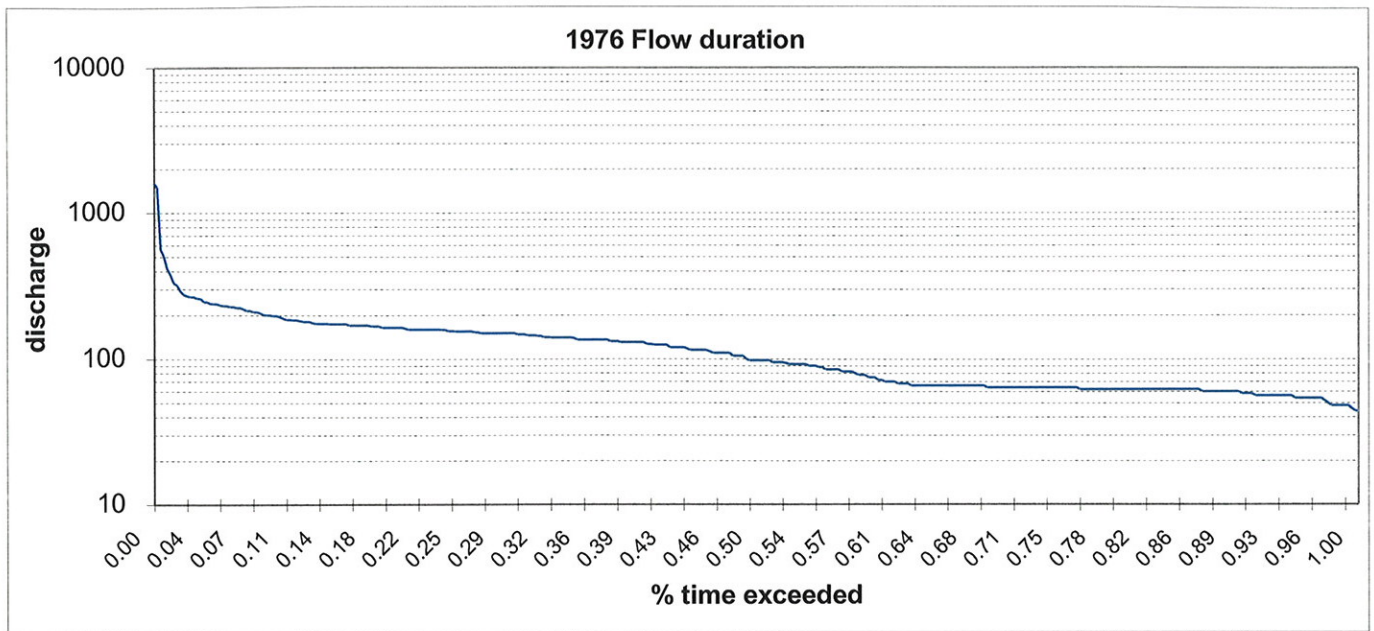
18. Spring and fall woundfin estimates were graphed for the four stations.
19. Speckled dace and red shiner (in spring and fall) were graphed at all stations.
20. Using the same steps we created another file for the river sections portrayed in Figures 8-10.

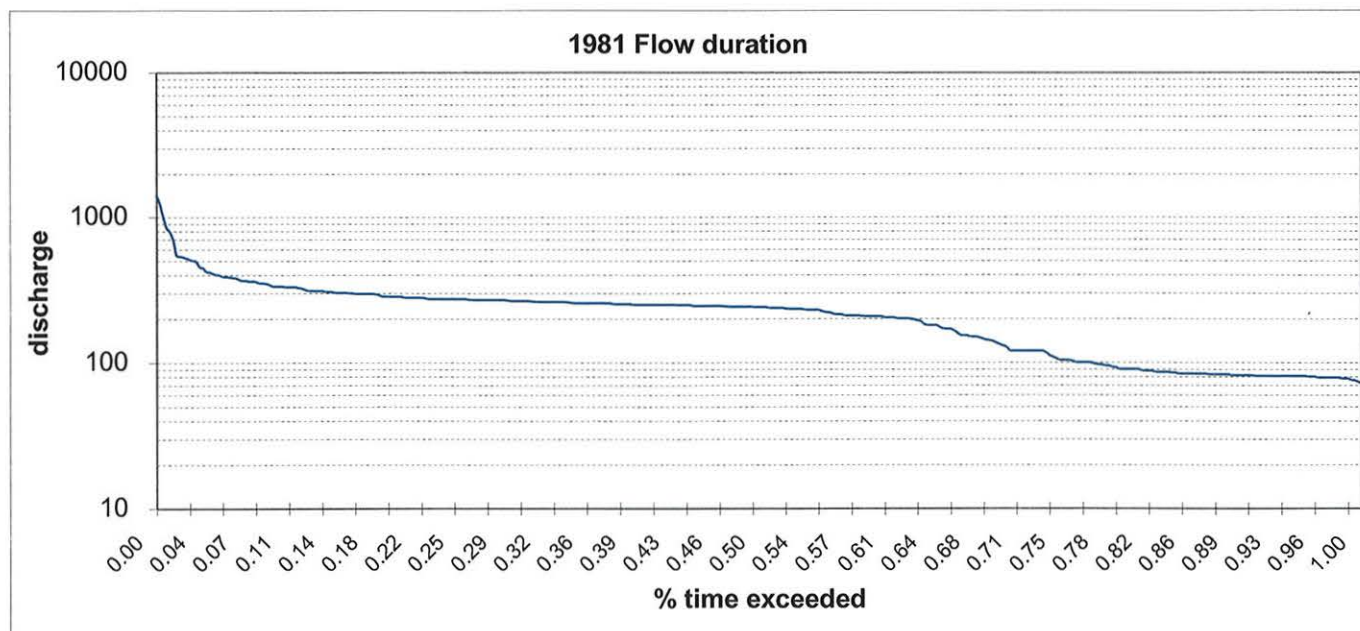
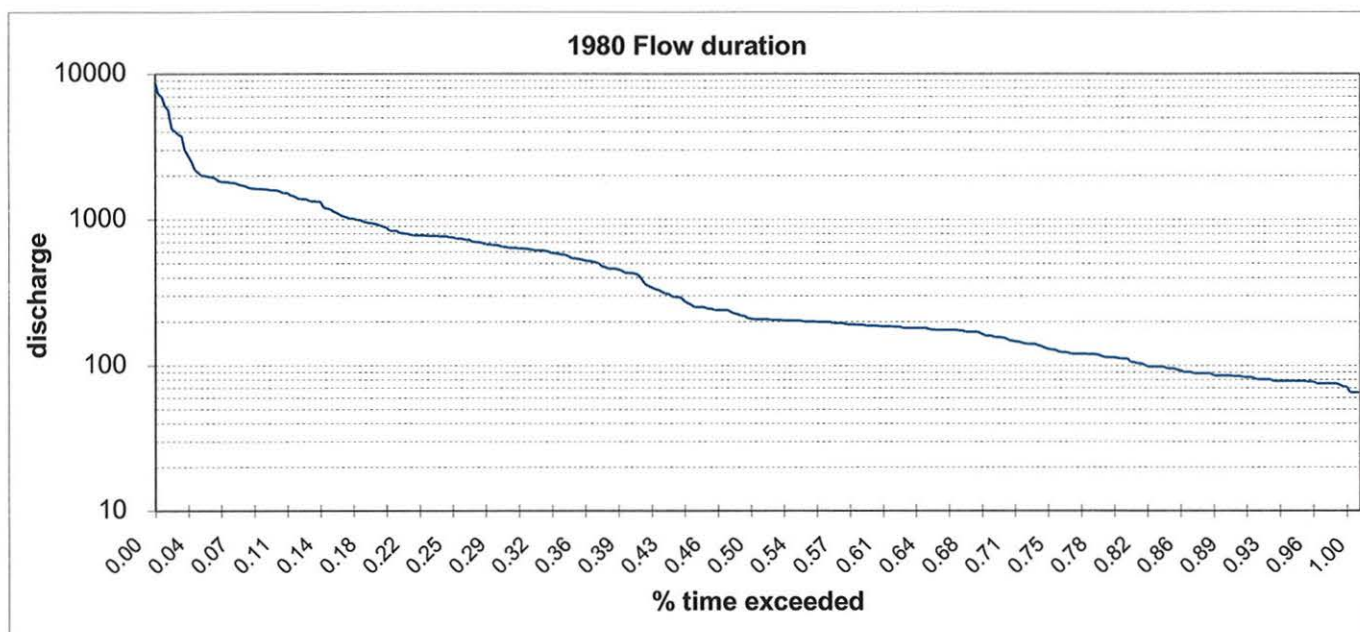
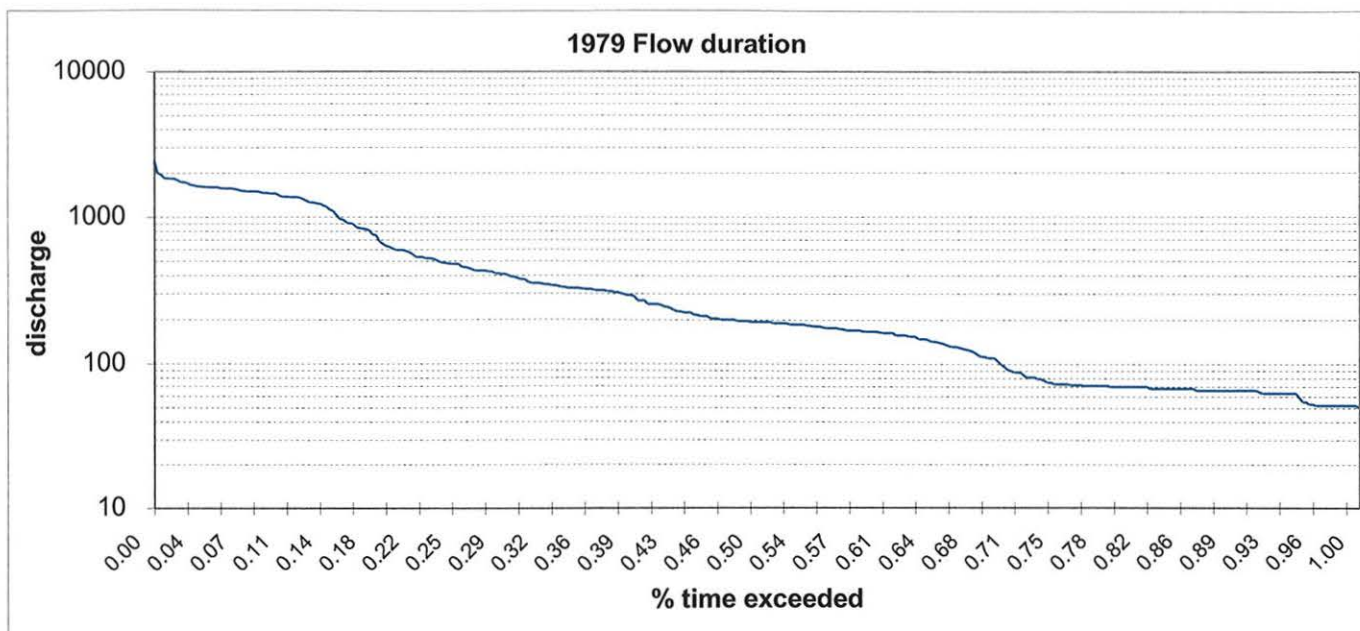
APPENDIX B

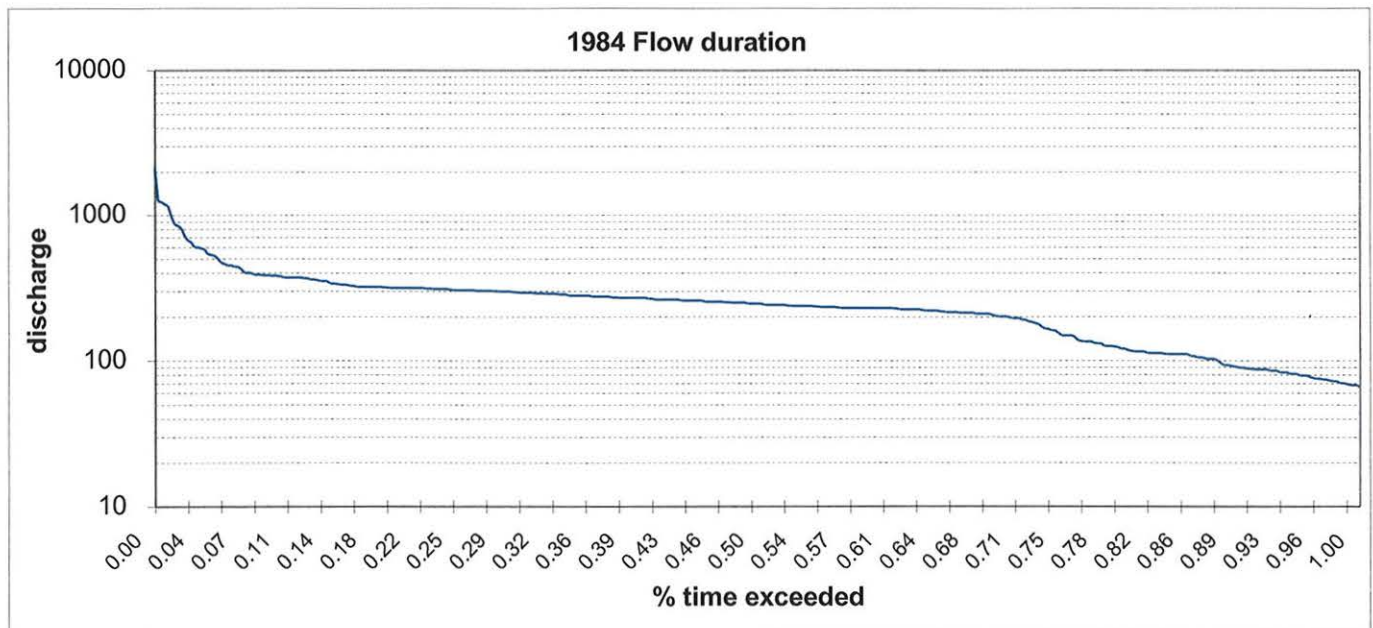
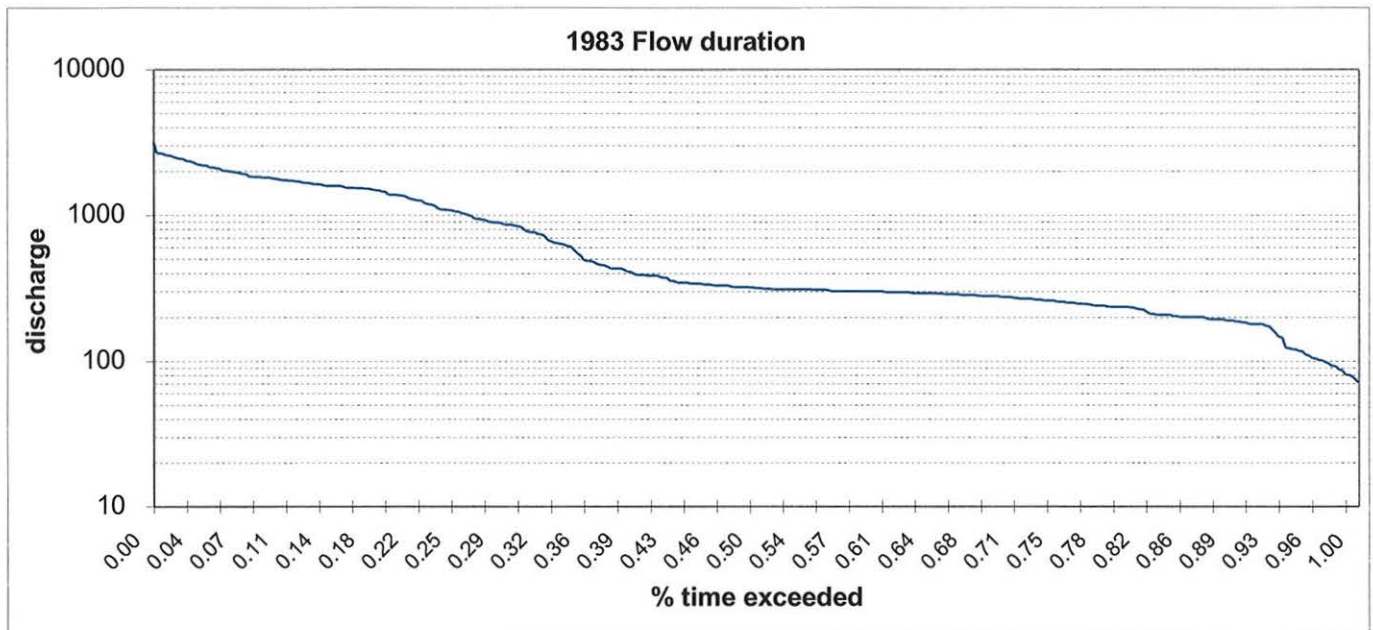
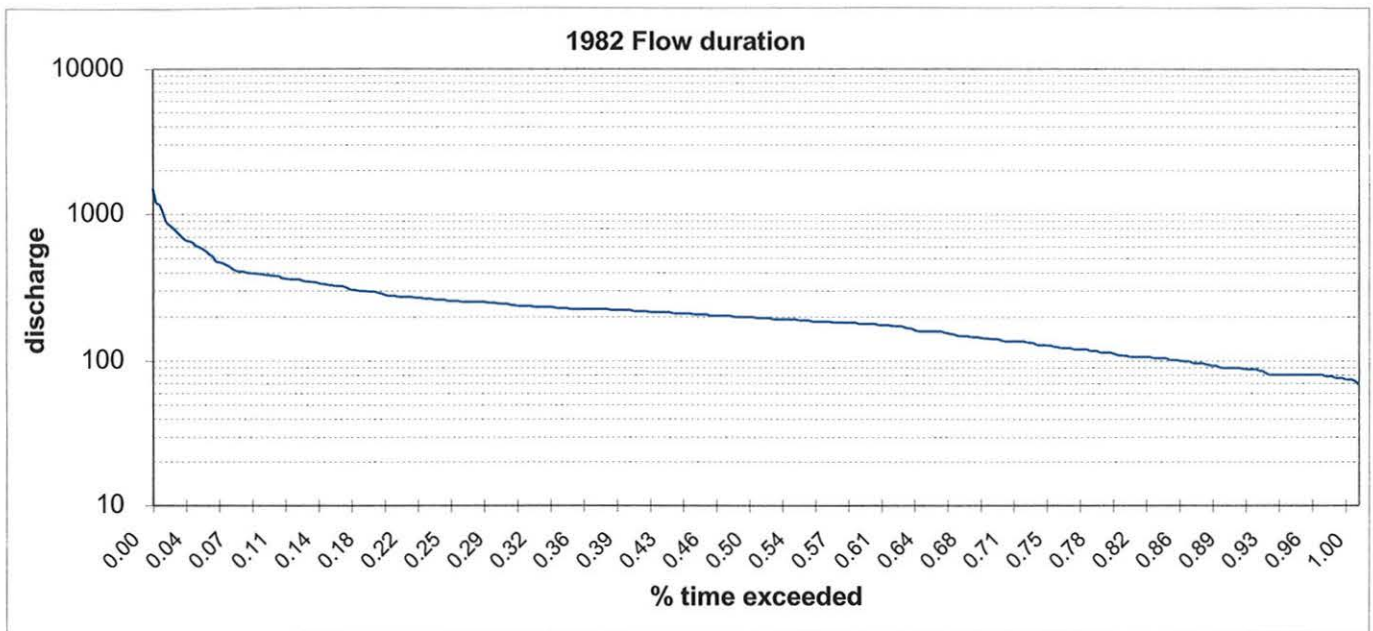
FLOW DURATION CURVES 1970-1999

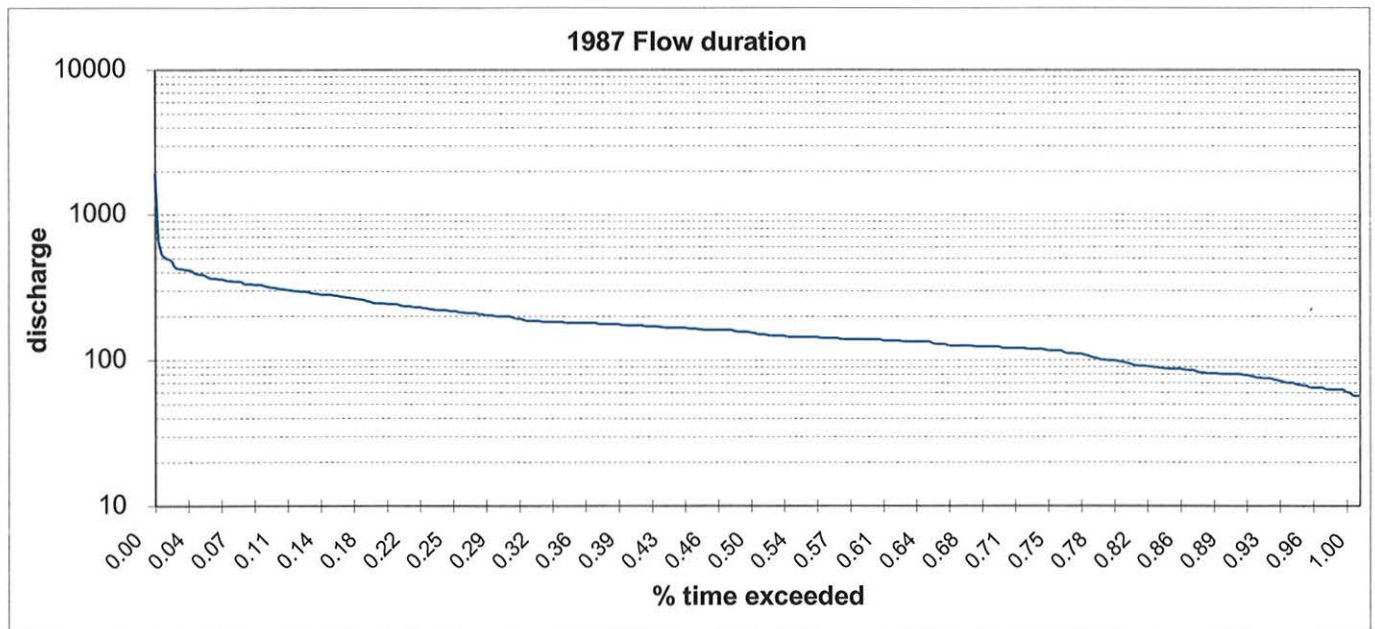
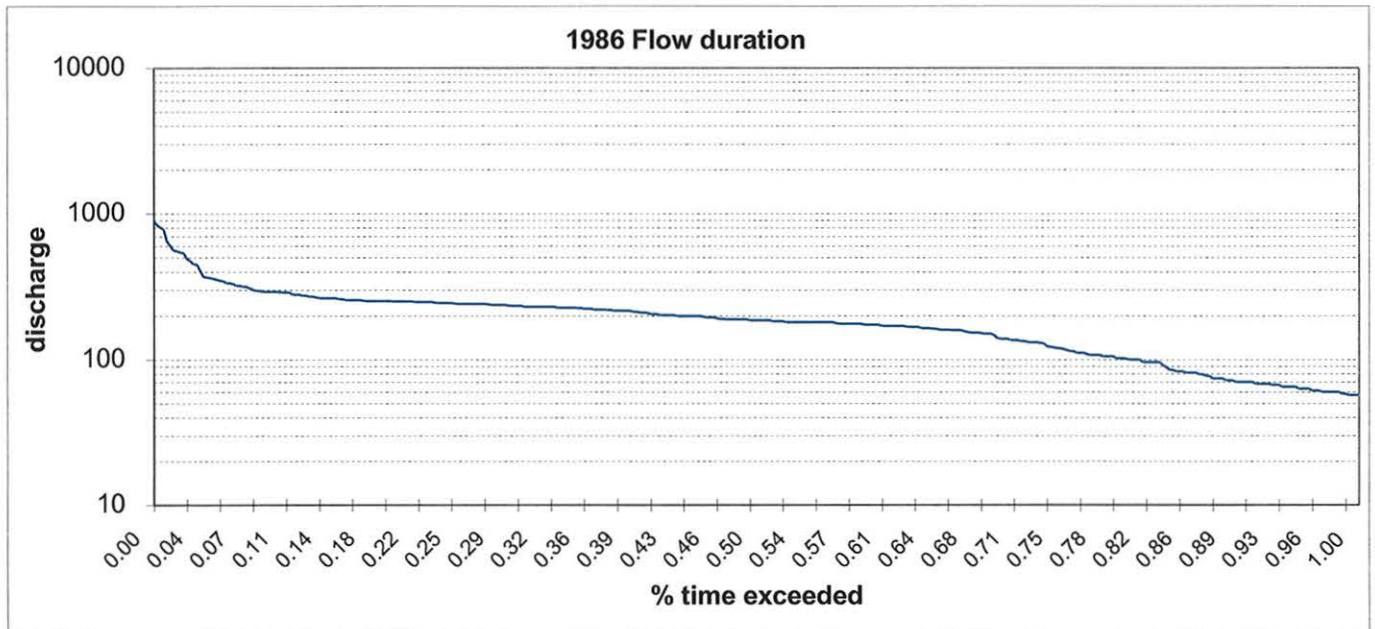
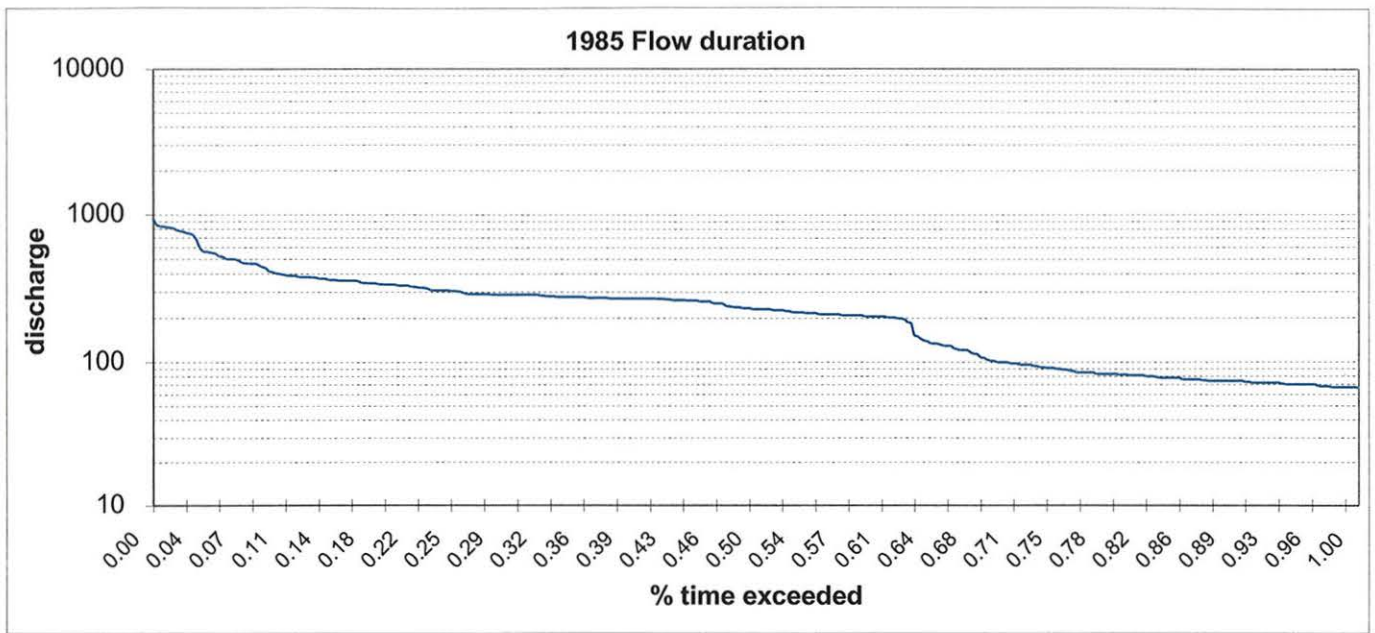


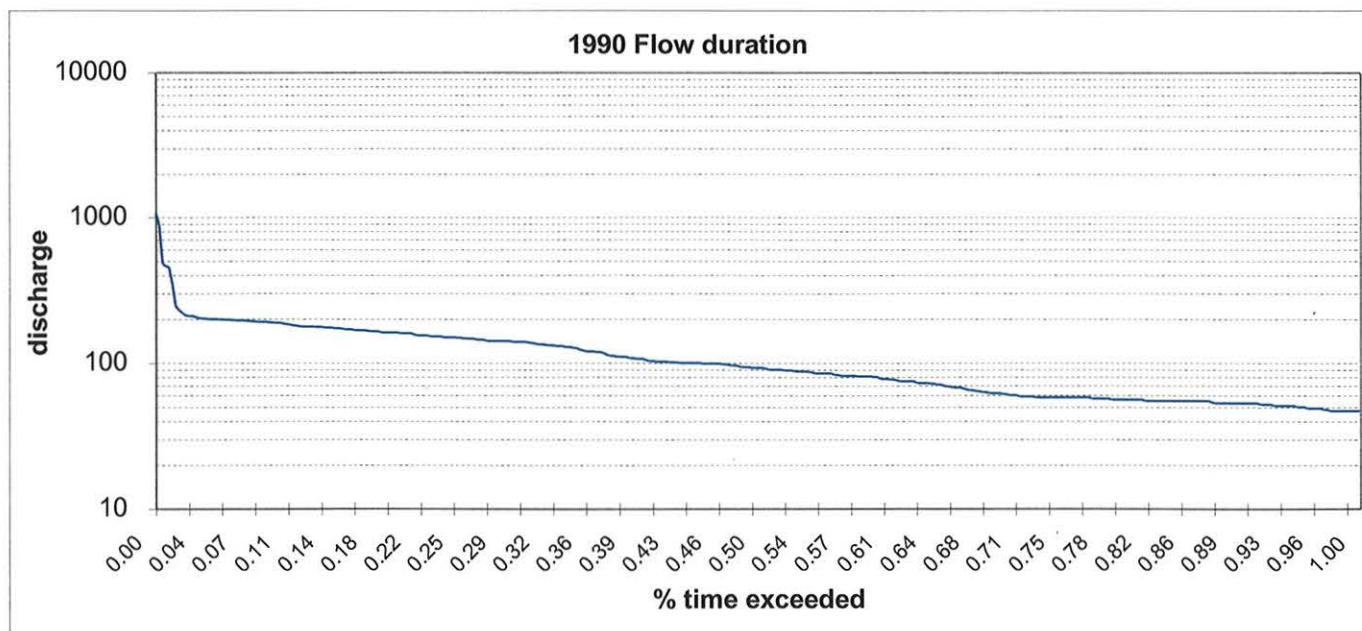
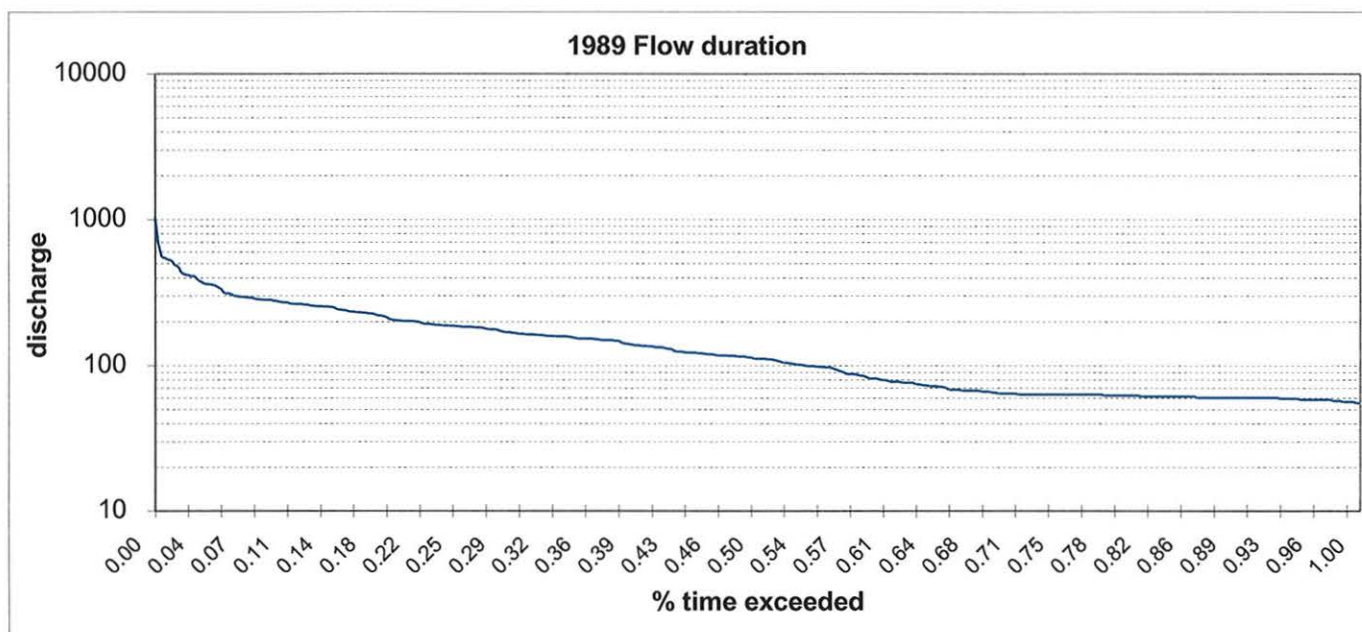
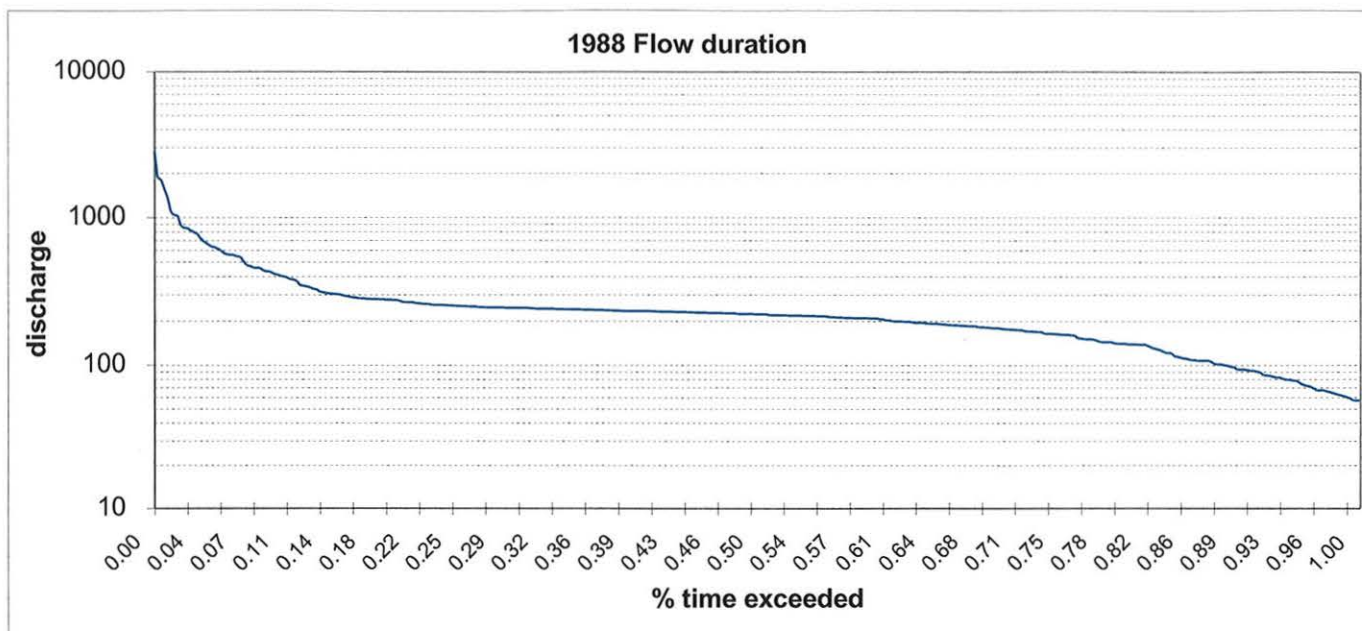


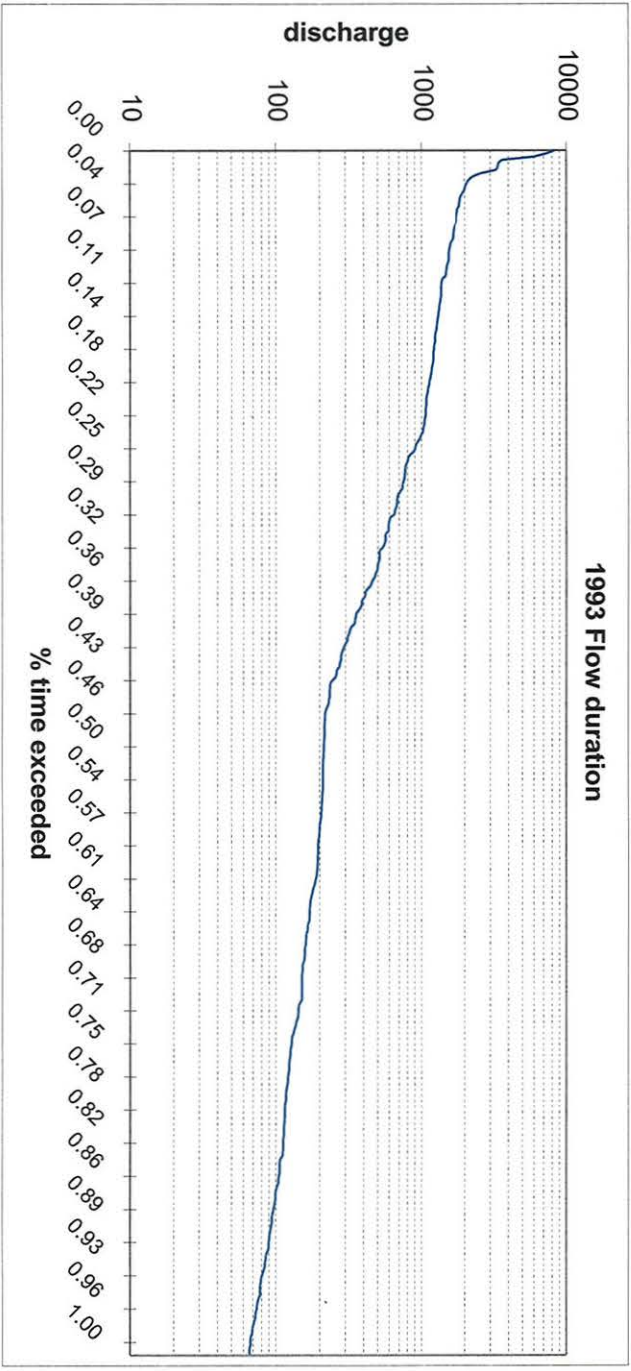
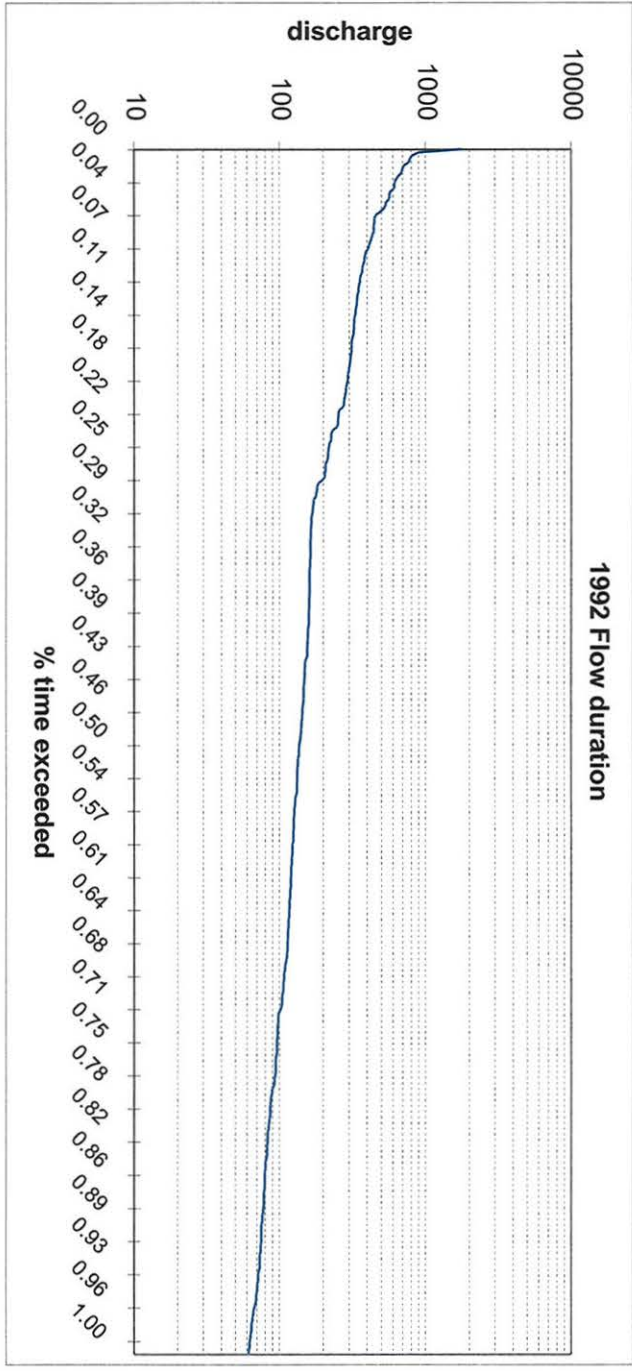
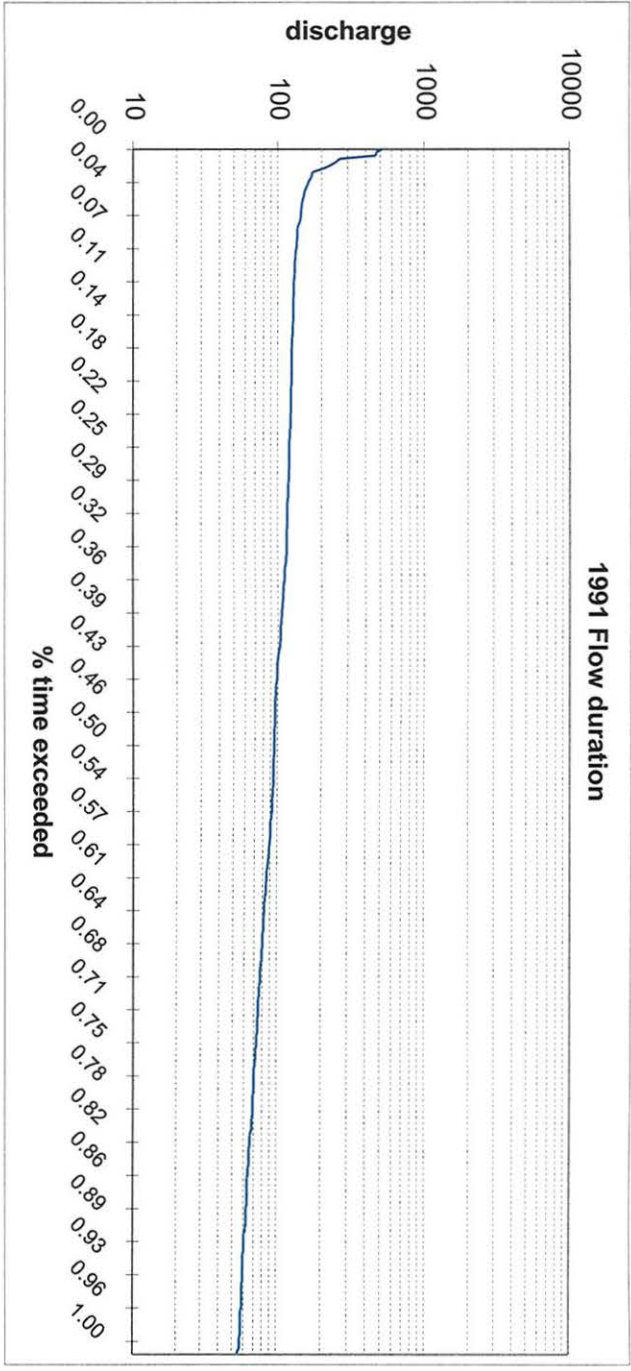


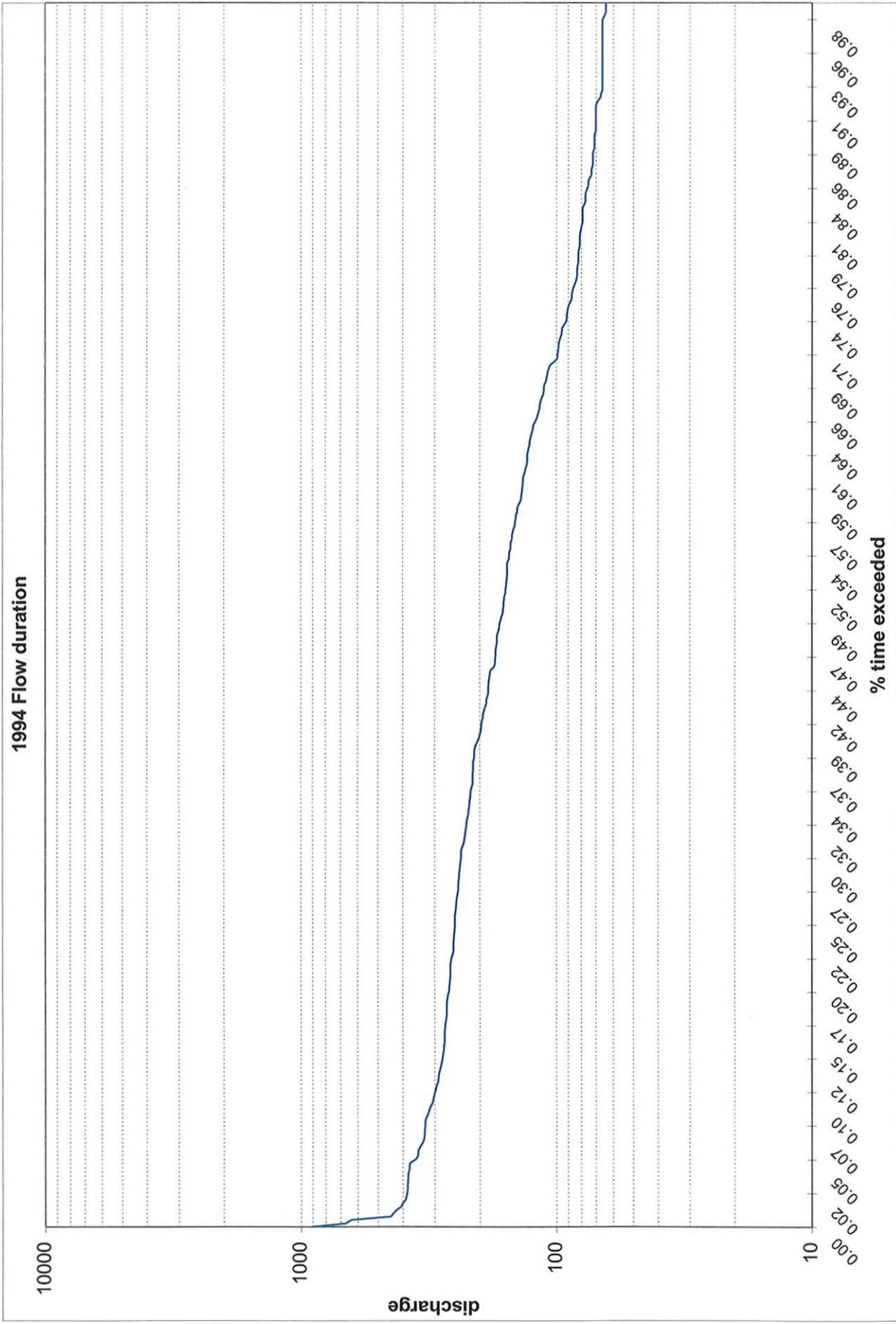


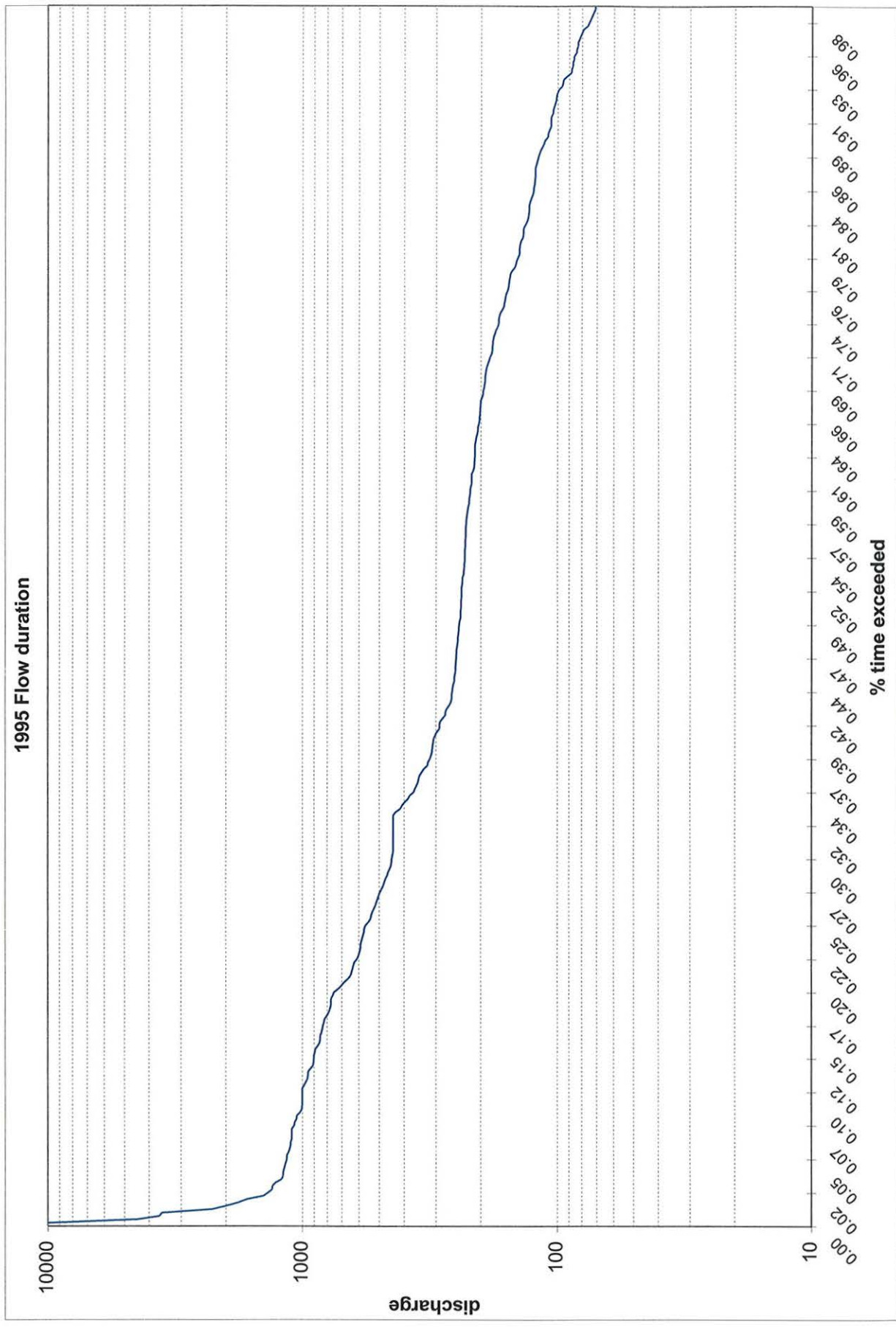












1996 Flow duration

