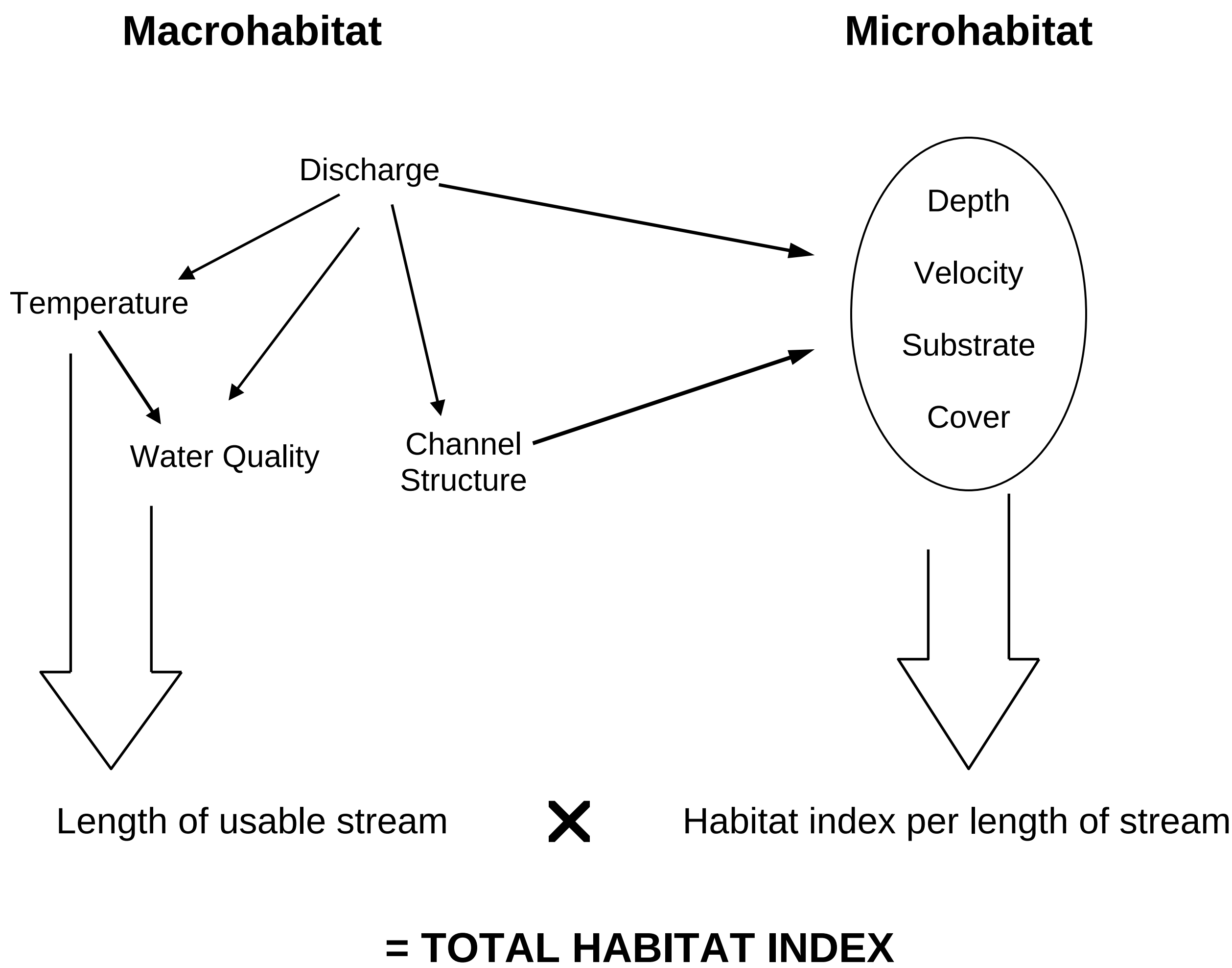


Figure 1. Conceptual diagram of fish habitat parameters associated with Physical Habitat Simulation System (PHABSIM) modeling (adapted from Stalnaker et al. 1995).

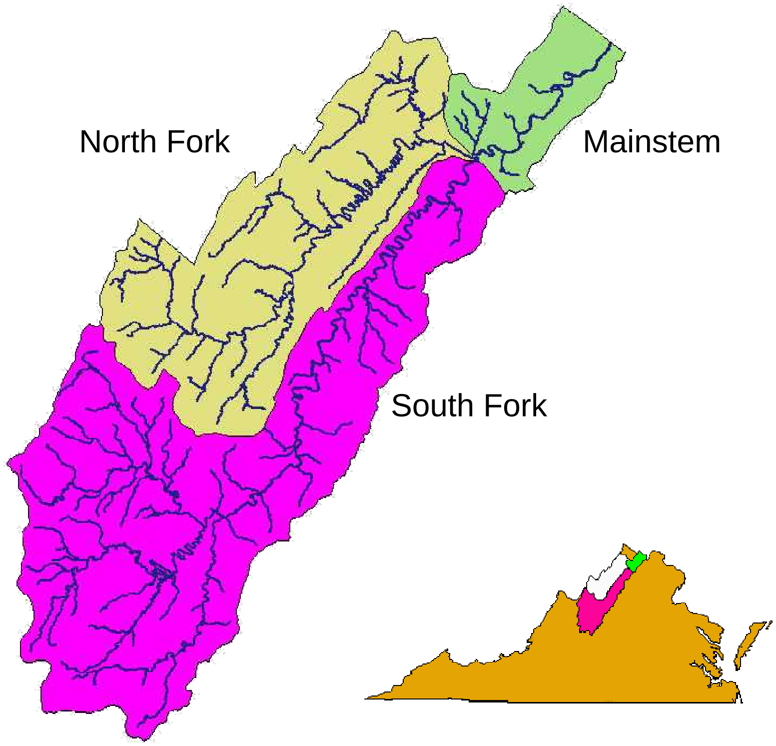


Figure 2. The Shenandoah River Basin hydrologic units: the mainstem, North Fork Shenandoah, and the South Fork Shenandoah rivers.

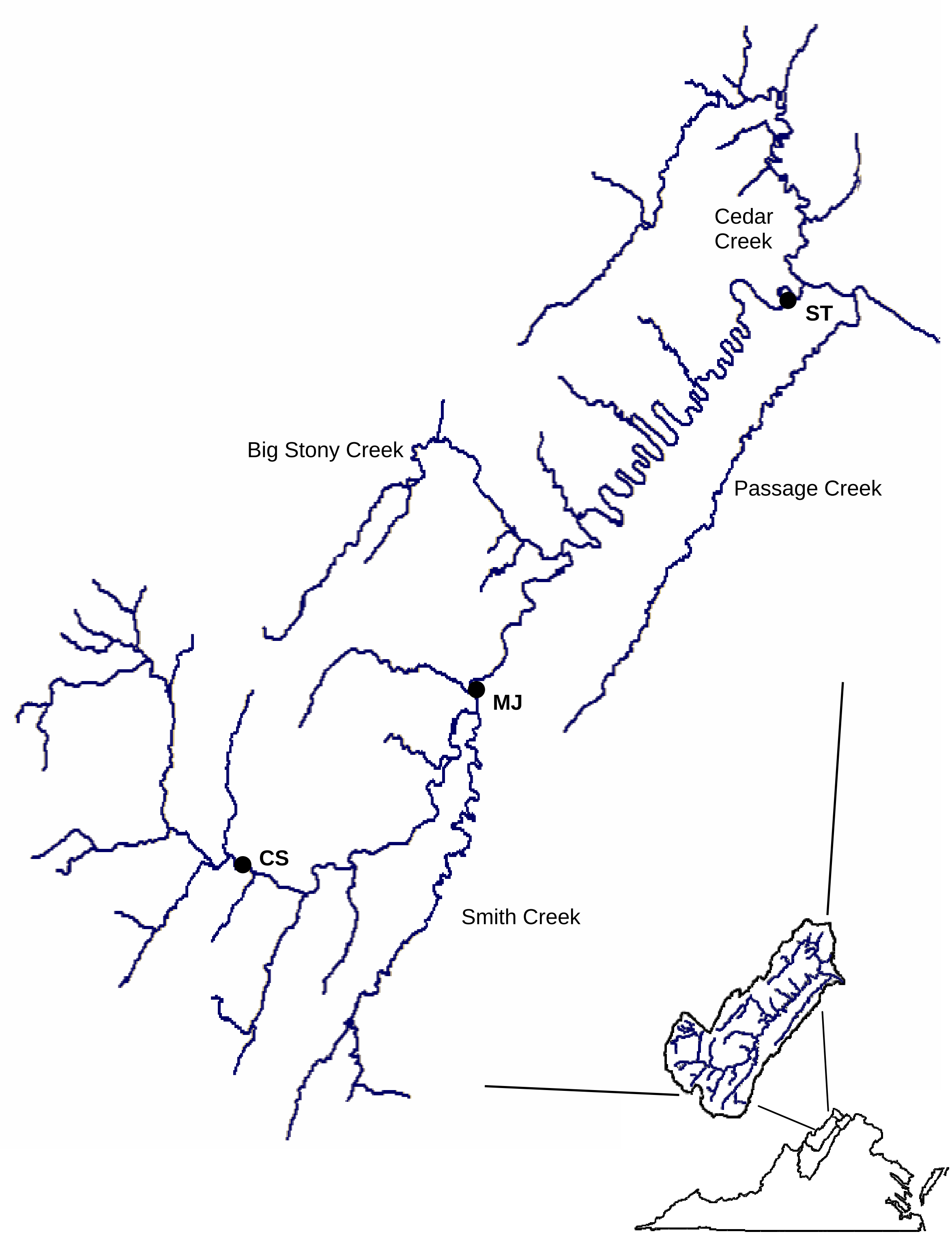


Figure 3. The North Fork Shenandoah River, its tributaries and gauging stations (Cootes Store – CS, Mount Jackson – MJ, Strasburg – ST).

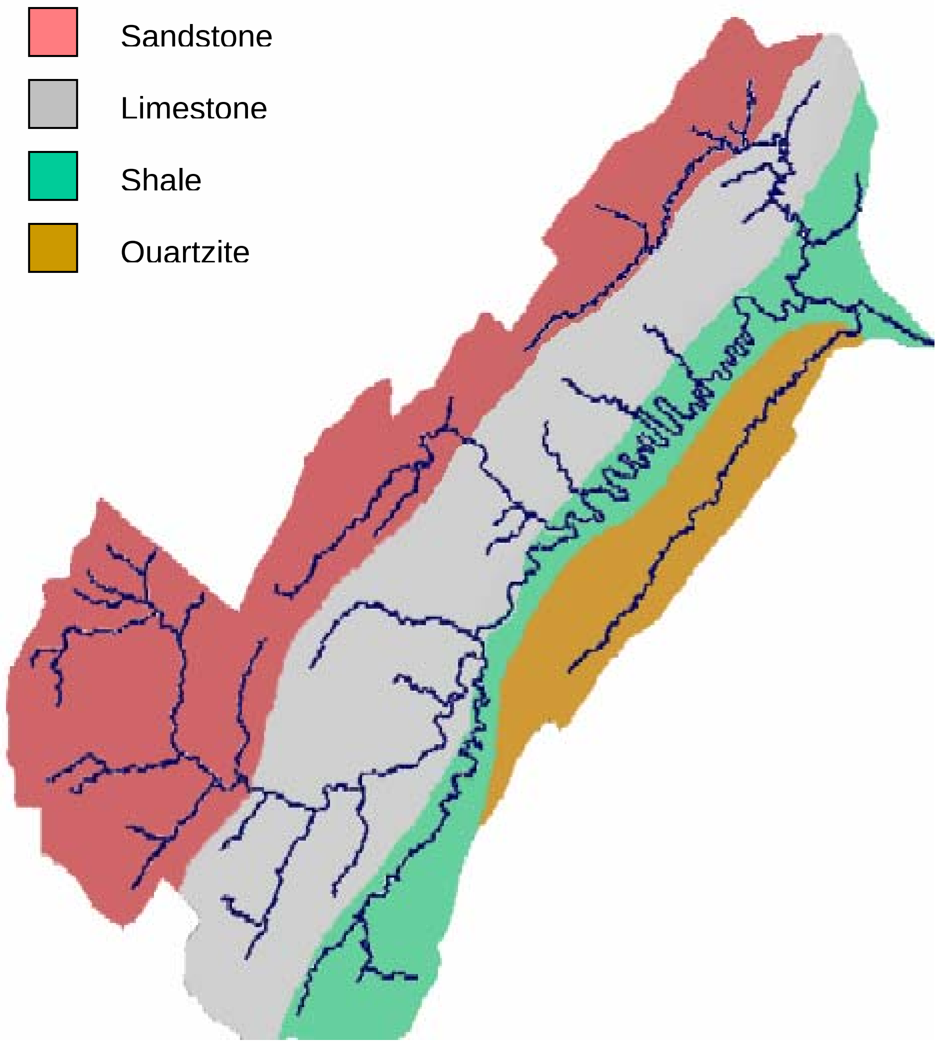


Figure 5. Geology of the North Fork Shenandoah River Basin. Map adapted from Hack 1965.

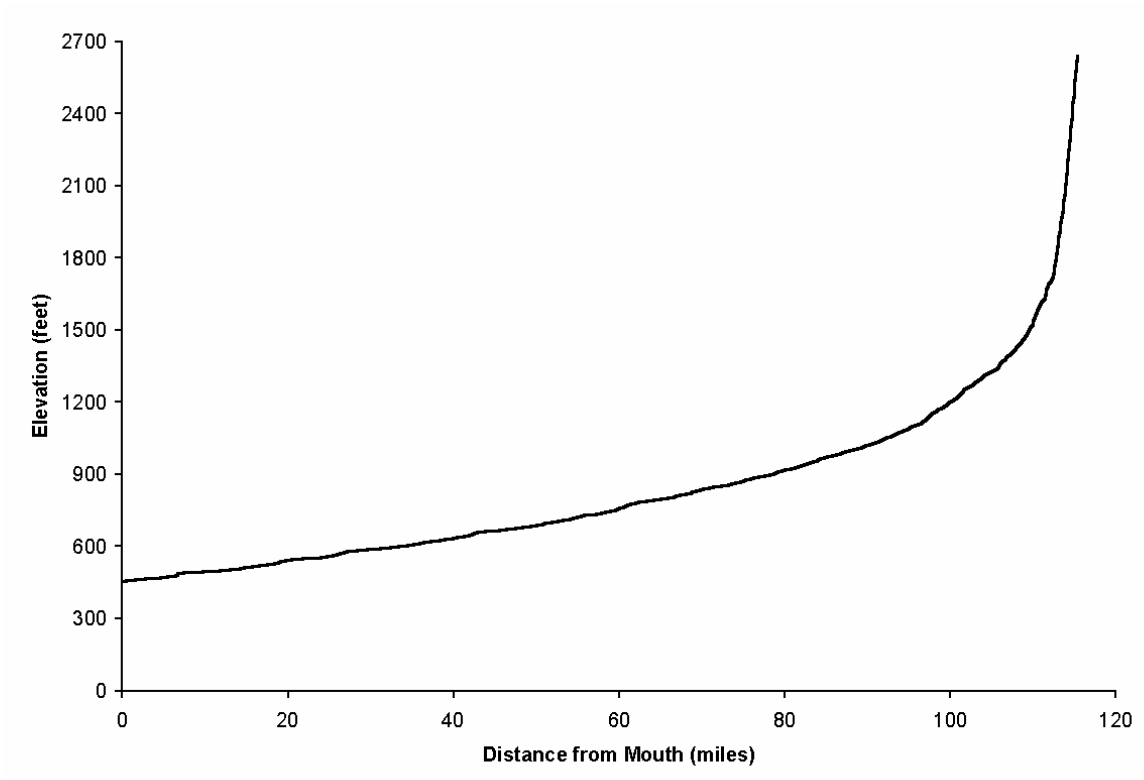


Figure 5. Stream profile of the North Fork Shenandoah River.

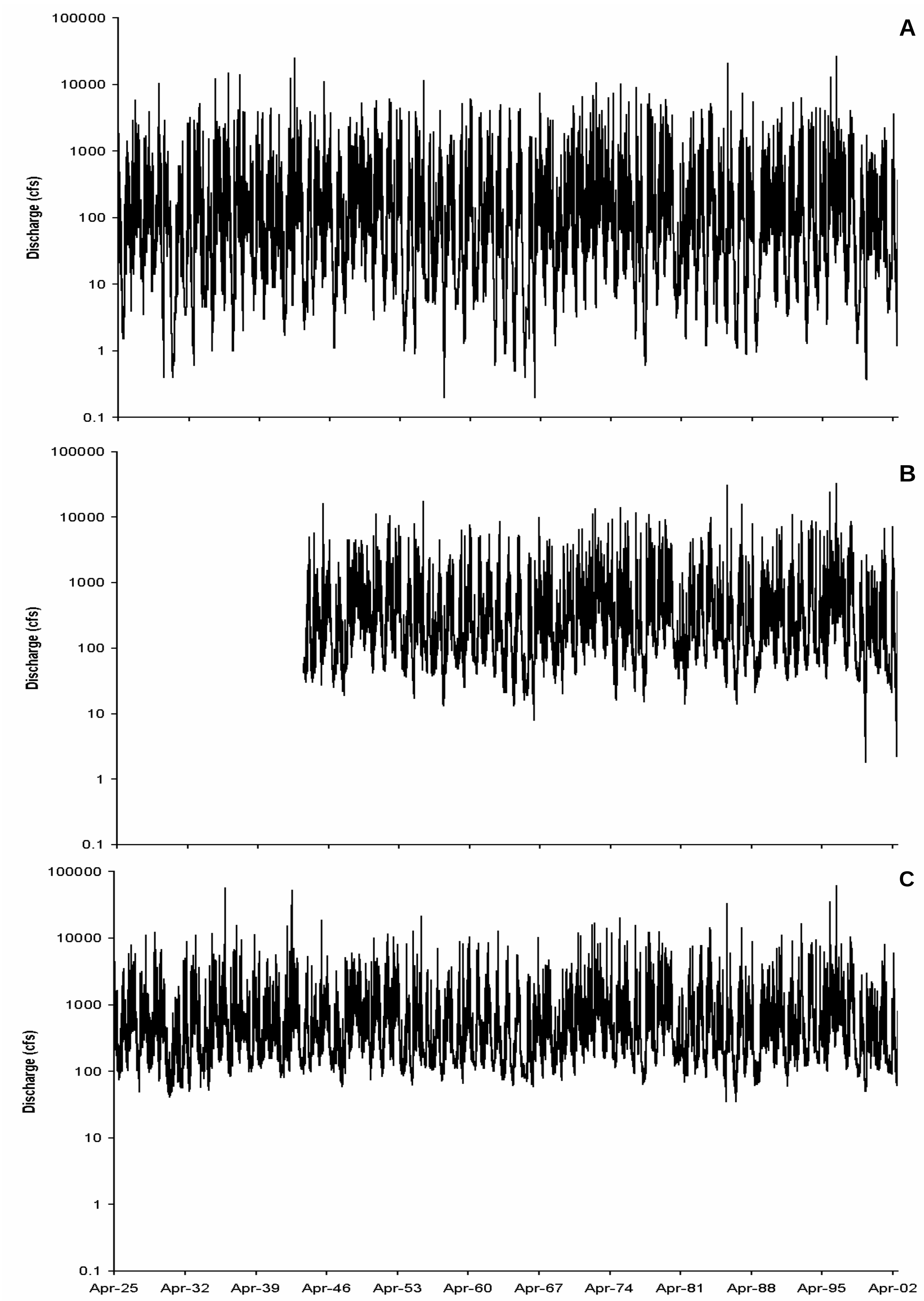


Figure 6. Daily mean flow hydrographs for the A) Cootes Store, B) Mount Jackson, and C) Strasburg gauging stations, Virginia, from April 1, 1925 to September 30, 2002.

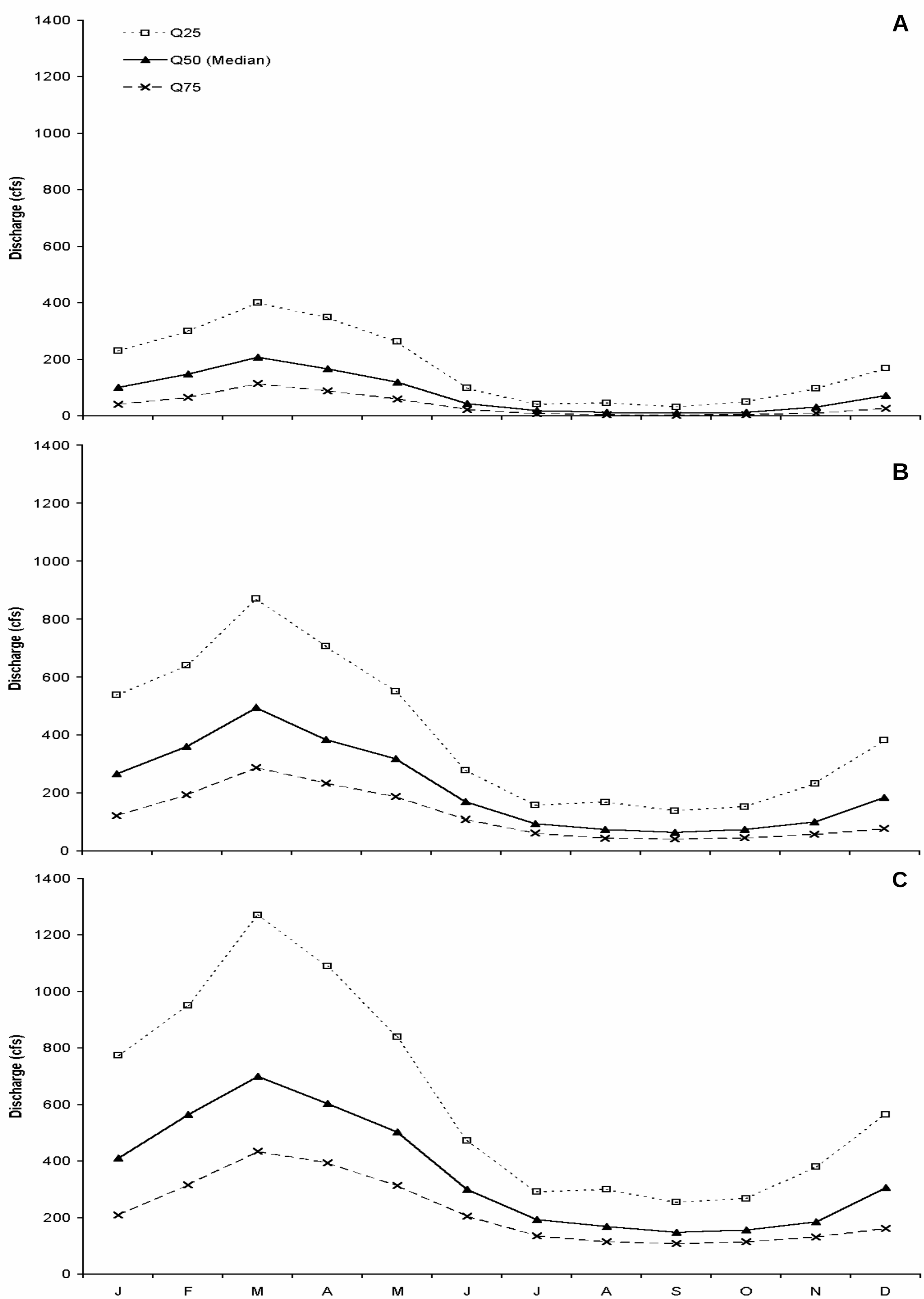


Figure 7. Comparison of monthly Q25, Q50, and Q75 values, for April 1, 1925 to September 30, 2002, at the A) Cootes Store, B) Mount Jackson, and C) Strasburg gauging stations, Virginia.

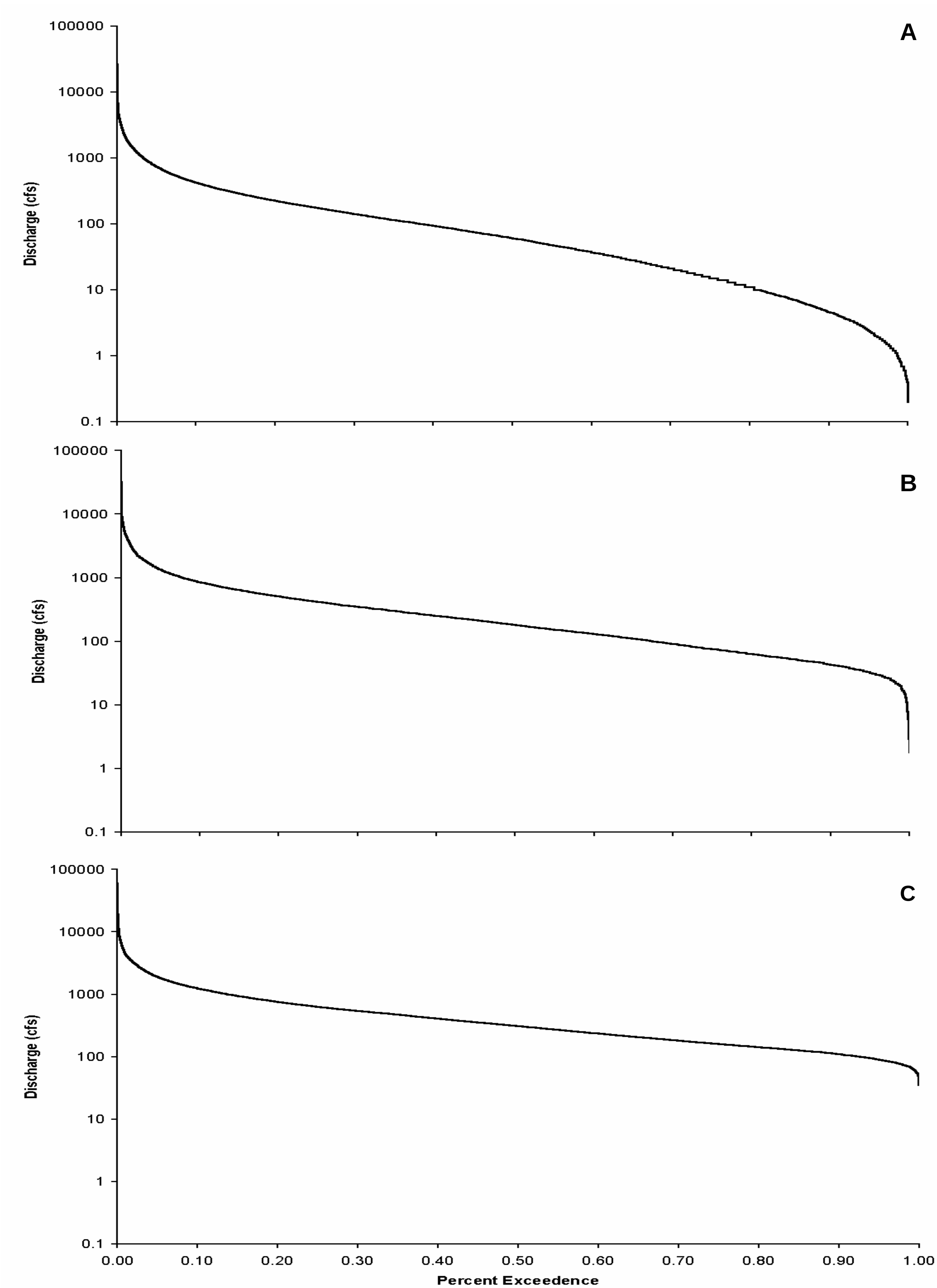


Figure 8. Daily mean flow duration curves for April 1, 1925 to September 30, 2002 at the A) Cootes Store, B) Mount Jackson, and C) Strasburg gauging stations, Virginia.

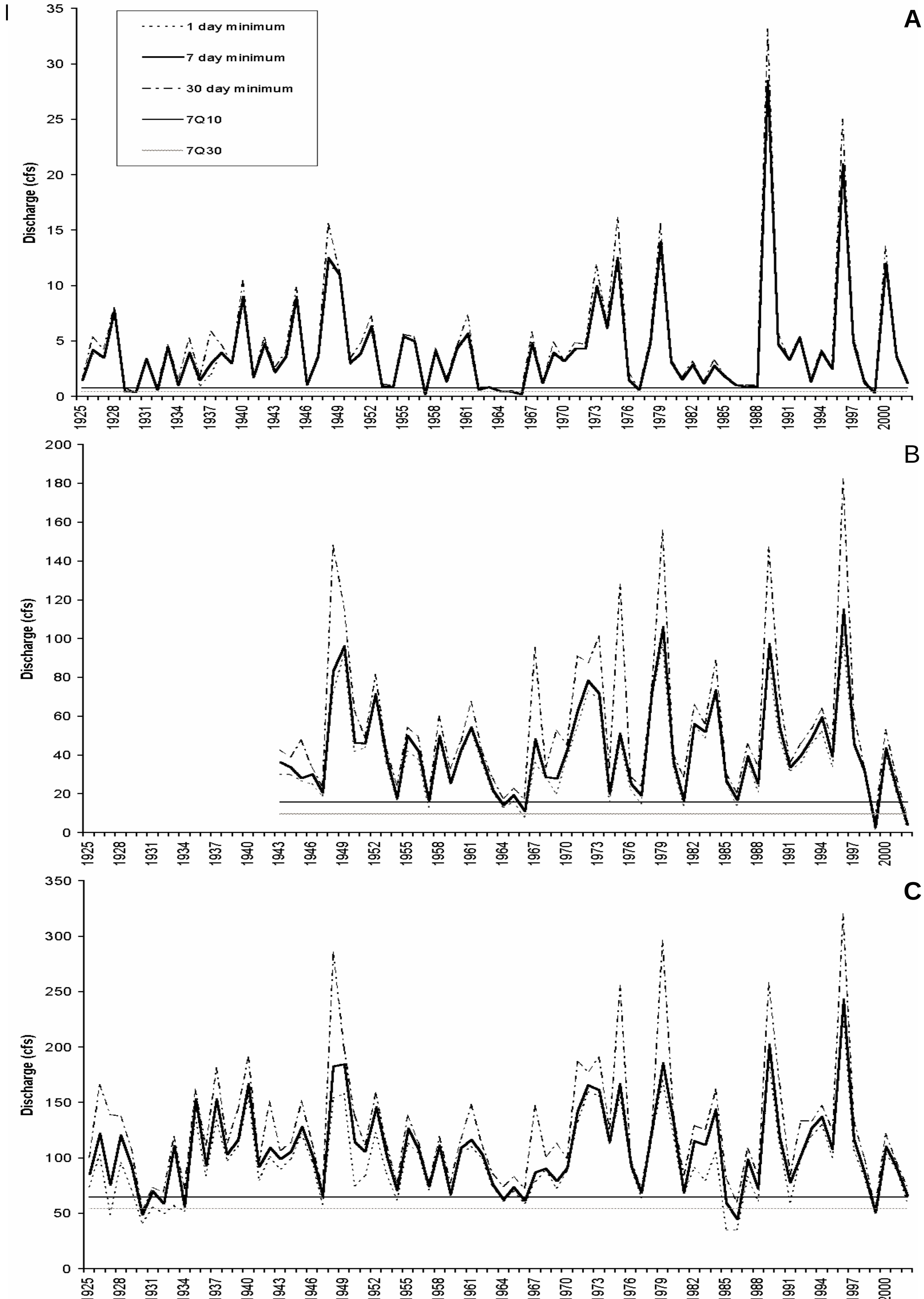


Figure 9: Low flow minimums and statistics for 1925 - 2002 climatic years at the A) Cootes Store, B) Mount Jackson, and C) Strasburg gauging stations, Virginia.

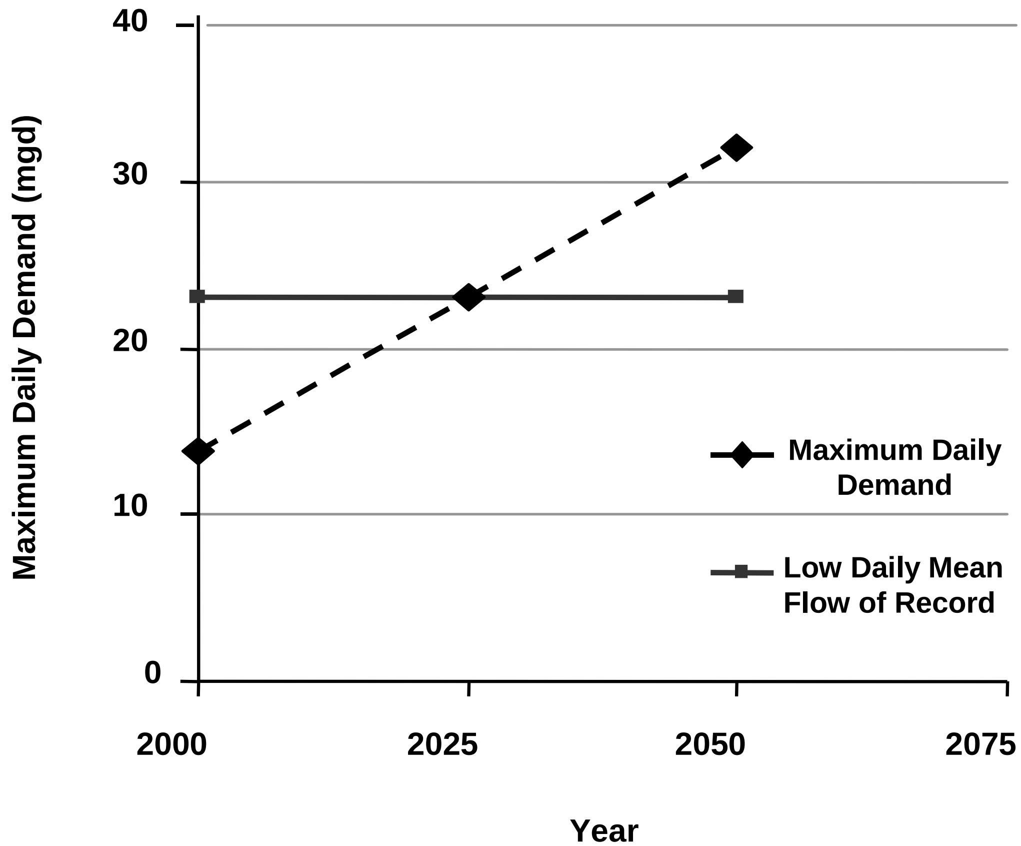
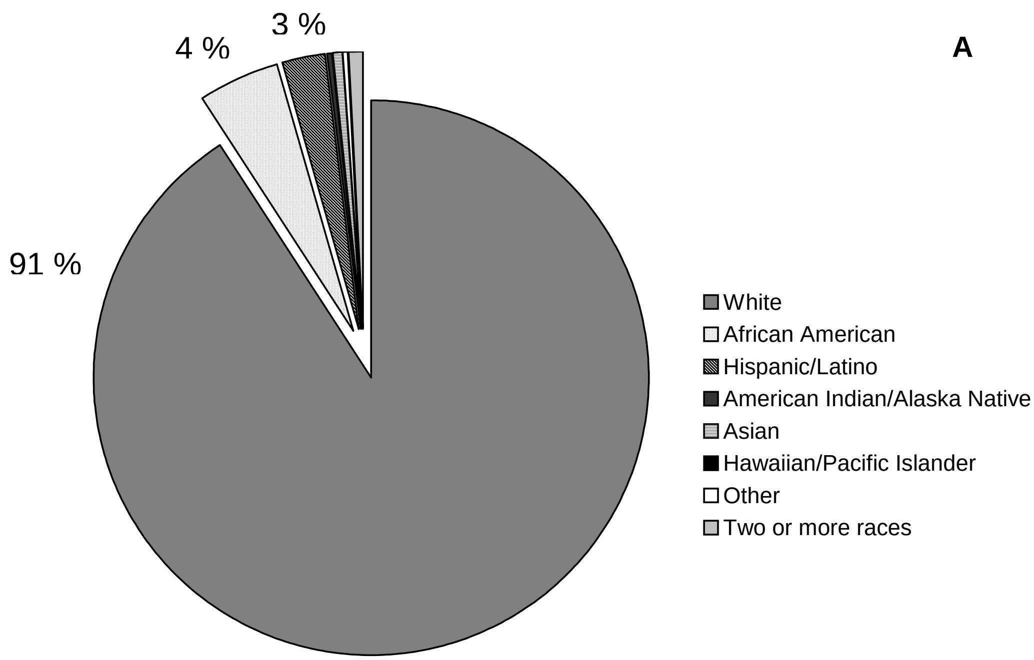


Figure 10. Supply and demand in the North Fork Shenandoah River basin. Based on current water use and population growth estimates, demand is projected to exceed supply in 2025 (Hayzen and Sawyer, and PA Consulting Group 2001).



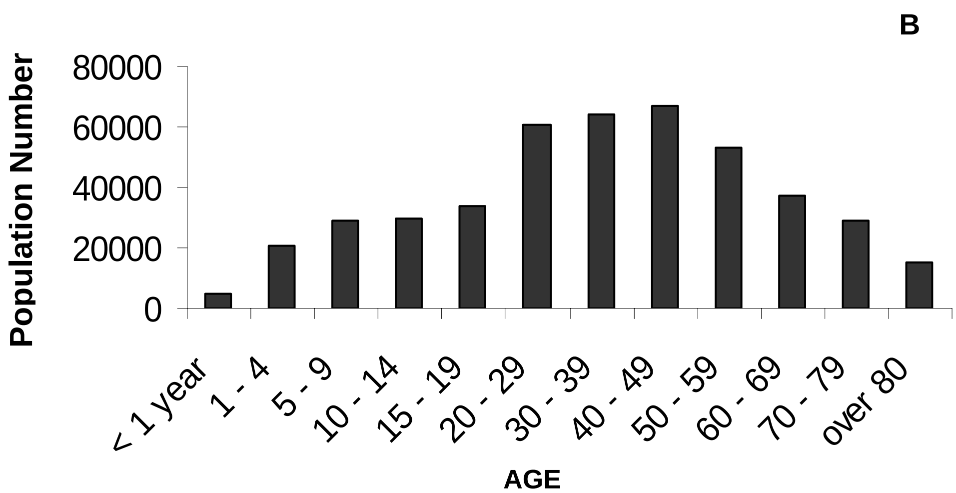


Figure 11. Demographics of the Shenandoah River Basin, Virginia based on U.S. Bureau of the Census of population and housing data for 2000. The pie chart A) depicts the distribution of population by race/ethnicity and bar graph B) depicts the distribution of population by age (N = 444, 071).

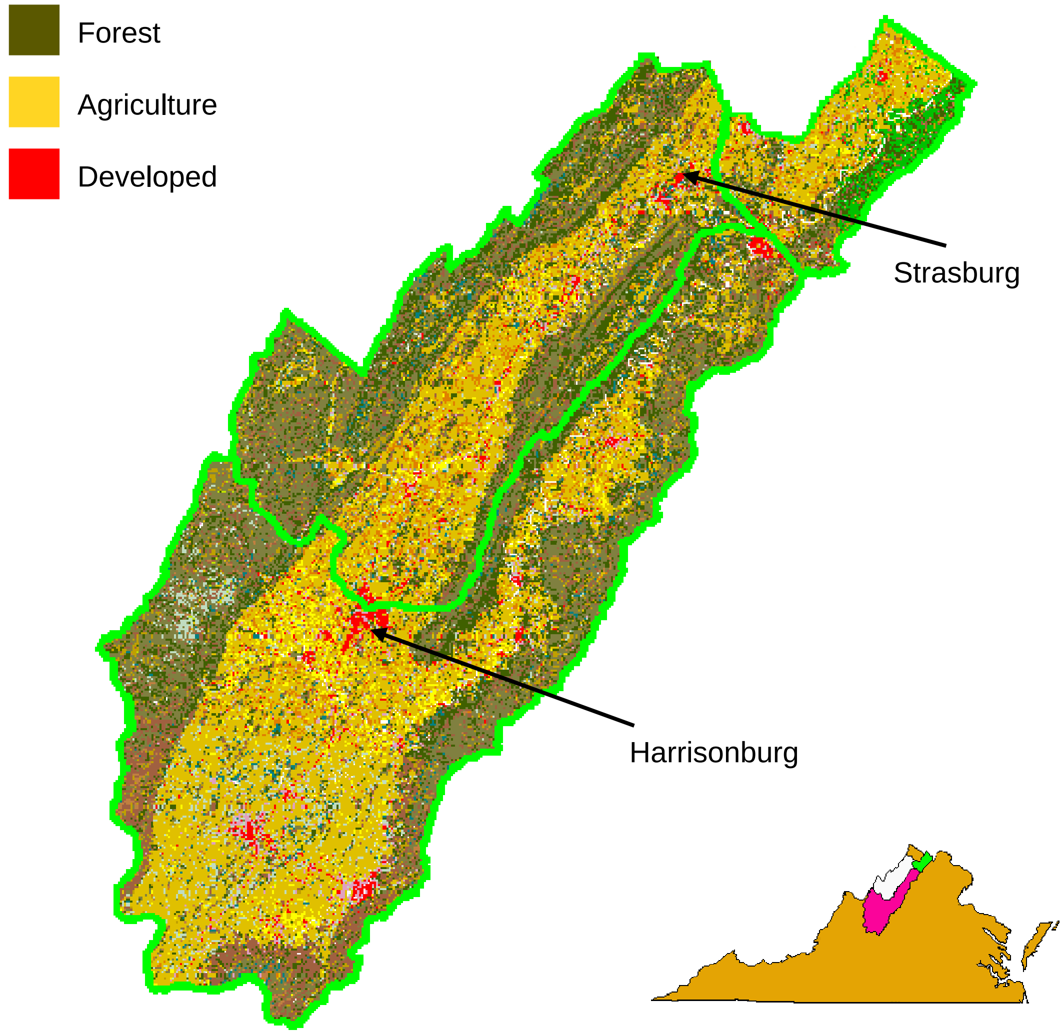


Figure 12. Landuse in the Shenandoah River basin.

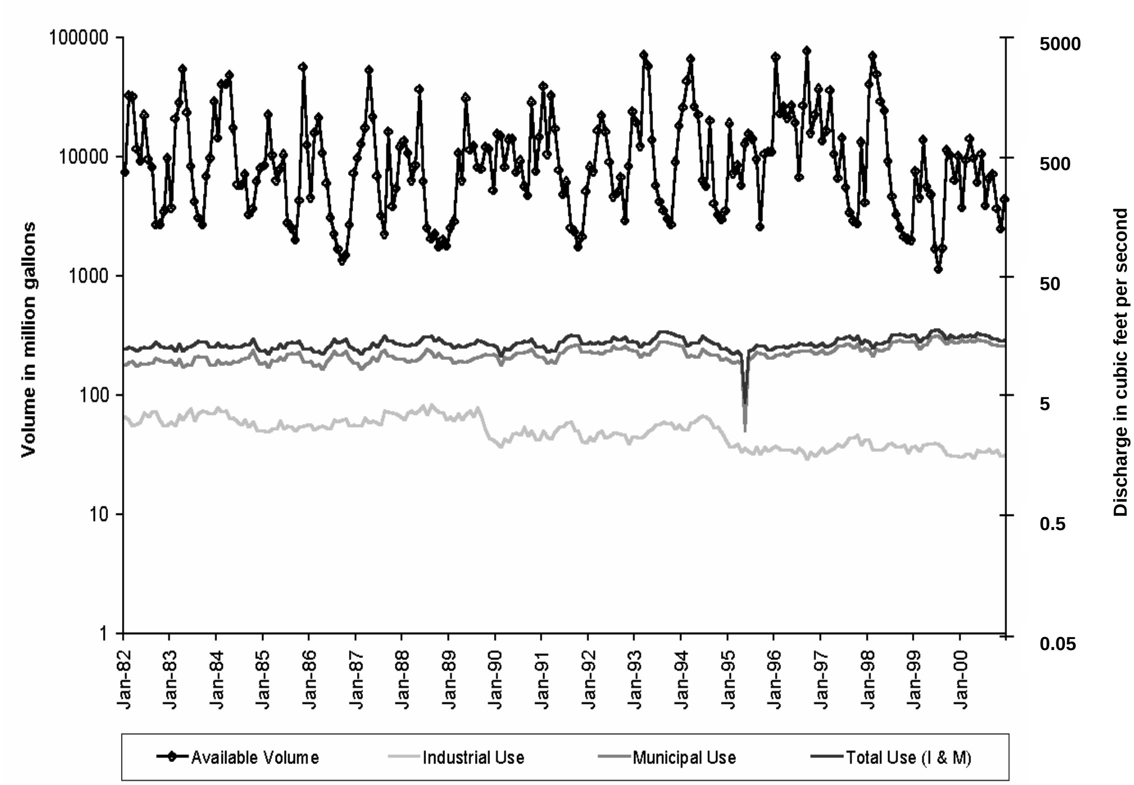


Figure 13. Comparison of North Fork Shenandoah River monthly available volume (mg) and discharge (cfs) at the Strasburg gauging station to permitted water use for the period 1982 to 2000.

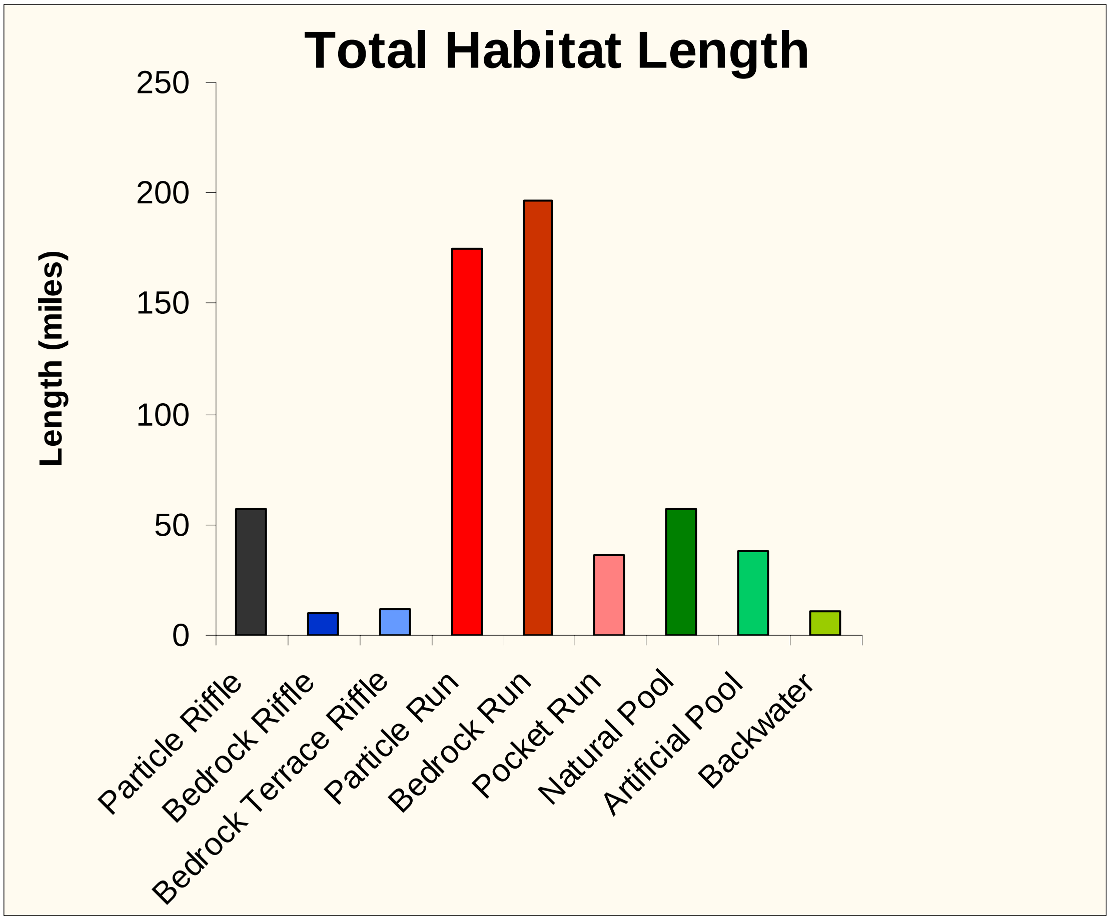
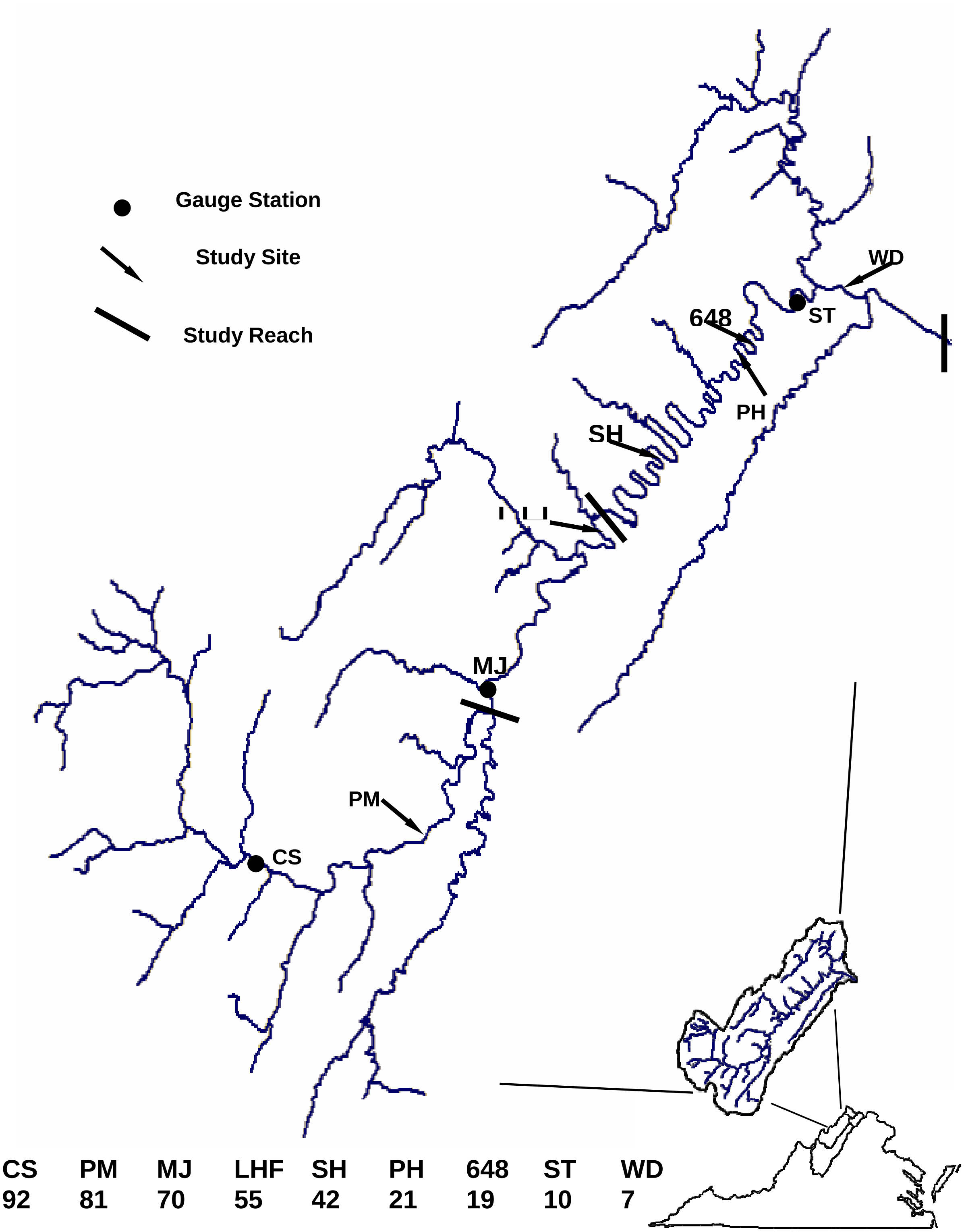


Figure 14. Habitat length along the North Fork Shenandoah River, Va.



site	CS	PM	MJ	LHF	SH	PH	648	ST	WD
rmi	92	81	70	55	42	21	19	10	7

Figure 15. Locations of gauging stations (CS – Cootes Store, MJ – Mount Jackson, and ST – Strasburg), study sites (PM – Plains Mill, LHF – Laurel Hill Farm, SH – Spring Hollow, PH – Posey Hollow, 648 – Route 648, and WD – Winchester Dam), and study reach boundaries on the North Fork Shenandoah River.

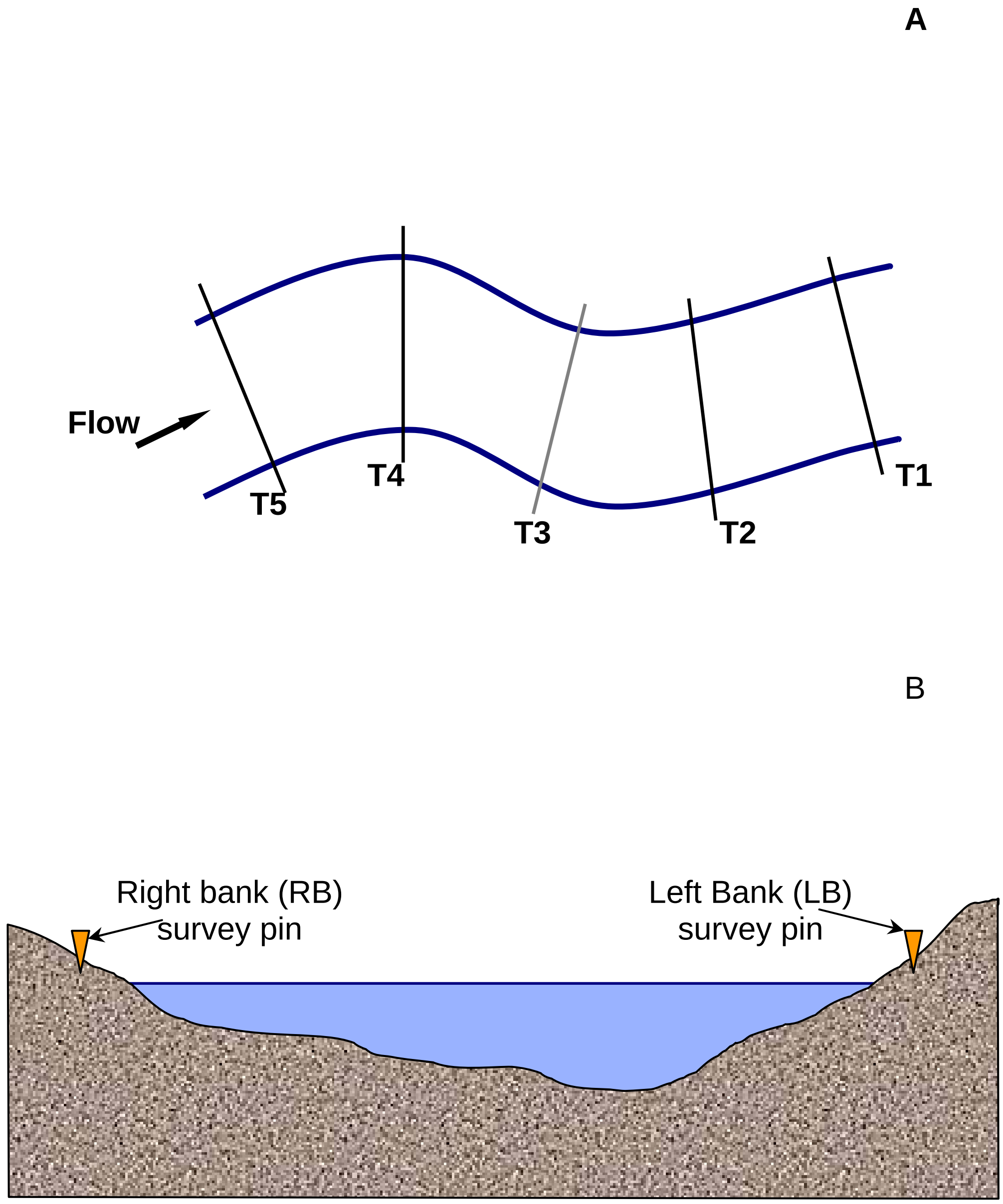


Figure 16. Topview (A) of transects at a site and (B) channel profile view (sideview) of an individual transect.

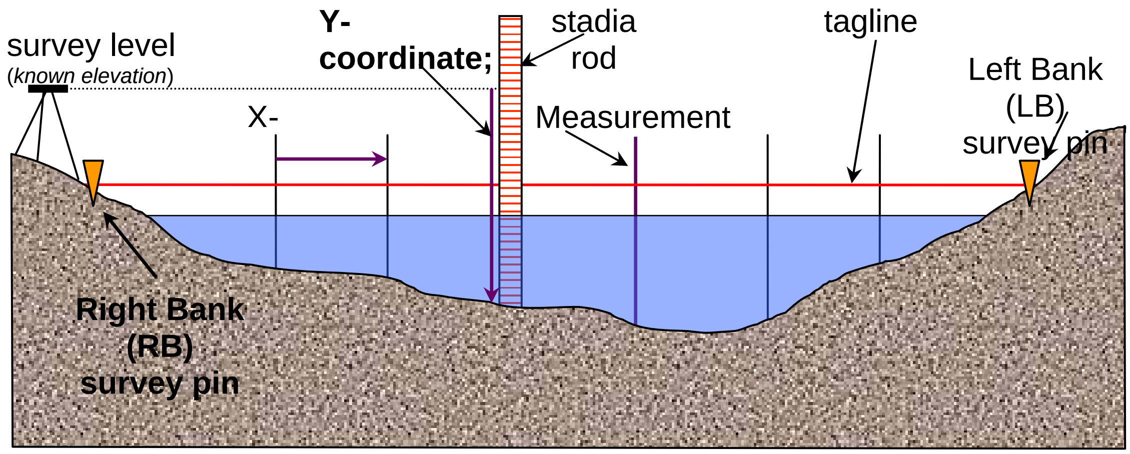


Figure 17. Sideview of physical data collection methods for establishing verticals and measuring the cross-sectional profile.

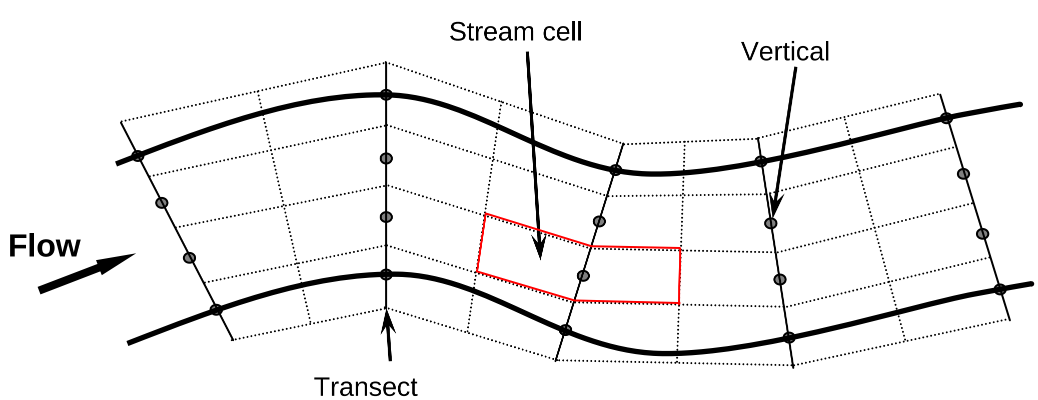


Figure 18. Physical data collection grid for a study site showing transects, verticals and stream cells. Each cell will have a unique combination of habitat variables, depth, velocity, and channel index.

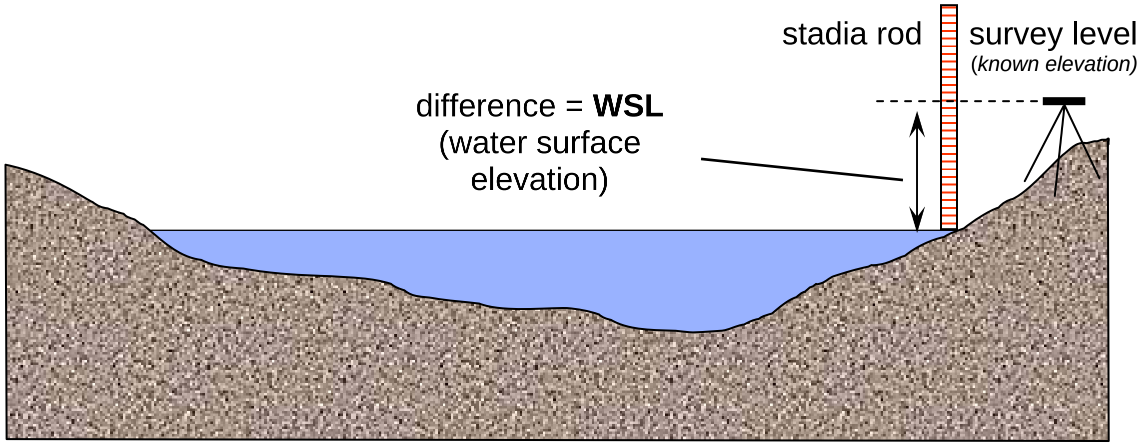


Figure 19. Diagram of water surface elevation measurement.

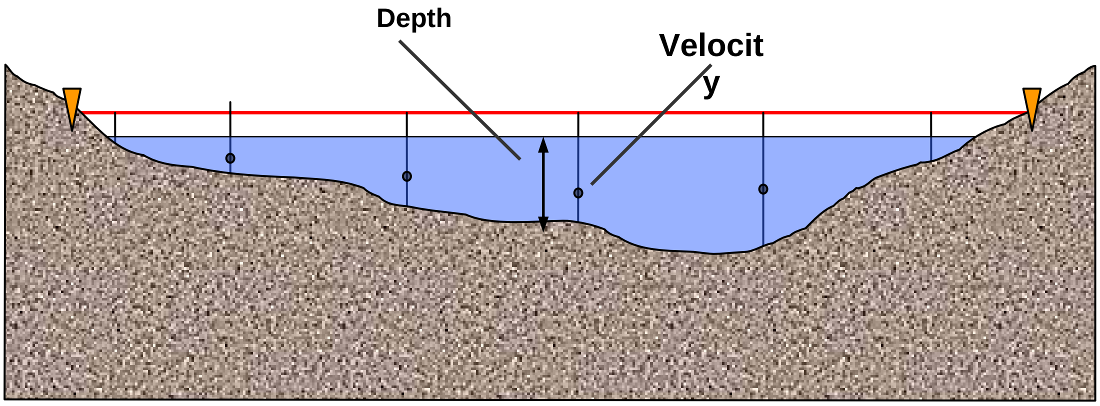


Figure 20. Representation of water depth and velocity measurements.

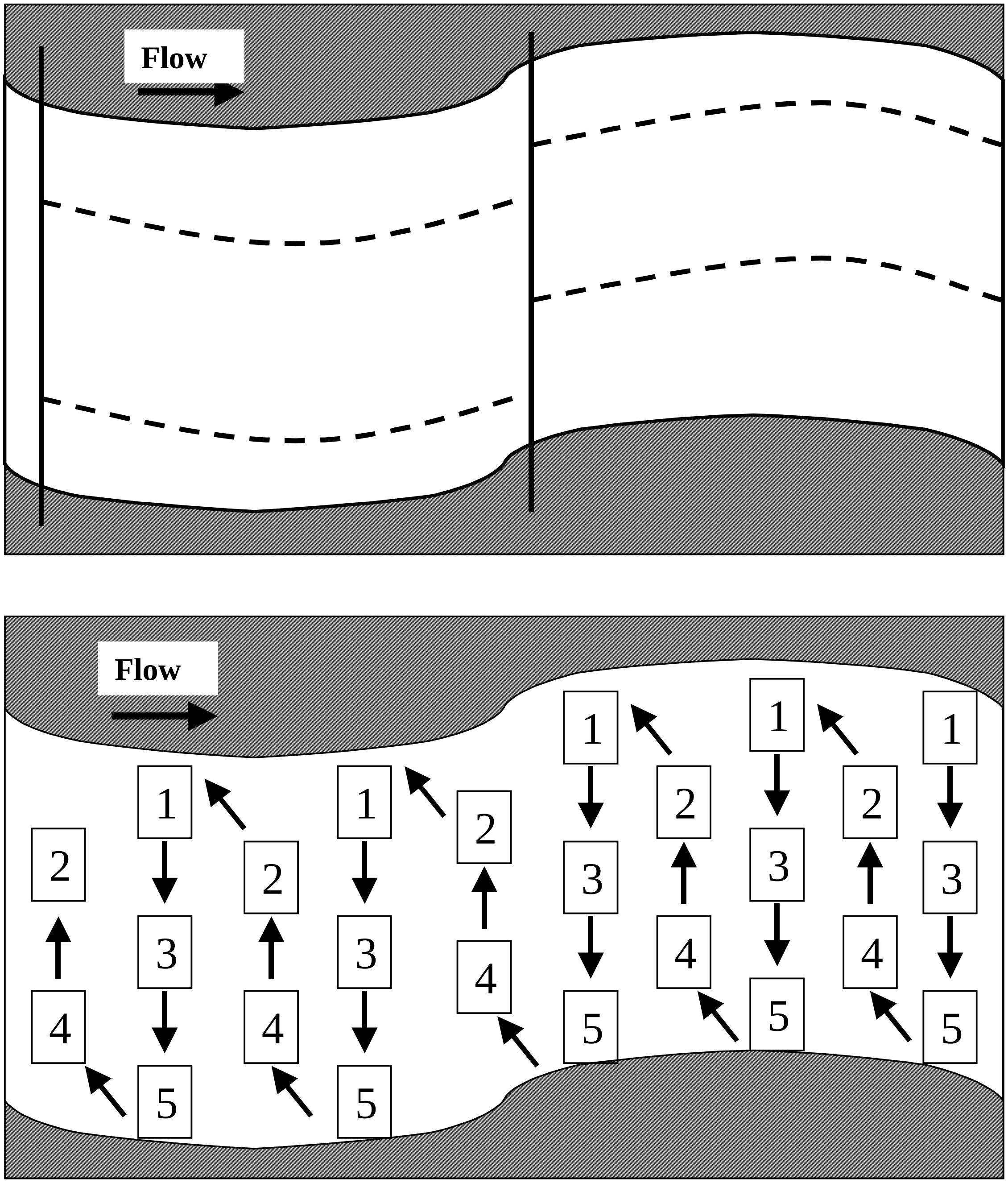


Figure 21. Sampling procedures for a 197 ft (60m) section of river. (Top) Solid lines represent the static lines across the river and the dashed lines represent the lanes being snorkeled. (Bottom) Numbered boxes represent locations where the anode was thrown and the arrows follow the pattern used to sample the river.

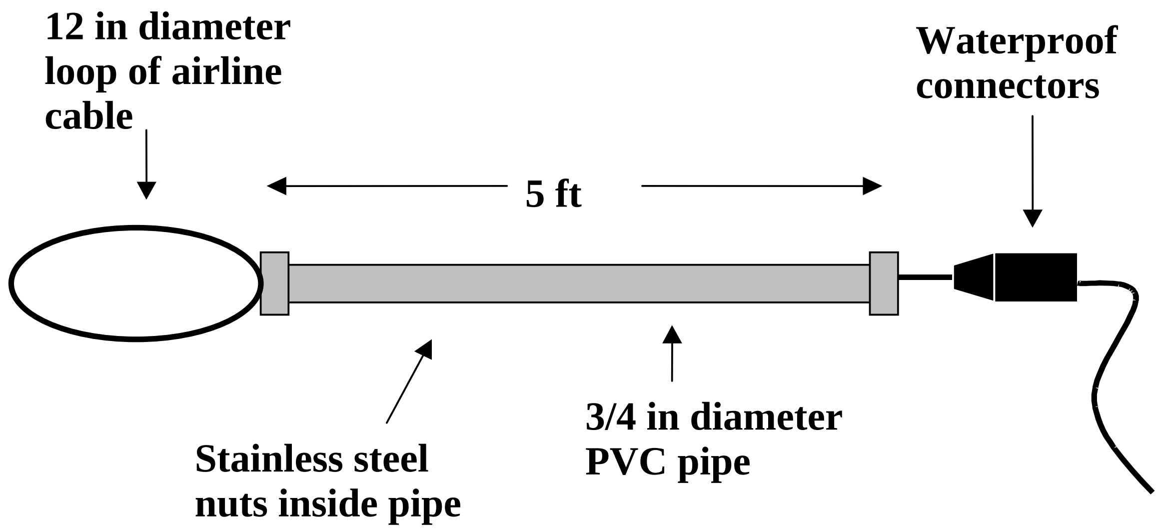
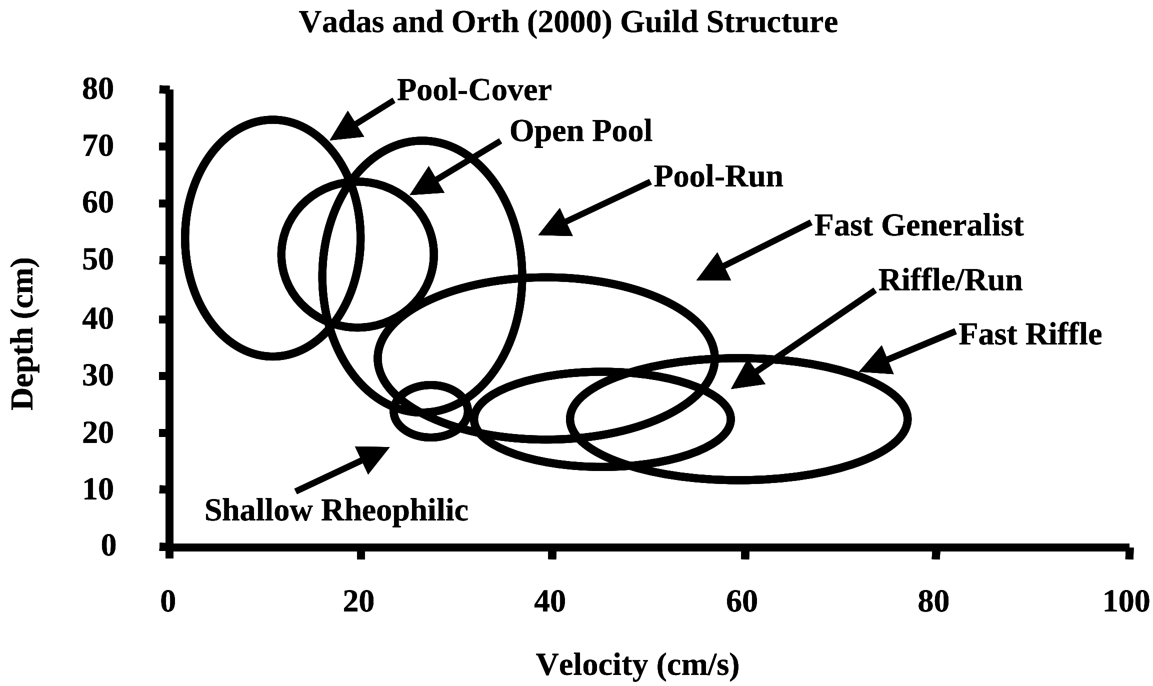


Figure 22. A diagram of the throwable anode.



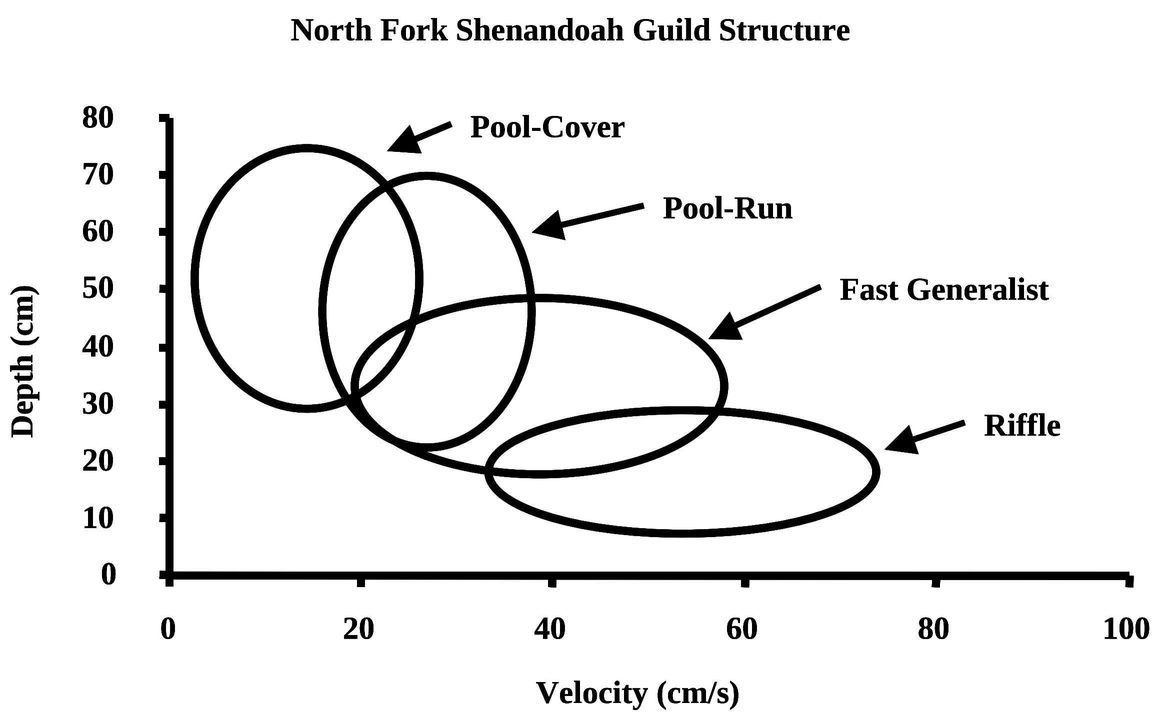


Figure 23. Diagrams of the guild structures used for this study. The Vadas and Orth diagram is the structure used as the basis for creating the bottom guild structure that was actually used on the North Fork.

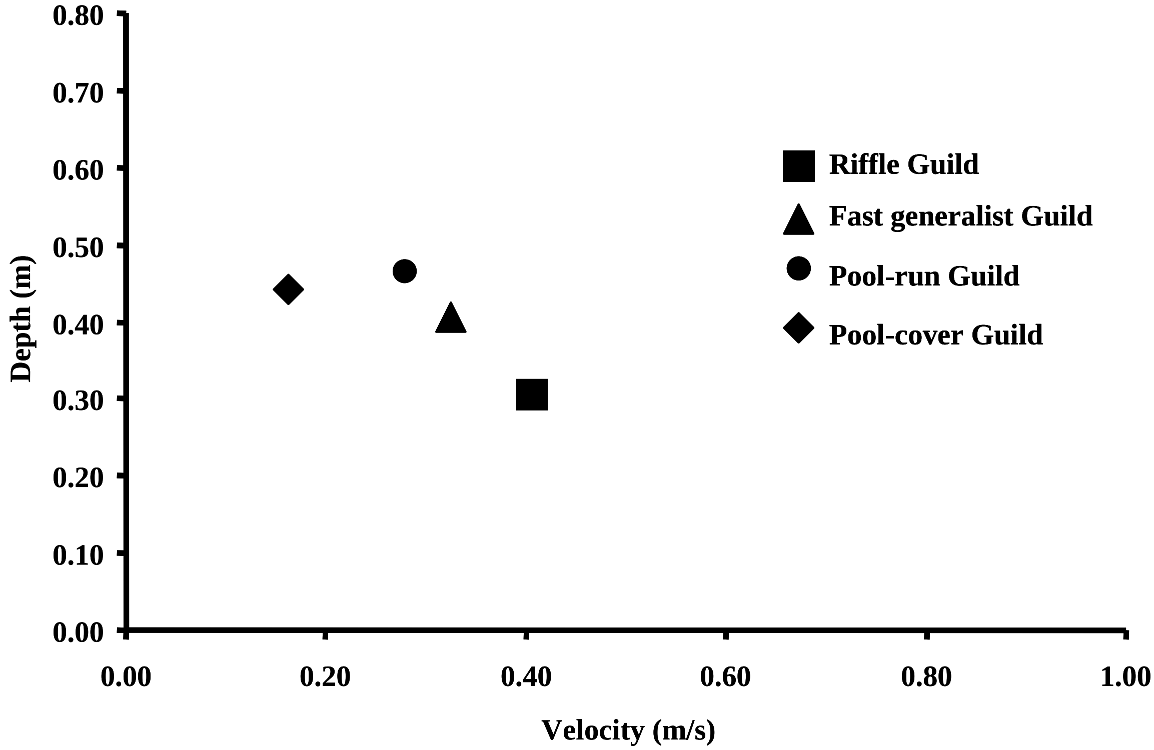


Figure 24. Mean depth and velocity locations for guild used to develop habitat suitability criteria in the North Fork Shenandoah River.

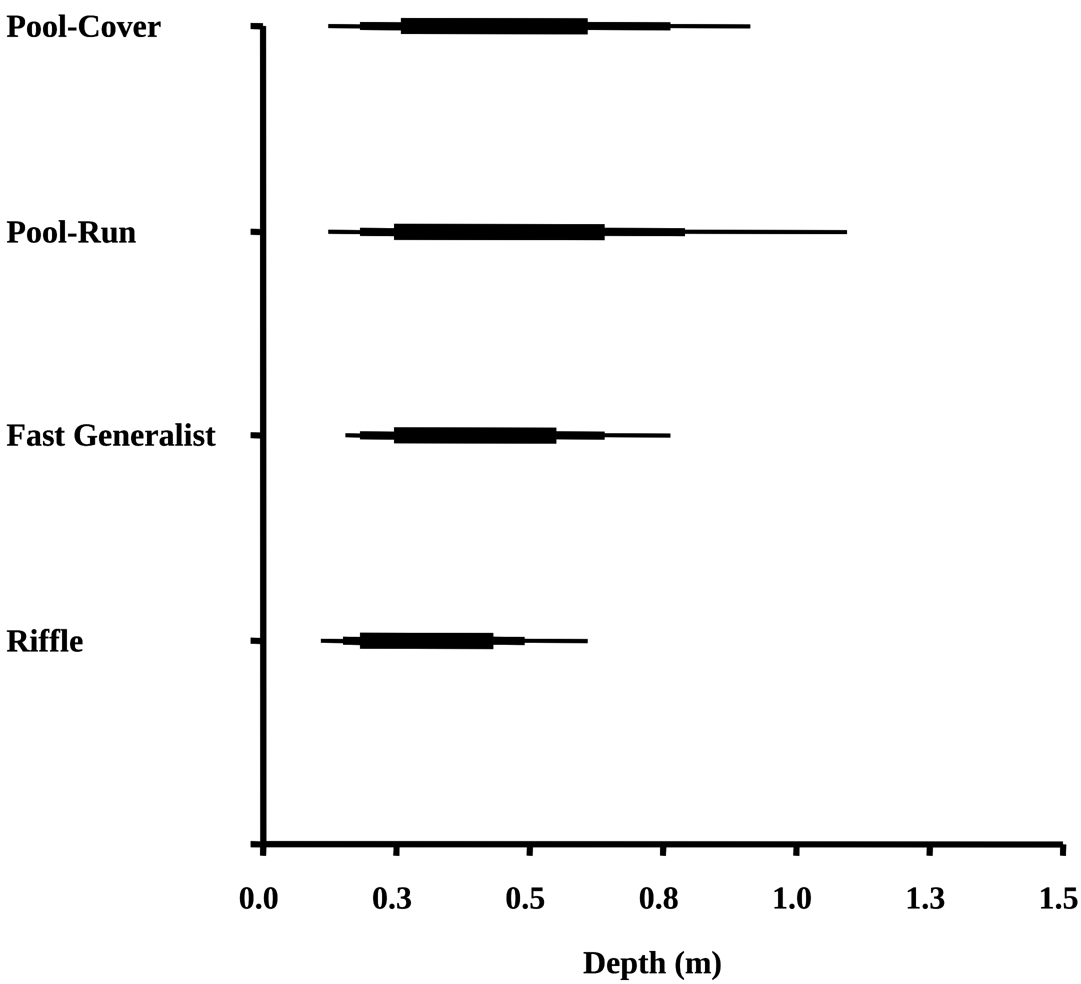


Figure 25. Depth habitat suitability criteria created using nonparametric tolerance limits for the four guilds sampled in the North Fork Shenandoah River during the summers of 2001 and 2002. Line width gradients are the central 50% (thickest line), central 75% (medium line), and the central 90% (thinnest line). For each guild the sample totals are: riffle n=338, fast generalist n=351, pool-run n=194, and pool-cover n=415.

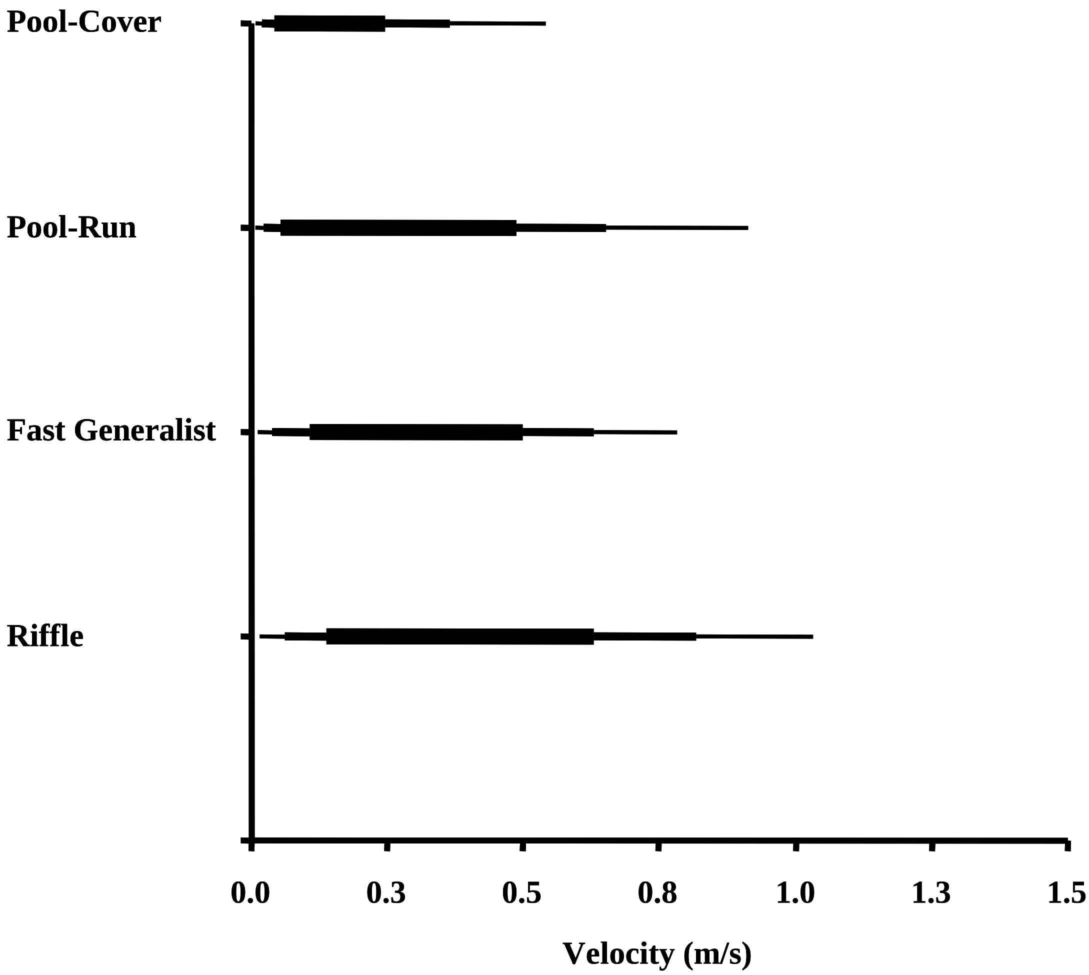


Figure 26. Velocity habitat suitability criteria created using nonparametric tolerance limits for the four guilds sampled in the North Fork Shenandoah River during the summers of 2001 and 2002. Line width gradients are the central 50% (thickest line), central 75% (medium line), and the central 90% (thinnest line). For each guild the sample totals are: riffle n=338, fast generalist n=351, pool-run n=194, and pool-cover n=415.

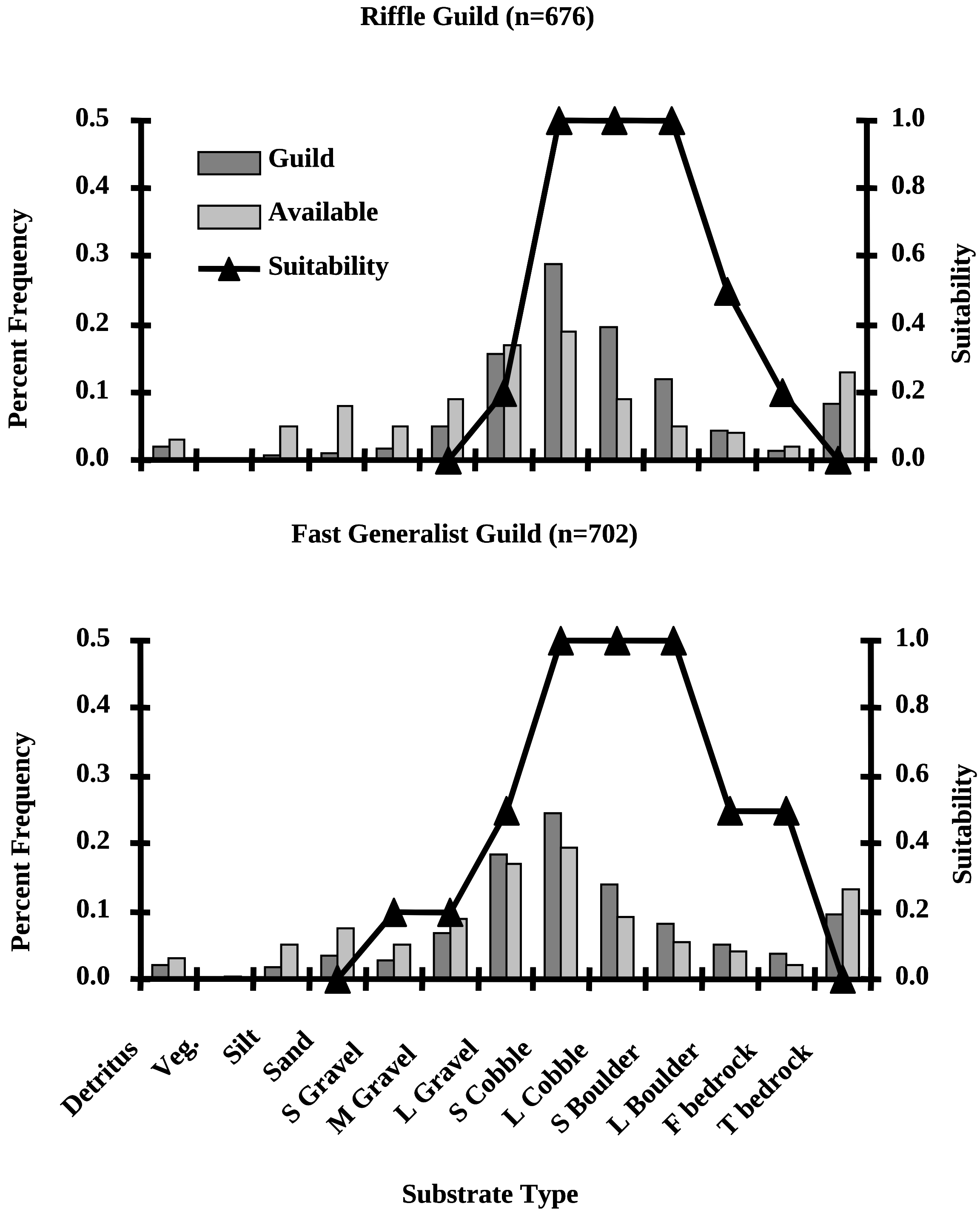


Figure 27. Riffle guild and fast generalist guild substrate habitat criteria. The guild bars represent the frequency that the substrate category was used by the guild and the available bars represent the frequency found in the North Fork Shenandoah River. Suitability values were based on the significance of the Strauss linear index values calculated.

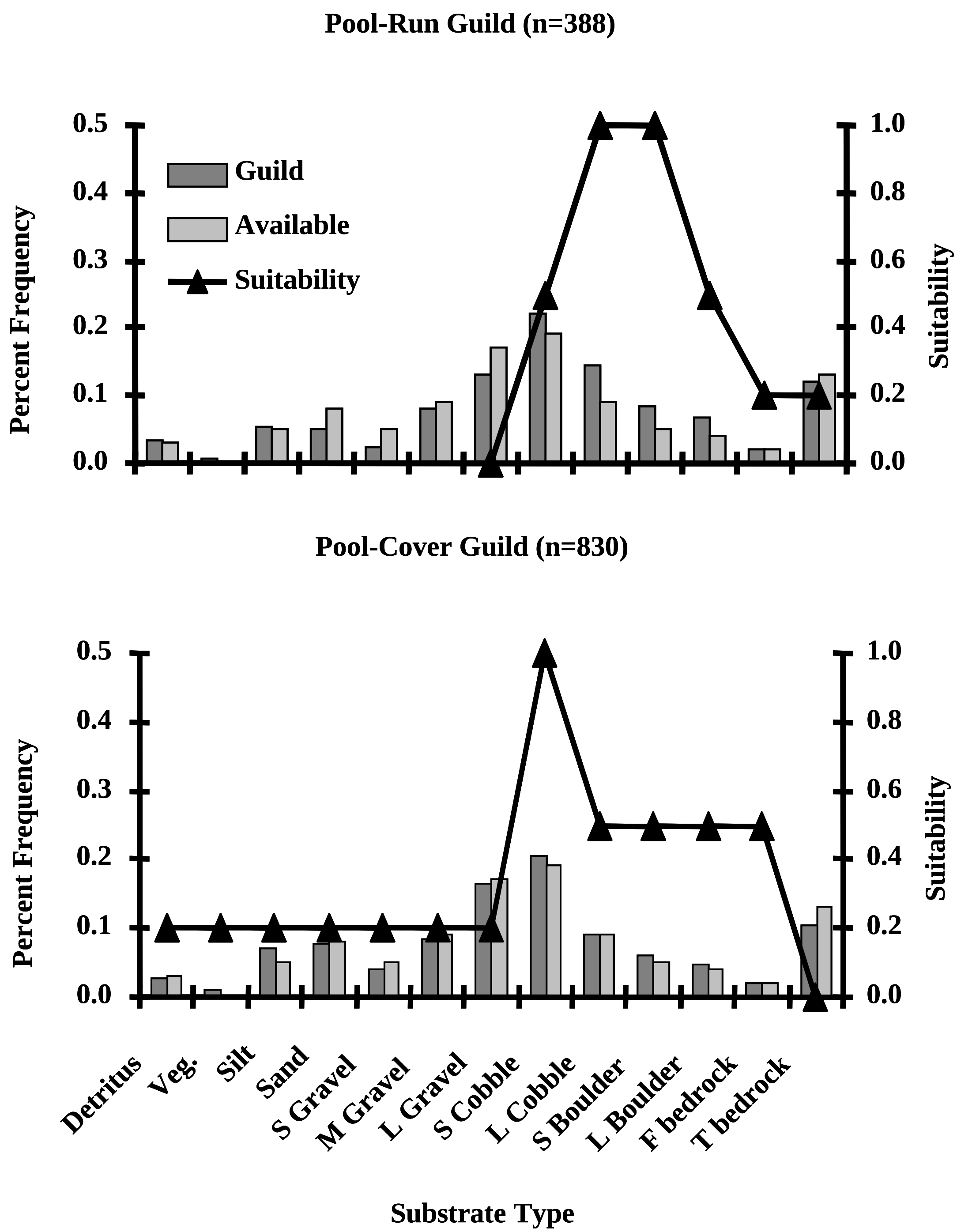


Figure 28. Pool-run guild and pool-cover guild substrate habitat criteria. The guild bars represent the frequency that the substrate category was used by the guild and the available bars represent the frequency found in the North Fork Shenandoah River. Suitability values were based on the significance of the Strauss linear index values calculated.

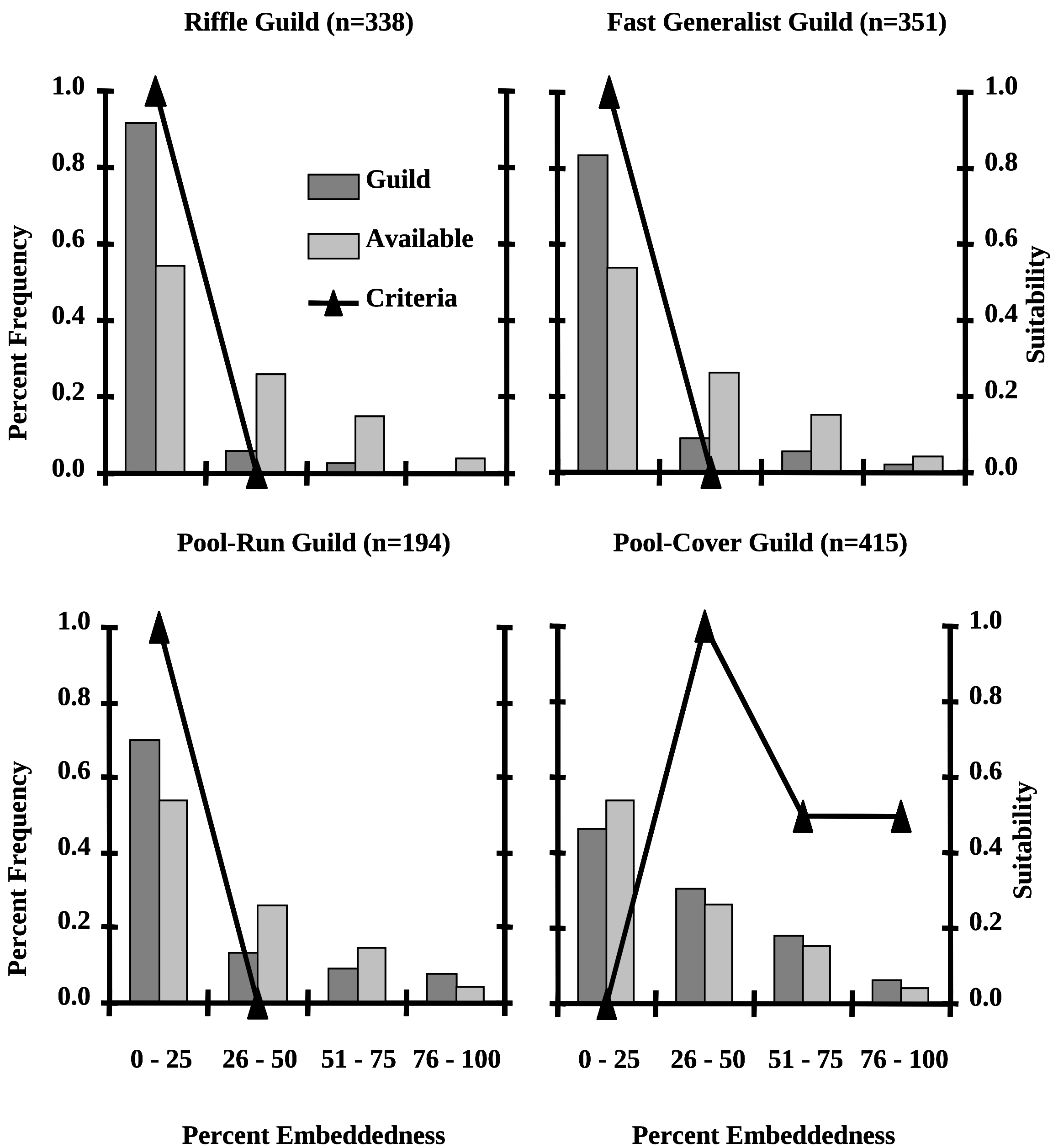


Figure 29. Habitat criteria for embeddedness. The guild bars represent the frequency that level of embeddedness was used by the guilds and the available bars represent the frequency found in the North Fork Shenandoah River. Suitability values were based on the significance of the Strauss linear index values calculated.

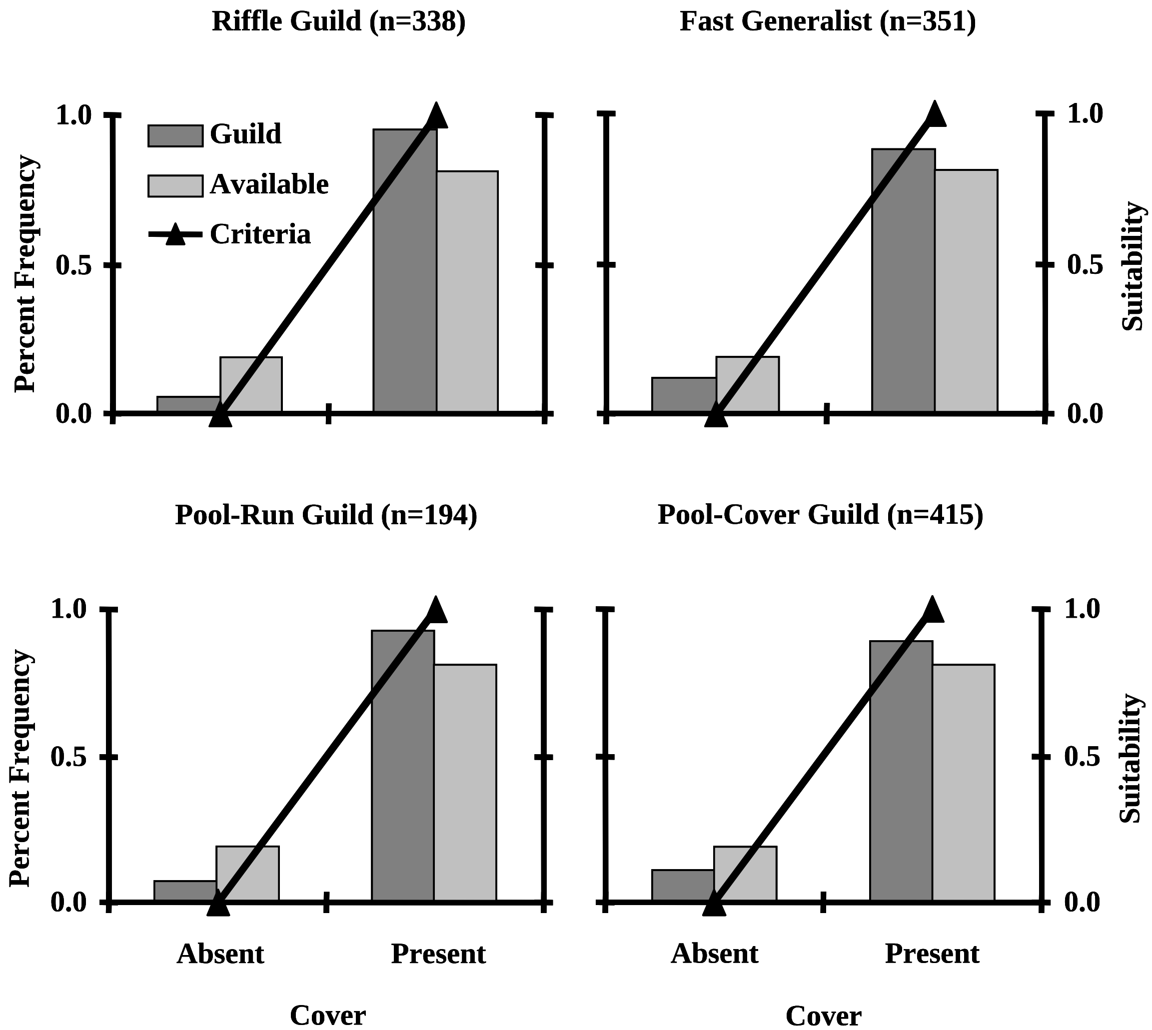


Figure 30. Habitat criteria for cover. The X-axis categories are cover presence or absence. The guild bars represent the frequency that cover was present or absent at guild locations and available bars represent the frequency that cover was present or absent in the North Fork Shenandoah River. Suitability values were based on the significance of the Strauss linear index values calculated.

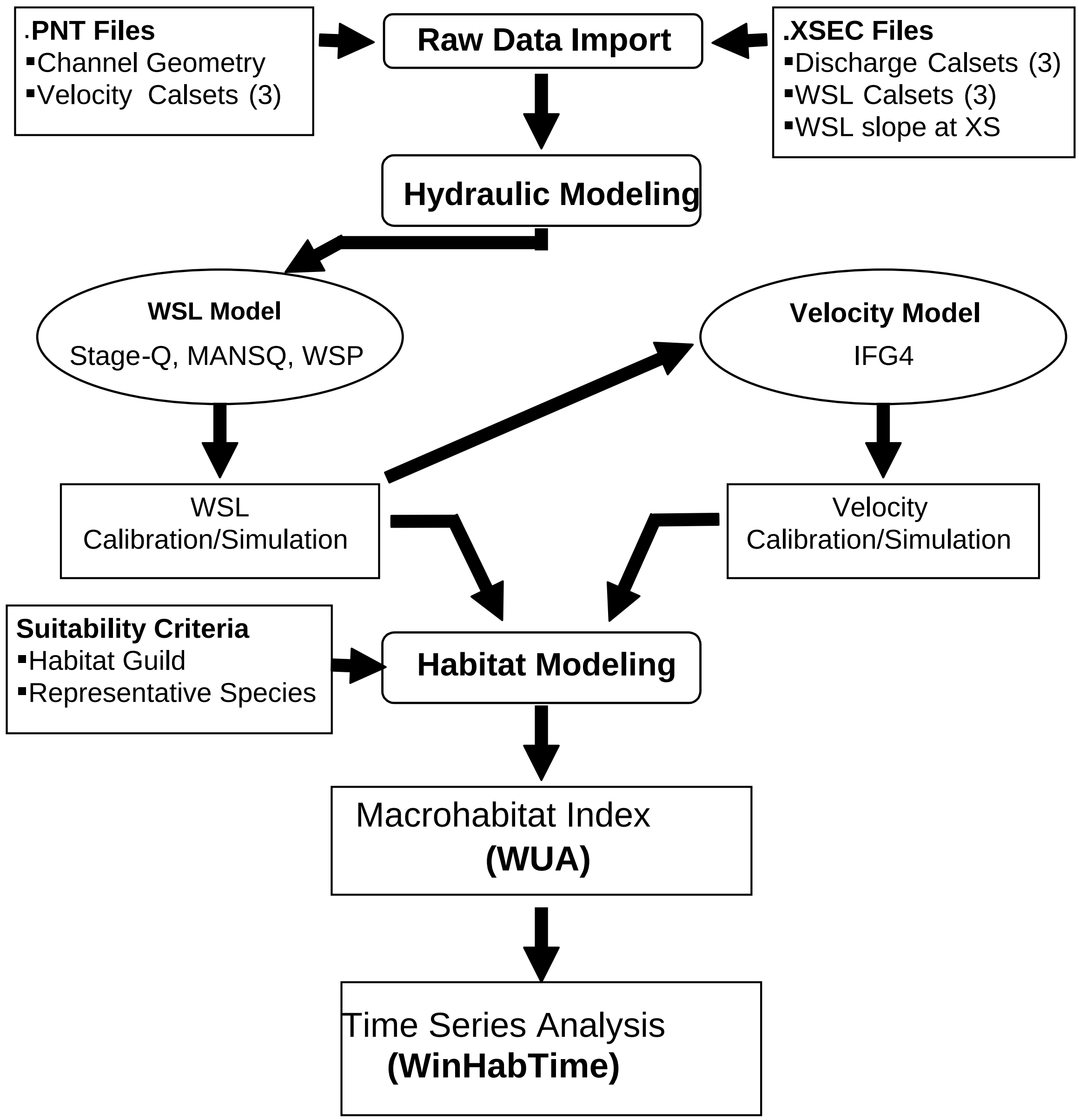


Figure 31. Schematic of the PHABSIM and Time Series modeling process. We used the PHABWin-2002 and WinHabTime modeling software produced by Dr. Thomas Hardy of the Institute of Natural Systems Engineering, Utah State University, for our analysis.

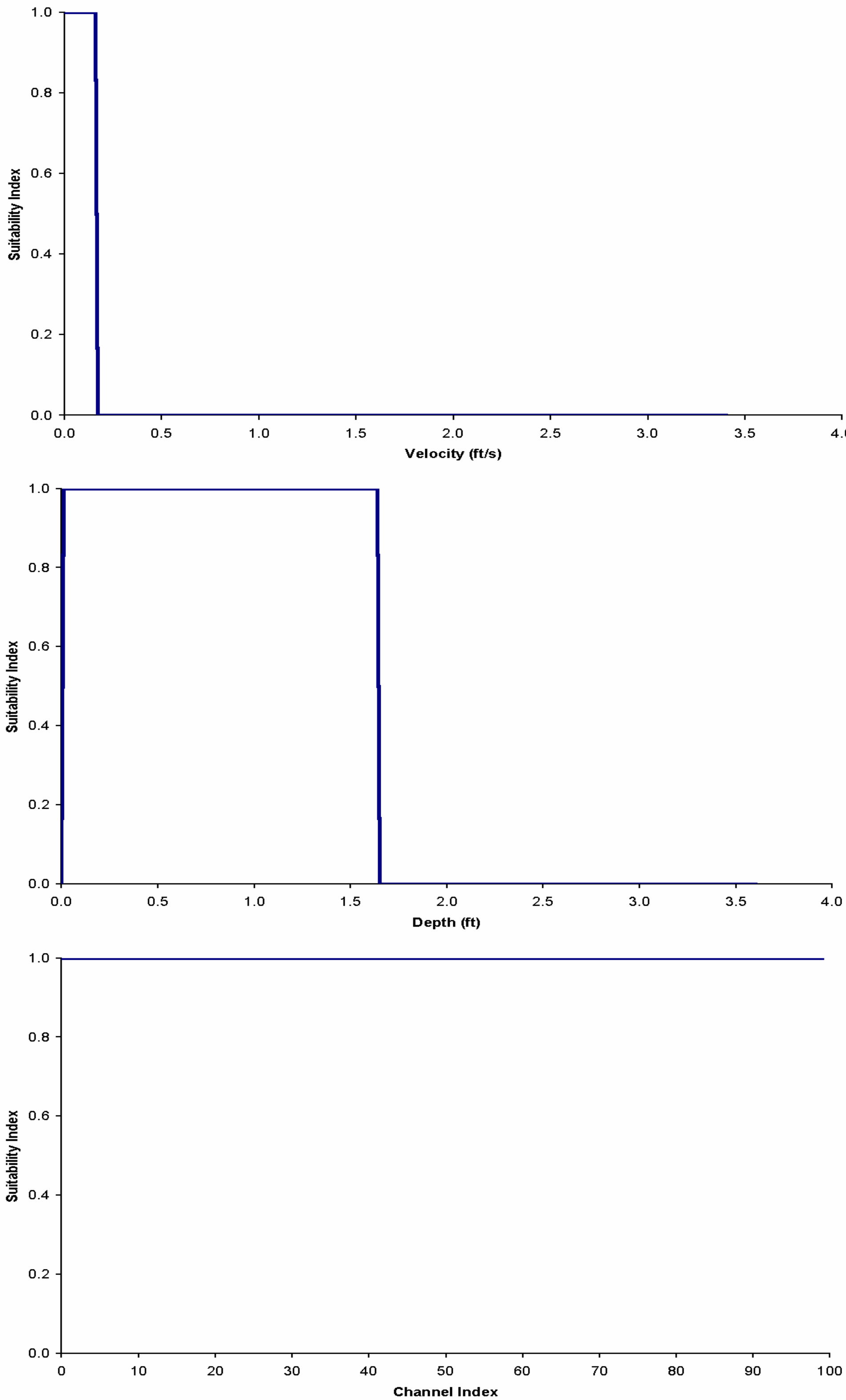


Figure 32. Velocity, depth, and channel index suitability curves for the algae – midge guild. This guild will facilitate algal bloom potential in the North Fork Shenandoah River, Virginia, during low flow conditions.

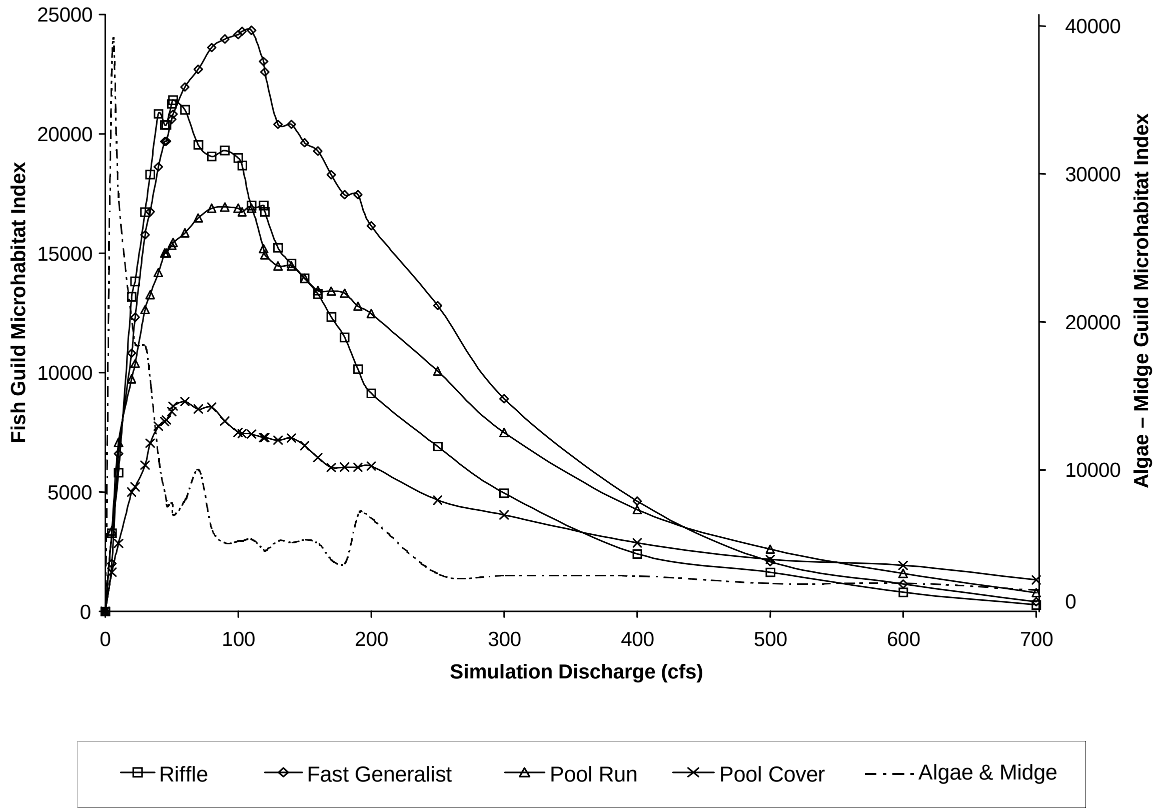


Figure 33. Usable microhabitat versus discharge for the fish habitat guilds and algae – midge habitat guild at the Plains Mill site using Cootes Store reach specific weighting factors.

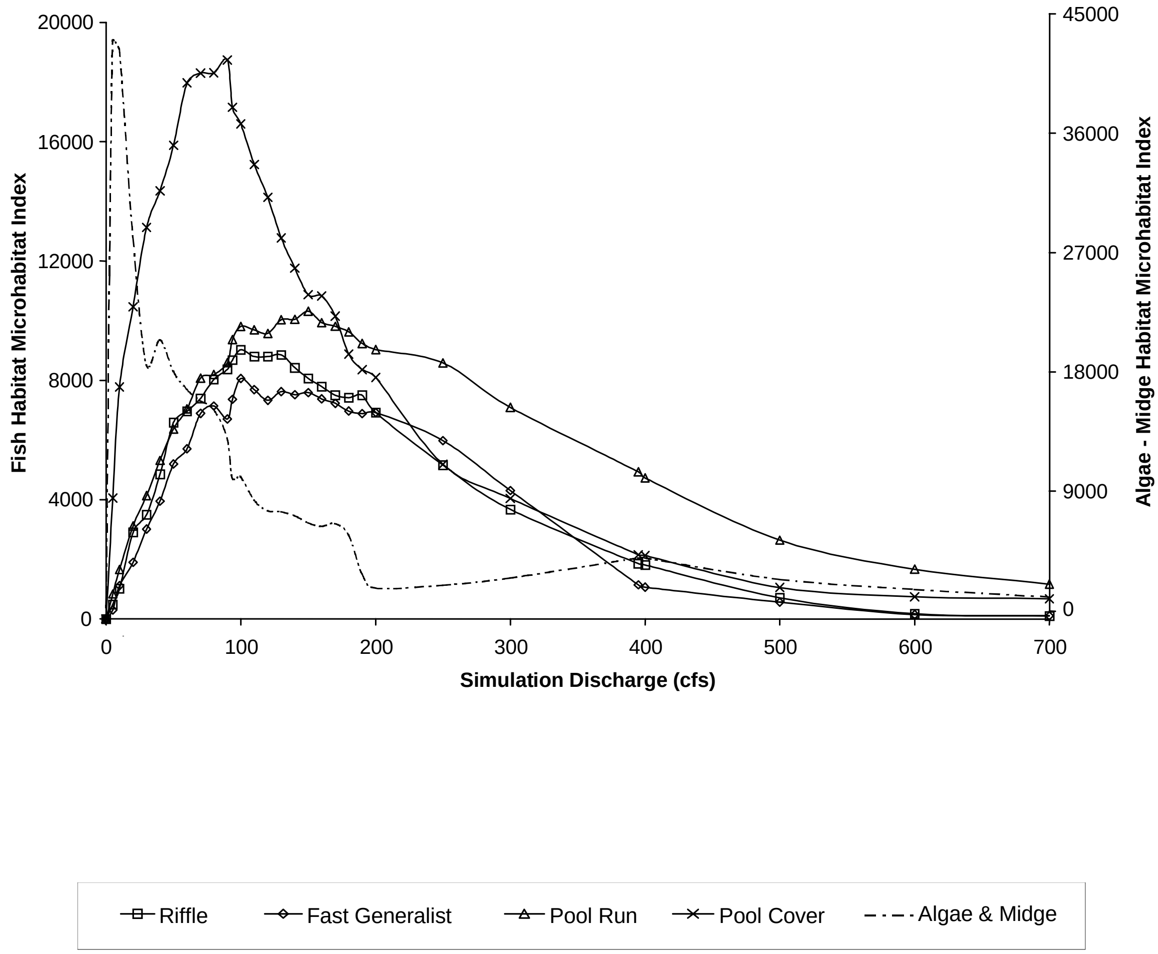


Figure 34. Usable microhabitat versus discharge for the fish habitat guilds and algae – midge habitat guild at the Laurel Hill Farm site using Mount Jackson reach specific weighting factors.

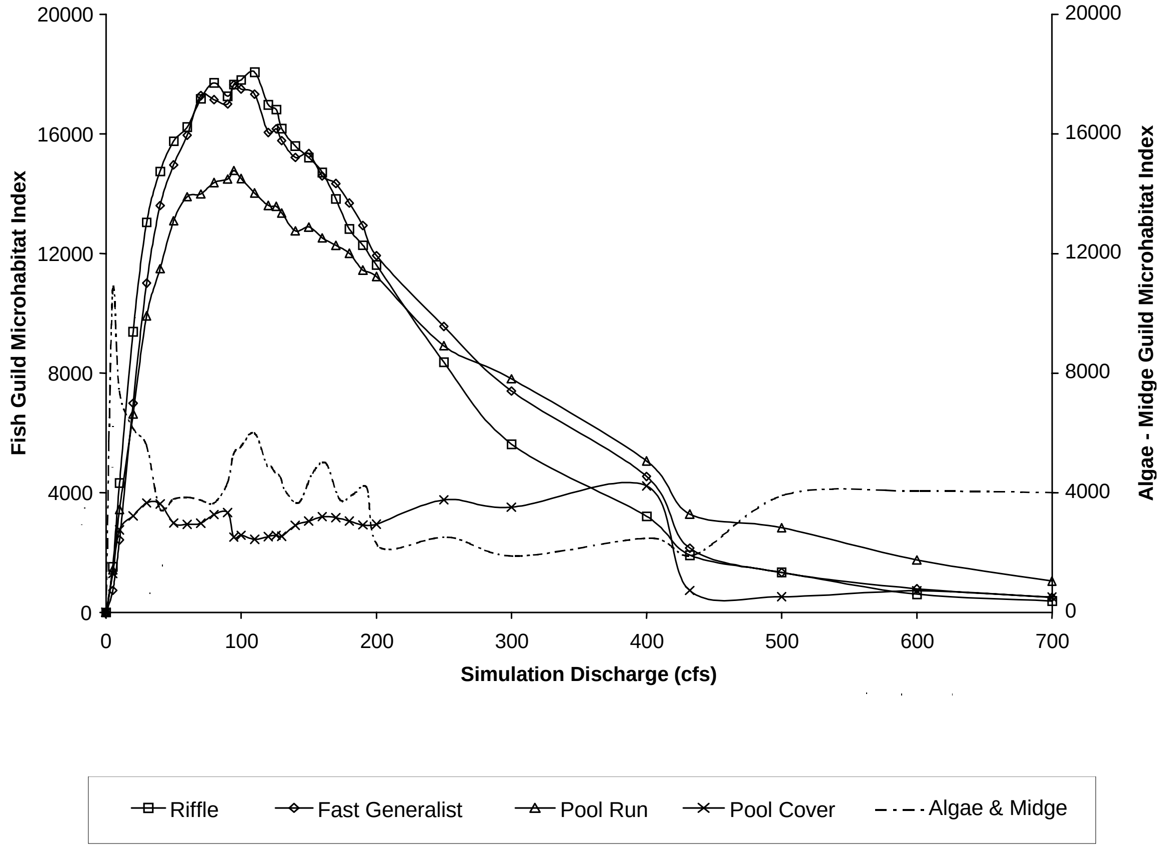


Figure 35. Usable microhabitat versus discharge for the fish habitat guilds and algae – midge habitat guild at the Spring Hollow site using Strasburg reach specific weighting factors.

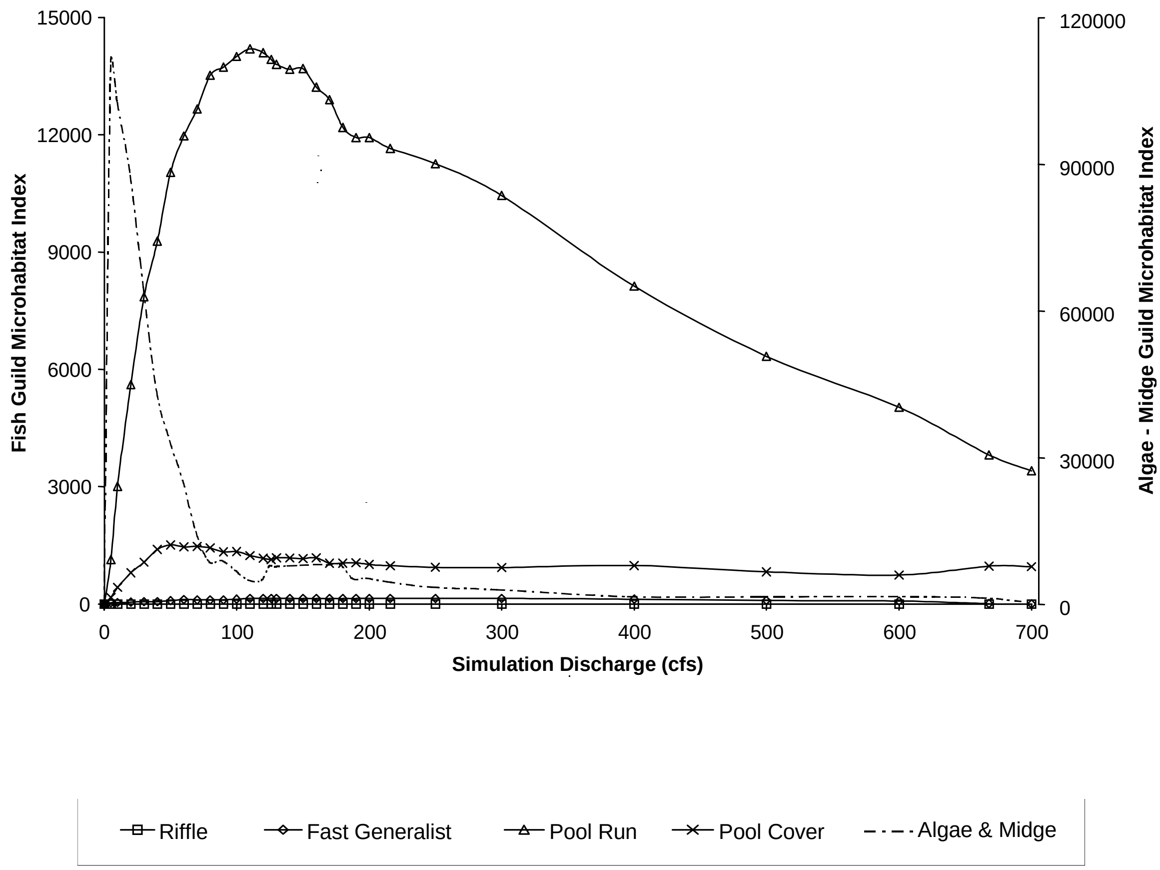


Figure 36. Usable microhabitat versus discharge for the fish habitat guilds and algae - midge habitat guild at the Posey Hollow site using Strasburg reach specific weighting factors.

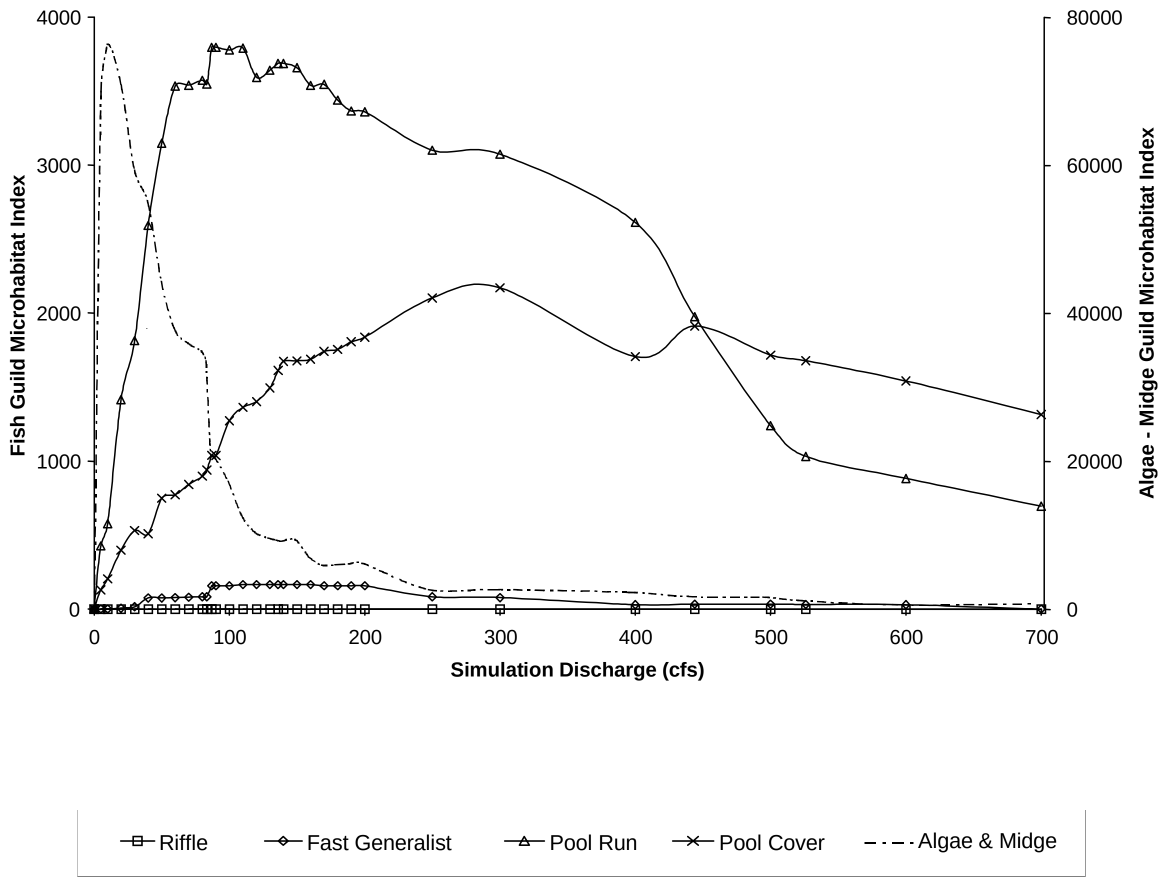


Figure 37. Usable microhabitat versus discharge for the A) fish habitat guilds and B) fish and algae habitat guilds at the Route 648 site using Strasburg reach specific weighting factors.

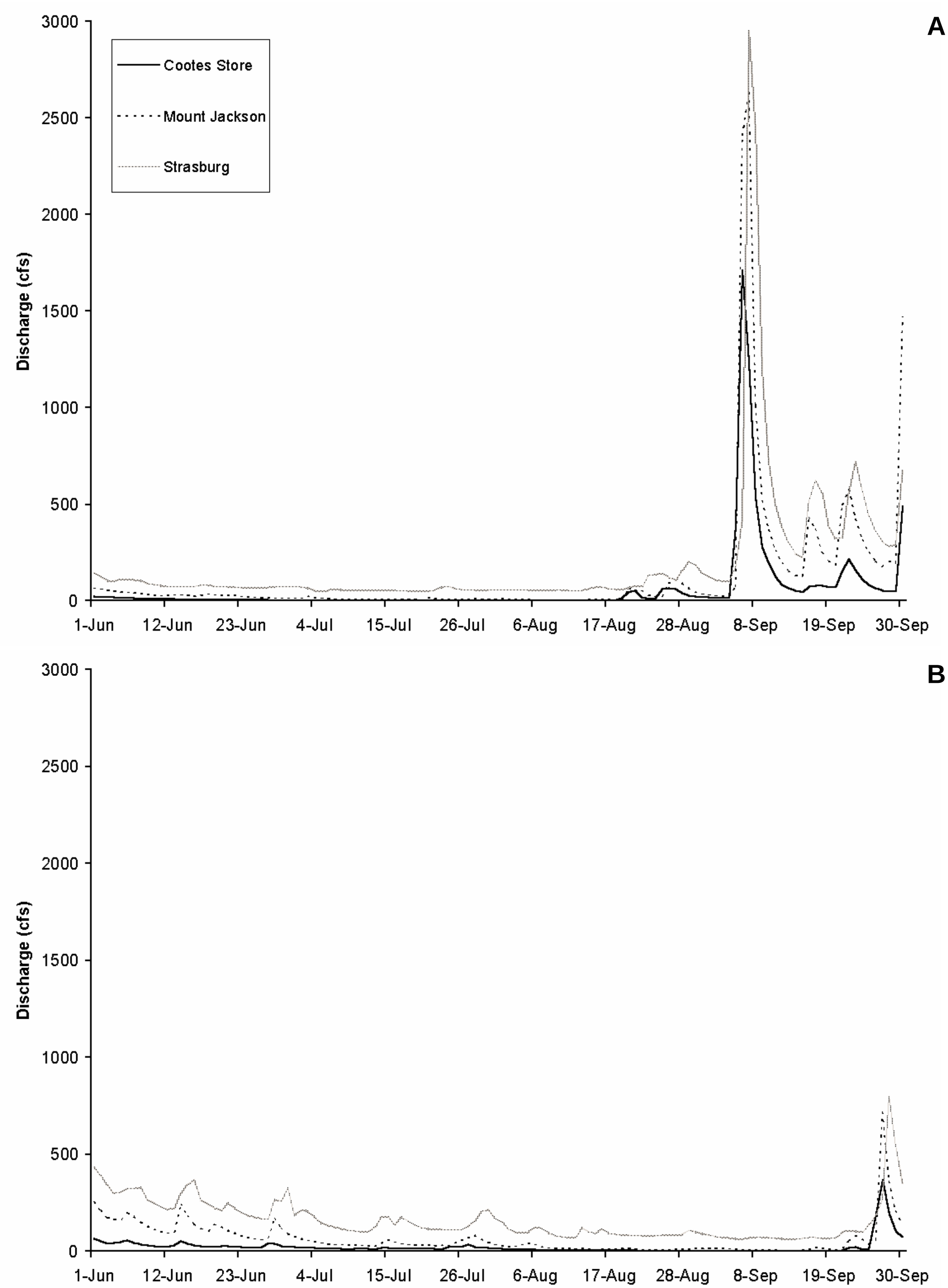


Figure 38. Daily mean discharge time series during A) summer 1999 and B) summer 2002 for the North Fork Shenandoah River, Virginia.

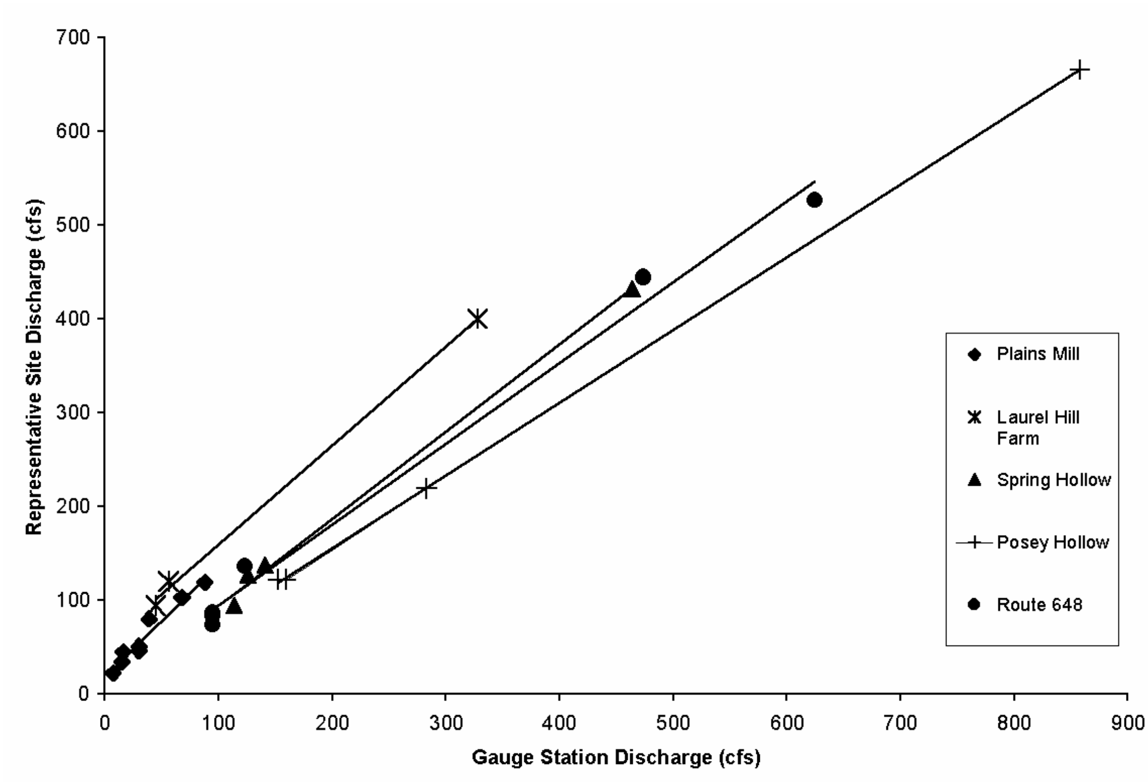


Figure 39. Gauge - site discharge correlation for the North Fork Shenandoah gauging stations and their representative sites (Cootes Store – Plains Mill, Mount Jackson – Laurel Hill Farm, Strasburg – Spring Hollow, Posey Hollow, Route 648). For Time Series analysis, the gauge station daily mean discharge was weighted to the representative site using the calculated linear regression equation for each gauge – site pair. Cootes Store daily mean discharge data was weighted to the Plains Mill site using the equation, $y = 1.1978x + 18.536$. Mount Jackson daily mean discharge data was weighted to the Laurel Hill Farm site using the equation, $y = 1.0574x + 53.459$. Strasburg daily mean discharge was weighted to: Spring Hollow using the equation, $y = 0.9315x + 0.4764$, Posey Hollow using the equation, $y = 0.7747x + 1.0224$, and Route 648 using equation, $y = 0.8604x + 8.9051$.

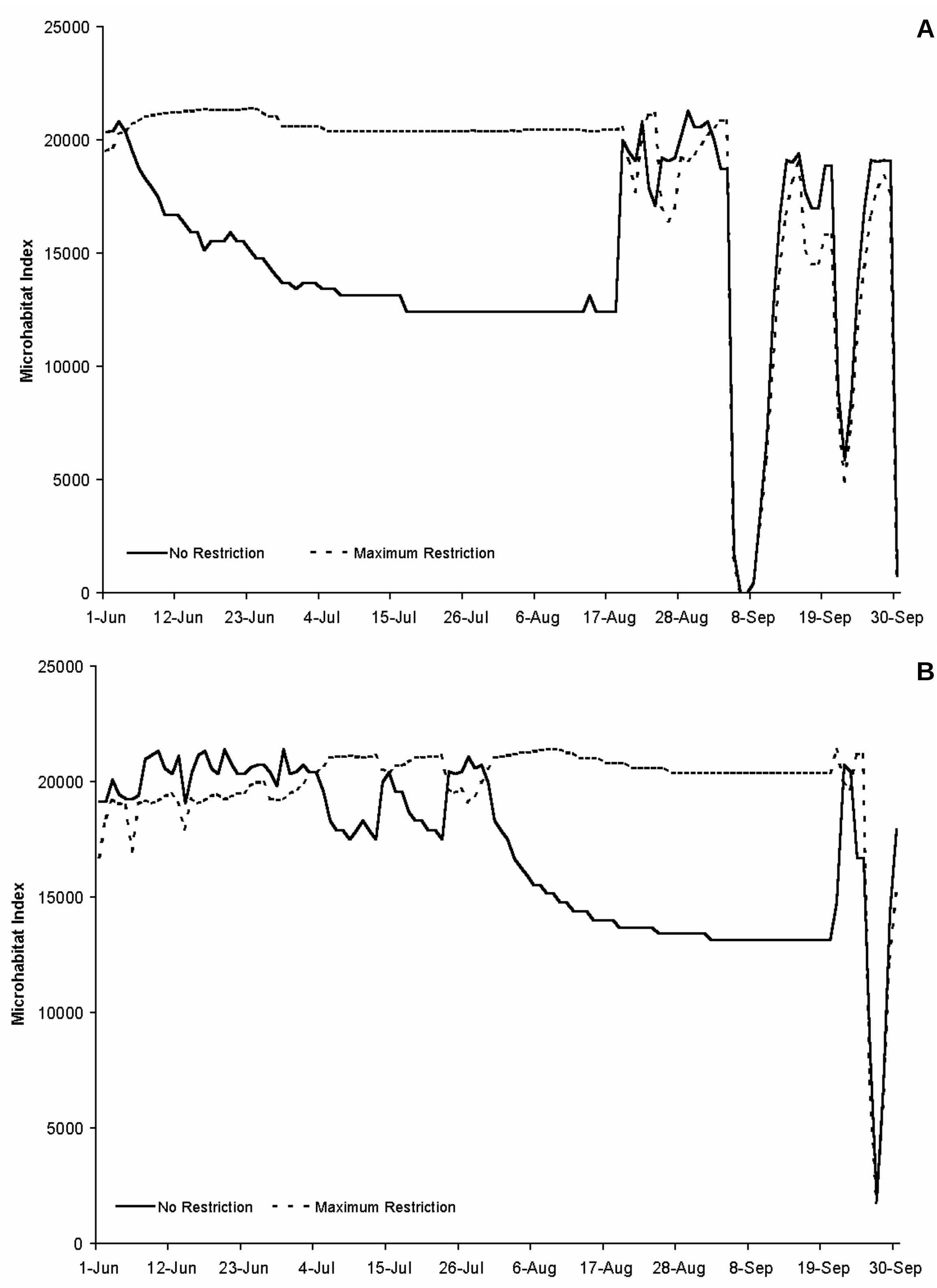


Figure 40. Summer 1999 (A) and 2002 (B) Plains Mill riffle guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

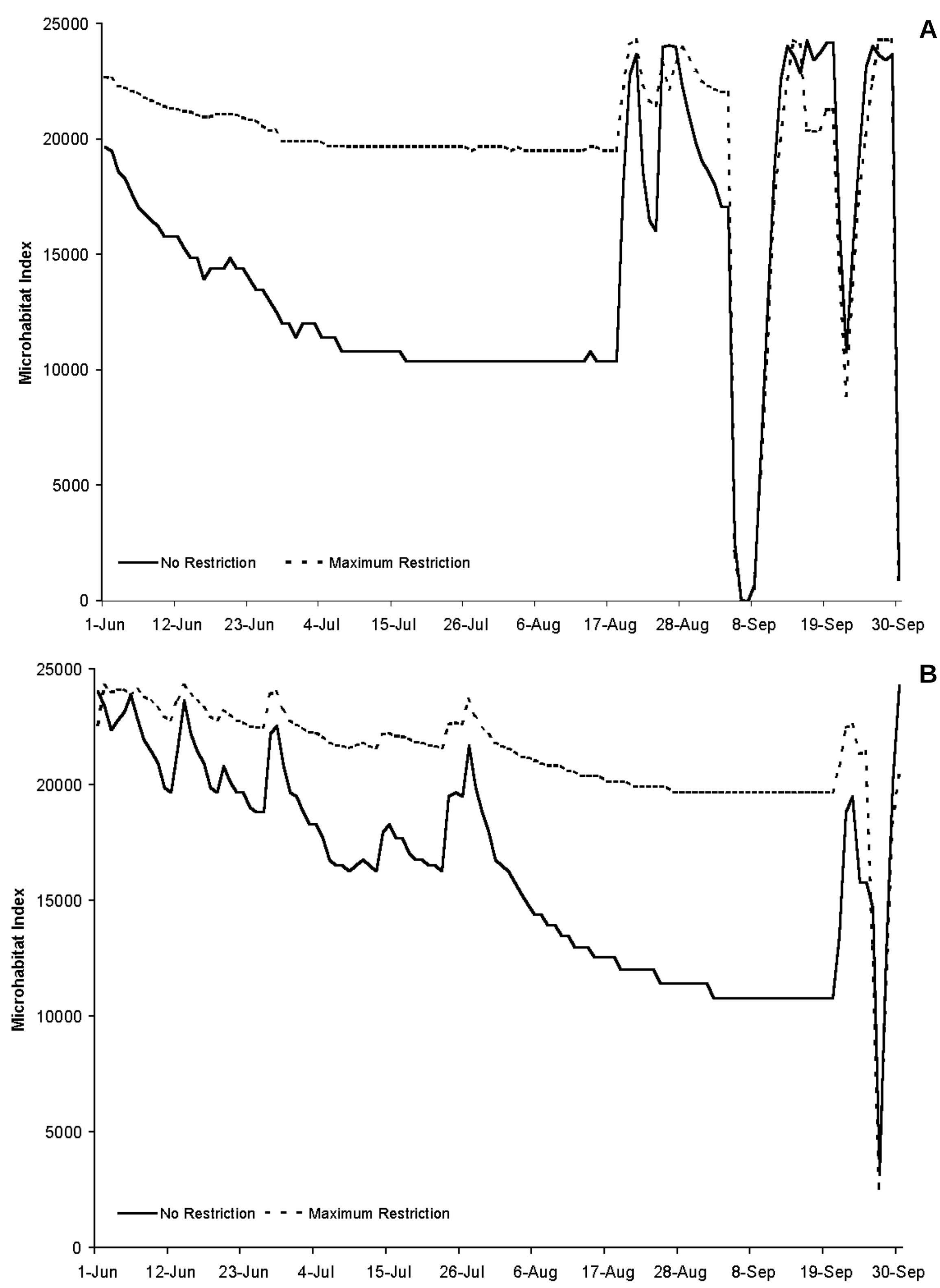


Figure 41. Summer 1999 (A) and 2002 (B) Plains Mill fast generalist guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

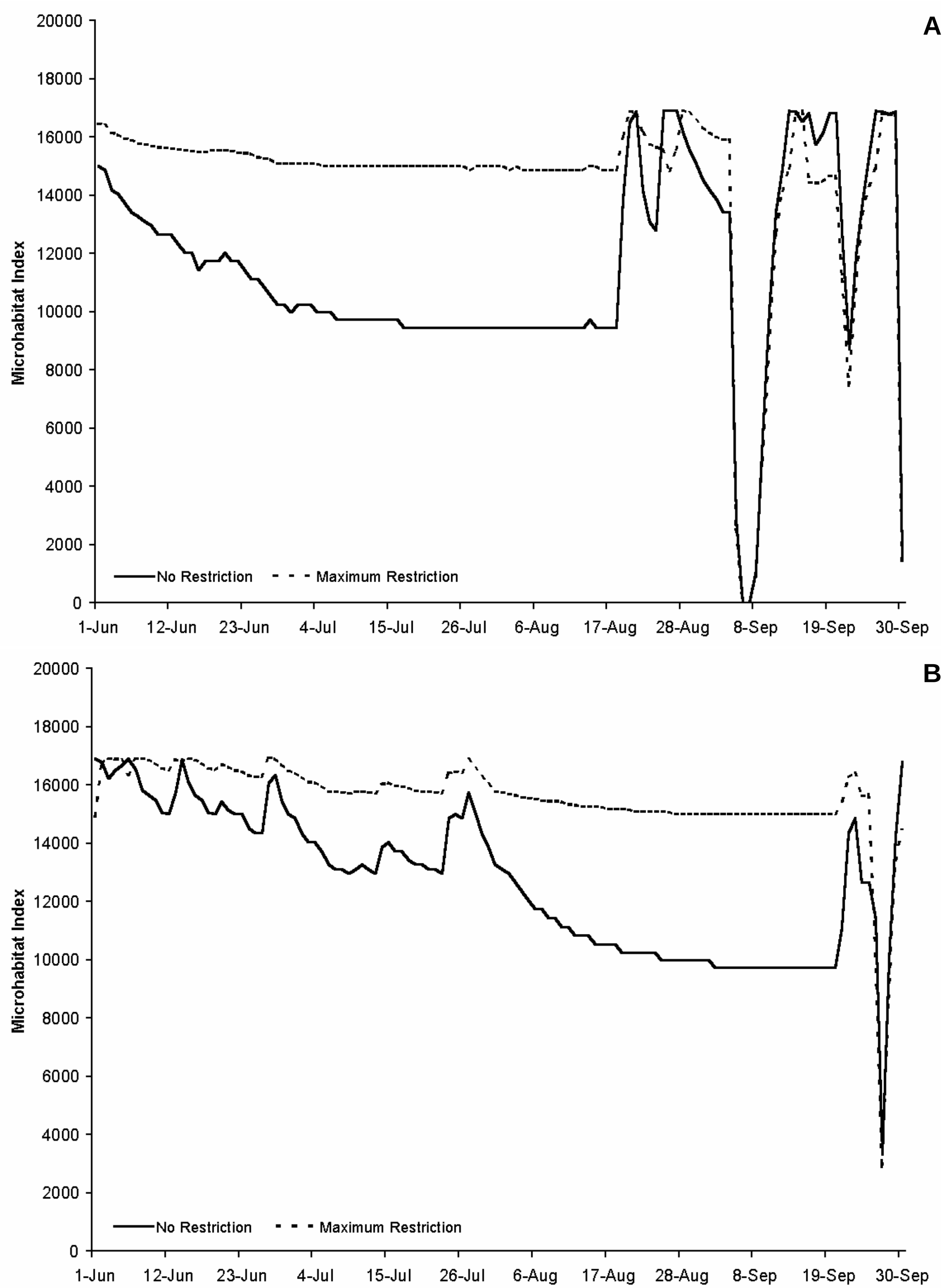


Figure 42. Summer 1999 (A) and 2002 (B) Plains Mill pool – run guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

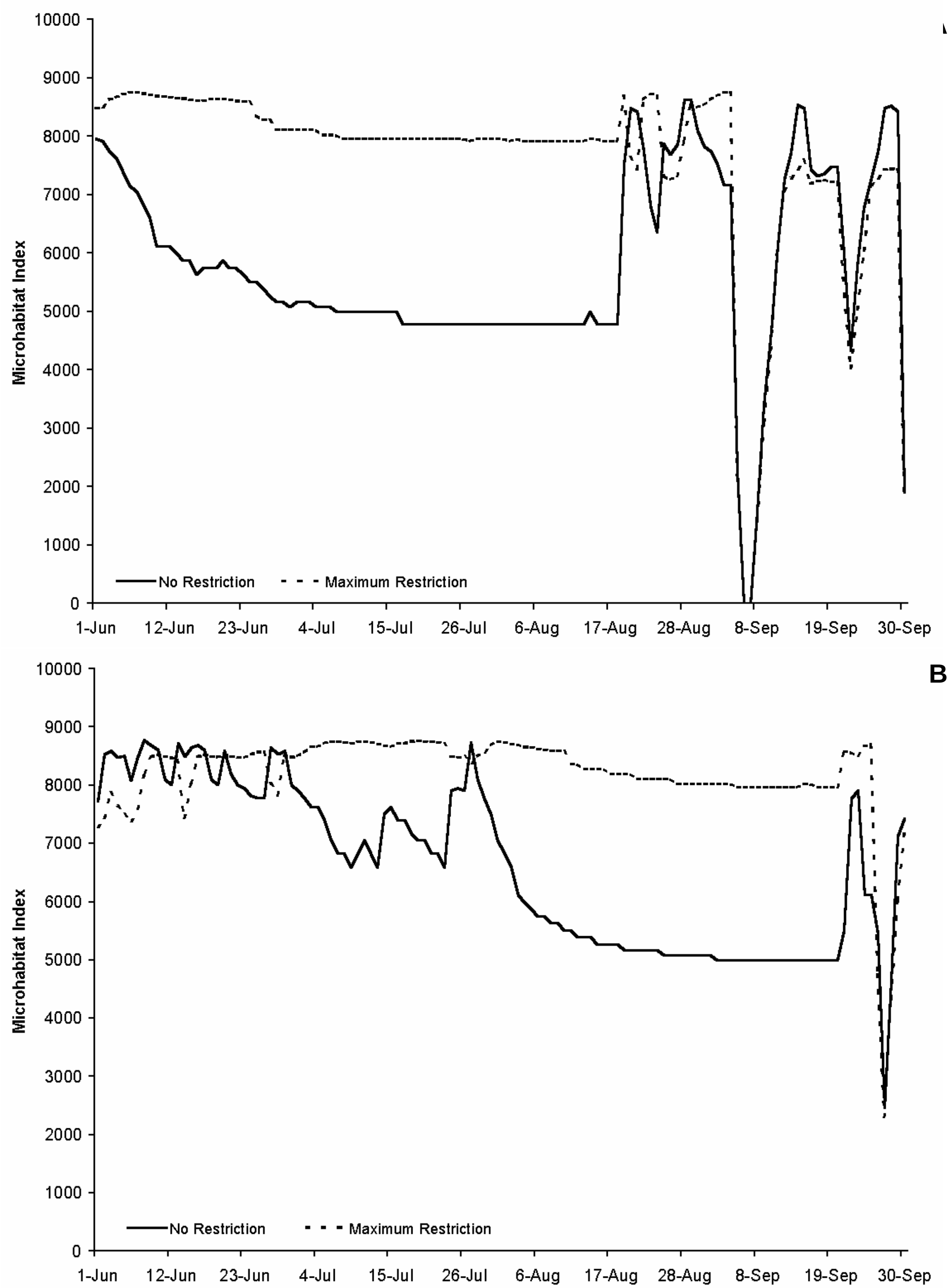


Figure 43. Summer 1999 (A) and 2002 (B) Plains Mill pool – cover guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

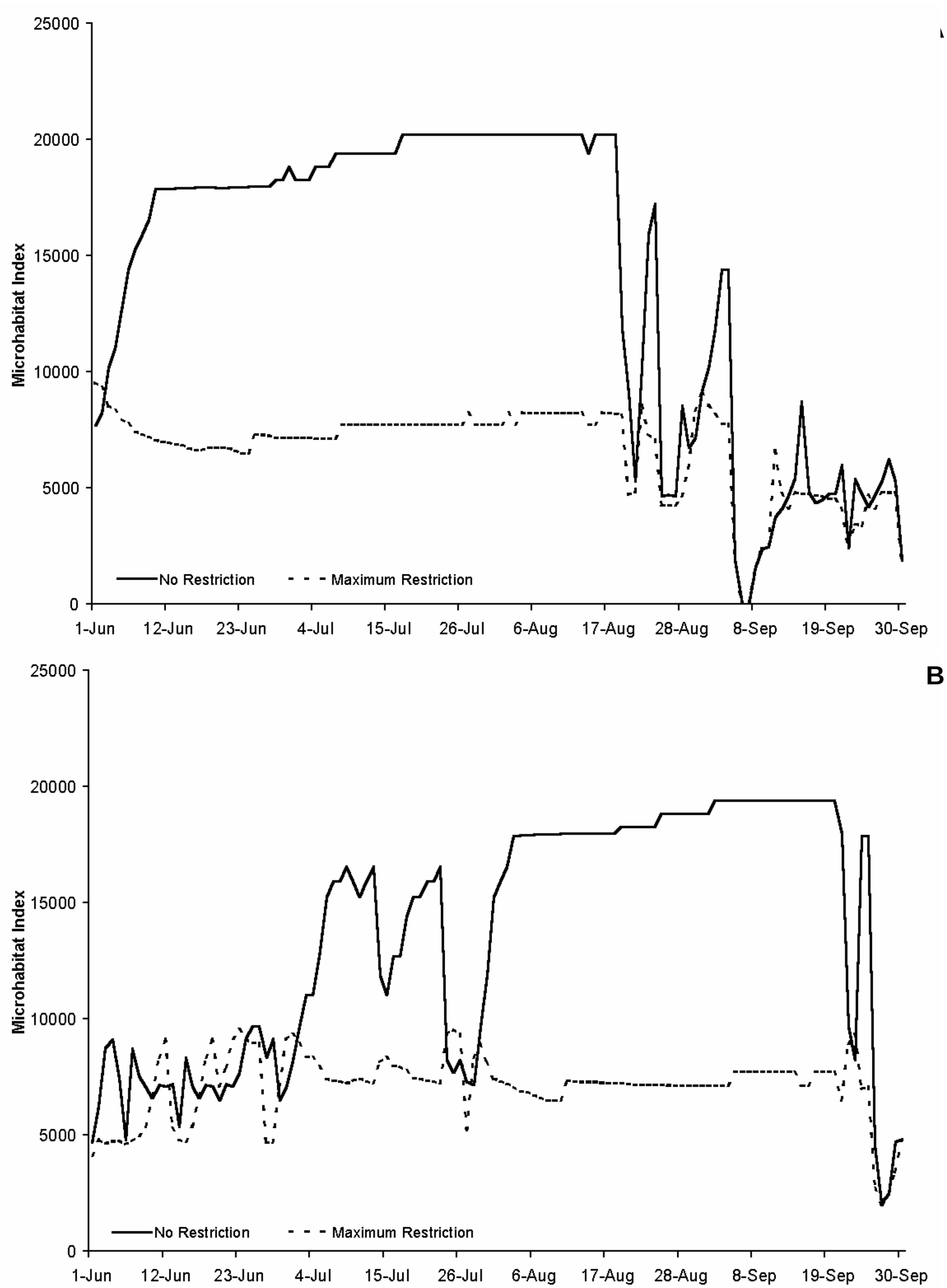


Figure 44. Summer 1999 (A) and 2002 (B) Plains Mill algae - midge guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

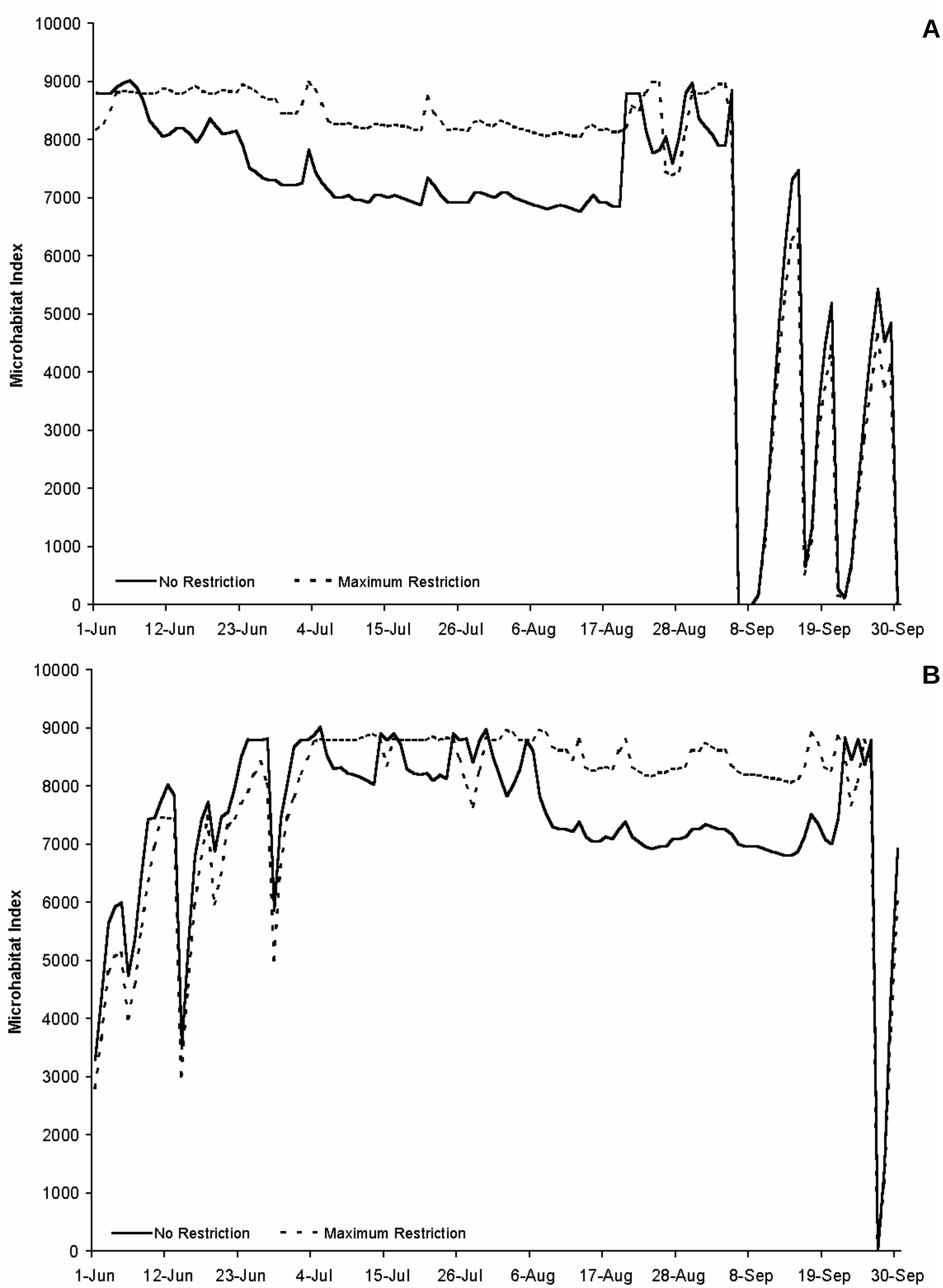


Figure 45. Summer 1999 (A) and 2002 (B) Laurel Hill Farm riffle guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

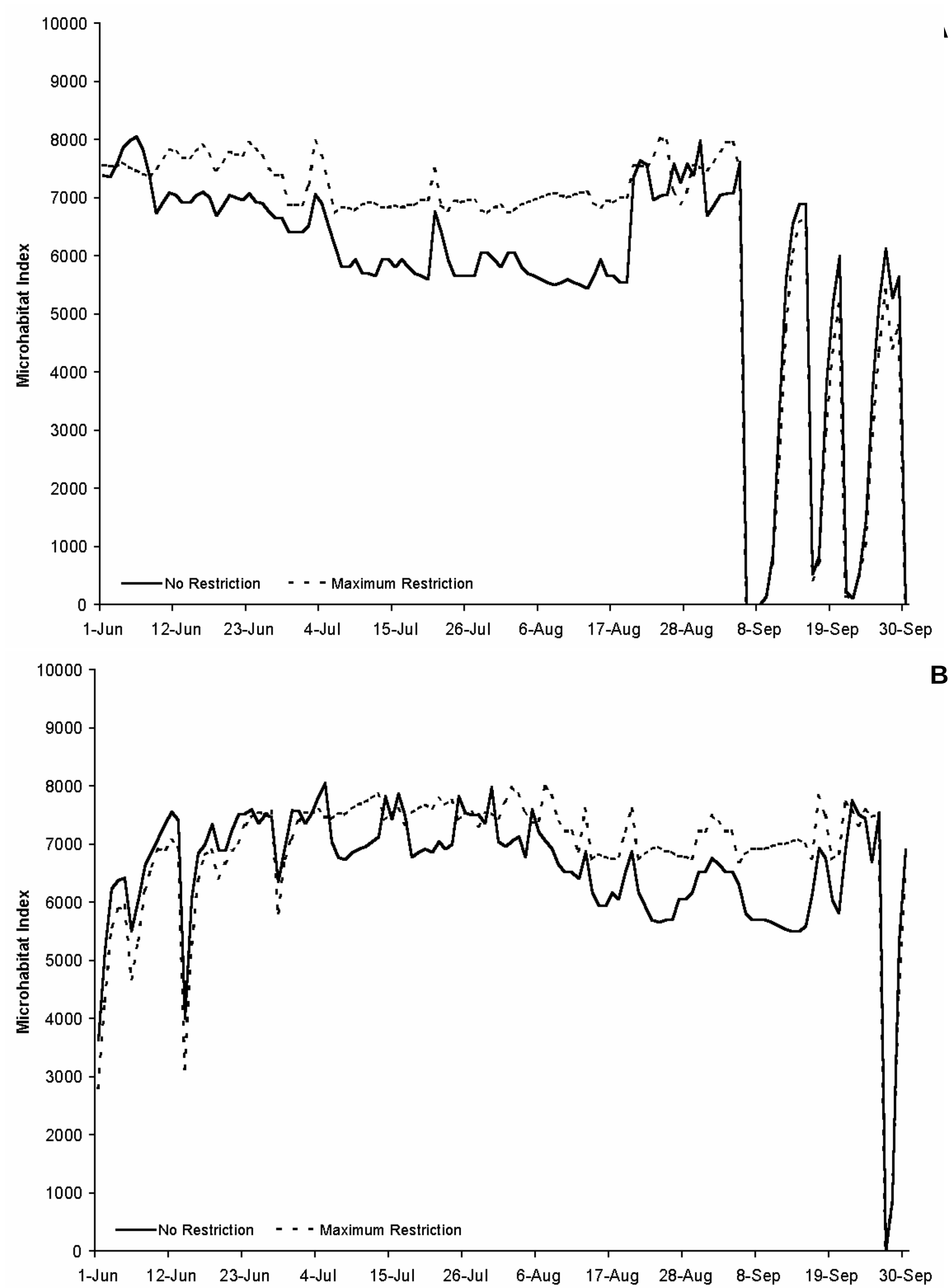
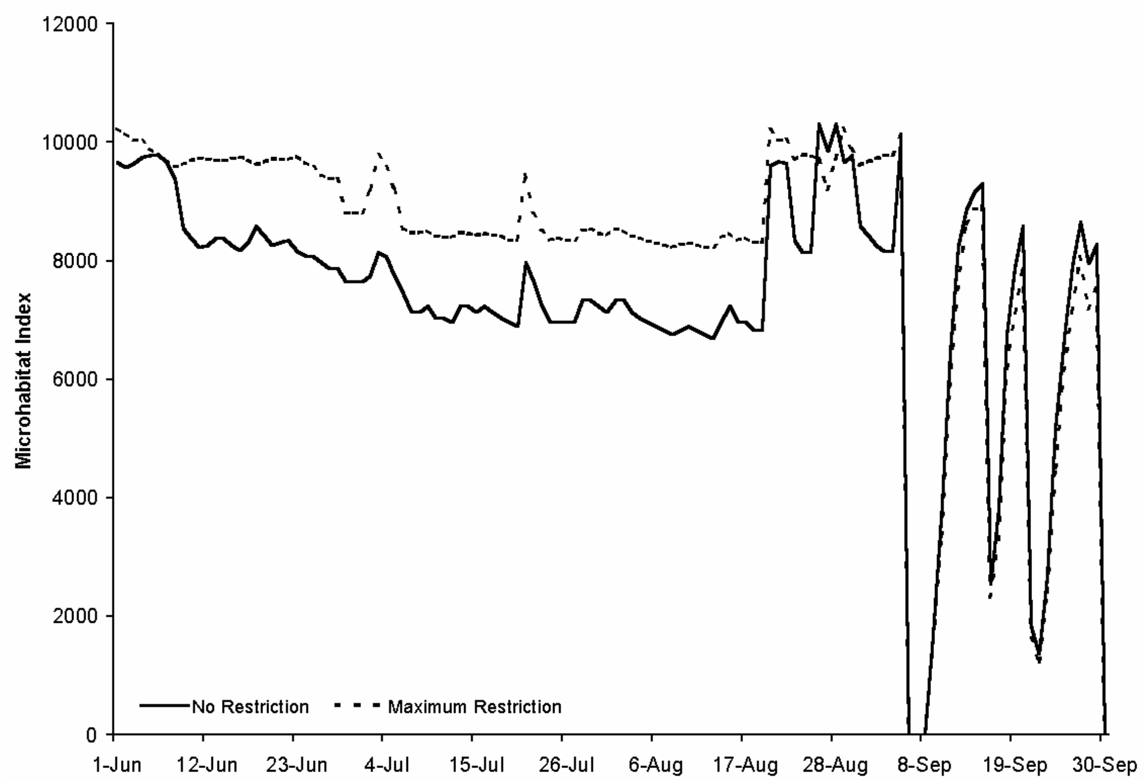


Figure 46. Summer 1999 (A) and 2002 (B) Laurel Hill Farm fast generalist guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).



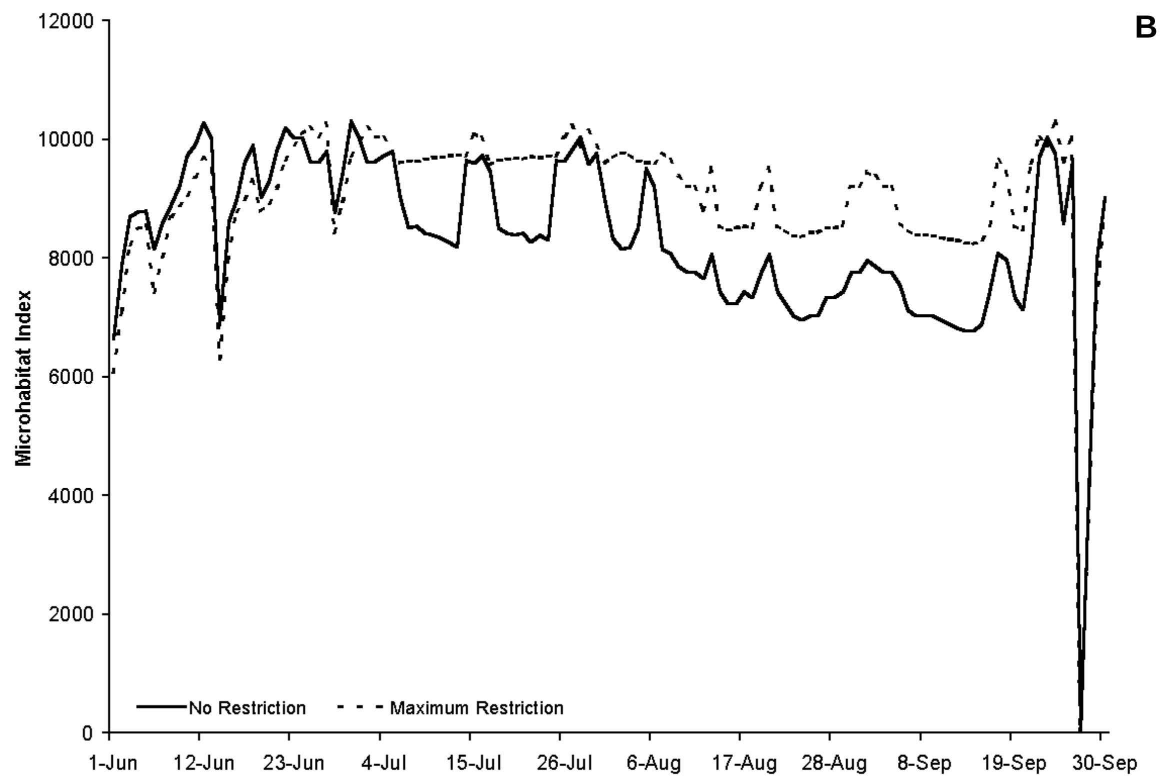


Figure 47. Summer 1999 (A) and 2002 (B) Laurel Hill Farm pool - run guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

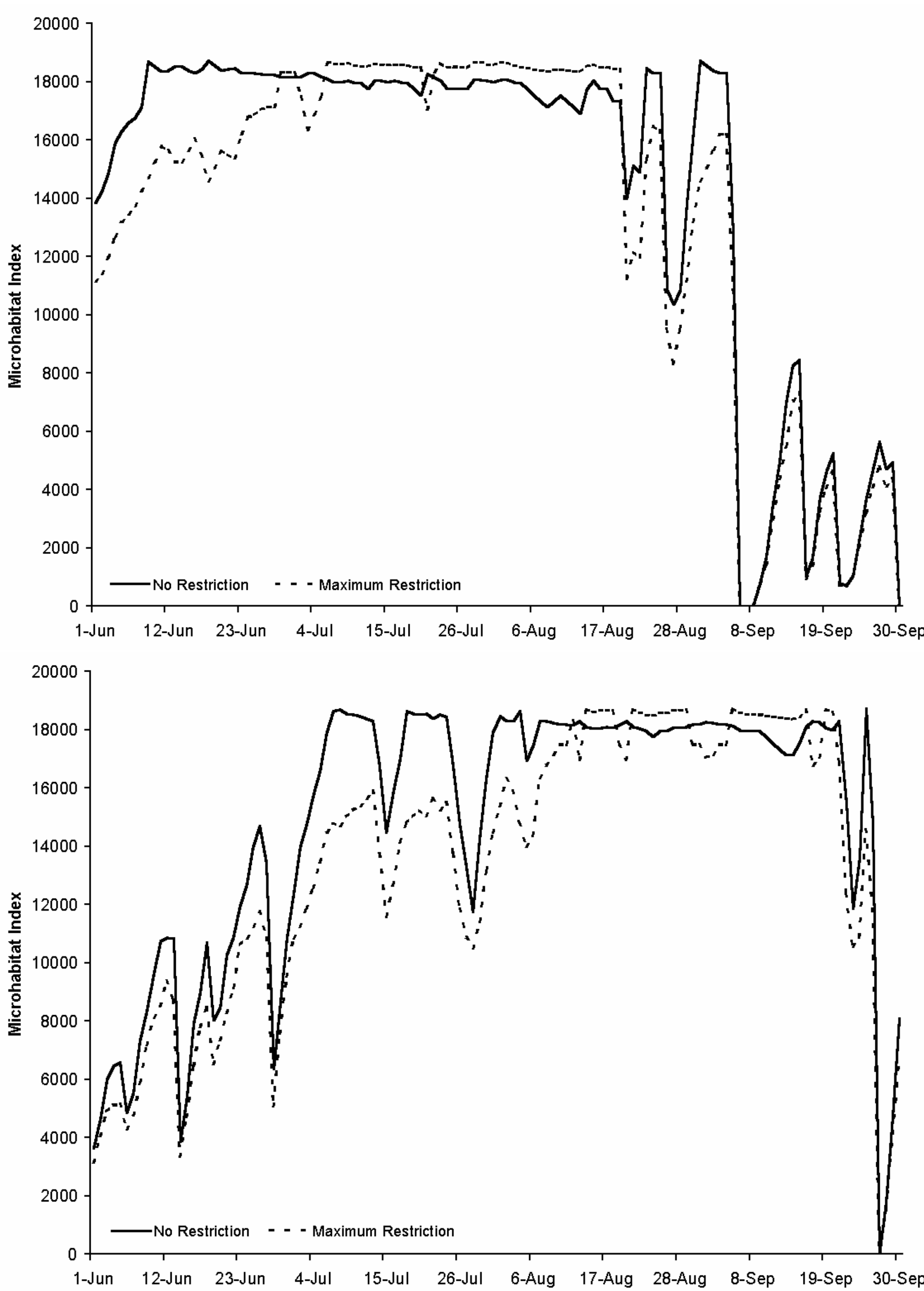


Figure 48. Summer 1999 (A) and 2002 (B) Laurel Hill Farm pool - cover guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

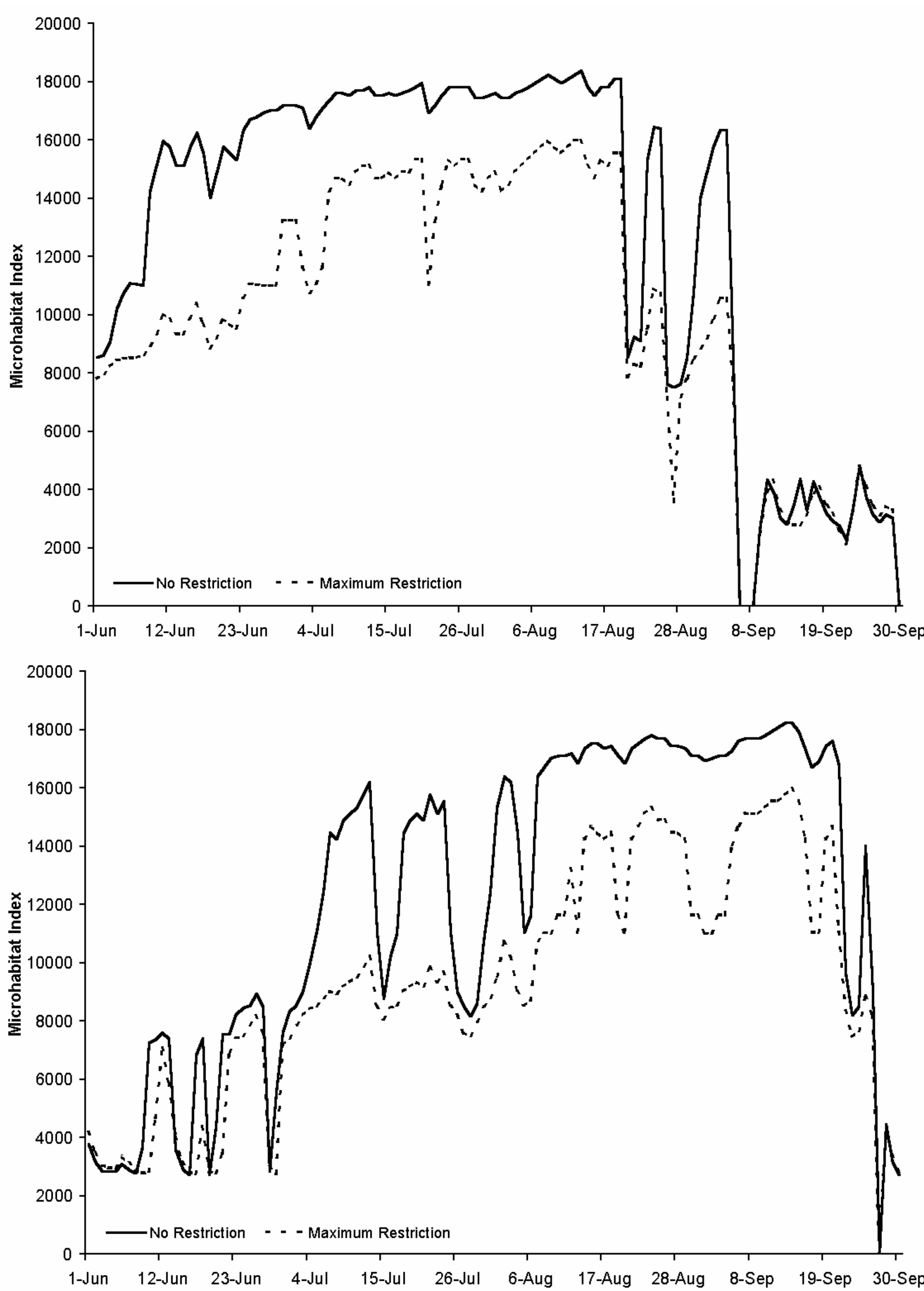


Figure 49. Summer 1999 (A) and 2002 (B) Laurel Hill Farm algae - midge guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

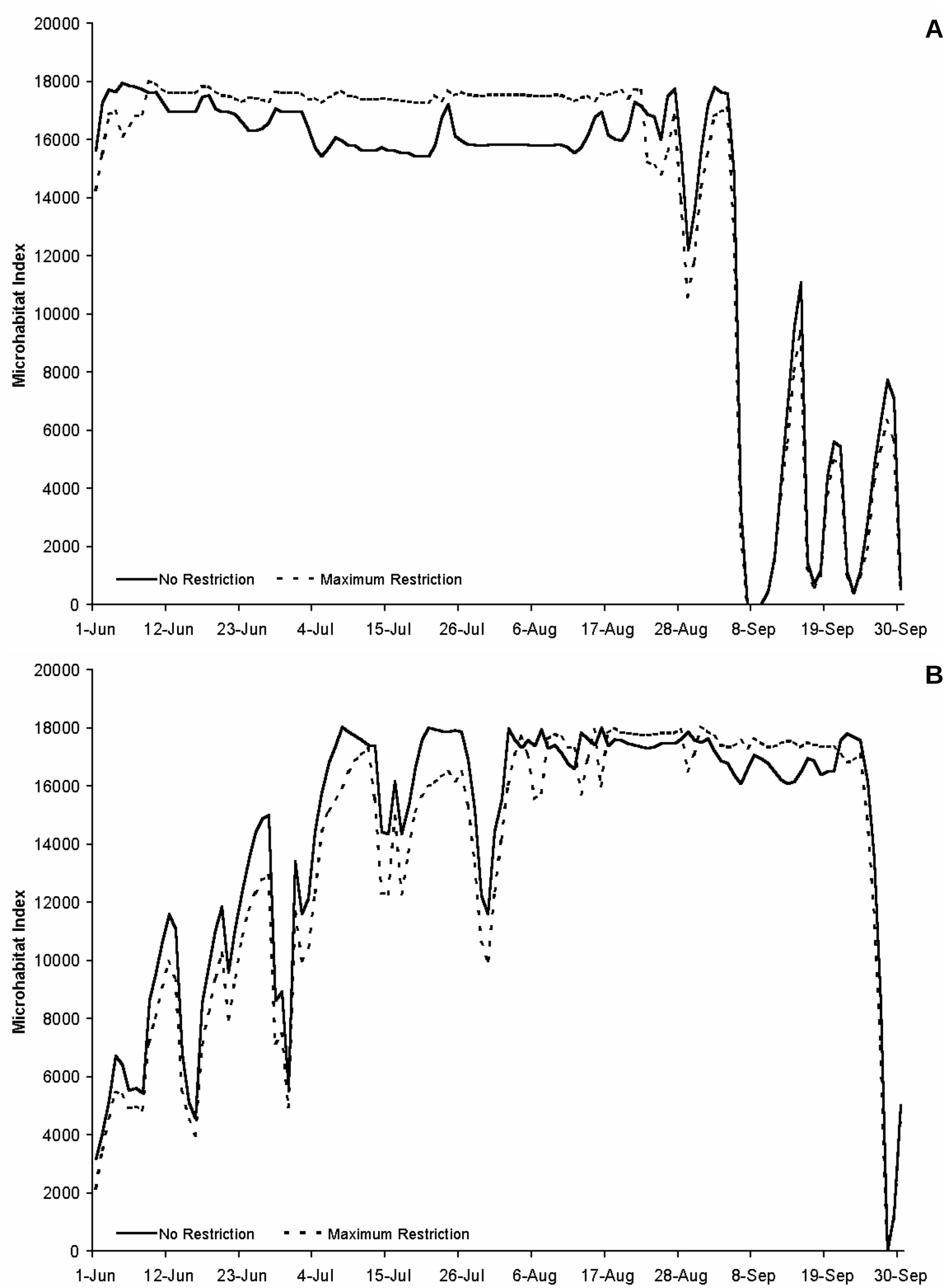


Figure 50. Summer 1999 (A) and 2002 (B) Spring Hollow riffle guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

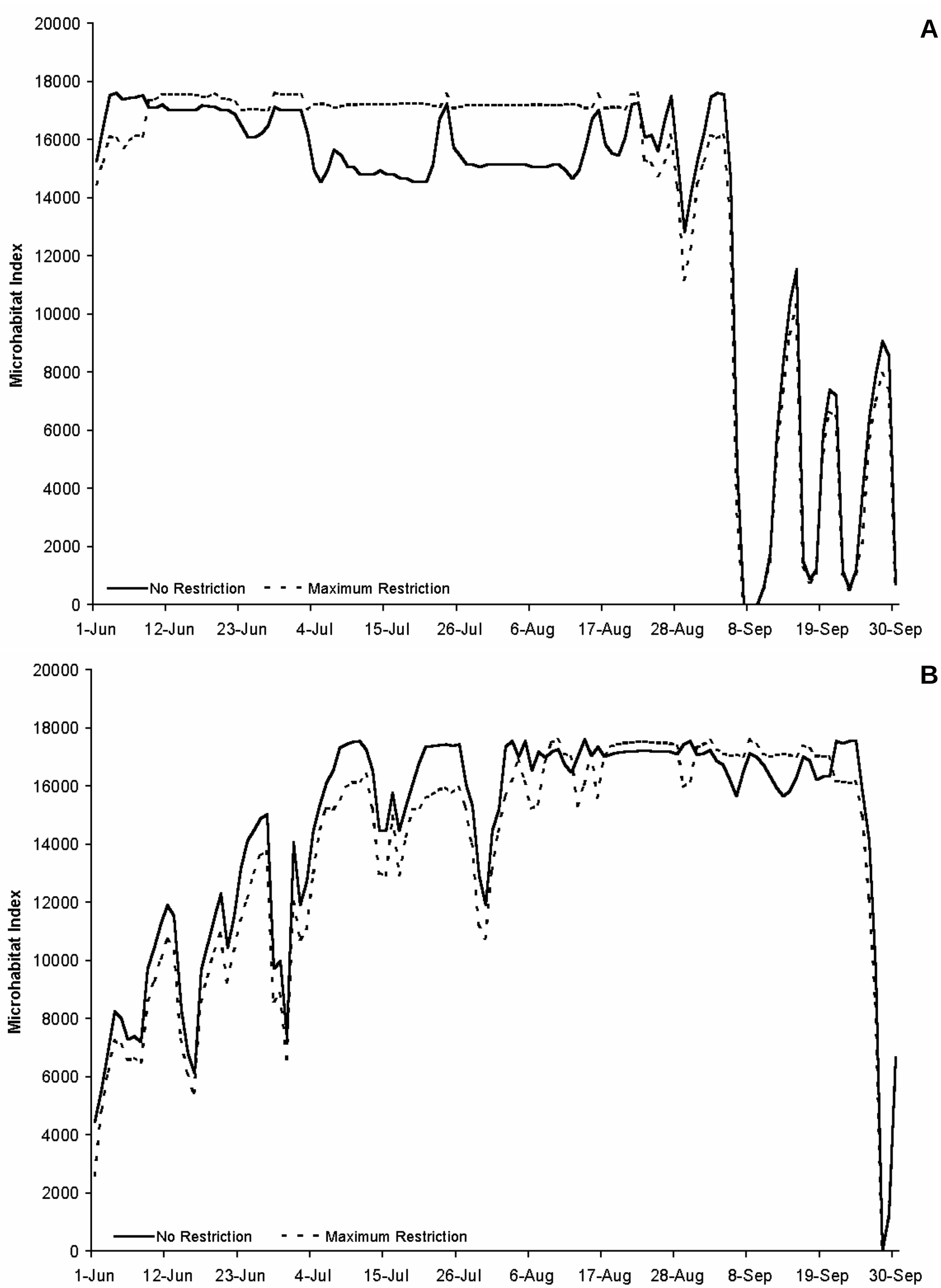


Figure 51. Summer 1999 (A) and 2002 (B) Spring Hollow fast generalist guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

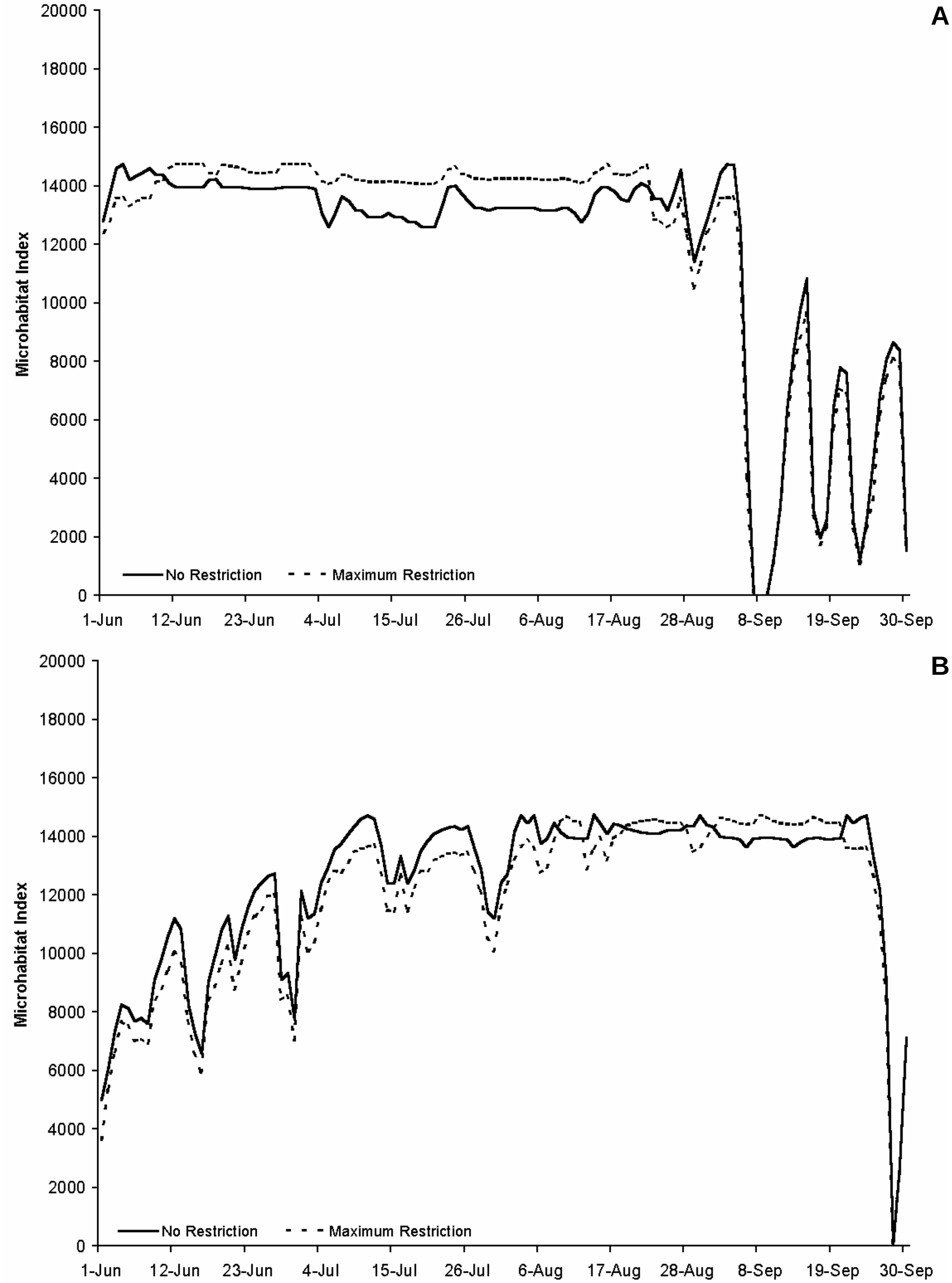


Figure 52. Summer 1999 (A) and 2002 (B) Spring Hollow pool - run guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

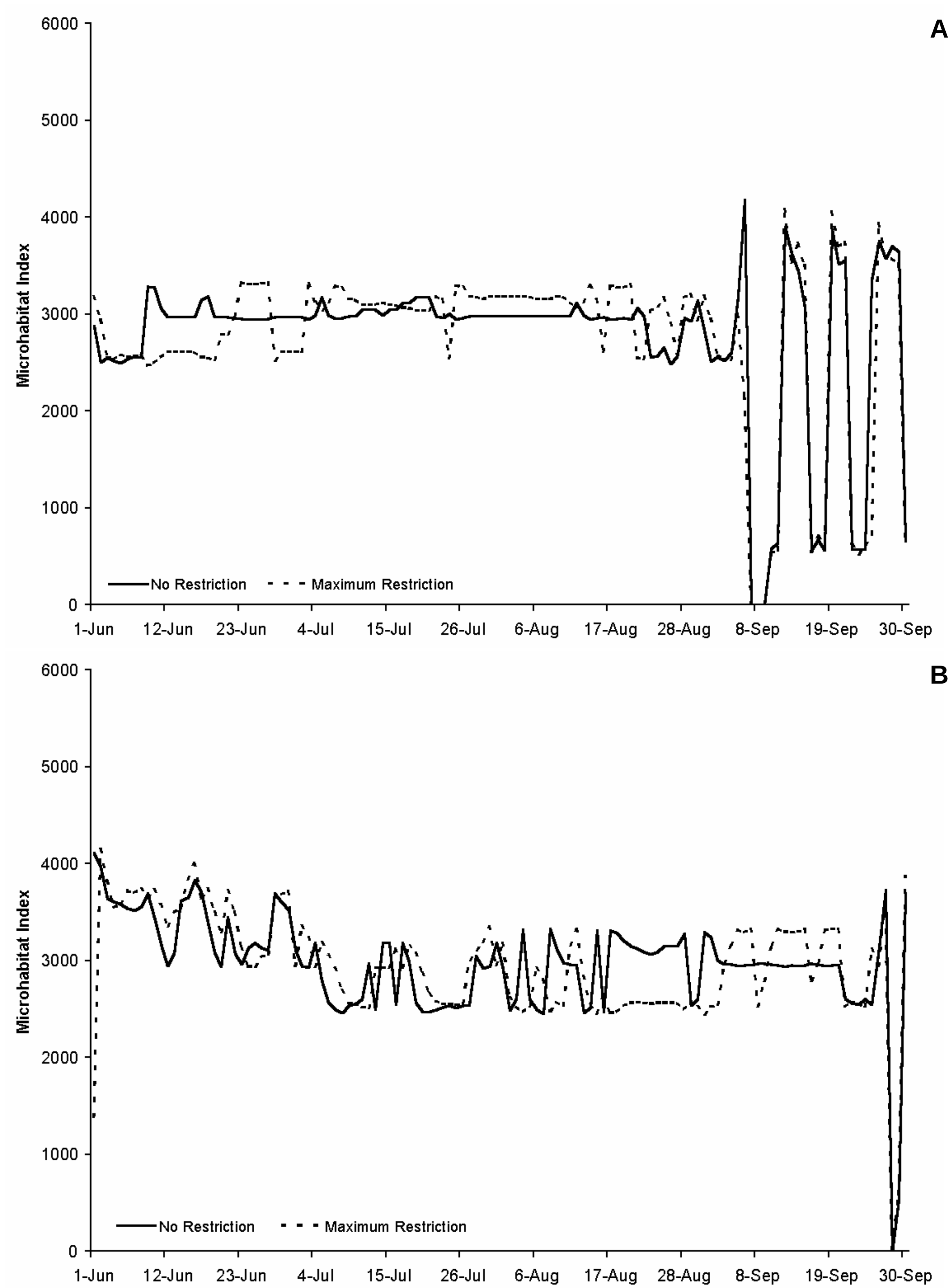


Figure 53. Summer 1999 (A) and 2002 (B) Spring Hollow pool - cover guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

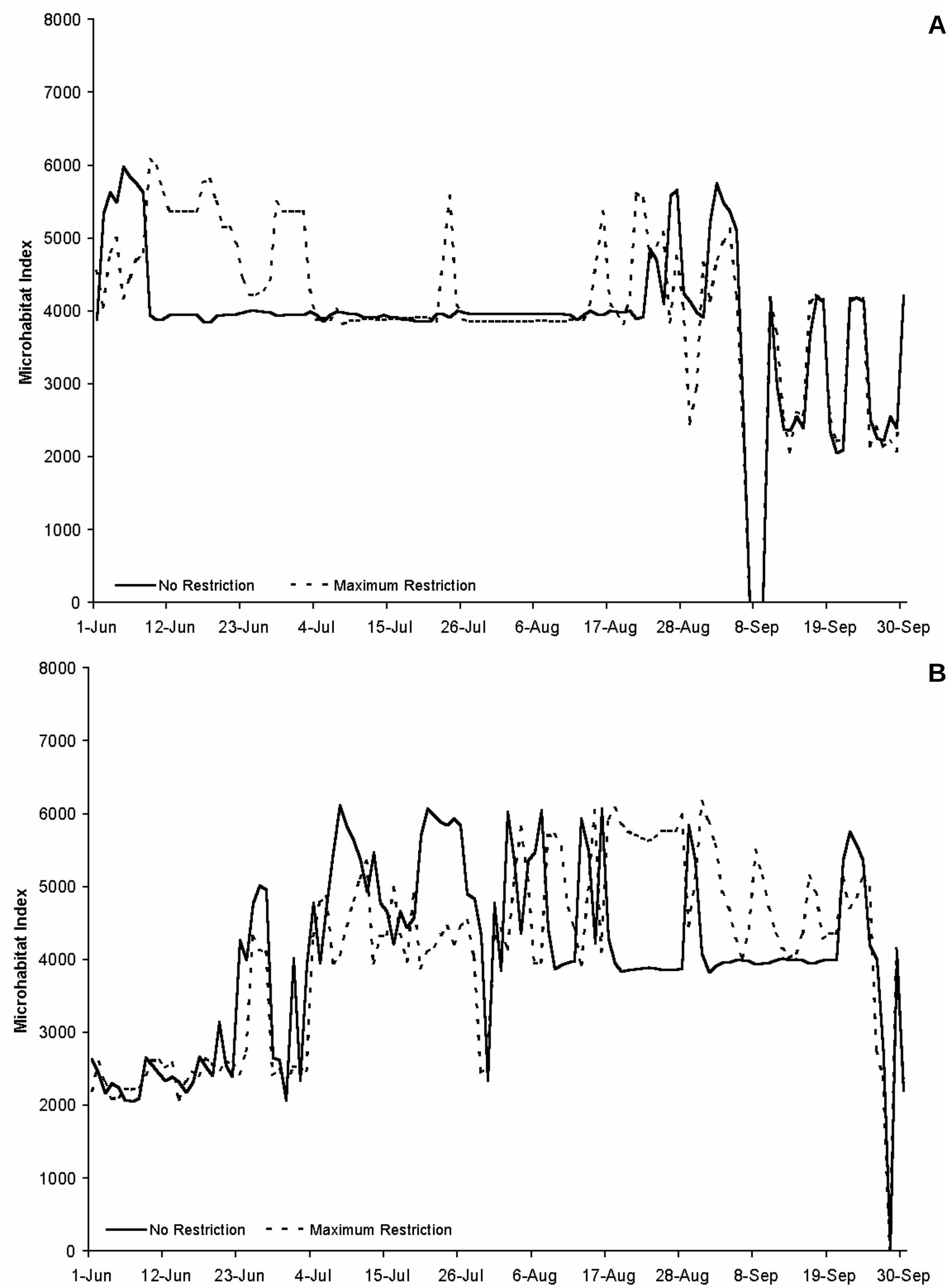


Figure 54. Summer 1999 (A) and 2002 (B) Spring Hollow algae - midge guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

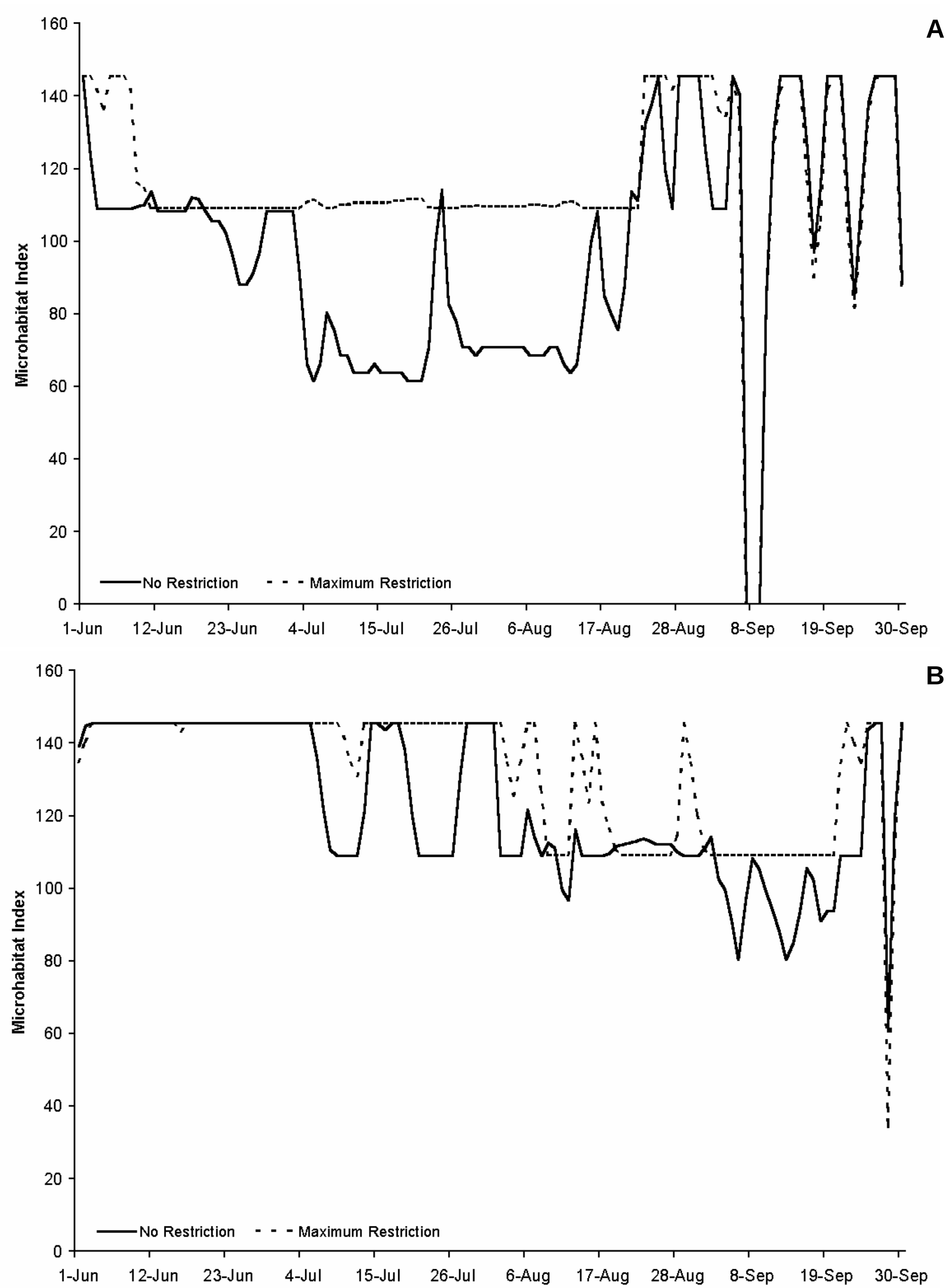


Figure 55. Summer 1999 (A) and 2002 (B) Posey Hollow fast generalist guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

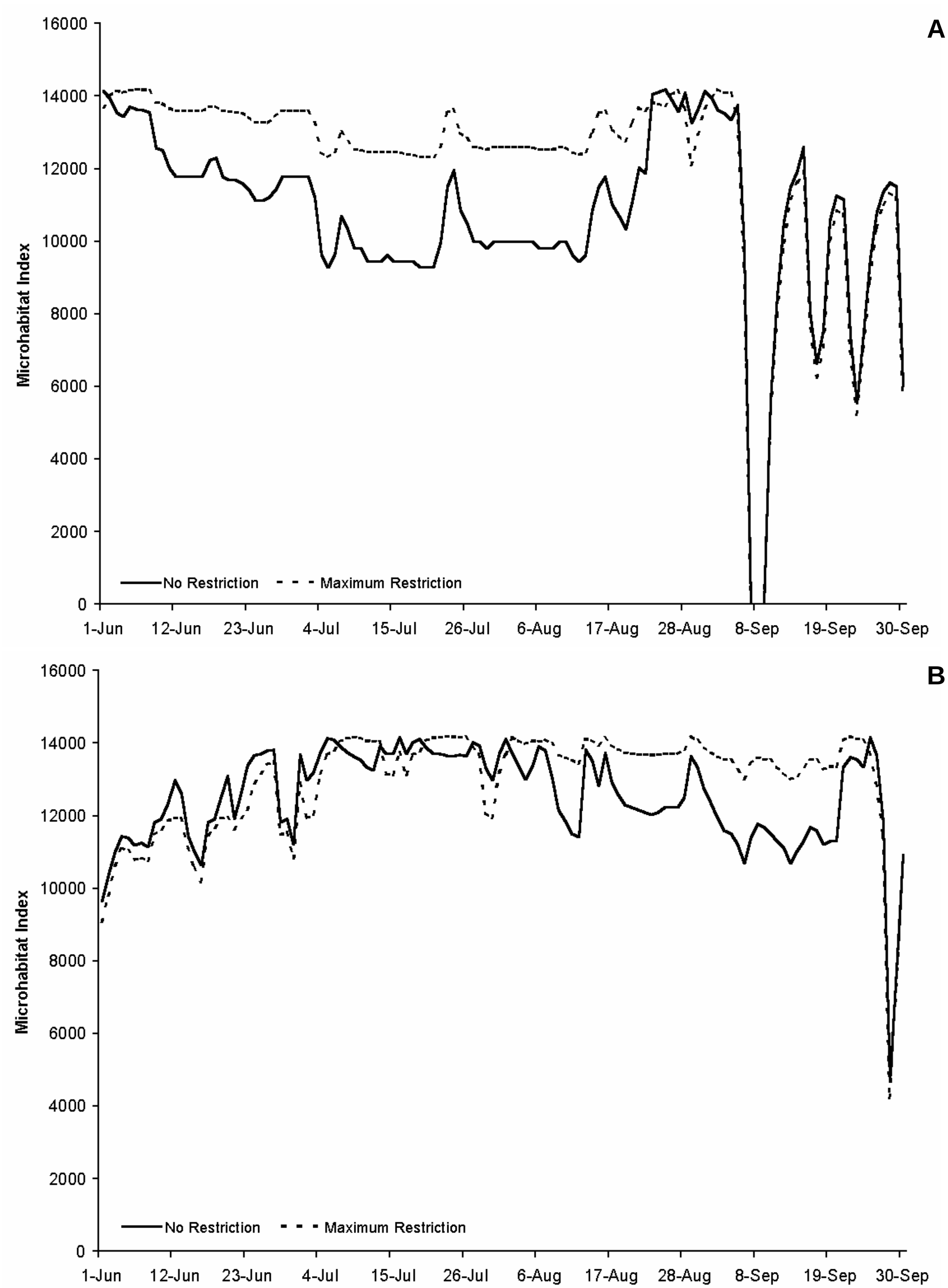


Figure 56. Summer 1999 (A) and 2002 (B) Posey Hollow pool - run guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

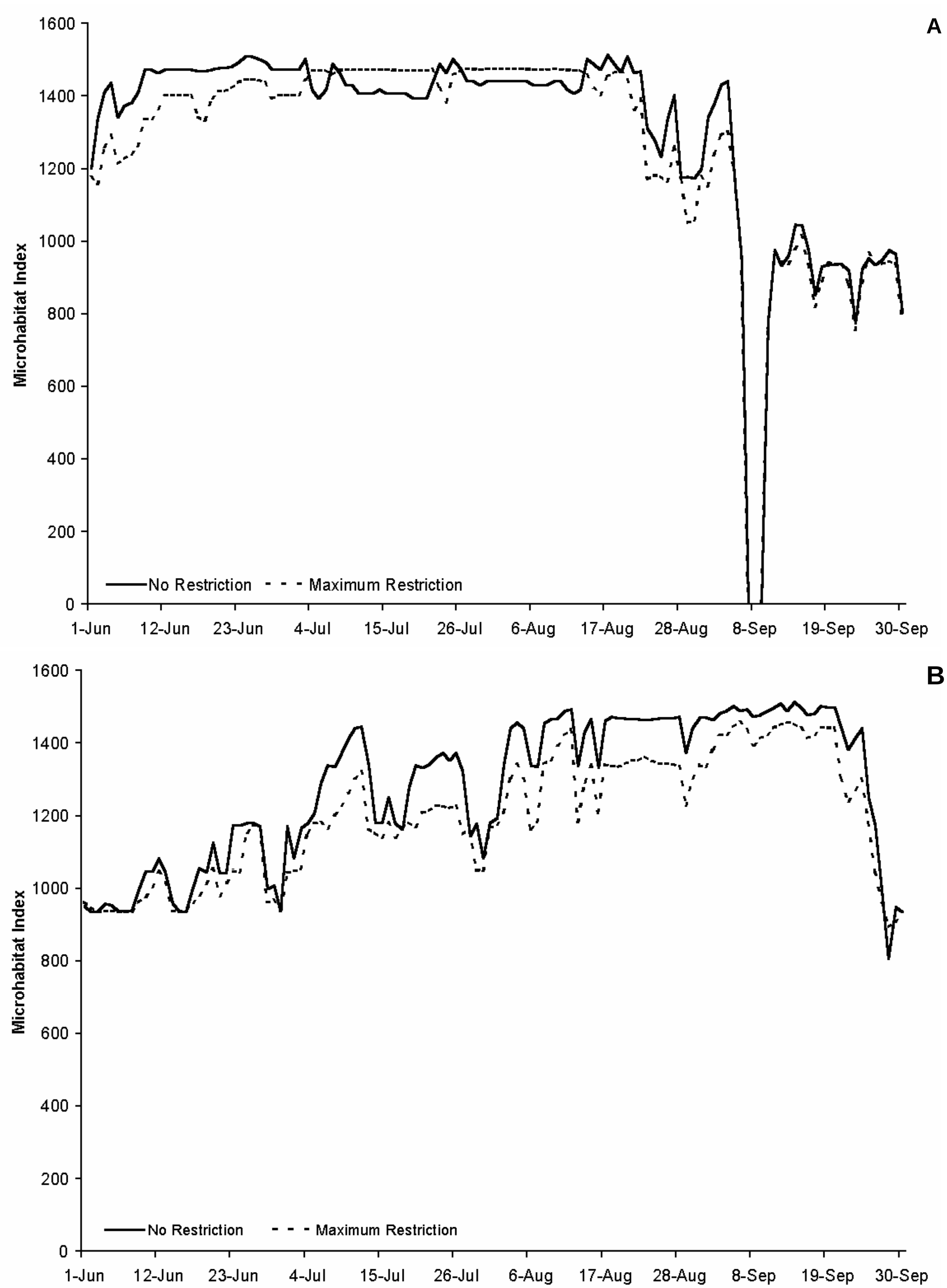


Figure 57. Summer 1999 (A) and 2002 (B) Posey Hollow pool - cover guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

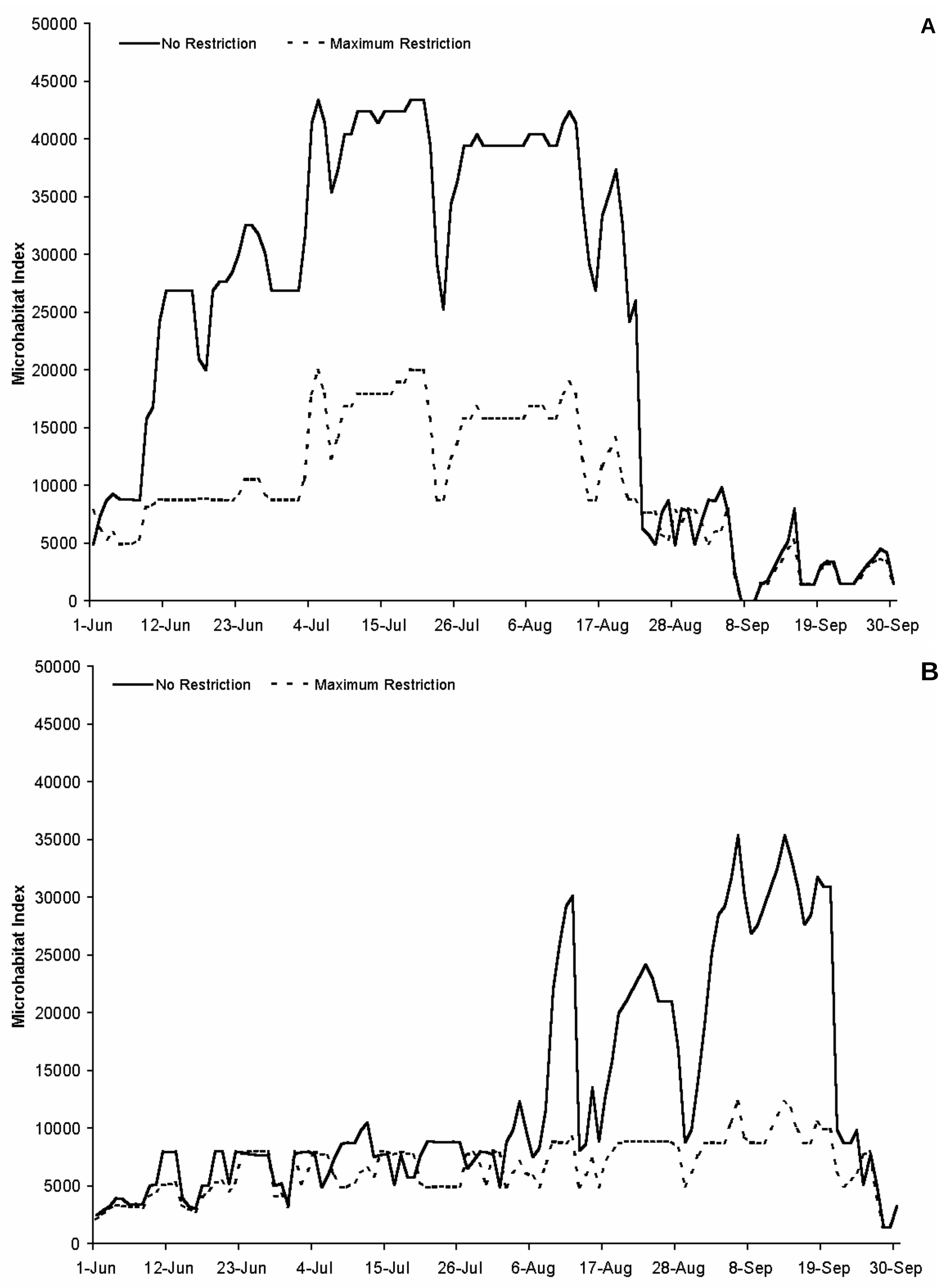


Figure 58. Summer 1999 (A) and 2002 (B) Posey Hollow algae - midge guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

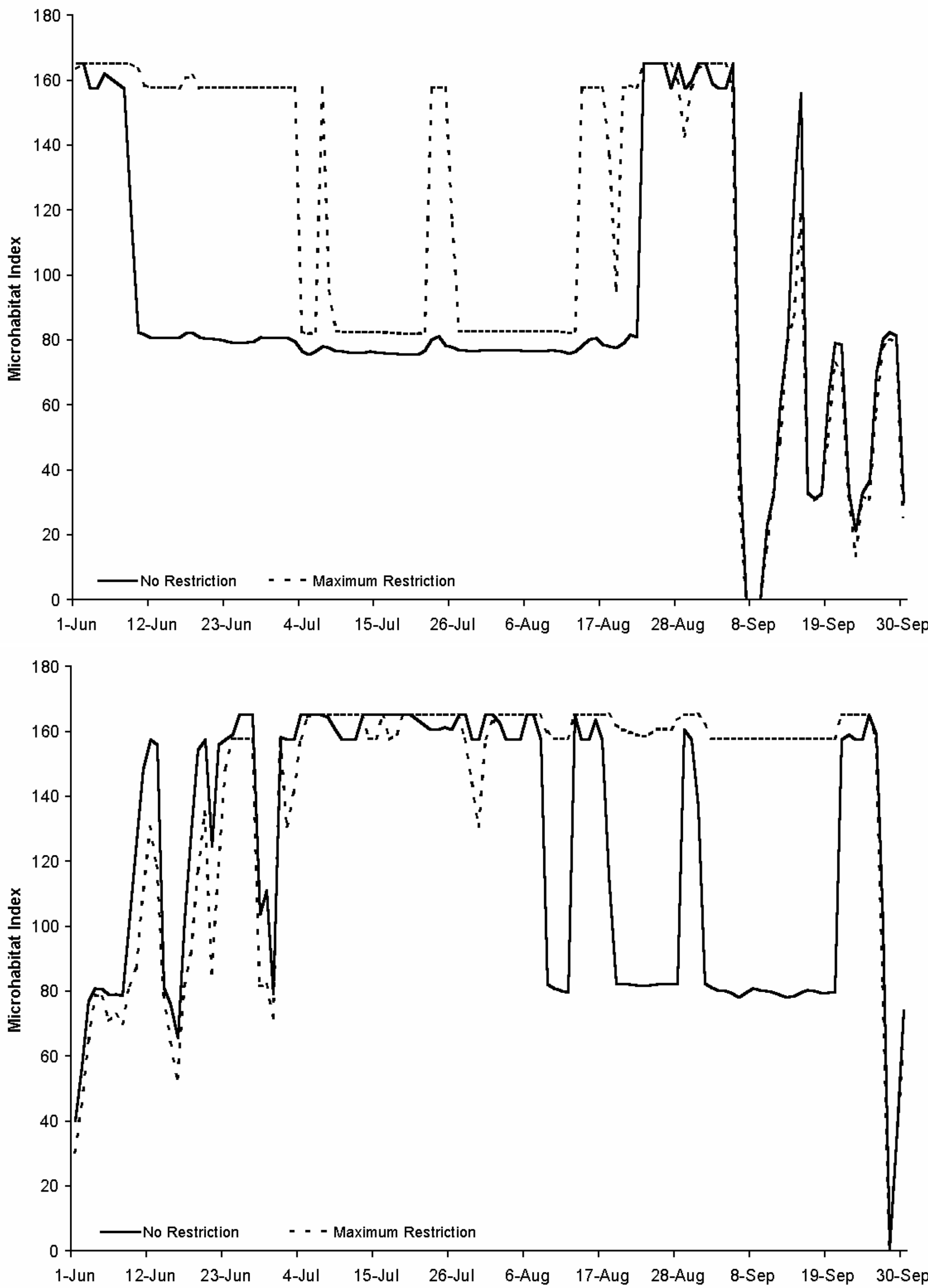


Figure 59. Summer 1999 (A) and 2002 (B) Route 648 fast generalist guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

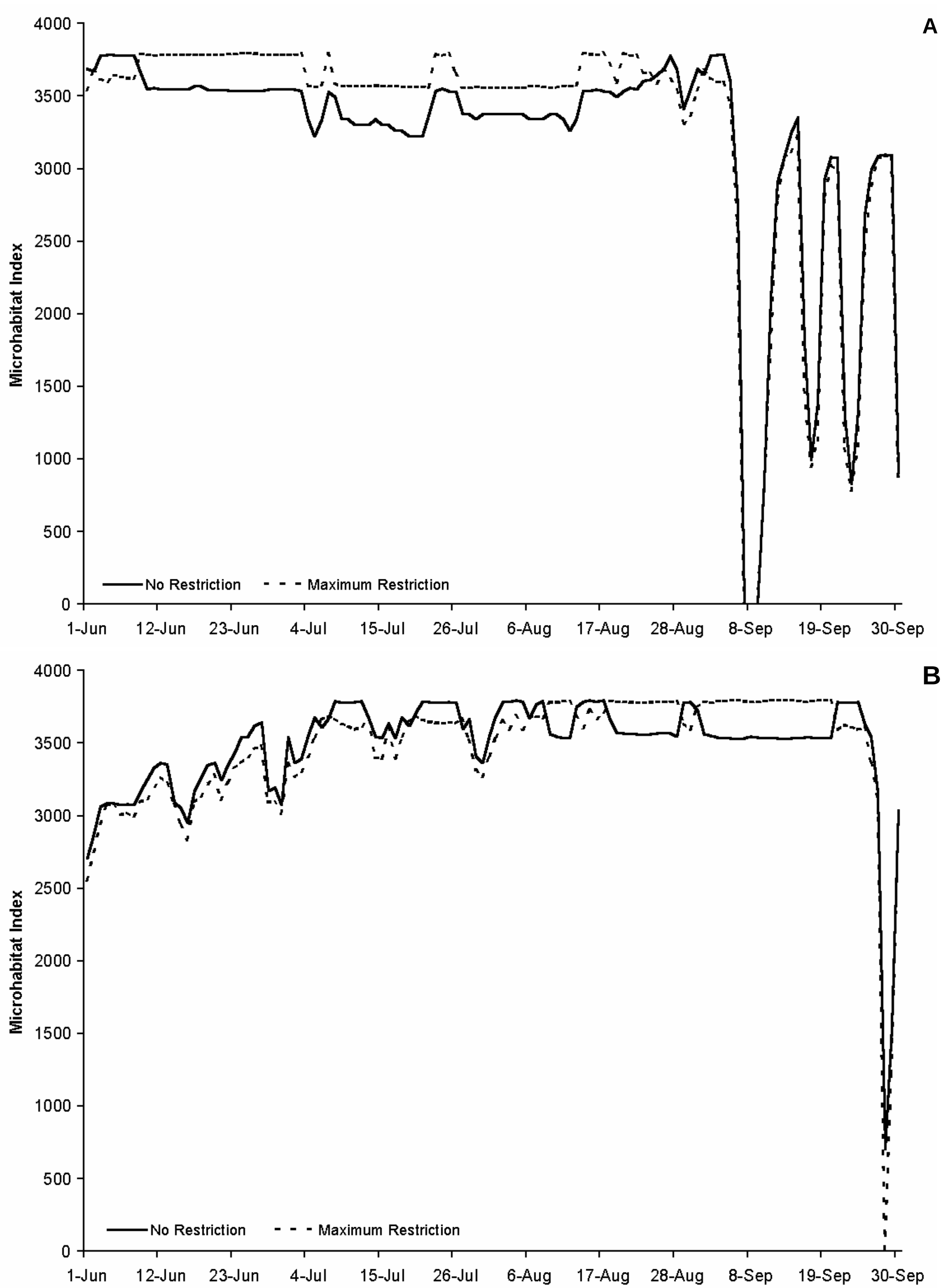


Figure 60. Summer 1999 (A) and 2002 (B) Route 648 pool - run guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

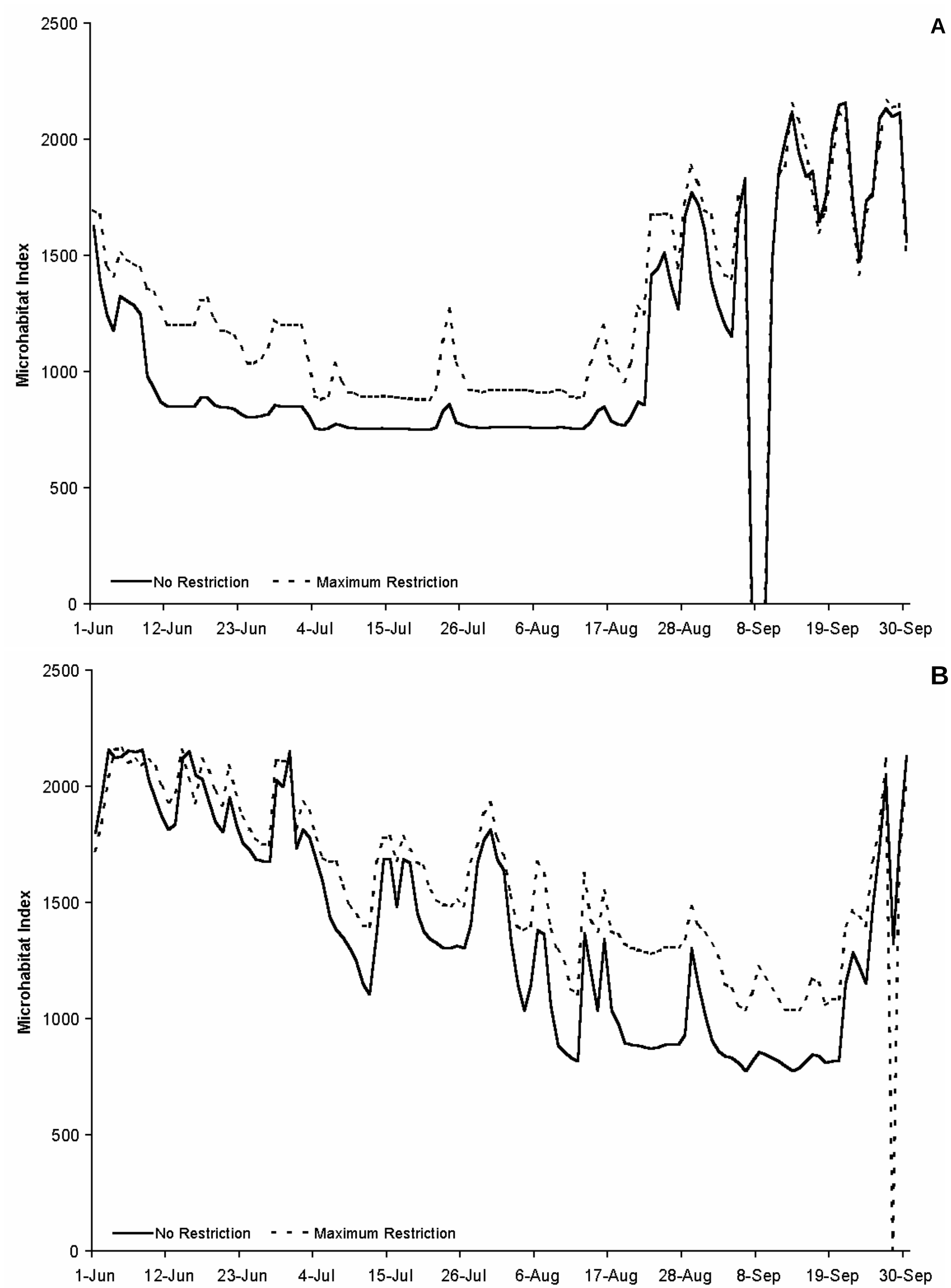


Figure 61. Summer 1999 (A) and 2002 (B) Route 648 pool - cover guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

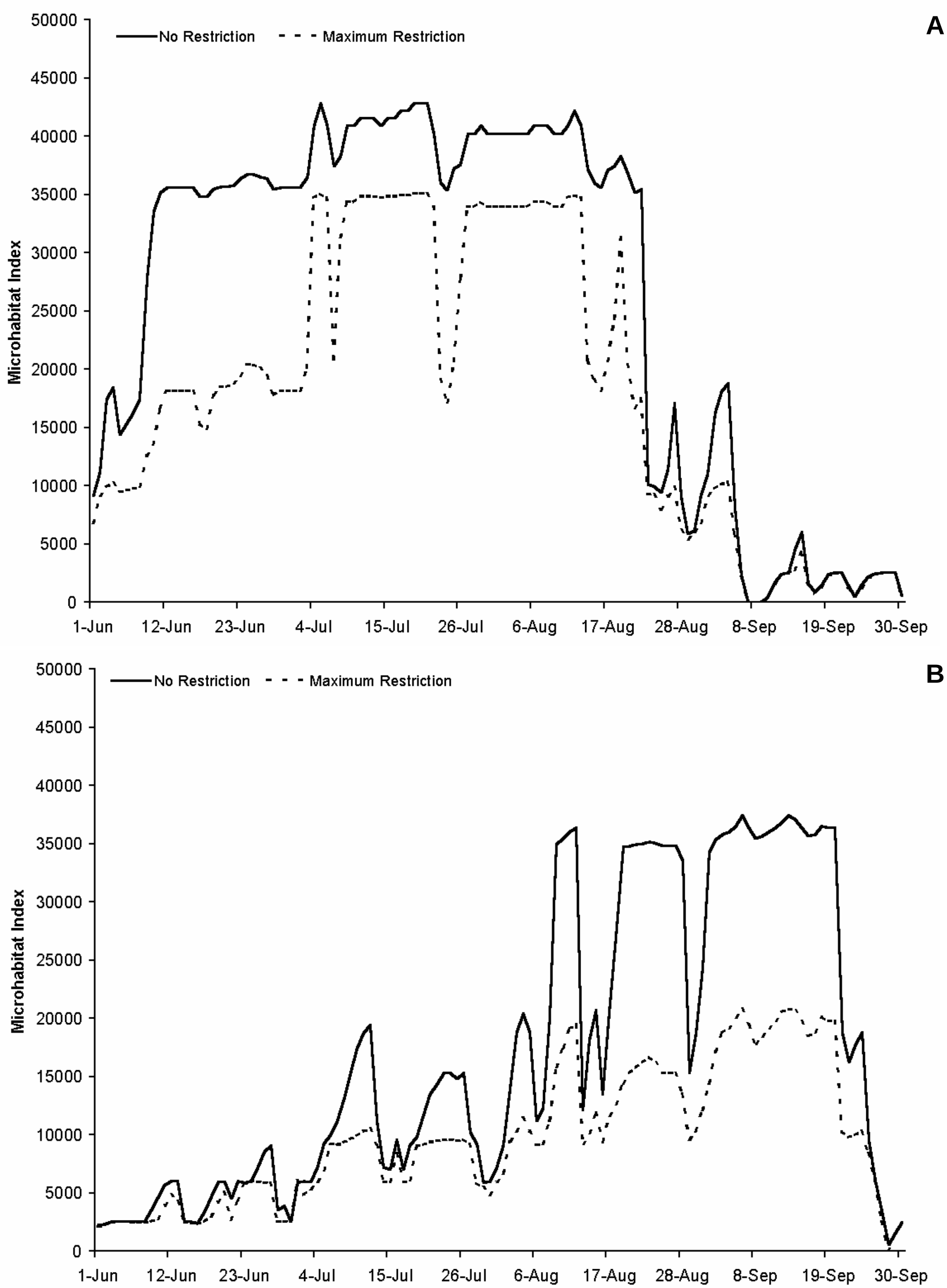


Figure 62. Summer 1999 (A) and 2002 (B) Route 648 algae - midge guild time series results depicting microhabitat index response to water allocation scenario range of non-restriction (solid line) to maximum restriction (dotted line).

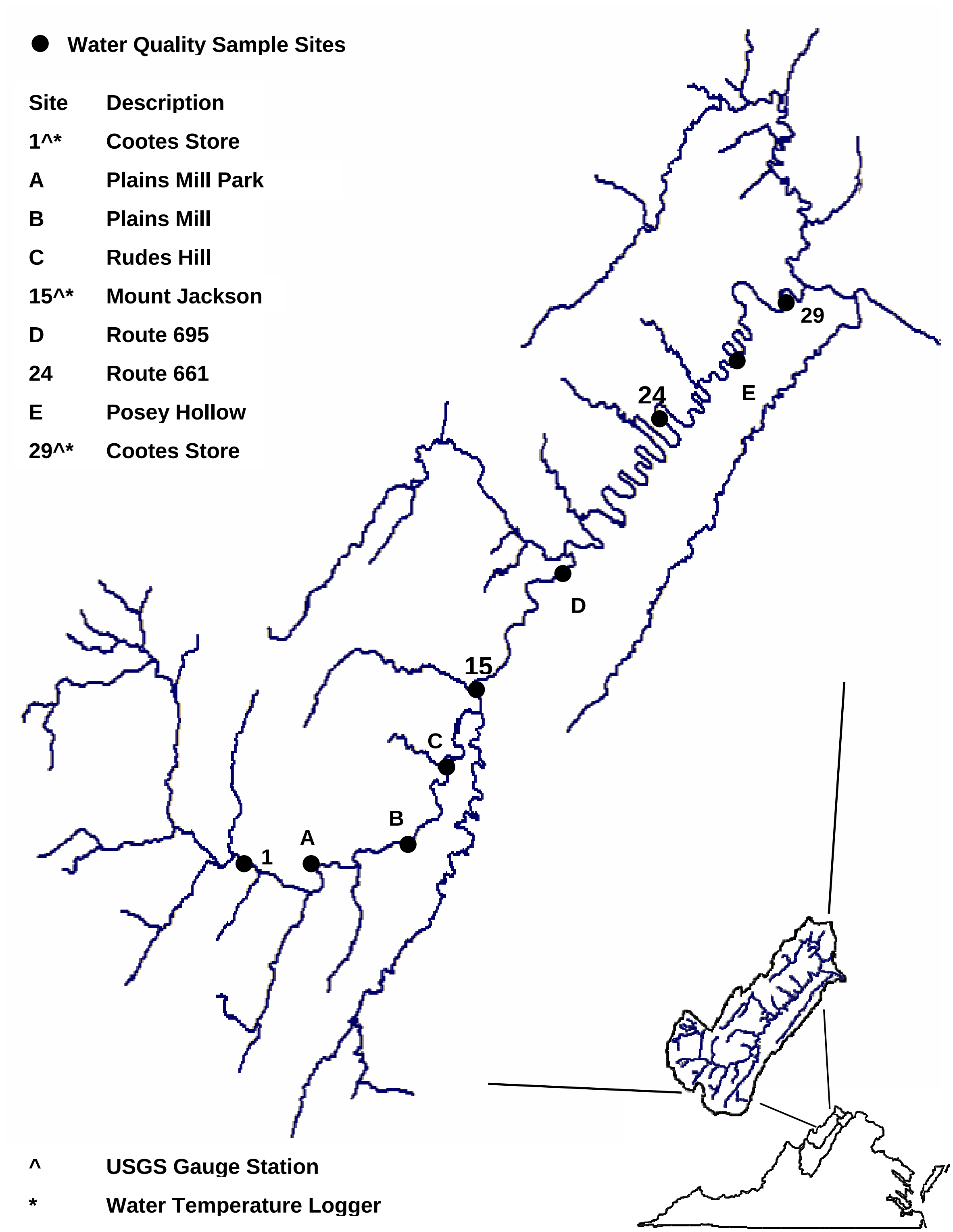


Figure 63. Locations of summer 2002 water quality sample sites on the North Fork Shenandoah River.

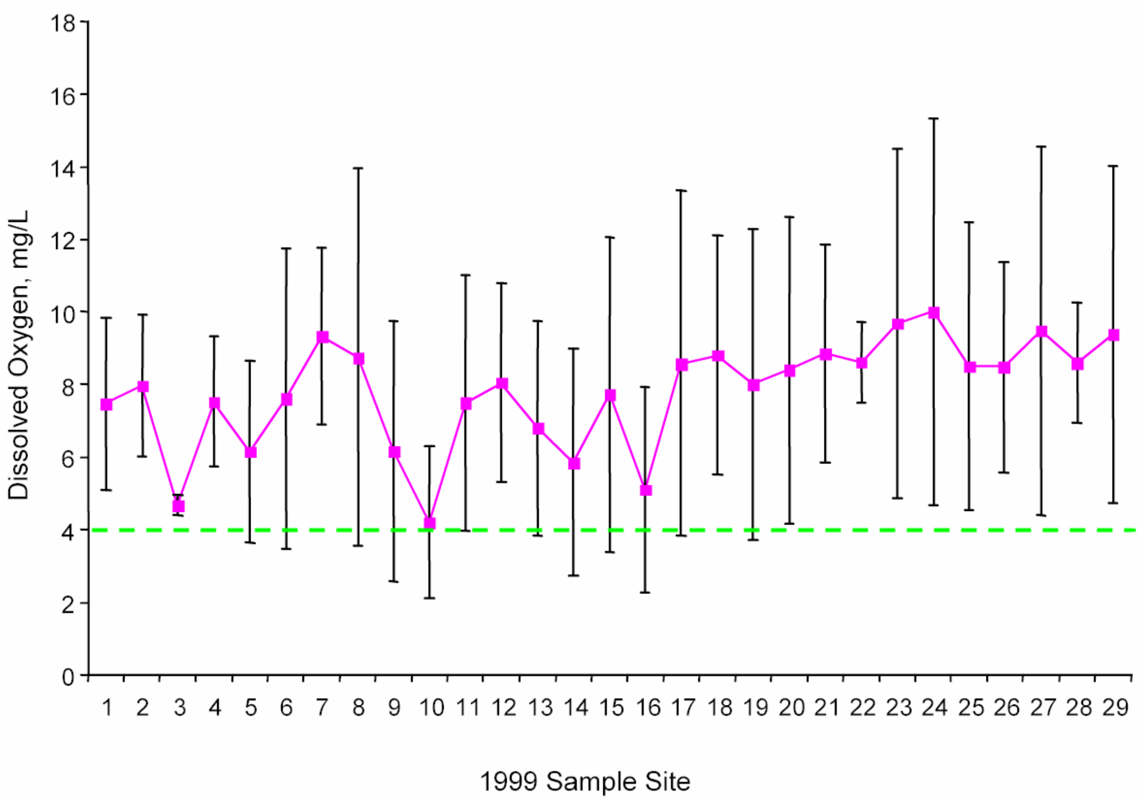


Figure 64. Average dissolved oxygen concentrations (mg/L) measured at North Fork Shenandoah River sample sites during July 27 – 29, 1999. Error bars represent minimum and maximum values measured during pre-dawn and late afternoon hours, respectively. The dashed green line marks the Virginia minimum standard of 4mg/L (State Water Control Board 2003).

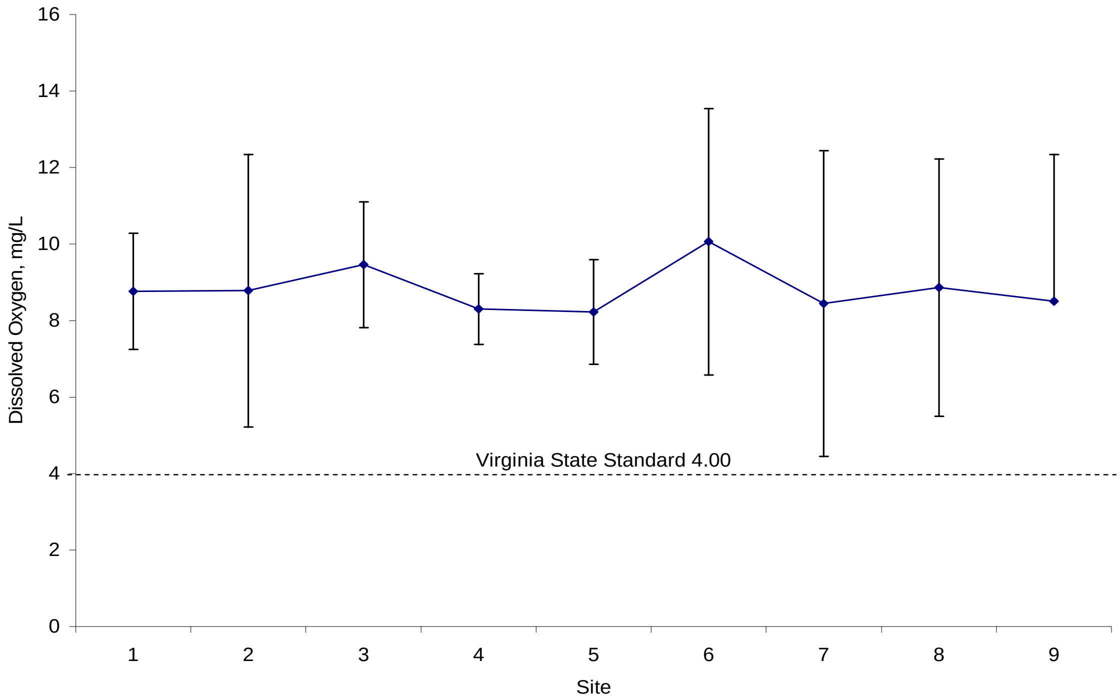


Figure 65. Average dissolved oxygen concentrations (mg/L) in NFSR (August 13, 2002) with error bars depicting minimum and maximum values determined from pre-dawn and late afternoon measurements.

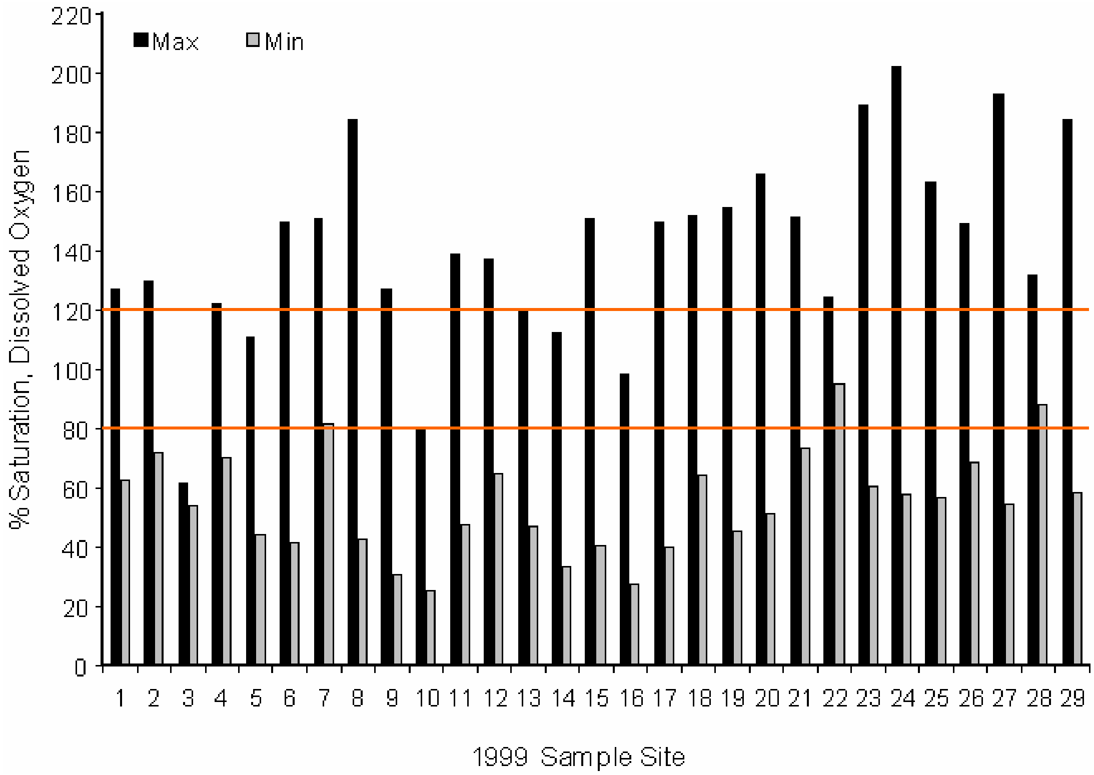


Figure 66. Minimum and maximum dissolved oxygen percent saturation levels measured at North Fork Shenandoah River sample sites during the pre-dawn and late afternoon hours of July 27 – 29, 1999. The orange lines mark the optimal percent saturation range of 80 – 120%.

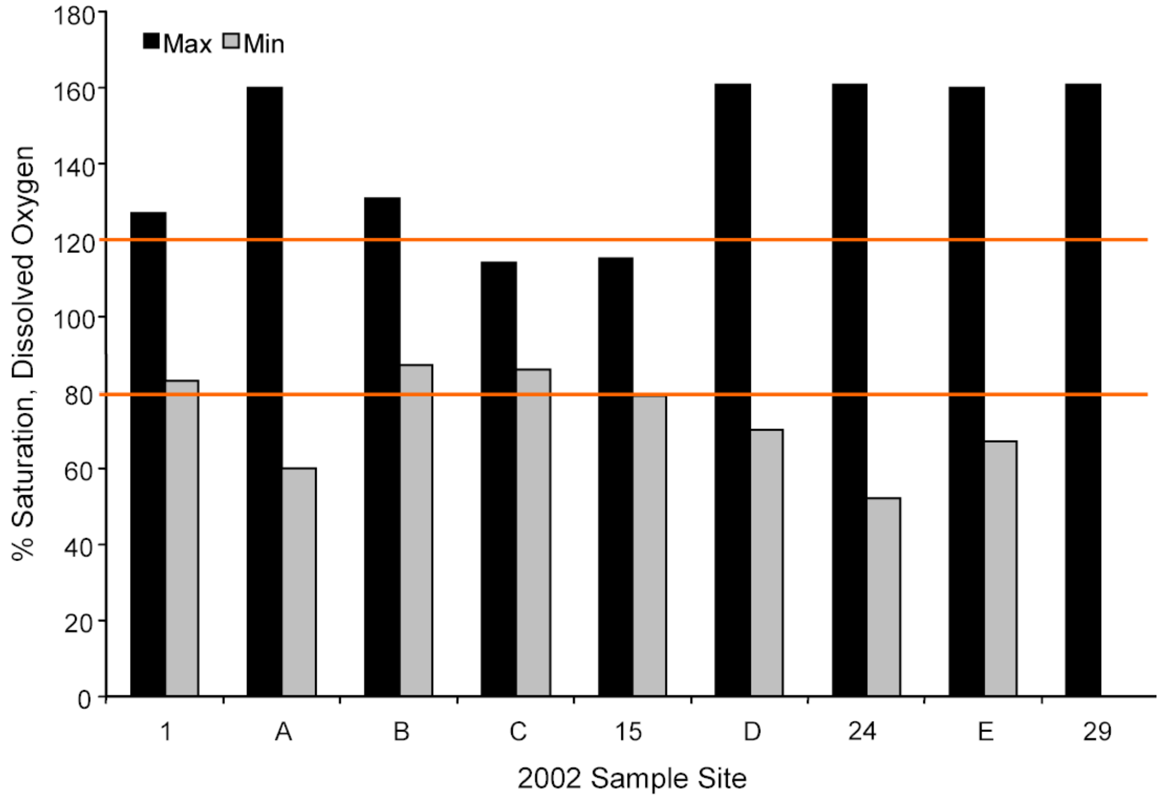


Figure 67. Minimum and maximum dissolved oxygen percent saturation levels measured at North Fork Shenandoah River sample sites during the pre-dawn and late afternoon hours of August 13 – 14, 2002. The orange lines mark the optimal percent saturation range of 80 – 120%. Note: site 29 has no minimum data.

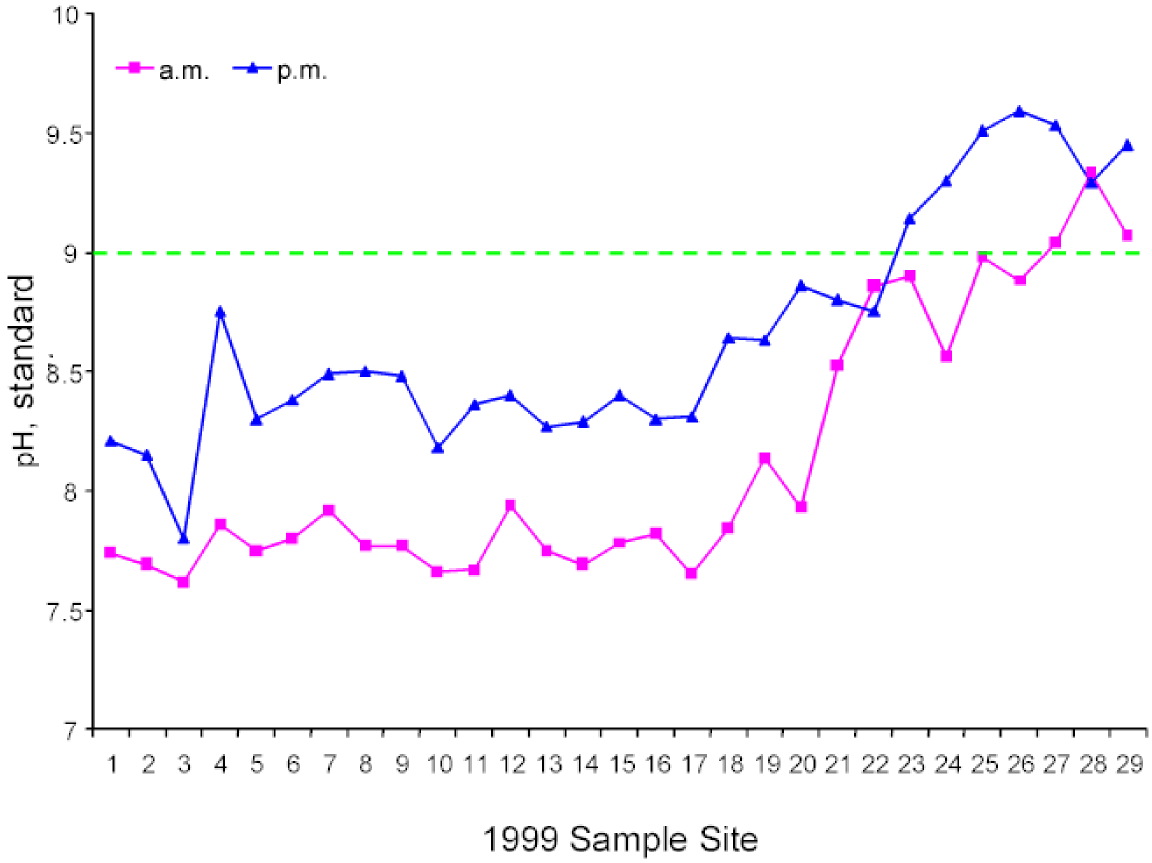


Figure 68. pH values measured at North Fork Shenandoah River sample sites during the pre-dawn (a.m.) and late afternoon (p.m.) hours of July 27 - 29, 1999. The dashed green line marks the Virginia maximum standard of 9.0 (State Water Control Board 2003). Seven sites are at or above the state standard, approaching lethal levels for fishes (Wetzel 1983, Chan et al. 2000).

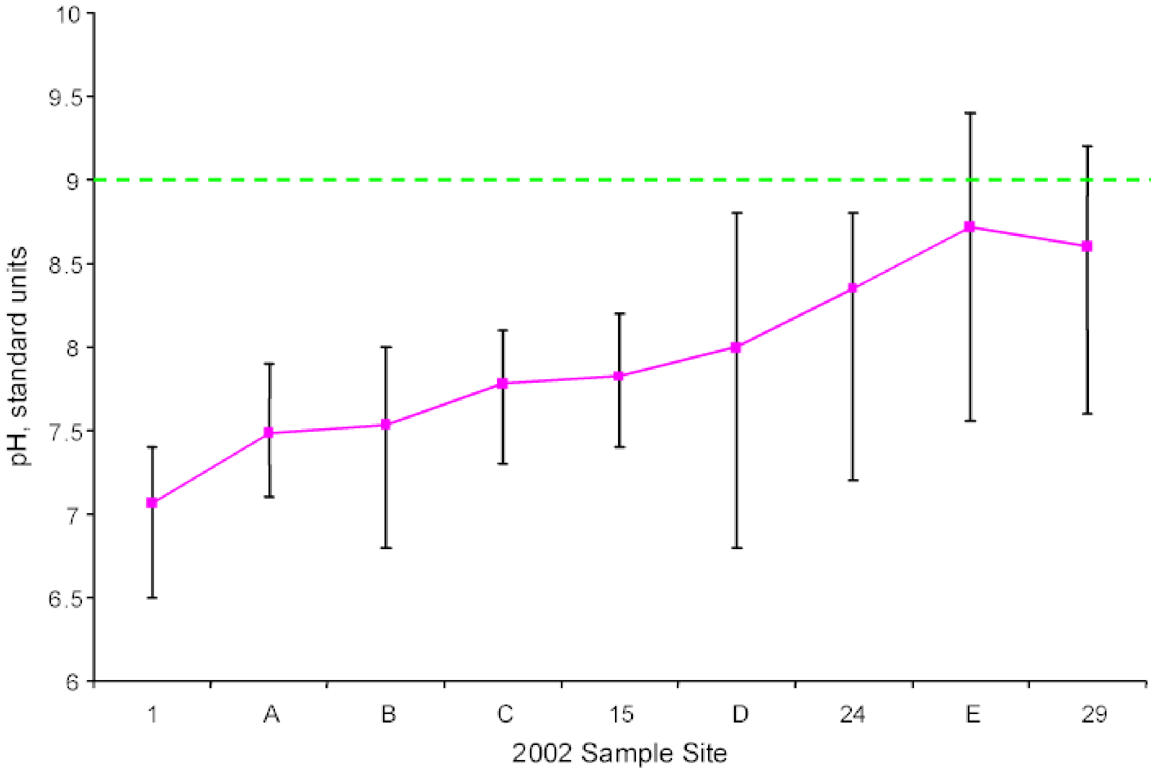


Figure 69. Average pH values measured at North Fork Shenandoah River sample sites on June 20, July 6, July 18, July 25, August 1, and August 8, 2002. Error bars represent minimum and maximum levels measured at each site. The dashed green line marks the Virginia maximum standard of 9.0 (State Water Control Board 2003).

Figure 70. Photograph of the North Fork Shenandoah River on July 18, 2002 showing algal bloom and low flows at Site D (Route 695). Algal blooms and low flows were common throughout the river during summer 2002.

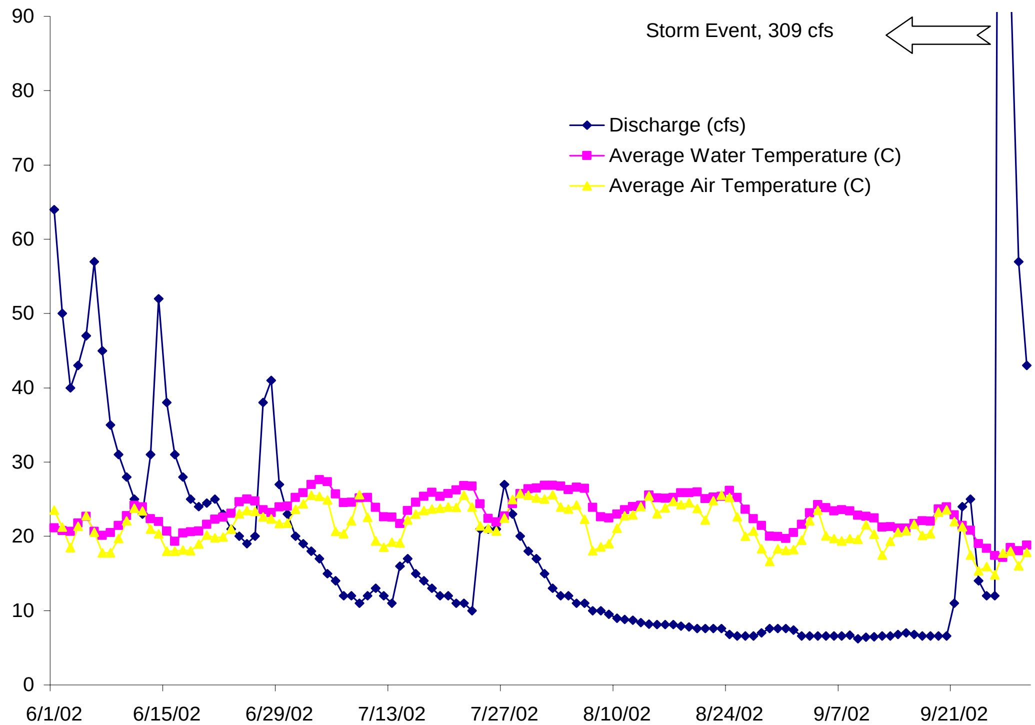


Figure 71. Summer 2002 streamflow, water temperature, and air temperature data for the Cootes Store gauge station (site 1) on the North Fork Shenandoah River.

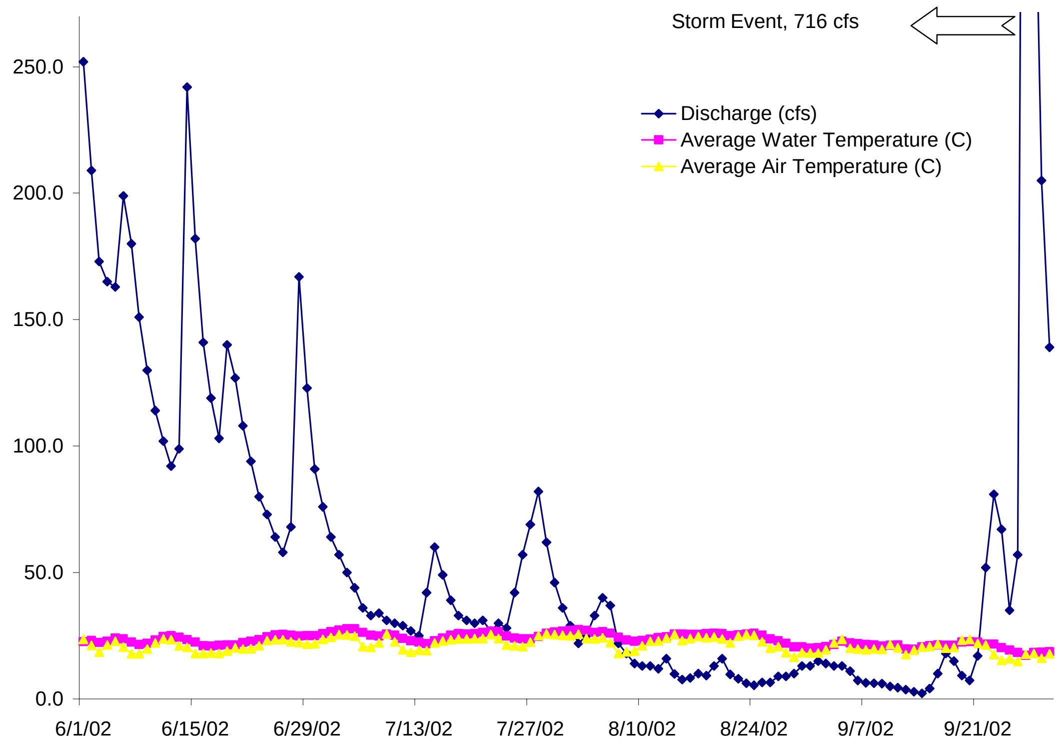


Figure 72. Mount Jackson air temperature, water temperature, and streamflow data for June – September 2002.

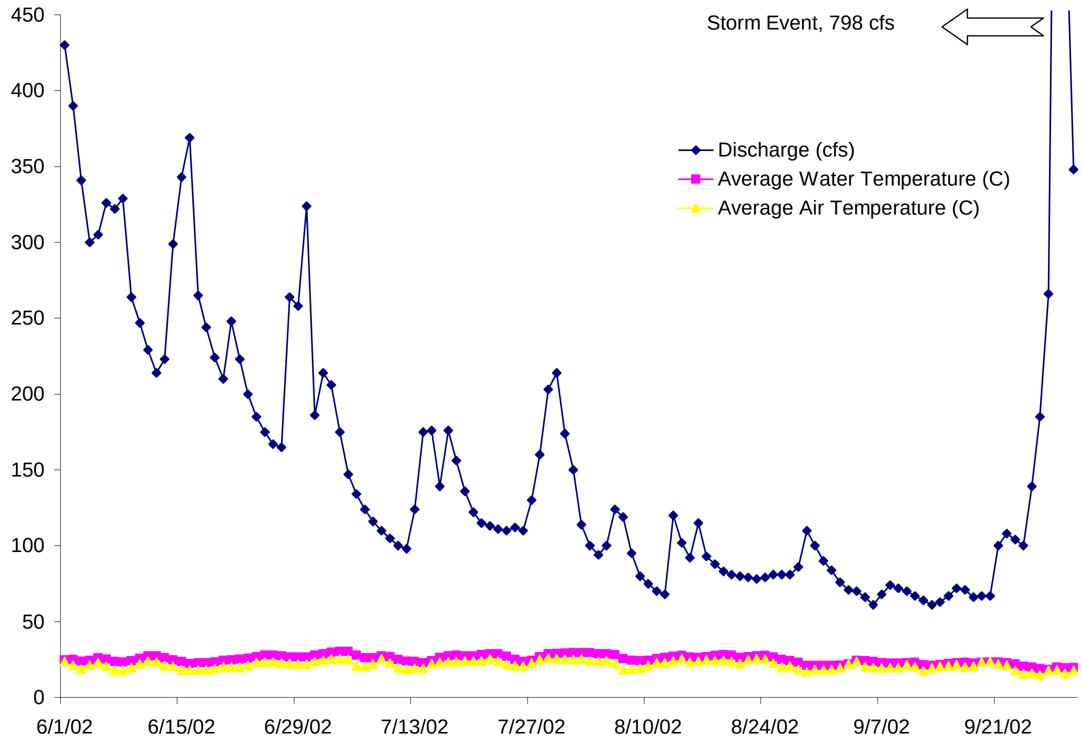


Figure 73. Mount Jackson air temperature, water temperature, and streamflow data for June – September 2002.

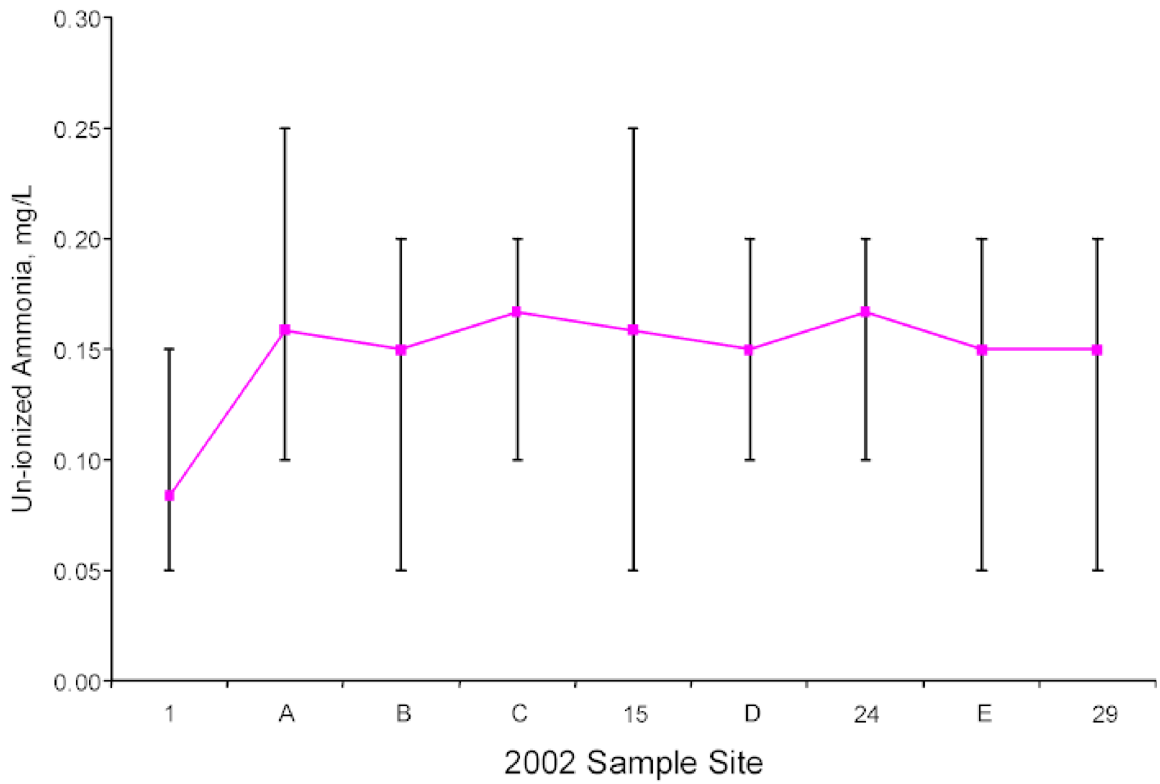


Figure 74. Average un-ionized ammonia (NH_3) concentrations measured at North Fork Shenandoah River sample sites on June 20, July 6, July 18, July 25, August 1, and August 8, 2002. Error bars represent minimum and maximum levels measured at each site.

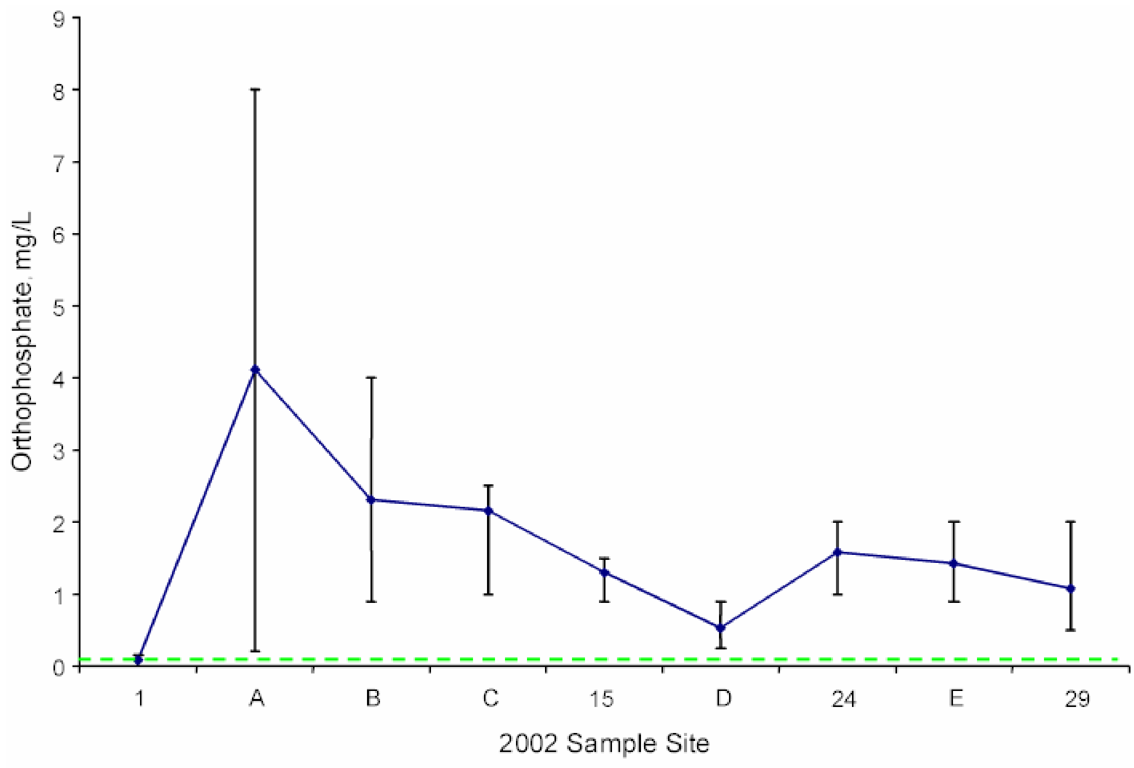


Figure 75. Average orthophosphate (PO_4^{-3}) concentrations measured at North Fork Shenandoah River sample sites on June 20, July 6, July 18, July 25, August 1, and August 8, 2002.in NFSR. Error bars represent minimum and maximum levels measured at each site. The dashed green line marks the EPA maximum standard of 0.1 mg/L.

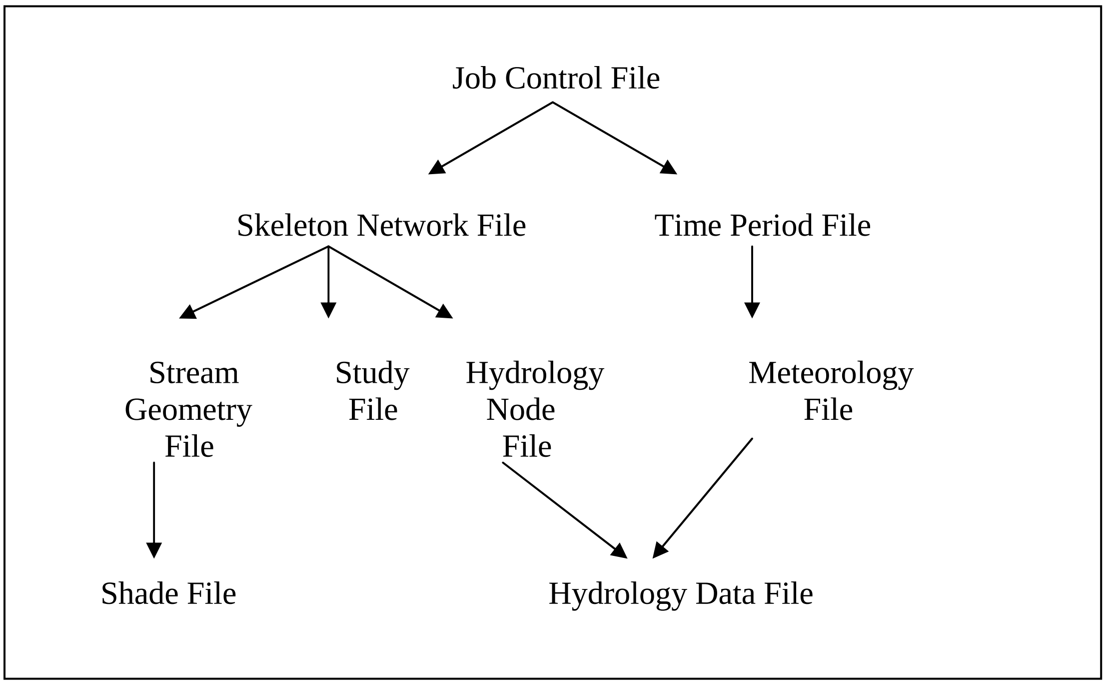


Figure 76. SNTEMP input file structure (USGS 1997).

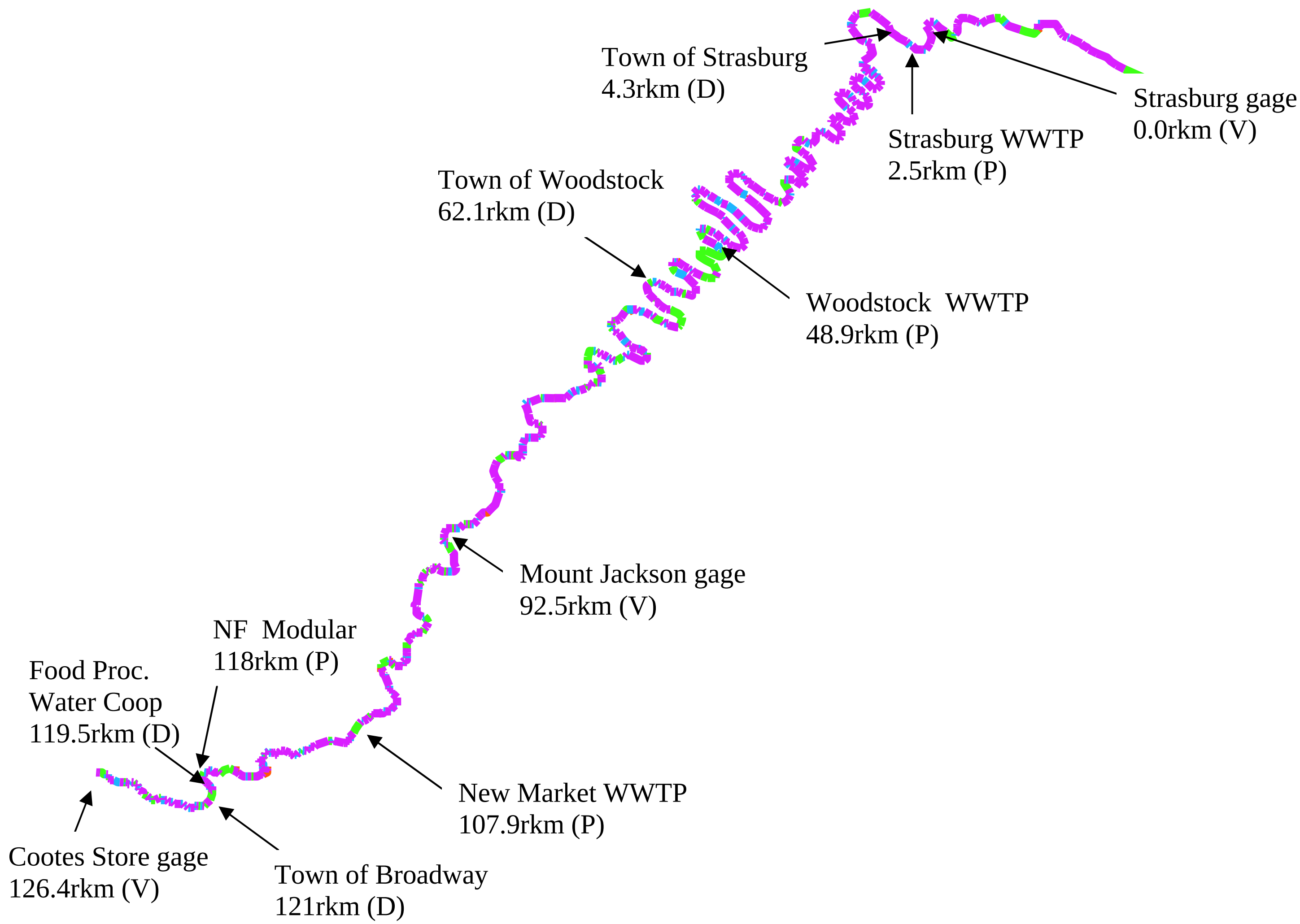


Figure 77. NFSR habitat map indicating Point Load (P), Diversion (D), and Validation (V) nodes.

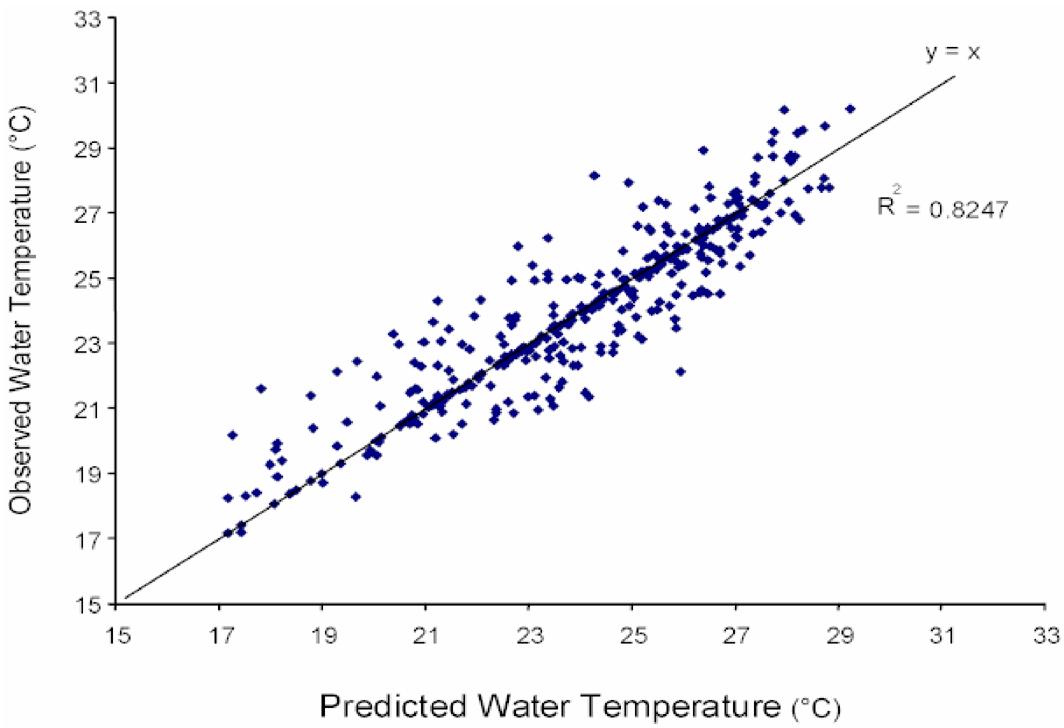


Figure 78. Goodness-of-fit graph comparing SNTEMP modeling results of predicted average daily water temperature to observed (measured) water temperature.

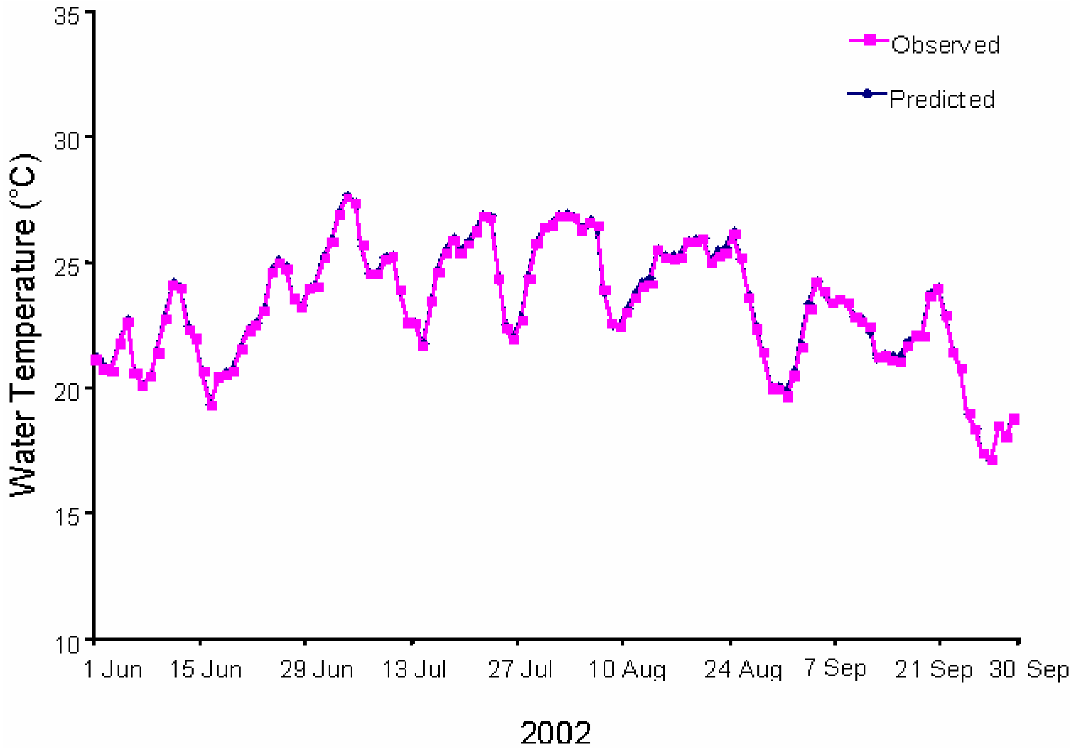


Figure 79. Comparison of observed (measured) and predicted (SNTEMP) average daily water temperatures for summer 2002 at the Cootes Store gauge station (site 1) on the North Fork Shenandoah River.

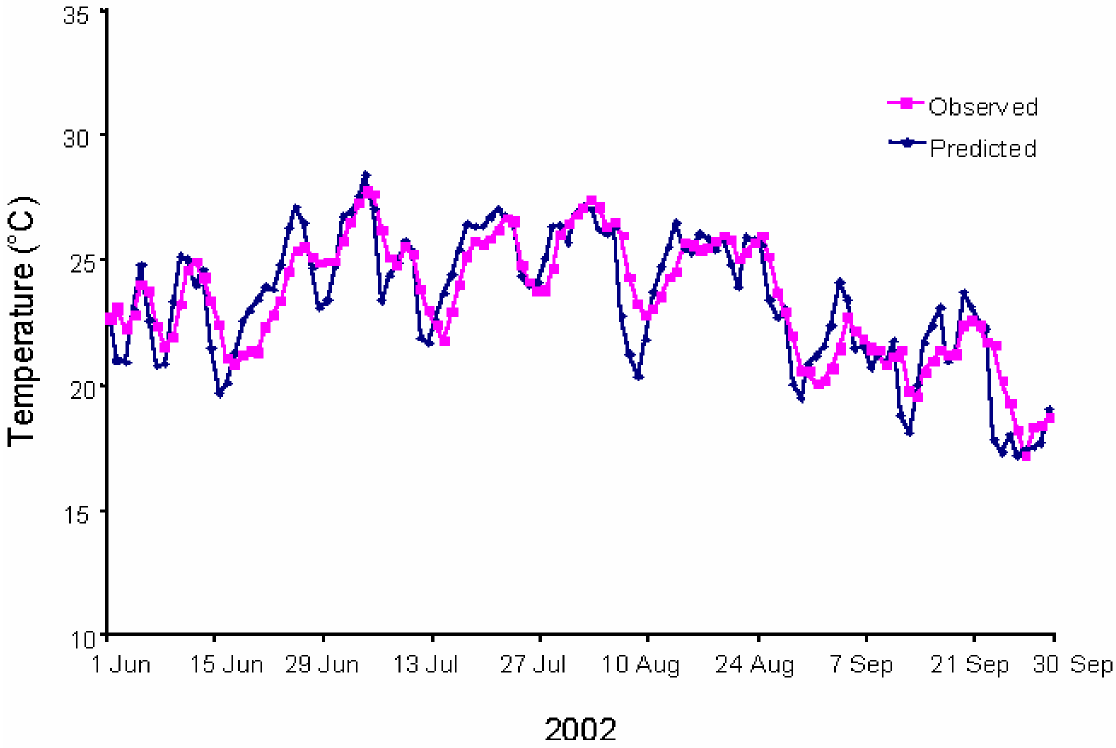


Figure 80. Comparison of observed (measured) and predicted (SNTEMP) average daily water temperatures for summer 2002 at the Mount Jackson gauge station (site 15) on the North Fork Shenandoah River.

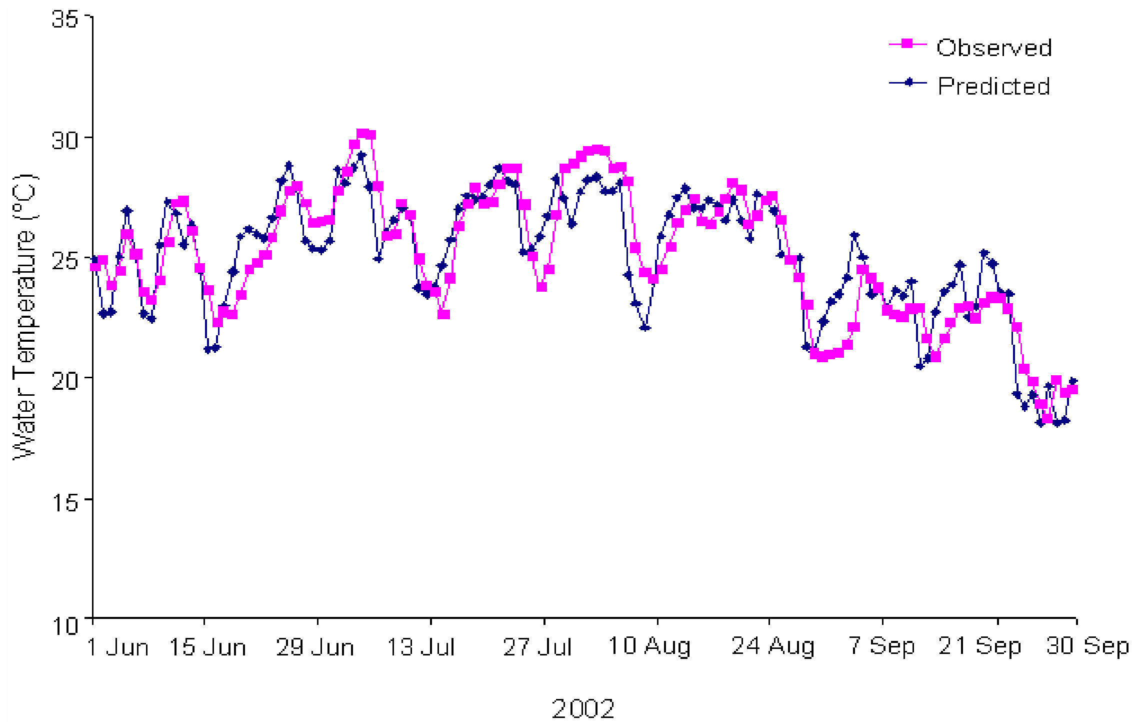


Figure 81. Comparison of observed (measured) and predicted (SNTEMP) average daily water temperatures for summer 2002 at the Strasburg gauge station (site 29) on the North Fork Shenandoah River.

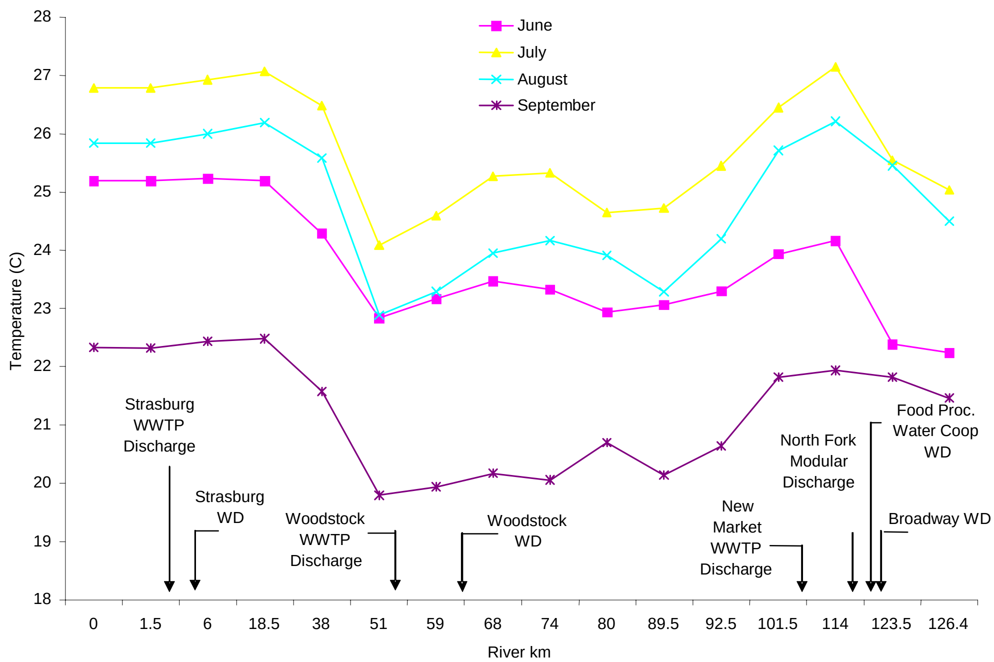


Figure 82. Modeled average temperature depicting a longitudinal profile along the NFSR during summer 2002 using SNTEMP. Three areas in the River show temperature peaks.

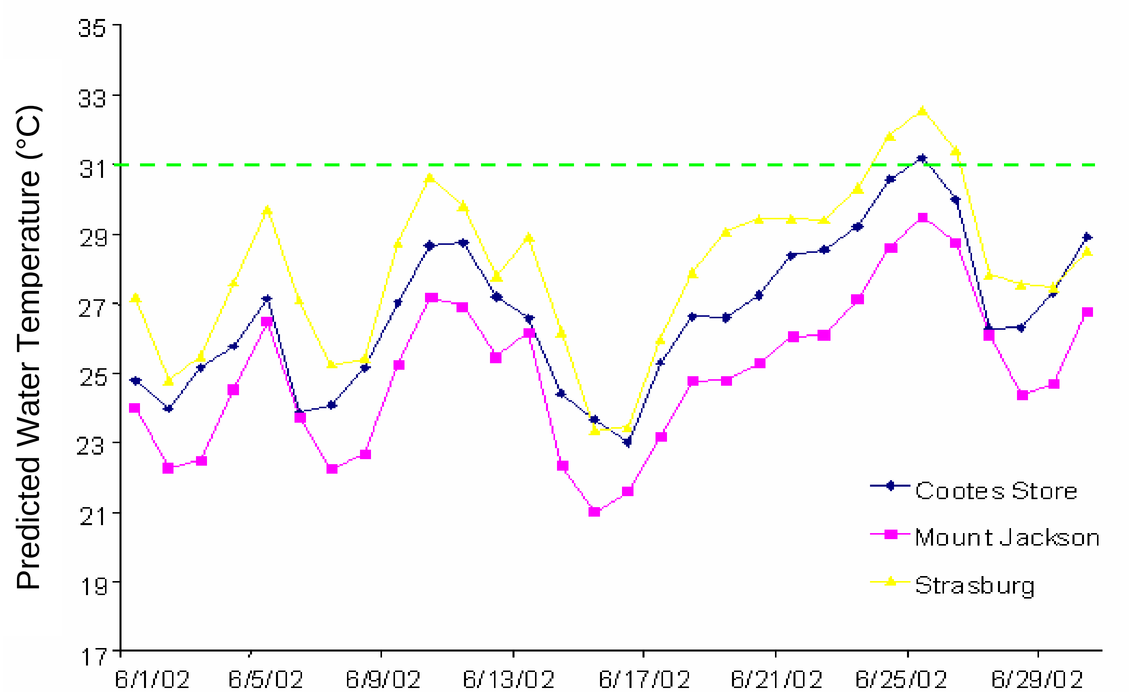


Figure 83. SNTEMP maximum daily water temperature predictions for June 2002 at the North Fork Shenandoah River gauging stations: Cootes Store, Mount Jackson, and Strasburg (sites 1, 15, and 29). The dashed green line marks the Virginia water quality standard of 31°C (State Water Control Board 2003).

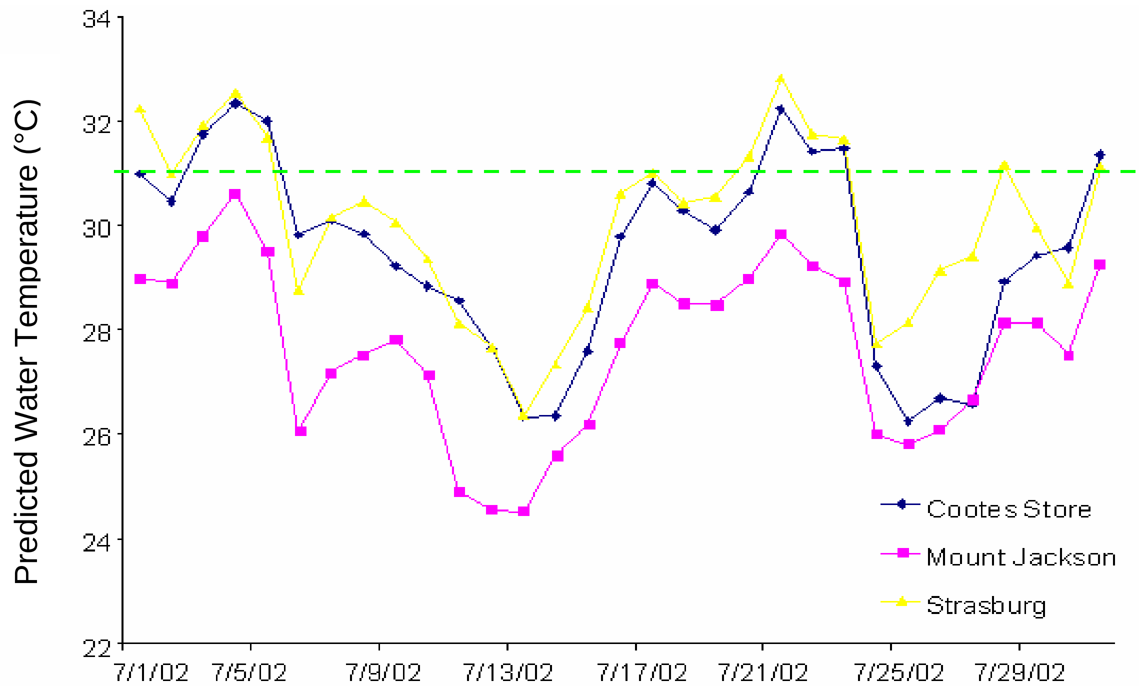


Figure 84. SNTEMP maximum daily water temperature predictions for July 2002 at the North Fork Shenandoah River gauging stations: Cootes Store, Mount Jackson, and Strasburg (sites 1, 15, and 29). The dashed green line marks the Virginia water quality standard of 31°C (State Water Control Board 2003).

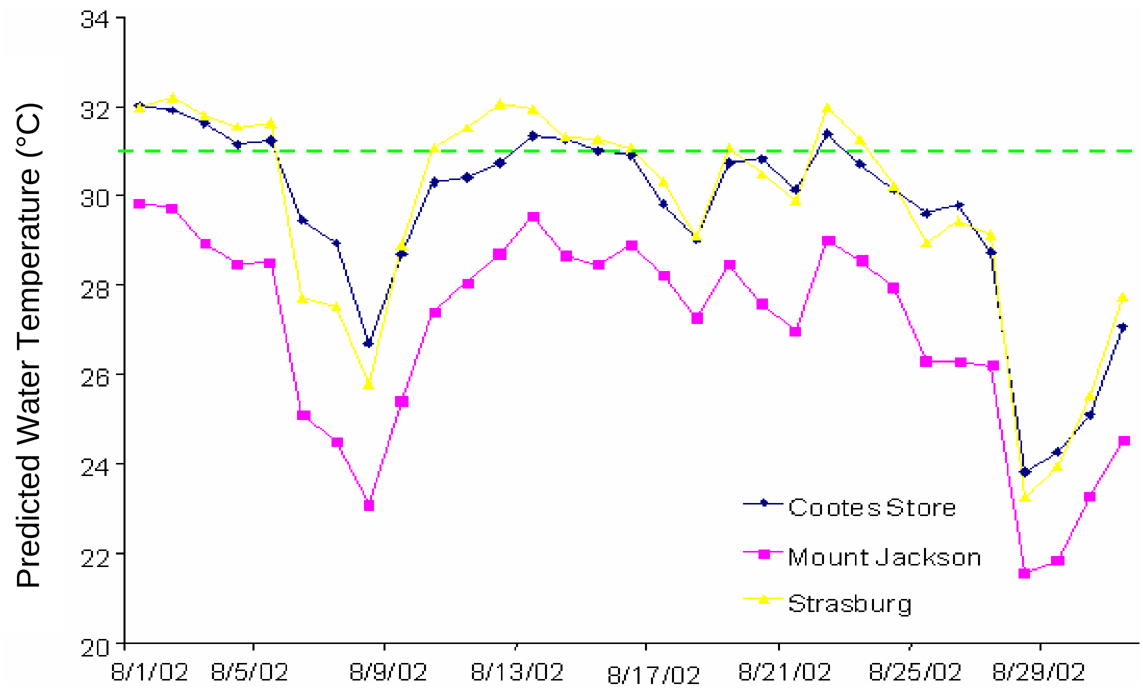


Figure 85. SNTEMP maximum daily water temperature predictions for August 2002 at the North Fork Shenandoah River gauging stations: Cootes Store, Mount Jackson, and Strasburg (sites 1, 15, and 29). The green dashed line marks the Virginia water quality standard of 31°C (State Water Control Board 2003).

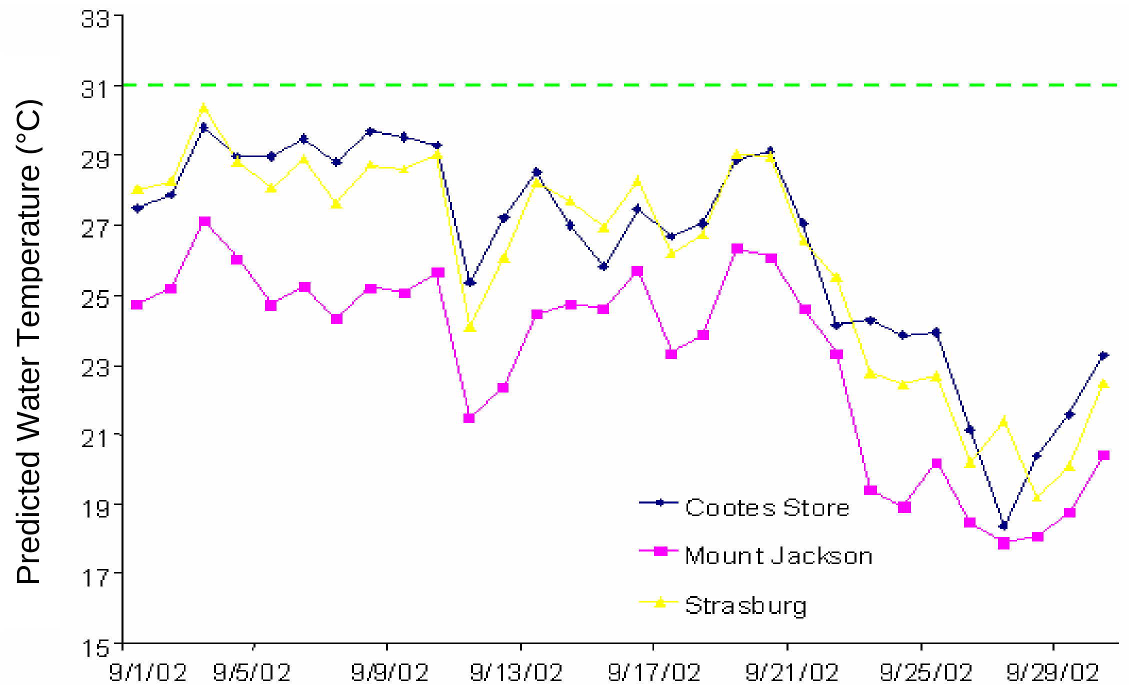


Figure 86. SNTEMP maximum daily water temperature predictions for September 2002 at the North Fork Shenandoah River gauging stations: Cootes Store, Mount Jackson, and Strasburg (sites 1, 15, and 29). The dashed green line marks the Virgina water quality standard of 31°C (State Water Control Board 2003).

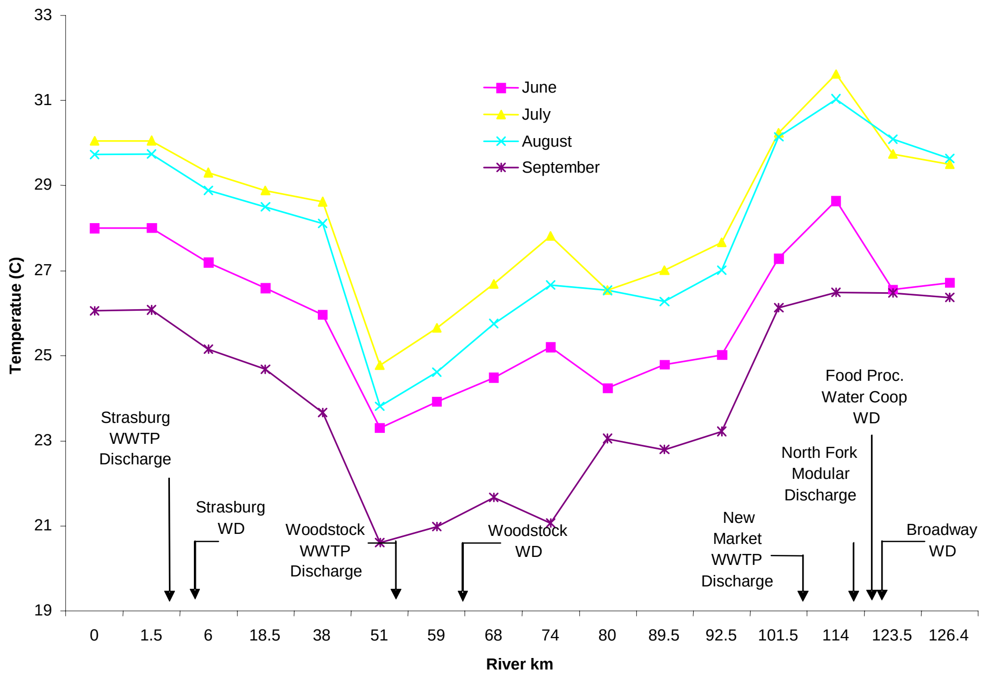


Figure 87. Modeled average maximum temperature depicting a longitudinal profile along the NFSR during summer 2002 using SNTEMP.

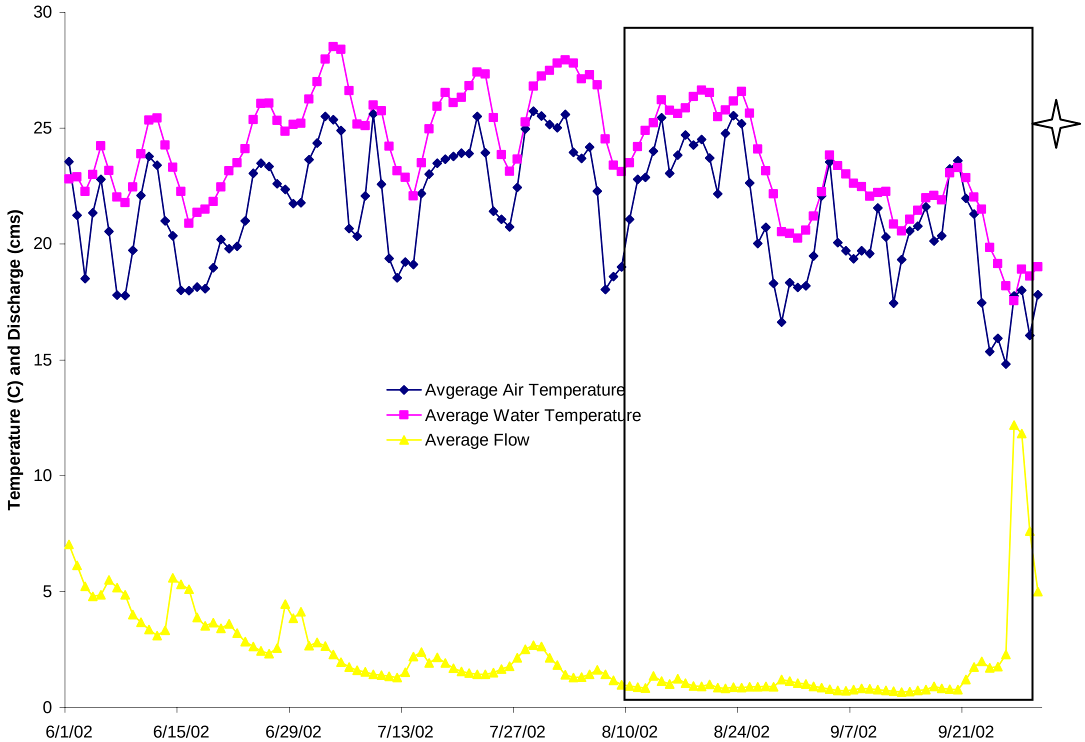


Figure 88. Observed water temperatures closely mimic observed air temperature variations throughout the NFSR, seemingly unaffected by the level of discharge.