Savannah River NUCLEAR SOLUTIONS℠
FLUOR • NEWPORT NEWS NUCLEAR • HONEYWELL

Scoping Summary for Optimization of the Savannah River Site Integrator Operable Unit Program (Phase II) (U)

SEMS Number: 35, 69, 70, 71, 74, 84

ERD-EN-2019-0007

March 2019 (Final)

SAVANNAH RIVER SITE • AIKEN, SOUTH CAROLINA

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy
and
Savannah River Nuclear Solutions, LLC
Aiken, South Carolina

TABLE OF CONTENTS

Section **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Tables **Page**

ATTACHMENTS

Attachment **Page**

This page was intentionally left blank.

1.0 BACKGROUND

The purpose of this scoping summary is to support an evaluation of the Integrator Operable Unit (IOU) program to identify optimization recommendations for Phase II and to reach Core Team agreement on an administrative path forward for the IOU program commencing in Fiscal Year (FY) 2020.

Savannah River Site (SRS) manages and monitors six IOUs that correspond to the surface water bodies (e.g., streams and lakes) and associated wetlands, including surface water, sediment/soil, and related biota associated with the major watersheds on the site. The IOU program includes the Savannah River and Floodplain Swamp (SRFS), Upper Three Runs (UTR), Fourmile Branch (FMB), Pen Branch (PB), Steel Creek (SC), and Lower Three Runs (LTR). The term "Integrator Operable Unit" is used to indicate that these surface water bodies and associated wetlands could receive contamination from multiple sources, including Resource Conservation and Recovery Act (RCRA)/Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) operable units (OUs), Site Evaluation Areas, National Pollutant Discharge Elimination System (NPDES) outfalls, and operational facilities. SRS manages and monitors the IOUs because they represent a possible pathway for the release of contamination from SRS activities to human health and ecological receptors.

The primary objectives of the SRS IOU program are to:

- Assess risk to potential human and ecological receptors from IOU contamination exposure;
- Evaluate the impact of waste units on the IOU;
- Determine if IOU early actions or reprioritization of OU implementation schedules are necessary and propose and implement early actions as required; and
- Complete the Remedial Investigation/Feasibility Study (RI/FS) process by defining the nature and extent of contamination, remedial action objectives, and final remedial actions if necessary.

The historical SRS IOU program is implemented in three phases to support a final CERCLA Record of Decision (ROD) for each IOU as follows:

- Phase I of the IOU program consisted of an assessment of all existing data to determine if early actions were necessary and to define additional data needs to assess potential impacts to the IOUs from inactive waste units. RI Work Plans have been approved for all six IOUs, and Phase I of the IOU program is complete.
- Phase II of the IOU program consists of ongoing sampling and assessment of the IOUs and refinement of the conceptual site model (CSM), continuing in parallel with the OU investigations within the watershed. The status of the IOUs during Phase II is currently documented through submittal of Periodic Reports (PRs) to the United States Environmental

Protection Agency (USEPA) and South Carolina Department of Health and Environmental Control (SCDHEC) for review and approval. Information in the PRs includes previously unreported data, wildlife surveys, OU sampling as it impacts the IOUs, newly identified OUs, early actions status and evaluation, refined CSM, data needs evaluation, and benchmark evaluation to assess contaminant threats to human health and ecological receptors.

The IOU program was designed to use the data compiled over many years/decades in Phase II to support the Phase III assessments. Phase II data from IOU sampling efforts, OU investigations, SRS annual environmental monitoring, SCDHEC Environmental Surveillance and Oversight Program (ESOP), and special studies conducted by various data stewards are combined in Phase II PRs (Table 2). Phase II concludes when the OU investigations specific to each IOU are complete. Phase II is complete for the LTR IOU and ongoing for the remaining five IOUs. To date, SRS has submitted twenty-eight (28) Phase II PRs (Table 3).

- Each IOU is addressed holistically in Phase III for final cleanup decision making. Phase III includes an assessment of all available data, development of the RI/Baseline Risk Assessment (BRA), completion of the RI/FS process through the ROD, and remedial actions, if warranted. The LTR IOU is currently in Phase III with the ROD issuance date scheduled for June 2020.

Over the past two decades, a vast amount of Phase II data was collected for the LTR IOU to support development of the RI/BRA. During Phase III scoping, the Core Team (representatives from USEPA, SCDHEC, and United States Department of Energy) determined that most of the historical data determined to be of a lower pedigree (i.e., missing or limited quality assurance/quality control records, dated procedures and analysis methods, older data no longer representative of baseline conditions, etc.) were not acceptable for use in the quantitative evaluations. As shown in Figure 2 and reported in the last PR for the LTR IOU, extensive Phase III characterization was required to support the LTR IOU RI/BRA. Similar issues with respect to the usability of historical data and the resulting need for considerable data collection in Phase III are anticipated for the five IOUs currently in Phase II.

Initial design of the IOU program was based on the presumed submittal of Phase III RODs in the 2020s timeframe. Since the inception of the IOU program, site operations and FFA commitments have extended the program several decades, and the next Phase III IOU field start is not scheduled until year 2049. Because IOU data reported in the PRs were usually collected a few years prior to the report generation, reporting by other data stewards now provides more useful and timely information.

2.0 PROBLEM WARRANTING PROGRAMMATIC ACTION

Phase III scoping for the LTR IOU revealed that a significant amount of the Phase II historical data from other data stewards and screening level data were not acceptable for use in the quantitative development of the RI/BRA, and extensive characterization was required to support Phase III. Optimization of Phase II of the IOU program is needed with respect to future data collection and reporting for the five remaining IOUs in Phase II.

3.0 SCOPE OF THE PROBLEM

Optimization of future data collection and reporting requirements for the IOU program impact the FFA IOU program schedule and future submittal of PRs for the five IOUs currently in Phase II. Major considerations include the following:

- Phase II demonstrated that the IOUs are well characterized and monitored to support early action determination. Areas of contamination at SRS are known and no new sources to the IOUs are expected. Refinement of the CSM for each IOU is complete and the sources potentially impacting each IOU are documented in FFA Appendices C and E. The identification of any new waste units will follow the appropriate regulatory process, but unless there are new releases, the impact(s) to an IOU would have already been observed/detected.
  - Benchmark comparisons to assess contaminant threat to human health and ecological receptors resulted in early actions for the addition of signage and/or fencing in 2003 (FMB IOU), 2004 (LTR IOU), and 2007 (SC IOU). After more than two decades of IOU data collection and evaluation, only one area (LTR IOU) implemented a time critical removal action in 2012 for contaminant removal and the addition of signage and fencing with funding from the American Reinvestment and Recovery Act. Except for biological data, no new IOU data needs are expected for the remaining five IOUs.
  - Collection of IOU specific data has decreased over time with no new Phase II IOU data needs anticipated for the five remaining IOUs. For the last six PRs submitted, only the LTR IOU PR4 and the SC IOU PR6 included previously unreported data (Figures 2 – 3). The other four IOUs reported only historical data and data from other stewards (Figures 4 – 7). An estimated forty-six (46) PRs will be submitted for the five IOUs currently in Phase II based on a 4-year reporting cycle and the current Phase III field start schedules[1] (Figure 1).

- A summary of the data compiled for the LTR IOU PR4 (final report) is shown in Figure 2. Instead of the normal Phase II data assessment, all IOU data in the LTR IOU final report were collected to support Phase III quantitative evaluations for the RI/BRA. Most of the historical data collected and reported in Phase II for the five remaining IOUs are not expected to be acceptable for Phase III quantitative evaluations. Additional characterization activities in Phase III are expected that will impact program costs and schedule.

- Most of the data compiled and reported by the IOU program was collected by other data stewards and are reported under other programs including the SRS Annual Environmental Report (ASER), SCDHEC ESOP, OU investigations (RFI/RI, groundwater reports, etc.), NPDES Monthly Discharge Monitoring Reports (DMR), Georgia Department of Natural Resources (GDNR), and SRS Operations and Maintenance (O&M) (Table 2). Review of the IOU program confirms that data reported by other programs is duplicated in the Phase II PRs (Figures 3-7).

[1] Federal Facility Agreement, Appendix E:3 Field Start, ROD Issuance and RA Start Dates (including Fiscal Year 2021+).

- The SRS ASER publishes a summary of the results of effluent monitoring and environmental surveillance of air, water, soil, sediment, vegetation and biota (including stream-specific information). Results are compared with historical data, background measurements, and applicable standards and requirements to ensure protectiveness of human health and the environment. Trending information for indicator radionuclide and metal contaminants in SRS streams and biota is provided in the annual report. Major changes or events affecting site conditions will be identified by SRS Operations, the Environmental Monitoring Program, and the SCDHEC ESOP program.

- The SRS Bioassessment Program was initiated in 1996 and conducted periodically through 2017. As shown by the data needs in Table 3, recent data collections in the IOU program focused on ecological surveys/biological data (fish and macroinvertebrate assemblages, fish tissue for onsite streams/water bodies, Savannah River Ecology Laboratory (SREL) ecological studies) and are compiled in a Bioassessment Report for the purpose of evaluating stream health in the IOUs (Attachment 1).

4.0 OBJECTIVES

- Reevaluate Phase II requirements and reach Core Team agreement on a refined IOU process that prepares for and focuses on final remedial decision making.

- Reach agreement on an implementation plan to incorporate Core Team optimization recommendations for the IOU program by FY2020.

5.0 UNCERTAINTY

- None

6.0 RESPONSE

After more than two decades of data collection and evaluations, the IOU program is a mature program. There is minimal uncertainty about contaminant levels and their impacts in the IOUs or associated human health risk since conditions are well understood, monitored, and not subject to significant change over time. IOU specific data collection for sediment and surface water media has decreased over time, and no new IOU data needs are anticipated for the five remaining IOUs in Phase II.

IOU data published in the PRs is usually collected a few years prior to report generation. Other reporting resources such as the SRS Bioassessment Report, the SCDHEC ESOP, and the SRS ASER provide more useful and timely information for ongoing evaluation of contaminant impact on the IOUs.

➢ The SRS ASER includes trending information for indicator radionuclide and metal contaminants in SRS streams and is published annually. The report provides a summary of effluent monitoring as well as environmental surveillance of air, water, soil, sediment, vegetation, biota, and agricultural products to monitor both radioactive and nonradioactive levels in these media.

- The SCDHEC ESOP conducts independent environmental surveillance and oversight and performs radiological and non-radiological monitoring (air, soil, water, fish, game, vegetation, milk, sediments, drinking water) on and around SRS. The SCDHEC ESOP report includes a comparison of SCDHEC data with SRS data. To date, the results of the SCDHEC ESOP monitoring have been consistent with those reported by SRS.

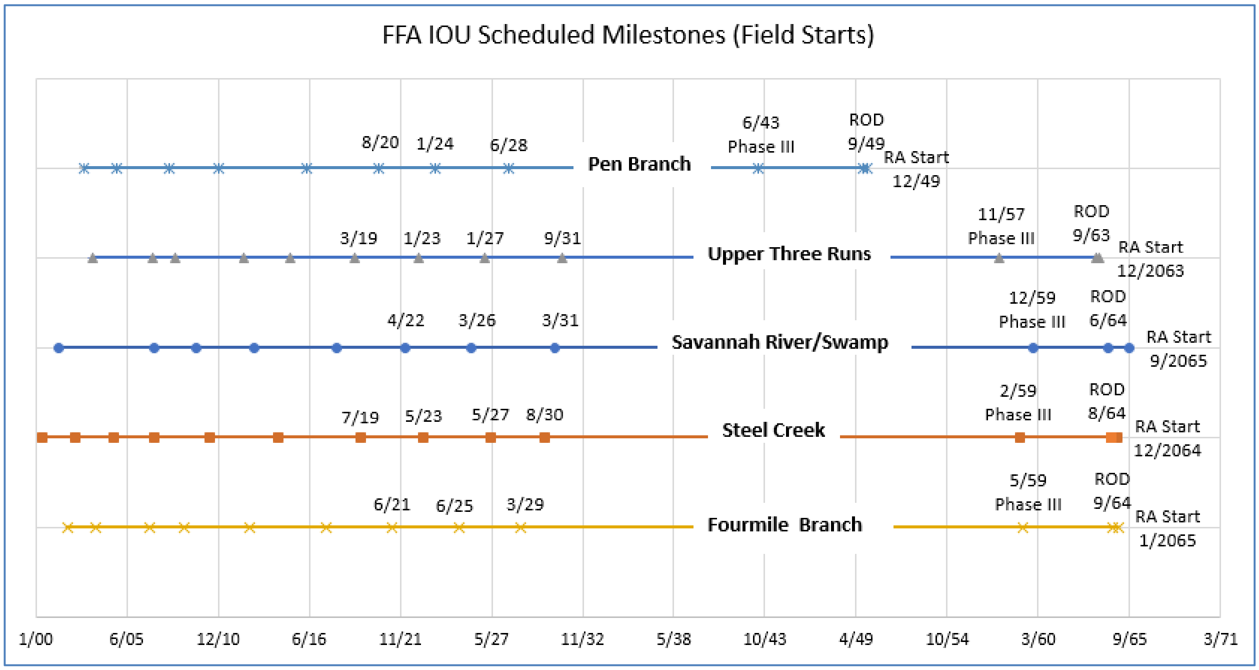
- The SRS IOU program includes bioassessment methods to determine the ability of a stream to support self-sustaining biological and ecological components typical of undisturbed, natural conditions. The SRS Bioassessment Program was initiated in 1996 and has been conducted periodically through 2017. The *Bioassessment of Streams on the Savannah River Site 1990 to 2017* (Attachment 1) is the most recent SRS Bioassessment Report. This report presents data from 1990 to 2017 to assess changes in biotic integrity within SRS streams with the ultimate objective of determining whether contamination released by SRS operations is degrading these ecosystems.

In light of the comprehensive and frequent data collection and reporting by other data stewards and programs, the current IOU Phase II effort is duplicative, and the value of IOU PR information for risk management does not warrant the large amount of resources necessary to sustain it and create the reports.

The Core Team agrees that the SCDHEC ESOP annual report and the SRS ASER, complimented with the SRS Bioassessment Report, are more useful and timely tools for monitoring the health of SRS stream systems. As per Core Team agreement, SRS will submit a Bioassessment Report every 7 years in place of Phase II PRs to continue monitoring the impact of waste units and operating facilities to the IOUs. Should a major change to site conditions occur as indicated by ongoing SRS environmental monitoring and the SCDHEC ESOP program, the Core Team will be advised to allow for discussion of future IOU data needs and reporting.

For the five remaining IOUs in Phase II, a scoping meeting will be held for each IOU five years prior to submittal of the respective RI/BRA to review existing data and scope submittal of a Phase III Work Plan/Sampling and Analysis Plan. This will allow the Core Team time to reach agreement on acceptable data for the respective RI/BRA and supports additional data collection efforts prior to a Phase III field start.

Based on the Core Team agreements from the March 21, 2019 scoping meeting, optimization of the IOU program for the five remaining IOUs currently in Phase II will be reflected in the FFA. The Bioassessment Report that replaces the Phase II Periodic Reports will be due in 2025. The Core Team will meet in early FY2020 to scope the contents of the Bioassessment Reports for future submittals.



RA – remedial action
ROD – ROD issuance date shown.

Figure 1. FFA Scheduled Milestones for Phase II IOUs

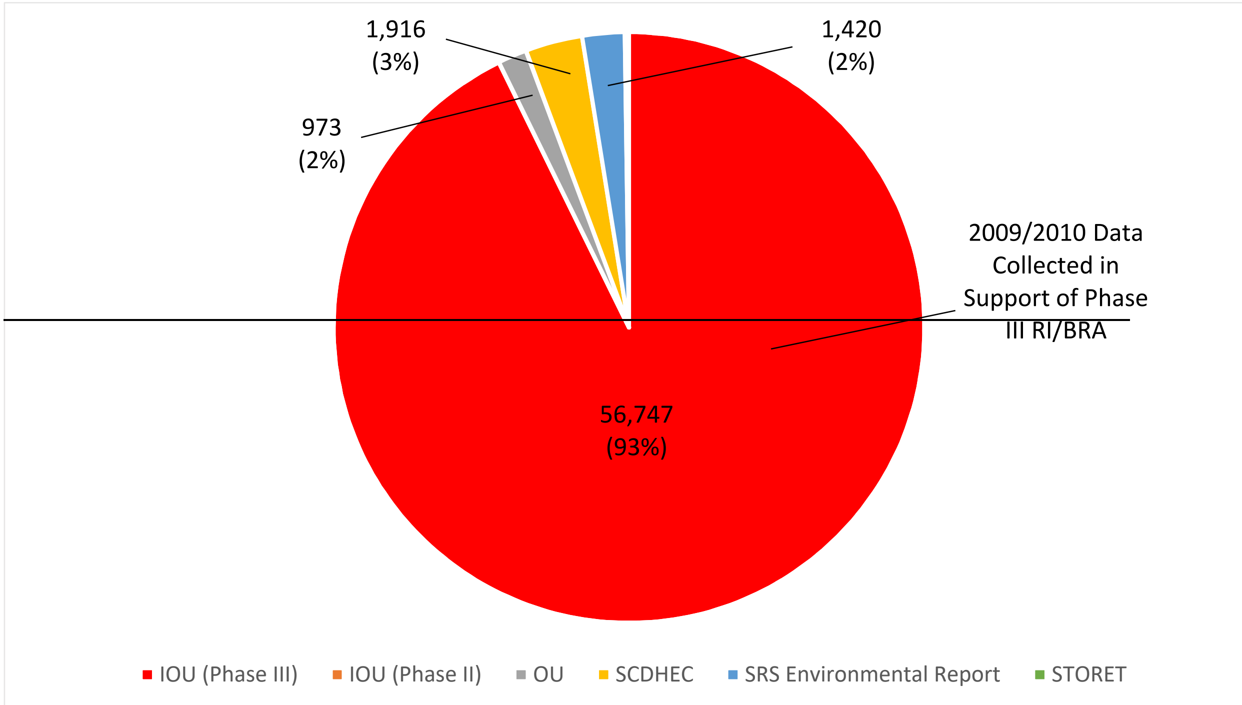


Figure 2. Data Summary LTR PR4 (2012) - # Records (% Records)

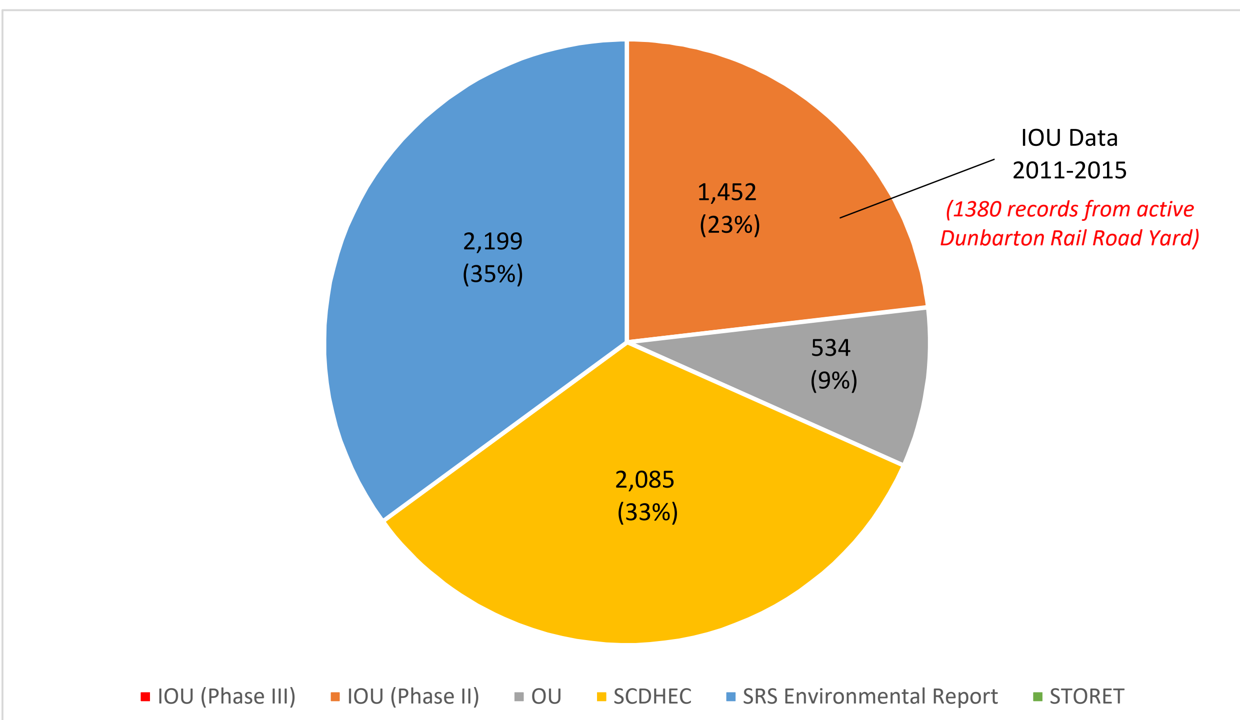


Figure 3. Data Summary SC PR6 (2018) - # Records (% Records)

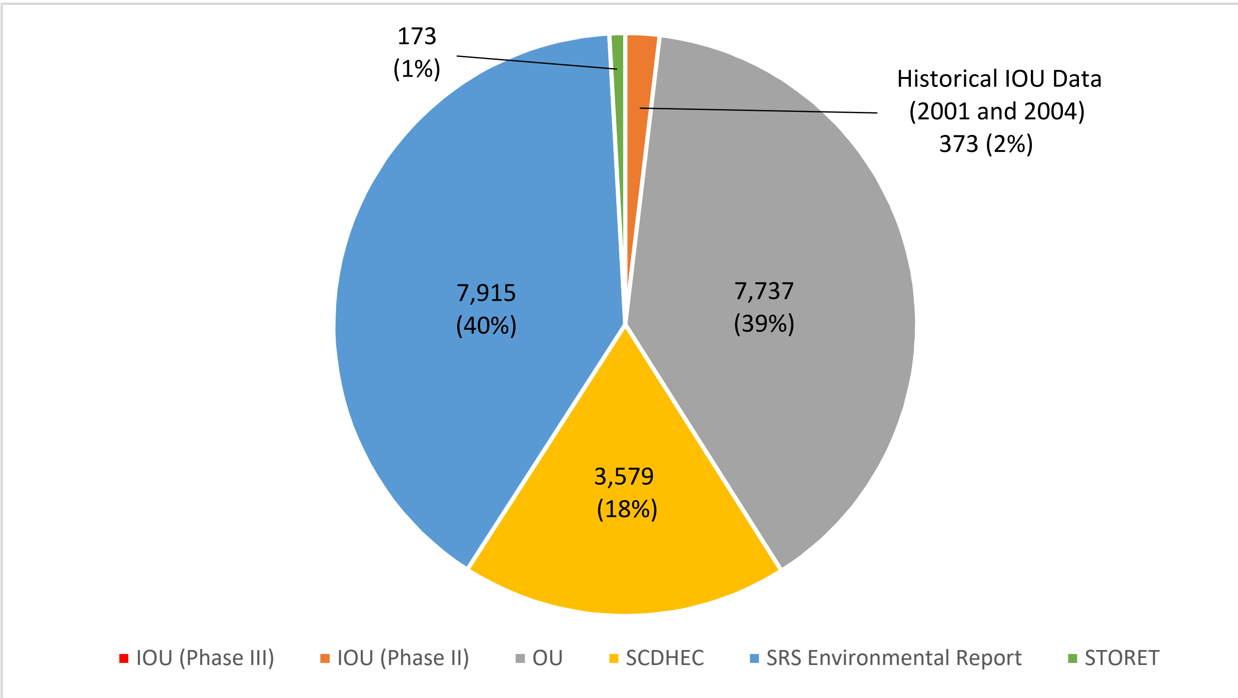


Figure 4. Data Summary UTR PR5 (2018) - # Records (% Records)

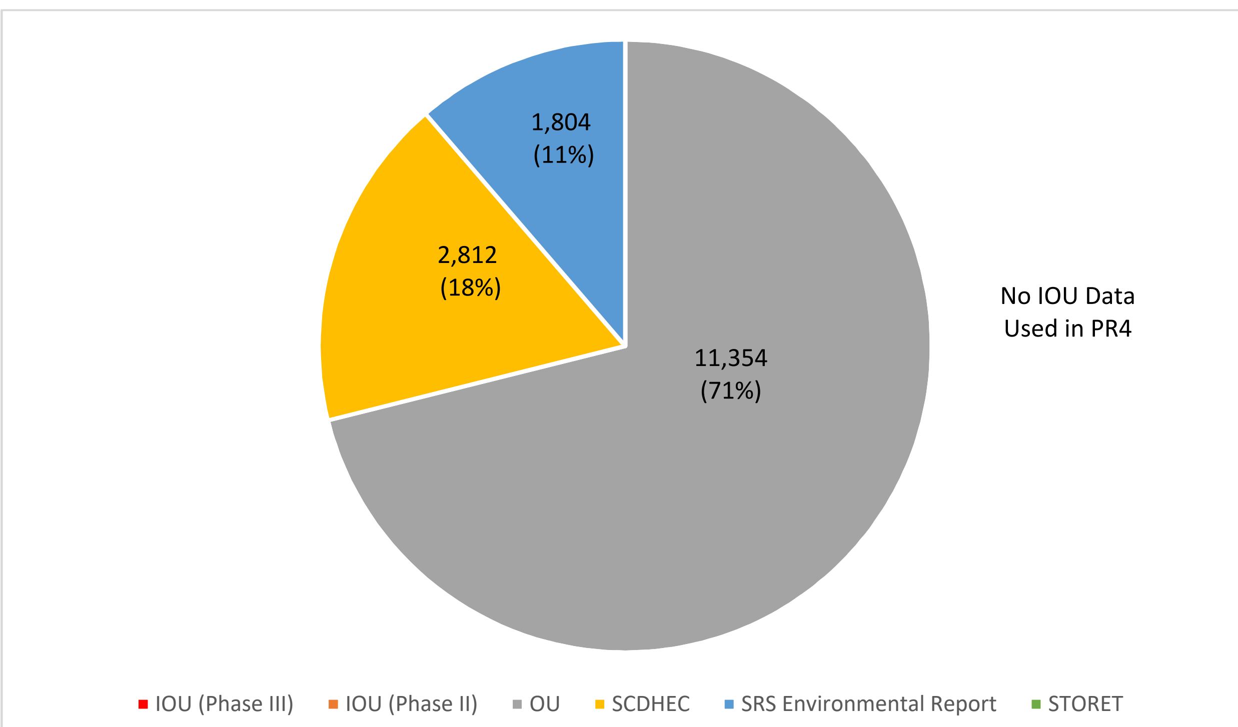


Figure 5. Data Summary PB PR4 (2016) - # Records (% Records)

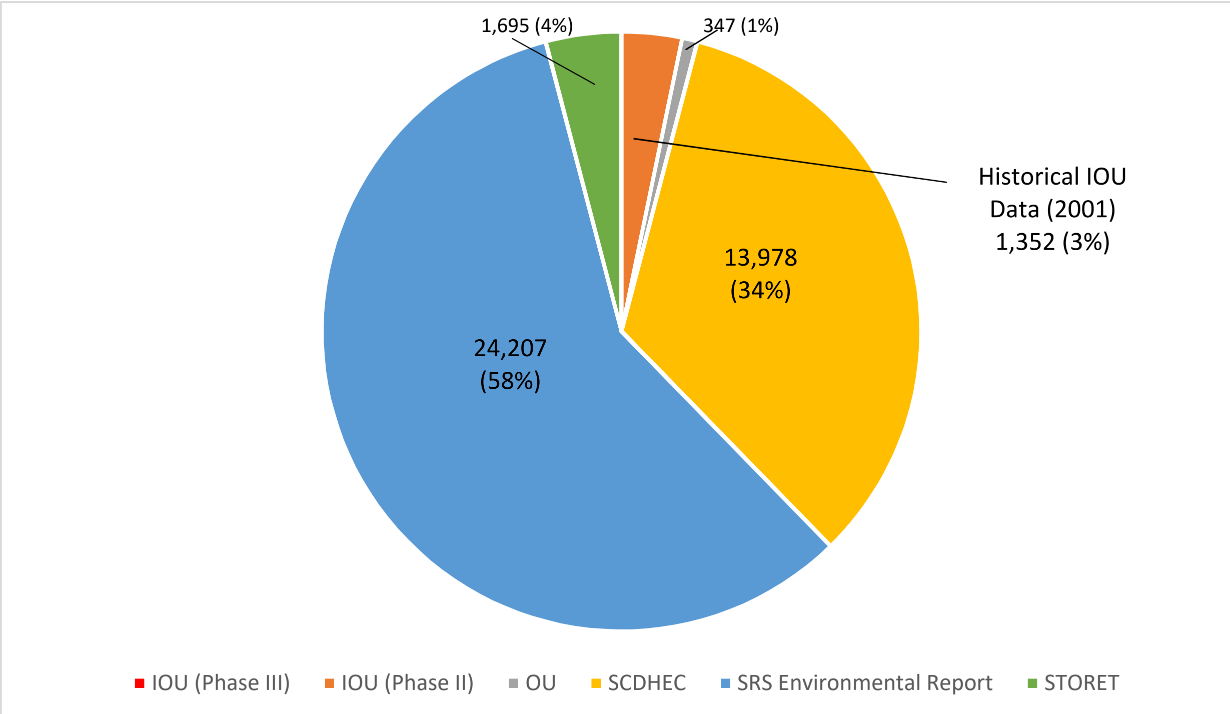


Figure 6. Data Summary FMB PR5 (2017) - # Records (% Records)

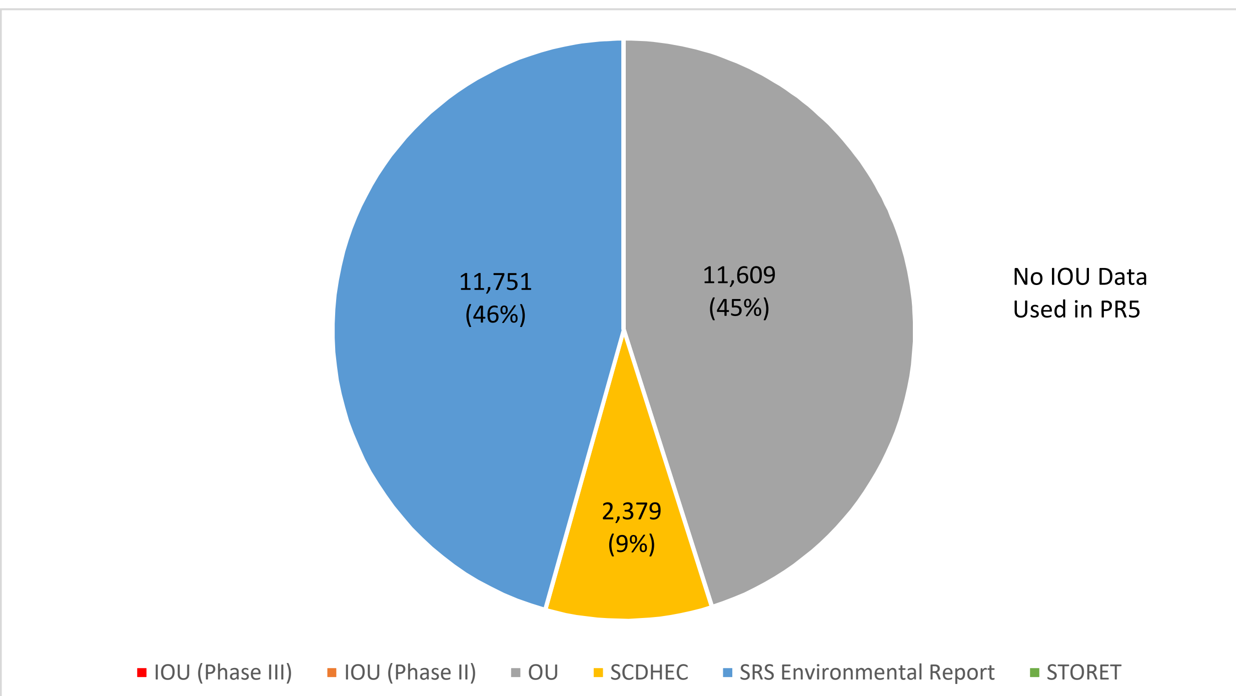


Figure 7. Data Summary SRFS PR4 (2017) - # Records (% Records)

Table 1. Record of Core Team Agreements[2]

Record of Core Team Agreements	
Date	**Description of Agreement**
3/21/2019	Core Team agreed to replace submittal of all future Phase II Periodic Reports (including PR5 for the Pen Branch IOU due in September 2019) with the Bioassessment of Streams on the Savannah River Site report submitted every 7 years beginning in 2025.
	Core Team agreed to scope the contents of the Bioassessment of Streams on the Savannah River Site report in early FY2020 including submittal frequency for future reports.

Table 2. Summary of Data Reported by Other Data Stewards

Environmental Media	Type of Surveillance	Analytes	Data Reported
Sediment	Stream and river surveillance	Radionuclides (Rads) and non-rads	SRS ASER, SCDHEC ESOP
	Basins	Rads and non-rads	SRS ASER, SCDHEC ESOP
	OU characterization/ investigation	Rads and non-rads	Groundwater reports (sediment media), OU reports (RFI/RI, etc.)
Surface water	Stream and river surveillance	Rads and non-rads	SRS ASER, SCDHEC ESOP
	Basins	Rads and non-rads	SRS ASER, SCDHEC ESOP
	OU characterization/ investigation	Rads and non-rads	Groundwater reports (surface water media), OU reports (RFI/RI, etc.)
	NPDES	Rads and non-rads	Monthly DMR submitted to SCDHEC, SRS ASER and SCDHEC ESOP
	Stormwater (Industrial)	Rads and non-rads	SRS ASER and SCDHEC ESOP
	Industrial wastewater outfalls	Rads and non-rads	SRS ASER and SCDHEC ESOP
	Unplanned spills or releases	Rads and non-rads	SRS O&M, SCDHEC, GDNR (Savannah River)
Fish	Monitoring at the mouth (UTR, FMB, SC, LTR) in SR and SR (upgradient and below SRS)	Rads and non-rads	SRS ASER, SCDHEC ESOP
Wildlife	Monitoring of deer, feral hogs, turkeys, and coyotes harvested on SRS	Rads	SRS ASER, SCDHEC ESOP

[2] Core Team agreements are documented at each phase of scoping and are retained for each successive phase in order to maintain a comprehensive list for the life of the project.

Table 3. Summary of IOU Periodic Reports

IOU PRs[3]		Data Need Identified	Early Action Identified
LTR IOU ROD (6/2020)	PR1 (December 2004)	• Develop risk-based benchmarks for lead. • Evaluate need for follow-up alpha, non-volatile beta, and gamma spectroscopy • Nature and extent of contamination south of R Area and northeast of P Area • Reconnaissance of LTR Tail section. • Collection of thermoluminescent dosimeter data, data for RI/BRA • Define background levels and develop background dataset • Extent of areas not previously sampled.	• Radiological postings and installation of fencing at public road crossings. • Fact Sheet to notify public about contamination in sediment/soil and fish.
	PR2 (March 2007)	• Evaluation of speciation data near R Area • Fish assemblage and macroinvertebrate monitoring. • Trophic modeling • Fish Tissue Sampling • Evaluation of Wildlife Survey • Collection of filtered surface water samples to assess bioavailability • Development of multi-media human health exposure scenario.	• No new early action. Continued early actions from PR1.
	PR3 (October 2009)	• Identify trophic modeling data needs from enhanced dataset. • Acquire additional data for trophic modeling database enhancement	• No new early action. Continued early actions from PR1.
	PR4 (August 2012)	• Review of sediment/soil data for evaluation of radium-226.	• Removal action for Cs-137 in three discernable sediment/soil areas in middle and lower subunits that exceeded 1x10-4 risk level for adolescent trespasser. Includes excavation, additional signs/fences, and inspections.

[3] IOU ROD issuance dates and approved Periodic Report dates shown.

Table 3. Summary of IOU Periodic Reports *(Continued)*

IOU PRs[3]		**Data Need Identified**	**Early Action Identified**
PB IOU ROD 9/2049	PR1 (April 2004)	• Alpha spec for screening exceedances in sediment	None
	PR2 (September 2007)	• Trophic modeling • Periodic sampling to assess macroinvertebrate and fish assemblages	None
	PR3 (November 2010)	• Metals data in biota and sediment to support trophic modeling	None
	PR4 (February 2016)	• Whole body fish samples per subunit • Index of Biotic Integrity (fish) and macroinvertebrate assemblage data to monitor stream health	None
UTR IOU ROD 9/2063	PR1 (January 2006)	• Alpha spec for screening exceedances in sediment/surface water	None
	PR2 (April 2008)	• Trophic modeling (river otter, belted kingfisher) • Periodic Fish Index of Biotic Integrity & macroinvertebrate monitoring • Fish based trophic study of Tims Branch	None
	PR3 (April 2012)	• Continue to compile data for trophic modeling	None
	PR4 (December 2014)	• Trophic modeling for additional receptors (raccoon and great blue heron)	None
	PR5 (July 2018)	• DGT samplers deployed to monitor contaminant levels and bioaccumulation in fish	None
SRFS IOU ROD 6/2064	PR1 (August 2006)	• Speciation for gross alpha exceedances (UTR) • Determine SRFS impact from A/M Area • Characterize SRFS impact in Beaver Dam Creek • Speciation for gross alpha, non-volatile beta trigger exceedances in D/TNX • Speciation for gross alpha trigger exceedance (PB) • Characterize potential impacts in swamp at mouth of PB • Speciation for gross alpha trigger exceedance in LTR. • Full data validation of 10% sampling data (deferred) • Trophic modeling for refinement of ecological constituents • Develop background level of Cs-137 in game for recreational hunter scenario	None
	PR2 (July 2009)	• Identify data needs in trophic modeling effort • Complete metals data from Beaver Dam Creek and determine if biological needs exist (SREL)	None

Table 3. Summary of IOU Periodic Reports *(Continued)*

IOU PRs[3]		Data Need Identified	Early Action Identified
SRFS IOU ROD 6/2064 *(cont'd)*	PR3 (February 2013)	• Develop Cs-137 background level in game for recreational hunter scenario • Collect background fish data to support Phase III	None
	PR4 (June 2017)	• Compile offsite data for Sr-89/90 in bone (deer); assess for use as background data; access leachability during cooking for ingestion	None
SC IOU ROD 8/2064	PR1 (February 2003)	• Confirm nonvolatile beta screening results where trigger level exceeded in SC headwaters. • Confirm gross alpha screening results in surface water where trigger level exceeded at SC-4.	None
	PR2 (August 2004)	• Independent study indicates Cs-137 contamination in sediment/soil in depositional area near SC-2A.	None
	PR3 (March 2007)	• Confirm nonvolatile beta and gross alpha results in sediment/soil were trigger level exceeded in Upper SC. • Habitat evaluation/reconnaissance in Upper SC • Periodic assessment of fish tissue in SC subunits • Fish assemblage and macroinvertebrate surveys in SC subunits • Trophic modeling to identify constituents of interest in SC subunits	• Signs placed at access roads to Upper SC to restrict access and inform onsite workers of Cs-137 contamination in sediment soil.
	PR4 (April 2010)	• Fish data from background location in Meyers Branch	None
	PR5 (June 2014)	• Sample location walked of Dunbarton Rail Road Yard • Sediment and surface water sampling at Dunbarton Rail Road Yard discharge points to the IOU • Sediment/soil and sediment data for selected metals and radionuclides from Meyers Branch • Crayfish and fish tissue (if needed) to support Phase III • Sediment soil and sediment data for cyanide, silver and thallium in Lower SC and Meyers Branch	None
	PR6 (September 2018)	• Recent fish data - DGT samplers deployed in SC to provide screening data to estimate bioavailable metal concentrations to support future human health and ecological screening.	None

Table 3. Summary of IOU Periodic Reports *(Continued/End)*

IOU PRs[3]		Data Need Identified	Early Action Identified
FMB IOU ROD 1/2065	PR1 (August 2003)	• Develop background dataset and define background level • Perform alpha and nonvolatile speciation for trigger exceedance in sediment and surface water. • Water sample to investigate impact of runoff from waste units 275 and 261. • Perform NaI screening in sediment and sediment/soil for Cs-137 to investigate contamination in lower FMB Corridor.	• Areas where dose (Cs-137) was measured above SRS radiological control thresholds (50 µrem/hr) were posted as Soil Contamination Areas (SCAs). • Access points leading to middle FMB were posted as radiological control areas (RCAs).
	PR2 (October 2005)	• Trophic modeling. • Periodic assessment of fish and macroinvertebrates. • Conduct Wildlife Survey. • Conduct fish/macroinvertebrate assessment and toxicological assessment. • Collect one surface water and sediment sample north of N Area.	• None
	PR3 (October 2008)	• Review biological mercury data. • Periodic assessment of fish and macroinvertebrates. • Conduct Wildlife Survey.	• None
	PR4 (May 2012)	• Periodic assessment of fish and macroinvertebrates. • Conduct Wildlife Survey. • Expand receptors used in trophic modeling (racoon and green/great blue heron) and incorporate additional metals data for biota.	• None
	PR5 (February 2017)	• Whole body fish samples per subunit. • Conduct fish and macroinvertebrate assessments. • Update trophic modeling effort to include racoon and green/great blue heron and additional biota data.	• None

SRNS-STI-2018-00492

ATTACHMENT 1

Bioassessment of Streams on the Savannah River Site, 1990 to 2017
SRNS-STI-2018-00492

This page was intentionally left blank.

SRNS-STI-2018-00492

BIOASSESSMENT OF STREAMS ON THE SAVANNAH RIVER SITE, 1990 TO 2017

Michael H. Paller
Savannah River Technology Center

Susan A. Blas
Soil and Groundwater Remediation Support

SRNS-STI-2018-00492

EXECUTIVE SUMMARY

Bioassessment is the use of information about the organisms within a stream to assess biotic integrity: the ability of a stream to support self-sustaining biological communities and ecological processes typical of undisturbed, natural conditions. The Savannah River Site (SRS) Integrator Operable Unit program includes three bioassessment methods: 1) the Index of Biotic Integrity (IBI) based on fish assemblage data collected from SRS streams by electrofishing, 2) the Multiple Habitat Sampling Protocol (MHSP) based on the collection of macroinvertebrates from natural stream substrates, and 3) the collection of macroinvertebrates with Hester-Dendy artificial substrates. Samples were collected from streams potentially impacted by SRS waste sites and industrial operations and reference streams largely free from SRS impacts. The SRS bioassessment program was initiated in 1996-1998 and has been conducted periodically through 2017. Additional fish assemblage data suitable for bioassessment were collected during 1990-1995. This report presents results from the entirety of this period to assess changes in biotic integrity within SRS streams with the ultimate objective of determining whether contamination with metals released by SRS operations is degrading these ecosystems.

Biotic integrity in Indian Grave Branch, Fourmile Branch, Lower Three Runs, the lower portion of Steel Creek, and the lower portion of Pen Branch has improved with time and is now comparable to biotic integrity in SRS reference streams. These streams formerly received discharges of high temperature reactor cooling water or were adversely affected by water discharged from reactor cooling reservoirs. With the discontinuation of reactor operations by 1988 or earlier, gradual habitat recovery permitted the establishment of aquatic communities that are now largely indistinguishable from those in reference streams. Aquatic communities within other potentially impacted SRS streams including Crouch Branch and McQueen Branch have consistently fallen within the reference site range or have also improved to reference site levels. The existence of healthy ecological communities in all of these streams indicates that contamination is insufficient to adversely impact ecological processes that sustain diverse ecological communities.

Unlike the preceding streams, upper Steel Creek has consistently exhibited low IBI scores indicating impairment of the fish community, but MHSP and Hester-Dendy scores within the reference site range, indicating healthy lower food chain communities. This discrepancy may be attributable to the presence of L Lake, a former reactor cooling reservoir that separates upper Steel Creek from lower Steel Creek and acts as a barrier to the upstream migration of fish. The migration of fish from more stable lower stream reaches to upper stream reaches is needed to replenish fish species lost to the relatively extreme conditions that often occur in stream headwaters (e.g., low water during droughts). Impairment of the upper Steel Creek fish community is unlikely the result of contamination because fish tissue contaminant levels are comparable to or lower than in some reference streams or portions of Steel Creek that have exhibited recovery.

All bioassessment methods indicated ecological impairment that has not improved with time in Tims Branch. This may be related to low oxygen levels and poor instream habitat. The latter is indicated by habitat assessment scores for Tims Branch that are substantially below the reference site average. Examination of metal levels in fish tissues showed that none of the elements for which data were available (As, Cd, Cu, Pb, Mn, Hg, Ni, and Zn) were elevated relative to levels in other SRS streams, which suggests that habitat degradation rather than contamination is responsible for ecological impairment in Tims Branch.

INTRODUCTION

The Savannah River Site Integrator Operable Unit (IOU) program represents an effort to assess the potential ecological risks of contaminants released from hazardous waste sites on the Savannah River Site (SRS). To better understand these risks, the 780 km^2 SRS has been partitioned spatially into Integrator Operable Units (IOUs) that correspond to the tributaries that drain the SRS into the Savannah River. IOUs are surface water bodies (e.g., streams, ponds, and lakes) and associated wetlands. They are "integrators" because they have the potential to receive contaminants from all Operable Units (sources of contamination) within their watersheds. This integration results from the transport of soluble contaminants from waste sites and discharges within the watershed to the stream by surface runoff or subsurface discharge. Organisms within the stream represent a further level of integration because the types of organisms in the stream and their condition is an integrated function of chemical and physical conditions in the stream.

The use of information about the organisms within a stream to assess environmental quality is termed bioassessment. Bioassessment explicitly evaluates effects on receptor organisms and reflects the cumulative effects of ecological disturbances (Plafkin et al. 1989). The Index of Biotic Integrity (IBI) is a bioassessment method that uses fish assemblage data to assess biotic integrity; i.e., the ability of a stream to support a self-sustaining biological community and ecological processes typical of undisturbed, natural conditions (Karr et al. 1986). The IBI is a multimetric index because it is composed of a number of community, population, and organism level variables (or metrics) that are ecologically important and sensitive to environmental disturbances of different types. These variables are measured at assessment sites, compared with the same variables in a range of similar but relatively undisturbed benchmark streams, and the results summarized in a single number that reflects the extent to which the assessment site resembles the benchmarks. The IBI has been adapted for use throughout the United States and numerous foreign countries (Plafkin et al. 1989, Klemm et al. 1993). It has been modified for use in SRS streams where it accurately discriminates undisturbed sites from sites affected by physical habitat alterations and chemical pollution (Paller et al. 1996).

Bioassessment often involves taxonomic assemblages other than fish including benthic macroinvertebrates and periphyton (Barbour et al. 1997). The inclusion of more than one taxonomic assemblage can increase the accuracy of an assessment because different taxonomic groups may respond differently to stressors (Mount et al. 1984, Barbour et al. 1997, Paller 2001). The South Carolina Department of Health and Environmental Control (SCDHEC) developed a bioassessment protocol termed the Multiple Habitat Sampling Protocol (MHSP) for macroinvertebrates collected from natural substrates in coastal plain streams (SCDHEC 1998). This methodology has been modified for SRS streams to produce more accurate results (Paller et al. 2007). Macroinvertebrates have also been collected from SRS streams with Hester-Dendy artificial substrates, which consist of variably spaced masonite plates threaded together and placed in streams for a period sufficient to permit colonization by benthic organisms. The uniform surface for colonization provided by the plates can reduce biases stemming from habitat differences among sites that can be confounded with contaminant related effects.

Bioassessment to determine the cumulative effects of SRS waste sites on the ecological health of SRS streams was initiated in 1996-1998 and has been conducted periodically through 2017. Additional fish assemblage data suitable for bioassessment was collected from 1990-1995. The objective of this report is to 1) present results from 1990-2017, 2) use this information to assess changes in the biotic integrity of SRS streams over time, and 3) compare biotic integrity among SRS streams. A comprehensive report on the SRS IOU bioassessment program was provided in 2004 (Paller and Dyer 2004). The current report includes results from this report plus the results of bioassessments conducted thereafter and results from 1990-1995.

Bioassessment is only part of process used to assess the ecological effects of contaminants in the SRS IOUs, which also includes the measurement of contaminant levels in sediment, fish, crayfish, and surface water and the use of contaminant exposure models to estimate potential doses to ecological receptors feeding near the top of SRS aquatic food chains. Summaries of contaminant data and the results of contaminant exposure modeling can be found in other reports (e.g., Paller et al. 2008).

METHODS AND MATERIALS

Study Area

The SRS and its associated streams are in the SandHill ecoregion, which covers about 20,600 km^2 in the southeastern United States and consists of the inland coastal plain that borders the fall line (Markewich and Markewich 1994; Schmidt 2013). The Sand Hills are characterized by deep sands with clay and silt and are dominated by longleaf pines (*Pinus palustris*) and turkey oaks (*Quercus cerris*). Many of the larger streams in the SandHill ecoregion are "blackwater," low-gradient, slow-flowing and fed by water seeping through sandy soils that underlie floodplains and swamps. The water is stained by decaying organic matter, usually acidic, and with little sediment (Sabater et al. 1993). These characteristics describe Upper Three Runs and its tributaries on the SRS but are less pronounced in SRS streams, such as Lower Three Runs, that are located farther southeast. Snags and other large woody material are the predominant instream structure in SRS streams, often forming debris dams that affect detrital dynamics and geomorphology and provide aquatic habitat (Benke and Meyer 1988). There are numerous natural habitat and environmental factors such as stream size, channel morphometry, instream structure, and water chemistry that can influence the composition of stream fish and macroinvertebrate assemblages in SRS and other SandHill streams (Sheldon 1968, Paller 1994, Paller et al. 2016). Streams on the SRS are species rich compared with other SandHill streams as a likely result of greater instream habitat diversity, less disturbed land coverage, more forested land, and closer proximity to species-rich source pools (Paller 2018).

Integrator Operable Units

The 780 km^2 SRS has been divided into six IOUs, five of which correspond to the drainage basins of the five major streams on the SRS: Upper Three Runs, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs (Figure 1). These are the subject of this report excluding the former reactor cooling reservoirs located in the Lower Three Runs and Steel Creek drainages. The remaining IOU is the portion of the Savannah River and Savannah River Swamp associated with the SRS (i.e., the portion extending from the upstream boundary of the SRS down to Lower Three Runs). Because they are large, the IOUs are subdivided into IOU subunits that correspond to portions of a stream that may differ in exposure to contamination or other SRS activities. This permits the assessment of spatial differences in levels of impact. Several IOU subunits have no waste sites or industrial facilities within their watershed boundaries and are considered reference subunits relatively undisturbed by SRS operations.

The Upper Three Runs IOU encompasses a large area that includes portions of Aiken and Barnwell counties located outside of the SRS (Figure 1). Approximately 250 km^2 of the Upper Three Runs watershed is within the SRS. Tributaries of Upper Three Runs located within the SRS include Tinker Creek, Tims Branch, Crouch Branch, and McQueen Branch. Mill Creek and Reedy Branch are also located within the Upper Three Runs IOU, but these streams discharge into Upper Three Run's main tributary, Tinker Creek, rather than directly into Upper Three Runs. There are several SRS operational facilities and waste areas within the Upper Three Runs IOU (WSRC 1998a), but much of Upper Three Runs is upstream from SRS industrial areas. Similarly, Tinker Creek and Mill Creek are largely undisturbed by SRS operations. Several chemical constituents of potential concern from human health or ecological perspectives have been found in water and/or sediments within portions of Upper Three Runs (Paller el al. 2008).

Fourmile Branch is a 24 km long stream that lies entirely within the SRS (Figure 1). The 57 km^2 Fourmile Branch watershed includes several SRS facilities, waste sites, and discharges (WSRC 1998b). Except for the extreme headwaters, most of Fourmile Branch is potentially influenced by SRS discharges and industrial operations. Both radioactive and nonradioactive constituents of potential concern have been detected in environmental media collected from Fourmile Branch (Paller el al. 2008). Fourmile Branch received large volumes of heated cooling water from C Reactor in the past, causing extensive habitat destruction and the elimination of most aquatic biota. Recovery and recolonization of Fourmile Branch began in 1985 with the shutdown of C-Reactor.

The Pen Branch IOU includes Pen Branch and its tributary Indian Grave Branch, both of which are entirely within the SRS (Figure 1). Pen Branch terminates in the Savannah River swamp, and unlike the other major streams on the SRS, does not have a clearly defined channel through the swamp to the Savannah River. Except for its extreme headwaters, nearly all Indian Grave Branch was affected by the past operation of K Reactor resulting in the type of habitat degradation described for Fourmile Branch. Heated cooling water from K Reactor entered Indian Grave Branch and flowed into Pen Branch where it caused further habitat destruction. Recovery began in 1988 with the cessation of K-reactor operations. Upper and middle Pen Branch are largely undisturbed by SRS operations.

The Steel Creek IOU includes Steel Creek and its major tributary, Meyers Branch (Figure 1). Steel Creek originates near P-Reactor and flows approximately 3 km before entering the headwaters of L Lake, a 7 km long, 400 ha cooling reservoir constructed in 1985. Water discharged from the L Lake dam enters the middle reach of Steel Creek, flows approximately 5 km to the Savannah River swamp, and then flows about another 2 km through the Savannah River floodplain swamp swamp to the Savannah River. All of Steel Creek is potentially affected by SRS discharges, waste sites, and/or industrial operations. The middle and lower portions of Steel Creek suffered extensive habitat degradation from the discharge of high temperature reactor cooling water during 1954 to 1968 and was affected to a lesser degree by discharge from L Lake following its construction. Industrial facilities and waste sites in the Steel Creek IOU, as well as potential contaminants of concern, are summarized in WSRC(1998c). Meyers Branch is largely unaffected by SRS operations.

Lower Three Runs drains the southeastern portion of the SRS (Figure 1). Its upper reaches were dammed to form Par Pond, a 1012 ha reservoir formerly used for cooling P and R Reactors. Water discharged from the Par Pond dam flows another 30 km through Lower Three Runs before entering the Savannah River. Throughout much of this distance, SRS property consists of only a narrow strip of land bordering the stream banks. Industrial facilities and waste units occurring in the upper reaches of the Lower Three Runs IOU are summarized in WSRC (1998d).

Fish sampling

The IBI was calculated for 134 fish assemblage samples collected from 50 sites during 1990, 1992, 1995, 1997-1998, 2000, 2003, 2007, 2009-2010, and 2017 (Table 1). Most samples were collected expressly for bioassessment in conjunction with the SRS IOU program. However, samples from 1990, 1992, 1995 and

2009-2010 were collected for other purposes but are included herein to help assess long-term trends. Samples for bioassessment were not collected from the Savannah River, L Lake, or Par Pond IOU subunits because IBI protocols have not been developed for large river or lentic ecosystems in the SandHill ecoregion.

All sites were sampled by direct current electrofishing, which effectively collected fish from the brush, root masses, snags, and other complex structure in SRS streams. The protocol used during 1990, 1992, and 1994/1995 employed five to seven successive passes made while moving upstream through 100–400 m stream segments (mean = 265 m, SD = 70, average 54 channel widths) with the objective of reducing catch rates to near zero by the last pass. Although some sample reach lengths were relatively short, all provided adequate data for assessing site-level assemblage structure when multiple electrofishing passes were employed (Paller 1995). Backpack electrofishing was used in small streams (under 5 m wide). Larger and more powerful gear (barge or boat) was used in larger streams to maintain sampling efficiency. Prior to sampling each site, electrofishing settings (primarily voltage) were adjusted to achieve the maximum catch rate that did not cause fish mortality. Block nets were deployed at the ends of the sample sites. All fish were counted, identified to species, and released.

A less intensive protocol was used to electrofish SRS streams in 1997, 2000, 2003, and 2007, consisting of one electrofishing pass made while moving upstream and sampling all microhabitats to collect as many fish as possible in a 150–200 m stream reach (average 42 channel widths). One backpack electrofisher and a two or three-person crew was used in small streams. Two back pack electrofishers and two crews, with a crew covering each bank, were used in larger streams (>5 m wide). A boat with a generator and electrofisher was used to sample the largest streams (13–17m wide). Block nets were not used because they did not improve catch rates, were difficult to keep in place, and field observations indicated little movement of fish from sites while sampling.

Samples from 2009–2010 were collected by direct current backpack electrofishing 150-210 m stream reaches, with most sites being 200 m long. Longer reaches were sampled in larger streams to better represent all habitats and species. One or two backpack electrofishers and a team of 2–6 personnel was used for electrofishing, with more equipment and personnel being used in larger streams. Two passes were made at each site. All fish were counted, identified, and released.

Samples taken during 2017 were collected by electrofishing four 50 m stream segments at each sample site for a total of 200 m. All sites were samples using a Smith-Root backpack electrofisher powered by a battery. One backpack electrofisher and a two-person crew were used to sample all sites. Two passes were made with the electrofisher through each 50 m section, while moving upstream. All microhabitats were sampled to collect as many species and individuals as possible. All fish caught were identified to species and released.

Macroinvertebrate sampling

A methodology similar to SCDHEC's (1998) Timed-Qualitative Multiple Habitat Sampling Protocol (MHSP) was used to collect 97 macroinvertebrate samples from 37 SRS stream sites in 1997, 2000, 2003, 2007, and 2017 (Table 2). The MHSP involved the collection of macroinvertebrates from natural substrates using a timed sampling approach consisting of three man-hours of sampling effort at each sampling location. All available natural habitats were sampled with a D-frame dip net, kick net, hand sieve, white plastic pan and fine mesh sampler with the objective of collecting as many different macroinvertebrate taxa as possible during the allotted time. Macroinvertebrates were placed in ethanol and returned to the laboratory for microscopic identification, usually to the genus level. The MHSP protocol is designed to ensure that all habitats at a site are thoroughly sampled to obtain a good representation of the macroinvertebrate community. Details of the sampling protocol are provided in SCDEC (1998).

In addition to the MHSP, Hester-Dendy multiplate artificial substrates were used to collect macroinvertebrates from 37 sites during 1997, 2000, 2007, and 2017 (Table 3). Artificial substrates provide a uniform substrate for macroinvertebrate colonization, which can theoretically reduce the influence of habitat differences among sites that could be confounded with the effects of contamination. Each Hester-Dendy artificial substrate sampler consisted of fourteen 7.6 cm plates separated by approximately 0.3-1.0 cm (total surface area of 0.179 m^2). Five samplers were deployed at each site in 1997, 2000, and 2007, and two samplers were deployed at each site in 2017. They were hung from a line stretched across the stream so they did not contact the bottom and retrieved after an approximately 28-day colonization period. Organisms were removed from the samplers, preserved in 70% ethanol, and taken to the laboratory for microscopic identification (usually to the genus level).

<u>Habitat</u>
In 2003, 2007, and 2017, habitat quality was assessed in conjunction with the MHSP using a methodology developed by SCDHEC (1998). Variables included epifaunal substrate, pool substrate, pool variability, sediment deposition, channel flow status, channel alteration, channel sinuosity, bank stability, vegetative protection, and riparian vegetation. Each of these variables were rated on a scale of one (poor) to 20 (optimal) for each sample site, and the scores were summed to produce an overall rating of habitat quality.

<u>Data Analysis</u>
The IBI used in this study was developed from the original IBI by adjusting for the composition of the ichthyofauna of the upper South Carolina coastal plain (Paller et al. 1996). It included 10 metrics, each scored one (poor), three, or five (best) which summed to a maximum total index value of 50 (Table 4). It also adjusted for differences in sample area (i.e., species/area effect), stream size, and sampling effort making it possible to directly compare IBI values from streams and sample areas of different size as well as stream reaches sampled with different numbers of electrofishing passes (Paller et al. 1996). The IBI was calculated for all stream reaches combined (in cases where multiple smaller sub-reaches were sampled) at each site on each date.

Data collected with the MHSP protocol were analyzed to produce a bioclassification rating based on two metrics: the number of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa and a biotic index (BI) value, as shown in SCDEC (1998). EPT are known for their sensitivity to water quality and habitat degradation. The BI is an index that reflects the average pollution tolerances of individual taxa collected from a site, weighted by abundance (Lenat, 1993). These metrics are included in the rating because of their known sensitivity to pollution and other types of habitat degradation. Each of the metrics is assigned a score of one (poor) to five (best), and the two scores are averaged to produce a combined bioclassification score.

Studies conducted at the SRS showed that the original MHSP sometimes produced inaccurate scores leading to its modification for use in SRS streams (Paller et al. 2007). The modification consisted of adjusting the EPT metric for stream size and adjusting the EPT scoring system by calibrating it against SRS streams known to be minimally disturbed. Because larger streams typically support greater macroinvertebrate diversity than smaller headwater streams (Vannote et al., 1980), they have more EPT taxa, as observed in SRS streams (Paller et al., 2007). The EPT metric was adjusted in three steps. First, EPT values at each site were regressed on the average stream width at each site to obtain the expected EPT for a given stream width (Figure 2). Second, a residual EPT, which corresponded to the EPT with the effects of stream size removed. was calculated for each site by subtracting the actual EPT from the expected

EPT. Positive residuals indicate more species than expected for a stream of a given size and negative residuals indicate less. Third, the residuals, now free of the effects of stream size, were plotted and the plot, excluding the upper 5% of the scores, was divided into five areas of equal size corresponding to the five bioclassification categories used in the MHSP (5=excellent, 4=good, 3=good-fair, 2=Fair, 1=Poor) (Figure 3).

The Hester-Dendy artificial substrate data were analyzed by calculating number of EPT taxa and the BI score for each site and comparing these metrics to their values at reference sites. A previously developed multimetric index for Hester-Dendy data (HDMI, Paller and Specht 1997) was not used herein because taxonomic composition data needed to compute the index were lacking for some samples.

The long duration of the SRS IOU bioassessment program permitted the analysis of temporal trends in the biotic integrity of SRS streams. These trends were assessed by plotting bioassessment scores against sample year for all samples from each stream regardless of sample location unless both potentially impacted and reference areas occurred in the same stream or different portions of the stream exhibited different trends in biotic integrity. In the latter case, separate plots were produced for different sites within the same stream. Average values were plotted for years in which more than one site was sampled in a stream or portion of a stream.

In addition to assessing temporal trends within streams, differences among streams were assessed by averaging all samples from a stream or portion of a stream and comparing the averages. Each average included all samples collected from a stream with the following exceptions: 1) potentially impacted and reference areas with the same stream were analyzed separately, 2) early samples from streams affected by reactor operations were excluded, as described in greater detail later, and 3) samples from upper Steel Creek and lower Steel Creek were analyzed separately because they were subjected to different types of impacts and exhibited different temporal trends (described in greater detail later).

The statistical significance of differences between IBIs at sites potentially influenced by the SRS (i.e., located downstream from SRS waste sites and industrial areas) and reference sites was assessed with the Kruskal-Wallis test ($P \leq 0.05$), followed by a Dunn's test for comparisons between the pooled reference sites and the potentially impacted sites within each stream ($P \leq 0.05$). The Kruskal-Wallis method was used rather than analysis-of-variance because none of the bioassessment indices used in this study were normally distributed. As a nonparametric method, the Kruskal-Wallis test focuses on differences among medians rather than differences among means.

<u>Reference sites</u>

Reference sites that represent biological communities under minimally or least disturbed conditions are essential for bioassessment because they provide standards against which other sites are compared to assess biotic integrity. Several streams and/or stream reaches on the SRS (designated by "R" in Tables 1, 2, and 3) represent high biodiversity, least-disturbed conditions for the Sandhills ecoregion of which the SRS is a part (Paller et al. 2016, Paller et al. 2017, Paller 2018). These streams served as reference sites for comparison with potentially impacted sites. All reference streams and stream reaches were upstream of SRS waste sites and industrial facilities, thus unlikely to be strongly influenced by SRS activities. Having several reference sites permits characterization of the range of variability associated with reference conditions as needed to accurately identify ecological degradation. The reference site range for each index included in this study (e.g., IBI, MHSP) was defined as the range for all reference sites excluding the lowest 5-10% of the reference site values. Five percent was used as the reference site cut-off when the number of reference site samples for an index was large, and ten percent was used as the reference site cut-off when the number of reference site samples was too small to accurately identify a 5% cut-off. The latter was the case with some of the Hester-Dendy data. Samples representing the lowest 5-10% of the range were excluded because they may represent index values that are atypical because of sampling error and/or other factors.

The formulas for calculating the IBI and MHSP indices used in this study adjusted for the effects of stream size (i.e., width) making it possible to use a single reference site cut-off for all sites regardless of stream size. However, the use of unadjusted EPT and BI values when comparing Hester-Dendy results necessitated the use of separate reference site cut-offs for small and large streams defined as streams less than 5m average width and greater than 5 m average width, respectively.

In a few cases, sites originally designated as reference sites were excluded from calculation of the reference site range. These included Upper Three Runs near Tyler Bridge Road and Road 8-1, originally intended as an IBI reference sites but excluded from the IBI reference range because they could not be sampled effectively, and Fourmile Branch near Road F and Meyers Branch near Rd 6.2, originally intended as MHSP and Hester-Dendy reference sites but excluded because of poor habitat.

RESULTS

<u>Temporal trends</u>

IBI

Reference streams and stream reaches including Tinker Creek, Mill Creek, upper Pen Branch, middle Pen Branch, and Meyers Branch were characterized by relatively high IBI values (Figure 4). Exceptions were reference sites in Upper Three Runs, which were below the range of the other reference sites and excluded from computation of the reference range. These sites in Upper Three Runs were characterized by deep water, fast currents, and overhanging vegetation that precluded effective electrofishing.

IBIs in some potentially impacted streams including McQueen Branch and Indian Grave Branch were within the reference site range throughout the sampling period (Figure 4). Crouch Branch, exhibited a temporary IBI decrease for uncertain reasons in the late 1990s before returning to reference site levels. However, there were two streams or portions of streams, Tims Branch and upper Steel Creek, that exhibited relatively low IBI values that did not increase over time. IBIs in Tims Branch were initially within the reference site range and then progressively decreased to below the reference site range by 2017. IBIs in upper Steel Creek were consistently below the reference site range during the 1990-2017 study period and showed no trend of increase.

Other potentially impacted streams including lower Steel Creek, lower Pen Branch, and Lower Three Runs exhibited IBIs that were below the reference site range in the earliest samples (1990) but by 2000-2005 increased to reference site levels (Figure 4). IBIs in Fourmile Branch, while never below the reference site range, also exhibited a general trend of increase over time. Streams that exhibited this increase formerly received large volumes of high temperature reactor cooling water, which resulted in extensive scouring of the stream bed and other types of severe habitat degradation. All cooling water releases to these streams stopped by 1988 or earlier except for a brief release of moderate temperature cooling water to Pen Branch in 1992. IBI increases in these streams likely resulted from secondary succession that contributed to the recovery of instream and riparian habitat. This lead to the establishment of more diverse fish communities generally comparable to the communities in reference streams.

MHSP

MHSP values in most reference streams including Tinker Creek, upper Upper Three Runs, upper Pen Branch, and middle Pen Branch were high throughout the 1997 to 2017 period in which MHSP samples were collected (Figure 5). MHSP values in two other reference streams, Mill Creek and Meyers Branch, were generally high but exhibited temporary decreases before returning to reference site levels. As observed with the IBI, several potentially impacted streams that received high temperature discharges of reactor cooling water exhibited MHSP increases over time as a likely consequence of habitat recovery following the cessation of reactor operations. These streams or portions of streams included Fourmile Branch, lower Pen Branch, Indian Grave Branch, and Lower Three Runs. Recovery of the macroinvertebrate communities in these streams appeared to occur more slowly than recovery of the fish communities (as reflected by the IBI) as a possible result of differences in habitat requirements or vagility between fish and macroinvertebrates. MHSP values also increased over time in Crouch Branch, although this stream did not receive reactor cooling water. As observed with the IBI, the MHSP remained consistently below reference site levels in Tims Branch. However, this was not the case in upper Steel Creek, where the IBI was depressed but the MHSP was within the reference site range (Figures 4 and 5).

Hester-Dendy artificial substrates

Results from the Hester-Dendy artificial substrates generally paralleled results from the MHSP, although EPT and BI numbers calculated from these two macroinvertebrate sampling techniques differed (Tables 2 and 3). EPT values were affected by stream size necessitating a somewhat higher reference site range for large streams than for small streams (Figure 6). Hester-Dendy EPT values for the reference streams or portions of streams (upper Upper Three Runs, Tinker Creek, Mill Creek, upper and middle Pen Branch, and Meyers Branch), were relatively high and did not exhibit consistent temporal trends (Figure 6). In contrast, Hester-Dendy EPT numbers in potentially impacted streams that formerly received reactor cooling water, including Fourmile Branch, lower Steel Creek, lower Pen Branch, Indian Grave Branch, and Lower Three Runs, increased over time as a likely result of gradual habitat recovery, as also observed with the IBI and MHSP. Hester-Dendy EPT numbers in Crouch Branch, also potentially impacted but not by cooling water discharges, were initially below reference site levels but later increased, resembling patterns observed for this stream with the MHSP and IBI. Except for Tims Branch, other potentially impacted streams remained within the reference site range during the study period. EPT numbers in Tims Branch were consistently low indicating low biotic integrity, as also observed with the other assessment methods.

Unlike the other metrics and indices discussed herein, BI values are inversely correlated with biotic integrity; i.e., higher values indicate lower biotic integrity. Like EPT values, BI values were affected by stream size resulting in slightly lower reference site ranges for large streams than small streams (Figure 7). Hester-Dendy BI values for the reference streams or portions of streams were relatively low, remaining below about 6.0 for large streams and 7.3 for small streams. In contrast, some of the potentially impacted streams exhibited higher values suggesting greater prevalence of pollution tolerant taxa. BI values in Fourmile Branch, upper Steel Creek, lower Pen Branch, Lower Three Runs, and Indian Grave Branch exhibited slight excursions above the reference site ranges for at least brief periods during the 1997-2017 Hester-Dendy sample period. However, all had decreased to within the reference site range by 2017. In contrast, BI values in Tims Branch remained well above reference site levels throughout most of the sample period, including 2017, indicating persistent predominance of pollution tolerant taxa.

Comparisons among streams

IBI

As previously described, the IBI was initially depressed in SRS streams that received reactor cooling water. The IBI later increased in these streams after reactor operations ceased and fish communities recovered. Therefore, samples collected prior to this recovery were excluded from the comparisons among streams because they represent conditions of habitat degradation associated with reactor operations that no longer exist. The excluded samples include those collected in 1990 from Fourmile Branch, lower Steel Creek, Pen Branch, and Lower Three Runs. Excluding these samples, the average IBI was below the lower reference site cut-off only in upper Steel Creek and Tims Branch (Figure 8). In addition, the Kruskal-Wallis test showed that the median IBI in both streams was significantly ($P \leq 0.05$) below the reference stream median (i.e., median for all reference sites combined).

MHSP

Like the IBI, the MHSP increased with time in streams or stream reaches that formerly received reactor cooling water as macroinvertebrate communities improved following the cessation of reactor operations. Samples collected prior to these improvements were excluded from comparisons among streams because they do not represent current conditions. Excluded samples were those from 2000 and earlier in Fourmile Branch, lower Steel Creek, lower Pen Branch, Indian Grave Branch, and Lower Three Runs. Comparisons of mean MHSP values with reference site limits showed that all potentially impacted streams except for Tims Branch were within the reference site range (Figure 9). Similarly, Kruskal-Wallis test results showed that Tims Branch was the only potentially impacted streams with a median MHSP significantly ($P \leq 0.05$) below the reference site median (i.e., median for all reference sites combined). These MHSP results are in general agreement with the IBI results. Together, they show that biological communities in most streams were indicative of high biotic integrity. Similarly, both methods indicated that biotic integrity in Tims Branch was low. In contrast to the IBI, however, MHSP scores for upper Steel Creek were relatively high and within the reference site range.

Hester-Dendy artificial substrates

As described for the MHSP data, Hester-Dendy samples collected during the recovery period from streams that received reactor cooling water were excluded when comparing SRS streams. Excluded samples included those from 2000 and earlier in Fourmile Branch, lower Steel Creek, lower Pen Branch, Indian Grave Branch, and Lower Three Runs. Average Hester-Dendy EPT numbers in potentially impacted small streams were somewhat lower than the averages for most small reference site streams but below the reference site cut-off only in Tims Branch (Figure 10). The median EPT in Tims Branch was 0.54, significantly ($P \leq 0.05$) lower than the reference site median. The average number of EPT in the large potentially impacted streams was above the cut-off for large reference streams in all cases and, in middle Upper Three Runs and lower Pen Branch, somewhat above the reference sites indicating high biotic integrity.

Average BI values for small reference site streams were below the reference site maximum cut-off for all streams except Tims Branch, which exhibited a BI significantly ($P \leq 0.05$) above the reference site median (Figure 11). As previously mentioned, high BI values indicate low biotic integrity. Average BI values for large reference site streams were below the reference site maximum cut-off for lower Steel Creek and lower Upper Thrre Runs but slightly above the reference site maximum cut-off for for Fourmile Branch and Lower Three Runs. However, in no cases were median BI values in these streams significantly different from the median BI values in the reference streams. In summary, the Hester-Dendy results generally concurred with the results from the other sampling methods indicating that biotic integrity in most potentially impacted SRS streams was comparable or nearly comparable to biotic integrity in SRS reference streams. The only exception was Tims Branch, which exhibits evidence of reduced biotic integrity, as also shown with the other methods.

DISCUSSION

Many SRS streams have improved over time and now support fish and macroinvertebrate communities comparable to those in reference streams. The largest improvements occurred prior to 2005 in streams that formerly received cooling water discharged from L, K, and C Reactors. This discharge, which was characterized by extreme temperatures and current velocities, resulted in extensive bed scouring, removal of instream structure, and death or exclusion of aquatic life in all but marginal backwater areas with cooler temperatures. Such conditions predominated throughout much of the middle and lower reaches of Pen Branch, Indian Grave Branch, and Fourmile Branch. They also occurred in middle and lower Steel Creek prior to the construction of L Lake, a cooling reservoir built in 1986 to mitigate the effects of reactor operations. Par Pond, constructed in the Lower Three Runs drainage in 1958 served a similar function. While these reservoirs substantially reduced water temperatures in Steel Creek and Lower Three Runs, both streams were adversely affected by high flow rates and moderately elevated temperatures in water discharged from the reservoirs until L and P reactors were shut down. With the discontinuation of all reactor operation by 1988 (except for a brief re-start of K Reactor in 1992), processes of secondary ecological succession began or continued in all cooling water receiving streams resulting in the gradual recovery of instream and riparian habit. While habitat in these streams or portions of streams (Fourmile Branch, lower Steel Creek, lower Pen Branch, Indian Grave Branch, and Lower Three Runs) is not identical to that in reference streams, recovery has been sufficient to permit the establishment of communities of aquatic macroinvertebrates and fish that are largely indistinguishable from those in high quality reference streams. The existence of these communities indicates that contamination by metals or other materials is insufficient to adversely impact ecological processes that sustain diverse ecological communities.

There are several other SRS streams or portions of streams that were not affected by the discharge of reactor cooling water but have waste sites or industrial areas in their watersheds that could serve as sources of contamination. These include Crouch Branch, Tims Branch, McQueen Branch, and upper Steel Creek. Fish and macroinvertebrate communities in McQueen Branch as indicated by IBI, MHSP, and Hester-Dendy results have been variable but consistently fallen within the reference site range. IBI, MHSP, and Hester-Dendy values for Crouch Branch were initially outside reference site ranges but by 2000 or slightly later had improved to reference site levels as indicated by all methods. Previous work (Specht and Paller 1998, Paller and Dyer 2004) suggested that degradation in Crouch Branch was partly related to the discharge of an NPDES effluent with elevated copper levels and that conditions improved with improvements in effluent quality. Recent bioassessment data confirm this improvement and suggest that ecological conditions in Crouch Branch are now characteristic of least disturbed streams within the ecoregion.

Upper Steel Creek has consistently exhibited IBI scores beneath the reference site range indicating that the fish community is impaired. However, MHSP and Hester-Dendy metrics for this portion of Steel Creek have remained within the reference site range, which indicates that environmental conditions are adequate for the maintenance of lower food chain communities. This is also suggested by habitat assessment scores in upper Steel Creek, which were slightly below the reference site average in 2007 but near reference site levels in 2017 (Figure 12). The discrepancy between bioassessment methods in upper Steel Creek may be attributable to the presence of L Lake, which separates upper Steel Creek from lower Steel Creek and acts as a barrier to the upstream migration of stream fish. Upstream migrations are needed to replenish species losses in the headwater reaches of streams, which are typically characterized by relatively harsh and variable environmental conditions (e.g., larger changes in temperature and flow) compared with lower reaches (Schlosser 1987). In such environments, the upstream migration of fish from more stable lower stream reaches is important in restoring species lost during environmental bottlenecks imposed by droughts and other extreme conditions. The presence of a reservoir such as L Lake constitutes a physical barrier that isolates upstream reaches and prevents such migrations. Isolation may not affect aquatic insects (which form the basis for the MHSP) as strongly as fish because many of the former have flying adult stages that can bypass physical obstacles.

Examination of fish tissue contaminant levels provided additional evidence that contamination is not responsible for low IBIs in upper Steel Creek. Of 15 metals (Al, Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Se, V, and Zn) measured in fish tissues as part of the ACP IOU program, only arsenic was substantially higher in fish from upper Steel Creek than in fish from Meyers Branch, a reference site, or fish from lower Steel Creek, where IBI vales recovered by 2003 (Paller and Blas 2013). Arsenic levels in fish from upper Steel Creek (slightly over 7 mg/kg), although higher than in fish from other locations in the Steel Creek IOU, were somewhat lower than in fish from reference sites in upper Pen Branch (about 10 mg/kg) (Paller and Blas 2015). These data suggest that the relatively low IBI in upper Steel Creek is more likely a result of the isolation of this stream reach by L Lake than the result of contamination by SRS waste sites or industrial operations.

All bioassessment methods indicated impaired ecological conditions in the upper portion of Tims Branch where the Road 2 sample site was located. They also indicated that conditions did not improve and may have worsened with time. Previous studies indicated that ecological impairment in Tims Branch was probably at least partly related to naturally occurring low oxygen levels and high iron levels (Specht and Paller 1998). High iron levels likely remain a problem in this stream as indicated by the presence of an orange floc on the stream bottom, which is probably ferric iron (personal observation by M. Paller). Also contributing to ecological impairment in Tims Branch is poor instream habitat. Habitat assessment scores for Tims Branch were substantially below the reference site average during 2003, 2007, and 2017, the three years for which such data were available (Figure 12). Examination of metal levels in fish tissues (Paller et al. 2011) showed that none of the elements for which data were available (As, Cd, Cu, Pb, Mn, Hg, Ni, and Zn) were elevated relative to levels in other SRS streams that exhibited favorable bioassessment results. These results suggest that ecological impairment in Tims Branch is more likely related to impaired habitat than the presence of contamination.

In summary, biotic integrity in most SRS streams is currently high and, in many streams, is much better than in the past. Only Tims, Branch and, to a lesser degree, the upper portion of Steel Creek continue to show evidence of biotic impairment. This impairment is probably habitat related in Tims Branch and associated with the presence of L Lake in upper Steel Creek rather than the result of toxicity associated with contaminants released by past or current SRS operations. Recent research has revealed that fish biodiversity in many SRS streams is relatively high – greater than in other streams within the Sandhills ecoregion and higher than in many North American streams (Paller 2018). Upper Three Runs, the SRS stream with the highest fish species richness (Paller 2018) is also known for its exceptional diversity of aquatic insects. These data suggest that SRS streams, especially Upper Three Runs, constitute an important natural resource.

REFERENCES

Barbour, M.T., J. Gerritsen, B.D. Snyder, J.B. Stribling. 1997. Revision to rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates, and fish. U.S. Environmental Protection Agency, EPA 841-D-97-002. Washington, D.C.

Benke, A.C., and J.L. Meyer. 1988. Structure and function of a blackwater river in the southeastern U.S.A. Proceedings International Association of Theoretical and Applied Limnology 23:1209-1218.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Special Publication 5 of the Illinois Natural History Survey.

Klemm, D.J., Q.J. Stober, J.M. Lazorchak. 1993. Fish field and laboratory methods for evaluating the biological integrity of surface waters. U.S. Environmental Protection Agency, EPA/600/R-92/111. Cincinnati, Ohio.

Lenat, D.R. 1993. A biotic index for the southeastern United States: Derivation and list of tolerance values, with criteria for assigning water-quality ratings. Journal of the North American Benthological Society 12:279-290.

Markewich, H. W., and W. Markewich. 1994. An Overview of Pleistocene and Holocene Inland Dunes in Georgia and the Carolinas: Morphology, Distribution, Age, and Paleoclimate, U.S. Geological Survey Bulletin no. 2069.

Mount, D.I., N. Thomas, M. Barbour, T. Norberg, T. Roush, R. Brandes. 1984. Effluent and ambient toxicity testing and in-stream community response on the Ottawa River, Lima, Ohio. Permits Division, Washington, D.C., and Office of Research and Development, Duluth, Minnesota. EPA 600/3-84-080.

Paller, M.H. 1994. Relationship between fish assemblage structure and stream order in South Carolina coastal plain streams. Transactions of the American Fisheries Society 123:150-161.

Paller, M.H., M.J.M. Reichert, J.M. Dean. 1996. Use of fish communities to assess environmental impacts in South Carolina coastal plain streams. Transactions of the American Fisheries Society 125:633-644.

Paller, M.H., and W.L. Specht. 1997. A multimetric index using macroinvertebrate data collected with artificial substrates. Journal of freshwater ecology 12:367-378.

Paller, M.H. 2001. Comparison of fish and macroinvertebrate bioassessments from South Carolina coastal plain streams. Aquatic Ecosystem Health & Management 4:175-186.

Paller M.H. and S.A. Dyer. 2004. Biotic integrity of streams in the Savannah River Site Integrator Operable Units, 1996-2003. WSRC-TR-2004-00562. Savannah River National Laboratory, Aiken, SC.

Paller M.H., F.D. Martin, L.D. Wike, and W.L. Specht. 2007. Factors influencing the accuracy of a macroinvertebrate bioassessment protocol in South Carolina coastal plain streams. Journal of Freshwater Ecology 22:23-32.

Paller M.H., S.A. Dyer, and D.P. Coughlin. 2008. Exposure of ecological receptors to metals in the Savannah River Site integrator operable units, analysis of refined data from multiple environmental media. WSRC-STI-2008-00365. Savannah River National Laboratory, Aiken, SC.

Paller, M.H., S.S. Dyer, and S. Scott. 2011. Ecological Effects of Contaminants in the Upper Three Runs Integrator Operable Unit. SRNL-TR-2011-00201. Savannah River National Laboratory, Aiken, SC.

Paller, M.H. and S.A. Blas. 2013. Potential risks to ecological receptors resulting from exposure to metals in the Steel Creek Integrator Operable Unit. SRNL-TR-2013-00147. Savannah River National Laboratory, Aiken, SC.

Paller, M.H. and S.A. Blas. 2015. Potential Risks to Ecological Receptors Resulting from Exposure to Metals in the Pen Branch Integrator Operable Unit. SRNL-TR-2015-00337. Savannah River National Laboratory, Aiken, SC.

Paller M.H., B.A. Prusha , D.E. Fletcher, E. Kosnicki, S.A.Sefick, M.S. Jarrell, S.C. Sterrett, A.M. Grosse, T.D. Tuberville and J.W. Feminella. 2016. Factors influencing stream fish species composition and functional properties at multiple spatial scales in the Sand Hills of the southeastern United States. Transactions of the American Fisheries Society 145:545-562.

Paller M.H., E. Kosnicki, B.A. Prusha , D.E. Fletcher, S.A.Sefick, and J.W. Feminella. 2017. Development of an Index of Biotic Integrity for the Sand Hills ecoregion of the Southeastern United States. Transactions of the American Fisheries Society 146:112-127.

Paller M.H. 2018. Estimating fish species richness across multiple watersheds. Diversity 10, 42.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, EPA/444/4-89-0001. Washington, D.C.

Sabater, F., J. L. Meyer, and R. T. Edwards. 1993. Longitudinal patterns of dissolved organic carbon concentration and suspended bacterial density along a blackwater river. Biogeochemistry 21:73-93.

SCDHEC (South Carolina Department of Health and Environmental Control). 1998. Standard operating and quality control procedures for macroinvertebrate sampling. Technical Report No. 004-98. Bureau of Water, Division of Water Monitoring, Assessment and Protection, Aquatic Biology Section.

Schlosser, I.J. 1987. A conceptual framework for fish communities in small warmwater streams. Pages 17-24 in W.J. Matthews and D.C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman, OK.

Schmidt, J. P. 2013. Sand Hills. New Georgia Encyclopedia. Web. 19 August 2013.

Sheldon, A. L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49:193-198.

Specht, W.L. and M.H. Paller. 1998. Instream biological assessment of NPDES point source discharges at the Savannah River Site, 1997-1998. WSRC-TR-98-00321, Westinghouse Savannah River Company, Savannah River Technology Center, Aiken, SC.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

WSRC (Westinghouse Savannah River Company). 1998a. RCRA facility investigation/remedial investigation work plan for the Upper Three Runs integrator operable unit (U). WSRC-RP-97-447, Rev.0-b. Westinghouse Savannah River Company, Aiken, SC.

WSRC (Westinghouse Savannah River Company). 1998b. Integrator operable unit work plan for the Fourmile Branch (U). WSRC-RP-97-448, Rev.0. Westinghouse Savannah River Company, Aiken, SC.

WSRC (Westinghouse Savannah River Company). 1998c. RCRA facility investigation/remedial investigation work plan for the Steel Creek integrator operable unit (U). WSRC-RP-97-446, Rev.0-b. Westinghouse Savannah River Company, Aiken, SC.

WSRC (Westinghouse Savannah River Company). 1998d. Integrator operable unit work plan for Lower Three Runs (U). WSRC-RP-97-449, Rev.0. Westinghouse Savannah River Company, Aiken, SC.

SRNS-STI-2018-00492

Table 1. Index of Biotic Integrity (IBI) sample sites. Also indicated are station type (reference [R] or potentially impacted by SRS waste sites or operations [PI]), year sampled, reach length sampled, number of electrofishing passes and the IBI value.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Reach length	Number passes	IBI
Fourmile Branch	Fourmile Branch	FMB	FMB-lower	PI	near Rd A13.2	33.191	-81.723	1995	173	5	42
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	1997	150	1	44
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2000	150	1	50
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2003	150	1	40
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2007	150	1	50
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2017	200	2	34
		FMB	FMB-middle	PI	Rd 4	33.275	-81.653	1997	150	1	20
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2000	150	1	44
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2003	150	1	48
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2017	200	2	50
		FMB	FMB-middle	PI	Rd A-7	33.244	-81.696	1990	250	7	36
		FMB	FMB-middle	PI	Rd A-7	33.244	-81.696	1997	150	1	42
		FMB	FMB-middle	PI	Rd A-7	33.244	-81.696	2007	150	1	46
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	1997	150	1	40
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	2000	150	1	44
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	2003	150	1	46
Lower Three Runs	Lower Three Runs	LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	1990	400	3	26
		LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2003	150	1	42
		LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2007	150	1	42
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	1990	220	7	22
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2003	150	1	34
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2007	150	1	44
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2010	195	2	38
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2017	200	2	34
		LTR	LTR-middle	PI	Rd B	33.234	-81.516	1995	300	5	36
Pen Branch	Indian Grave Branch	IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	1997	150	1	48
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2000	150	1	48
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2003	150	1	48

Table 1. Continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Reach length	Number passes	IBI
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2007	150	1	44
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2017	200	2	50
	Pen Branch	PB	PB-lower	PI	below Rd A13.2	33.205	-81.647	1990	380	7	48
		PB	PB-lower	PI	Rd A	33.183	-81.667	1990	160	7	30
		PB	PB-lower	PI	Rd A	33.183	-81.667	1995	240	5	44
		PB	PB-lower	PI	Rd A	33.183	-81.667	1997	150	1	48
		PB	PB-lower	PI	Rd A13.2	33.160	-81.686	1990	100	6	24
		PB	PB-lower	PI	Rd A13.2	33.160	-81.686	2000	150	1	46
		PB	PB-lower	PI	Rd A13.2	33.160	-81.686	2003	150	1	46
		PB	PB-lower	PI	Rd A13.2	33.160	-81.686	2007	150	1	48
		PB	PB-lower	PI	Rd A13.2	33.160	-81.686	2017	200	2	46
		PB	PB-middle	R	between Rds C & B	33.227	-81.636	2009	200	2	50
		PB	PB-middle	R	Rd B	33.204	-81.647	1990	200	7	42
		PB	PB-middle	R	Rd B	33.204	-81.647	1995	300	5	50
		PB	PB-middle	R	Rd B	33.204	-81.647	1997	150	1	46
		PB	PB-middle	R	Rd B	33.204	-81.647	2000	150	1	50
		PB	PB-middle	R	Rd B	33.204	-81.647	2003	150	1	50
		PB	PB-middle	R	Rd B	33.204	-81.647	2007	150	1	44
		PB	PB-middle	R	Rd B	33.204	-81.647	2017	200	2	50
		PB	PB-upper	R	Rd C	33.233	-81.624	1995	300	5	46
		PB	PB-upper	R	Rd C	33.233	-81.624	1997	150	1	50
		PB	PB-upper	R	Rd C	33.233	-81.624	2000	150	1	50
		PB	PB-upper	R	Rd C	33.233	-81.624	2003	150	1	42
		PB	PB-upper	R	Rd C	33.233	-81.624	2007	150	1	44
		PB	PB-upper	R	Rd C	33.233	-81.624	2009	150	2	42
		PB	PB-upper	R	Rd C	33.233	-81.624	2017	200	2	40
Steel Creek	Steel Creek	SC	SC-lower	PI	Cypress Bridge	33.122	-81.628	1990	340	3	24
		SC	SC-lower	PI	Rd A	33.146	-81.629	1990	180	7	32
		SC	SC-lower	PI	Rd A	33.146	-81.629	1996	180	7	39
		SC	SC-lower	PI	Rd A	33.146	-81.629	2000	180	7	45

Table 1. Continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Reach length	Number passes	IBI
		SC	SC-lower	PI	Rd A	33.146	-81.629	2003	150	1	46
		SC	SC-lower	PI	Rd A	33.146	-81.629	2007	150	1	46
		SC	SC-lower	PI	Rd A	33.146	-81.629	2017	200	2	48
		SC	SC-middle	PI	Rd B-5	33.186	-81.635	1990	220	5	28
		SC	SC-upper	PI	P area	33.222	-81.598	1996	150	1	28
		SC	SC-upper	PI	Rd C	33.212	-81.606	1990	180	7	30
		SC	SC-upper	PI	Rd C	33.212	-81.606	1997	150	1	28
		SC	SC-upper	PI	Rd C	33.212	-81.606	2000	150	1	22
		SC	SC-upper	PI	Rd C	33.212	-81.606	2003	150	1	28
		SC	SC-upper	PI	Rd C	33.212	-81.606	2007	150	1	22
		SC	SC-upper	PI	Rd C	33.212	-81.606	2017	200	2	22
	Meyers Branch	MB	SC-MB	R	boardwalk	33.150	-81.626	1990	300	7	44
		MB	SC-MB	R	headwaters	33.194	-81.579	2009	160	2	40
		MB	SC-MB	R	upstream from Old Dunbarton Rd	33.176	-81.582	2009	200	2	48
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	1990	400	7	44
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	1997	150	1	46
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2000	150	1	46
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2003	150	1	50
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2007	150	1	50
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2017	200	2	46
		MB	SC-MB	R	Rd 9	33.167	-81.603	1990	140	7	50
		MB	SC-MB	R	Rd 9	33.167	-81.603	1995	300	4	38
Upper Three Runs	Upper Three Runs	UTR	UTR-lower	PI	Rd A	33.239	-81.744	1992	300	6	36
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	1998	150	1	34
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2000	150	1	44
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2003	150	1	42
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2007	150	1	44
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	1992	300	7	46
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	1995	200	4	34
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2003	150	1	46

SRNS-STI-2018-00492

Table 1. Continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Reach length	Number passes	IBI
		UTR	UTR-middle	PI	Cato Rd	33.252	-81.719	1992	300	5	44
		UTR	UTR-middle	PI	Rd F-4	33.308	-81.671	1992	300	6	38
		UTR	UTR-middle	PI	Rd F-5	33.312	-81.653	1992	300	7	44
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	1992	300	4	38
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2000	150	1	32
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2003	150	1	24
		UTR	UTR-upper	*	Tyler Bridge Rd	33.353	-81.631	1992	300	6	28
		UTR	UTR-upper	*	Tyler Bridge Rd	33.353	-81.631	1998	150	1	26
		UTR	UTR-upper	*	Tyler Bridge Rd	33.353	-81.631	2007	150	1	32
	Crouch Branch	CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	1992	300	5	38
		CB	UTR-middle	PI	lower CB (near UTR)	33.298	-81.655	1995	281	5	24
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	1997	150	1	28
		CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2000	150	1	46
		CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2003	150	1	46
		CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2007	150	1	46
		CB	UTR-middle	PI	lower CB	33.298	-81.657	2017	200	2	38
	Tims Branch	TB	UTR-TB	PI	Rd 2	33.315	-81.714	1995	294	4	42
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	1997	150	1	38
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2000	150	1	36
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2003	150	1	30
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2007	150	1	20
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2017	200	2	22
	McQueen Branch	MQ	UTR-TC	PI	Rd 8	33.305	-81.626	2009	150	2	36
		MQ	UTR-TC	PI	Rd E-2 branch	33.307	-81.631	1990	350	7	42
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2000	150	1	34
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2003	150	1	36
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2007	150	1	42
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2009	150	2	44
		MQ	UTR-TC	PI	Rd Z	33.310	-81.634	1997	150	1	44

Table 1. Continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Reach length	Number passes	IBI
	Mill Creek	MC	UTR-TC	R	mid-reach	33.301	-81.587	2009	150	2	34
		MC	UTR-TC	R	Rd E-2	33.333	-81.607	1990	320	7	48
		MC	UTR-TC	R	Rd E-2	33.334	-81.609	2007	150	1	48
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	1990	280	3	40
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	1997	150	1	40
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2000	150	1	40
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2003	150	1	50
	Tinker Creek	TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	1990	300	7	50
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	1992	300	7	40
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	1995	241.5	4	44
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2003	150	1	46
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2007	150	1	48
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2017	200	2	42
		TC	UTR-TC	R	between Ken Pd Rd and Rd 8-1	33.369	-81.558	2009	210	2	50
		TC	UTR-TC	R	Rd 8-1	33.356	-81.583	1990	240	7	36
		TC	UTR-TC	R	Tyler Bridge Rd	33.337	-81.713	1990	360	5	36

*Intended as reference sites but not used because they could not be effectively sampled.

Table 2. Multiple Habitat Sampling Protocol (MHSP) sample sites. Also shown are station type (reference [R] or potentially impacted by SRS waste sites or operations [PI]); year sampled; and EPT (Ephemeroptera Plecoptera, and Trichoptera), BI (Biotic Index), and MHSP scores for each site. EPT and BI scoring protocols are described in the text.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	EPT score	BI score	MHSP
Fourmile Branch	Fourmile Branch	FMB	FMB-lower	PI	Rd A	33.214	-81.713	1997	2	2	2
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2000	2	2	2
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2003	4	3	3.5
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2007	4	4	4
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2017	5	5	5
		FMB	FMB-middle	PI	Rd 4	33.275	-81.653	2003	3	2	2.5
		FMB	FMB-middle	PI	RD A	33.214	-81.713	2007	3	2	2.5
		FMB	FMB-middle	PI	RD A-6	33.248	-81.696	2000	1	2	1.5
		FMB	FMB-middle	PI	RD A-6	33.248	-81.696	2017	3	3	3
		FMB	FMB-middle	PI	RD A-7	33.244	-81.696	1997	2	3	2.5
		FMB	FMB-middle	PI	RD A-7	33.244	-81.696	2003	3	3	3
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	1997	1	3	2
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	2000	1	2	1.5
		FMB	FMB-upper	*	Rd F	33.281	-81.612	1997	2	2	2
		FMB	FMB-upper	*	Rd F	33.281	-81.612	2000	2	1	1.5
Lower Three Runs	Lower Three Runs	LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2003	1	2	1.5
		LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2017	4	5	4.5
		LTR	LTR-lower	PI	Stinson Bridge	33.135	-81.454	2000	1	2	1.5
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2000	1	4	2.5
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2003	2	3	2.5
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2017	3	4	3.5
Pen Branch	Indian Grave Branch	IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	1997	3	2	2.5
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2000	3	2	2.5
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2003	3	3	3
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2007	4	2	3
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2017	4	4	4
	Pen Branch	PB	PB-lower	PI	Rd A	33.183	-81.667	1997	2	2	2
		PB	PB-lower	PI	Rd A	33.183	-81.667	2000	3	3	3

Table 2. continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	EPT score	BI score	MHSP
		PB	PB-lower	PI	Rd A	33.183	-81.667	2003	2	3	2.5
		PB	PB-lower	PI	Rd A	33.183	-81.667	2007	4	2	3
		PB	PB-lower	PI	Rd A13.2	33.205	-81.647	2007	5	4	4.5
		PB	PB-lower	PI	Rd A13.2	33.205	-81.647	2017	3	5	4
		PB	PB-middle	R	Rd B	33.204	-81.647	1997	3	3	3
		PB	PB-middle	R	Rd B	33.204	-81.647	2000	3	4	3.5
		PB	PB-middle	R	Rd B	33.204	-81.647	2003	2	4	3
		PB	PB-middle	R	Rd B	33.204	-81.647	2007	5	3	4
		PB	PB-middle	R	Rd B	33.204	-81.647	2017	4	5	4.5
		PB	PB-upper	R	Rd C	33.233	-81.624	1997	4	3	3.5
		PB	PB-upper	R	Rd C	33.233	-81.624	2000	2	2	2
		PB	PB-upper	R	Rd C	33.233	-81.624	2003	4	5	4.5
		PB	PB-upper	R	Rd C	33.233	-81.624	2007	2	2	2
		PB	PB-upper	R	Rd C	33.233	-81.624	2017	5	5	5
Steel Creek	Meyers Branch	MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	1997	5	4	4.5
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2000	4	2	3
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2003	3	2	2.5
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2007	5	4	4.5
		MB	SC-MB	*	Rd 6.2 (upper)	33.207	-81.566	2003	2	1	1.5
		MB	SC-MB	R	Rd 9	33.167	-81.603	2007	5	4	4.5
		MB	SC-MB	R	Rd 9	33.167	-81.603	2017	4	5	4.5
	Steel Creek	SC	SC-lower	PI	Rd A	33.146	-81.629	2007	5	3	4
		SC	SC-lower	PI	Rd A	33.146	-81.629	2017	3	4	3.5
		SC	SC-middle	PI	below L Lake dam	33.158	-81.631	2007	2	3	2.5
		SC	SC-upper	PI	P area	33.222	-81.598	2003	3	4	3.5
		SC	SC-upper	PI	Rd C	33.212	-81.606	1997	3	2	2.5
		SC	SC-upper	PI	Rd C	33.212	-81.606	2000	4	5	4.5
		SC	SC-upper	PI	Rd C	33.212	-81.606	2017	4	3	3.5
Upper Three Runs	Upper Three Runs	UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2007	5	5	5
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2017	5	5	5

Table 2. continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	EPT score	BI score	MHSP
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	1997	4	5	4.5
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2000	4	5	4.5
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2003	2	5	3.5
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2007	4	5	4.5
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2017	3	5	4
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	1997	4	5	4.5
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2000	4	5	4.5
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2007	4	4	4
		UTR	UTR-upper	R	Tyler Bridge Rd	33.353	-81.631	2003	4	3	3.5
		UTR	UTR-upper	R	Tyler Bridge Rd	33.353	-81.631	2007	4	4	4
		UTR	UTR-upper	R	Tyler Bridge Rd	33.353	-81.631	2017	5	5	5
	Crouch Branch	CB	UTR-middle	PI	lower CB	33.298	-81.657	2017	4	4	4
		CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2003	3	3	3
		CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2007	4	5	4.5
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	1997	2	2	2
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	2000	2	1	1.5
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	2003	2	2	2
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	2007	3	3	3
	McQueen Branch	MQ	UTR-TC	PI	Rd F	33.298	-81.630	2000	2	3	2.5
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2007	4	4	4
		MQ	UTR-TC	PI	Rd Z	33.31	-81.634	1997	5	5	5
		MQ	UTR-TC	PI	Rd Z	33.31	-81.634	2003	5	5	5
		MQ	UTR-TC	PI	Rd Z	33.31	-81.634	2007	4	1	2.5
	Mill Creek	MC	UTR-TC	R	Rd E-2	33.333	-81.607	2007	3	2	2.5
		MC	UTR-TC	R	Rd E-2	33.333	-81.607	2017	5	5	5
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	1997	4	4	4
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2000	5	5	5
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2003	3	4	3.5
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2003	5	4	4.5
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2007	2	1	1.7

SRNS-STI-2018-00492

Table 2. continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	EPT score	BI score	MHSP
	Tims Branch	TB	UTR-TB	PI	Rd 2	33.315	-81.714	1997	2	3	2.5
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2000	1	2	1.5
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2003	2	1	1.5
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2017	2	2	2
	Tinker Creek	TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2003	4	3	3.5
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2007	3	3	3
		TC	UTR-TC	R	Rd 2-1	33.338	-81.605	2017	5	5	5
		TC	UTR-TC	R	Tyler Bridge Rd	33.337	-81.713	2003	5	4	4.5
		TC	UTR-TC	R	Tyler Bridge Rd	33.337	-81.713	2007	5	5	5

*Intended as reference sites but not used because of poor habitat

SRNS-STI-2018-00492

Table 3. Hester-Dendy artificial substrate sample sites. Also shown are station type (reference [R] or potentially impacted by SRS waste sites or operations [PI]); year sampled; the number of samplers deployed at each site; and the mean Biotic Index (BI) value, total number of EPT (Ephemeroptera Plecoptera, and Trichoptera) taxa, and total number of taxa for all samplers at each site.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Number samplers	Mean BI	Mean number EPT	Mean number taxa
Fourmile Branch	Fourmile Branch	FMB	FMB-lower	PI	Rd A	33.214	-81.713	1997	5	5.9	2.8	5.8
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2000	5	6.5	3.4	17.2
		FMB	FMB-lower	PI	Rd A	33.214	-81.713	2007	5	6.4	3.4	19.4
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2007	5	5.3	10.2	27.2
		FMB	FMB-lower	PI	Rd A13.2	33.171	-81.742	2017	2	4.7	4.0	11.0
		FMB	FMB-middle	PI	Rd 4	33.275	-81.653	2007	5	7.8	2.6	16.4
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2000	5	6.6	3.0	10.8
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2007	5	7.5	2.2	15.6
		FMB	FMB-middle	PI	Rd A-6	33.248	-81.696	2017	2	6.0	6.0	16.5
		FMB	FMB-middle	PI	Rd A-7	33.244	-81.696	1997	5	6.4	5.6	5.2
		FMB	FMB-middle	PI	Rd A-7	33.244	-81.696	2007	5	6.0	3.2	19.0
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	1997	5	7.1	0.2	2.2
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	2000	5	6.5	1.6	9.6
		FMB	FMB-middle	PI	Rd C	33.273	-81.669	2007	5	7.2	1.0	8.4
		FMB	FMB-upper	*	Rd F	33.281	-81.612	1997	5	8.1	0.0	1.0
		FMB	FMB-upper	*	Rd F	33.281	-81.612	2000	5	8.8	0.4	4.0
Lower Three Runs	Lower Three Runs	LTR	LTR-lower	PI	HW 125 (Rd A)	33.073	-81.477	2007	5	4.9	1.0	14.0
		LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2007	5	5.4	8.2	27.8
		LTR	LTR-lower	PI	Patterson Mill	33.176	-81.481	2017	2	5.5	5.5	13.0
		LTR	LTR-lower	PI	Stinson Bridge	33.135	-81.454	2000	5	5.9	4.2	12.2
		LTR	LTR-lower	PI	Stinson Bridge	33.135	-81.454	2007	5	5.6	6.6	22.6
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2000	5	4.7	5.4	14.6
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2007	5	6.1	5.2	24.0
		LTR	LTR-middle	PI	Donora Station	33.222	-81.509	2017	2	5.6	7.0	13.5
		LTR	LTR-middle	PI	Rd B	33.234	-81.516	2007	5	9.1	0.3	11.3
Pen Branch	Indian Grave Branch	IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	1997	5	6.6	1.4	4.6
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2000	5	7.0	3.2	13.8
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2007	5	7.4	1.8	12.3

SRNS-STI-2018-00492

Table 3. continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Number samplers	Mean BI	Mean number EPT	Mean number taxa
		IGB	PB-IGB	PI	near cooling tower site	33.203	-81.675	2017	2	6.2	2.5	11.0
	Pen Branch	PB	PB-lower	PI	Rd A	33.183	-81.667	1997	5	6.5	1.0	9.8
		PB	PB-lower	PI	Rd A	33.183	-81.667	2000	5	5.9	7.0	19.8
		PB	PB-lower	PI	Rd A	33.183	-81.667	2007	5	6.7	8.4	25.8
		PB	PB-lower	PI	Rd A13.2	33.205	-81.647	2007	5	5.5	7.4	19.8
		PB	PB-lower	PI	Rd A13.2	33.205	-81.647	2017	2	5.8	6.0	16.0
		PB	PB-middle	R	Rd B	33.204	-81.647	1997	5	5.2	4.2	4.2
		PB	PB-middle	R	Rd B	33.204	-81.647	2000	5	4.7	5.2	14.6
		PB	PB-middle	R	Rd B	33.204	-81.647	2007	5	5.4	3.2	10.6
		PB	PB-middle	R	Rd B	33.204	-81.647	2017	2	5.4	6.0	13.5
		PB	PB-upper	R	Rd C	33.233	-81.624	1997	5	5.5	3.8	2.0
		PB	PB-upper	R	Rd C	33.233	-81.624	2000	5	5.8	3.6	10.2
		PB	PB-upper	R	Rd C	33.233	-81.624	2007	5	7.3	1.6	7.2
		PB	PB-upper	R	Rd C	33.233	-81.624	2017	2	6.6	1.0	6.0
Steel Creek	Meyers Branch	MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	1997	5	4.8	3.2	3.6
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2000	5	6.5	3.6	19.2
		MB	SC-MB	R	Old Dunbarton Rd	33.185	-81.582	2007	5	6.1	1.8	7.4
		MB	SC-MB	R	Rd 9	33.167	-81.603	2007	5	4.8	5.6	13.8
		MB	SC-MB	R	Rd 9	33.167	-81.603	2017	2	5.5	7.5	15.5
	Steel Creek	SC	SC-lower	PI	below L Lake dam	33.158	-81.631	2007	5	6.3	5.0	22.0
		SC	SC-lower	PI	Rd A	33.146	-81.629	2007	5	5.9	4.6	18.8
		SC	SC-lower	PI	Rd A	33.146	-81.629	2017	2	4.9	8.5	14.5
		SC	SC-upper	PI	P area	33.222	-81.598	2007	5	8.1	0.0	8.0
		SC	SC-upper	PI	Rd C	33.212	-81.606	1997	5	5.8	1.6	3.4
		SC	SC-upper	PI	Rd C	33.212	-81.606	2000	5	5.0	5.6	9.4
		SC	SC-upper	PI	Rd C	33.212	-81.606	2007	5	5.6	5.2	17.4
		SC	SC-upper	PI	Rd C	33.212	-81.606	2017	2	5.4	3.5	10.0
Upper Three Runs	Upper Three Runs	UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2007	5	5.5	7.0	19.2
		UTR	UTR-lower	PI	Rd A.2	33.236	-81.756	2017	2	4.6	7.0	13.5
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	1997	5	4.8	7.0	7.4

SRNS-STI-2018-00492

Table 3. continued.

IOU	Stream	Stream abbrev.	IOU subunit	Type	Location	Latitude	Longitude	Year sampled	Number samplers	Mean BI	Mean number EPT	Mean number taxa
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2000	5	5.8	5.0	14.0
		UTR	UTR-lower	PI	Rd C	33.286	-81.695	2007	5	4.9	10.6	25.0
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	1997	5	3.7	6.0	5.4
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2000	5	5.5	3.0	13.4
		UTR	UTR-upper	R	Rd 8-1	33.363	-81.639	2007	5	5.9	7.2	23.4
		UTR	UTR-upper	R	Tyler Bridge Rd	33.353	-81.631	2007	5	4.2	7.2	23.0
		UTR	UTR-upper	R	Tyler Bridge Rd	33.353	-81.631	2017	2	4.6	3.5	11.5
	Crouch Branch	CB	UTR-middle	PI	lower CB (near UTR)	33.301	-81.661	2007	5	5.1	2.6	8.2
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	1997	5	8.9	0.0	1.0
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	2000	5	5.4	0.0	6.0
		CB	UTR-middle	PI	near Rd 4	33.291	-81.649	2007	5	9.4	1.8	6.0
	Tims Branch	TB	UTR-TB	PI	Rd 2	33.315	-81.714	1997	5	6.7	0.8	7.5
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2000	5	7.8	0.8	4.0
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2007	5	8.3	0.6	5.4
		TB	UTR-TB	PI	Rd 2	33.315	-81.714	2017	2	7.8	0.0	4.5
	McQueen Branch	MQ	UTR-TC	PI	Rd F	33.298	-81.630	2000	5	7.3	0.0	2.4
		MQ	UTR-TC	PI	Rd F	33.298	-81.630	2007	5	6.5	3.0	14.8
		MQ	UTR-TC	PI	Rd Z	33.31	-81.634	1997	5	5.2	2.4	2.2
		MQ	UTR-TC	PI	Rd Z	33.31	-81.634	2007	5	7.4	1.6	17.2
	Mill Creek	MC	UTR-TC	R	Rd E-2	33.333	-81.607	2007	5	5.5	6.0	14.0
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	1997	5	4.9	3.8	4.0
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2000	5	5.7	6.2	15.4
		MC	UTR-TC	R	Telephone cable Rd	33.32	-81.591	2007	5	8.2	2.6	16.0
	Tinker Creek	TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2007	5	4.9	4.5	11.5
		TC	UTR-TC	R	Kennedys Pond Rd	33.372	-81.530	2017	2	5.4	4.0	12.0
		TC	UTR-TC	R	Tyler Bridge Rd	33.337	-81.713	2007	5	5.7	4.2	14.0

*Intended as reference sites but not used because of poor habitat

SRNS-STI-2018-00492

Table 4. Metrics and scoring criteria used in the Index of Biotic Integrity (IBI) modified for use in SRS streams. Individual metrics are assigned scores of one, three, or five.

	Scoring criteria		
Metrics	1	3	5
Species richness			
Percentage of expected number of total species (TSP)[a]	<70	70-90	>90
Percentage of expected number of native minnow species (CSP)[a]	<55	55-80	>80
Percentage of expected number of piscivorous species (PSP)[a]	<65	65-85	>85
Percentage of expected number of madtom and darter species (BSP)[a]	<55	55-80	>80
Species composition			
Percent native minnows	<20	20-35	>35
Percent sunfish	<5 and >45	25-45	5-24
Trophic composition			
Percent generalized insectivores	>75	50-75	<50
Local indicator species			
Percent tolerant fish	>15	5-15	<5
Fish abundance (Number/100 m^2)			
Stream orders 1-3, ≥4 passes[b]	<25		≥25
Stream orders 1-3, 1 pass	<10		≥10
Stream order 4, ≥4 passes	<5		≥5
Stream order 4, 1 pass	<2		≥2
Fish condition			
Percent with disease or anomalies	>5	2-5	<2

[a] Percentage determined on the basis of sample site surface area and sampling effort (Paller et al. 1996)
[b] Passes refer to number of electrofishing passes through the sample reach

SRNS-STI-2018-00492

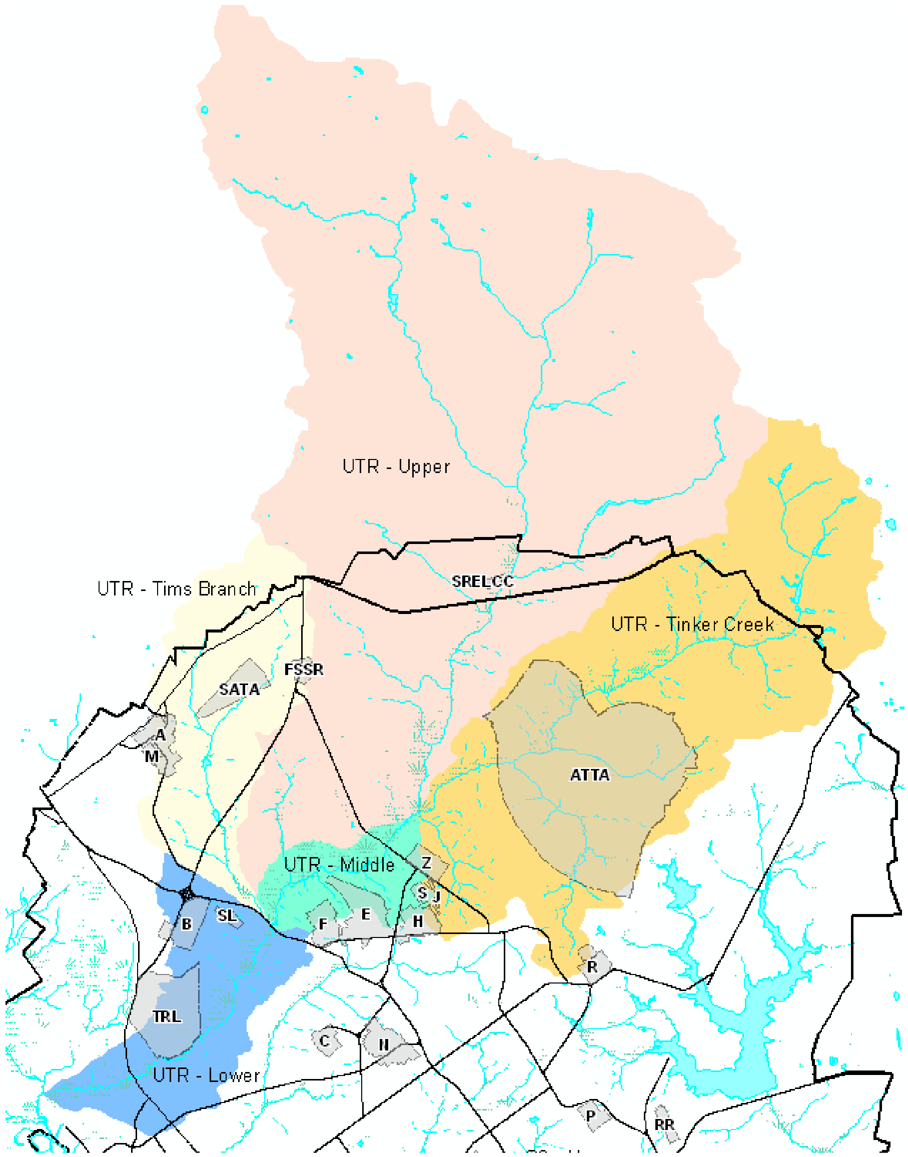


Figure 1. Maps of the Savannah River Site Integrator Operable Unit (IOU) subunits.

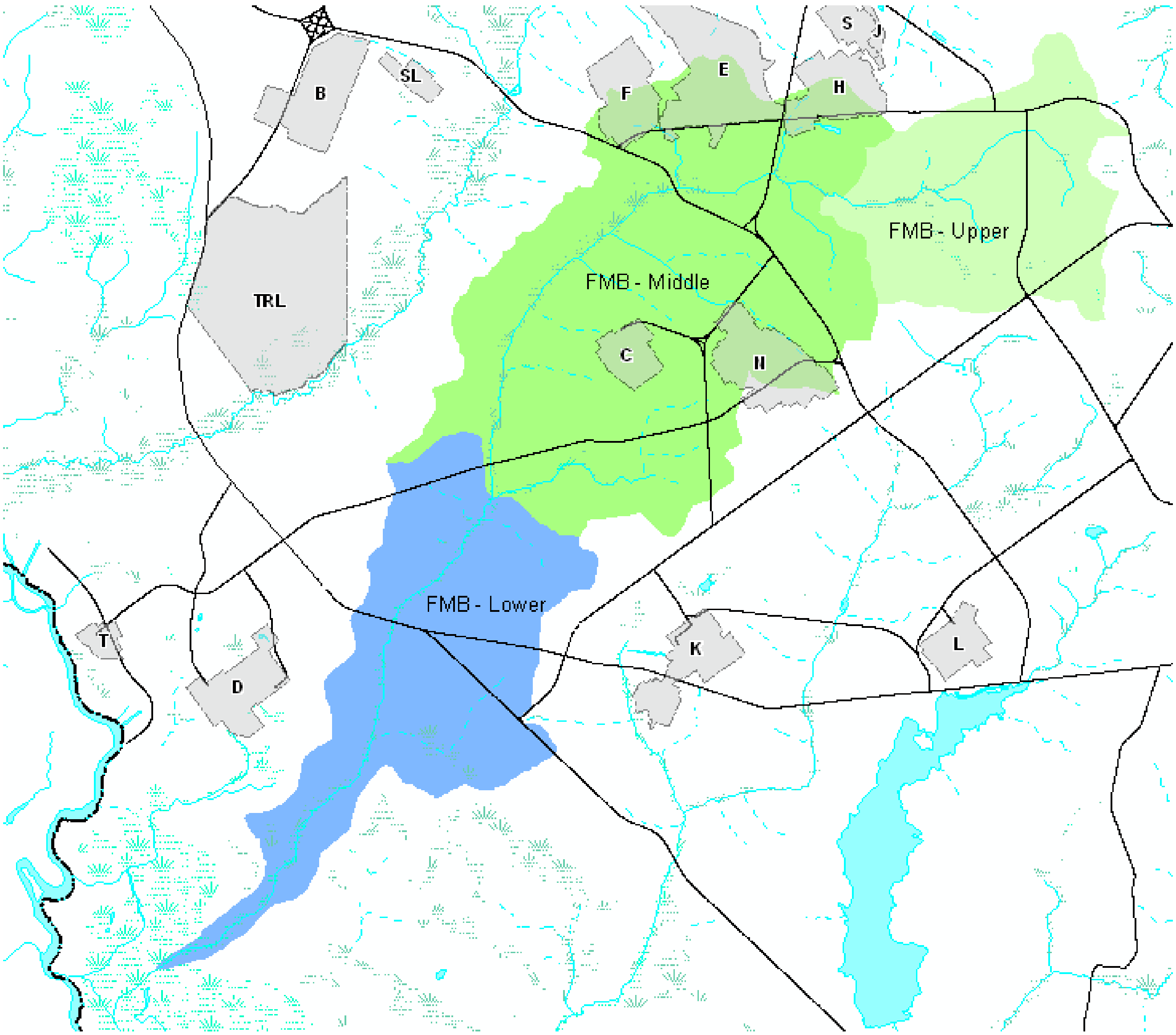


Figure 1. continued. Fourmile Branch (FMB) subunits

SRNS-STI-2018-00492

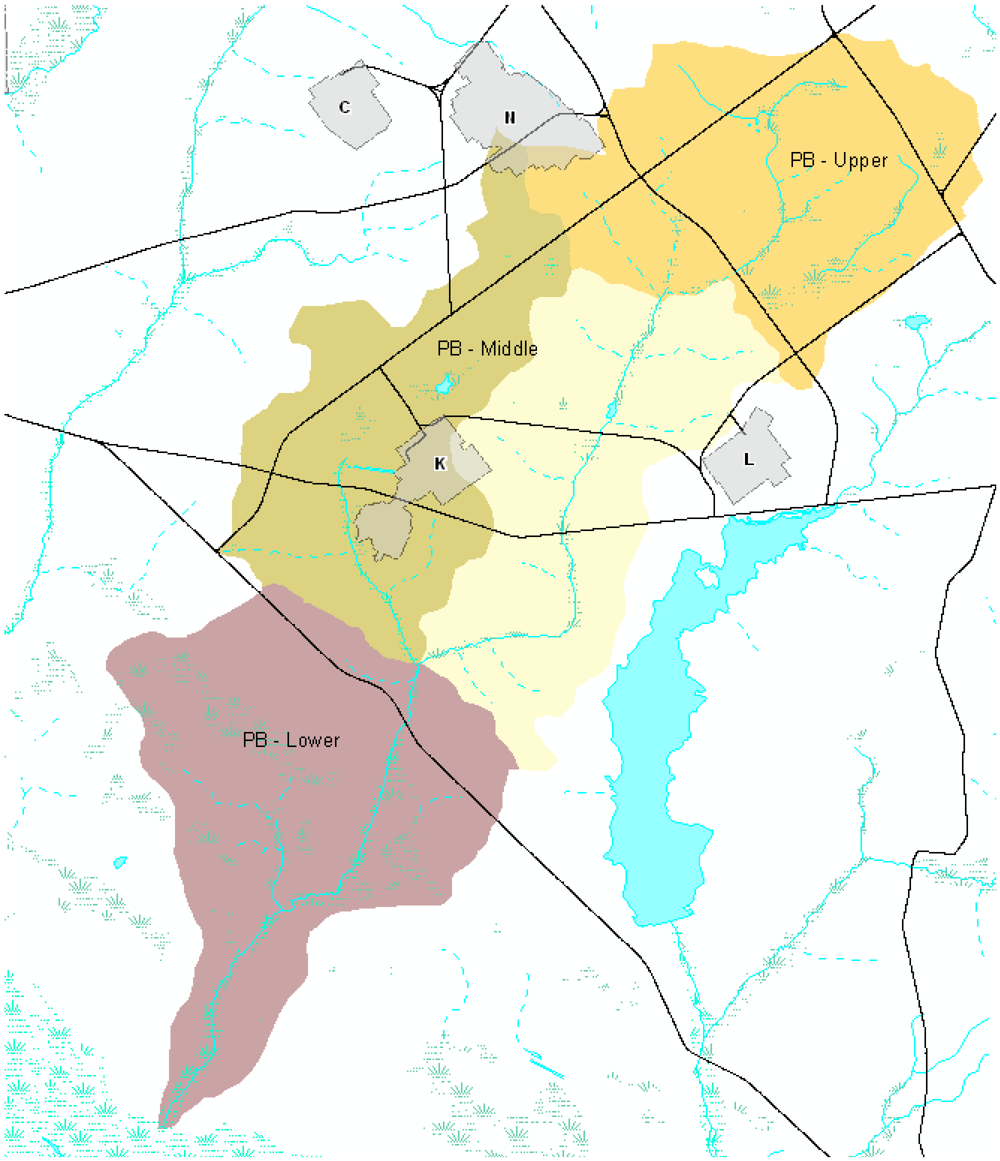


Figure 1 continued. Pen Branch (PB) subunits

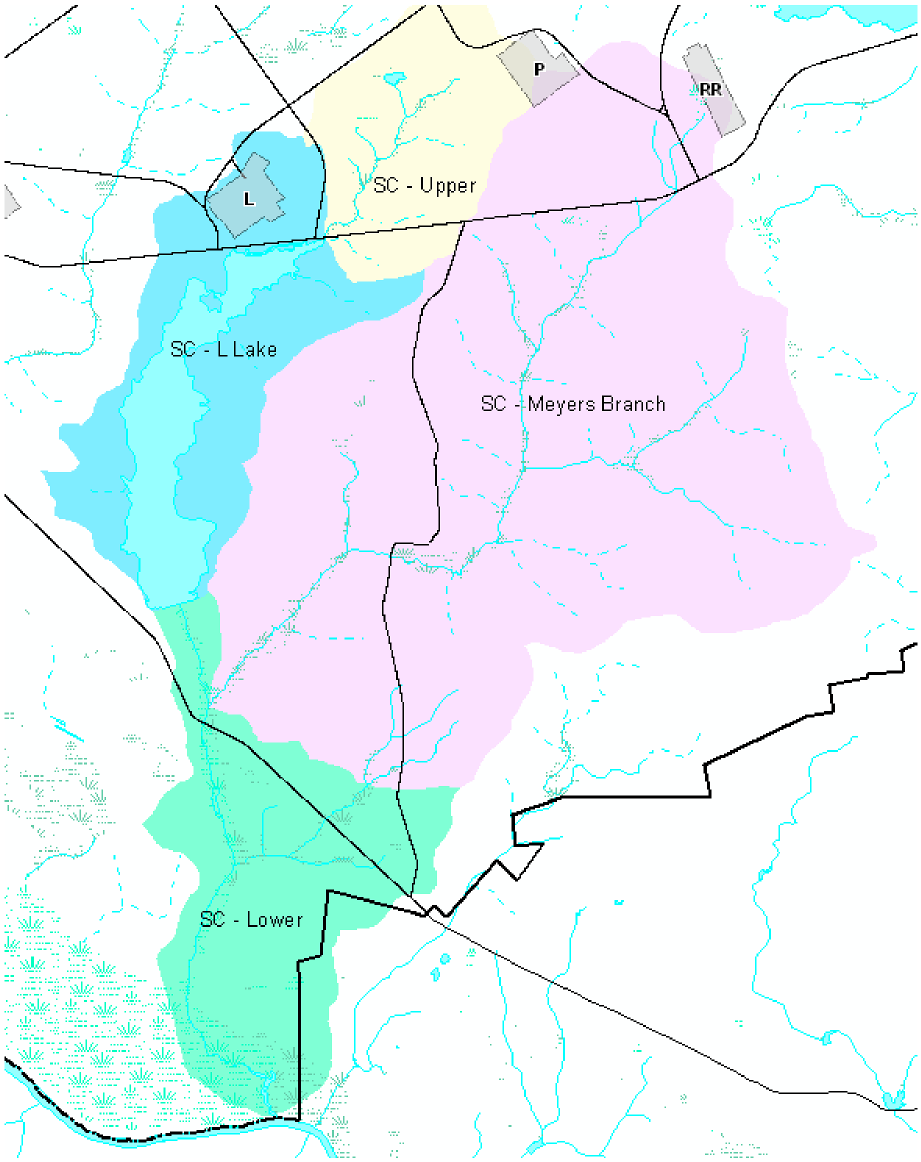


Figure 1. continued. Steel Creek (SC) subunits

SRNS-STI-2018-00492

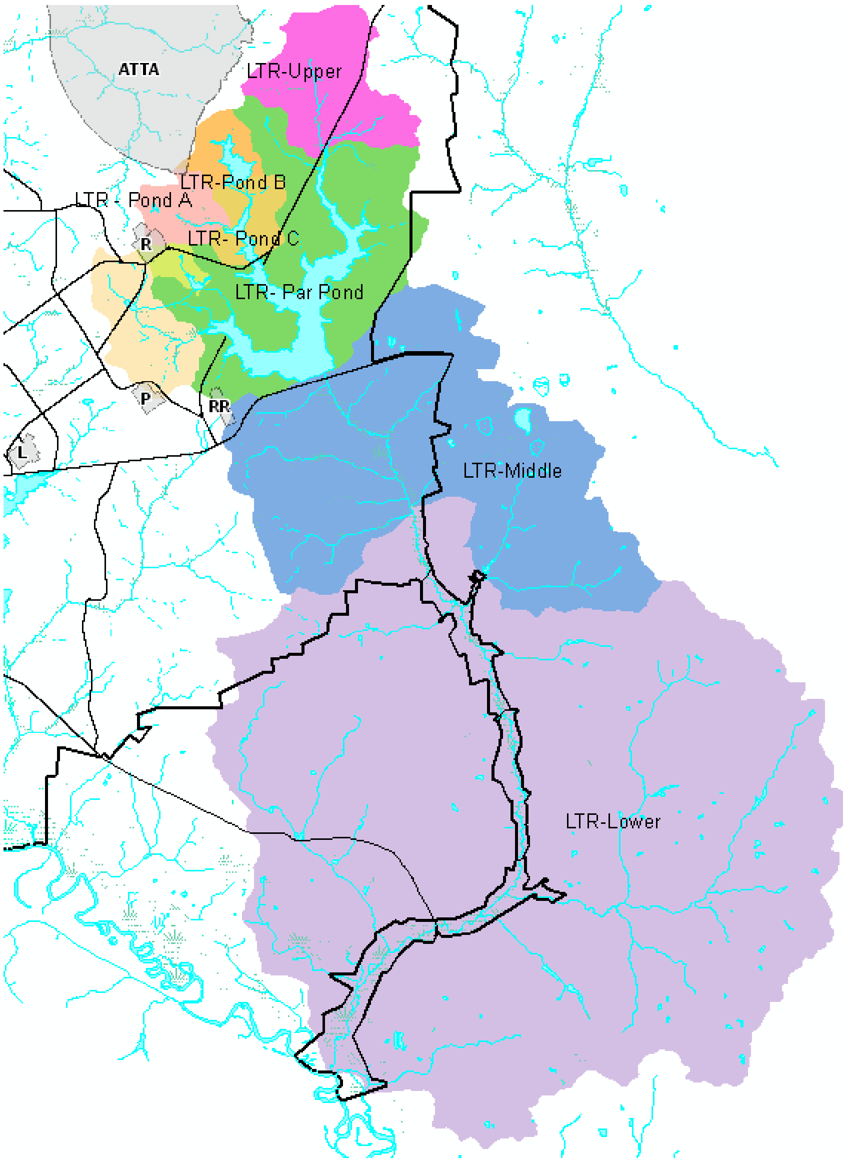


Figure 1. continued. Lower Three Runs (LTR) subunits

SRNS-STI-2018-00492

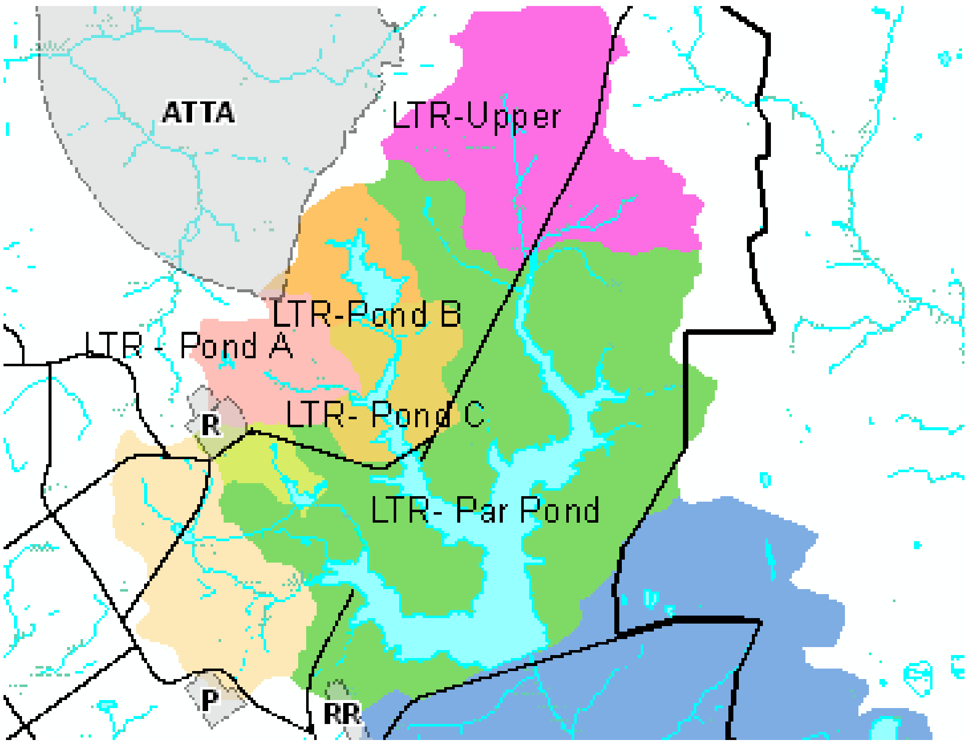


Figure 1. continued. Lower Three Runs (LTR) and Par Pond subunits

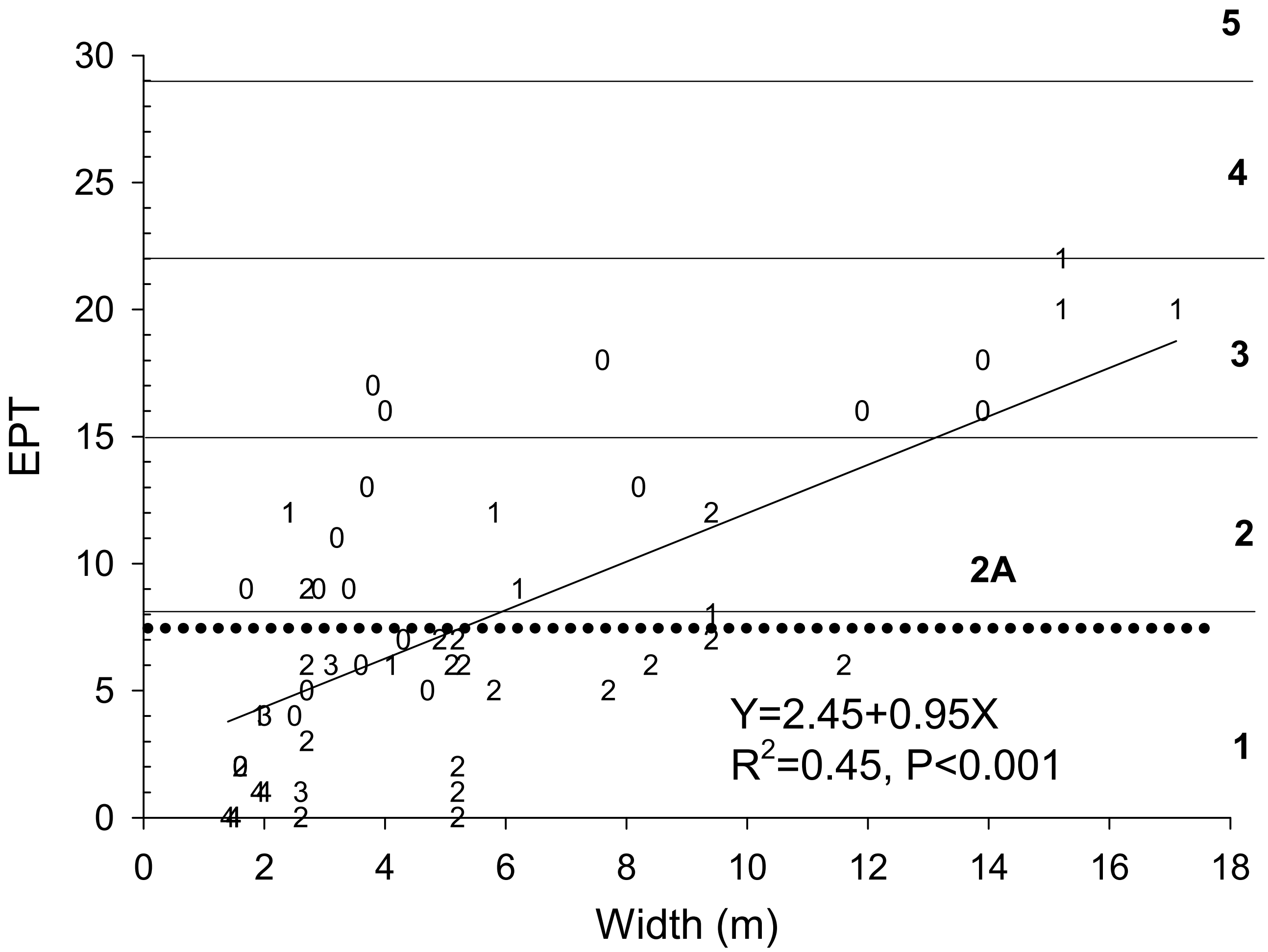


Figure 2. Regression of EPT on stream width. Sample site symbols indicate level of disturbance (0=undisturbed to 4=highly disturbed). Numbers 1-5 on the left indicate unadjusted MHSP scoring intervals for EPT taken from SCDHEC (1998). Dotted line represents the average EPT for all sites. Taken from Paller et al. (2007).

SRNS-STI-2018-00492

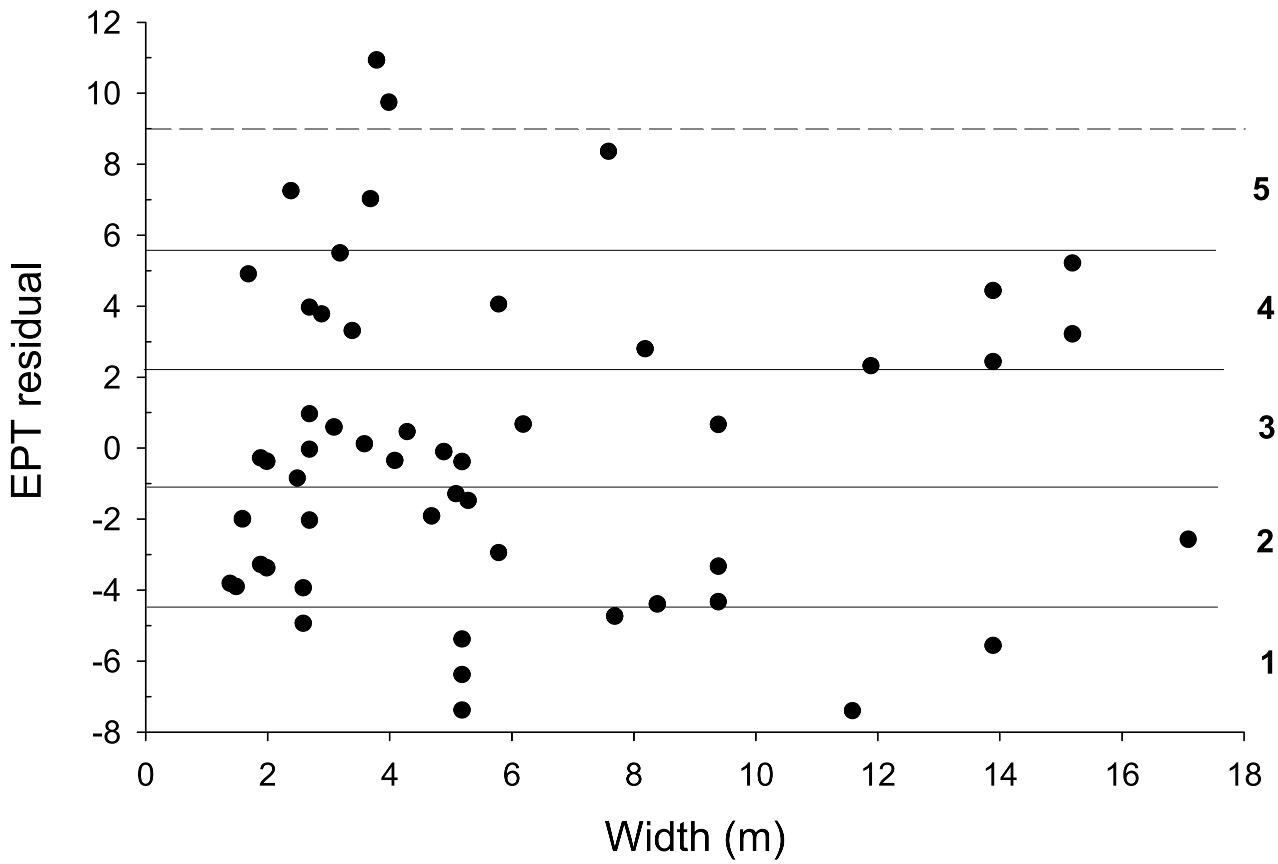


Figure 3. Distribution of EPT residuals (derived from the regression of EPT on stream width) divided into five scoring intervals after excluding the upper 5% (shown by the dashed line). Higher EPT residuals indicate greater than expected EPT and receive higher scores. Taken from Paller et al. (2007).

SRNS-STI-2018-00492

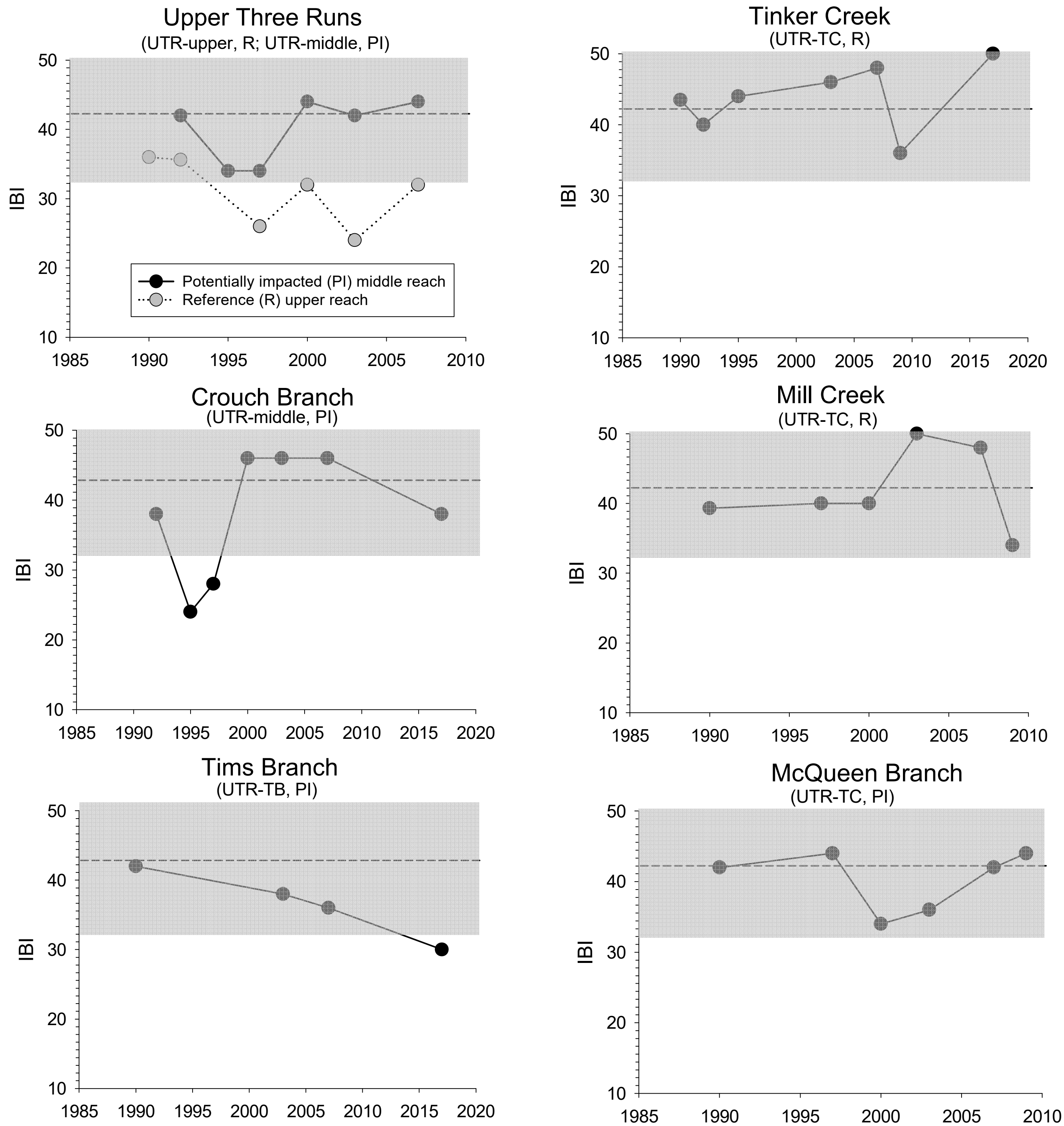


Figure 4. IBI trends in SRS streams depicted by plotting average IBI values over time. Indicated in parentheses are the Integrator Operable Unit (IOU)s that contain the sample sites in each stream or portion of stream and whether the sample sites were reference (R) or potentially impacted (PI).

SRNS-STI-2018-00492

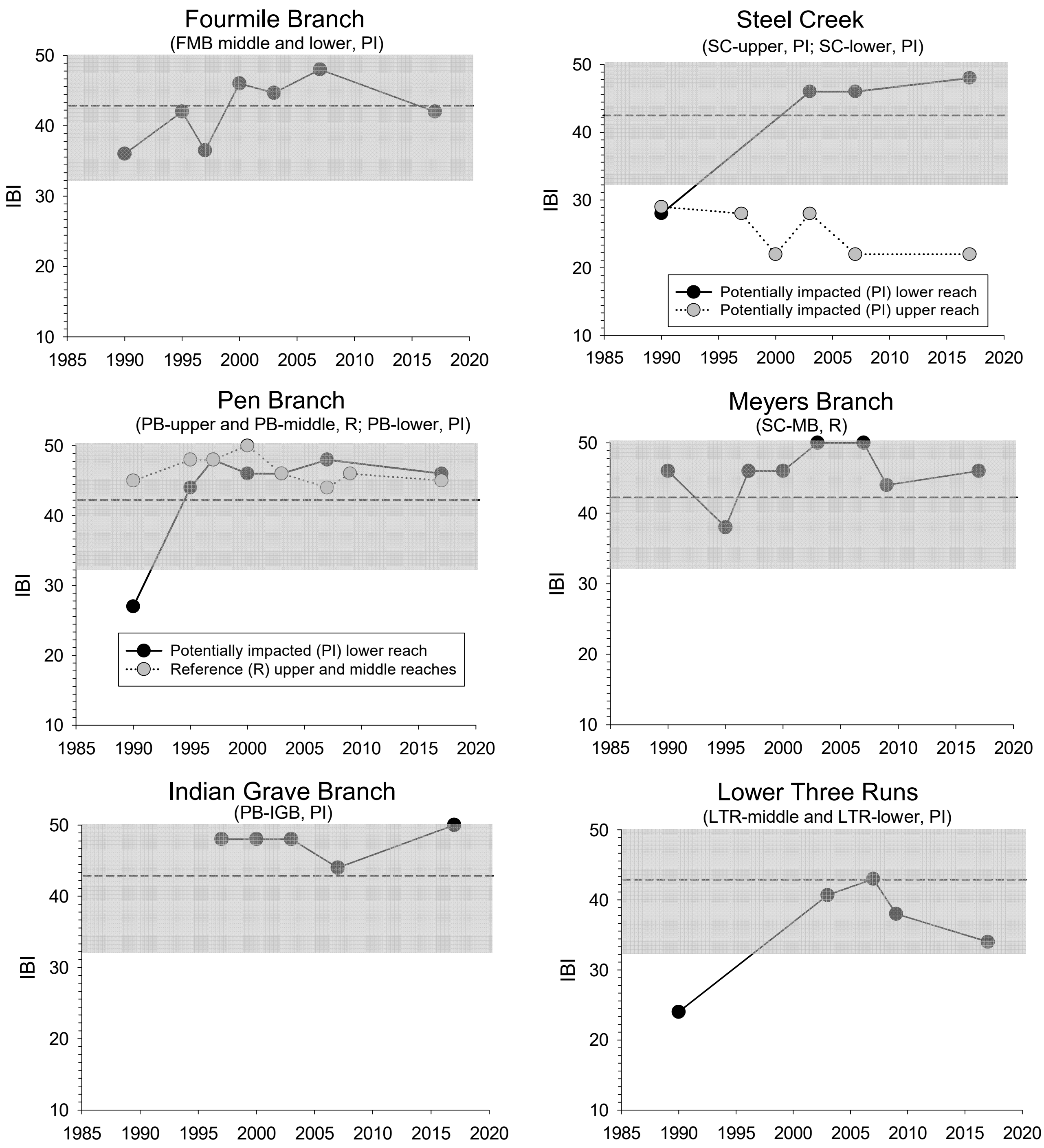


Figure 4. continued.

SRNS-STI-2018-00492

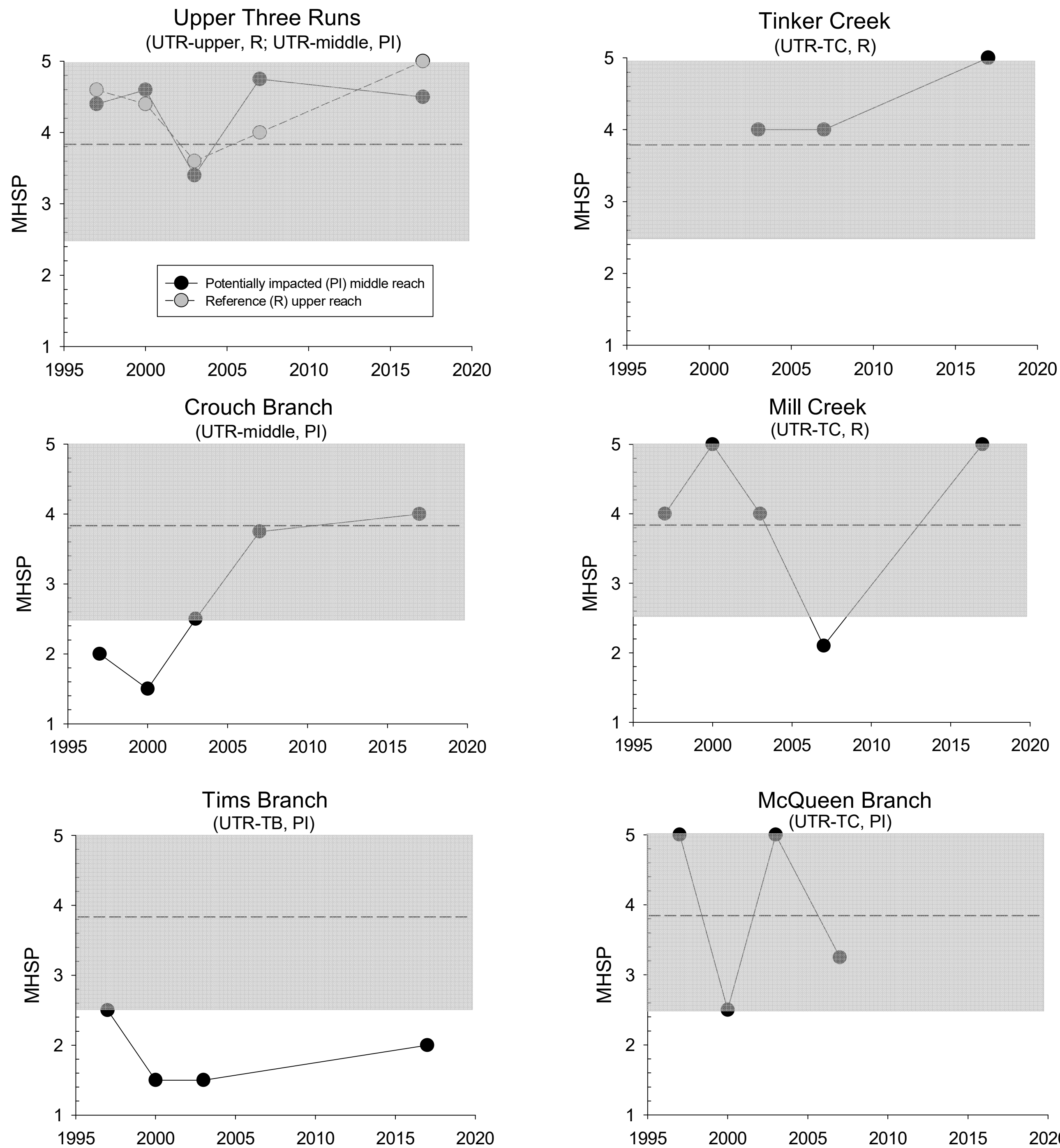


Figure 5. MHSP trends in SRS streams depicted by plotting average MHSP values over time. Indicated in parentheses are the Integrator Operable Unit (IOU)s that contain the sample sites in each stream or portion of stream and whether the sample sites were reference (R) or potentially impacted (PI).

SRNS-STI-2018-00492

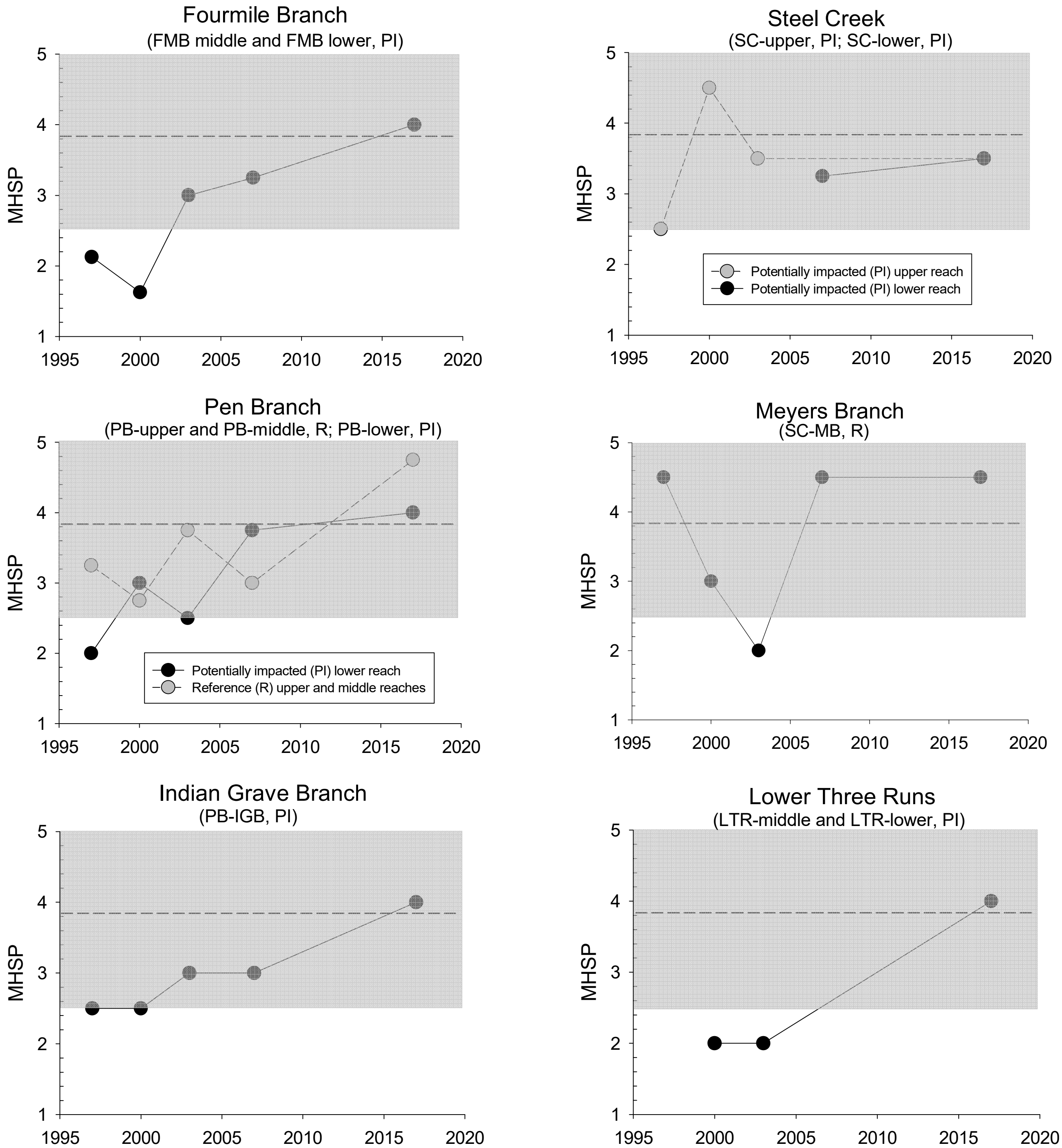


Figure 5. continued.

SRNS-STI-2018-00492

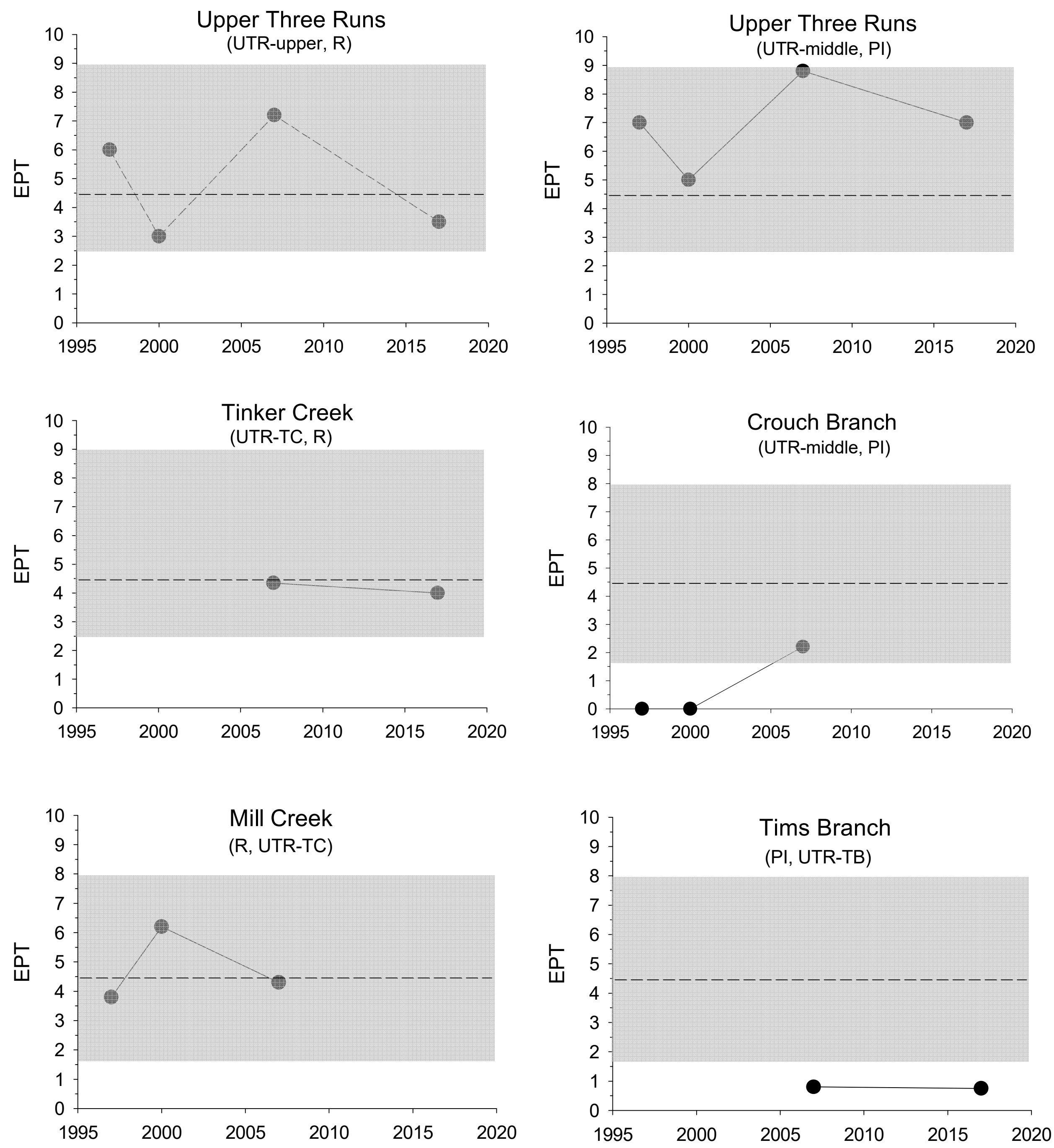


Figure 6. Hester-Dendy EPT trends in SRS streams depicted by plotting average EPT numbers over time. Indicated in parentheses are the Integrator Operable Unit (IOU)s that contain the sample sites in each stream or portion of stream and whether the sample sites were reference (R) or potentially impacted (PI).

SRNS-STI-2018-00492

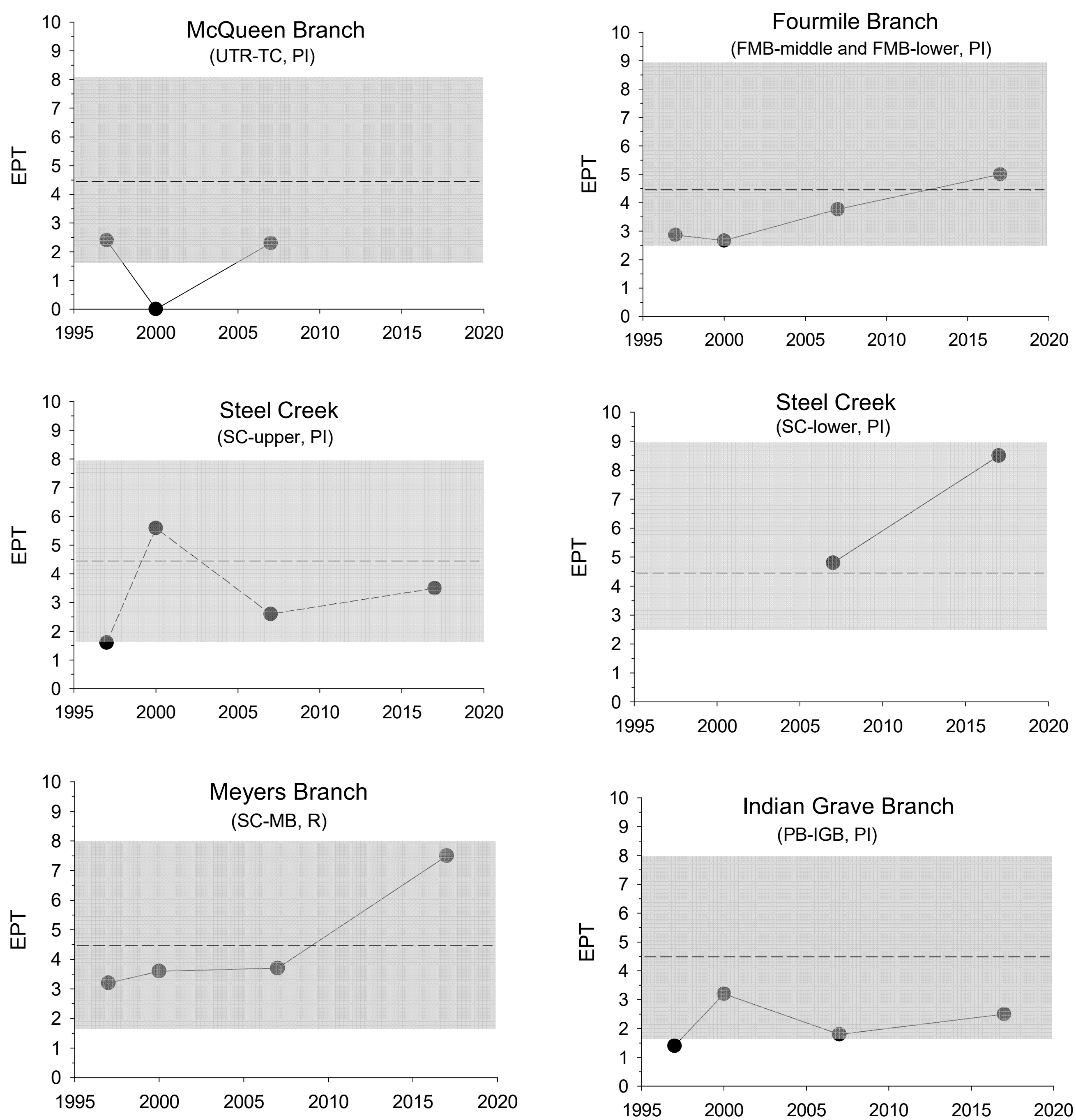


Figure 6. continued.

SRNS-STI-2018-00492

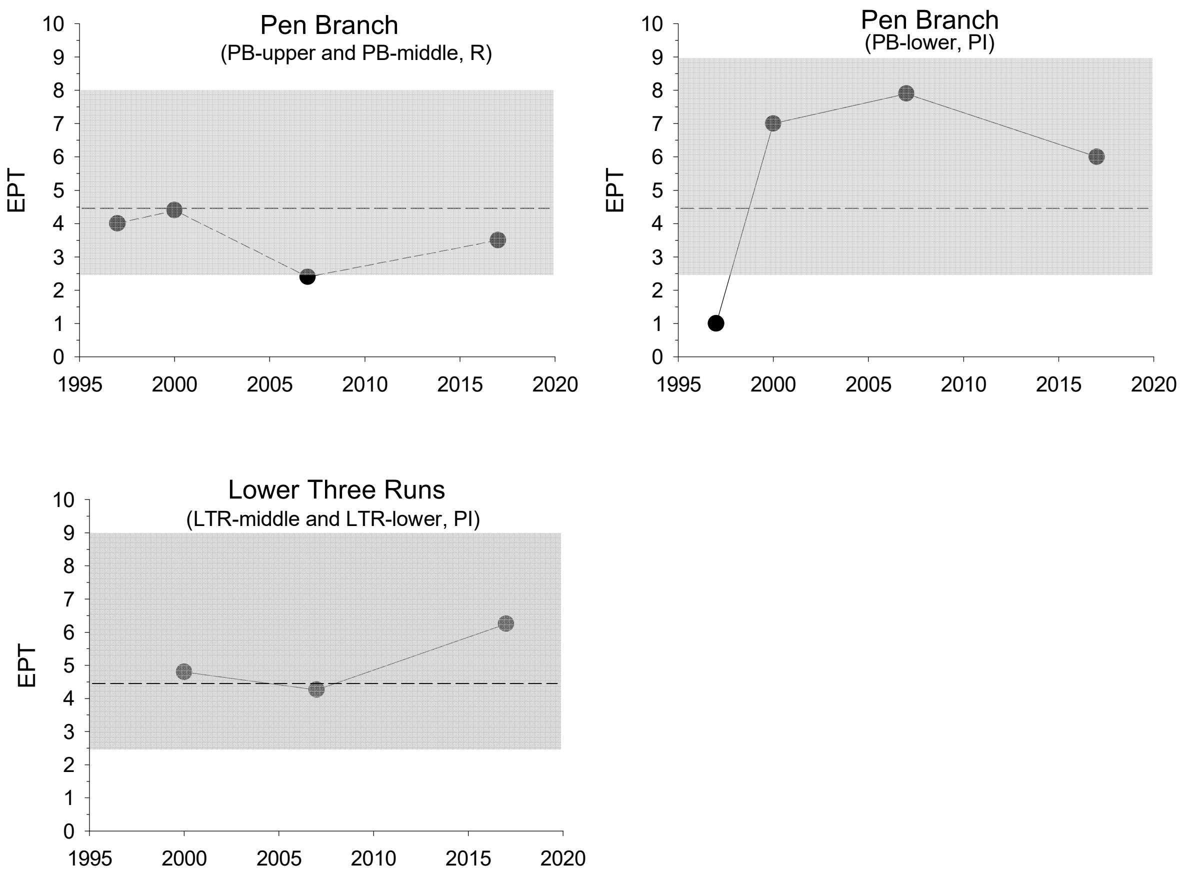


Figure 6. continued.

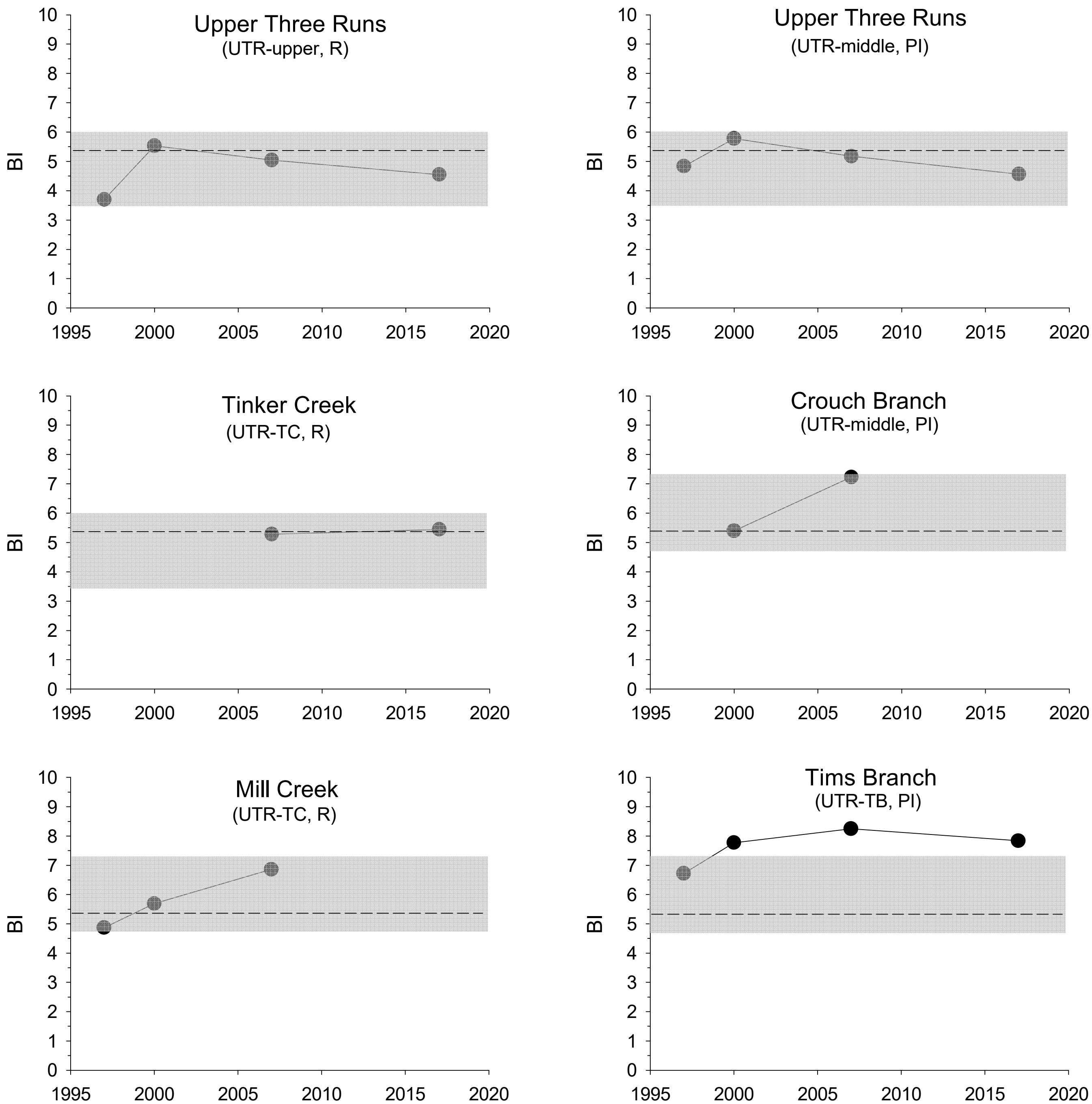


Figure 7. Hester-Dendy BI trends in SRS streams depicted by plotting average BI values over time. Indicated in parentheses are the Integrator Operable Unit (IOU)s that contain the sample sites in each stream or portion of stream and whether the sample sites were reference (R) or potentially impacted (PI).

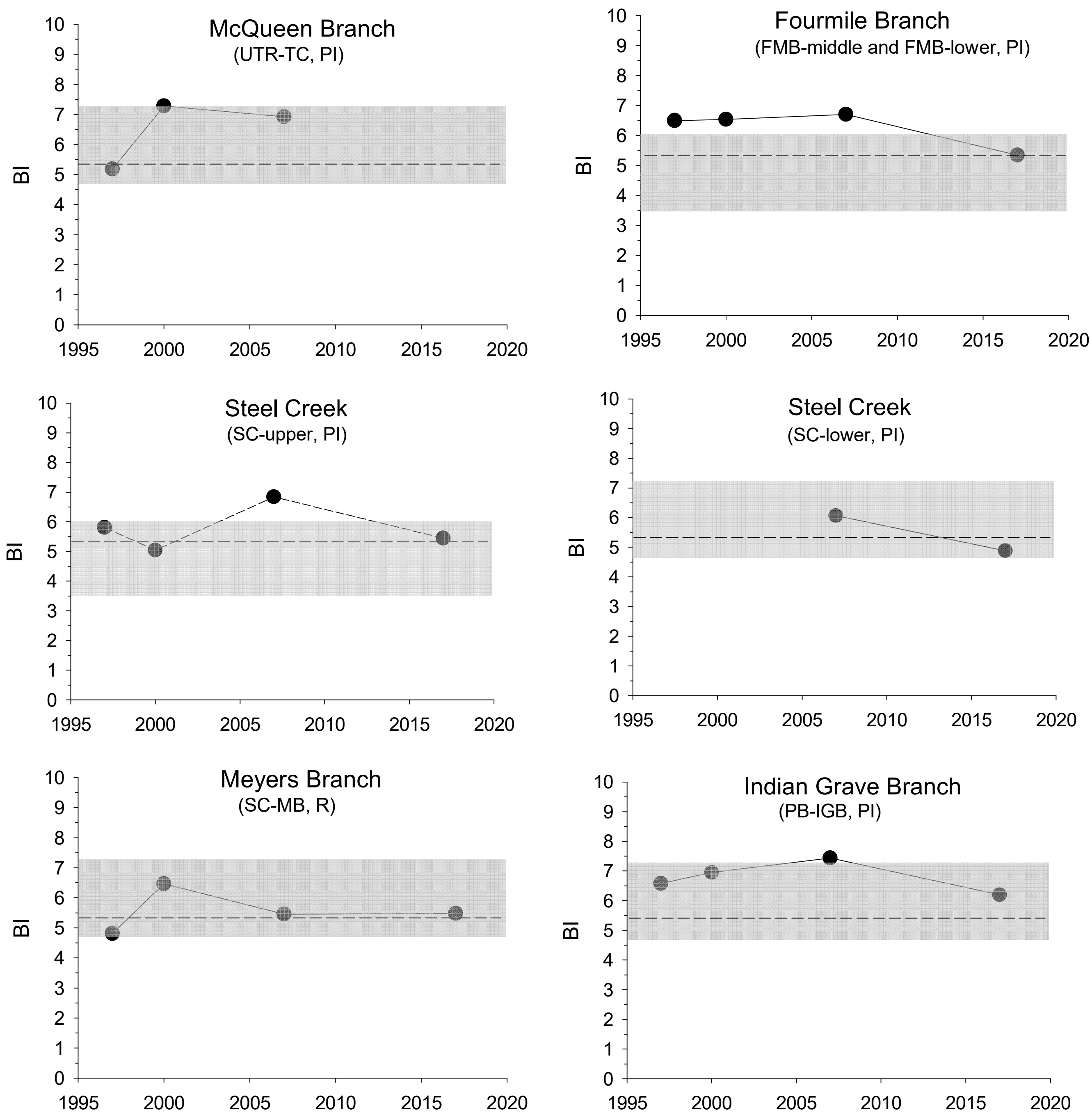


Figure 7. continued.

SRNS-STI-2018-00492

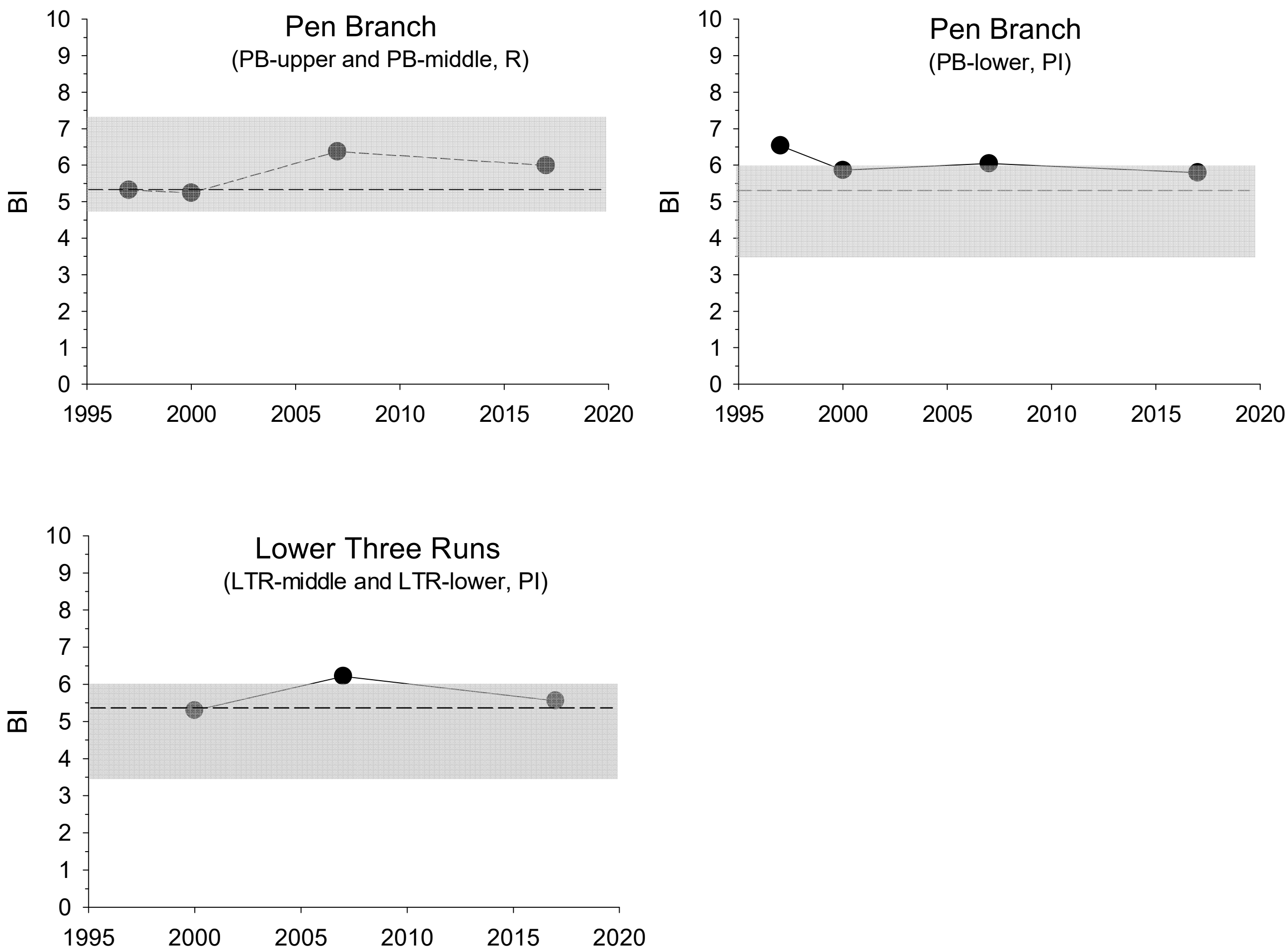


Figure 7. continued.

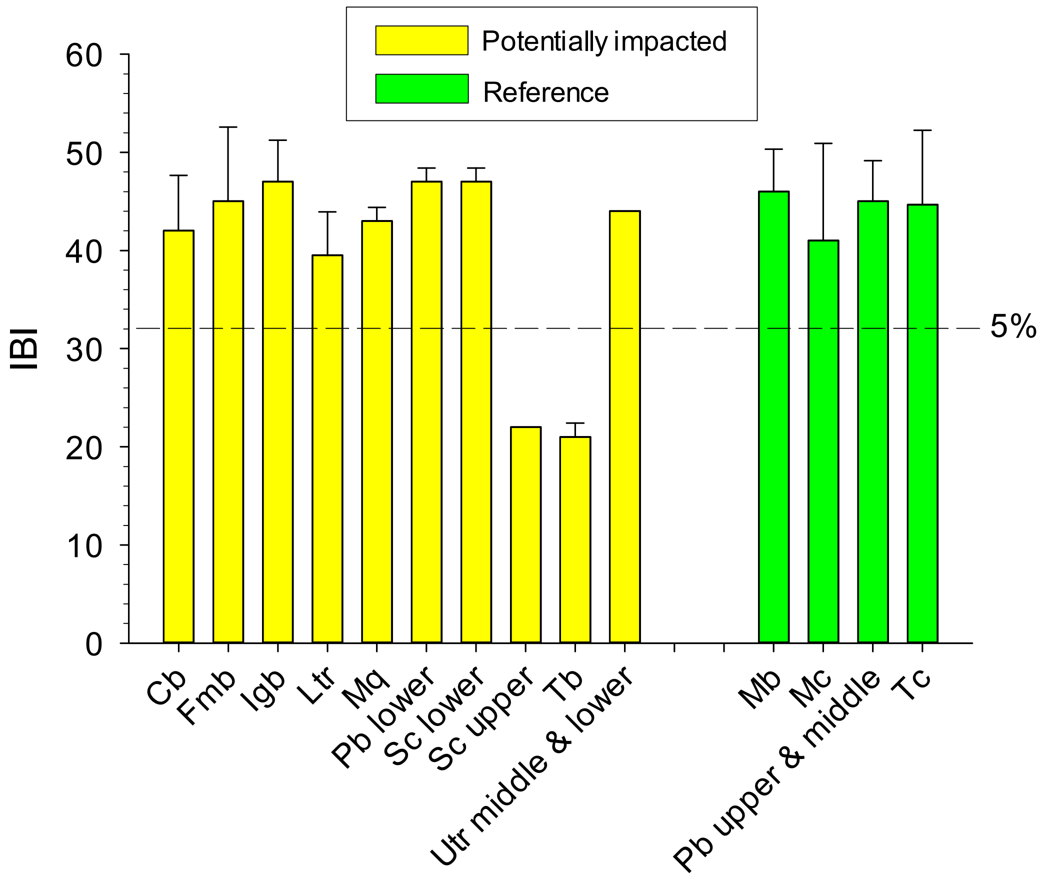


Figure 8. Average IBI values in reference and potentially impacted SRS streams. The dashed line is the cut-off value for reference sites corresponding to the lower 5% of the reference site range.

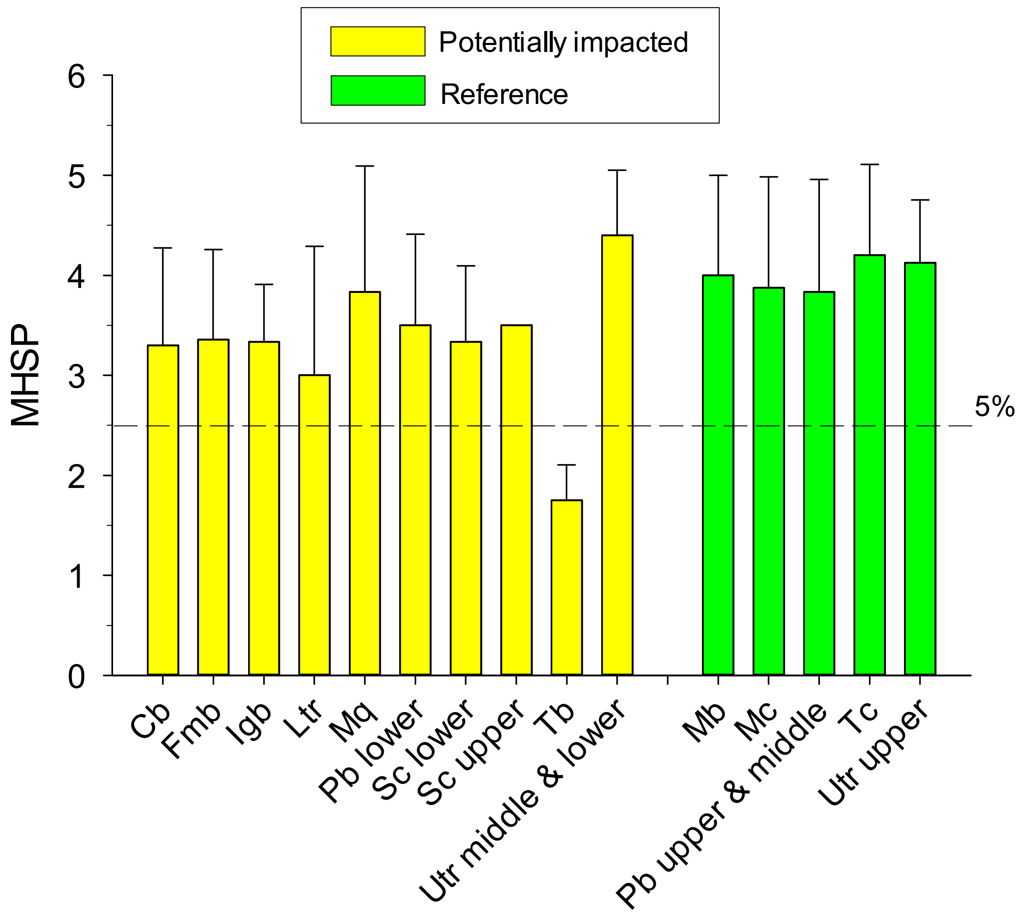


Figure 9. Average MHSP values in reference and potentially impacted SRS streams. The dashed line is the cut-off value for reference sites corresponding to the lower 5% of the reference site range.

SRNS-STI-2018-00492

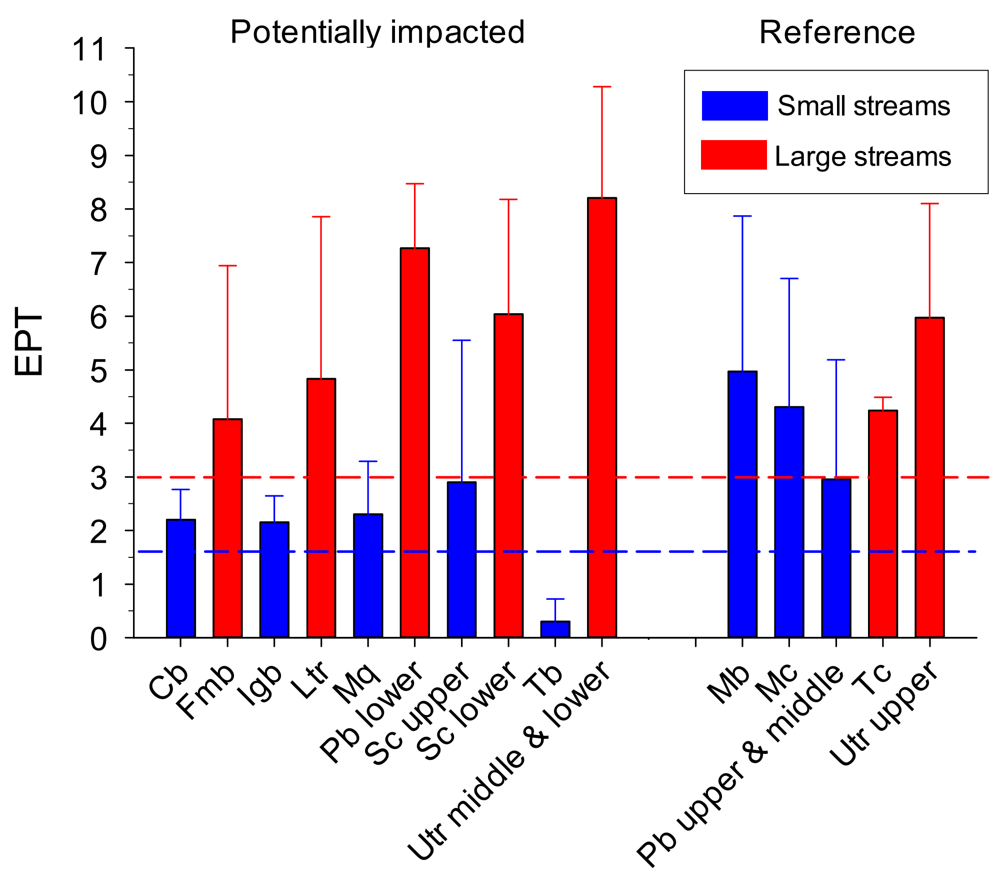


Figure 10. Average Hester-Dendy EPT numbers in reference and potentially impacted SRS streams. Dashed lines are the cut-off value for reference sites corresponding to the lower 5-10% of the reference site ranges for small streams (<5 m wide) and large streams (≥5 m wide).

SRNS-STI-2018-00492

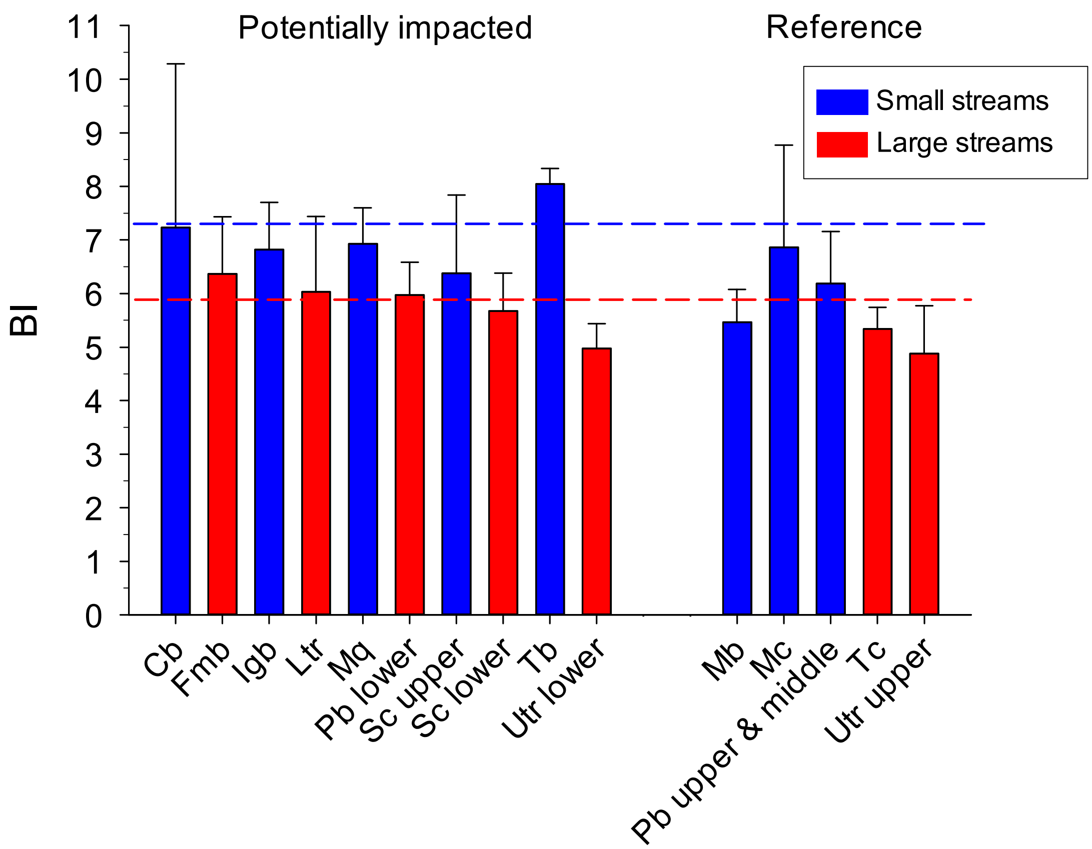


Figure 11. Average Hester-Dendy BI scores in reference and potentially impacted SRS streams. Dashed lines are the cut-off value for reference sites corresponding to the upper 5-10% of the reference site ranges for small streams (<5 m wide) and large streams (≥5 m wide).

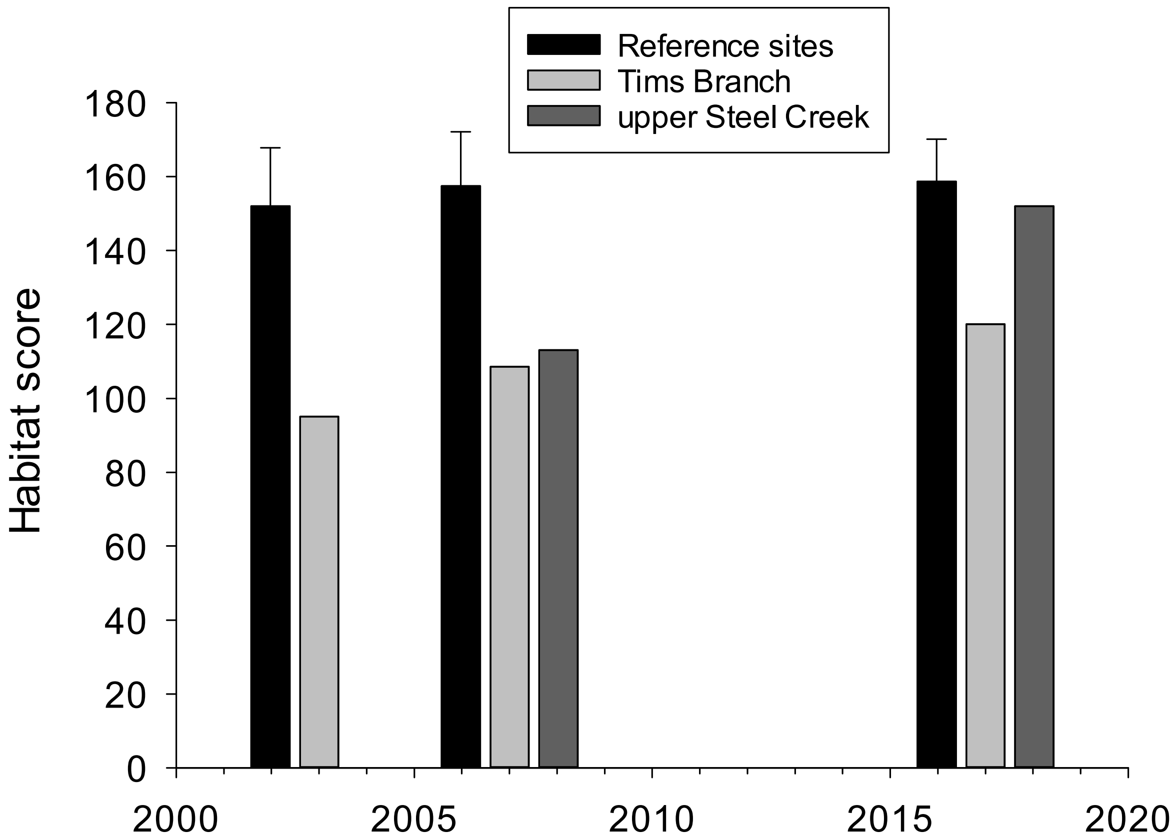


Figure 12. Average habitat assessment scores for reference sites compared with sites in upper Steel Creek and Tims Branch.