SUMMER INTERNSHIP TECHNICAL REPORT

Groundwater/Surface Water Interface and Radioactive Contaminant Ecological Risk Assessment Using EPA Method at the F- Area Seepage Basins - Savannah River Site (SRS) Aiken, S.C.

DOE-FIU SCIENCE & TECHNOLOGY
WORKFORCE DEVELOPMENT PROGRAM

Date submitted:

October 13, 2017

Principal Investigators:

Juan Carlos Morales, MPH, DOE Fellow
Mohammed R. Albassam, DOE Fellow
Florida International University

Mr. Skip Chamberlain, Mentor
U.S Department of Energy Office of Environmental Management

Florida International University Program Director:

Leonel Lagos Ph.D., PMP®

Submitted to:

U.S. Department of Energy
Office of Environmental Management
Under Cooperative Agreement # DE-EM0000598

Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

ABSTRACT

The interface where groundwater intersects surface water is a very complex environmental phenomenon that is found in many landscapes. Most surface water bodies in the eastern United States such as lakes, rivers, and wetland systems are connected to groundwater. The groundwater/surface water interchange in a hydrological system may result in contamination of the surface water if the groundwater system contains a contaminant plume or vice versa depending on the direction of flow in the system. From 1955 until 1988, operations in the F-Area at the Savannah River Site discharged radioactive and hazardous metals into seven unlined seepage basins. In 1988, the basins were closed and then covered with a low permeability engineered barrier system to reduce further groundwater infiltration. Since then, extensive efforts by the U.S. Department of Energy's Office of Environmental Management (DOE EM) were made to monitor and control contaminant migration through the F-Area groundwater system. The purpose of this study is to evaluate the potential harmful effects to aquatic biota from exposure to chronic low-level radioactive contaminants as groundwater migrates to the seep-line to surface creeks at the F-Area seepage basins (FASB). Dose rate evaluations will estimate internal exposures from selected radionuclides for the *Lepomis auritus* species inhabiting the surface waters of Four Mile Branch. This study will assess the impacts of potential leakage of contaminated effluents which might continue to migrate into groundwater reservoirs. Fish tissue and water quality data from the stream were previously collected near the headwater areas to Four Mile Creek and Pen Branch seeplines during site monitoring activities. Gross alpha and gross beta radioactivity were measured using health physics standards and EPA methods. The risk of detrimental effects to aquatic biota from radiation exposure are then compared to the calculated radiation dose rate to biota using DOE's recommended dose rate limit of 0.4 µGy h^{-1}. Data suggests that low levels of contaminants are migrating from the FASB and reaching surface waters in Fourmile Creek. Further analysis of radionuclide sensitive fish species should provide insight into the levels of contaminant concentrations as well to further determine the role of the groundwater/surface water interaction in Fourmile Creek.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

EPA	Environmental Protection Agency
DOE	Department of Energy
EM	Office of Environmental Management
FASB	F-Area Seepage Basins
I-129	Iodine-129
U-234/238	Uranium-234/238
TC-99	Techneitum-99
Sr-90	Strontium-90
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions
Km	Kilometer
Kg	Kilogram
ERA	Ecological Risk Assessment
NPL	National Priorities List
λ	Decay Rate
Km	Kilometer
Kg	Kilogram
μGy h^{-1}	Micro Gray per Hour

1. INTRODUCTION

The U.S Department of Energy Office of Environmental Management (DOE EM) program was established in 1989 to address the nation's Cold War environmental legacy resulting from five decades of nuclear weapons production and government-sponsored nuclear energy research. While pursuing this mission, DOE EM is committed to sound safety principles and will continue to maintain and demand the highest safety performance to protect workers and communities where DOE EM cleanup activities occur. The Office of Environmental Management has an overall straightforward goal. This goal is to complete their remediation mission in a safe, secure, and compliant manner and to do so within prescribed costs and schedules. As the largest environmental cleanup program in the world, DOE EM has been mandated to remediate up to 107 sites across the country. Nearly 91 of the total 107 sites have been successfully closed.

Figure 1. U.S. Department of Energy- EM challenges.

(1946-1960)

Atomic Energy Comminsoon established

President Truman announces the Atomic Energy Program

SRS is selected to be the plant under Du Pont

After the contruction of P,L and K reactors the first shipment of Plutonium is dispatched to AEC.

First shipment of Triutium is dispatched to AEC

(1960- 1980)

Heavy Water Reactor Component Test Reactor goes into operation testing the heavy water system for civilian use

R-reactor and HWCTR are shut-down

L-reactor shuts down for upgrades

K- reactor becomes automated by computers

SRP begins the environmental cleanup program

(1980-2000)

Construction of the saltstones begins

Dupont bails out from SRS management

Contruction of colling towers begins for the K-reactor

The cold war ends and production comes to a halt

Workforce transition programs are initiated

Vitrification is introduced to manage radioactive materials

(2000-present)

K-Reactor is set to be the storage facility

F canyon and FB Line facilities completed their last production run to process legacy materials.

Uranium is converted to generate enectricity for the Tennessee Valley Authority

The site adopts Enterprise (E-SRS) vision and business strategies for securing future new missions

Figure 2. Savannah River Site history timeline involving production, remediation, decommissioning and new technologies (SRS, 2017).

The Savannah River Site (SRS) covers 198,344 acres (310 square miles) located in Aiken, Barnwell, and Allendale counties in South Carolina. During construction, a total of five reactors were built in order to generate nuclear fuel for the defense program. The primary motive of the construction was to produce the basic materials necessary in the fabrication of nuclear weapons, primarily tritium and plutonium-239. Five reactors were also built in an effort to produce these materials for our nation's defense programs. In support of these efforts, the Savannah River National Laboratory (SRNL) was created. SRNL has evolved to be designated as the only national laboratory for DOE EM and is the nation's only complete nuclear material management facility.

At SRS**,** the mass of contamination released to soils, groundwater, and streams was largest in the first two decades of site operations, but lingering contamination remains. Since then, DOE has mandated site clean-up and funded activities which resulted in an extensive effort to remediate the site and to minimize impacts to the environment from these historical activities.

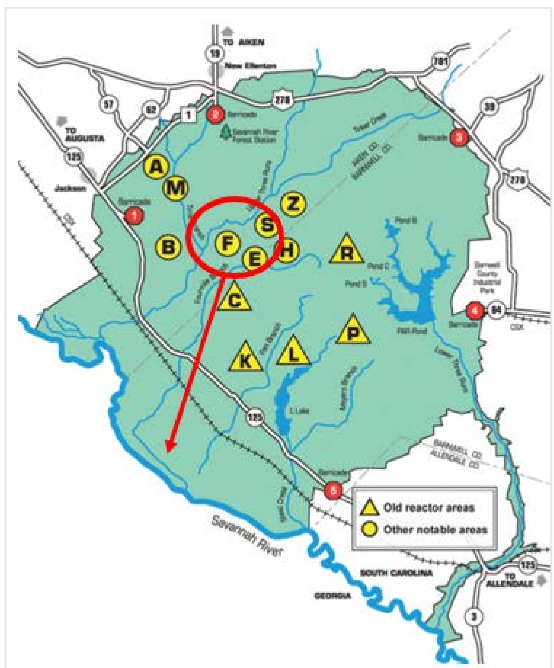


Figure 3. Savannah River Site, F- Area contaminant Flow direction to Savannah River.

The primary objectives of this study include:

- Understand the concept of the groundwater/surface water interface phenomenon at the SRS F-Area,
- Develop a conceptual ecological risk assessment model for the SRS F-Area, and
- Determine the ecological role in health physics by monitoring the effective dose rates of radionuclides in the *Lepomis auritus* fish species.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2017, DOE Fellow interns Juan Morales and Mohammed Albassam spent 10 weeks at the U.S. Department of Energy Office of Environmental Management in Washington D.C. under the supervision and guidance of Mr. Skip Chamberlain. The interns' project was initiated on June 2, 2017 and continued through August 12, 2017 with the objective of studying the groundwater/surface water interface and developing a conceptual ecological risk assessment model for the SRS F-Area.

3. RESEARCH DESCRIPTION AND RESULTS

Groundwater/Surface Water Interface Phenomenon

The interface between groundwater and surface water is characterized by complex interactions in the hydrology and geochemistry. Many surface water bodies in the eastern United States, such as lakes, rivers, and wetlands systems, are connected to groundwater. The mechanism of this connection can be simplified to the following three ways: 1) the surface water body loses water (outflow) through its bed, 2) the surface water gains water through its bed from the groundwater inflow, or 3) both scenarios take place at the same time. The subsurface location where these scenarios occur is called the hyporheic zone transition zone (Figure 4).

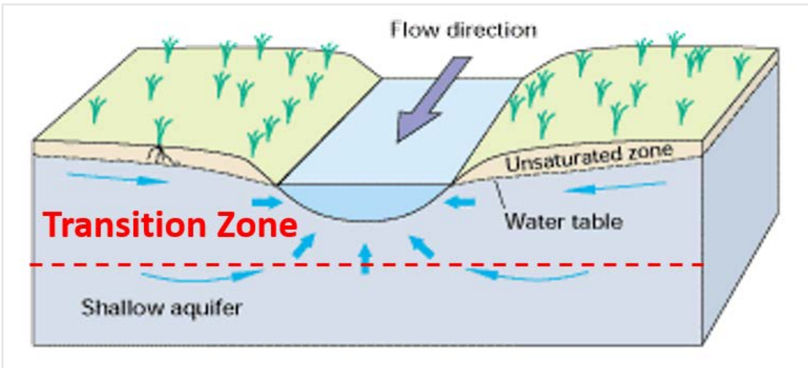


Figure 4. A geological cross section shows the hyporheic zone location where the groundwater interfaces with surface water.

The groundwater/surface water transition zone is an ecological community with important ecosystem functions affecting several trophic levels, from microbes to fish. As an ecotone (i.e., a transition from the groundwater ecosystem to the surface water ecosystem), this zone provides key ecological services to the surface water ecosystem. It provides food for benthic macroinvertebrates; the microbial community serves as the food base for the small organisms within the zone that in turn are food for the benthic macroinvertebrates; it provides and maintains unique habitats or refugia, particularly in upwelling zones; and it cycles nutrients and carbon in the aquatic ecosystems.

The interchange of the groundwater/surface water in a hydrological system can contaminate the surface water, especially if the groundwater system contains a plume of contaminants that will be discharged through the transition zone to the surface water body above it. The interface of groundwater/surface water in the transition zone can be affected by many factors, such as recharge amount, seepage rate, climate changes, and the geological properties of the area; these factors play a major rule in the fate and transport of contaminants through this zone.

F- Area Seepage Basins (Area of Concern) Overview

From 1955 to 1988, the operational activities at the F-Area seepage basins (FASB) resulted in the discharge of radioactive and hazardous heavy metals into three seepage basins, contaminating the underlying soil and upper aquifers (Friday 1997). The FASB are near the

Fourmile Branch and Upper Three Runs Creek. The facility operated until 1988, having received effluent since 1955. The FASB are approximately 6.5 acres in size at an elevated 55 to 90 meters (180 to 295 ft) above sea level. Land cover characteristics are predominantly grasslands, gravel roads and densely forested areas. The FASB location is in the central point of the SRS. There is a gentle slope from the basins to Fourmile Branch with an average gradient of 92.6 ft/mi (45.5 m/km).

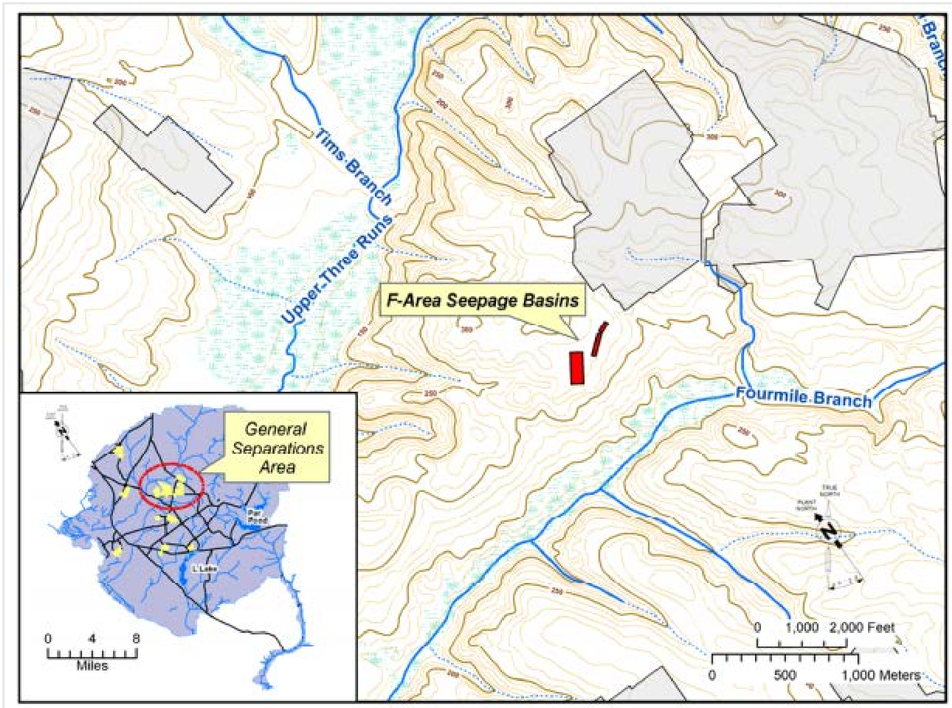


Figure 5. Location of F-Area Seepage Basins (SRNL 2013).

GEOLOGY AND GROUNDWATER CHARACTERISTICS OF THE F-AREA, SC

The land use at SRS, including the F-Area, can be characterized in three major categories, 435.1 CA):

- Undeveloped (73%)
- Wetlands/Streams/Lakes (22%)
- Developed (e.g., facilities, roads, etc.) (5%)

The FASB are located above the Atlantic Coastal Plain aquifer which is the main aquifer in parts of three states: South Carolina, North Carolina, and Georgia (Figure 6). The main Atlantic Coastal Plain aquifer is divided into the following six regional aquifers based on location (from bottom to top): the Tertiary sand aquifer, the Middendorf aquifer, the Floridian aquifer system, the Cape Fear aquifer, the Black Creek aquifer, and the surficial aquifer. The aquifer system that is located under the F-Area has a local name; it is called the Upper Three Run aquifer and is an unconfined system.

Figure 6. Map of the Atlantic Coastal Plain aquifer.

The transmissivity values of the aquifer ranges from 1000 to 30000 feet squared per day; the vertical hydraulic conductivity ranges from $6x10^{-1}$ to $3x10^{-2}$ feet per day, and the storage coefficient ranges from 0.15 (unit less) for unconfined conditions to 0.0005 for confined conditions. In addition, the natural pH of the groundwater was measured to be in the range of approximately 4.9 to 7.7.

The main recharge source for the Atlantic Coastal Plain aquifer is precipitation. Figure 7 shows rain fall data for the years 2012 to 2016. The data was extracted from the United States Geological Survey (USGS) for Aiken County, SC, and uses MIKE SHE model inputs.

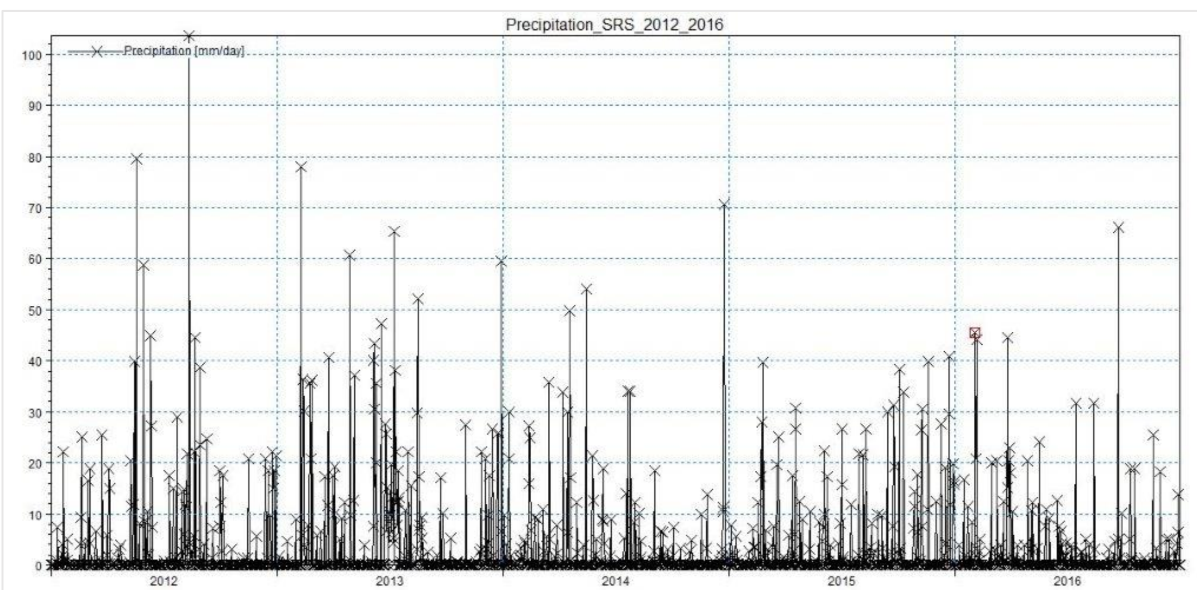


Figure 7. Rain fall data (2012-2016) for SRS (USGS 2017).

From Figure 7, the daily rainfall data ranges from 0 to more than 100 mm/day. The depth to the water table varies and is dependent on the season (wet or dry). The change in water level impacts the nature of the groundwater/surface water interface in the area.

The geology of the site is made up of heterogeneous poorly consolidated quartz sands and clays. The quartz sands contain varying amounts of surface active minerals consisting mostly of kaolinite and goethite. Other minor clay minerals are present as well. The plume is stratified within the water table aquifer, moving mostly within the highly transmissive Irwinton Sand along the top of a local confining unit commonly referred to as the Tan Clay, which confines the aquifer below. The plume crops out at seeplines along a stream, Fourmile Branch, approximately 400-600 meters from the basins (SRNL 2013).

Since the plume created by the FASB is still active, SRS designed multiple strategies in order to control its movement and treat the contaminated groundwater for iodine-129, uranium-234/238, and strontium-90 which, together with tritium, are considered to be the risk-driving radionuclides. Technetium-99 is also present in the groundwater but accounts for a smaller fraction of the total risk. A pump-and-treat strategy was used in 1997-2004 which involved extracting groundwater from downgradient and then treating it using precipitation/flocculation, ion exchange, and reverse osmosis. After treatment, the water was re-injected back in the aquifer upgradient of the seepage basins.

In 2004, the pump-and-treat system was replaced by a hybrid funnel-and-gate system that was installed about 300 meters from the stream (WSRC 2005, SRNS 2012). The purpose of the funnel-and-gate is to slow the migration of contaminated groundwater and to funnel it through *in situ* treatment zones at the gates. Extensive geologic characterization showed that much of the plume migrated along “troughs” at the top of the clay layer that confines the lower aquifer. The walls (or engineered subsurface barriers) were installed across these features to slow contaminant migration and force it through the gates. The treatment zones at the gates attenuate migration of uranium, Sr-90, and I-129 by sorption or precipitation. Tritium migration is slowed by the walls and an additional decrease in tritium concentration is achieved as the stratified plume mixes with less contaminated groundwater as it migrates up through the gates (SRNL 2013).

The groundwater/surface water interface occurs near Fourmile Branch. Many observation wells and injection wells based on the water flow (surface and ground) have been constructed for both monitoring and treating the contaminant groundwater and to slow the spread of the contamination plume (Figure 8).

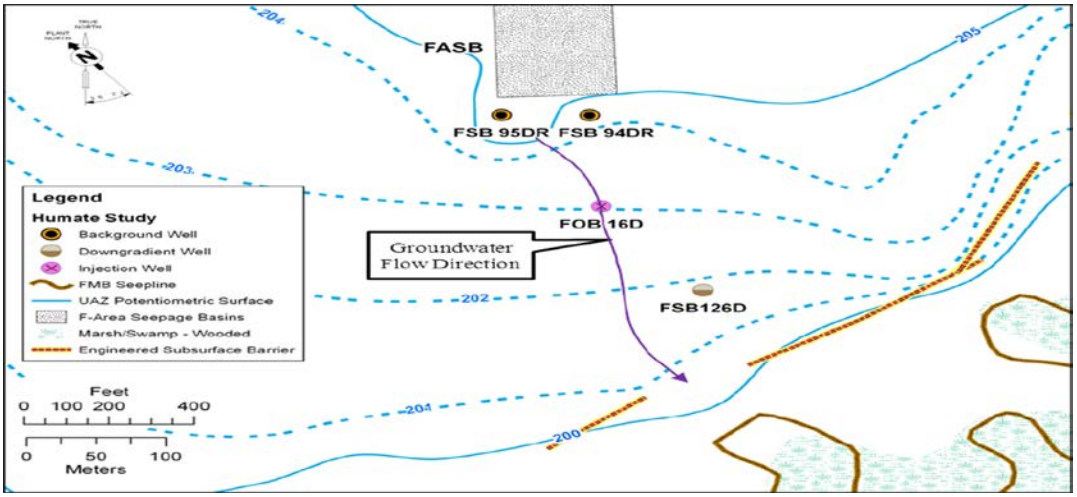


Figure 8. Well locations and the direction of both surface and groundwater (SRNL 2013).

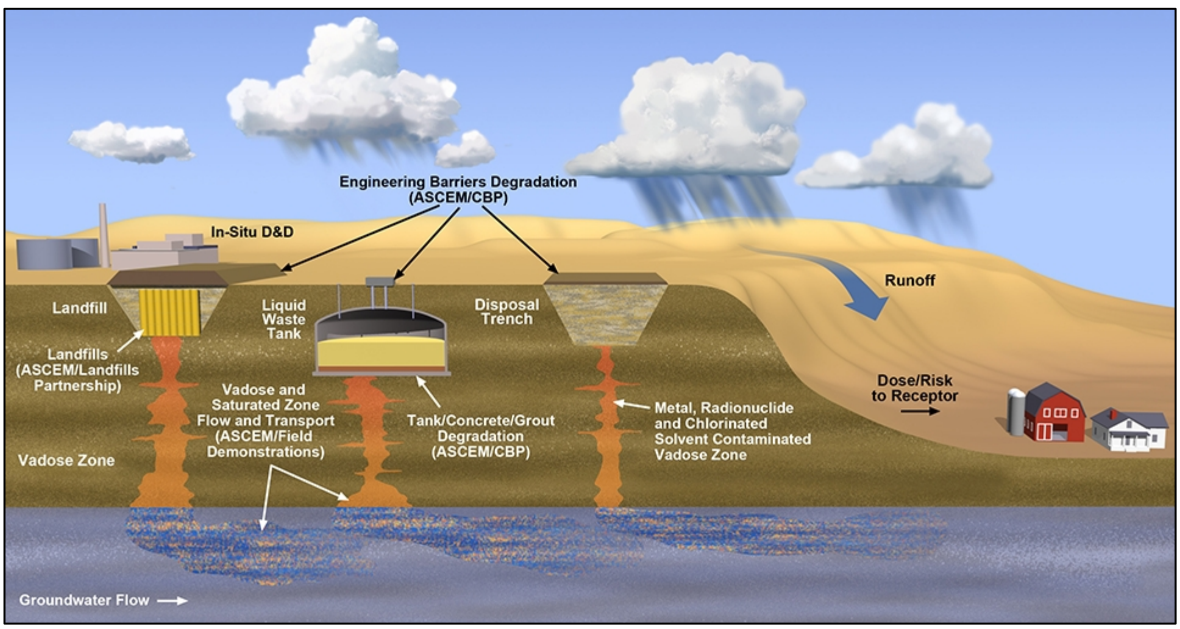


Figure 9. Groundwater contaminant plume using ASCEM/ CBP Model (ASCEM, 2017).

Groundwater/surface water dynamics allow contaminants to migrate, creating the possibility for human and animal exposure (ATSDR 2017). For example, uranium deposited on land can be reincorporated into soil, washed into surface water, or stuck to plants roots. Uranium in groundwater or surface water can be transported large distances. Moreover, uranium contains capabilities to bind to root crops such as potatoes, turnips and parsnips. Because uranium in the soil and water can bind to these crops, the concentrations in the human diet directly relates to contact to these stressors (ATSDR 2017).

Ecological Risk Assessment

SRS has around 5 major drainage basins: Lower Three Runs, Steel Creek, Fourmile Branch, Pen Branch, and Upper Three Runs. From these, data was extrapolated from wells near Fourmile Branch, confirming the presence of radionuclides in the groundwater.

SRS, and the F-Area field research site in particular, holds large quantities of contaminants in the groundwater plume. Most of these contaminants are very important from the risk perspective. This paper will highlight three contaminants of interest: iodine-129, uranium 234/238, and techneitum-99.

Fish tissue data from the mouth of Fourmile Creek with surface waters from FMC001F, FMC001H, and FMC002H were analyzed to determine the radionuclide dose rate for gross gamma (γ) and gross beta (β) isotopes.

Radionuclide Concentrations

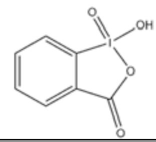
Iodine-129

Iodine is a metal found naturally throughout the environment. The most common isotope is stable iodine-127 which is much more abundant than the radioactive contaminants (iodine-129 and iodine-131). Moreover, iodine-129 is released at very low levels into the environment from facilities that separate and reprocess nuclear reactor fuels and waste storage facilities. It has a long half-life, and thus persists in soil and groundwater. Iodine-131 has a half-life of 8 days and is usually only an environmental problem when released to the atmosphere in large quantities during a nuclear accident, such as at Chernobyl.

I-129 has previously shown great potential as a hydrological tracer in specific circumstances, such as evapotranspiration in large watersheds, groundwater/surface water interactions and natural organic matter cycling in freshwater systems, as both iodine isotopes are largely associated with macromolecular matter (Moran et al. 2002).

Iodine-129 is one of the most used radioisotopes and it has a great impact to the environment if released. Radioactive iodine can disperse rapidly in air and water. In soil, however, it combines easily with organic materials and moves more slowly through the environment. If released, I-129 will remain in the environment for millions of years (EPA 2017).

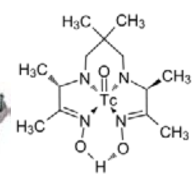
Table 1. Iodine-129 (F-Area) Hazard Identification

Iodine-129: Structure	 
Chemical Formula	^{129}I
Atomic Number	53
Atomic Mass	128.9 u
Half Life	$1.57\text{x}10^{7}$ years
Density	$4.93\ \frac{g}{cm^3}$
Concentration in the Groundwater Plume (F-Area)	$741\ \frac{pCi}{L}$
Clean Up Requirement Concentration	$1\ \frac{pCi}{L}$

Technetium-99

Technetium-99 is present in air, seawater, soil, plants and animals at very low concentrations. Because of its long half-life, Tc-99 remains in the environment for an extended period of time. Organic matter in soil and sediment slow the transport of Tc-99. In the presence of oxygen, plants readily take up technetium compounds from the soil. Some plants, such as brown algae in seawater, are able to concentrate Tc-99. Sea animals can also concentrate Tc-99 in their bodies (EPA 2017).

Table 2. Technetium-99 (F- Area) Hazard Identification

Technetium-99:Structure	 
Chemical Formula	^{99}Tc
Atomic Number	43
Atomic Mass	98.9 u
Half Life	$2.13\ \text{x}\ 10^{5}$ years
Density	$11.5\ \frac{g}{cm^3}$
Concentration in the Groundwater Plume (F-Area)	$313\ \frac{pCi}{L}$
Clean Up Requirement Concentration	$50\ \frac{pCi}{L}$

Uranium-234/238

Uranium is present naturally in virtually all soil, rock and water. Rocks break down to form soil. Soil can be moved by water and blown by wind, which moves uranium into streams, lakes and surface water. More than 99 percent of the uranium found in the environment is in the form of U-238. Uranium-234 is less than one percent of all forms of natural uranium, but is much more radioactive. It gives off almost half of the radioactivity from all forms of uranium found in the environment (EPA 2017). Reports state that only a small amount of depleted uranium was released in 1984 into the Upper Three Runs Creek.

One of the most important characteristics of uranium is its half-life. For example, U-234 has a very long half-life (around 20,000 years) and U-238 nearly 5 billion years.

Table 3. Uranium-234/238 (F- Area) Hazard Identification

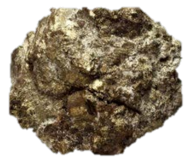
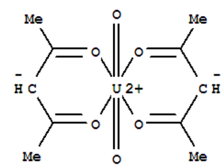
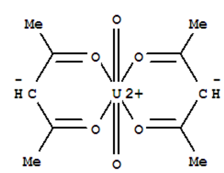
Uranium-234 Structure	 
Chemical Formula	$^{234}U,$
Atomic Number	92
Atomic Mass	238 u
Half Life	2.46 x 10^{5} years
Density	19.1 $\frac{g}{cm^3}$
Concentration in the Groundwater Plume (F-Area) Mass Concentration of **2.7 E-5 mg/L**	170 $\frac{pCi}{L}$
Uranium-238 Structure	 
Chemical Formula	^{238}U
Atomic Number	92
Atomic Mass	238 u
Half Life	4.468 x 10^{9} years
Density	19.1 $\frac{g}{cm^3}$
Concentration in the Groundwater Plume (F-Area)	170 $\frac{pCi}{L}$

Table 4. Average Energies of Selected Alpha Emitters including those of Naturally Occurring Alpha Decay Series

Isotope	Biological concen-tration factor	Radiological half life	Average alpha & alpha revolt (MeV)	Maximum beta energy (MeV)	Average beta energy (MeV)	Average gamma energy (MeV)
Uranium-234	10	2.47E+05 y	4.84E+00	-	1.32E+02	1.73E-03
Uranium-238	10	4.51E+09 y	4.26E+00	-	1.00E-02	1.36E-03
Tc-99	20	2.12E+05 y	-	2.95E-01	1.01E-01	-
I-129	10	1.7E+07 y	-	1.8E-01	3.75E-02	1.5E-01

Table 5. Maximum Concentration in Fish Tissue (Sunfish) per Kilogram from the Savannah River Site Locations from (2001-2008) (CDC 2008)

Units in pCi/g (Bq/kg)											
Radionuclide	August Lock and Dam	Mouth of Beaver Dam Creek	Mouth of Four Mile Creek	Highway 17 A Bridge Area	Highway 301 Bridge Area	Mouth of Lower Three Runs Creek	Mouth of Steel Creek	Stokes Bluff Landing	Mouth of Upper Three Runs Creek	West Bank Landing (Control)	ALL Locations
Iodine- 129	0.74	0.59	0.26	1.96	0.41	1.92	0.41	0.41	0.78	0.3	1.96
Uranium-234	0.185	0.011	0.981	0.126	0.022	0.011	0.155	0.192	0.015	0.026	0.981
Uranium-238	0.215	0.007	0.944	0.148	0.018	0.011	0.141	0.111	0.018	0.0222	0.944
Technetium-99	1.78	1.44	5.44	26.11	1.85	2.55	3.37	1	4.48	N/A	26.11

Calculating the Radiation Dose Rates to Aquatic Organisms

The Redbreast Sunfish (*Lepomis auritus*) is native to the Atlantic watersheds of South Carolina and Georgia. It is mostly found in the southern and eastern regions of the Pennsylvania, Delaware, Susquehanna and Potomac River watersheds (PA 2017). Its definitive species lives in a variety of habitats in freshwater around the 7.0-7.5 pH range. Commonly a length of around 10.8 cm for both males and females, these fish have a maximum length of 30.5 cm as adults. Its life cycle and mating behavior is determined by temperature and ecological impacts.

Isotope: ^{234}U, ^{238}U, ^{99}Tc, ^{129}I
Geometry: Small Fish
Activity in organism: 0.981, 0.944, 5.44
0.26 Bq/kg wet weight
Water activity: Use BCF to calculate (Bq/L)
Sediment activity: 0.5 Bq/ kg wet weight

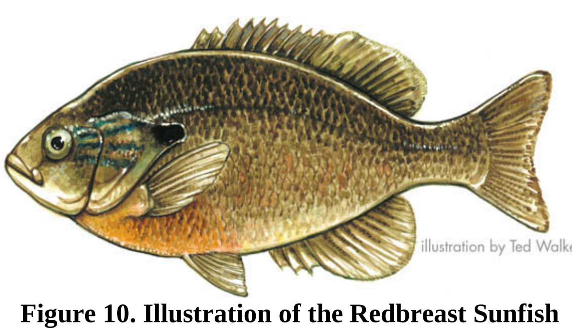


Figure 10. Illustration of the Redbreast Sunfish native to small tributaries at the SRS Four Mile Branch (F-Area)

Calculating the internal (γ- radiation dose rate) $^{234}\boldsymbol{U}$ ***:***

$D_{\gamma} = 5.76\ x\ 10^{-4} E_{\gamma} n_{\gamma} (1 - \Phi) C_S R \quad \mu Gy\ h^{-1}$

$D_{\gamma} = (5.76\ x\ 10^{-4})(1.73\ x\ 10^{-3})(2.39)(\frac{0.981}{10})(0.5)$

$D_{\gamma} = 1.17\ x\ 10^{-7} \quad \mu Gy\ h^{-1}$

Calculating the internal (β- radiation dose rate) $^{234}\boldsymbol{U}$***:***

$D_{\beta} = 5.76\ x\ 10^{-4} E_{\beta} n_{\beta} C_0 \quad \mu Gy\ h^{-1}$

$D_{\beta} = (5.76\ x\ 10^{-4})(1.32\ x\ 10^{-2})(2.39)(0.981) \quad \mu Gy\ h^{-1}$

$D_{\beta} = 1.78\ x\ 10^{-5} \quad \mu Gy\ h^{-1}$

Calculating the internal (γ- radiation dose rate) $^{238}\boldsymbol{U}$ ***:***

$D_{\gamma} = 5.76\ x\ 10^{-4} E_{\gamma} n_{\gamma} (1 - \Phi) C_S R \quad \mu Gy\ h^{-1}$

$D_{\gamma} = (5.76\ x\ 10^{-4})(1.36\ x\ 10^{-3})(2.39)(\frac{0.981}{10})(0.5)$

$D_{\gamma} = 9.2\ x\ 10^{-8} \quad \mu Gy\ h^{-1}$

Calculating the internal (β- radiation dose rate) $^{238}\boldsymbol{U}$***:***

$D_{\beta} = 5.76\ x\ 10^{-4} E_{\beta} n_{\beta} C_0 \quad \mu Gy\ h^{-1}$

$D_{\beta} = (5.76\ x\ 10^{-4})(1\ x\ 10^{-2})(2.39)(0.981) \quad \mu Gy\ h^{-1}$

$D_{\beta} = 1.35\ x\ 10^{-5} \quad \mu Gy\ h^{-1}$

Calculating the internal (γ- radiation dose rate) $^{99}\boldsymbol{Tc}$ ***:***

$D_{\gamma} = 5.76\ x\ 10^{-4} E_{\gamma} n_{\gamma} (1 - \Phi) C_S R \quad \mu Gy\ h^{-1}$

$D_{\gamma} = No\ data\ for\ ^{99}Tc\ Average\ (\gamma)\ \text{energy} \quad \mu Gy\ h^{-1}$

Calculating the internal (β- radiation dose rate) $^{99}\boldsymbol{Tc}$***:***

$D_{\beta} = 5.76\ x\ 10^{-4} E_{\beta} n_{\beta} C_0 \quad \mu Gy\ h^{-1}$

$D_{\beta} = (5.76\ x\ 10^{-4})(1.01\ x\ 10^{-1})(0.146)(5.44) \quad \mu Gy\ h^{-1}$

$D_{\beta} = 4.62\ x\ 10^{-5} \quad \mu Gy\ h^{-1}$

Calculating the internal (γ- radiation dose rate) $^{129}\boldsymbol{I}$ ***:***

$D_{\gamma} = 5.76\ x\ 10^{-4} E_{\gamma} n_{\gamma} (1 - \Phi) C_S R \quad \mu Gy\ h^{-1}$

$D_{\gamma} = (5.76\ x\ 10^{-4})(1.5\ x\ 10^{-1})(0.0945)(\frac{0.26}{10})(0.5)$

$D_{\gamma} = 1.06\ x\ 10^{-7} \quad \mu Gy\ h^{-1}$

Calculating the internal (β- radiation dose rate) ^{129}***I:***

$$D_\beta = 5.76\ x\ 10^{-4} E_\beta n_\beta C_0 \quad \mu Gy\ h^{-1}$$
$$D_\beta = (5.76\ x\ 10^{-4})(3.75\ x\ 10^{-2})(0.0945)(0.26) \quad \mu Gy\ h^{-1}$$
$$D_\beta = 5.31\ x\ 10^{-5} \quad \mu Gy\ h^{-1}$$

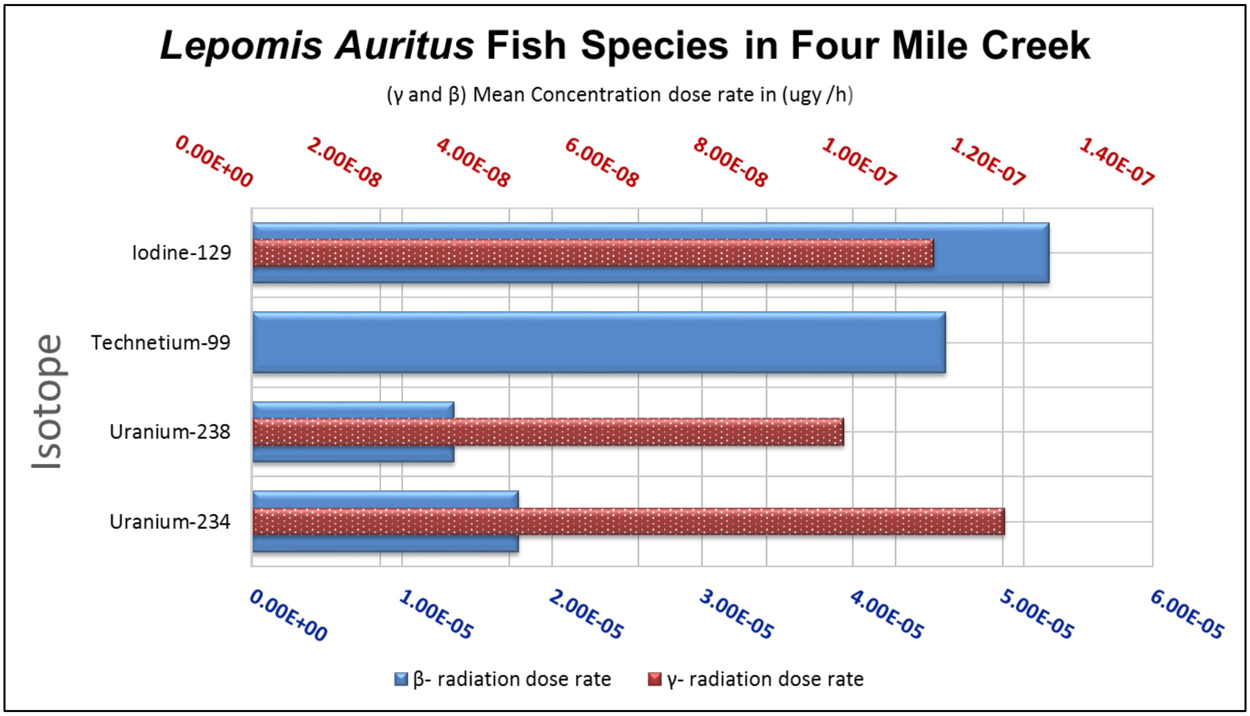


Figure 11. Total dose rate concentration for isotopes of concern in Four Mile Creek.

Bioaccumulation Rates

Bioaccumulation is known as the gradual build up over time of a specific chemical in a living organism and it is based on the media that contains the contaminants. To summarize, the contaminated groundwater with radionuclides such as iodine-129, uranium-234/238, and technetium-99 coming from the F-Area seepage basins may discharge contaminants to surface waters (Four Mile Branch) through its transition zone. In this study, the bioaccumulation rates of these contaminants were calculated for a specific fish species (*Lepomis auritus*) presently living in the bodies of water surrounding the FASB.

Bioaccumulation factor in (*Lepomis auritus):*

$$BAF = \frac{C_{fish}}{C_{medium}}$$

Where:

C_{fish} is the concentration of the contaminant in the fish (USDOE, 2011) (Table 2)

C_{medium} is the concentration of the contaminant in the medium (Dixon, Rogers 1992)

Bioaccumulation factor for iodine-129:

$$BAF_{Iodine-129} = \frac{C_{fish}}{C_{medium}} = \frac{0.26\,\frac{pCi}{g}}{46.8\,\frac{pCi}{L}} = 5\,x\,10^{-3}\,\frac{g}{L}$$

Bioaccumulation factor for technetium-99:

$$BAF_{Technetium-99} = \frac{C_{fish}}{C_{medium}} = \frac{5.44\,\frac{pCi}{g}}{51.2\,\frac{pCi}{L}} = 0.11\,\frac{g}{L}$$

Bioaccumulation factor for uranium-234:

$$BAF_{Uranium-234} = \frac{C_{fish}}{C_{medium}} = \frac{0.981\,\frac{pCi}{g}}{1\,\frac{pCi}{L}} = 0.981\,\frac{g}{L}$$

Bioaccumulation factor for uranium-238:

$$BAF_{Uranium-238} = \frac{C_{fish}}{C_{medium}} = \frac{0.944\,\frac{pCi}{g}}{1\,\frac{pCi}{L}} = 0.944\,\frac{g}{L}$$

Based on the BAF rate calculations, BAF values > 1 indicate that the accumulation in the organism is greater than that of the medium (*e.g.,* soil or water) from which the contaminant was taken, and BAF values < 1 indicate that the accumulation in the organism is less than the medium. The majority of the radionuclide releases to the Four Mile Creek are associated with the F- and H- separations areas (Murphy 1991). There are direct low-level releases of radionuclides from process outfalls and indirect releases from migration through the groundwater which was previously released to open seepage basins. Different types of fish were also analyzed, widening the ability to produce correlations. In this particular scenario, data was cleaned and only the Sunfish species is portrayed.

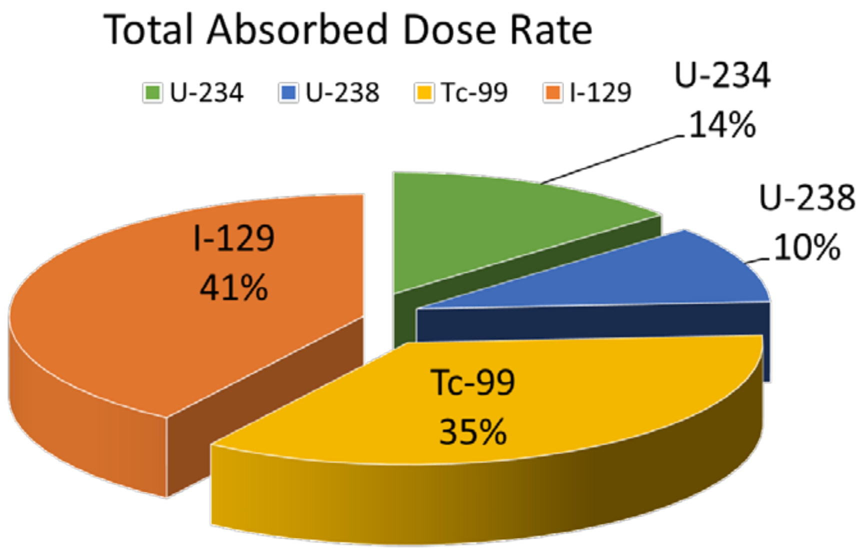


Figure 12. Contribution of analyzed radionuclides to the absorbed dose rate.

<u>**Decay Rate of Radionuclides**</u>

Calculating the decay rate of uranium-234:

$$\text{Decay Rate } (\lambda) = \frac{Ln\ 2}{Half\ Life} = \frac{Ln\ 2}{2.46\ x\ 10^5} = 2.82\ X\ 10^{-6}\ year^{-1}$$

Calculating the decay rate of uranium-238:

$$\text{Decay Rate } (\lambda) = \frac{Ln\ 2}{Half\ Life} = \frac{Ln\ 2}{4.468\ x\ 10^9} = 1.55\ X\ 10^{-10}\ year^{-1}$$

Calculating the decay rate of iodine-129:

$$\text{Decay Rate } (\lambda) = \frac{Ln\ 2}{Half\ Life} = \frac{Ln\ 2}{1.57x10^7} = 4.4X10^{-8}\ year^{-1}$$

Calculating the decay rate of techneitum-99:

$$\text{Decay Rate } (\lambda) = \frac{Ln\ 2}{Half\ Life} = \frac{Ln\ 2}{2.13x10^5} = 3.254X10^{-6}\ year^{-1}$$

Table 6. SRS Radionuclide Vertebrate and Invertebrate Characterization (1993-2008)

Table 5. Radionuclides Reported in Biota at or Near SRS From 1993 Through 2008

Radionuclide	Biota Type						
	Fish	Shellfish	Game Animals	Farm/ Domestic Animals	Milk	Agricultural Crops	Other Vegetation (Not Crops)
Gross alpha	X	X		X		X	X
Gross beta	X	X		X		X	X
Americium-241	X					X	
Beryllium-7						X	X
Cesium-134					X		
Cesium-136					X		
Cesium-137	X	X	X	X	X	X	X
Cobalt-60	X	X		X	X	X	X
Curium-244	X						
Iodine-129	X				X		
Plutonium-238	X	X	X	X		X	X
Plutonium-239	X	X	X	X	X	X	X
Potassium-40	X	X	X	X	X	X	X
Strontium-89		X	X	X	X	X	X
Strontium-89/90	X	X		X	X	X	X
Strontium-90	X	X	X	X	X	X	X
Technetium-99	X						
Tritium (hydrogen-3)	X	X	X	X	X	X	X
Uranium-234	X				X		X
Uranium-235	X				X		X
Uranium-238	X				X		X
Uranium/plutonium ratio				X		X	

Sources: Data provided by DOE, GDNR, and SCDHEC electronically or from their annual environmental reports. (WSRC ND[b through p]; SRNS ND; SCDHEC ND[a through j], 2005, 2006a, 2006b, 2010; GDNR 2005; Blackman 2009b)

Table 7. Summary of Groundwater Radionuclides Concentration in F-Area with their Clean-up Requirement Standards

Name of Isotope	Concentration (pCi/L)	Sample Media	Regulatory Driver	Cleanup Requirement
I-129	741	Groundwater	YES	1
U	341	Groundwater	YES	15
Sr-90	614	Groundwater	YES	8
Tc-99	313	Groundwater	YES	50
Ra	181	Groundwater	NO	5
Cs-137	77	Groundwater	NO	50
AM-241	23	Groundwater	NO	15
C-14	524	Groundwater	NO	50

A summary of recent analyses of radioactivity in groundwater from the FASB is provided in Table 7. Historical groundwater data was reviewed from well locations in order to monitor and identify compliance of the current groundwater actions.

Table 8. Total Dose Rate Concentrations for Sunfish in Four Mile Branch (SRS 2017)

Isotope Name	**B**	**γ**
Uranium-234	1.78 x 10^-5	1.17 x 10^-7
Uranium-238	1.35 x 10 ^-5	9.2 x 10^-8
Iodine-129	5.31 x 10^-5	1.06 x 10^-7
Technetium-99	4.62 x 10^-5	N/A

4. CONCLUSION

Several factors make the dose of radionuclides difficult to measure in an organism. For example, some radionuclides behave differently depending on species and organs associated with exposure. Tissue samples may have different radiation doses in the gills or bones, for example. Conclusions for this report show no quantifiable risk of detrimental responses affecting the *Lepomis auritus* species of Sunfish.

The U.S. Department of Energy guideline states that the threshold for radionuclide concentration in surface waters is 0.4 µGy h^{-1} (1 rad per day). Tables 4 and 5 summarize different reports of fish tissue samples and average energies of selected gross gamma (γ) and gross beta (β) isotopes, including those of naturally occurring alpha decay series.

The majority of the radionuclide contamination in Fourmile Branch is associated with the F-Area seepage basins. There are direct and indirect forms of fish being exposed. Based on the literature, most of the exposure is from groundwater plumes containing radionuclides. Other studies evaluated the effects at the organism level and their concern with viability. Lastly, the total dose rate was compared with other similar organisms to determine closely related effects.

Characterization of the baseline environment of the FASB included abiotic investigations. These included sampling of groundwater and surface waters. The study has been primarily performing monitoring and surveillance efforts to update the annual SRS environmental reports. Radioisotopes of uranium-234, uranium-238, iodine-129, and technetium-99 were found in the sediment, groundwater, surface water and fish tissue. The maximum radioactivity found was 300 pCi/L for Tc-99 near FASB in Fourmile Branch in 1994. The most recent and comprehensive sampling and analysis of sediment near the seepage basins occurred in 2008. The majority of the non-radiological constituents did not exceed the background levels. The average mean for Tc-99 was 4.85 $x10^{-1}$ pCi/L for 2008 at FM-2 at near road 4. Moreover, the semi-annual sampling program indicated that the surface waters and groundwater at the F- Area seeplines and Fourmile Branch contained contaminants associated with the seepage basins. Radioisotopes whose activity exceeded drinking water standards or maximum concentration levels included I-129 at an average concentration of 2.3 pCi/L.

In the case of iodine-129 and technetium-99, the concentration in the medium is noticeably higher than the concentration in the fish tissue; whereas, in the case of uranium, the concentration in the fish tissue and the medium is almost equal. To sum up, the bioaccumulation in the Sunfish tissue in Four Miles Branch is stable in most cases. However, there are some concerns regarding uranium since the BAF rates were very close to 1. Although groundwater and surface water are usually evaluated as separate systems, they are connected by the groundwater/surface water transition zone in a hydrologic continuum (Winter 2000). Since groundwater moves along flow paths from areas of recharge to discharge, it has the capability to exchange contaminants between systems. This report summarizes the importance of site remediation and values to substantially reduce the spread of contaminant plumes. The management of water and remediation of contamination requires the understanding of hydrological and health physics processes. Thanks to a multidisciplinary approach between hydrogeology, biochemistry, ecology and health physics, the groundwater/surface water interface can be studied using different parameters to help monitor the migration of contaminants and assure the safety of the workers, the public, and the environment.

5. REFERENCES

About SRNL - Our History. N.p., n.d. Web. 19 June 2017.

Advanced Simulation Capability for Environmental Management (ASCEM). (n.d.). Retrieved July 05, 2017, from http://esd1.lbl.gov/research/projects/ascem/

Agency for Toxic Substances and Disease Registry. Centers for Disease Control and Prevention. Centers for Disease Control and Prevention, 12 June 2011. (PDF) Web. 14 June 2017.

Aucott, W. R. (1997, August 01). Hydrology of the southeastern Coastal Plain aquifer system in South Carolina and parts of Georgia and North Carolina. Retrieved June 20, 2017, from https://pubs.er.usgs.gov/publication/pp1410E.

Aucott, W. R. (1997, August 01). Hydrology of the southeastern Coastal Plain aquifer system in South Carolina and parts of Georgia and North Carolina. Retrieved June 20, 2017, from https://pubs.er.usgs.gov/publication/pp1410E.

Cummins, C. L., Hetrick, C. S., & Martin, D. K. (1991). Radioactive releases at the Savannah River Site, 1954--1989 (No. WSRC-RP-91-684). Westinghouse Savannah River Co., Aiken, SC (United States).

DOE-EM. (2002). EIS-0303: Final Environmental Impact Statement. Retrieved June 22, 2017, from https://energy.gov/nepa/downloads/eis-0303-final-environmental-impact-statement.

Evaluation of Exposures to Contaminants in Biota Originating from the Savannah River Site (USDOE). (2011, August). Retrieved from https://www.atsdr.cdc.gov/hac/pha/savannahriversite/srsbiotaphapc082411cc.pdf

Fernandes, H. M., Veiga, L. H. S., Franklin, M. R., Prado, V. C. S., & Taddei, J. F. (1996). Environmental impact assessment of uranium mining and milling facilities: a study case at the Poços de Caldas uranium mining and milling site, Brazil. In International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts (Vol. 1, No. 33, pp. 41A-42A).

Friday, G. P. (1997). Environmental summary of the F-and H-area seepage basins groundwater remediation project, Savannah River site (No. WSRC-TR--97-0130). Westinghouse Savannah River Co.

Investigations into a case of tree stress and mortality in wetlands. (1992, July). Retrieved from http://images.library.wisc.edu/EcoNatRes/EFacs/Wetlands/Wetlands21/reference/econatres.wetlands21.vrogers.pdf

Jorque, M. A., Golshir, G. H., & Davis, B. (1998). Groundwater Treatment at SRS: An Innovative Approach (No. WSRC-RP--97-849-Rev. 2; CONF-980307--). Westinghouse Savannah River Co., Aiken, SC (United States).

Millings, M. (2013). PRELIMINARY DATA REPORT: HUMATE INJECTION AS AN ENHANCED ATTENUATION METHOD AT THE F-AREA SEEPAGE BASINS, SAVANNAH RIVER SITE (No. SRNL-STI-2013-00514). SRS.

Millings, M. (2013). Preliminary Data Report: Humate Injection as an Enhanced Attenuation Method at the F-Area Seepage Basins, Savannah River Site. doi:10.2172/1096604.

Millings, M. (2013). Preliminary Data Report: Humate Injection as an Enhanced Attenuation Method at the F-Area Seepage Basins, Savannah River Site. doi:10.2172/1096604.

Moran, J. E., Oktay, S. D., & Santschi, P. H. (2002). Sources of iodine and iodine 129 in rivers. Water resources research, 38(8).

Murphy Jr, C. E., & Loehle, C. (1991). Levels of radioactivity in fish from streams near F-Area and H-Area seepage basins (No. WSRC-RP--91-242). Westinghouse Savannah River Co., Aiken, SC (United States).

PA.Gov. Sunfishes. N.p., n.d. Web. 06 July 2017.

Paller, M. H., & Storey, C. (1990). Effects of outcropping groundwater from the F-and H-Area seepage basins on the distribution of fish in Four Mile Creek (No. WSRC-TR-90-502). Westinghouse Savannah River Co., Aiken, SC (USA).

Proceedings of the Ground-Water/Surface-Water Interactions (n.d.). Retrieved June 9, 2017, from https://www.bing.com/cr?IG=7F91A6FA5C344125A93E50E5ABB88159&CID=0C7BFD7E52E46A6932BBF7E253E26BDE&rd=1&h=sS1Zc6TrgTmDbOba8usBmvsnbS3-0fUggAOi05JfPGI&v=1&r=https%3a%2f%2fwww.epa.gov%2fsites%2fproduction%2ffiles%2f2015-06%2fdocuments%2fgwsw_workshop.pdf&p=DevEx,5062.1.

Radionuclide Basics: Iodine. EPA. Environmental Protection Agency, 04 May 2017. Web. 20 June 2017.

Search Superfund Site Information. EPA. Environmental Protection Agency, 28 Dec. 2016. (PDF) Web. 14 June 2017.

SRNL. Facts. (n.d.). Retrieved July 11, 2017, from http://srnl.doe.gov/factsht.htm

Toxic Substances Portal - Uranium. (n.d.). Retrieved June 14, 2017, from https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=439&tid=77.

USGS.Precipitation. (n.d.). Retrieved June 17, 2017, from https://waterdata.usgs.gov/sc/nwis/current/?type=precip&group_key=county_cd

Waste Management Facility (U), SRNS-RP-2012-00045, Savannah River Nuclear Solutions.

WSRC, 2005. Annual Corrective Action Report for the F-Area Hazardous Waste.

6. ACKNOWLEDGEMENTS

We would like to thank all of the research scientists who provided us with help and guidance during this research, most importantly Mr. Skip Chamberlain, Mr. Kurt Gerdes, Ms. Carol Eddy-Dilek, Dr. Miles Denham, and Dr. James Poppiti, for all their support and mentorship at the Office of Environmental Management (DOE EM) and Savannah River Site (SRS). Our appreciation also extends to Dr. Leonel Lagos, program director for the DOE-FIU Science and Technology Workforce Development Program and to all the good friends and colleagues we made throughout this internship.