HRSD

November 3, 2020

James C. Bennett Jr., Section Chief
Drinking Water & Source Water Protection Branch
Source Water & UIC Section
1650 Arch Street
Philadelphia PA, 19103
Mail Code: 3WD22

Dear Mr. Bennett:

HRSD's Sustainable Water Initiative for Tomorrow (SWIFT) is moving forward with its next significant milestone: implementation of its first full-scale facility, a 16 million gallons per day (MGD) facility located at the HRSD James River Treatment Facility. As a managed aquifer recharge program, HRSD SWIFT will add advanced water treatment processes to up to five HRSD wastewater treatment facilities to produce a highly treated water (SWIFT Water$^{\text{TM}}$) that meets drinking water standards and is compatible with the receiving aquifer. Secondary effluent from HRSD's existing treatment facilities will be treated at SWIFT facilities and SWIFT Water$^{\text{TM}}$ will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. When fully implemented, HRSD will have the capacity to recharge approximately 100 MGD of SWIFT Water$^{\text{TM}}$.

This UIC permit application package for James River SWIFT is a culmination of learning gained through two years of operation of the SWIFT Research Center (SRC), located at HRSD's Nansemond Treatment Facility in Suffolk, VA. The SRC has housed a successful collaborative research program with a goal of optimizing advanced treatment performance and recharge well operations ahead of full-scale implementation. With a maximum capacity of 1 MGD, the SRC has successfully recharged over 400 million gallons to the PAS, a first and important achievement toward creating a sustainable supply of groundwater for eastern Virginians.

SWIFT continues to gain support within the state and local communities. Not only has the state recognized SWIFT as a key element for improving the sustainability of groundwater in Virginia, but it is also recognized as a mechanism to support Virginia's efforts to meet its Chesapeake Bay Restoration goals. HRSD's extensive outreach to neighbors and community leaders regarding the SWIFT program at the James River facility garnered broad support for the SWIFT program and its proposed layout of facilities in the surrounding area.

As another demonstration of commitment to full-scale SWIFT, the Virginia General Assembly enabled an independent oversight body, the Potomac Aquifer Recharge Oversight Committee and its companion Potomac Aquifer Recharge Monitoring Laboratory (PARML), to provide independent oversight and monitoring of the SWIFT treatment processes, observe the aquifer response to the recharge, and confirm compliance with SWIFT program performance targets. The PAROC includes representation from the Virginia Department of Environmental Quality, the Virginia Department of

PO Box 5911, Virginia Beach, VA 23471-0911 • 757.460.7003

Commissioners: Frederick N. Elofson, CPA, Chair • Maurice P. Lynch, PhD, Vice-Chair • Vishnu K. Lakdawala, PhD
Michael E. Glenn • [illegible] Molly Joseph Ward
www.hrsd.com

Health, and regional stakeholders with a vested interest in protecting the underground sources of drinking water.

Most recently, federal support has been expressed through EPA's Water Infrastructure Finance and Innovation Act (WIFIA). HRSD received a $225 million Water Infrastructure Finance and Innovation Act (WIFIA) loan to support James River SWIFT. This loan represented the first installment of EPA's commitment to provide a total of $1.05 billion in WIFIA loans to help finance full-scale implementation of SWIFT. Additionally, the SWIFT program schedule has been incorporated into the implementation schedule for HRSD's wet weather commitments developed to satisfy the requirements of our Consent Decree (Civil Action No. 2:09-cv-481). The integrated schedule allows prioritization of the region's wastewater and stormwater investments to ensure that the projects and activities that achieve the most significant environmental benefits (SWIFT in particular) occur first.

Much of the information presented in the application package was developed as part of an iterative process with the PAROC and the National Water Research Institute's (NWRI) independent advisory panel. These entities provided significant input into the detailed appendices, Appendix A James River SWIFT Water Quality Targets and Appendix B James River SWIFT Aquifer Monitoring and Contingency Plan. These two documents established the framework for monitoring both in SWIFT Water and within the aquifer and identified the water quality evaluations and layered performance controls necessary to ensure the protection of public health and preservation of the underground source of drinking water.

Please do not hesitate to call anytime if I can be of assistance on any issue. I can be reached by cell phone at 757-274-7904 or by email at thenifin@hrsd.com.

Respectfully,

Ted Henifin, P.E.
General Manager

C: Mark Nelson, EPA Region III
Potomac Aquifer Recharge Oversight Committee
Ryder Bunce, VDH
Scott Kudlas, VDEQ
Glen Daigger, University of Michigan, NWRI Panel Chair

OMB No. 2040-0042 Approval Expires 4/30/2022

United States Environmental Protection Agency

Underground Injection Control
Permit Application for a Class V Well

(Collected under the authority of the Safe Drinking Water Act. Sections 1421, 1422, and 40 CFR Part 144)

For Official Use Only

Date Received

Permit Number

Read Attached Instructions Before Starting

I. Owner Name, Address, Phone Number and/or Email	II. Operator Name, Address, Phone Number and/or Email
HRSD 1434 Air Rail Ave Virginia Beach VA 23455 Contact Ted Henifin: 757-460-4212	HRSD James River Treatment Plant 111 City Farm Rd Newport News VA 23602

III. Commercial Facility	IV. Ownership	V. Permit Action Requested	VI. SIC Code(s)	VII. Indian Country
☐ Yes ☒ No	☐ Private ☐ Federal ☒ State/Tribal/ Municipal	☒ New Permit ☐ Permit Renewal ☐ Modification ☐ Add Well to Area Permit ☐ Other	9511 4952	☐ Yes ☒ No

VIII. Type of Permit (For multiple wells, use additional page(s) to provide the information requested for each additional well)

	Number of Wells	Well Field and/or Project Names
☐ A. Individual ☒ B. Area	10	HRSD James River SWIFT

IX. Class and Type of Well (see reverse)

A. Class	B. Type (enter code(s))	C. If type code is "X," explain.
V	B	

X. Well Status

☐ A. Operating ☐ B. Conversion ☒ C. Proposed

Date Injection Started:

Date Well Constructed:

XI. Well Information

API Number:

Permit (or EPA ID) Number:

Full Well Name: HRSD James River SWIFT

XII. Location of Well or, for Multiple Wells, Approximate Center of Field or Project

Locate well in two directions from nearest lines of quarter section and drilling unit Surface Location

____ 1/4 of ____ 1/4 of Section ____ Township ____ Range ____

____ ft. from (N/S) ____ Line of quarter section

____ ft. from (E/W) ____ Line of quarter section.

Latitude: 37 05' 04.8" N

Longitude: 76 31' 47.1" W

XIII. Attachments

In addition to this form, complete Attachments A-U (as appropriate for the specific well class) on separate sheets. Submit complete information, as required in the instructions and list all attachments, maps or other figures, by the applicable letter.

XIV. Certification

I certify under the penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possiblity of fine and imprisonment. (Ref. 40 CFR § 144.32)

Name and Official Title *(Please Type or Print)*	Signature	Date Signed
Edward G. Henifin, General Manager		11/03/2020

EPA Form 7520-6 (Rev. 4-19)

Attachment A: Maps and Area of Review (AOR)

A.1 Part I. Well Locations

The James River SWIFT Facility is located at HRSD's James River Treatment Facility at 101 City Farm Rd. in Newport News, VA 23602, along the James River. JR SWIFT will consist of ten Managed Aquifer Recharge (MAR) wells and two clustered monitoring well (MC) sites, each containing four depth discrete monitoring wells (Table A.1). Within the AOR, there are three private wells and two City-owned irrigation wells, all classified as non-potable, and all screened in the surficial aquifer (Table A.2).

Table A.1: Coordinates for MAR well and MW locations.

SWIFT Managed Aquifer Recharge Wells		
Well Number	Northing	Easting
JR_MAR_01	3560084.87	12056249.13
JR_MAR_02	3560468.94	12056939.61
JR_MAR_03	3560839.09	12056065.77
JR_MAR_04	3561257.81	12056795.54
JR_MAR_05	3559400.44	12057941.70
JR_MAR_06	35600270.34	12057823.93
JR_MAR_07	3561174.08	12057730.07
JR_MAR_08	3562403.26	12056654.33
JR_MAR_09	3563378.24	12056392.09
JR_MAR_10	3563697.84	12057415.81
SWIFT Monitoring Wells		
Well Number	Northing	Easting
Well Cluster JR_MC1	3561623.00	12056379.05
JR_MC1_UA		
JR_MC1_UB		
JR_MC1_UC		
JR_MC1_MA		
Well Cluster JR_MC2	3563670.58	12056894.02
JR_MC2_UA		
JR_MC2_UB		
JR_MC2_UC		
JR_MC2_MA		

Table A.2: Coordinates and relevant information for existing wells within AOR.

Existing Wells within AOR, City of Newport News				
Identification	Northing	Easting	Total Well Depth	Well Type
108 River Birch Ct	3563713.46	12055022.49	26 ft	Class IV, irrigation
328 Peach Tree Crescent	3564437.78	12055846.94	30 ft	Class IV, irrigation
45 Island View Drive	3563870.87	12055419.84	28 ft	Class IV, irrigation
Park Irrigation 1	3563693.35	12057172.33	Not available	Class IV, irrigation
Park Irrigation 2	3563693.35	12057079.01	Not available	Class IV, irrigation

The well locations and Area of Review (AOR) are shown in Figure A.1 and included in a GIS file submitted electronically.

A.2 Part II. Area of Review Determination

A ¼ mile buffer around the area of the wellfield area boundary was used to define the AOR, see Figure A.1.

Figure A.1: Proposed locations of Managed Aquifer Recharge (MAR) Wells for JR SWIFT and monitoring wells. MAR and monitoring well locations may be adjusted based on site specific conditions but will lie within the area of the wellfield denoted by the blue boundary. Private wells are identified in blue and red. The three private wells that have been constructed within the AOR are less than 50 feet deep and screen the surficial Columbia Aquifer. All existing and potential future wells based on available permit applications are classified as non-potable and each of these private well users is connected to the public water supply for potable water use (Newport News Waterworks). The brackish groundwater quality contained in the upper and middle zones of the Potomac Aquifer System (UPA and MPA) makes using these aquifers for potable, irrigation, commercial, or industrial supplies impractical. Note well features are not to scale.

A.3 Part III. Maps

Figure A.1 documents the AOR, identifying the proposed MAR and monitoring well locations along with identifying landmarks. Figure A.2 provides a topographic depiction of the AOR with a 1-mile buffer identified around the AOR. There are no known outcrops of injection and confining formations, no known surface water intake and discharge structures, and no known hazardous waste treatment, storage, or disposal facilities.

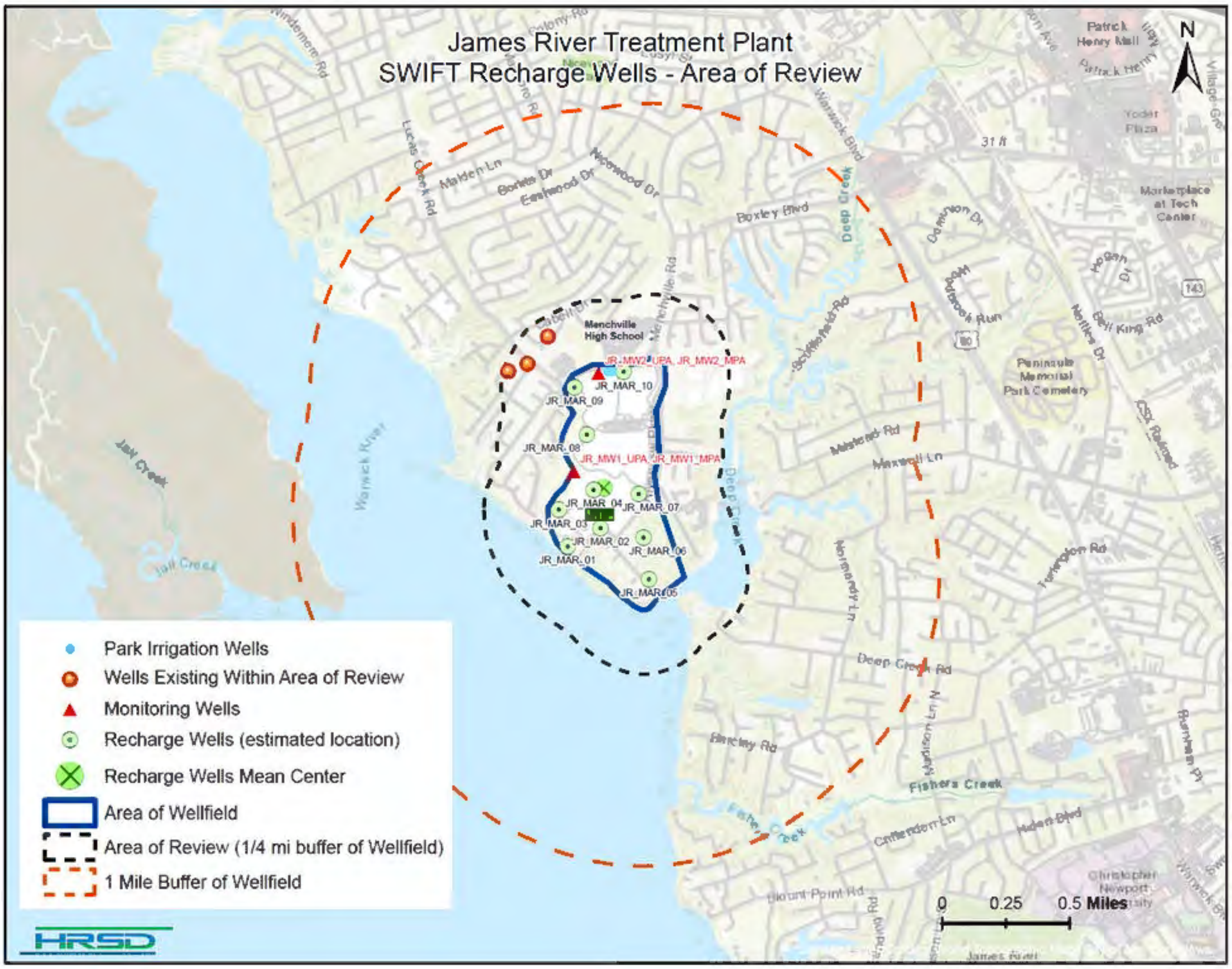


Figure. A.2: Topographic map of AOR with 1-mile buffer of wellfield. MAR and monitoring well locations may be adjusted based on site specific conditions but will lie within the area of the wellfield denoted by the blue boundary. Private wells are identified in blue and red. Note well features are not to scale.

A.4 Part IV. Area of Review Wells and Corrective Action Plan

There are no wells within the AOR that penetrate the proposed confining zone(s) of the target aquifer, therefore no corrective action plan is necessary.

A search of the private well database maintained by the Virginia Department of Health and permitted well database maintained by the Virginia Department of Environmental Quality revealed only three constructed wells located within the AOR. They are all installed within the surficial aquifer and are classified as non-potable, irrigation wells. These addresses are all supplied potable water from Newport News Waterworks. Construction details are in Table A.3.

The target recharge zones (Potomac aquifer) occur between approximately 400 to 1,200 feet below the ground surface (ft bgs). There are four confining zones above the Potomac Aquifer:

- Yorktown Eastover confining unit
- Saint Mary's-Calvert confining unit
- Chickahominy confining unit
- Exmore confining unit

See Attachment B, Figure B.10 for details of the hydrogeologic section at James River based on the James River Test Well.

The wells identified within the AOR have a total depth between 26 to 30 ft bgs and do not penetrate the confining zone of the target aquifer.

Available well construction details are shown in the table below.

Table A.3: Construction details for private wells located within AOR.

Address	Well Type	Status	Well Class*	Depth of casing (ft bgs)	Minimum grout depth (ft bgs)	Total Well Depth (ft bgs)	Type of casing	Diameter of casing (inches)	Annular space grout type
108 River Birch Ct, Newport News, VA 23602	irrigation	installed	IV	20	20	26	PVC Plastic	2	Bentonite
328 Peach Tree Cr, Newport News, VA 23602	irrigation	Installed	IV	20	20	30	Sch 40 PVC WC	1.25	Neat cement
45 Island View Dr, Newport News, VA 23602	irrigation	installed	IV	20	20	28	Sch 40 PVC WC	2	Neat cement

*Virginia Department of Health Class IV well is defined as non-potable use.

A.5 Part V. Land Owner Information

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
LAWSON MICHAEL R & CYNTHIA B		318 HILLSIDE TER	190000309	3 RUTH CIRCLE	HAMPTON	VA	23666
WEIMER KATHARINE L		314 HILLSIDE TER	190000311	314 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
WATSON WILLIAM J III	WATSON SALLIE T	116 BLUFF TER	190000327	116 BLUFF TERRACE	NEWPORT NEWS	VA	23602
BOOKOUT CALVIN C ET UX		409 MENCHVILLE RD S	190000106	409 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
RUSS LAURA A TRUSTEE OF LAURA A		211 BLUFF TER	190000350	211 BLUFF TERRACE	NEWPORT NEWS	VA	23602
COOK STEPHEN T	COOK JENNIFER B	108 OVERLOOK CV	190000274	108 OVERLOOK COVE	NEWPORT NEWS	VA	23602
WHITLEY CLARENCE E UX		403 MENCHVILLE RD S	190000103	403 MENCHVILLE RD S	NEWPORT NEWS	VA	23602
SMITH RICHARD O III	SMITH LOIS R	403 HARBORVIEW LN	190000261	403 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
WEBB MARK E	WEBB ROBYN L	360 WOOD DUCK LN	190000231	360 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
LASSITER WILLIAM S	LASSITER PATRICIA W	359 WOOD DUCK LN	190000233	359 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
SCHILLING MARK S		359 WATERFOWL LN	190000247	359 WATERFOWL LANE	NEWPORT NEWS	VA	23602
WILLIAMS NANCY K		9 CAMELLIA DR	179000123	9 CAMELIA DRIVE	NEWPORT NEWS	VA	23602
NOVOTNY JOSEPH AUGUST	NOVOTNY TINA LOUISE	20 CAMELLIA DR	179000121	4 CAMELLIA DR	NEWPORT NEWS	VA	23602
TAYLOR HORTENSE ANN TRUSTEE		306 OLD MENCHVILLE RD # B	179000102	306 B OLD MENCHVILLE RD	NEWPORT NEWS	VA	23602
PATERNO CHRISTOPHER A & CAROLINE	PATERNO	334 HILLSIDE TER	190000345	334 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
WALKER RICHARD C	WALKER ANN J	313 HILLSIDE TER	190000304	313 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
HARVEY JERRY L		329 HILLSIDE TER	190000339	329 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
GREW GARY W		205 BLUFF TER	190000336	205 BLUFF TERRACE	NEWPORT NEWS	VA	23602
NURSE JASMINE G		401 MENCHVILLE RD S	190000102	401 MENCHVILLE RD S	NEWPORT NEWS	VA	23602
FITZGERALD JOEL E	FITZGERALD ELIZABETH UPOLE	355 WOOD DUCK LN	190000235	355 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
MONTGOMERY ROBERT M	BATTS JANICE E	442 MARINA LN	190000210	442 MARINA LANE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
RAGUS LEONARD ADOLPH TRUSTEE	RAGUS DONNA LEE TRUSTEE	352 WOOD DUCK LN	190000227	352 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
YAHATTA NATNOPADOL	YAHATTA LORINA	19 CAMELLIA DR	179000136	19 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
KIRKLAND LAWRENCE W	KIRKLAND MARSHA ANN	640 DEEP CREEK RD	199000205	640 DEEP CREEK ROAD	NEWPORT NEWS	VA	23606
MOLIKEN MARTY S & SUSAN M MOLIKEN	& JEFFREY A DEYONG	635 DEEP CREEK RD	200000451	665 DEEP CREEK ROAD	NEWPORT NEWS	VA	23606
WARTHAN DANIEL KEITH & JENNIFER		320 HILLSIDE TER	190000308	320 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
PLARR MAXWELL J		316 HILLSIDE TER	190000310	316 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
TAYLOR H A III & VANDA L TAYLOR		102 BLUFF TER	190000333	102 BLUFF TERRACE	NEWPORT NEWS	VA	23602
FRADY FAMILY LIVING TRUST		301 HILLSIDE TER	190000318	301 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
JOHNSON JAMES A TR	JOHNSON CELIA C TR	118 BLUFF TER	190000312	118 BLUFF TERRACE	NEWPORT NEWS	VA	23602
NEMCEFF JACK L II		208 BLUFF TER	190000322	208 BLUFF TERRACE	NEWPORT NEWS	VA	23602
HACKETT MARGARET E		209 BLUFF TER	190000349	209 BLUFF TERRACE	NEWPORT NEWS	VA	23602
BATTS GEORGE J	BATTS ELIZABETH M	366 MENCHVILLE RD S	190000263	366 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
ROY GEORGE J ET UX		324 HILLSIDE TER	190000342	51 MEROKEE PLACE	FARMINGDALE	NY	11735
MEDICI SUZANNE MICHELE		309 HILLSIDE TER	190000302	309 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
THOMPSON BRENDA		310 HILLSIDE TER	190000315	310 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
BAKER CYNTHIA A TR	CYNTHIA A BAKER REVOCABLE TRUST	106 BLUFF TER	190000329	3 BAKERS LANE	POQUOSON	VA	23662
LAWRENCE SHERRILYN SLATE TRUSTEE		210 BLUFF TER	190000321	210 BLUFF TERRACE	NEWPORT NEWS	VA	23602
IMHOF MARK N		201 BLUFF TER	190000334	201 BLUFF TERRACE	NEWPORT NEWS	VA	23602
VA HOME LLC		407 MENCHVILLE RD S	190000105	1505 OAK HILL COURT	VIRGINIA BEACH	VA	23322
WOLF EVELYN A		412 HARBORVIEW LN	190000275	228 KEITH RD	NEWPORT NEWS	VA	23602
BOOKBINDER SHEILA B ET VIR		112 OVERLOOK CV	190000272	112 OVERLOOK COVE	NEWPORT NEWS	VA	23602
COMER JOHN B JR & ANN MARIE COMER		110 OVERLOOK CV	190000273	110 OVERLOOK COVE	NEWPORT NEWS	VA	23602
BEASLEY LUKE D	BEASLEY JULIA A	111 OVERLOOK CV	190000267	111 OVERLOOK COVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
RAMEY DONALD D		448 MARINA LN	190000222	103 BELGRAVE ROAD	NEWPORT NEWS	VA	23602
WILSON GARY A	WILSON CHERYL C	356 WOOD DUCK LN	190000229	356 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
BLANCHE JOHN B III	BLANCHE DOROTHY W	106 CANVASBACK TRL	190000239	106 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
WHITAKER AARON E	WHITAKER DEBRA L	109 CANVASBACK TRL	179000205	109 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
LAND JUSTIN B & HEATHER M LAND		107 CANVASBACK TRL	179000204	107 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
RODRIGUEZ HUMBERTO	RODRIGUEZ MARIA L	7 CAMELLIA DR	179000124	7 CAMELLIA DR	NEWPORT NEWS	VA	23602
NOVOTNY JOSEPH A	NOVOTNY TINA L	2 CAMELLIA DR	179000131	4 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
RIFFE WAYNE A II	RIFFE ERIKA D	458 MENCHVILLE RD S	190000216	458 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
BOWEN PATRICIA A		306 HILLSIDE TER	190000317	306 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
KIEFFER JEAN PIERRE G		114 BLUFF TER	190000326	114 BLUFF TERRACE	NEWPORT NEWS	VA	23602
WALTZ CHRISTOPHER	WALTZ BECKY A	409 HARBORVIEW LN	190000258	409 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
ODOM CATHERINE A		114 OVERLOOK CV	190000271	114 OVERLOOK COVE	NEWPORT NEWS	VA	23602
FORBES PHILIP J III	FORBES LYNN C	109 OVERLOOK CV	190000266	109 OVERLOOK COVE	NEWPORT NEWS	VA	23602
WILLIAM ROGER JR ET UX		357 WATERFOWL LN	190000248	357 WATERFOWL LANE	NEWPORT NEWS	VA	23602
PATTERSON RYAN J		353 WOOD DUCK LN	190000236	353 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
WILSON RUBIN R	WILSON PAULETTE L	219 CABELL DR	167000416	219 CABELL DRIVE	NEWPORT NEWS	VA	23602
YOUNG KAREN D ET VIR		230 WEATHERFORD WAY	168000617	230 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
MAXEY REMICK		231 WEATHERFORD WAY	168000616	231 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
BARCLAY LAWRENCE J	BARCLAY ELEANOR J	226 SHERBROOKE DR	167000408	226 SHERBROOKE DRIVE	NEWPORT NEWS	VA	23602
ROBINSON LAMON	JEFFERSON BENYETTA MONTOYA	24 LUCAS CREEK RD	167000465	24 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
FOSTER JOHN J JR TR	FOSTER RHONDA R TR	329 PEACH TREE CRES	167000448	329 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
BROWN JEREON M	BROWN FRANCES M	228 SHERBROOKE DR	168000118	228 SHERBROOKE DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
KROPP WAYNE J	KROPP MONICA B	235 WEATHERFORD WAY	168000614	235 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
HOWELL EDDIE L	HOWELL ALICIA R	237 WEATHERFORD WAY	168000613	237 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
PROTZMAN SARAH K		318 OLD MENCHVILLE RD	179000120	164 CARNEGIE DRIVE	NEWPORT NEWS	VA	23606
HUFFMAN GAY C TR	HUFFMAN GAY C TR	25 LUCAS CREEK RD	167000333	P O BOX 6368	NEWPORT NEWS	VA	23606
WICKER PAUL JULIAN TR	WICKER JOAN WILSON TR	1 E GOVERNOR DR	189000119	1 EAST GOVERNOR DR	NEWPORT NEWS	VA	23602
LEE JA HYUN & CHANG B TRUSTEES OF		37 E GOVERNOR DR	178000330	37 GOVERNOR DRIVE EAST	NEWPORT NEWS	VA	23602
MANZLAK NANCY A		7 HORSE PEN RD	189000414	7 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
EUBANK WILLIAM T	EUBANK ALLYSON G	31 W GOVERNOR DR	178000220	31 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
FARRAR GEORGE C IV	FARRAR JEAN H	18 ISLAND VIEW DR	178000515	18 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
DIANA GLORIA V TRUSTEE	GLORIA V DIANA REVOCABLE LIVING TRUST	14 E GOVERNOR DR	189000127	14 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
CATES GREGORY A	CATES JOYCE E	6 E GOVERNOR DR	189000123	6 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
LIFFICK MATTHEW K	LIFFICK MARION G	6 RIVER POINT CIR	189000204	6 RIVER POINT CIR	NEWPORT NEWS	VA	23602
GILLIKIN VICKY M & BARRY G	GILLIKIN	5 RIVER POINT CIR	189000203	5 RIVER POINT CIRCLE	NEWPORT NEWS	VA	23602
VASQUEZ FELIPE R	VASQUEZ ELSA S	55 W GOVERNOR DR	178000211	55 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
BOUTEILLER DAVID L	BOUTEILLER NANCY M	50 RAMSHAW LN	178000227	50 RAMSHAW LANE	NEWPORT NEWS	VA	23602
CYRUS ERIKA E		270 LOU MAC CT	168000504	270 LOU MAC COURT	NEWPORT NEWS	VA	23602
URIE ANDREA	URIE JAMISON	108 TERRI BETH PL	168000518	108 TERRI BETH PLACE	NEWPORT NEWS	VA	23602
ALEXANDER GAIL F		336 HILLSIDE TER	190000344	336 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
STEIN SARA ANN TR	SARA ANN STEIN REVOCABLE TRUST	332 HILLSIDE TER	190000346	332 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
JOHNSON LEIGH G		326 HILLSIDE TER	190000341	326 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
CAMPBELL HUGH B	CAMPBELL DIANNA S	462 MENCHVILLE RD S	190000217	462 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
CLOHERTY SEAN M		206 BLUFF TER	190000323	206 BLUFF TERRACE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
FORBES PHILIP J IV TR	FORBES GINA L TR	413 HARBORVIEW LN	190000256	413 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
CECCONI MARION E		207 BLUFF TER	190000348	207 BLUFF TERRACE	NEWPORT NEWS	VA	23602
HEYWARD ANTHONY J	HEYWARD CATHERINE J	405 HARBORVIEW LN	190000260	405 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
GRINSTEAD MICHAEL C	GRINSTEAD CELIA A	113 OVERLOOK CV	190000268	113 OVERLOOK COVE	NEWPORT NEWS	VA	23602
DEVER JOHN T TR	JOHN T DEVER LIVING TRUST	360 WATERFOWL LN	190000244	361 WATERFOWL LANE	NEWPORT NEWS	VA	23602
HOUSLEY TIMOTHY M	HOUSLEY SUSAN D	118 CANVASBACK TRL	190000225	118 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
WILLIAMS CHARLES B		3 CAMELLIA DR	179000126	3 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
WALSETH LISA M		11 CAMELLIA DR	179000133	11 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
GUTHRIE ROBERT W TRS OF		18 CAMELLIA DR	179000116	18 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
CARRO CARL T	CARRO DARYL L	316 OLD MENCHVILLE RD	179000119	316 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
SMITH HUDSON D;MELISSA E SMITH &	ANNA L EDENTON	300 OLD MENCHVILLE RD	179000132	300 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		292 ADRIENNE PL # B	168000353	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
SOK CHANTHOEUN	SOK SAMBATH T	230 CABELL DR	167000441	230 CABELL DRIVE	NEWPORT NEWS	VA	23602
HARRIS ROBERT L ET UX		232 CABELL DR	168000148	232 CABELL DRIVE	NEWPORT NEWS	VA	23602
GOLDBERG ALAN B & DEBORAH C		35 ISLAND VIEW DR	178000541	35 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
HANSON ERIC P	HANSON LESLIE L	25 ISLAND VIEW DR	178000536	25 ISLAND VIEW DR	NEWPORT NEWS	VA	23602
BOERNER MATTHEW R	BOERNER PAMELA L	27 ISLAND VIEW DR	178000537	27 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
BAY MINA FREEZE		42 E GOVERNOR DR	178000335	42 GOVERNOR DR E	NEWPORT NEWS	VA	23602
PEARSON NEVILLE A ET UX		44 E GOVERNOR DR	178000334	44 EAST GOVERNOR DR	NEWPORT NEWS	VA	23602
MCDONOUGH JOHN D		94 SHOEMAKER CIR	178000338	94 SHOEMAKER CIRCLE	NEWPORT NEWS	VA	23602
HART POWELL H		96 SHOEMAKER CIR	178000337	96 SHOEMAKER CIRCLE	NEWPORT NEWS	VA	23602
NEIGHBORS THOMAS E	NEIGHBORS STEPHANIE D	20 HORSE PEN RD	189000404	20 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
CARRITHERS DONALD R & CAROL M	CARRITHERS	11 FLAX MILL RD	189000219	11 FLAX MILL ROAD	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
HUNT ELVA W		4 BLACKSMYTHE LN	178000238	4 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
ROGALA RICHARD	ROGALA ASTRID H	189 LORI CIR	168000363	189 LORI CIRCLE	NEWPORT NEWS	VA	23602
HOKE GREGORY A	HOKE BETTY K	198 LORI CIR	168000369	198 LORI CIRCLE	NEWPORT NEWS	VA	23602
QUEEN SCOTT		295 ADRIENNE PL	168000341	295 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
TIDEWATER PROPERTY TWO L L C		287 LOU MAC CT	168000323	429 WESTON ROAD	YORKTOWN	VA	23692
HAYS GARY E	HAYS MICHELLE M	333 PEACH TREE CRES	167000446	333 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
BRANTLEY LORRIE L P ET VIR		28 LUCAS CREEK RD	167000463	28 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
MICHALAK MARK M & JENNIFER D	GURNICKE	313 TAHOE DR	168000155	313 TAHOE DRIVE	NEWPORT NEWS	VA	23602
MILES ANTHONY C SR	MILES BARBARA D	230 SHERBROOKE DR	168000119	230 SHERBROOKE DRIVE	NEWPORT NEWS	VA	23602
TEASLEY CHRISTOPHER C	TEASLEY JOAN Y	204 LENTZ PL	167000454	204 LENTZ PLACE	NEWPORT NEWS	VA	23602
DEHART ALBERT L JR	DEHART MARY E T	229 CABELL DR	167000421	229 CABELL DRIVE	NEWPORT NEWS	VA	23602
HUDGINS KELLY L &	LESLIE R COOPER JR	243 CABELL DR	168000137	243 CABELL DRIVE	NEWPORT NEWS	VA	23602
LEBLANG STEVEN S	LEBLANG LINDA S	115 CANVASBACK TRL	179000208	115 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
LAUGHRUN JERRY S	LAUGHRUN SUSAN C	113 CANVASBACK TRL	179000207	113 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
LEWTON WILLIAM R JR	LEWTON SUSAN L	105 CANVASBACK TRL	179000203	105 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
STURGIS WILLIAM T	STURGIS RHONDA L	8 CAMELLIA DR	179000110	8 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
WELCHER BRENT C	WELCHER MIRANDA L	40 W GOVERNOR DR	178000307	40 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
PULTZ RICHARD L	PULTZ DONNA S	42 W GOVERNOR DR	178000306	42 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
GRAHAM KEITH D	GRAHAM CINDY	11 HORSE PEN RD	189000416	11 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
HOEGGER JULIE		11 BLACKSMYTHE LN	178000245	11 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
HARRIS TERRY W	HARRIS TAMMY K	30 LUCAS CREEK RD	167000462	30 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
BECKERDITE WILLIAM G ET UX		33 W GOVERNOR DR	178000219	33 WEST GOVERNOR DR	NEWPORT NEWS	VA	23602
LOEWUS J DAVID	LOEWUS JOAN B	54 HARDWICK RD	178000206	54 HARDWICK RD	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
WAXMAN HOWARD A	WAXMAN SUSAN M	38 ISLAND VIEW DR	178000505	38 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
EDWARDS ROBERT G		12 BLACKSMYTHE LN	178000254	12 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
MILLER MARK G		125 MONARCH DR	168000412	125 MONARCH DRIVE	NEWPORT NEWS	VA	23602
BECRAFT CHARLES ERIC &	KATHLEEN A MOODY	287 ADRIENNE PL	168000343	287 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
TOMPKINS GARY J	TOMPKINS LINDA K	283 ADRIENNE PL	168000345	283 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
APPLEGATE ELAINE M		277 LOU MAC CT	168000306	182 LINDEN LANE	PRINCETON	NJ	8540
BURTON EDWARD F JR	BURTON DEBORAH S	274 LOU MAC CT	168000502	274 LOU MAC COURT	NEWPORT NEWS	VA	23602
BURRELL VERONICA D		273 LOU MAC CT	168000512	273 LOU MAC COURT	NEWPORT NEWS	VA	23602
CRAWLEY ELAINA M		267 LOU MAC CT	168000509	267 LOU MAC COURT	NEWPORT NEWS	VA	23602
CAVALIER INVESTMENT COMPANY		274 MENCHVILLE RD	168000513	525 OYSTER POINT RD SUITE F	NEWPORT NEWS	VA	23602
VANSANT BARBARA H	HILL MICHAEL P	638 DEEP CREEK RD	199000206	638 DEEP CREEK ROAD	NEWPORT NEWS	VA	23606
DANIELS LARRY M TR	DANIEL DEBRA A TR	112 BLUFF TER	190000325	112 BLUFF TERRACE	NEWPORT NEWS	VA	23602
DENNARD ARTHUR L	DENNARD THERESA G	454 MENCHVILLE RD S	190000279	454 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
PICKENS EDWARD W ET UX		100 BLUFF TER	190000332	100 BLUFF TERRACE	NEWPORT NEWS	VA	23602
PELTZ EDGAR E TRUSTEE OF		120 BLUFF TER	190000313	120 BLUFF TERRACE	NEWPORT NEWS	VA	23602
HARBOR VIEW ASSOCIATES		200 OLD MARINA LN	190000278	12484 WARWICK BLVD	NEWPORT NEWS	VA	23606
MOODY MARIAH JUSTINE		404 HARBORVIEW LN	190000265	525 OYSTER POINT ROAD STE F	NEWPORT NEWS	VA	23602
VINYARD LINDA S		446 MARINA LN	190000212	845 BROMPTON COURT	NEWPORT NEWS	VA	23608
POWER SHARYN FOX		358 WOOD DUCK LN	190000230	358 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
JOHNSON FANNIE W		353 WATERFOWL LN	190000250	353 WATERFOWL LANE	NEWPORT NEWS	VA	23602
CARROW GARLAND L	CARROW JOYCE E	100 CANVASBACK TRL	190000254	100 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
CALLAHAN JOHN J TR	CALLAHAN MARY ANN J TR	15 CAMELLIA DR	179000134	15 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
WILLIAMS CHARLES GREGORY		1 CAMELLIA DR	179000107	3 CAMELLIA DR	NEWPORT NEWS	VA	23602
HAYES RODNEY E	HAYES SANDRA M	327 PEACH TREE CRES	167000449	327 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
WOMACK SWANNANOA E TRUSTEE	SWANNANOA E WOMACK REVOCABLE LIVING TR	233 CABELL DR	168000132	233 CABELL DRIVE	NEWPORT NEWS	VA	23602
CONATSER ROBERT ALEXANDER	CONATSER TIFFANY	318 PEACH TREE CRES	167000433	318 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
THOMPSON WESLEY L	THOMPSON KATHLEEN C	336 PEACH TREE CRES	167000440	336 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
BOHAC NATHAN JOHN	BOHAC TAMARIS	59 CABELL DR	178000127	59 CABELL DRIVE	NEWPORT NEWS	VA	23602
AIRHART DONALD W	AIRHART STARLA L	37 ISLAND VIEW DR	178000542	37 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
SNIDER LOYD A	SNIDER JODY R	109 RIVER BIRCH CT	178000135	109 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
ALSTON PATRICIA H		20 E GOVERNOR DR	178000346	20 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
BATCHELOR TIMOTHY	SUMNER LINDSAY	93 SHOEMAKER CIR	178000339	93 SHOEMAKER CIRCLE	NEWPORT NEWS	VA	23602
WEIMER DANIEL & THERESA WEIMER TR		21 HORSE PEN RD	189000423	21 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
LAMBERT CHADWICK		27 W GOVERNOR DR	178000222	27 WEST GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
GATEWOOD BERNARD	GATEWOOD SUSAN	51 CABELL DR	178000234	51 CABELL DRIVE	NEWPORT NEWS	VA	23602
BUTCHER BRIAN K	BUTCHER VALERIE M	6 BLACKSMYTHE LN	178000237	6 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
JEFFERIES GARY R	JEFFERIES MIN S	227 WOODBURNE LN	169000514	227 WOODBURNE LANE	NEWPORT NEWS	VA	23602
PRUITT LORIE QUINN		284 KELLY PL	168000406	284 KELLY PLACE	NEWPORT NEWS	VA	23602
COOK TIMOTHY F		188 LORI CIR	168000373	188 LORI CIRCLE	NEWPORT NEWS	VA	23602
MELCHOR ROBERT L	MELCHOR MARINA C	284 MENCHVILLE RD	168000312	284 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
BRUNSON WILLIAM L ET UX		39 W GOVERNOR DR	178000216	39 W GOVERNOR DR	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		524 MENCHVILLE RD S	199000103	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
GRAHAM JOSIAH R		225 CABELL DR	167000419	225 CABELL DRIVE	NEWPORT NEWS	VA	23602
HARTIGAN PATRICK M	HARTIGAN PATRICIA M	312 TAHOE DR	168000157	312 TAHOE DRIVE	NEWPORT NEWS	VA	23602
LEWALLEN WESLEY A	LEWALLEN CATHERINE M	16 LUCAS CREEK RD	167000469	16 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
SOLOMON AARON S	SOLOMON ANNETTE M	307 TAHOE DR	168000152	307 TAHOE DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
BRUNDAGE COLE E	BRUNDAGE PAMELA D	470 MENCHVILLE RD S	190000219	470 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
BROADHEAD TASHIKO LYNN BRADSHAW		312 PEACH TREE CRES	167000555	312 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
SPITZER ROBERT L	SPITZER LESLEY H	242 CABELL DR	168000164	242 CABELL DRIVE	NEWPORT NEWS	VA	23602
NYBERG NICHOLAS A &	ANA-LIZA AQUINO NYBERG	18 LUCAS CREEK RD	167000468	18 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
DONALDSON CHARLES M	DONALDSON SONDRA M	224 CABELL DR	167000425	224 CABELL DRIVE	NEWPORT NEWS	VA	23602
CAMPBELL ROBERT K & AMY L TRS OF		226 CABELL DR	167000424	408 TRISTEN DRIVE	YORKTOWN	VA	23693
WISE MICHELLE T		314 PEACH TREE CRES	167000432	12740 WEST INDIAN SCHOOL RD	LITCHFIELD PARK	AZ	85340
LOVELL WILLIAM D		240 CABELL DR	168000163	240 CABELL DR	NEWPORT NEWS	VA	23602
LOUDER DEAN W	LOUDER DONNA T	250 CABELL DR	168000168	250 CABELL DRIVE	NEWPORT NEWS	VA	23602
GIVENS DARRIS S	GIVENS LINDA L	233 WEATHERFORD WAY	168000615	233 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
GRAY LAUREN J	GRAY TERRY A	309 TAHOE DR	168000153	309 TAHOE DR	NEWPORT NEWS	VA	23602
MORRIS DONALD F	MORRIS TAMMIE L	206 LENTZ PL	167000453	206 LENTZ PLACE	NEWPORT NEWS	VA	23602
BROWNING MICHAEL L	BROWNING MARIA A	27 E GOVERNOR DR	178000325	27 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
RICHARDSON STEPHEN P		50 W GOVERNOR DR	178000302	50 GOVERNOR DRIVE W	NEWPORT NEWS	VA	23602
WILLIAMS KAREN N TR	KAREN N WILLIAMS TRUST	10 E GOVERNOR DR	189000125	10 EAST GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
SPANOS JOYCE A TRUSTEE OF THE		13 HORSE PEN RD	189000417	13 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
NIPP ROBERT S	NIPP ARLENE K	7 BLACKSMYTHE LN	178000243	7 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
RODGERS STEWART T UX		26 W GOVERNOR DR	178000314	26 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
INDRA NICHOLAS E	INDRA PAMELA A	24 FLAX MILL RD	189000121	24 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
LEE MAJOR CLINTON		13 SWAMP GATE RD	178000414	13 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
KEELING WARREN F	KEELING MARY O	46 RAMSHAW LN	178000225	46 RAMSHAW LANE	NEWPORT NEWS	VA	23602
RAPER JAMES L ET UX		9 E GOVERNOR DR	189000115	9 GOVERNOR DRIVE EAST	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
SHEVER-BROWN SANDRA K		20 W GOVERNOR DR	178000317	447 UPSHIRE CIRCLE	GAITHERSBURG	MD	20878
WASHINGTON BENJAMIN Y	WASHINGTON CYNTHIA	31 E GOVERNOR DR	178000327	31 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
SWAIN RAYMOND C ET UX		26 E GOVERNOR DR	178000344	26 E. GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
DEJESUS CINTRON JOSE A	DEJESUS CINTRON ELIZABETH A	10 HORSE PEN RD	189000409	10 HORSE PEN RD	NEWPORT NEWS	VA	23602
KRAMER JOSEPH T	KRAMER NANCY G	47 CABELL DR	178000236	47 CABELL DRIVE	NEWPORT NEWS	VA	23602
GRAY DAVID L ET UX		7 PLANTATION RD	178000410	7 PLANTATION RD	NEWPORT NEWS	VA	23602
CORLISS JAMES E & ANNE R TRS OF		5 HORSE PEN RD	189000413	5 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
MINGEE GERALD G	MINGEE GLORIA W	6 CANTER CT	189000420	6 CANTER COURT	NEWPORT NEWS	VA	23602
HESSLER RANDIE L & FLORLIZA E	GATBONTON	263 LOU MAC CT	168000507	263 LOU MAC COURT	NEWPORT NEWS	VA	23602
SHIFLETT HERMAN C	SHIFLETT SHARRON D	257 LOU MAC CT	168000433	257 LOU-MAC COURT	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS SCHOOL BOARD		275 MENCHVILLE RD	168000102	12465 WARWICK BOULEVARD	NEWPORT NEWS	VA	23606
NOE RICHARD G	NOE KATHY L	231 CABELL DR	167000422	231 CABELL DRIVE	NEWPORT NEWS	VA	23602
GHOLSON LAWRENCE ANTONIO II	GHOLSON TIJUANA A	22 LUCAS CREEK RD	167000466	22 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
MIN CHANG KUN	MIN CHUNG HWA	240 WEATHERFORD WAY	168000622	240 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
TAYLOR MICHAEL	TAYLOR ZEBRINA M	242 WEATHERFORD WAY	168000623	242 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		522 MENCHVILLE RD S	199000104	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
BOTE-TSHIEK KASONGA E ET UX		32 LUCAS CREEK RD	167000461	32 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
HERRING HENRY LOFTIN II ET UX		222 CABELL DR	167000426	222 CABELL DRIVE	NEWPORT NEWS	VA	23602
VAZQUEZ BROCK T	VAZQUEZ SAMANTHA L	304 COLLETTE CT	167000430	304 COLLETTE COURT	NEWPORT NEWS	VA	23602
KRAUSE RICHARD SCOTT & JOAN L	KRAUSE	205 LENTZ PL	167000452	205 LENTZ PLACE	NEWPORT NEWS	VA	23602
STEVENSON MARK L	STEVENSON REBECCA M	326 PEACH TREE CRES	167000436	326 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
SHAW STEPHEN & ALICE SHAW		305 TAHOE DR	168000151	305 TAHOE DRIVE	NEWPORT NEWS	VA	23602
JANUS JOSEPH P	JANUS MICHELLE M	239 WEATHERFORD WAY	168000612	239 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
LOTT LACY		323 PEACH TREE CRES	167000455	C/O LACY BORRERO	NEWPORT NEWS	VA	23602
LAM SAN		317 PEACH TREE CRES	167000458	6109 JOHN JACKSON DR	WILLIAMSBURG	VA	23188
MENEFEE DWAYNE D	MENEFEE TONYA Y	20 LUCAS CREEK RD	167000467	20 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
ELEFTHERIOU MICHALAKIS	PETRAKOS ERENE	104 RIVER BIRCH CT	178000143	104 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
KEAN ROBERT B ET UX		34 W GOVERNOR DR	178000310	34 WEST GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
GREGERSON WILLIAM EDWARD TR	WILLIAM EDWARD GREGERSON AND SALLY LEW G	37 W GOVERNOR DR	178000217	1006 OLD DENBIGH BLVD APT 205	NEWPORT NEWS	VA	23602
LYSTLUND JAMES T ET UX		9 SWAMP GATE RD	178000413	9 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
WALLS JAMES S JR & NANCY S WALLS		42 ISLAND VIEW DR	178000503	42 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
KLICH PHILLIP J ET UX		22 FLAX MILL RD	189000202	22 FLAX MILL RD	NEWPORT NEWS	VA	23602
HUFFMAN CHARLES A III & GAY C	HUFFMAN TRUSTEES	27 LUCAS CREEK RD	167000334	BOX 6368	NEWPORT NEWS	VA	23606
MOROTINI WALTER H	MOROTINI BARBARA B	44 W GOVERNOR DR	178000305	44 GOVERNOR DRIVE W	NEWPORT NEWS	VA	23602
KELLIS DOUGLAS A & HELEN W		5 E GOVERNOR DR	189000117	5 E GOVERNOR DR	NEWPORT NEWS	VA	23602
SYRETT DAVID M TRUSTEE & ROSE		9 BLACKSMYTHE LN	178000244	9 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
BARKER PHILLIP M	BARKER BETTY W	321 PEACH TREE CRES	167000456	321 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
GRAHAM LEROY JR	GRAHAM LORETTA P	2 W GOVERNOR DR	189000120	104 RAYMOND DRIVE	NEWPORT NEWS	VA	23602
SCHULTZ NELLIE SMITH TRUSTEE		28 E GOVERNOR DR	178000343	28 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
MIXER FRANCES T	MIXER ELDON E	12 E GOVERNOR DR	189000126	12 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
HOLMES WOODROW L JR ET UX		51 W GOVERNOR DR	178000212	51 W. GOVERNOR DR	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
PHILLIPS LEWIS III TRUSTEE OF THE		30 ISLAND VIEW DR	178000509	30 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
SULLIVAN GARY L		276 MENCHVILLE RD	168000308	276 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
HAMPTON ROADS SANITATION DISTRICT		101 CITY FARM RD	190000114	P O BOX 5915	VIRGINIA BEACH	VA	23471
DAWSON JOHN B TRUSTEE		46 HARDWICK RD	178000210	46 HARDWICK ROAD	NEWPORT NEWS	VA	23602
SMITH HUDSON		302 OLD MENCHVILLE RD	179000103	302 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
CARNRIKE MANDY L		172 LORI CIR	168000414	172 LORI CIRCLE	NEWPORT NEWS	VA	23602
YENG PHALY		182 LORI CIR	168000376	182 LORI CIRCLE	NEWPORT NEWS	VA	23602
LEON HAROLD G UX		285 ADRIENNE PL	168000344	285 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
BAUM GLENN B	BAUM JENNIFER D	115 MONARCH DR	168000302	115 MONARCH DRIVE	NEWPORT NEWS	VA	23602
W & W PROPERTIES LLC		109 MONARCH DR	168000305	PO BOX 6236	NEWPORT NEWS	VA	23606
PEACH WILLIAM F JR UX		624 BURCHER RD	200000401	624 BURCHER RD	NEWPORT NEWS	VA	23606
J & M MANAGEMENT L L C		665 DEEP CREEK RD	200000443	665 DEEP CREEK RD	NEWPORT NEWS	VA	23606
WILBUR MATTHEW LEE	WILBUR LAURA KI	39 ISLAND VIEW DR	178000543	39 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
HARRISS DAVID J	HARRISS KIMBERLY K	12 SWAMP GATE RD	178000403	12 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
ELDER GERALD F	ELDER SANDRA S	26 HORSE PEN RD	189000401	26 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
MATZGANNIS MICHAEL G ET UX		2 FLAX MILL RD	189000214	2 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
SIMONS DAVID J	SIMONS TRACI L	5 W GOVERNOR DR	189000106	5 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
MITCHELL JOHN L	MITCHELL HELEN T	18 BLACKSMYTHE LN	178000251	18 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
FIELDS WILLIAM A	FIELDS AGNES J	26 ISLAND VIEW DR	178000511	26 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
SIMMONS RONALD K ET UX		116 MONARCH DR	168000347	116 MONARCH DRIVE	NEWPORT NEWS	VA	23602
EASTER DANIEL R ET UX		289 LOU MAC CT	168000322	289 LOU MAC COURT	NEWPORT NEWS	VA	23602
MILLER WALTER C	MILLER LINDA M B	34 E GOVERNOR DR	178000341	34 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
DAWSON FRANK	DAWSON PATRICIA A	5 SWAMP GATE RD	178000412	5 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
			1				
HARRAH GEORGE E	HARRAH SHARON J	351 WATERFOWL LN	190000251	351 WATERFOWL LANE	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		116 CANVASBACK TRL	190000255	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
BARBER G RAYMOND	KRAMER EDWARD G	350 WOOD DUCK LN	190000226	P O BOX 2179	VIRGINIA BEACH	VA	23450

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
OLVERA JAMES K TR	OLVERA LEIGH	341 PEACH TREE CRES	167000442	341 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
LAWSON CLIFTON RAY TR	CLIFTON RAY LAWSON REVOCABLE TRUST	40 E GOVERNOR DR	178000336	104 YORKVILLE ROAD	YORKTOWN	VA	23692
ISHAM JONATHAN N ET UX		4 HORSE PEN RD	189000412	4 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
MCCROSKEY JOHN H	MCCROSKEY JANE	16 HORSE PEN RD	189000406	16 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
POLIZOS MILTIADIS ET UX		22 HORSE PEN RD	189000403	22 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		1 W GOVERNOR DR # B	189000108	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
CLEMENTS JUDSON C TR	JUDSON C CLEMENTS LIVING TRUST	21 FLAX MILL RD	189000201	21 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
RODDEY BRIAN K	TURNER KIMBERLY L	197 LORI CIR	168000367	197 LORI CIRCLE	NEWPORT NEWS	VA	23602
O'NEIL KELLY M	O'NEIL SHARON L	195 LORI CIR	168000366	195 LORI CIRCLE	NEWPORT NEWS	VA	23602
RUCKER SHERRIE R		290 ADRIENNE PL	168000351	290 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
CUSTER-WEISS SHARON J ET VIR		109 DAVID CIR	168000329	109 DAVID CIRCLE	NEWPORT NEWS	VA	23602
GORBETT MICHAEL T	GORBETT TAMMY K	352 WATERFOWL LN	190000240	352 WATERFOWL LANE	NEWPORT NEWS	VA	23602
SWANSON TIMOTHY D	SWANSON KIMBERLY W	5 PLANTATION RD	178000409	5 PLANTATION RD	NEWPORT NEWS	VA	23602
BARTLEY JAMES MARCUS	BARTLEY LAURA A	24 HORSE PEN RD	189000402	24 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
SHORT MICHAEL D		108 MONARCH DR	168000326	P O BOX 1053	YORKTOWN	VA	23692
WOLF STEVEN D	WOLF SUSAN D	117 CANVASBACK TRL	190000224	117 CANVASBACK TRL	NEWPORT NEWS	VA	23602
ALLEN CHARLES L	ALLEN KIMBERLY L	238 WEATHERFORD WAY	168000621	238 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
WEST GEORGE A		324 PEACH TREE CRES	167000435	324 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
MCCULLERS LINWOOD A	MCCULLERS SARAH N	110 RIVER BIRCH CT	178000140	110 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
DOVE JAMES E	DOVE BEVERLY A	2 PLANTATION RD	189000301	2 PLANTATION ROAD	NEWPORT NEWS	VA	23602
LEIGH DANIEL S ET UX		19 W GOVERNOR DR	178000224	19 W GOVERNOR DR	NEWPORT NEWS	VA	23602
THORNTON HAROLD EUGENE TRS OF		23 W GOVERNOR DR	178000223	23 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
WOOD JACK E	WOOD SUSANNE S	22 ISLAND VIEW DR	178000513	22 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
CITY OF NEWPORT NEWS		231 WOODBURNE LN	169000516	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
BICKETT KENNETH W	BICKETT SUSAN S	286 KELLY PL	168000405	286 KELLY PLACE	NEWPORT NEWS	VA	23602
BECK VERNON C	BECK A CAROLYN	285 KELLY PL	168000404	285 KELLY PLACE	NEWPORT NEWS	VA	23602
BROWN RONALD M	BROWN CHERYL P	283 KELLY PL	168000403	283 KELLY PLACE	NEWPORT NEWS	VA	23602
MOSS JAMES N & NINA H MOSS TRS		180 LORI CIR	168000377	106 ERIC NELSON RUN	YORKTOWN	VA	23693
SHORT MICHAEL D		292 LOU MAC CT	168000333	33 ENSIGNE SPENCE	WILLIAMSBURG	VA	23185
DANNER LINDA S	GREEN ALBERT C JR	308 OLD MENCHVILLE RD	179000104	308 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
BUCKLE EVARIS R & ETHEL N BUCKLE		235 CABELL DR	168000133	235 CABELL DRIVE	NEWPORT NEWS	VA	23602
RICHARDSON YONG SAM &	FAITH WOLHUI RICHARDSON	239 CABELL DR	168000135	239 CABELL DRIVE	NEWPORT NEWS	VA	23602
JOHNSON TYRONE & CELESTINE	BLAKE-JOHNSON	111 RIVER BIRCH CT	178000136	111 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
CHASE CHRISOPHER C	CHASE DANIELLE N	57 CABELL DR	178000538	57 CABELL DR	NEWPORT NEWS	VA	23602
BOONE RICHARD D		3 PLANTATION RD	178000408	3 PLANTATION ROAD	NEWPORT NEWS	VA	23602
HAYES GARY L ET UX		1 PLANTATION RD	189000302	1 PLANTATION ROAD	NEWPORT NEWS	VA	23602
BARRINGER SHERIDAN R	BARRINGER PAMELA G	23 HORSE PEN RD	189000424	23 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
NGUYEN TUY QUOC ET UX		3 W GOVERNOR DR	189000107	3 W. GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
PALL LAURA ROSE	BUTLER CHRISTOPHER JAMES	24 ISLAND VIEW DR	178000512	24 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		229 WOODBURNE LN	169000515	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
ZAGURSKY KEVIN K & JUANITA M		295 LOU MAC CT	168000319	295 LOU MAC COURT	NEWPORT NEWS	VA	23602
EDWARDS ELLEN R		632 SNUG HARBOR LN	200000135	632 SNUG HARBOR LANE	NEWPORT NEWS	VA	23606
NAPIER LISA OGIBA		303 TAHOE DR	168000150	303 TAHOE DRIVE	NEWPORT NEWS	VA	23602
GRIMES LIONEL T	GRIMES KIM R	45 ISLAND VIEW DR	178000546	45 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
ELEFANTE BENJAMIN E		281 ADRIENNE PL	168000346	848 YORKSHIRE LANE	NEWPORT NEWS	VA	23608

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
RIPPY JOHN M	RIPPY JANET M	472 MENCHVILLE RD S	190000220	472 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
JOHNSON ERVIN JR	JOHNSON CAROLYN J	332 PEACH TREE CRES	167000438	332 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
HUNTINGTON CHARLES D	HUNTINGTON NICHELLE A	302 COLLETTE CT	167000431	302 COLLETTE COURT	NEWPORT NEWS	VA	23602
ALFRED ANDREW J III	ALFRED ALICE W	244 CABELL DR	168000165	244 CABELL DRIVE	NEWPORT NEWS	VA	23602
OWENS KELLY		248 WEATHERFORD WAY	168000626	248 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
ORENDAIN EUGENE M	ORENDAIN MARYANN	215 CABELL DR	167000414	215 CABELL DR	NEWPORT NEWS	VA	23602
CERNY DANIEL W	CERNY MELODY	221 CABELL DR	167000417	221 CABELL DRIVE	NEWPORT NEWS	VA	23602
GARLICK WILLIAM LEWIS JR	GARLICK IMELDA O	238 CABELL DR	168000162	238 CABELL DRIVE	NEWPORT NEWS	VA	23602
WOOD RALPH P JR	WOOD PAMELA S	108 RIVER BIRCH CT	178000141	108 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
GUNTER JOHN C	GUNTER GAIL S	13 E GOVERNOR DR	178000318	13 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
GOLDMAN RANDALL D	GOLDMAN HAE JUNG C	29 E GOVERNOR DR	178000326	29 GOVERNOR DRIVE EAST	NEWPORT NEWS	VA	23602
FERGUSON JERRY D JR	FERGUSON MONICA D	14 HORSE PEN RD	189000407	14 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
CHOU JUNG-SUNG	CHOU HSU CHIN-CHUN	49 CABELL DR	178000235	49 CABELL DRIVE	NEWPORT NEWS	VA	23602
KERSCHL NICHOLAS T	KERSCHL MICHELLE K	51 HARDWICK RD	178000204	51 HARDWICK RD	NEWPORT NEWS	VA	23602
TRAN DUYEN P		44 ISLAND VIEW DR	178000502	44 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
MALDON SEAN P ET UX		46 ISLAND VIEW DR	178000501	46 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
PRAK SARIM	PRAK PHY YORN	126 MONARCH DR	168000401	126 MONARCH DRIVE	NEWPORT NEWS	VA	23602
HUMES JOHN F	HUMES KASIE L	110 MONARCH DR	168000327	110 MONARCH DRIVE	NEWPORT NEWS	VA	23602
WILLIAMS ROBERT L	WILLIAMS TOINETTE M	183 LORI CIR	168000360	183 LORI CIRCLE	NEWPORT NEWS	VA	23602
LONERGAN THOMAS J III		181 LORI CIR	168000359	181 LORI CIRCLE	NEWPORT NEWS	VA	23602
STILLS NATASHA		269 LOU MAC CT	168000510	269 LOU MAC COURT	NEWPORT NEWS	VA	23602
MAINE ROBERT S & RHONDA MAINE		112 TERRI BETH PL	168000520	943 CHATSWORTH DRIVE	NEWPORT NEWS	VA	23601
GREGERSON SALLY L	GREGERSON DAVID C	110 TERRI BETH PL	168000519	110 TERRI BETH PLACE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
M & W CONSULTING LLC		617 BURCHER RD	200000133	753 C THIMBLE SHOALS BLVD	NEWPORT NEWS	VA	23606
FRICKE FAMILY REVOC LIV TRUST		466 MENCHVILLE RD S	190000281	466 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
MAHONEY KEVIN M	ROBINSON LAUREN M	305 HILLSIDE TER	190000320	305 HILLSIDE TERRACE UNIT 28	NEWPORT NEWS	VA	23602
LAZARUS DAVID S	LAZARUS JOY S	213 BLUFF TER	190000351	213 BLUFF TERRACE	NEWPORT NEWS	VA	23602
NORFLEET BENJAMIN E JR	NORFLEET LUCY M	402 HARBORVIEW LN	190000264	402 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
HOBGOOD SARAH M		364 OLD MENCHVILLE RD	190000206	364 OLD MENCHVILLE RD	NEWPORT NEWS	VA	23602
NORFLEET WILLIE N TR	WILLIE N NORFLEET LIVING TRUST	2 NORMILL LNDG	190000209	2 NORMILL LANDING	NEWPORT NEWS	VA	23602
SCARLETT WILLIAM D JR	SCARLETT LESLIE G	351 WOOD DUCK LN	190000237	351 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
COX MILBURN G JR	COX MARINA M	102 CANVASBACK TRL	190000253	102 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
BELL JEFFREY A	BELL BRENDA L	111 CANVASBACK TRL	179000206	111 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
WILLIAMS CHARLES GREGORY TRUSTEE	CHARLES B WILLIAMS TRUST	1 CAMELLIA DR # B	179000108	29 CHANNEL LANE	HAMPTON	VA	23664
ROEBUCK MARK A SR & DONNA L	ROEBUCK	10 CAMELLIA DR	179000112	10 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
HAMPTON ROADS SANITATION DISTRICT		201 CITY FARM RD	189000303	P O BOX 5915	VIRGINIA BEACH	VA	23471
HUFFMAN CHARLES A III	HUFFMAN GAY C	642 DEEP CREEK RD	199000203	660 DEEP CREEK ROAD	NEWPORT NEWS	VA	23606
SCHULTZ ALLEN W	SCHULTZ SARAH M	43 ISLAND VIEW DR	178000545	43 ISLANDVIEW DRIVE	NEWPORT NEWS	VA	23602
MILLS WILLIAM A		112 RIVER BIRCH CT	178000139	112 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
SERYI ANDREI	SERAIA ELENA	10 W GOVERNOR DR	189000111	10 W GOVERNOR DR	NEWPORT NEWS	VA	23602
NORRIS LYNDA A		18 W GOVERNOR DR	189000114	18 W GOVERNOR DR	NEWPORT NEWS	VA	23602
TAYLOR DAVID W	TAYLOR ANNE MARIE	15 HORSE PEN RD	189000418	15 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
SCULL CARLOS	SCULL GLORIA	14 FLAX MILL RD	189000208	14 FLAX MILL RD	NEWPORT NEWS	VA	23602
MAPLES JOHN M JR & CATHY A MAPLES	TRUSTEES	16 FLAX MILL RD	189000207	16 FLAX MILL ROAD	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
BLAND JAMES R JR		186 LORI CIR	168000374	186 LORI CIRCLE	NEWPORT NEWS	VA	23602
GASKILL RUSSELL A		199 LORI CIR	168000368	199 LORI CIRCLE	NEWPORT NEWS	VA	23602
QUINN COLETTE MICHELLE		291 LOU MAC CT	168000321	291 LOU MAC COURT	NEWPORT NEWS	VA	23602
HANCOCK RONNIE G & BARBARA L	HANCOCK	290 MENCHVILLE RD	168000315	290 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
BERARD ROLLAND M TRUSTEE OF THE	ROLLAND M BERARD LIVING TRUST	227 CABELL DR	167000420	227 CABELL DR	NEWPORT NEWS	VA	23602
ZHENG YI DI		217 CABELL DR	167000415	217 CABELL DRIVE	NEWPORT NEWS	VA	23602
SAN KAT	SAN NINA TEK	304 TAHOE DR	168000161	304 TAHOE DRIVE	NEWPORT NEWS	VA	23602
DIAZ BRIZEIDA TORRES	LANDRAU FERNINAND LOPEZ	234 WEATHERFORD WAY	168000619	234 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
HILL RONALD LESTER	HILL MARY M	236 WEATHERFORD WAY	168000620	236 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
CHEATHAM HARRIET E TRUSTEE		213 CABELL DR	167000413	213 CABELL DRIVE	NEWPORT NEWS	VA	23602
SLEETH JASON R & CHRISTA ANN	SLEETH	244 WEATHERFORD WAY	168000624	244 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
GARRISON MICHAEL A	GARRISON CHLOE C I	15 E GOVERNOR DR	178000319	15 E GOVERNOR DR	NEWPORT NEWS	VA	23602
REILLY JOAN T TRS OF		32 W GOVERNOR DR	178000311	32 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
PHAUP JAMES H	PHAUP OLIVIA N	33 E GOVERNOR DR	178000328	33 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
AMAN REBECCA S	SHWAYDER ROBERT C	48 W GOVERNOR DR	178000303	9 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
CLARK SCOTT E	CLARK CORNELIA	19 E GOVERNOR DR	178000321	19 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
CABRAL ELADIA A	CABRAL JOSE MIGUEL	54 W GOVERNOR DR	178000301	54 WEST GOVERNOR DR	NEWPORT NEWS	VA	23602
HARRIS SHIRLEY A		35 W GOVERNOR DR	178000218	35 GOVERNOR DRIVE WEST	NEWPORT NEWS	VA	23602
BREITBEIL JAMES T	BREITBEIL SHELLY H	45 W GOVERNOR DR	178000214	45 W GOVERNOR DR	NEWPORT NEWS	VA	23602
CACCAVALE FREDERICK A	CACCAVALE PATRICIA N	36 ISLAND VIEW DR	178000506	36 ISLAND VIEW DR	NEWPORT NEWS	VA	23602
STRICKLAND CYNTHIA L		288 ADRIENNE PL	168000350	288 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
DICKSON PAUL T & ESLY D DICKSON		113 MONARCH DR	168000303	113 MONARCH DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
CHRISTENSEN MILDRED S TRUSTEE	CHRISTENSEN CARL A TRUSTEE	114 TERRI BETH PL	168000521	C/O CARL A. CHRISTENSEN	NEWPORT NEWS	VA	23602
LIGGIERI CARMELO		259 LOU MAC CT	168000505	91 ROUND HILL ROAD	WASHINGTONVILLE	NY	10992
HOWARD ERNEST E		276 LOU MAC CT	168000501	276 LOU MAC COURT	NEWPORT NEWS	VA	23602
MATTE RICHARD M		118 MONARCH DR	168000357	118 MONARCH DRIVE	NEWPORT NEWS	VA	23602
			1				
WALKER RICHARD C	WALKER ANN J	311 HILLSIDE TER	190000303	225 WHITE SAND COURT	COLONIAL HEIGHTS	VA	23834
GAMMELL TRACY A		327 HILLSIDE TER	190000338	327 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
ROMANO ANTHONY	ROMANO SHARLENE F	307 HILLSIDE TER	190000301	307 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
AYSCUE ROBERTA G		104 BLUFF TER	190000328	104 BLUFF TERRACE	NEWPORT NEWS	VA	23602
BONINE AARON C	BONINE LAUREN M	303 HILLSIDE TER	190000319	303 HILLSIDE TERRACE UNIT 27	NEWPORT NEWS	VA	23602
ALBERTS DANNA M		204 BLUFF TER	190000324	204 BLUFF TERRACE	NEWPORT NEWS	VA	23602
HARRAH GEORGE E II	HARRAH DIANE T	411 HARBORVIEW LN	190000257	411 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
DANNER JOSEPHINE MURRAY TRUSTEE OF	JOSEPHINE MURRAY DANNER REVOCABLE TRUST	362 OLD MENCHVILLE RD	190000205	C/O JAMES RICHARDSON, TRUSTEE	CROZET	VA	22932
DUNLAP DAVID M	DUNLAP MARY ELIZABETH	357 WOOD DUCK LN	190000234	357 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
BERG ROBERT CO TRUSTEE	BERG MARGOT E CO TRUSTEE	354 WOOD DUCK LN	190000228	354 WOOD DUCK LANE	NEWPORT NEWS	VA	23602
MATTHEWS BONNIE K ET ALS		310 OLD MENCHVILLE RD	179000101	308 B OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
COX LEON EDWARD		330 HILLSIDE TER	190000347	330 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
WILLIAMS NANCY J		308 HILLSIDE TER	190000316	308 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		700 DEEP CREEK RD	199000211	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
KELLY TRUMILLER B TRUSTEE OF THE		325 HILLSIDE TER	190000337	325 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
CASANOVA LISA A		312 HILLSIDE TER	190000314	312 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
BOMBELYN BRIAN	BOMBELYN LINDSEY R	456 MENCHVILLE RD S	190000280	456 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
WALKER PAMELA KAY TRUSTEE	PAMELA KAY WALKER LIVING TRUST	203 BLUFF TER	190000335	44 COTTON CREEK CIRCLE	BLACK MOUNTAIN	NC	28711
DEWALL JUSTIN A	DEWALL GRETCHEN D	116 OVERLOOK CV	190000270	116 OVERLOOK COVE	NEWPORT NEWS	VA	23602
MOORE DAVID	MOORE LINDA	401 HARBORVIEW LN	190000262	401 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
DEVER JOHN T TR	DEVER PEGGY E TR	361 WATERFOWL LN	190000246	361 WATERFOWL LANE	NEWPORT NEWS	VA	23602
BILLINGS DAVID J	BILLINGS SARA B	360 OLD MENCHVILLE RD	190000204	360 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
FOLEY ANDREW W III	FOLEY VICKIE R	358 WATERFOWL LN	190000243	358 WATERFOWL LANE	NEWPORT NEWS	VA	23602
LAHR STEVEN R	LAHR KAREN S	358 OLD MENCHVILLE RD	190000203	358 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
WEATHERLESS AMANDA M		349 WATERFOWL LN	190000252	349 WATERFOWL LANE	NEWPORT NEWS	VA	23602
WARTHAN GUY R	WARTHAN ANNE C	17 CAMELLIA DR	179000135	17 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
SESPENE BRANDON R & ARLENE	PENAFLOR SESPENE	12 CAMELLIA DR	179000113	12 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
MATTHEWS BONNIE K ET ALS		314 OLD MENCHVILLE RD	179000117	308B OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
TAYLOR HORTENSE ANN TRUSTEE		312 OLD MENCHVILLE RD	179000118	306 B OLD MENCHVILLE RD	NEWPORT NEWS	VA	23602
CREQUE BROCK & MICHELLE CREQUE		334 PEACH TREE CRES	167000439	334 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
TAYLOR KARON W		246 CABELL DR	168000166	246 CABELL DRIVE	NEWPORT NEWS	VA	23602
BANKS ELWOOD B JR	BANKS CARLA Y W	301 COLLETTE CT	167000427	301 COLLETTE COURT	NEWPORT NEWS	VA	23602
WOJTKOWSKI SHAUN T	WOJTKOWSKI DEBRA A	315 PEACH TREE CRES	167000459	315 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
MADISON ERNEST W	MADISON ELLEN B	234 CABELL DR	168000149	234 CABELL DRIVE	NEWPORT NEWS	VA	23602
WRIGHT ADAM	WRIGHT CASSIE	22 W GOVERNOR DR	178000316	22 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
MANRIQUEZ CARLOS G	QUINTANA ADELENA	36 W GOVERNOR DR	178000309	36 WEST GOVERNOR DR	NEWPORT NEWS	VA	23602
WILSON MICHAEL G ET UX		38 W GOVERNOR DR	178000308	38 GOVERNOR DRIVE W	NEWPORT NEWS	VA	23602
GERE SCOT B ET UX		8 HORSE PEN RD	189000410	8 HORSE PEN ROAD	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
LAINE ELLIOTT G TRUSTEE	LAINE ROSALIE G TRUSTEE	12 HORSE PEN RD	189000408	12 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
BOYD JOHN WILLIAM		9 FLAX MILL RD	189000218	9 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
PANHOLZER ADAM P	PANHOLZER AMY A	48 CABELL DR	178000231	48 CABELL DRIVE	NEWPORT NEWS	VA	23602
PALKOWSKI JAMES G	PALKOWSKI DIANA M	17 E GOVERNOR DR	178000320	17 GOVERNOR DRIVE E	NEWPORT NEWS	VA	23602
WILLIAMS CHARLES W ET UX		5 CANTER CT	189000419	5 CANTER COURT	NEWPORT NEWS	VA	23602
BOXER WILLIAM M	BOXER ADA M	29 W GOVERNOR DR	178000221	29 W GOVERNOR DR	NEWPORT NEWS	VA	23602
GREEN JESSICA J		52 HARDWICK RD	178000207	52 HARDWICK RD	NEWPORT NEWS	VA	23602
RODGERS KIMBERLY D ET VIR		53 HARDWICK RD	178000205	53 HARDWICK ROAD	NEWPORT NEWS	VA	23602
HUEMER INGO J	HUEMER CATHERINE E	40 ISLAND VIEW DR	178000504	40 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
CHRISTENSEN CARL A	CHRISTENSEN MARGARET A	127 MONARCH DR	168000411	127 MONARCH DRIVE	NEWPORT NEWS	VA	23602
GRIGSBY JAMES BRIAN		174 LORI CIR	168000413	174 LORI CIRCLE	NEWPORT NEWS	VA	23602
CURTIS TYLER		111 MONARCH DR	168000304	111 MONARCH DRIVE	NEWPORT NEWS	VA	23602
CAVALIER INVESTMENT COMPANY		268 MENCHVILLE RD	168000516	525 OYSTER POINT RD SUITE F	NEWPORT NEWS	VA	23602
HAMILTON ALFONZO M JR	SHAZIER KIANA C	275 LOU MAC CT	168000307	275 LOU MAC COURT	NEWPORT NEWS	VA	23602
HINSON NELSON G ET UX		7 E GOVERNOR DR	189000116	7 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
HUFFMAN CHARLES A III	HUFFMAN GAY C	644 DEEP CREEK RD	199000204	P O BOX 6368	NEWPORT NEWS	VA	23606
CRECCA VITO MICHAEL		232 SHERBROOKE DR	168000120	232 SHERBROOKE DRIVE	NEWPORT NEWS	VA	23602
DEPP ROBERT G ET UX		113 RIVER BIRCH CT	178000138	113 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
MASON RONALD W	MASON LISA	12 W GOVERNOR DR	189000112	12 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
WILLIAMS PHILIP G	WILLIAMS MARIANNE C	4 SWAMP GATE RD	178000407	4 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
CAPLINGER JACOB W III	CAPLINGER PAULA S	9 PLANTATION RD	178000411	9 PLANTATION ROAD	NEWPORT NEWS	VA	23602
MCBRIDE CHARLES EARL		8 SWAMP GATE RD	178000405	8 SWAMP GATE RD	NEWPORT NEWS	VA	23602
SATCHELL STEPHEN S	SATCHELL WENDY K	4 CANTER CT	189000421	4 CANTER COURT	NEWPORT NEWS	VA	23602
SMITH RICHARD TYLER		12 FLAX MILL RD	189000209	12 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
HUNT JAMES L	HUNT MARGARET W	15 W GOVERNOR DR	189000102	15 GOVERNOR DRIVE W	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
REUSS ROBERT	REUSS PAMELA J	17 BLACKSMYTHE LN	178000248	17 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
TRISKA JOHN C & JUDITH B TRISKA		19 BLACKSMYTHE LN	178000249	19 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
SWANSON RICHARD A TR & LYNNETTE J		196 LORI CIR	168000370	196 LORI CIRCLE	NEWPORT NEWS	VA	23602
WALKER STEWART	WALKER PATRICIA	293 LOU MAC CT	168000320	293 LOU MAC COURT	NEWPORT NEWS	VA	23602
REASONS DAVID L	REASONS KIMBERLY H	292 MENCHVILLE RD	168000316	292 MENCHVILLE RD	NEWPORT NEWS	VA	23602
HOLLAND ALONZO M	HOLLAND TRACEY D	313 PEACH TREE CRES	167000460	313 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
PERKINSON CHRISTOPHER S	PERKINSON JENNIFER L	228 CABELL DR	167000423	228 CABELL DRIVE	NEWPORT NEWS	VA	23602
O'CONNELL LEO K		20 ISLAND VIEW DR	178000514	20 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
BURROUGHS RONALD B	BURROUGHS JOYCE R	414 HARBORVIEW LN	190000276	414 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
DREYBUS GEORGE N III	DREYBUS PAUL	405 MENCHVILLE RD S	190000104	115 PARKWAY DR	NEWPORT NEWS	VA	23606
KURZ DIANE L ET VIR		407 HARBORVIEW LN	190000259	407 HARBORVIEW LANE	NEWPORT NEWS	VA	23602
RITENOUR STEVEN M	RITENOUR KATHLEEN M	115 OVERLOOK CV	190000269	115 OVERLOOK COVE	NEWPORT NEWS	VA	23602
SENEY FRANKLIN D		444 MARINA LN	190000211	444 MARINA LANE	NEWPORT NEWS	VA	23602
LAND RAVEN R	LAND DEBBIE S	355 WATERFOWL LN	190000249	355 WATERFOWL LA	NEWPORT NEWS	VA	23602
DAVENPORT MICHAEL J	DAVENPORT ELIZABETH H	356 WATERFOWL LN	190000242	356 WATERFOWL LANE	NEWPORT NEWS	VA	23602
WEAVER LARRY D	WEAVER MICHELE ROSIER	354 WATERFOWL LN	190000241	354 WATERFOWL LANE	NEWPORT NEWS	VA	23602
DUELL ROY M UX		5 CAMELLIA DR	179000125	11 PHEASANT DR	POQUOSON	VA	23662
NOVOTNY JOSEPH A	NOVOTNY TINA L	4 CAMELLIA DR	179000130	4 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
SMITH DONNA M TRUSTEE		310 OLD MENCHVILLE RD # B	179000105	310 B OLD MENCHVILLE RD	NEWPORT NEWS	VA	23602
MORTON CLARKE J		328 HILLSIDE TER	190000340	328 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
HIXON PATRICIA J &	WILLIAM FRANCIS FINOCCHIO TRS	322 HILLSIDE TER	190000343	322 HILLSIDE TERRACE	NEWPORT NEWS	VA	23602
HACKMAN JOHN ROBERTS TRUSTEE	HACKMAN KAREN JANE TRUSTEE	361 WOOD DUCK LN	190000232	361 WOOD DUCK LANE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
CLARK DANIEL	CLARK LAURA	362 WATERFOWL LN	190000245	362 WATERFOWL LANE	NEWPORT NEWS	VA	23602
MORROW FRANKLIN WARREN ET UX		356 OLD MENCHVILLE RD	190000202	356 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
BIRCH HARRY K	BIRCH CECILIA F	103 CANVASBACK TRL	179000202	103 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
LUBERTAZZI DANNY L	LUBERTAZZI MICHELLE A	101 CANVASBACK TRL	179000201	101 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
BRYANT CHRISTOPHER W	BRYANT SHANNON L	16 CAMELLIA DR	179000115	16 CAMELLIA DRIVE	NEWPORT NEWS	VA	23602
SMITH DONNA M TRUSTEE		310 OLD MENCHVILLE RD # C	179000127	310 B OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
LIN ZHI SHUN	CHEN MEI FEN	241 CABELL DR	168000136	241 CABELL DRIVE	NEWPORT NEWS	VA	23602
BARBOUR KENNEDY J	BARBOUR URSULA W	328 PEACH TREE CRES	167000437	328 PEACH TREE CRES	NEWPORT NEWS	VA	23602
NUTTYCOMBE CHARLES W SR	NUTTYCOMBE ELIZABETH W	95 SHOEMAKER CIR	178000340	95 SHOEMAKER CIRCLE	NEWPORT NEWS	VA	23602
CHABO YSAAC J	CHABO ANGELICA T	28 ISLAND VIEW DR	178000510	28 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
CARR JESSICA D		282 KELLY PL	168000407	282 KELLY PLACE	NEWPORT NEWS	VA	23602
PULLEN FRANCIS J	PULLEN HARUMI	193 LORI CIR	168000365	193 LORI CIRCLE	NEWPORT NEWS	VA	23602
MABE MEGAN ELIZABETH		194 LORI CIR	168000371	194 LORI CIRCLE	NEWPORT NEWS	VA	23602
RIFFLE ABIGAIL L		298 ADRIENNE PL	168000338	298 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
AJJ PROPERTIES LLC		294 MENCHVILLE CT	168000317	1700 BASSETT ST., #1901	DENVER	CO	80202
HANRAHAN MICHAEL J	HANRAHAN RENATE	46 E GOVERNOR DR	178000333	46 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
CANTRELL ZACHARY A	CANTRELL KWANRUEN C	306 TAHOE DR	168000160	306 TAHOE DRIVE	NEWPORT NEWS	VA	23602
SAETANG SIOPOR	SAETANG NALI K	305 COLLETTE CT	167000429	1714 DUKE ROAD	GLOUCESTER POINT	VA	23062
PASSMORE MICHAEL K	PASSMORE BARBARA A	303 COLLETTE CT	167000428	303 COLLETTE COURT	NEWPORT NEWS	VA	23602
EDWARDS JOSEPH SAMUEL III	EDWARDS LINDA	246 WEATHERFORD WAY	168000625	246 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
WILSON JACOB M III	WILSON TRICIA F	203 LENTZ PL	167000451	203 LENTZ PLACE	NEWPORT NEWS	VA	23602
BRUNT JEFFERY J	BRUNT TAMIRA M	322 PEACH TREE CRES	167000434	322 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
SHEPHERD MARY ANNE		232 WEATHERFORD WAY	168000618	232 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
STIFLE IAN JOHN	STIFLE SARAH CHRISTINE	201 LENTZ PL	167000450	201 LENTZ PLACE	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS SCHOOL BOARD		701 MENCHVILLE RD	167000401	12465 WARWICK BOULEVARD	NEWPORT NEWS	VA	23606
BALINA LEONIE D		106 RIVER BIRCH CT	178000142	106 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
GILLROY PATRICK A	GILLROY CAROLYN C	24 W GOVERNOR DR	178000315	24 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
GALLUCCI CHARLES L	GALLUCCI JANIS R	25 E GOVERNOR DR	178000324	25 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
CLARK ANTHONY D SR	CLARK JENISE E	3 E GOVERNOR DR	189000118	3 GOVERNOR DRIVE EAST	NEWPORT NEWS	VA	23602
GILBERT ANNE E		43 W GOVERNOR DR	178000215	43 GOVERNOR DRIVE W	NEWPORT NEWS	VA	23602
WALLIN LEONARD A II		50 CABELL DR	178000232	50 CABELL DRIVE	NEWPORT NEWS	VA	23602
SORENSEN REBECCA V		14 BLACKSMYTHE LN	178000253	14 BLACKSMYTHE LN	NEWPORT NEWS	VA	23602
HOLDER SHERRIN K		13 BLACKSMYTHE LN	178000246	13 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
LADD NELLIE D TRUSTEE	LADD JOINT TRUST	43 E GOVERNOR DR	178000332	43 GOVERNOR DRIVE EAST	NEWPORT NEWS	VA	23602
AMUNDSON ERLING P	AMUNDSON JUDITH E	48 HARDWICK RD	178000209	48 HARDWICK ROAD	NEWPORT NEWS	VA	23602
SCRIMGEOUR MICHAEL A	CARPENTER JESSICA L	119 MONARCH DR	168000355	119 MONARCH DR	NEWPORT NEWS	VA	23602
STAPLES LARRY D		272 MENCHVILLE RD	168000514	272 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
DYKAS BRIAN G	DYKAS MARY L	261 LOU MAC CT	168000506	261 LOU MAC COURT	NEWPORT NEWS	VA	23602
GLASCOCK CHONG S		278 MENCHVILLE RD	168000309	103 CLARDEN CT	YORKTOWN	VA	23692
CROSBY CODI M	CROSBY JONATHAN L	106 TERRI BETH PL	168000517	106 TERRI BETH PLACE	NEWPORT NEWS	VA	23602
LAMBLEY ANDREW S	LAMBLEY KELLY D	331 PEACH TREE CRES	167000447	331 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
HIGHSMITH JUDITH A		335 PEACH TREE CRES	167000445	335 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
WEST LAWRENCE E	WEST DONNA	310 TAHOE DR	168000158	310 TAHOE DRIVE	NEWPORT NEWS	VA	23602
ADAMS ROY K		308 TAHOE DR	168000159	308 TAHOE DRIVE	NEWPORT NEWS	VA	23602
TOMPKINS GLENN E	TOMPKINS ROLINDA B	245 CABELL DR	168000138	245 CABELL DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
BUNCH LEONARD P	BUNCH SELETA	337 PEACH TREE CRES	167000444	337 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
MARTIN KEVIN S & JACQUELINE E	MARTIN	339 PEACH TREE CRES	167000443	339 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
MATTHEWS BONNIE KAY		308 OLD MENCHVILLE RD # B	179000128	308 B OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
MOORE CHRISTOPHER D		304 OLD MENCHVILLE RD	179000137	308 OLD MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
GORI GEORGE G		296 MENCHVILLE CT	168000318	296 MENCHVILLE CT	NEWPORT NEWS	VA	23602
BANKS GERALD F		3 FLAX MILL RD	189000215	3 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
HUFFMAN CHARLES A III		61 HAUGHTON LN	208000101	12284 WARWICK BLVD SUITE 2-A	NEWPORT NEWS	VA	23606
MILLNER TAYLOR W & THOMAS L		1 NORMILL LNDG	190000208	1 NORMILL LANDING	NEWPORT NEWS	VA	23602
BOLDY JAMES R	BOLDY NICOLE L	108 CANVASBACK TRL	190000238	108 CANVASBACK TRAIL	NEWPORT NEWS	VA	23602
STROTHERS ADRIA P		26 LUCAS CREEK RD	167000464	26 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
STARK CEDRIC D &	STEFANIE M DUPLESSIS	237 CABELL DR	168000134	237 CABELL DRIVE	NEWPORT NEWS	VA	23602
WHITE PEGGY DAIL TRUSTEE OF		24 E GOVERNOR DR	178000345	24 E GOVERNOR DR	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		1 PLANTATION RD # A	178000416	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
JACKSON ERIC R & CELESTINE C TRS		16 SWAMP GATE RD	178000401	16 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
CRENSHAW WALTER A JR	CRENSHAW CONSTANCE P	8 FLAX MILL RD	189000211	8 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
SCICCHITANO JEREMY & ELIZABETH F	SCICCHITANO	45 RAMSHAW LN	178000230	45 RAMSHAW LANE	NEWPORT NEWS	VA	23602
ANZIO ROBERT M	ANZIO BARBARA J	128 MONARCH DR	168000402	128 MONARCH DRIVE	NEWPORT NEWS	VA	23602
WILKS MICHAEL T & JENNIFER H	WILKS	192 LORI CIR	168000372	192 LORI CIRCLE	NEWPORT NEWS	VA	23602
COLLIGAN WILLIAM R	COLLIGAN PATRICIA J	299 ADRIENNE PL	168000339	299 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
WALLACE WAYNE K	WALLACE ANDREA G	292 ADRIENNE PL	168000352	292 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
WOOD CHARLES A	WOOD DANIA M	294 LOU MAC CT	168000335	294 LOU MAC COURT	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
TRISTANI ROBERT J		108 DAVID CIR	168000331	108 DAVID CIRCLE	NEWPORT NEWS	VA	23602
MONROE HELLEN M		286 MENCHVILLE RD	168000313	286 MENCHVILLE RD	NEWPORT NEWS	VA	23602
KEAFER DALE B	KEAFER MICHELLE	33 ISLAND VIEW DR	178000540	33 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
FIGUENICK DIANE SIMPSON	FIGUENICK VINCENT	16 BLACKSMYTHE LN	178000252	16 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
MOORE ROBERT E	MOORE LAURA L	120 MONARCH DR	168000358	120 MONARCH DRIVE	NEWPORT NEWS	VA	23602
KORNITZER CAROLINE O	KORNITZER NICHOLAS S	28 W GOVERNOR DR	178000313	28 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
RONDOMANSKI JAMES E	GRIZOTTI PRISCILA L	21 E GOVERNOR DR	178000322	21 EAST GOVERNOR DR	NEWPORT NEWS	VA	23602
HUFFMAN ERIC	HUFFMAN KATHLEEN G	30 W GOVERNOR DR	178000312	30 W GOVERNOR DR	NEWPORT NEWS	VA	23602
LOUK GARY B JR	LOUK MARISA	23 E GOVERNOR DR	178000323	23 GOVERNOR DR E	NEWPORT NEWS	VA	23602
BELOTE R FRANKLIN JR TR	BELOTE PATRICIA VERHINE TR	46 W GOVERNOR DR	178000304	46 W GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
KEATLEY WILLIAM E	KEATLEY VIRGINIA E	39 E GOVERNOR DR	178000331	39 EAST GOVERNOR DR	NEWPORT NEWS	VA	23602
ANDERSON JOYCE QUERRY		10 PLANTATION RD	178000415	10 PLANTATION ROAD	NEWPORT NEWS	VA	23602
SHWAYDER REBECCA L		9 HORSE PEN RD	189000415	9 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
LUCKMAN JEFFREY M	LUCKMAN LORI D	16 ISLAND VIEW DR	178000516	16 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
SANCHEZ WAYNE M	SANCHEZ DAWN M	6 W GOVERNOR DR	189000110	6 W GOVERNOR DR	NEWPORT NEWS	VA	23602
KELLER ROBERT F JR	KELLER DONNA F	4 E GOVERNOR DR	189000122	4 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
WELLIVER BRADLEY S ET UX		18 FLAX MILL RD	189000206	18 FLAXMILL RD	NEWPORT NEWS	VA	23602
ROBERTS DONALD R ET UX		4 RIVER POINT CIR	189000205	4 RIVER POINT CIR	NEWPORT NEWS	VA	23602
STONE JEROME SR	STONE DONNA M	49 W GOVERNOR DR	178000213	49 WEST GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
DEMUTH S H SR & ILENE D DEMUTH		49 HARDWICK RD	178000203	49 HARDWICK ROAD	NEWPORT NEWS	VA	23602
FORREST WILLIAM A	FORREST SANDRA G	52 CABELL DR	178000233	52 CABELL DRIVE	NEWPORT NEWS	VA	23602
MUSSELWHITE GARY L	HAUSE DEBORAH M	32 ISLAND VIEW DR	178000508	32 ISLAND VIEW DR	NEWPORT NEWS	VA	23602
MELTON THAD	MELTON KAREN	176 LORI CIR	168000354	176 LORI CIRCLE	NEWPORT NEWS	VA	23602
HARRIS VICTOR S ET UX		284 ADRIENNE PL	168000348	284 ADRIENNE PL	NEWPORT NEWS	VA	23602
COX PAULA		266 LOU MAC CT	168000434	266 LOU MAC COURT	NEWPORT NEWS	VA	23602
MCARTHUR JESSIE JR ET UX		311 TAHOE DR	168000154	311 TAHOE DRIVE	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
STOREY JUSTINE V JACKSON &	FREDDIE B STOREY	31 ISLAND VIEW DR	178000539	31 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
MERRITT MARJORIE L ET VIR		102 RIVER BIRCH CT	178000144	124 WILL SCARLET LN	WILLIAMSBURG	VA	23185
HENDERSON ARTHUR P JR	HENDERSON NANCY R	13 FLAX MILL RD	189000220	13 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
LONG DAVID RONALD	LONG SHAWN MARIE	1 W GOVERNOR DR	189000109	1 GOVERNOR DR W	NEWPORT NEWS	VA	23602
IM TON SUN ET UX		34 ISLAND VIEW DR	178000507	34 ISLAND VIEW DR	NEWPORT NEWS	VA	23602
FAISON ROBERT B		191 LORI CIR	168000364	733 LEONARD LANE	NEWPORT NEWS	VA	23601
PAPP ROBERT Z UX		297 ADRIENNE PL	168000340	297 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
ALDRIDGE JAMES W	ALDRIDGE THEOLANDA R	293 ADRIENNE PL	168000342	293 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
MAINSTAY INVESTMENTS LLC		284 LOU MAC CT	168000328	704 THIMBLE SHOALS BLVD STE 300A	NEWPORT NEWS	VA	23606
VITO SARAH E		102 MONARCH DR	168000310	102 MONARCH DRIVE	NEWPORT NEWS	VA	23602
BILLINGS JONATHAN M		100 MONARCH DR	168000311	100 MONARCH DRIVE	NEWPORT NEWS	VA	23602
TAYLOR ROBERT N & ELEANOR P		633 SNUG HARBOR LN	200000151	633 SNUG HARBOR LANE	NEWPORT NEWS	VA	23606
SAUNDERS JOHN W	SAUNDERS PAMELA M	6 SWAMP GATE RD	178000406	6 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
GOODWYN KATHERINE N		10 SWAMP GATE RD	178000404	10 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
SIMKO ERIC J MD		18 HORSE PEN RD	189000405	18 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
MACHADO BENNY R		296 LOU MAC CT	168000334	296 LOU MAC COURT	NEWPORT NEWS	VA	23602
DALE C SHENK LIVING TRUST	SHENK DALE C TR	110 DAVID CIR	168000330	325 CONNISTON RD., UNIT #2	WEST PALM BEACH	FL	33405
BOLING ALVIN E	BOLING CHONG S	248 CABELL DR	168000167	248 CABELL DRIVE	NEWPORT NEWS	VA	23602
LLOYD HAROLD G JR & CAROLINE C	LLOYD	250 WEATHERFORD WAY	168000627	250 WEATHERFORD WAY	NEWPORT NEWS	VA	23602
GAPPERT CINDY A		223 CABELL DR	167000418	223 CABELL DRIVE	NEWPORT NEWS	VA	23602
CLARK MANWELL A D		319 PEACH TREE CRES	167000457	319 PEACH TREE CRESCENT	NEWPORT NEWS	VA	23602
RUDOLPH JOHN K ET UX		314 TAHOE DR	168000156	314 TAHOE DRIVE	NEWPORT NEWS	VA	23602
COSTA GRANT L	COSTA DEBRA W	35 E GOVERNOR DR	178000329	35 EAST GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
JONES ROBERT M	JONES RUTH W	8 E GOVERNOR DR	189000124	8 E GOVERNOR DR	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
WATROUS RONALD K	WATROUS MICHELLE T	6 HORSE PEN RD	189000411	6 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
FLEMING CHRISTOPHER R		15 BLACKSMYTHE LN	178000247	15 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
TRUITT GLORIA H ET VIR		107 RIVER BIRCH CT	178000134	107 RIVER BIRCH COURT	NEWPORT NEWS	VA	23602
YOKE WILLARD E II	YOKE LYNN M	49 RAMSHAW LN	178000228	49 RAMSHAW LANE	NEWPORT NEWS	VA	23602
PAN NORAMA	POL PHUSSANDAN	184 LORI CIR	168000375	24 BUFFALO GAP CT	N. LAS VEGAS	NV	89084
LY HOY CHIN		117 MONARCH DR	168000356	117 MONARCH DRIVE	NEWPORT NEWS	VA	23602
GARRETT VICKIE FRYE		286 ADRIENNE PL	168000349	286 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
JEFFRIES MYCHAL E		270 MENCHVILLE RD	168000515	270 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
EDMONDSTON KEVIN ROBERT	EDMONDSTON JENNIFER LYNN	271 LOU MAC CT	168000511	271 LOU MAC COURT	NEWPORT NEWS	VA	23602
HAYWOOD BOBBY SR	HAYWOOD ELLEN A	272 LOU MAC CT	168000503	272 LOU MAC COURT	NEWPORT NEWS	VA	23602
DELNICKI JAMES	DELNICKI MIRIAM L	265 LOU MAC CT	168000508	265 LOU MAC COURT	NEWPORT NEWS	VA	23602
HUFFMAN CHARLES A III UX		660 DEEP CREEK RD	199000201	P O BOX 6368	NEWPORT NEWS	VA	23606
CLANCY PATRICIA E		354 OLD MENCHVILLE RD	190000201	354 OLD MENCHVILLE RD	NEWPORT NEWS	VA	23602
WILSON RANDALL R	WILSON MARTHA G	311 PEACH TREE CRES	167000556	311 PEACH TREE CRESENT	NEWPORT NEWS	VA	23602
MACDONALD RICHARD E	MACDONALD GRACE D	41 ISLAND VIEW DR	178000544	41 ISLAND VIEW DRIVE	NEWPORT NEWS	VA	23602
HAAS BRYAN D		29 LUCAS CREEK RD	178000137	29 LUCAS CREEK ROAD	NEWPORT NEWS	VA	23602
VERDE FLORIN P	VERDE IOANA C	32 E GOVERNOR DR	178000342	32 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
WAIBLE EDMOND J	WAIBLE DEBRA L	18 E GOVERNOR DR	178000347	18 E GOVERNOR DRIVE	NEWPORT NEWS	VA	23602
SHEPLEY RAYMOND III	SHEPLEY ALICE F	14 SWAMP GATE RD	178000402	14 SWAMP GATE ROAD	NEWPORT NEWS	VA	23602
LANDERS JAMES H	LANDERS JILL M	19 HORSE PEN RD	189000422	19 HORSE PEN ROAD	NEWPORT NEWS	VA	23602
RANCORN NELSON C III	RANCORN GENAY B	4 FLAX MILL RD	189000213	4 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
BRINKER DAVID R	BRINKER CYNTHIA L	7 FLAX MILL RD	189000217	7 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
MAYO SAMUEL N III ET UX		50 HARDWICK RD	178000208	50 HARDWICK RD	NEWPORT NEWS	VA	23602
ARCEO KAYLEE A		48 RAMSHAW LN	178000226	48 RAMSHAW LANE	NEWPORT NEWS	VA	23602
DENBIGH PLANTATION GARDEN CLUB		10 BLACKSMYTHE LN	178000255	16 HORSE PEN ROAD	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
TUCKER DONALD G TR	TUCKER CLAUDIA M TR	20 BLACKSMYTHE LN	178000250	20 BLACKSMYTHE LANE	NEWPORT NEWS	VA	23602
DANGERFIELD CHRISTOPHER ET UX		185 LORI CIR	168000361	185 LORI CIRCLE	NEWPORT NEWS	VA	23602
PEREZ-VALENTIN RICARDO		294 ADRIENNE PL	168000336	294 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
COX AMBERT	COX REBECCA F	106 DAVID CIR	168000332	106 DAVID CIR	NEWPORT NEWS	VA	23602
RIGSBY ROBERT R		288 MENCHVILLE RD	168000314	705 MCPHERSON AVE	FAYETTEVILLE	NC	28303
GARDNER JESSE		283 LOU MAC CT	168000325	283 LOU MAC COURT	NEWPORT NEWS	VA	23602
BRIOTA SILVIU		285 LOU MAC CT	168000324	285 LOU MAC COURT	NEWPORT NEWS	VA	23602
HUNTER WILLIAM F & MARY MORGAN C	HUNTER	16 W GOVERNOR DR	189000113	16 W GOVERNOR DR	NEWPORT NEWS	VA	23602
PATTERSON ROGER K & NANCY M TRS		6 FLAX MILL RD	189000212	6 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
WILLIAMS MITCHELL G	WILLIAMS NAMHEE	47 RAMSHAW LN	178000229	47 RAMSHAW LANE	NEWPORT NEWS	VA	23602
BENNER KEVIN R	BENNER CHRISTINE B	187 LORI CIR	168000362	187 LORI CIRCLE	NEWPORT NEWS	VA	23602
HITE JORDAN & MEGAN COOK		296 ADRIENNE PL	168000337	296 ADRIENNE PLACE	NEWPORT NEWS	VA	23602
JONES JOHN P ET UX		5 FLAX MILL RD	189000216	5 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
VANDAM CORNELIS P	VANDAM REBECCA M	15 FLAX MILL RD	189000221	PO BOX 4676	DAVIS	CA	95617
FALEN STEVEN W	FALEN SUSAN L	17 FLAX MILL RD	189000222	17 FLAX MILL RD	NEWPORT NEWS	VA	23602
HAUSE KYLE T JR	HAUSE DEBORAH M	19 FLAX MILL RD	189000223	19 FLAX MILL ROAD	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		100 CITY FARM RD	190000101	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
DAVIS SCOTT E	DAVIS CYNTHIA K	214 BLUFF TER	190000307	214 BLUFF TERRACE	NEWPORT NEWS	VA	23602
HOOVER CORRINE A TRUSTEE		216 BLUFF TER	190000306	216 BLUFF TERRACE	NEWPORT NEWS	VA	23602
COPES JERRY B ET UX		218 BLUFF TER	190000305	218 BLUFF TERRACE	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		494 MENCHVILLE RD S	190000221	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
SIMMONS TRAVOLIS A ET UX		103 BLUFF TER	190000330	103 BLUFF TERRACE	NEWPORT NEWS	VA	23602
PENN JUNIUS ET UX		101 BLUFF TER	190000331	101 BLUFF TERRACE	NEWPORT NEWS	VA	23602
OGLE SOLOMON D		477 MENCHVILLE RD S	190000116	477 MENCHVILLE RD SOUTH	NEWPORT NEWS	VA	23602

Landowner 1	Landowner 2	Site Address	Parcel ID	Owner Address	City	State	Zip
WHITE WILLIAM T		461 MENCHVILLE RD S	190000110	461 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
GRIFFIN KENNETH B		459 MENCHVILLE RD S	190000109	459 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
MARTIN JACOB C		457 MENCHVILLE RD S	190000108	457 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
FAULK CHARLIE M ET UX		435 MENCHVILLE RD S	190000118	491 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
FAULK CHARLIE M ET UX		491 MENCHVILLE RD S	190000115	491 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
FAULK CHARLIE M ET UX		483 MENCHVILLE RD S	190000117	491 MENCHVILLE ROAD S	NEWPORT NEWS	VA	23602
HAYNES SELWYN L		504 MENCHVILLE RD S	199000101	504 MENCHVILLE ROAD SOUTH	NEWPORT NEWS	VA	23602
CITY OF NEWPORT NEWS		520 MENCHVILLE RD S	199000105	2400 WASHINGTON AVE	NEWPORT NEWS	VA	23607
ADAMS LEONA FRANSKE & WILLIAM		508 MENCHVILLE RD S	199000102	160 MENCHVILLE ROAD	NEWPORT NEWS	VA	23602
COASTAL VA HOMES LLC		463 MENCHVILLE RD S	190000119	1624 LASKIN RD SUITE 736-136	VIRGINIA BEACH	VA	23451
COASTAL VA HOMES LLC		463 MENCHVILLE RD S	190000111	1624 LASKIN RD SUITE 736-136	VIRGINIA BEACH	VA	23451

Attachment B: Geological and Geophysical Information

B.1 Part I. Geologic Data

Select Relevant Previous Studies

The United States Geological Survey (USGS) and the Virginia Department of Environmental Quality (DEQ) have conducted many investigations to characterize the geology and hydrogeology of the Virginia Coastal Plain (VCP) physiographic province. A great degree of interest in the groundwater resources of the VCP stems from the relatively large reliance on these aquifers as a source of supply for municipal, residential, industrial, commercial, and agricultural uses. These studies characterize the hydrogeologic framework, groundwater flow and water quality of the aquifer system and have been funded in large part by the Environmental Protection Agency (EPA) through grants to DEQ, USGS, DEQ and Hampton Roads localities through the Hampton Roads Planning District Commission (HRPDC).

The most recent and relevant literature characterizing the hydrogeology, groundwater flow, and groundwater quality in the VCP, including the area of James River SWIFT (JR SWIFT), include the following (in chronological order):

McFarland, E.R., 2015, A conceptual framework and monitoring strategy for movement of saltwater in the Coastal Plain aquifer system of Virginia: U.S. Geological Survey Scientific Investigations Report 2015–5117, 30 p., 1 pl., (available online at http://dx.doi.org/10.3133/sir20155117).

McFarland, E.R., 2013, Sediment distribution and hydrologic conditions of the Potomac aquifer in Virginia and parts of Maryland and North Carolina: U.S. Geological Survey Scientific Investigations Report 2013–5116, 67 p.,3 attachments, 2 plates, (available online at http://pubs.usgs.gov/sir/2013/5116/).

Eggleston, Jack, and Pope, Jason, 2013, Land subsidence and relative sea-level rise in the southern Chesapeake Bay region: U.S. Geological Survey Circular 1392, 30 p., (available online at http://dx.doi.org/10.3133/cir1392)

McFarland, E.R., 2010, Groundwater-quality data and regional trends in the Virginia Coastal Plain, 1906–2007: U.S. Geological Survey Professional Paper 1772, 86 p., 14 pls. (available online at http://pubs.usgs.gov/pp/1772/)

Heywood, C.E., and Pope, J.P., 2009, Simulation of groundwater flow in the Coastal Plain aquifer system of Virginia: U.S. Geological Survey Scientific Investigations Report 2009–5039, 115 p.

McFarland, E.R., and Bruce, T.S., 2006, The Virginia Coastal Plain Hydrogeologic Framework: U.S. Geological Survey Professional Paper 1731, 118 p., 25 pls. (available online at http://pubs.water.usgs.gov/pp1731/).

Powars, D.S., 2000, The effects of the Chesapeake Bay impact crater on the geological framework and correlation of the hydrogeologic units of southeastern Virginia, south of the James River: U.S. Geological Survey Professional Paper 1622, 53p.

Powars, David S. and Bruce, T. Scott, 1999, The Effects of the Chesapeake Bay Impact Crater on the Geological Framework and Correlation of Hydrogeologic Units of the Lower York-James Peninsula,

Virginia, U.S. Geological Survey Professional Paper 1612, (available online at https://pubs.usgs.gov/pp/p1612/front.html).

McFarland, E.R., 1999, Hydrogeologic Framework and Ground-Water Flow in the Fall Zone of Virginia, U.S. Geological Survey Water Resources Investigations Report 99-4093.

Harsh, J.F., and Laczniak, R.J., 1990. Conceptualization and analysis of groundwater flow system in the coastal Plain of Virginia and adjacent parts of Maryland and North Carolina: U.S. Geological Survey Professional Paper 12404-F, 100p. 1990

Meng, A.A., III and Harsh, J.F., 1988, Hydrogeologic Framework of the Virginia Coastal Plain: U.S. Geological Survey Professional Paper 1404-C, 82 p.

The narrative below provides a summary of the geology and hydrogeology of the VCP, including the area of JR SWIFT. It relies heavily on McFarland and Bruce, 2006 and Powars and Bruce, 1999 and expresses the latest published interpretations of the geologic and hydrogeologic framework at the location of James River SWIFT.

B.1.1 General Regional Geologic and Hydrogeologic Framework

Overview

The James River SWIFT site (JR SWIFT) is in southeastern Virginia between the James and York Rivers. The area lies within the Virginia Coastal Plain (VCP) Physiographic Province (Figure B-1) and is underlain by an eastward thickening wedge of marine and non-marine sediments ranging in age from early Cretaceous to Holocene. Along the coastline, several thousands of feet of interlayered, unconsolidated and semi-consolidated sediment, consisting of gravel, sand, silt, shell and clay deposits (McFarland and Bruce, 2006) overlie pre-Cretaceous crystalline rocks defining the basement.

Figure B-1: Location of Virginia Coastal Plain, taken from McFarland and Bruce, 2006

Coastal Plain sedimentation and deposition represent a seaward progradation of fluvial plans and deltas controlled by fluctuations in sea level on a subsiding continental margin (McFarland and Bruce, 2006, Meng and Harsh, 1988). The VCP sediment wedge comprises a thick sequence of nonmarine sediments mostly of Cretaceous age overlain by a relatively thinner sequence of marine sediments of Tertiary age and capped by very thin Quaternary aged terrace and flood-plain deposits. The VCP sediments dip gently to the southeast. The average structural dip of the oldest and deepest deposits is approximately 40 ft/mile and is less than 3 ft/mile for the youngest and shallowest deposits (Meng and Harsh, 1988).

In general, the geologic units present in the VCP appear in Figure B-2 (taken from McFarland and Bruce, 2006, and Powers and Bruce, 1999). Formations from youngest to oldest include:

- Holocene – undifferentiated (alluvium, swamp, beach)
- Pleistocene – undifferentiated (Tabb, Shirely, Chuckatuck, Charles City and Windsor Formations)
- Late Pliocene - Bacons Castle and Chowan River Formations
- Early Pliocene – Yorktown Formation

- Late Miocene – Eastover Formation
- Late Miocene - Saint Marys Formation
- Early and mid-Miocene – Calvert Formation
- Late Oligocene - Old Church Formation
- Early Oligocene – Delmarva beds
- late Eocene – Chickahominy Formation, Exmore tsunami-breccia and megablock beds
- Mid-Eocene – Piney Point Formation
- Early Eocene – Nanjemoy Formation, Marlboro Clay
- Late Paleocene – Marlboro Clay and Aquia Formation
- Early Paleocene – Brightseat Formation
- Late Cretaceous – upper Cretaceous beds (various glauconite and quartz sands, clays, red beds) and the upper Cenomanian beds
- Early Cretaceous – Potomac Formation

Corresponding to the regional geologic formations and groups listed above are 19 hydrostratigraphic units: described by eight aquifers separated by 11 confining units/zones. The geologic and corresponding hydrostratigraphic units appear in Figure B-2 (McFarland and Bruce, 2006).

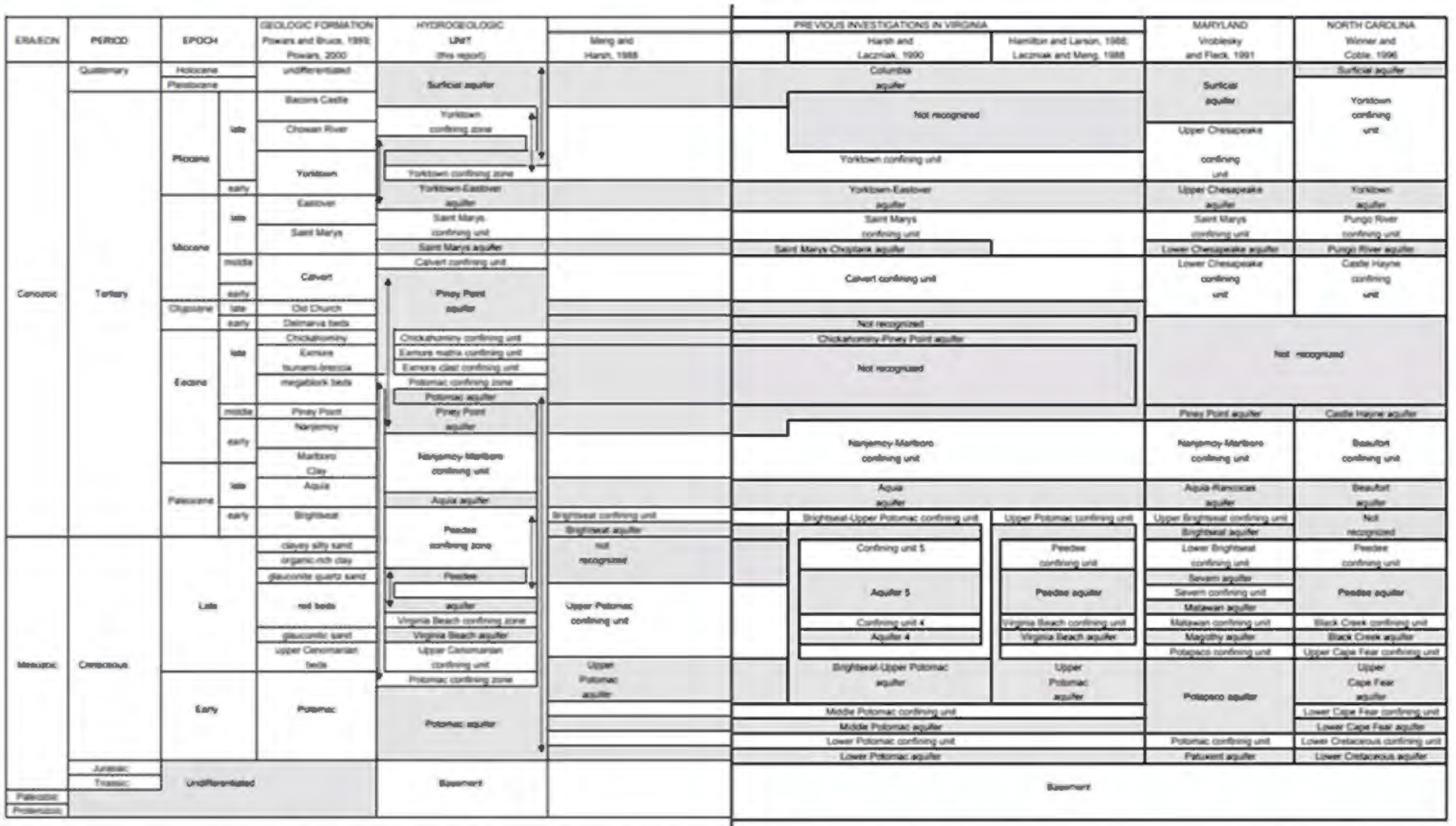


Figure 3. Stratigraphic correlations of hydrogeologic units of the Virginia Coastal Plain. (Vertical arrows indicate major hydrologic not depicted.)

associations that cross stratigraphic boundaries. Minor overlaps of hydrogeologic units among adjacent geologic formations are

Taken from Virginia Coastal Plain Hydrogeologic Framework, McFarland and Bruce, 2006, Figure 3

Figure B-2, Stratigraphic correlations of Hydrogeologic Units of the Virginia Coastal Plain

James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

Chesapeake Bay Impact Crater

Disrupting the VCP section, the Chesapeake Bay Impact Crater (CBIC), located near the mouth of the Chesapeake Bay, was formed by the impact of a bolide in the Eocene epoch, approximately 35 million years ago (Powars, 2000, Powars and Bruce, 1999). The impact crater diameter measures greater than 50 miles. The impact displaced or disturbed all the sediments within and immediately around the crater. Sediments and bedrock fragments filling the crater are known as the Exmore tsunami-breccia formation (Exmore matrix and Exmore clast confining unit) along with megablock beds of the Potomac formation (Potomac aquifer and confining unit), buried by approximately 1,000 feet of post impact sediments. The James River SWIFT site is situated relatively close to the outer rim of the CBIC as mapped in Figure B-1 above. A relatively thin layer of the Exmore matrix was present in the James River Test Well log (see Figure B.10 and Table B.1 below).

Western Boundary

The Piedmont Physiographic Province lies to the west of the VCP. The Fall Zone describes the border between the VCP and Piedmont and measures several miles wide. This zone, making up the transition from Piedmont to VCP, is characterized by falls and rapids along streams. Crystalline rock composing the Piedmont dips beneath the VCP sediments and makes up the basement rock, the lower boundary of the aquifer system. The Fall Zone was a significant source of recharge to the confined aquifer system prior to large drawdowns near major pumping centers (McFarland, 1999).

Basement

A series of gently dipping regional structural highs and lows, known as arches and embayments (or basins), have been produced by differential subsidence. The Hampton Roads area of Virginia is located along the axis of one of these regional structural features known as the Norfolk Arch (Meng and Harsh, 1988). The arch forms an east-west structural ridge of crystalline basement rock that separates the Salisbury Embayment to the north from Albemarle Embayment to the south. Thicker accumulations of sediment occurred in the basins as compared to over the arches. The arches separated characteristic depositional sequences within the adjoining basins. Sediments of the Salisbury Embayment, north of the Norfolk Arch, feature glauconite-rich, sands and silts characteristics of slow sedimentation on inner and outer continental shelf depositional environments. By comparison sediments of the Albemarle Embayment, south of the Norfolk Arch, appear characteristically carbonate-rich typical of near shore deposition. The VCP section beneath the JR SWIFT, located proximal to the Norfolk Arch, area exceeds 1,300 ft, to the bedrock surface.

The Potomac Aquifer and SWIFT

The Potomac aquifer forms the target recharge aquifer for the JR SWIFT injection. At over 900 feet thick it represents the deepest, thickest and most extensive aquifer at the JR SWIFT site. It is laterally extensive across the entire North Atlantic Coastal Plain, except for the area of the CBIC. Approximately 75% of the withdrawals in the VCP aquifer system come from the Potomac aquifer and cover many different uses including potable and non-potable, public and private (Heywood and Pope, 2009).

Early studies conducted by the USGS, DEQ, and Virginia Department of Mineral Resources describing the VCP hydrogeologic framework designated geologic units of the Cretaceous Potomac Formation as a single aquifer (McFarland and Bruce, 2006). Meng and Harsh (1988) later described the hydrogeologic framework of the VCP as part of the USGS Regional Aquifer System Assessment. In this definitive effort the Potomac Formation was subdivided into three distinct aquifers, the Upper Potomac, Middle Potomac and Lower Potomac aquifers. This framework was carried forward into the development of a groundwater flow model of the VCP aquifer system (Harsh and Laczniak, 1990). According to McFarland (2013) the three separate Cretaceous aquifers construct was necessary to conform the frameworks and models of bordering states, better matching those of Maryland and North Carolina. These efforts were combined with other hydrogeologic frameworks and groundwater flow models into a northern Atlantic Coastal Plain hydrogeologic framework (Trapp, 1992) and a single flow model for the entire North Atlantic Coastal Plain (Leahy and Martin, 1993). The framework of Meng and Harsh remained the most authoritative reference until 2006.

In 2006, McFarland and Bruce published a new interpretation of the hydrogeologic framework of the VCP incorporating significant additional boreholes. Of the most notable aspects involves characterizing the Potomac Formation as a single, undivided, heterogeneous hydrostratigraphic unit referred to as the Potomac aquifer. The confining zones within the Potomac aquifer are not continuous but relatively local in extent and the potentiometric surfaces are relatively similar in a regional context. Another significant change in their framework is the explicit inclusion of the CBIC (described above). As well, this hydrogeologic framework was used to develop a new groundwater flow model (Heywood and Pope, 2009) that is still being used to evaluate permit applications by DEQ for groundwater withdrawal permits.

SWIFT applies the hydrogeologic framework of the VCP as defined by McFarland and Bruce (2006) when describing the hydrogeology at the SWIFT sites and targeting aquifers for MAR; and the subsequent model developed by Heywood and Pope (2009) to model the hydraulic impact of SWIFT recharging. However, due to the thickness and interbedded nature of the Potomac aquifer, subdividing the aquifer into different zones to provide greater resolution when describing geochemistry and recharge capacity of aquifer units selected for MAR, SWIFT also adopts intermediate designations referencing sub-zones of the Potomac aquifer system (PAS).

Professional Geologists within the SWIFT Program Management Team (PMT) with assistance from DEQ geologists determined the elevations of the sub-zones based on lithology, geophysical signatures and groundwater water quality. To ensure accuracy and uniformity in describing aquifer units supporting MAR, the PMT consistently applies these zone designations throughout the SWIFT Program and across the SWIFT sites.

Locally to the James River site, these sub-zones display the following:

- A distinct water quality signature
- Separation by relatively thicker interbedded fine grain units (acting much like confining units during packer testing)
- Slightly different hydraulic heads

This section discretizes the PAS into three zones including the upper zone, middle zone, and lower zone that are used throughout the permit application (in attachments and the appendix documents). The depths of these units encountered at the James River SWIFT site are noted in Figure B-10. For the reader's convenience the section abbreviates the units as UPA, MPA and LPA but do not necessarily line up with the altitude designations of the previous studies, mentioned above, denoting the Upper Potomac, Middle Potomac and Lower Potomac aquifers.

The Potomac aquifer is primarily Cretaceous in age and composed of a highly interbedded fluvial-deltaic depositional environment. It is characterized by coarse-grained quartz and feldspathic sands and gravels and interbedded clays corresponding to the Potomac Formation. It is classified in McFarland and Bruce (2006) as a heterogeneous aquifer as deposits associated with variable environments including braided streams, meandering streams and deltas resulting in distinct changes in texture across relatively small distances. The Potomac aquifer forms a hydraulically continuous unit on a regional scale, with discontinuous confining zones interbedded within the aquifer, but locally maintains characteristics of differentiated hydraulic units due to discontinuities from finer grained interbeds. McFarland and Bruce, 2006, devote some discussion to megablocks of the Potomac within the CBIC and their relationship to hydraulic conductivity, however the JR SWIFT site does not lie directly in the CBIC so that discussion is not included here.

The Potomac aquifer is underlain by igneous and metamorphic basement rock, with some sedimentary rocks from the Triassic basins. It is capped almost continuously by the Potomac confining unit, however, in the JR SWIFT test well this confining unit is missing and the fine grained sediments of the Exmore Matrix and Chickahominy units confine the Potomac (see Table B.1 below). The aquifer outcrops at its western edge near the Fall Zone and is incised by the major rivers in this area. The aquifer dips as it progresses eastward and lies approximately 400 feet below grade at the JR SWIFT site with the basement rocks occurring at approximately 1320 feet below grade.

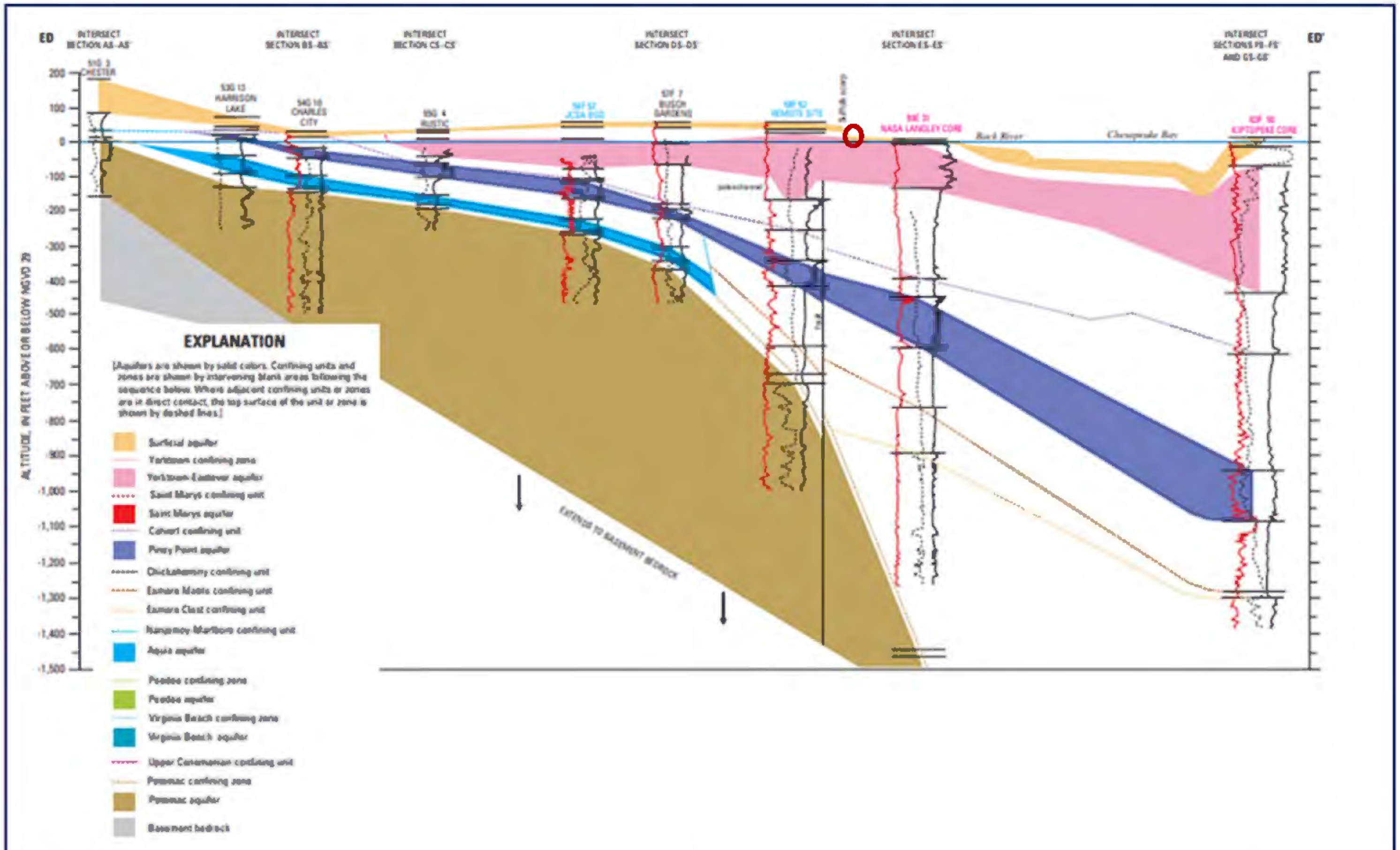
Figure B-3 and B-4 provide a hydrogeologic cross-section taken from McFarland and Bruce (2006) of a transect through the York James Peninsula near the JR SWIFT site. Figures B-5, B-6 and B-7 provide hydrogeologic transects and cross sections through the York James Peninsula from Powers and Bruce (1999). All transects show the absence of the hydrostratigraphic sequence between the Potomac aquifer and the Calvert confining unit. On the cross sections presented in B-6 and B-7, the missing units are superimposed against the figure, the colors represent what is present in the transect.

○ **James River SWIFT approximate location**

▬ **Transect of ED – ED'**

Taken from Virginia Coastal Plain Hydrogeologic Framework, McFarland and Bruce, 2006, Plate 1

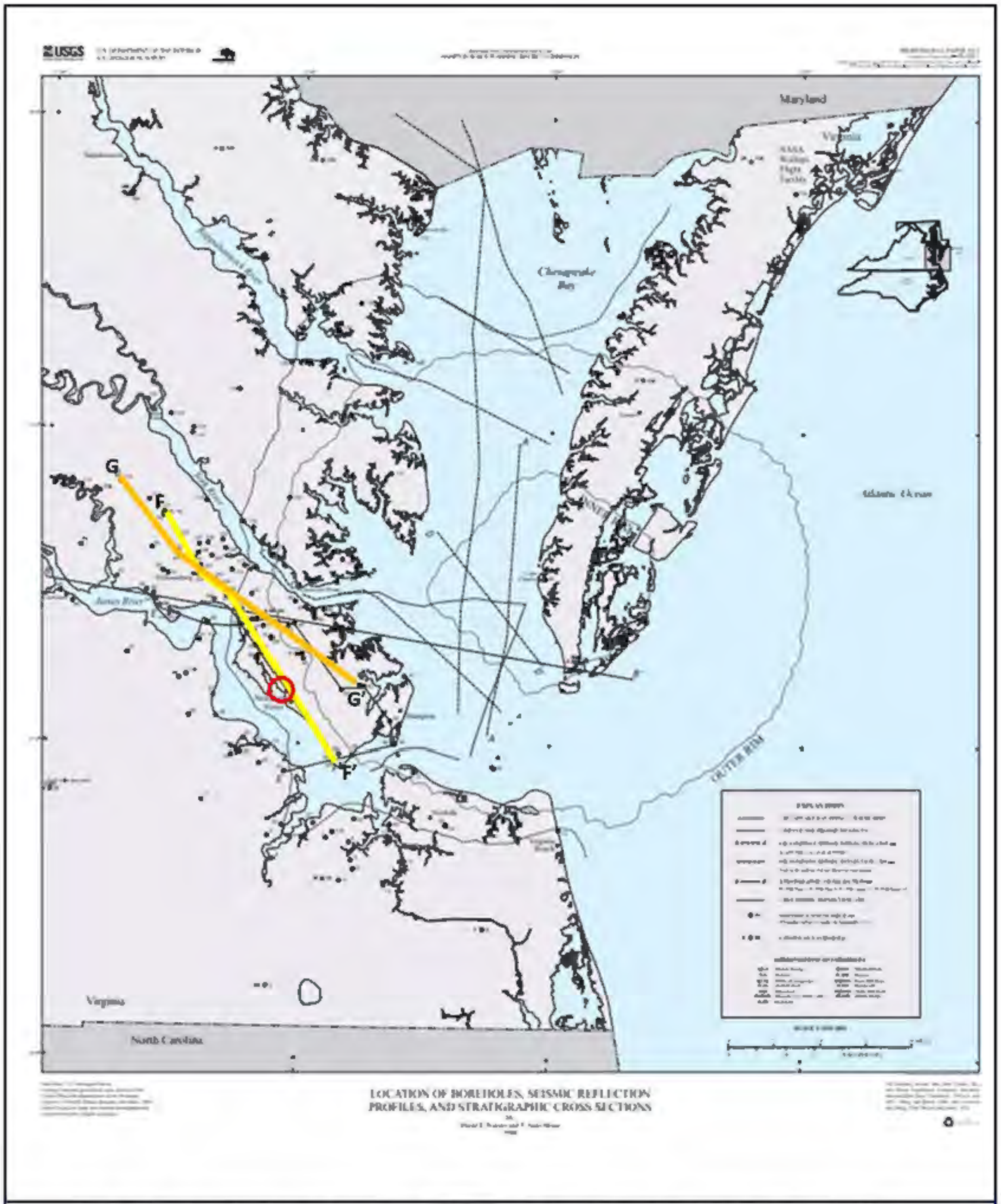
Figure B-3, Location of Hydrogeologic Section ED-ED'
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA



○ **James River Treatment Plant approximate location**

Taken from Virginia Coastal Plain Hydrogeologic Framework, McFarland and Bruce, 2006, Plate 4

Figure B-4, Hydrogeologic Section ED-ED' in the Virginia Coastal Plain
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA



Taken from USGS PP 1612, Powers and Bruce, 1999

○ **James River Treatment Plant approximate location**

Figure B-5, Map Illustrating Transects for Hydrogeologic Cross Sections
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

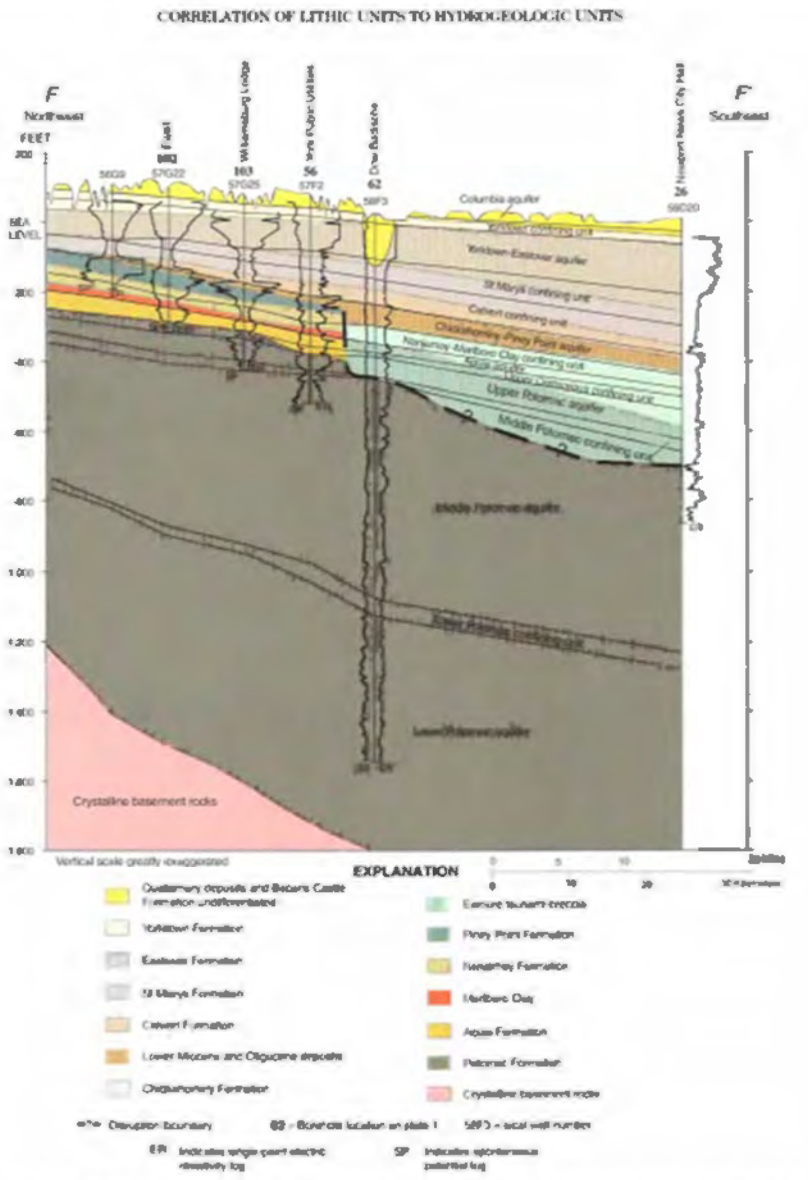


Figure 17. Hydrogeologic section across the lower York-James Peninsula (from Meng and Harsh, 1988) and geological reinterpretation overlain in color (line of section shown on pl. 1).

Taken from USGS PP 1612, Powers and Bruce, 1999

Figure B-6, Regional Hydrogeologic Cross Section F-F'
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

THE EFFECTS OF THE CHESAPEAKE BAY IMPACT CRATER ON THE GEOLOGICAL FRAMEWORK AND CORRELATION OF HYDROGEOLOGIC UNITS OF THE LOWER YORK-JAMES PENINSULA, VIRGINIA

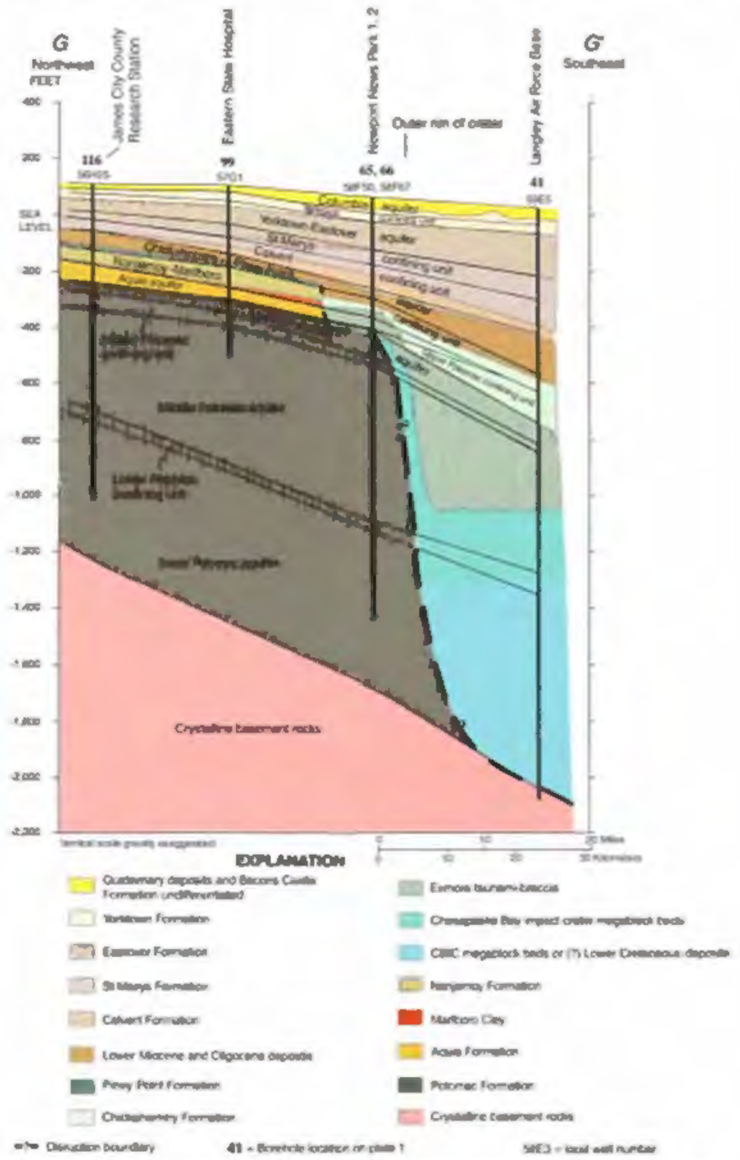


Figure 10. Hydrogeologic section across the lower York-James Peninsula (from Laczniak and Meng, 1988) and geological reinterpretation overlain in color (line of section shown on pl. 1).

Taken from USGS PP 1612, Powers and Bruce, 1999

Figure B-7, Regional Hydrogeologic Cross Section G-G'
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS

B.1.2 Groundwater Flow

Regional groundwater flow boundaries include the Fall Zone to the west, which separates the relatively impervious, metamorphic and igneous rocks of the Piedmont from the permeable sediment of the VCP; the freshwater-saltwater interface to the east; and the granitic basement rock underlying the Coastal Plain. Discharge ultimately occurs at springs, streams, lakes, the Chesapeake Bay, and the Atlantic Ocean (Heywood and Pope, 2009).

Figure B-8 displays the regional pre-development groundwater flow patterns in the Coastal Plain aquifer system (from McFarland and Bruce, 2006). Figure B-9 is modified from Heywood and Pope (2009) and indicates recharge flow direction imposed over the relatively current modeled potentiometric surface of the Potomac aquifer (target recharge aquifer).

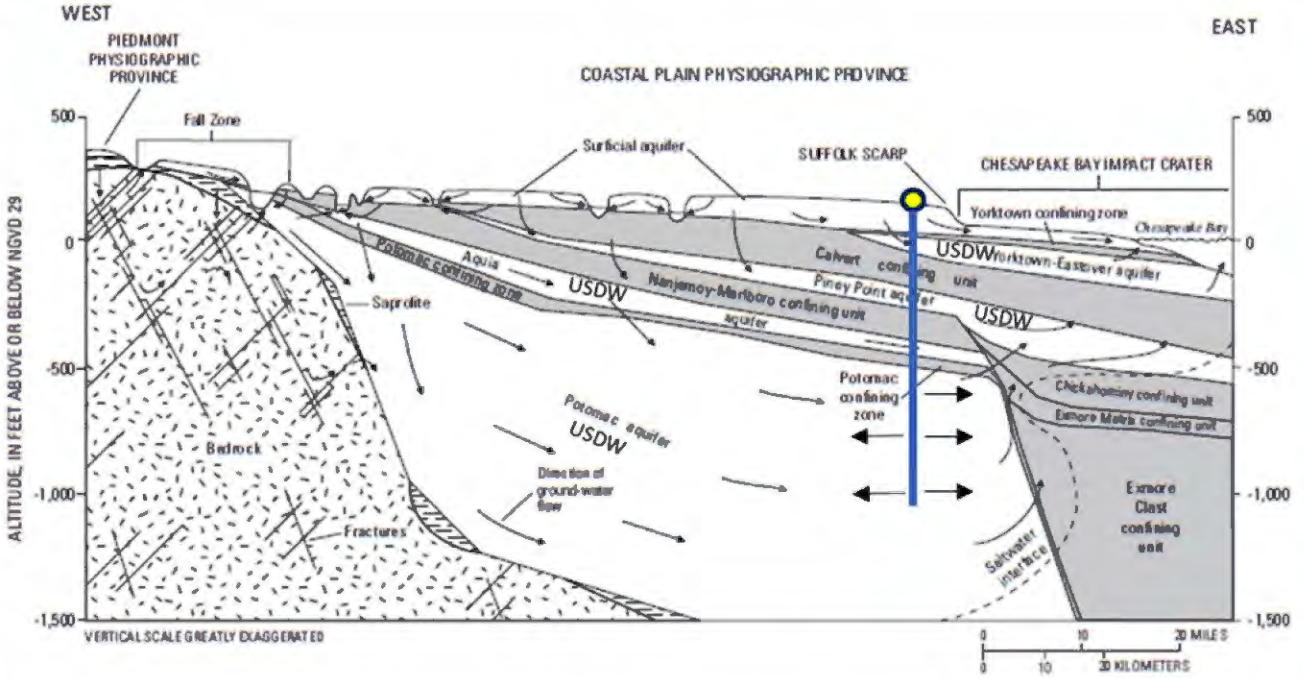


Figure 2. Generalized hydrogeologic section and directions of ground-water flow in the Virginia Coastal Plain (altitude relative to National Geodetic Vertical Datum of 1929).

Note: not all USDW in the cross section are present beneath JR SWIFT site. See Table B-2 above.

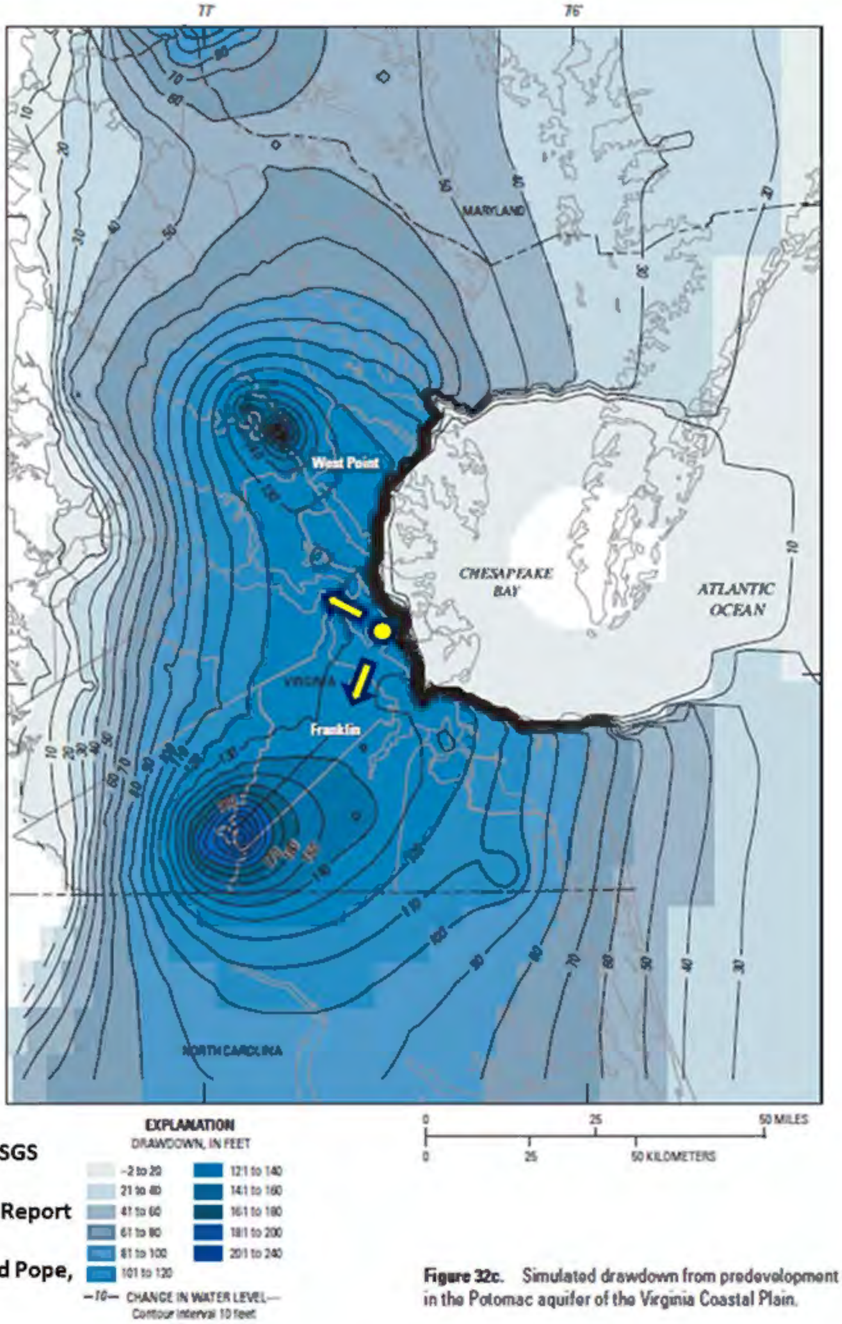
Modified from USGS Groundwater Professional Paper 1731, (McFarland and Bruce, 2006)

● **James River Treatment Plant approximate location**

▮ **Approximate depth of injection well**

Figure B-8, All USDW and Direction of Groundwater Movement
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS



Taken from USGS Scientific Investigation Report 2009-5039, (Heywood and Pope, 2009)

Figure 32c. Simulated drawdown from predevelopment to 2003 in the Potomac aquifer of the Virginia Coastal Plain.

⇨ Regional groundwater flow direction at JRTP

● JRTP/JR-SWIFT

N

Figure B-9, Regional Groundwater Flow Direction
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS

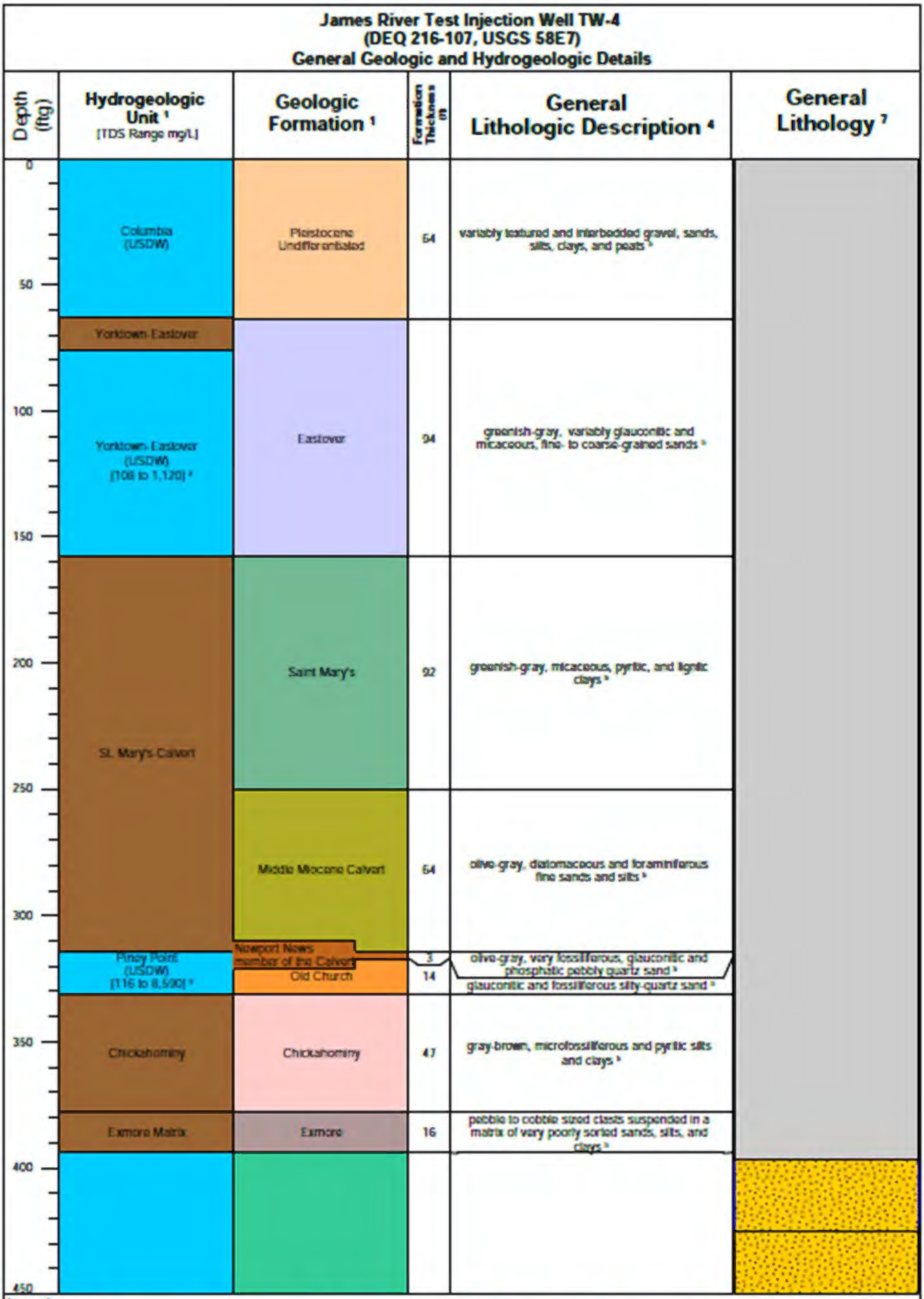
B.1.3 James River SWIFT Site Hydrogeologic Details

Not all VCP units were encountered beneath JR SWIFT. Based on plates 8 through 25 provided in McFarland and Bruce, 2006, hydrogeologic units present and absent beneath the JR SWIFT site are noted in Table B-1.

Table B-1, Hydrogeologic Units Present at JR SWIFT

Hydrogeologic Unit	**Present**	**Absent**	**Depth of occurrence (ft below ground)**
Surficial Columbia Aquifer			0
Yorktown confining zone	X		63
Yorktown-Eastover aquifer	X		76
Saint Marys-Calvert confining unit	X		158
Saint Marys aquifer		X	
Piney Point aquifer	X		314
Chickahominy confining unit	X		331
Exmore matrix confining unit	X		378
Exmore clast confining unit		X	
Nanjemoy-Marlboro confining unit		X	
Aquia aquifer		X	
Peedee confining zone		X	
Peedee aquifer		X	
Virginia Beach confining zone		X	
Virginia Beach aquifer		X	
Upper Cenomanian confining unit		X	
Potomac confining zone		X	
Potomac aquifer	X		394
Basement rock	X		1314

A test boring and test well (JR TW-4) was installed at the HRSD James River Treatment Plant. Geologic core samples were collected during the borehole drilling operation. The cores were logged by field geologists and sent to a specialty geologic lab (Mineralogy Inc.) for mineralogical analysis. The Testing Program is described in Section B.2 of this Attachment. Figure B-10 below provides information on the geologic formations present at JR SWIFT, the corresponding hydrogeologic units, and the units screened by test well TW-4 and anticipated for the permanent MAR wells.



James River Test Injection Well TW-4
(DEQ 216-107, USGS 58E7)
General Geologic and Hydrogeologic Details

Hydrogeologic Unit [1] [TDS Range mg/L]	Geologic Formation [1]	Formation Thickness (ft)	General Lithologic Description [4]
Columbia (USDW)	Pleistocene Undifferentiated	64	variably textured and interbedded gravel, sands, silts, clays, and peats [5]
Yorktown-Eastover Yorktown-Eastover (USDW) [108 to 1,120] [2]	Eastover	94	greenish-gray, variably glauconitic and micaceous, fine- to coarse-grained sands [5]
St. Mary's-Calvert	Saint Mary's	92	greenish-gray, micaceous, pyritic, and lignitic clays [5]
	Middle Miocene Calvert	64	olive-gray, diatomaceous and foraminiferous fine sands and silts [5]
Piney Point (USDW) [116 to 8,500] [3]	Newport News member of the Calvert	3	olive-gray, very fossiliferous, glauconitic and phosphatic pebbly quartz sand [5]
	Old Church	14	glauconitic and fossiliferous silty-quartz sand [5]
Chickahominy	Chickahominy	47	gray-brown, microfossiliferous and pyritic silts and clays [5]
Exmore Matrix	Exmore	16	pebble to cobble sized clasts suspended in a matrix of very poorly sorted sands, silts, and clays [5]

Legend

🟦 Aquifer	🟫 Confining Unit	🟪 Bedrock	▤ Clay	🟨 Fine Sand	▨ Medium Sand	▨ Coarse Sand	🟪 Bedrock	⬜ No Core Data

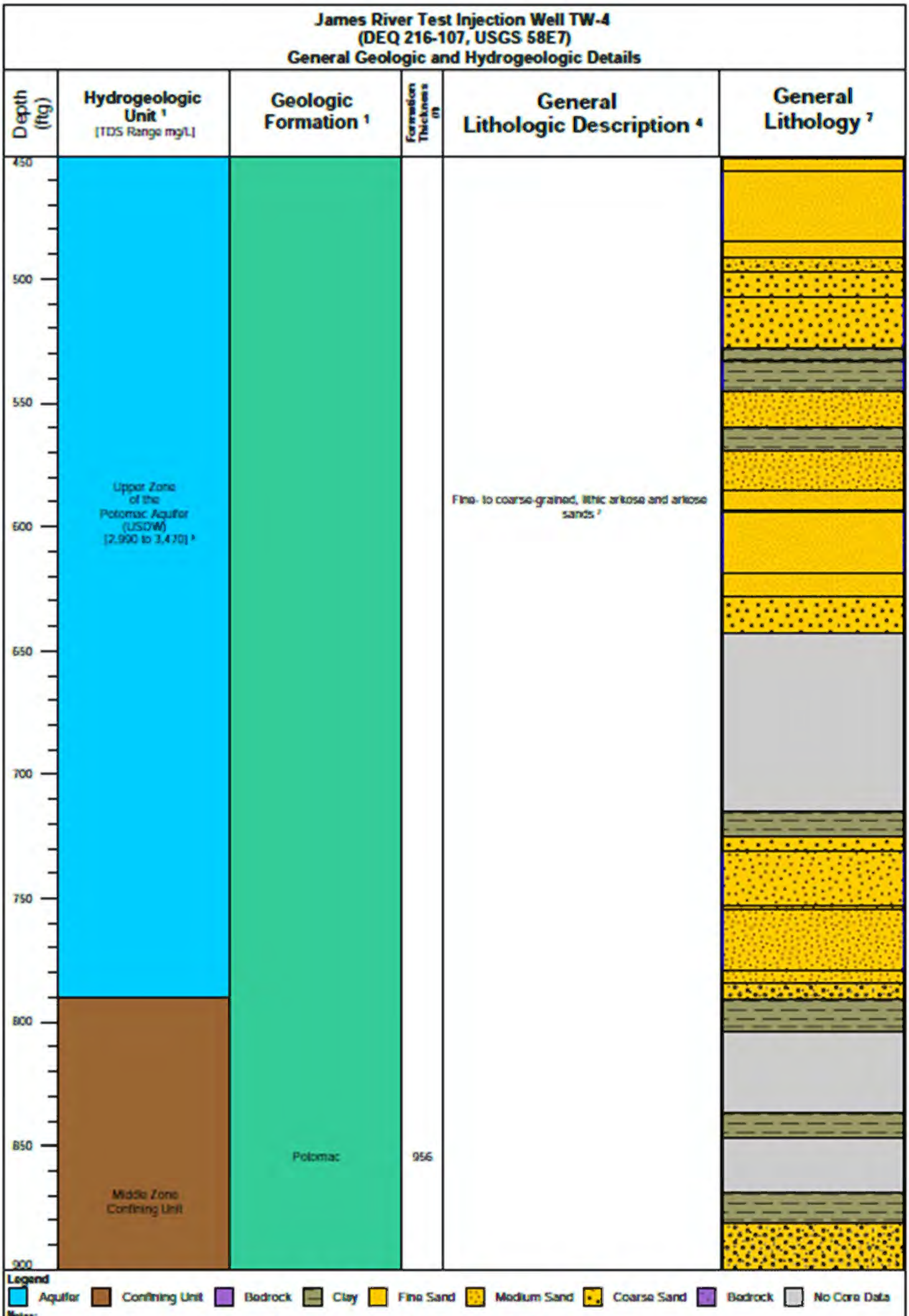
Notes:

1. Hydrogeologic Units and Geologic Formations were established through direct conversation with T. Scott Bruce of the Virginia DEQ.
2. TDS values were reported in *Quality of Ground Water in the Coastal Plain Physiographic Province of Virginia*, Focazio M.J., et al., 1993.
3. TDS values were established by Mineralogy-INC using core samples from TW-4.
4. Lithologic Descriptions are general descriptions with lithologies of Geologic Formations varying locally and regionally.
5. General Lithologic Descriptions were established from *The Virginia Coastal Plain Hydrogeologic Framework*, McFarland and Bruce, 2006.
6. General Lithologic Descriptions were established through laboratory analysis of core samples that was conducted by Mineralogy-INC.
7. General Lithology was established during coring at TW-4. Vertical dashed blue lines indicate lithology was inferred using geophysical log data.

All aquifers shown in the Hydrogeologic Units section are potential USDW.

Figure B.10
Geological Data at James River TW-4
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS



Notes:

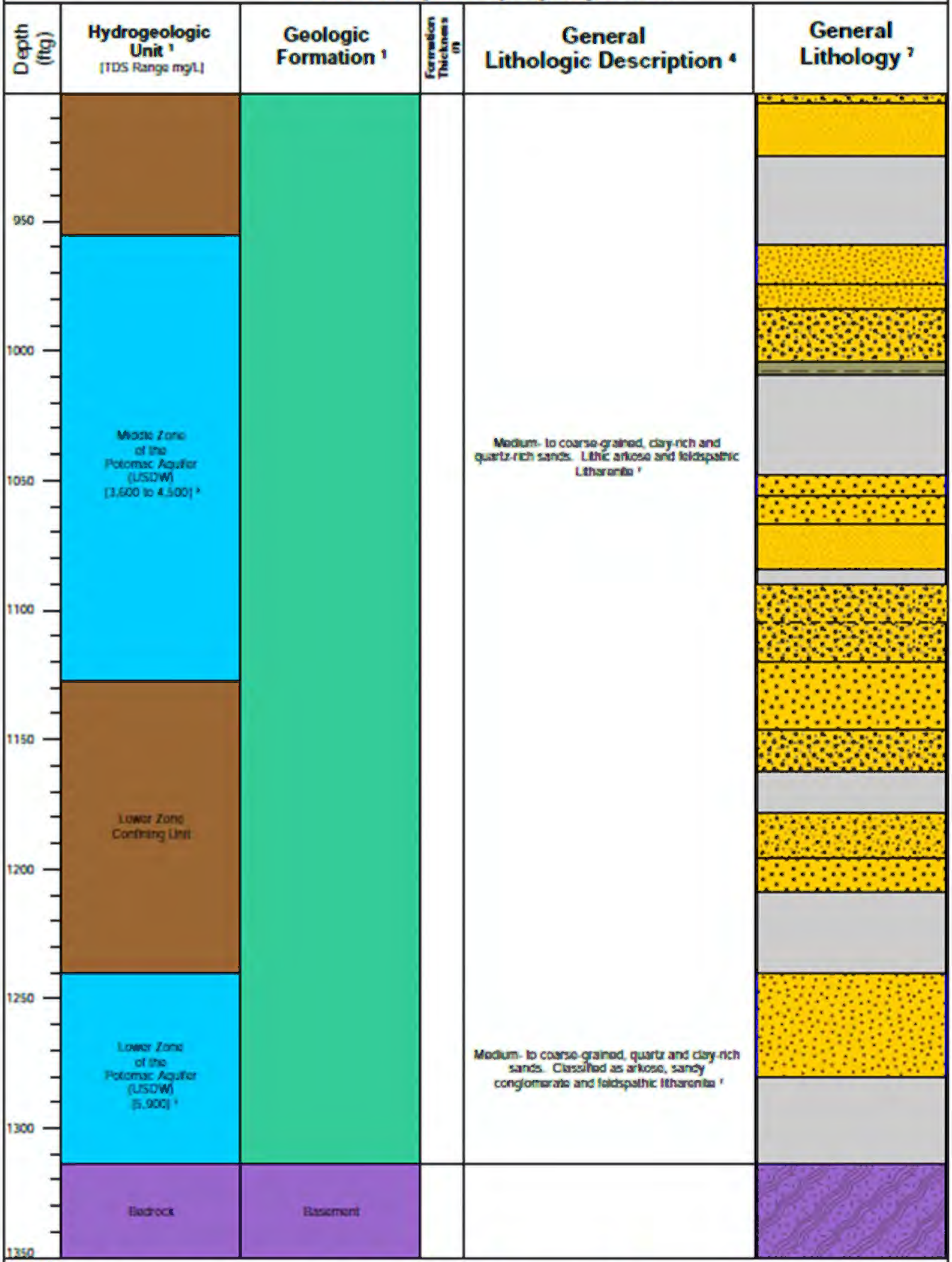
1. Hydrogeologic Units and Geologic Formations were established through direct conversation with T. Scott Bruce of the Virginia DEQ.
2. TDS values were reported in *Quality of Ground Water in the Coastal Plain Physiographic Province of Virginia*, Focazio M.J., et al., 1993.
3. TDS values were established by Mineralogy INC using core samples from TW-4.
4. Lithologic Descriptions are general descriptions with lithologies of Geologic Formations varying locally and regionally.
5. General Lithologic Descriptions were established from *The Virginia Coastal Plain Hydrogeologic Framework*, McFarland and Bruce, 2006.
6. General Lithologic Descriptions were established through laboratory analysis of core samples that was conducted by Mineralogy INC.
7. General Lithology was established during coring at TW-4. Vertical dashed blue lines indicate lithology was inferred using geophysical log data.

All aquifers shown in the Hydrogeologic Units section are potential USDW.

Figure B.10
Geological Data at James River TW-4
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS

James River Test Injection Well TW-4
(DEQ 216-107, USGS 58E7)
General Geologic and Hydrogeologic Details



Legend

🟦 Aquifer 🟫 Confining Unit 🟪 Bedrock ▤ Clay 🟨 Fine Sand ▨ Medium Sand ▨ Coarse Sand 🟪 Bedrock ⬜ No Core Data

Notes:

1. Hydrogeologic Units and Geologic Formations were established through direct conversation with T. Scott Bruce of the Virginia DEQ.
2. TDS values were reported in *Quality of Ground Water in the Coastal Plain Physiographic Province of Virginia*, Focazio M.J., et al., 1993.
3. TDS values were established by Mineralogy INC using core samples from TW-4.
4. Lithologic Descriptions are general descriptions with lithologies of Geologic Formations varying locally and regionally.
5. General Lithologic Descriptions were established from *The Virginia Coastal Plain Hydrogeologic Framework*, McFarland and Bruce, 2006.
6. General Lithologic Descriptions were established through laboratory analysis of core samples that was conducted by Mineralogy INC.
7. General Lithology was established during coring at TW-4. Vertical dashed blue lines indicate lithology was inferred using geophysical log data.

All aquifers shown in the Hydrogeologic Units section are potential USDW.

Figure B.10
Geological Data at James River TW-4
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS

B.2 Formation Testing Program

An extensive Test Well Program designed to obtain critical data for informing the design and operation of the proposed Class V managed aquifer recharge (MAR) wells at the JR SWIFT was performed between October and December 2018. The James River Treatment Plant Test Well Geochemical Compatibility Report (Appendix D) discusses the results of step drawdown testing, constant rate aquifer testing, packer testing, water quality sampling, and mineralogical testing in upper (UPA), middle (MPA) and lower (LPA) zones of the Potomac aquifer system (PAS). This report fully characterizes the hydraulic, water quality and mineralogy of the PAS including analysis of core taken from the aquifer and confining zones within the PAS.

Appendix D also discusses interpretation of these data using geochemical equilibrium models to assess the following issues:

- Mixing between recharge water and native groundwater (NGW)
- Speciation of amorphous mineral phases in the PAS.
- Reactions between reactive minerals like pyrite and siderite and dissolved oxygen (DO) in the recharge water.
- Reactions between recharge water and interstitial clay minerals in the PAS
- Simulating conditioning of clay minerals with aluminum salts.
- Determining the necessary pH and alkalinity for the recharge water to preclude releasing iron, manganese, and/or arsenic from reactive, metal-bearing minerals.

To date, HRSD has conducted similar test well programs in the PAS at other potential SWIFT facilities including Nansemond (NP SWIFT), York River (YR SWIFT), Williamsburg (WB SWIFT), and the Virginia Initiative Plant (VIP SWIFT).

Attachment D describes the testing planned for the permanent MAR wells at HRSD's James River SWIFT facility. The program will examine the fluid pressure, temperature, and physical, chemical, and radiological characteristics of the PAS and native groundwater (NGW). HRSD will employ borehole geophysical logging techniques, step drawdown tests, and constant rate aquifer tests to evaluate:

- Characteristics of confining units overlying the PAS.
- Hydraulic coefficients (skin coefficient, well losses, well efficiency, etc.) of each of the 10 MAR wells.
- The bulk transmissivity and storage coefficients for the PAS units screened by the MAR wells.

B.3 Porosity and Permeability

Table B.2 shows the porosity and permeability values obtained from cores taken from the target recharge aquifer (Potomac) and packer testing results, respectively.

Table B-2: Porosity and Hydraulic Conductivity, Test-Well 4 – JR SWIFT.

Core Interval (fbg)	Screen Interval (#)	Aquifer	Porosity				Hydraulic Conductivity (ft/day)
			Intergranular (%)	Secondary (%)	Moldic (%)	Total (%)	
427.5-428.6	1	UPA	23	0	0	0	29.33
491-492.9	2	UPA	12	1	0	13	29.33
578-579.6	3	UPA	13.3	2	0	15.3	29.33
637.5-640	4	UPA	8.7	3.3	0	12	29.33
779-781.5	6	MPA	23.3	1.3	0	24.6	37.21
886.5-889	Between 6 and 7	MPA	21.3	1.7	0	23	37.21
912.5-915	Between 6 and 7	MPA	22	2.7	0	24.7	37.21
974-976.5	7	LPA	16.3	6	0	22.3	10.00
1056-1058.5	8	LPA	15.7	1.3	0	17	10.00
1120-1122.5	9	LPA	20.3	1.7	0	22	10.00
1178-1180.5	Between 9 and 10	LPA	11.3	5	0	16	10.00

Notes:

fbg: feet below grade

Screen number counting from shallowest to deepest

Hydraulic conductivity values are averaged per aquifer

B.3 Known or Suspected Fracture Systems

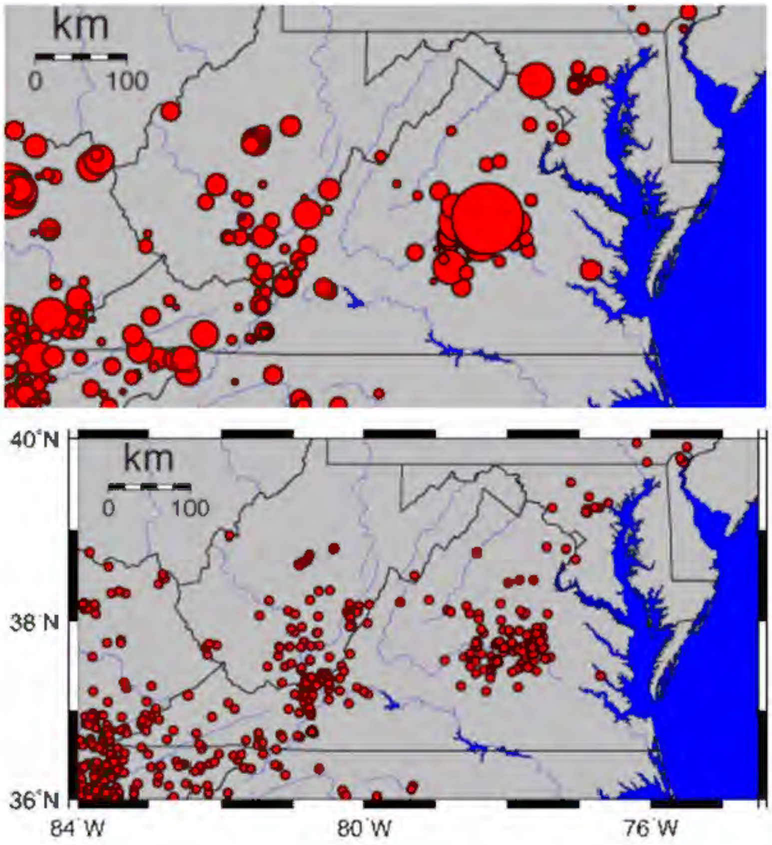
There are no known faults and fractures in the ¼ mile Area of Review within the injection formation, or overlying formations. Regional fracturing in the Coastal Plain sediments is interpreted from limited coring and geophysical data in the area proximal to the Chesapeake Bay Impact Crater (CBIC). As well, radial faulting of the crystalline basement rock has also been interpreted by the USGS associated with the CBIC. Little is known regarding the basement rock and associated fracture zones, the top of which lies over 1,200 feet below the ground surface and approximately 200 feet below the lowest target injection zone.

B.4 Seismic History

The Coastal Plain of Virginia has a history of low seismic activity. Seismic activity is tracked in Virginia by the Virginia Tech Seismological Observatory (VTSO). According to their website (http://www.magma.geos.vt.edu/vtso/), Virginia has experienced over 160 earthquakes since

1977 of which 16% were felt, none of these occurring in the HRSD service area. This equates to an average of one earthquake occurring every month with two felt each year. Until the magnitude 5.8 earthquake in 2011, the largest earthquake to occur in Virginia was the magnitude 5.8 Giles County earthquake in 1897. The 1897 earthquake represents the third largest in the eastern US in the last 200 years and was felt in twelve states. Seismic activity (seismicity) has been known for several decades to be strongest in and around Giles County and in central Virginia, not in the Coastal Plain physiographic province. The VTSO has concentrated seismic monitoring stations in these two areas, as shown in Figure B.10, taken from the VTSO website, shows earthquakes (circles, scaled to) in and near Virginia from 1774 through 1994.

As part of a modeling study with Virginia Tech, HRSD is evaluating the feasibility of installing a seismic monitoring network proximal to the site with a goal of collecting approximately 4-5 years of background seismicity prior to operating JR SWIFT. Such monitoring stations will also allow HRSD to track seismicity after managed aquifer recharge operation start at JR SWIFT.



Taken from the Virginia Tech Seismological Observatory web page: http://www.magma.geos.vt.edu/vtso/va_quakes.html

Figure B.11, Seismic History
James River SWIFT Facility
Hampton Roads Sanitation District
Virginia Beach, VA

B.7. Formation Testing Program for Full Scale Injection Wells

The testing planned for the permanent MAR wells at the JR SWIFT facility include establishing the following:

- fluid pressure,
- temperature,
- physical and chemical characteristics of the formation (native groundwater) and injection fluids (recharge)

Testing for estimated fracture pressure is not applicable to JR SWIFT due to the unconsolidated nature of the sediments that make up the Virginia Coastal Plain aquifer system. The maximum allowable recharge pressure, as measured at the wellhead, is 30 psi while recharging. This recharge pressure includes components of both recovered pressure in the aquifer (mounding of pressure in the aquifer due to recharge) and anticipated well losses due to progressive plugging of the well during operation. In other words, a portion of the maximum pressure experienced at the recharge wellhead, while recharging, strongly corresponds to the recharge well's specific capacity (injectivity), controlled by losses to turbulent flow caused by clogging, instead of draw-up in the aquifer. Thus, pressures contributed by draw-up in the aquifer will always represent a relatively smaller fraction of the pressure measured at the MAR wellheads during MAR operations.

Prior to the onset of significant pumping occurring in the early-mid 1900s, the PAS displayed artesian pressures in the location of the JR SWIFT site, with the potentiometric surface in the aquifer exceeding the ground surface. The historic pre-pumping water level in the aquifer at this location was simulated by the regional model and ranged between 40 and 50 feet above mean sea level (Heywood and Pope, 2009). Since that time, the PAS has been heavily used for municipal, commercial, and industrial water supply needs, resulting in a continuous and steady decline of the potentiometric surface at the rate of one to three feet per year in many areas. PAS depletion is well documented and is closely approximated in Figure B-9 of this attachment, showing the simulated drawdown in the PAS from pre-development to 2003. The excessive drawdown has resulted in land subsidence (Eggleston and Pope, 2013), increased risk of potential withdrawal-induced movement of saltwater in the Virginia Coastal Plain aquifer system (McFarland, 2015) and significant reductions in groundwater withdrawal permit allocations.

A static water level of approximately 98 feet *below* mean sea level (114 feet *below* ground surface) was observed in the JR test well (TW-4) in October of 2018. Water levels in test wells across the SWIFT sites have ranged from 95 to 150 feet below the ground surface indicating depletion of the PAS. Recharge from SWIFT at the James River site will likely restore pressures in the aquifer to pre-pumping levels within several tens of years after initiating MAR operations; helping to mitigate land subsidence, saltwater intrusion and bolster available groundwater supply.

Appendix B describes testing procedures during full-scale MAR well installation.

Pressures, temperatures and chemical characteristics of the native groundwater established during the JR Test Well Program appear in Tables B-3, B-4 and B-5.

Table B-3: Fluid Pressure

	Static Water Level (fbg)	Maximum Recharge Level (in feet of head at the wellhead)	Maximum Recharge pressure (PSI at the wellhead)
Fluid Pressure	-108	+69.18	30

Table B-4: Fluid Temperature(s)

	SWIFT Water (°C)	Aquifer Zones	
		Upper Potomac (°C)	Middle Potomac (°C)
Temperature	20 to 28$^{(1)}$	26.8	25.8

Table B-5: Native groundwater chemistry, test well at James River

Test Intervals		**72 HR CRT[1]**	**Packer Test 1 (398-524 fbg[2])**	**Packer Test 2 (570-636 fbg)**	**Packer Test 3 (735-790 fbg)**	**Packer Test 4 (960-1000 fbg)**	**Packer Test 5 (1048-1122 fbg)**	**Packer Test 6 (1240-1280 fbg)**	**Estimated Recharge Chemistry[3]**	**PMCL/ SMCL**
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
pH	standard units	6.32	6.76	7.71	6.14	7.20[6]	7.26	7.62	7.2 to 7.8	6.5 to 8.5
ORP[4]	mV	54.9	-133.8	-95	-70.3	-108	-103.2	-99.6	NA	
Eh (corrected)[5]	mV	254.9	66.2	105	129.7	92	96.8	100.4	NA	
Specific Conductivity	µs/cm	3113	4635	4088	5200[7]	6230	6690[7]	8700[7]	NA	
Temperature	ºC	20.27	25.97	23.57	26.77	25.87	25.8	26.59	15 to 26	
Turbidity	NTU	1.51	1.63	2.12	5.53	0.52	0.43	6.19		
Field Sulfide as S	mg/L	0	0	0	0.04	0	0	0.01	NA	
Field Sulfate as SO_4	mg/L	58	70	69	106	90	104	183	NA	
Field Iron (ferrous as Fe^{2+})	mg/L	0.22	2.35	2.31	1.35	1.34	2.07	2.22	NA	
Field Iron (total)	mg/L	0.91	2.04	2.01	1.7	1.79	2.22	3.14	NA	
Aluminum, dissolved	mg/L	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010	<0.04	0.1
Aluminum, total	mg/L	0.063	<0.010	0.014	0.036	<0.010	<0.010	<0.010	<0.04	0.1
Arsenic, dissolved	µg/L	<1.00	0.25	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Arsenic, total	µg/L	<1.00	0.24	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Iron, dissolved	mg/L	0.203	2.49	2.74	1.39	1.46	2.07	2.28	0.07	0.3
Iron, total	mg/L	0.241	2.45	2.79	1.58	1.48	2.05	2.25	0.07	0.3
Manganese, dissolved	mg/L	0.0217	0.0518	0.0575	0.0527	0.0533	0.0829	0.142	0.01	0.05
Manganese, total	mg/L	0.0226	0.0504	0.0581	0.0539	0.0542	0.0852	0.142	0.01	0.05
Magnesium, total	mg/L	4.78	6.71	6.93	9.00	10.6	15.8	25.6	3.6	
Potassium, total	mg/L	15.4	19.6	19.6	20.4	24.6	29	36.9	13	
Sodium, total	mg/L	777	970	979	1060	1240	1500	1930	68	
Calcium, total	mg/L	13.2	19.8	20.7	25.4	29.6	42.1	63.8	34	
Sulfate	mg/L	70.3	90.6	91.6	119	126	175	275	53	250
Chloride	mg/L	825	1460	1490	1770	1830	2290	3070	106	250
Alkalinity	mg/L	326	273	265	258	240	222	217	38	
Nitrate/Nitrite-N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.7	
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.1	10
Total Kjeldahl Nitrogen	mg/L	0.52	0.69	0.66	0.78	0.79	0.92	1.03	2.6	
Fluoride	mg/L	2.16	0.913	0.920	0.863	0.793	0.601	<0.500	0.65	4
Silica as SiO_2	mg/L	25.5	38.5	38.1	36.6	40.5	39.4	33.9	NE	
Silicon as Si	mg/L	11.9	18.0	17.8	17.1	18.9	18.4	15.8	NE	

Table B-5: Native groundwater chemistry, test well at James River

Test Intervals		72 HR CRT[1]	Packer Test 1 (398-524 fbg[2])	Packer Test 2 (570-636 fbg)	Packer Test 3 (735-790 fbg)	Packer Test 4 (960-1000 fbg)	Packer Test 5 (1048-1122 fbg)	Packer Test 6 (1240-1280 fbg)	Estimated Recharge Chemistry[3]	PMCL/ SMCL
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
Dissolved organic carbon	mg/L	0.16	0.13	0.11	<0.10	0.21	0.14	0.13	4	
Total organic carbon	mg/L	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	4	
Total phosphorus	mg/L	0.20	0.14	0.17	0.17	0.13	0.08	0.04	0.02	
Orthophosphate as P	mg/L	0.19	0.04	0.03	0.05	0.02	0.02	0.01	0.01	
Total dissolved solids	mg/L	1880	2990	3060	3470	3590	4460	5800	420	
Total suspended solids	mg/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	0.05	
Hardness, Total	mg eq	52.6	77.1	80.2	100	118	170	265	99	
Ammonia as N	mg/L	0.44	0.56	0.54	0.60	0.61	0.86	0.91	0.52	
BOD5	mg/L	<2	<2	<2	<2	<2	<2	<2	1	
COD	mg/L	<9.0	<12.0	<12.0	<12.0	<12.0	<15.0	<15.0	<10	
Gross Alpha	pCi/L	9.3	6.8	9.7	13	14	14	16	NE	15
Gross Beta	pCi/L	15	16	23	27	27	28	30	NE	
Ra 226 + Ra 228	pCi/L	1.1	ND	ND	1.4	1.6	4.8	8.8	NE	5
Uranium	µg/L	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.500	NE	
Calculated species										
Ionic strength	mol/L	0.047	0.07475	0.0765	0.08675	0.08975	0.1115	0.145	0.0105	
Ionic balance (Stuyfzand, 1993)	%	4.3	5.5	5.7	9.3	2.8	2.3	3.6	6.6	
Ca + Mg/Na + K	meq/L ratio	0.028	0.025	0.027	0.031	0.029	0.052	0.063	0.597	
Organic phosphorous	mg/L	0.137	0.127	0.160	0.153	0.123	0.073	0.037	0.01	
Organic nitrogen	mg/L	0.08	0.13	0.12	0.18	0.18	0.06	0.12	2.08	

Notes:

[1] CRT - constant rate test

[2] fbg - feet below grade

[3] Estimated Recharge Chemistry based on JRTP effluent sampling in January 2015 and 2019 and mathematical modeling to estimate chemistry of JR SWIFT Water.

[4] ORP - oxidation/reduction potential

[5] Eh = ORP + 200 mV

[6] Instrument issue, pH estimated using PHREEQC

[7] Instrument issue, specific conductivity estimated by 1.5 x TDS

NA - Not applicable

ND – Non-detect

NM – Not measured

NE – Not estimated

HRSD will employ borehole geophysical logging techniques, step drawdown tests, and constant rate aquifer tests to evaluate:

- Characteristics of confining units overlying the PAS.
- Hydraulic coefficients (skin coefficient, well losses, well efficiency, etc.) of each of the 10 MAR wells.
- The bulk transmissivity and storage coefficients for the PAS units screened by the MAR wells.

Testing the PAS will include the following:

1) Measuring the static water level in each MAR and monitoring well.
2) Measuring pumping and recharge levels in each MAR and monitoring well.
3) Evaluating the physical and chemical characteristics of the PAS through geophysical logging, water quality sampling, and collecting samples for radionuclide analysis.

HRSD conducted a thorough study of the PAS during the test well program referenced above; therefore, coring, mineralogical analysis, and packer testing are not proposed as activities during the full-scale injection well testing program.

Attachment C: Well Construction Information

Attachment C describes construction procedures for managed aquifer recharge (MAR) wells and monitoring wells at JR SWIFT, including the casing, screen assembly, cementing program, geophysical logging procedures, plumbing and alignment testing, filter pack installation, along with the borehole drilling and hydraulic testing.

C.1 Part I. Well Schematics

C.1.1 Typical Well Construction Schematics

Figure C.1 provides representative well construction details for a managed aquifer recharge (MAR) well at James River SWIFT (JR SWIFT). The MAR wells will screen across the upper and middle zones of the Potomac Aquifer System (UPA and MPA) at JR SWIFT. Figure C.2 shows MAR well construction relative to the Underground Sources of Drinking Water (USDW) present at the JR SWIFT site. Figures C.3, C.4 and C.5 indicate the construction of a Typical SWIFT monitoring well cluster including four total monitoring wells at varying screen depths. The Potomac Aquifer is the receiving aquifer; however, the exact screen depths and lengths will vary from the schematics based on data collected at each site during drilling. The exact screen placement will be determined from the drill cuttings and geophysical log obtained on the pilot boring of each of the ten MAR well sites.

Upon constructing the MAR wells and monitoring wells, HRSD will update the construction details to as-built status before receiving authorization to recharge from US EPA. HRSD will run a gyroscopic survey to evaluate the plumbness and alignment test on the final casing and make subsequent corrections, if required. After installing grout from the top or the sand filter pack to a depth of approximately 100 feet below grade (fbg), HRSD will run a cement bond log to demonstrate the external integrity of each MAR well. The empty annular space will provide a ringing signature for the casing for comparison with the cemented portion of the wellbore. Upon grouting the annular space to grade, HRSD will conduct a pressure test, currently planned at 120 psi, to demonstrate the internal integrity of the outer casing. Also, HRSD will submit all theoretical to actual cementing comparisons and casing documentation for US EPA review.

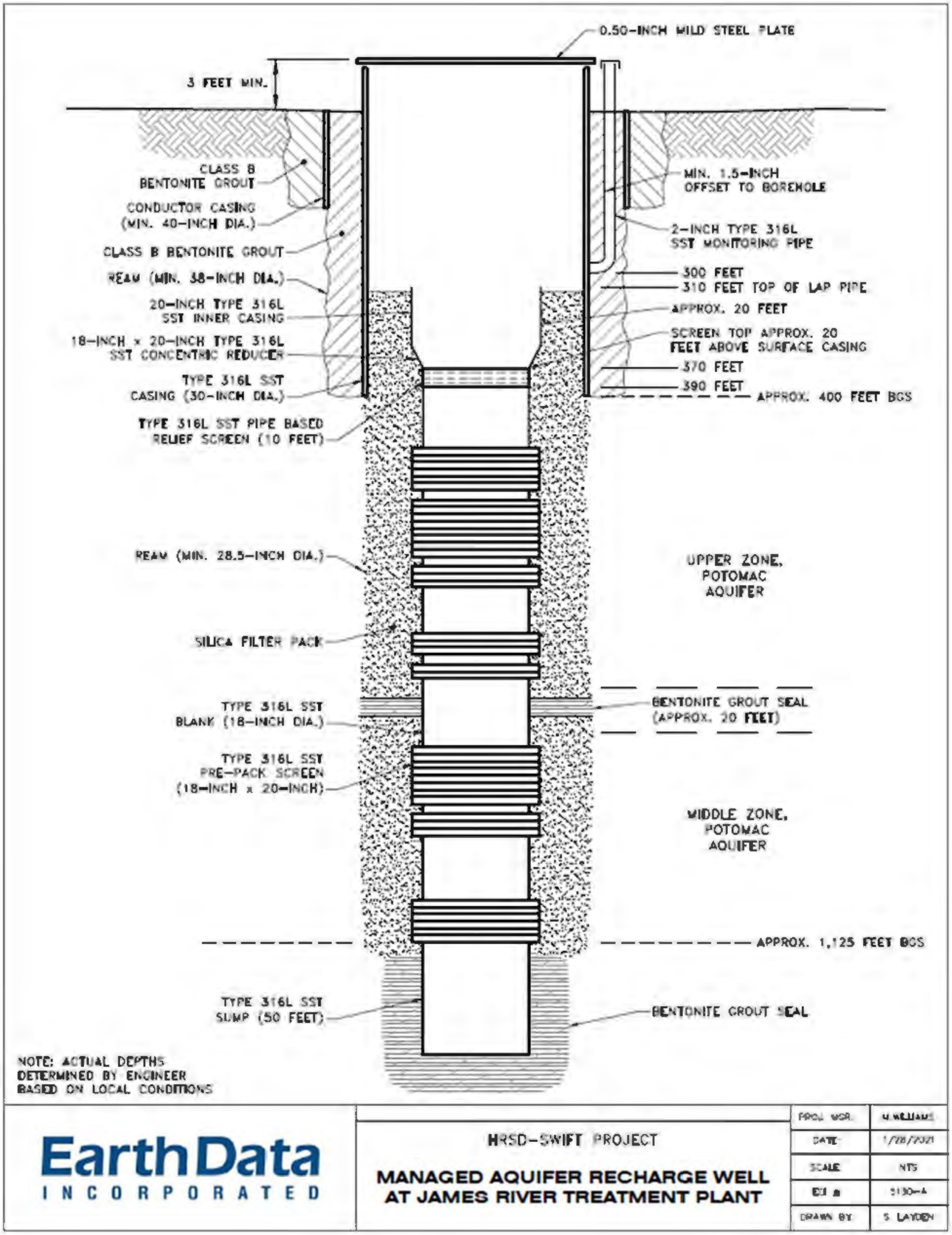


Figure C.1: Proposed Managed Aquifer Recharge Well at JR SWIFT. Elevations and materials of construction may change according to site specific conditions.

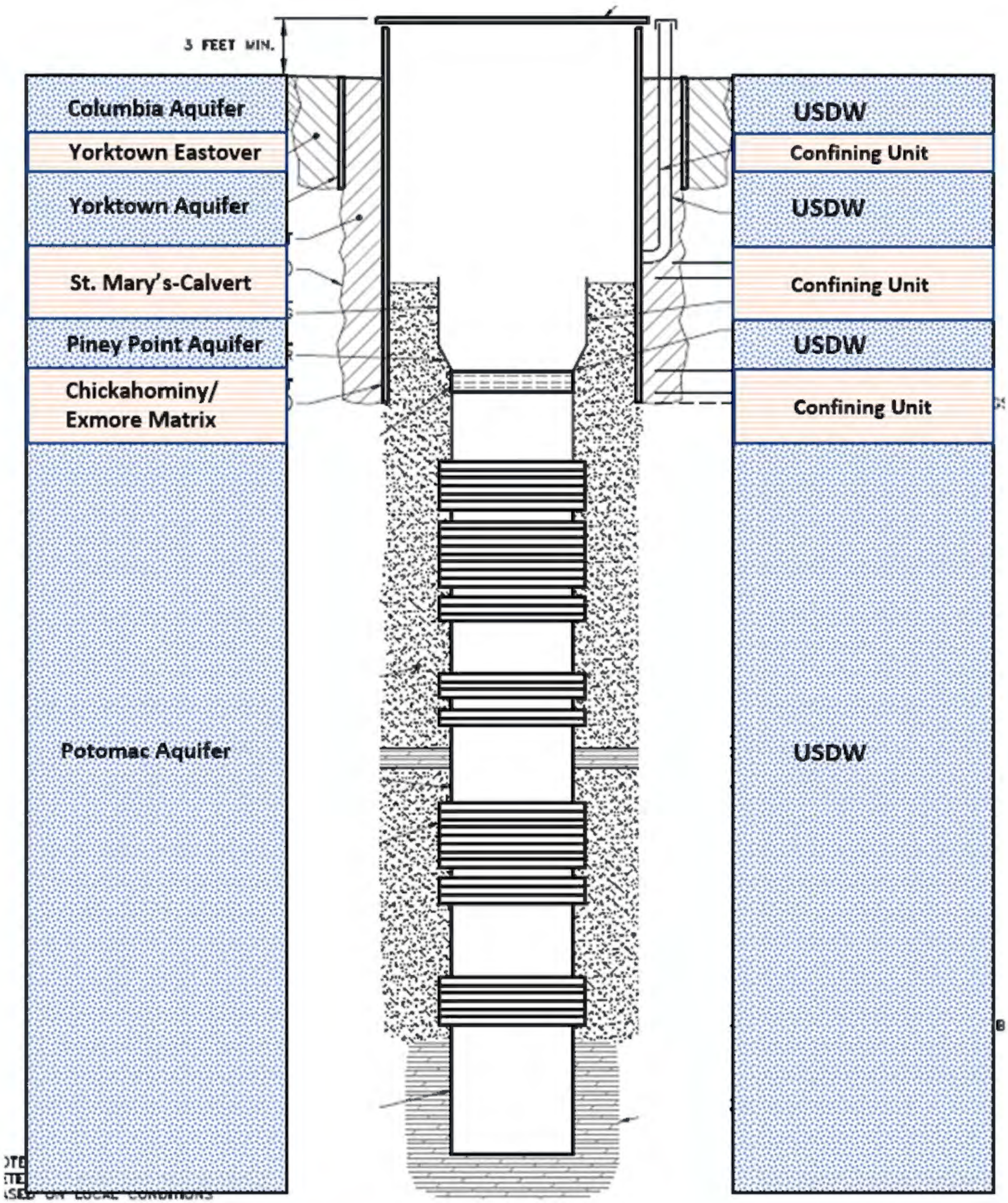
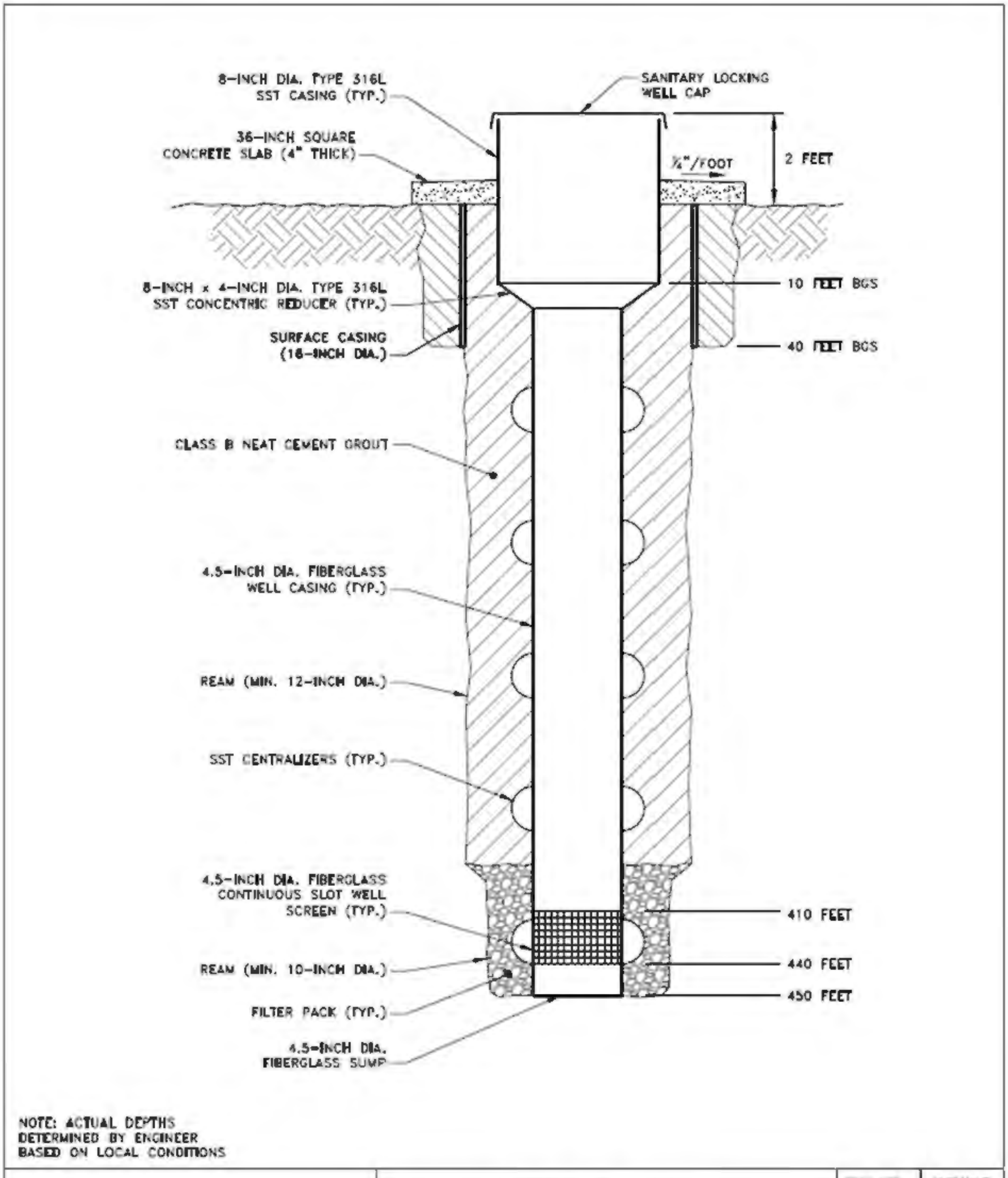


Figure C.2: Hydrostratigraphic section adjacent to MAR well including USDWs.



NOTE: ACTUAL DEPTHS
DETERMINED BY ENGINEER
BASED ON LOCAL CONDITIONS

EarthData
INCORPORATED

HRSD-SWIFT PROJECT
JAMES RIVER TREATMENT PLANT
JR_MC1_UA
UPPER ZONE OF THE POTOMAC AQUIFER

PROJ. MGR.	M. WILLIAMS
DATE	5/25/2021
SCALE	NTS
EDI #	5130-B
DRAWN BY	S. LAYDEN

Figure C.3: Typical Shallowest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

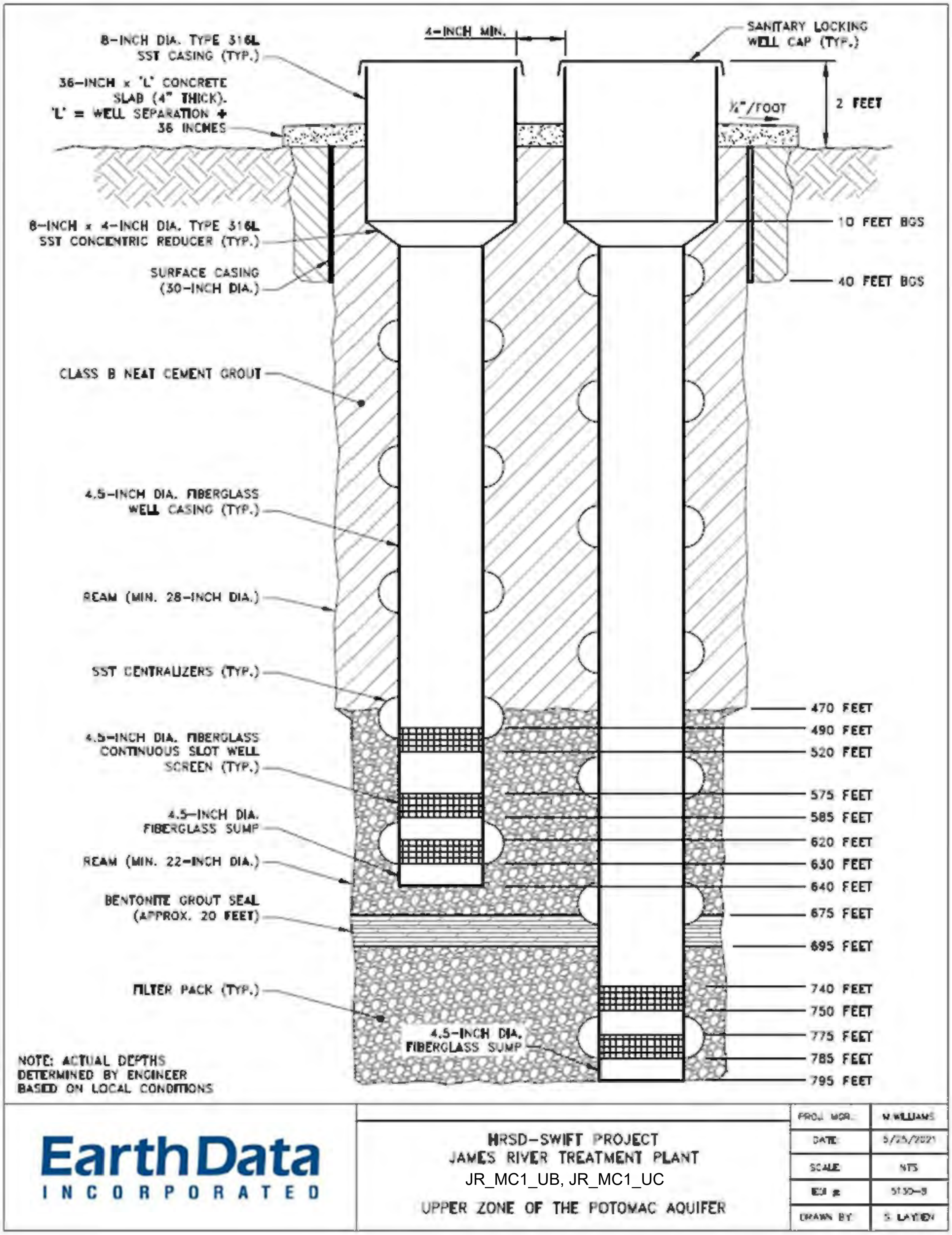


Figure C.4: Typical deeper Upper Zone Nest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

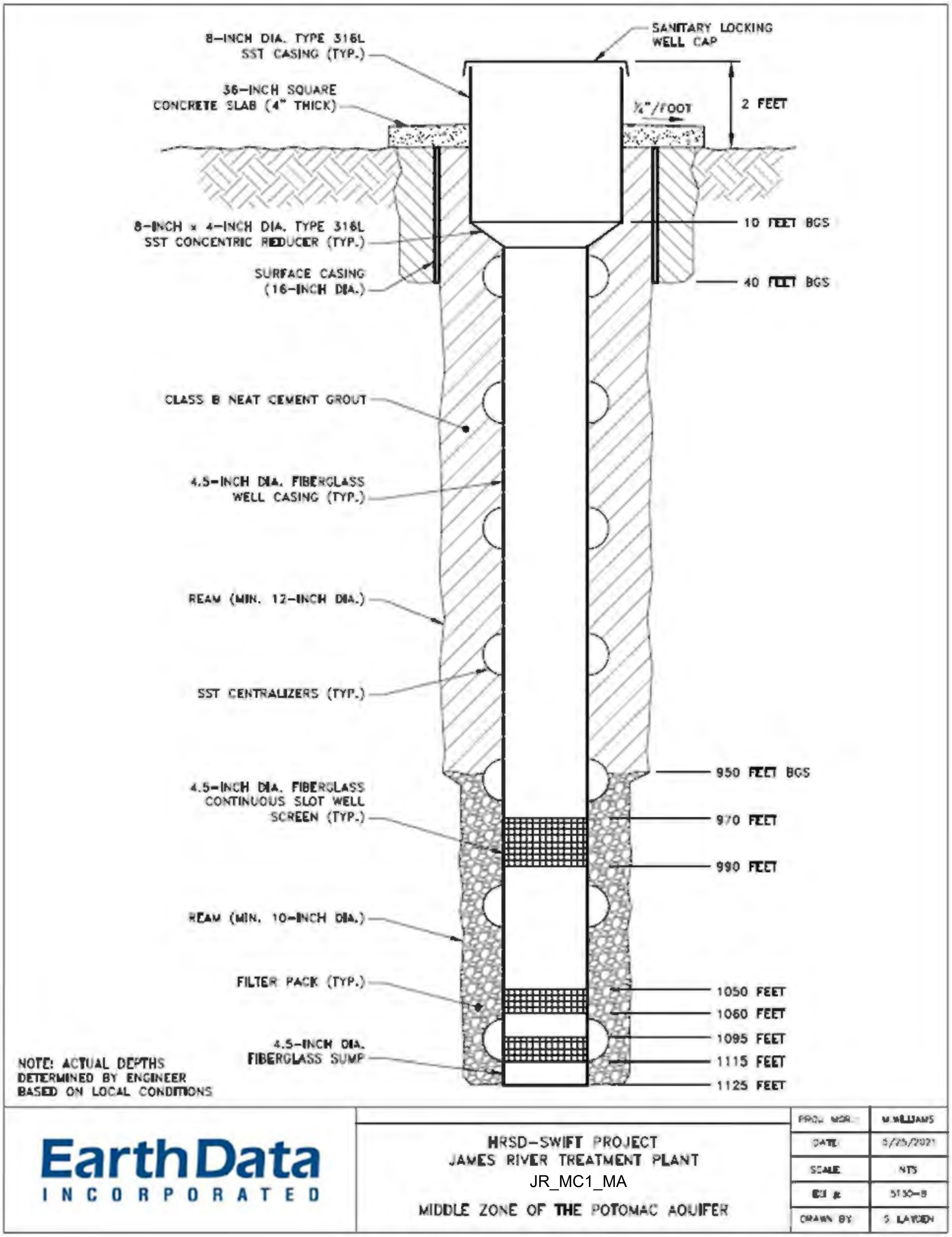


Figure C.5 Typical Middle Zone Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

C.1.2 Proposed Injection Procedures

C.1.2.1 Introduction

HRSD is installing up to ten managed aquifer recharge (MAR) wells for the recharge of a maximum of 16.6 million gallons per day (MGD) SWIFT Water from JR SWIFT facility. Each MAR well should achieve an injection capacity that exceeds 2.0 MGD. Thus, HRSD may run the ten MAR wells together at 1.5 MGD, or run 7 to 8 wells at 2 MGD, each, with individual wells entering service when others require maintenance. HRSD will run varying combinations to determine which operational protocol provides the greatest recharge/economic efficiencies.

C.1.2.1 Injection (recharge operations)

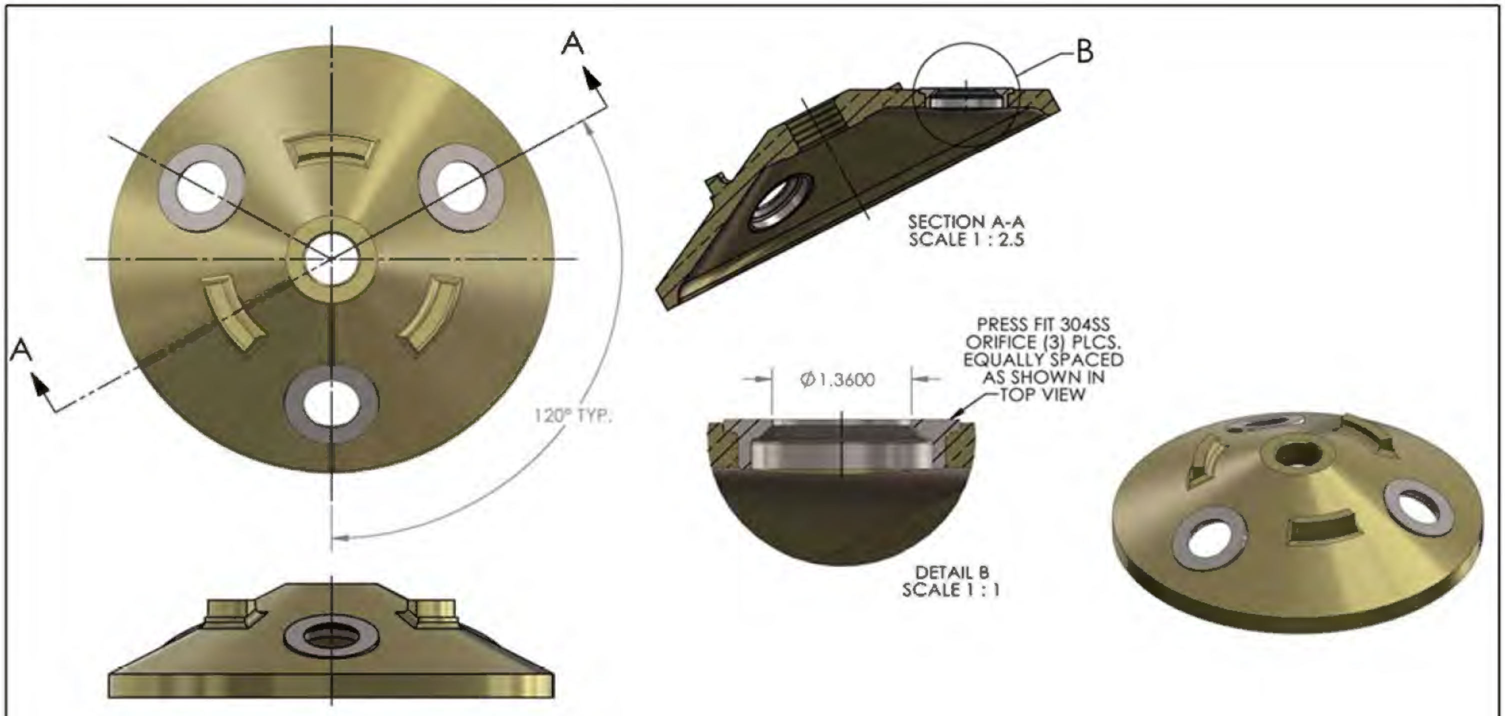
The advanced water treatment plant (AWT) at James River (JR SWIFT) will treat secondary wastewater to drinking water standards with analytes meeting primary maximum contaminant levels (PMCLs). Treatment processes at the AWT will consist of sedimentation/flocculation (floc/sed), ozonation, biologically active filtration (BAF) using granular activated carbon, granulated activated carbon (GAC), and disinfection by ultraviolet lamps with the option to use either free chlorine or chloramines to limit biofouling of the well.

AWT effluent (recharge) will enter a pump station that conveys recharge to the active MAR wells through a common manifold. HRSD's distributed control system (DCS) will record recharge flowrates, water levels, and wellhead pressures at each MAR well. Each MAR well will contain a pump for backflushing and either a foot valve or a downhole control valve (DHCV), employed to control recharge flowrates while maintaining a positive pressure in the pump column and wellhead (Figures C.5 and C.6). Maintaining a positive pressure in the recharge piping prevents recharging under a vacuum, and entraining air into the recharge water. Inducing a vacuum in the recharge piping can promote hydraulic difficulties with chemical feed systems.

HRSD anticipates equipping eight MAR wells with a foot valve designed to recharge the PAS aquifer. The foot valve mounts on the bottom of the pump column and will contain several stainless-steel inserts, orifice-type openings set to a relatively narrow range of recharge rates around 2 MGD. Two MAR wells will contain a DHCV, allowing HRSD to set more exact rates, and more importantly recharge rates lower than 2 MGD to achieve the total plant flow of 16.6 MGD.

Unlike the foot valves, the SMART-V type DHCV valve will mount in the column piping, directly above the pump. Recharge will exit the DHCV through ports mounted on the side of the unit that act as orifices. Hydraulically adjusting the size of the ports controls the recharge rate while imposing small, a positive pressure of the operator's choosing. Operators at HRSD's research facility (SRC) routinely set the DHCV to deliver recharge flows to +/- 10 gpm, and wellhead pressures of +/- 1 pound per square inch (PSI).

MAR wells will recharge the PAS at rates around 2 MGD. Recharge water levels in each MAR well could potentially extend up to 23 feet above the ground surface, or 10 PSI at the wellhead. During MAR operations, HRSD will determine if recharge levels should extend higher than 10 PSI. HRSD will look at operating recharge rates, interference between wells, and how quickly recharge levels climb to 10 PSI. Recharge pressures are not intended to exceed 30 PSI at the wellhead. Operators will track recharge levels and wellhead pressures to determine the need for routine, or extraordinary maintenance, like invasive well rehabilitation.



NOTES:

1. ORIFICE DIAMETER CALCULATED BY CH2MHill
2. PROJECT: BTMUA ASR WELL NO. 15
3. SUBMITTAL NO: 56B
4. CONTRACT NO: 708003
5. SPEC. SECTION: 11212-01 VT PUMP DATA SHEET (FOOT VALVE) & RFI-009

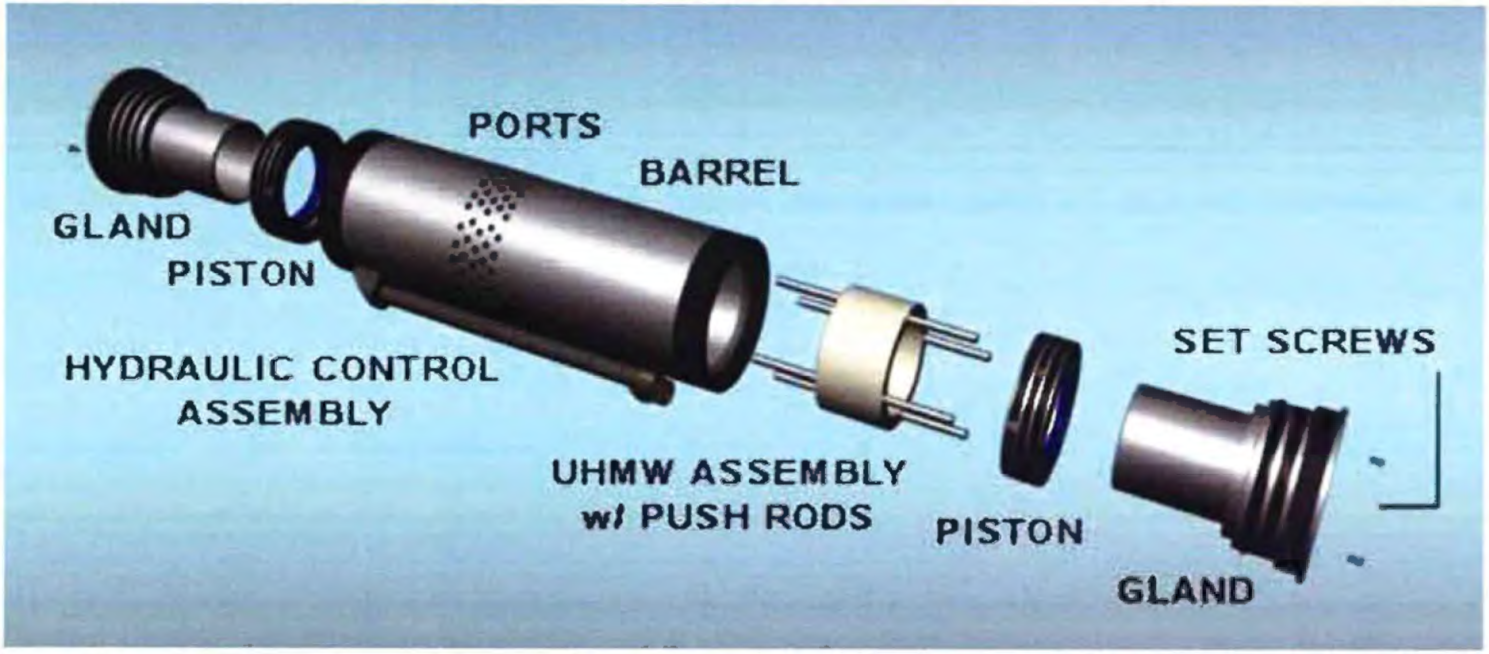
Figure K-2. Cross Section of Foot Valve Face
James River Swift Facility
Hampton Roads Sanitation District
Virginia Beach, VA

JACOBS

Source: FLOWMATIC Valves catalog sheet.

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 8X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f100_8X93158.dgn

Figure C.5: Cross Section of Foot Valve Face.



Source: 3R Valve

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f101_6X93158.dgn

JACOBS

Figure C.6: Diagram showing sliding assembly on downhole control valve.

C.1.2.3 Routine Maintenance

Even the highest quality drinking water contains some amount of total suspended solids (TSS), that if left to accumulate in the wellbore (screen and filter pack), will clog a MAR well and reduce its performance. MAR wells installed in sandy aquifers like the Potomac Aquifer System (PAS) have proven particularly susceptible to clogging from TSS entrained in the recharge water. To preclude TSS from accumulating in the well screen and filter pack, HRSD operators will backflush each operational MAR well at frequent intervals. As an example, operators at the SRC backflush test well TW-1, daily for approximately 30 minutes. HRSD anticipates a similar backflushing schedule for MAR wells at JR SWIFT.

C.1.2.4 Invasive Rehabilitation Measures

Even maintaining the most aggressive backflushing schedule, MAR wells at JR SWIFT will require invasive well rehabilitation (rehab) to maintain the well's specific injectivity and backflushing specific capacity. At present, it is anticipated invasive rehab will occur at every active MAR well on a 5 to 7-year frequency. Early operational data may impact the plan for the frequency at which rehab will occur. Invasive rehab includes the following activities:

- Pre-rehab specific capacity test
- Pump removal
- Video survey of MAR well
- Swab and airlift pumping of well screen
- Chemical addition (e.g., acid or surfactant during a second swabbing pass)
- Test pump installation
- Over-pumping development
- Post rehab specific capacity test
- Test pump removal
- Post rehab video survey
- Re-installation of repaired or replaced DHCV and pump

Upon resuming MAR operations, HRSD operators will track well performance to ensure that rehab measures restored Specific Injectivity (SI) and Backflushing Specific Capacity (BSC) to near original values, and to determine the rate of performance decline following a rehab.

C.1.2.5 Monitoring

HRSD plans to install monitoring wells at two sites at JR SWIFT. Each site will contain 4 monitoring wells which allow discretized monitoring of the recharge intervals, three with screens in the UPA and one with screens in the MPA. These wells may lie up to 50 feet apart to preclude interference during drilling. The lower two UPA wells will be nested in the same borehole, with a 20' thick bentonite seal between the screen zones. The four monitoring wells will feature a single-cased design (Figures C.3-C.5) with 4-inch diameter carbon steel or fiberglass reinforced plastic (FRP) casing extending to the top screen with screen and blank assemblies that, in aggregate, match the recharge intervals in the closest MAR wells. Further details of construction are discussed in C.2.3. below.

HRSD will equip the downhole portion of each monitoring well with a pressure transducer and permanent sampling pump. The pressure transducer will record water levels to the DCS system. HRSD operators will monitor the response of water levels in the UPA and MPA to MAR operations.

C.1.3 Surface Trace

To ensure the plumbness and alignment (P&A) of the wellbore, HRSD will perform gyroscopic survey of the entire pilot boring. The survey will allow the drilling contractor to correct any issues regarding the later P&A of the outer well casing. The contractor will run a second survey after installing and grouting the 24-inch diameter casing to confirm its P&A. Interpretation of the surveys will follow the AWWA standard (AWWA 100) for P&A testing.

C.2 Part II. Well Construction Procedures

C.2.1 Introduction

Detailed plans and specifications will be prepared that define the scope of work, materials of construction and testing requirements and will be used to procure a drilling contractor to install the MAR and monitoring wells at JR.

A drilling contractor will assume responsibility for industry standard means and methods when constructing the wells in accordance with the UIC permit. The contractor will prepare the site for drilling, including installing a surface casing, constructing temporary pads for the drilling rig and mud control system, and setting up drilling equipment for drilling, installing, developing, and testing the MAR and monitoring wells.

The contractor will erect temporary facilities to contain borehole and drilling fluids during construction and testing of the wells. The contractor will provide a design for a drilling fluid containment structure with the appropriate removal of cuttings, fluids and waste, with their proper disposal. The contractor will propose a suitable plan for the disposing of drilling fluids, cuttings and waste, including identifying an acceptable disposal site. The contractor will clean up spillage during drilling, installation, development and testing activities. Approval from the appropriate agencies will be obtained prior to constructing the wells.

C.2.2 MAR Well Drilling, Installation, Development and Testing

The following summarizes the general procedures for drilling, installing, developing and testing up to ten MAR wells at JR SWIFT.

Pit Casing

A minimum 40-inch surface casing will be installed and grouted to surface to support the weight of the rig. A 14-inch diameter pilot hole will be drilled from the base of the surface casing to approximately 1290 fbg using conventional closed-circulation mud rotary methods. Drill cutting samples will be collected at set depth intervals during pilot hole drilling (e.g., every 10 feet of depth) to characterize the lithology, with a grain size distribution (GSD) analysis performed on cutting samples from Potomac Aquifer System.

A borehole deviation survey and geophysical logging that includes at a minimum the following suite of logs: natural gamma ray, spontaneous potential, single point resistance, short normal resistivity, and long normal resistivity will be performed in each borehole. The geophysical logs and GSD results will be used to design casing and screen elevations, along with individual screen slot sizes, pre-packed screen annulus filter fill, and filter pack grade for the borehole annular space.

Surface casing

A 30-inch diameter 2205 duplex or Type 316L stainless steel casing will then be installed to the top of the Potomac Aquifer formation, encountered around 400 fbg. A gyroscopic survey will be run to evaluate plumbness and alignment in outer casing from grade to the length of the casing prior to grouting. The contractor will provide a cement plan to the EOR prior to cementing operations. The annular space of the 30-inch casing will be grouted using either the

Halliburton method that drives grout from the casing bottom to around 100 feet bls or the tremie method. If using tremie method as an alternative, the tremie pipe will be kept 15 feet above bottom of hole and retracted as grout fills annular space.

Mechanical integrity testing

Internal and external mechanical tests will be conducted to demonstrate the integrity of the casing and grout seal. The internal integrity test will involve pressurizing the internal portion of the casing with water to a pressure anticipated to approximate 120 pounds per square inch (PSI) and then shutting the casing in for two hours. The casing must maintain the pressure without dropping 10 percent of the total pressure for the two-hour shut-in period.

The external mechanical integrity test will entail running a cement bond log from grade to the entire length of the casing. The empty space from grade to 100 feet bls will allow the log to display a ringing, unbonded signature. The remaining annular space, from grade to 200 feet bls, will be grouted using the tremie method. The borehole for the target aquifer (PAS) will then be drilled out using reverse circulation method.

Production casing, screen and blank assembly

An 18-inch x 20-inch diameter inner casing and pre-packed screen assembly will screen across the UPA and MPA, extending to approximately 1,120 fbg and comprising approximately 270 ft of screen, including 180 and 90 ft screening the UPA and MPA respectively. The screen assembly will consist of 18-inch x 20-inch diameter, pre-packed, dual-wall screen separated by stainless steel blanks and ending in a 50-foot long, stainless steel sump. The material for the pre-pack well screen, blank sections and sump will consist of 2205 duplex or Type 316L stainless steel. Estimated screen length and depths are based upon data gathered at the James River test well and will be adjusted depending on highly localized conditions of each MAR well. The pre-packed screen assembly will likely display screen slot sizes and annular space fill customized to individual sand zones. The annular space around the screen will be sounded and a filter pack installed in the borehole annular space.

The well will be developed using air lifting methods to remove drilling fluids and assist filter pack settling. The screen sections will be swabbed and any formation materials found in the bottom of the well removed. The well will then be over-pumped using a temporary pump, for two to three days until the pumping level stabilizes and turbidity measurements fall below 5 nephelometric units (NTU).

Grout isolation seals in recharge zone

The Virginia Department of Environmental Quality (VADEQ) requires installing a minimum 10-foot long bentonite seal in the annular area containing the sand filter pack to separate the upper (UPA) and middle (MPA) recharge zones of the PAS within the well. HRSD will target a minimum seal length of 20 ft.

The seal will be installed at approximately 870 fbg to 900 fbg; exact depths will vary depending upon MAR well site-specific formation depths encountered.

Hydraulic performance testing

Step drawdown testing will be conducted on the completed well. Steps will start at rate of approximately 1,000 gpm, and incrementally increase pumping rate by 200 gpm in seven steps until reaching 2,100 gpm. Pump at each step for 60 minutes. Following the step drawdown test a 24-hour constant rate pumping test will be conducted at 2,100 gpm. A video survey along with a dynamic flow log will be conducted on the well after completion of testing to confirm casing and screen elevations and to check on condition of screen.

Aquifer Conditioning

HRSD will condition the upper and middle zones of the PAS to stabilize interstitial clays and preclude clay dispersion, an issue when recharge exhibits a significantly lower ionic strength (IS > one order of magnitude) than native groundwater in the storage aquifer. The conditioning will involve recharging a 0.05 to 0.1 molar, aluminum salt solution into the screened intervals in each well using packers to isolate individual or groups of screens for direct placement of the solution. The solution volume treats the aquifer out to a radius of 14 feet from the well bore. Aluminum ions and hydrous aluminum oxide, exhibiting +3 to +6 charges, respectively will create much greater positive charge density, increasing the attraction between clay particles, attachments to framework grains, and inter-layers in the atomic structure of clay minerals. The treatments should stabilize clay minerals in perpetuity against the rigors of managed aquifer recharge operations.

Starting in October 2017, HRSD tested several differing treatments at monitoring and test wells at four of the five planned SWIFT facilities. Moreover, TW-1 at the SRC, treated in early 2018, has shown no evidence of clay dispersion after 2.5 years of MAR operations.

C.2.3 Monitoring Well Drilling, Installing, and Testing

Section C.2.3 describes the general procedure for drilling, installing, developing and testing a monitoring well set in the MPA of the Potomac Aquifer at JR SWIFT. A nearly identical procedure is used for installing a monitoring well in the UPA. Only the elevation of the screens and casing may change.

Drilling borehole and logging

The deepest borehole will be drilled into the MPA zone (approximately 1,000 fbg (feet below grade) using conventional mud rotary methods. Deviation and geophysical logging surveys including at a minimum, the following suite of logging parameters: including natural gamma, spontaneous potential, single point resistance, short normal resistivity, and long normal resistivity will be conducted on the open borehole.

Well construction

HRSD plans to install four monitoring wells at each of the two JR SWIFT monitoring sites. Three separate boreholes will be drilled at each monitoring site. Two of the boreholes will contain a single well and one borehole will contain a nest of two wells. Three of the wells will be screened in the UPA and one in the MPA. These wells may lie up to 50 feet apart to preclude interference during drilling. The four monitoring wells will feature a single-cased design (Figure C.3) with 4.5-inch diameter carbon steel or fiberglass reinforced plastic (FRP) casing extending to the top screen. The screen and blank assemblies will, in aggregate, match the recharge intervals in the closest MAR wells. Thus, monitoring well screens will target the sand units of the UPA and MPA. Screens will either be Type 316L stainless steel wire wrap or fiberglass reinforced continuous slot well screen surrounded by U.S. Silica (or equivalent) filter pack. Each well will include a minimum 10-foot long sump at the base of the deepest well screen. The annular space above will be grouted using tremie method from the top of the gravel filter pack to grade. Development of the MWs will include airlift pumping of the drilling fluids and swabbing of the screen interval and over-pumping with a test pump for two days.

The 4.5-inch diameter monitoring well casings will accommodate a permanently installed, sampling pump, set to around 200 fbg each well. The sampling pumps will deliver a steady purging rate of 10 gpm against a total dynamic head (TDH) of 275 feet. As water levels rebound in the UPA and MPA, purging rates should increase as the TDH declines. In addition to the sampling pump, each monitoring well will be equipped with a pressure transducer that will record water levels to the plant’s DCS.

A 13-foot long, 8-inch diameter steel surface casing with a locking cap will cover the 4.5-inch diameter inner casing, extending 10 feet below grade. A 2-ft square concrete pad (4-ft square concrete pad for the nexted well pair) will surround each monitoring well. The monitoring wells will be installed in an enclosure to protect the them from vehicular traffic and maintenance activities. Refer to Appendix B for additional details on monitoring well construction and aquifer monitoring.

C.2.4 Construction Program

The major elements of the MAR and monitoring well construction program involve the following:

C.2.4.1 Drilling Methods

The contractor is required to drill pilot borings for the MAR and monitoring wells using the conventional mud rotary method. To prevent clogging of the aquifer and hasten development, the Contractor will use reverse circulation methods when reaming the borehole in the PAS for MAR wells.

Backplugging the pilot hole will help prevent vertical migration of fluids. The engineer will notify the EPA of construction progress, including notifications prior to mobilizing and prior to commencing drilling.

C.2.4.2 Formation Evaluation

The engineer will evaluate the formations encountered by several methods including lithological evaluation of cuttings, evaluation of formation fluid while drilling, grain size distribution analysis, and geophysical logging.

C.2.4.3 Geophysical Logging Program

The geophysical logging program will support characterizing the physical, geochemical, and hydraulic characteristics of the PAS, along with providing the information necessary to design each MAR and monitoring well. Logs will provide information on the borehole size for cementing casing and backplugging pilot holes. Logs will help verify proper cementing of casing and confirm the mechanical integrity of the outer casing.

Geophysical logs selected for various stages of the construction and testing of the injection and monitoring well include as follows: caliper, gamma ray, spontaneous potential, dual induction, long and short-normal resistivity, log-derived water quality, static and dynamic temperature, static and dynamic, fluid resistivity, static and dynamic flowmeter cement top temperature, cement bond log, and a video survey. At the completion of construction, a comprehensive well completion report, including interpretation of the logs will be sent to the EPA.

C.2.4.4 Casing and Cement

Casing depth and diameters are graphically shown in the downhole well profiles for the MAR and monitoring well in Figures C.1 and C.3 – C.5. All casing joints will be water-tight, while casings will be installed to the approximate depths proposed. An engineer will select actual casing depths based on the drilling and geophysical logging of the MAR well and monitoring well borings.

The cementing plan is designed to support casing and prevent the movement of groundwater behind the casing. In addition, all pilot holes will be backplugged with cement. Backplugging will help eliminate the possibility of creating a two-hole well where the reamed hole deviates from the pilot hole. Specifications for cement material are presented in Section 13196, Article 2.05.

Sulfate-resistant cement is specified for all cementing of casings and pilot hole backplugging.

The location of the proposed casing depths is approximated from the James River Test Well and summarized as follows:

MAR Well

- 60 fbg (MAR) – This depth represents a potential setting for the drilling contractor’s surface casing, useful for preventing collapse of the wellbore near the ground surface.
- 400 fbg (MAR) – The MAR outer well casing will extend to the base of the confining bed overlying the first sand interval screened by the MAR well. Setting casing at this depth will facilitate construction below 400 fbg. The casing will isolate the PAS aquifer from overlying units.
- 310 fbg (MAR) An approximate 60-foot length of 20-inch diameter stainless steel casing (lap pipe) will extend between the approximate depths of 370 fbg and 310 fbg. This casing will provide a reservoir for the filter pack above the top of the relief screen.
- 1,130 fbg (MAR) The inner casing deeper than 390 fbg will consist of 18-inch diameter, Schedule 40 Stainless Steel blank sections between screens and a 50-foot long diameter sump.

Monitoring Wells

- 410 fbg (MW) – Typifies the depth of 4.5-inch diameter casing extending to the top of the shallowest screen in the UPA. Screens in the monitor wells set in the UPA will screen portions of each of the six sand intervals that comprise the aquifer and match screen intervals in the closest MAR well.
- 970 fbg (MW) – The depth for 4.5-inch diameter casing extending to the shallowest screen situated in the MPA. Screens in monitoring wells set in the MPA will screen portions of each of the three sand intervals that make up the aquifer and match MPA screens in the closest MAR well.

Actual screen and casing elevations will be determined based on drill cuttings and geophysical logs of each well borehole.

C.2.4.5 Water Quality Testing

HRSD will sample each MAR well near the end of a 24-hour constant rate aquifer test for a comprehensive list of water quality analytes (Appendix B, Aquifer Monitoring Plan and Appendix C, Analytical Parameters and Methods). In addition to the analytes listed in Table 3.1 of Appendix B, HRSD will analyze samples for the major ions in water, including: calcium, magnesium, potassium, sodium, iron, manganese, arsenic, sulfate, chloride and alkalinity.

C.2.5 Description of Alarms

There are no shutoff devices located specifically at each MAR well house though a high well level alarm is being considered for each MAR well. The water quality is monitored throughout the SWIFT AWT at Critical Control Points and Critical Operating Points (CCPs, COPs). Limits are set and if water quality is detected outside the required CCP/COP, automated procedures will divert the SWIFT Water from the recharge wells, keeping water that does not meet the required specifications from entering the aquifer. A description of the alarms and shut down procedures is contained in Attachment D, Table D.4. As well, groundwater monitoring procedures are included in the James River SWIFT Aquifer Monitoring and Contingency Plan (Appendix B).

C.2.5 Previous Logs

A borehole geophysical log (beginning next page) was collected at the JR SWIFT Test Well site, located on the JR treatment plant. Note: the well ID referenced in the header of the log is incorrect. The James River Test Well is TW-4. TW-1 is the designation for the test well installed at the SRC.

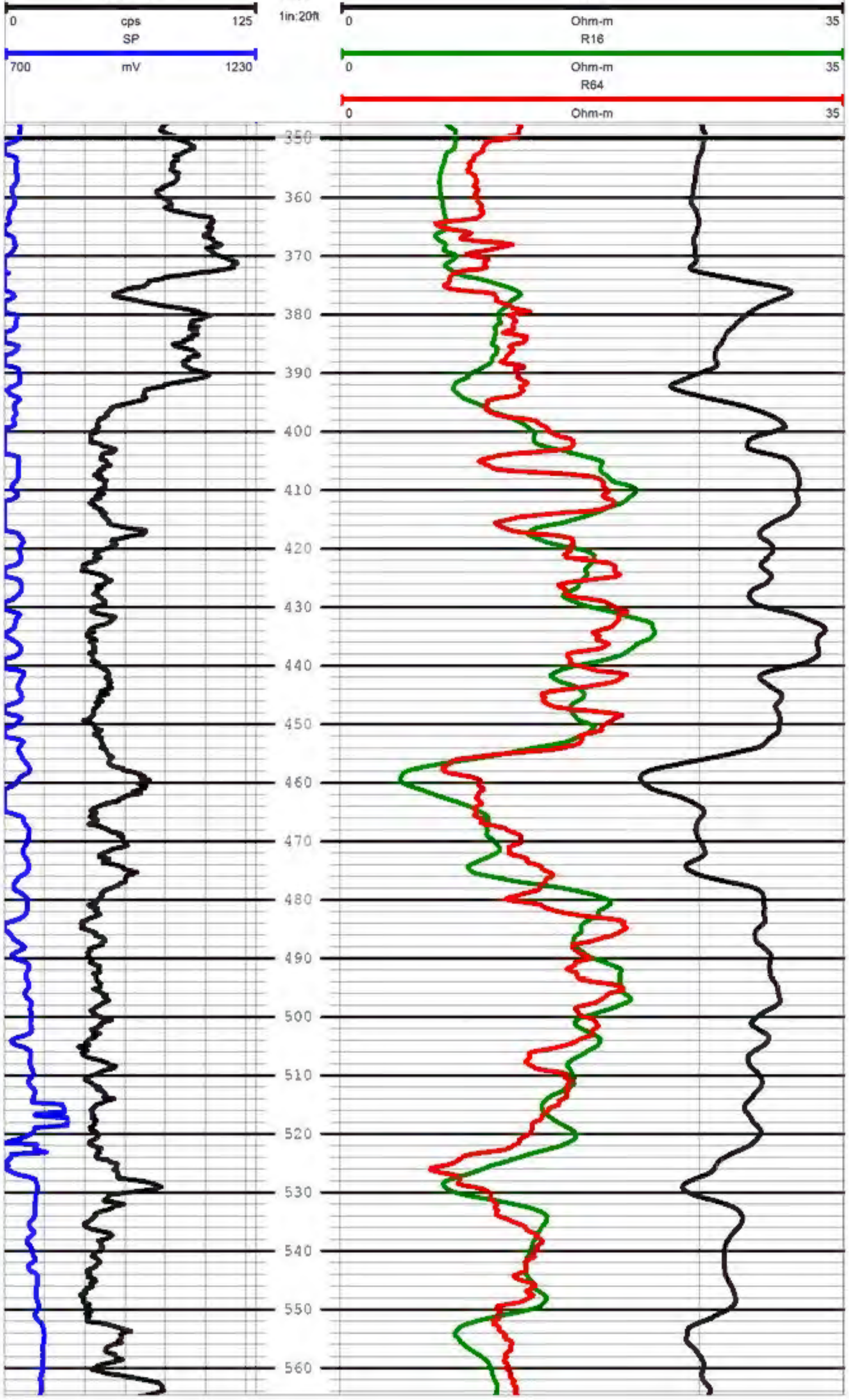
Earth Data Incorporated
131 Comet Drive, Centreville, MD 21617
Phone: (410) 758-8160 / Facsimile (410) 758-8168
www.earthdatainc.com

WELL I.D.
TW 1
DEQ 216-107
USGS 58E7

Logging Date: *10/16/18*
Logging Speed: *17 ft/min* x **Up** **Down**
BOC: *347 ft* **TD:** *1315.63*

Project:	*HRSD James River WWTP TW1 DEQ 216-107*	**Bit Size:**	*7.5 inches*	**EDI Job No.:**	*5009*
Client:	*AC Schlutes of Maryland Job No. H7636*	**Fluid Type:**	*Mud Based Water*	**Technician:**	*Jeff Chipman*
		LAT:	*37° 05' 11.890" N*		
Location:	*111 City Farm Rd Newport News, VA*	**LONG:**	*76° 32' 04.254" W* **Casing Material:** *Drill Rods*	**Witness:**	*Scott Bruce Keegan Hartman*

Notes: *Elevation of ground surface is 27.31 ft, RTK GPS Accuracy Less than 1 ft vertical. Horizontal Datum NAD83 RTK Centimeter. Logged through 347 ft of drill string. Pilot hole total depth reported from driller as 1317.1 ft, Geophysical logged to 1315.63 ft.*



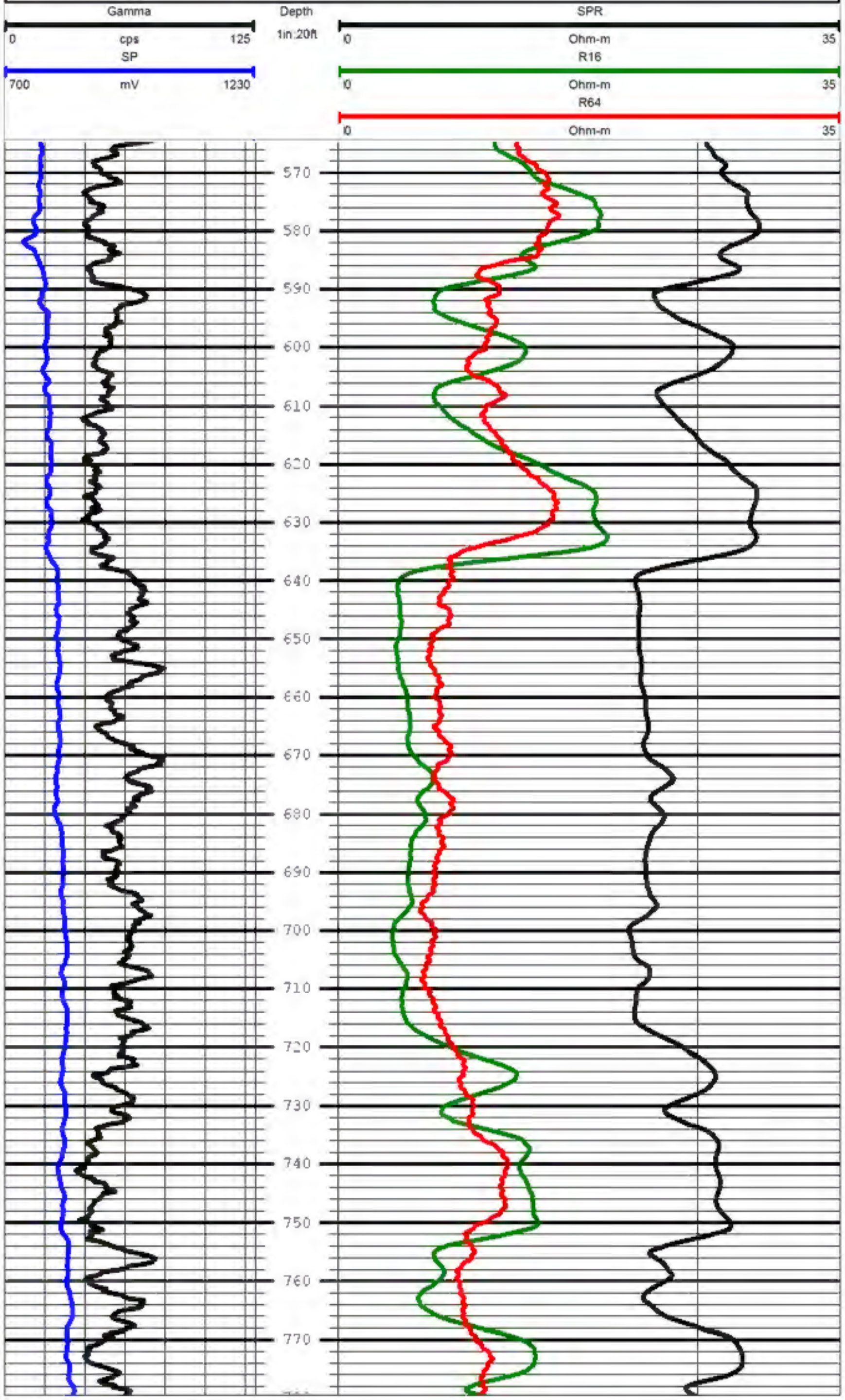
Earth Data Incorporated
131 Comet Drive, Centreville, MD 21617
Phone: (410) 758-8160 / Facsimile (410) 758-8168
www.earthdatainc.com

WELL I.D.
TW 1
DEQ 216-107
USGS 58E7

Logging Date: 10/16/18
Logging Speed: 17 ft/min x Up Down
BOC: 347 ft **TD:** 1315.63

Project:	HRSD James River WWTP TW1 DEQ 216-107	**Bit Size:**	7.5 Inches	**EDI Job No.:**	5009
Client:	AC Schlutes of Maryland Job No. H7636	**Fluid Type:**	Mud Based Water	**Technician:**	Jeff Chipman
Location:	111 City Farm Rd Newport News, VA	**LAT:** 37° 05' 11.890" N **LONG:** 76° 32' 04.254" W	**Casing Material:** Drill Rods	**Witness:**	Scott Bruce Keegan Hartman

Notes: Elevation of ground surface is 27.31 ft, RTK GPS Accuracy Less than 1 ft vertical. Horizontal Datum NAD83 RTK Centimeter. Logged through 347 ft of drill string. Pilot hole total depth reported from driller as 1317.1 ft, Geophysical logged to 1315.63 ft.



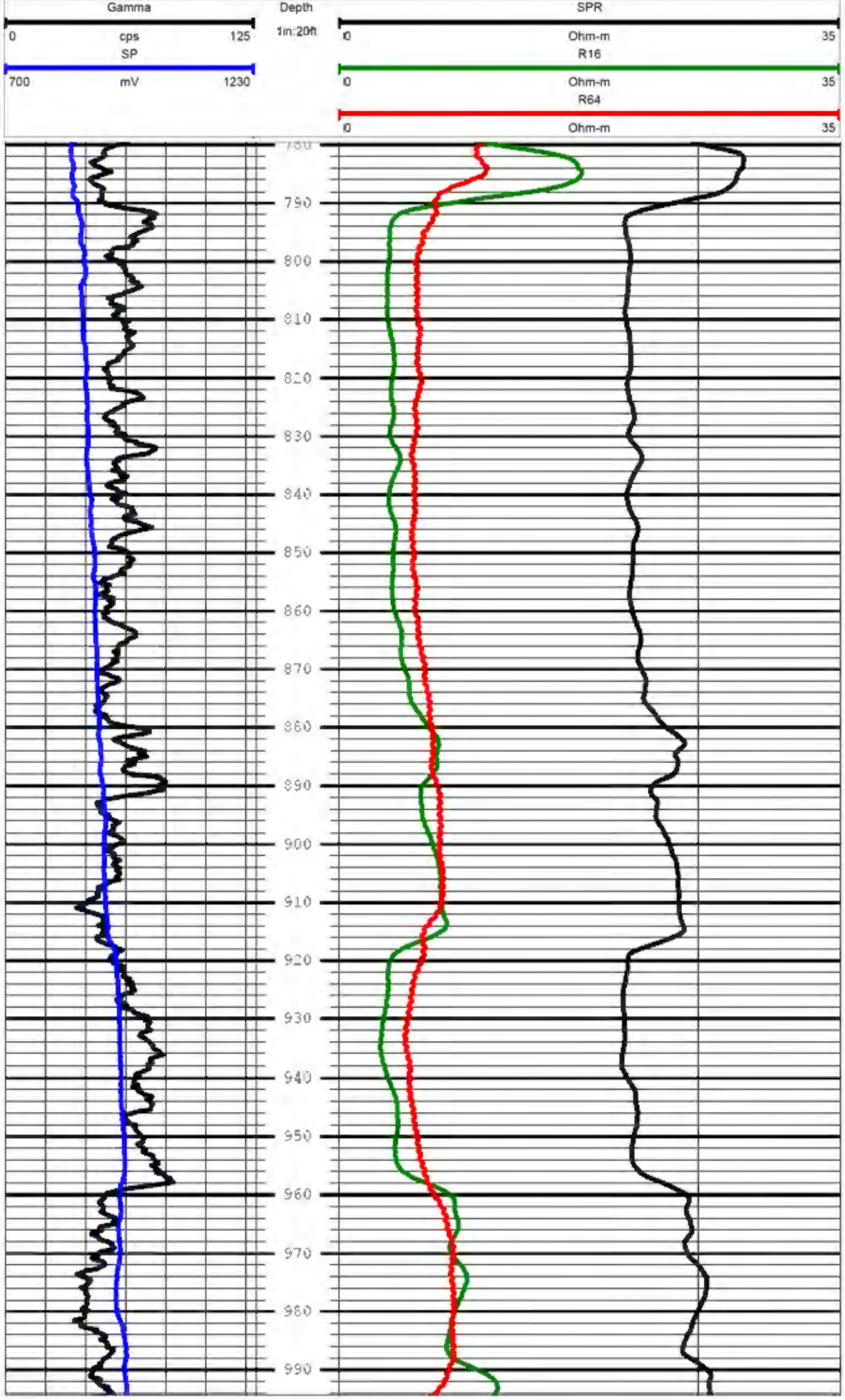
Earth Data Incorporated
131 Comet Drive, Centreville, MD 21617
Phone: (410) 758-8160 / Facsimile (410) 758-8168
www.earthdatainc.com

WELL I.D.
TW 1
DEQ 216-107
USGS 58E7

Logging Date: 10/16/18
Logging Speed: 17 ft/min x Up Down
BOC: 347 ft **TD:** 1315.63

Project:	HRSD James River WWTP TW1 DEQ 216-107	**Bit Size:**	7.5 Inches	**EDI Job No.:**	5009
Client:	AC Schlutes of Maryland Job No. H7636	**Fluid Type:**	Mud Based Water	**Technician:**	Jeff Chipman
		LAT:	37° 05' 11.890" N		
Location:	111 City Farm Rd Newport News, VA	**LONG:**	76° 32' 04.254" W	**Casing Material:** Drill Rods	**Witness:** Scott Bruce Keegan Hartman

Notes: Elevation of ground surface is 27.31 ft, RTK GPS Accuracy Less than 1 ft vertical. Horizontal Datum NAD83 RTK Centimeter. Logged through 347 ft of drill string. Pilot hole total depth reported from driller as 1317.1 ft, Geophysical logged to 1315.63 ft.



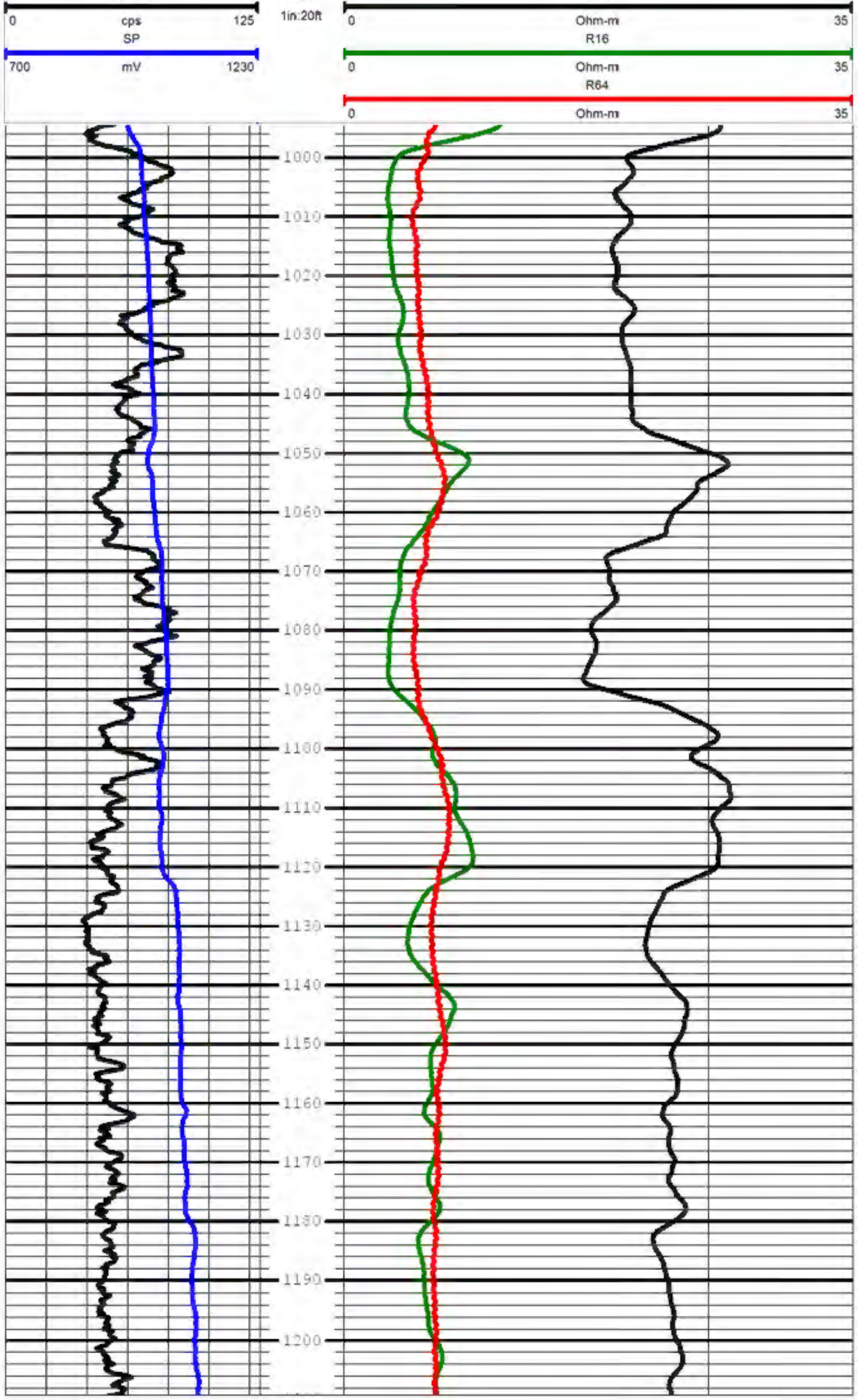
Earth Data Incorporated
131 Comet Drive, Centreville, MD 21617
Phone: (410) 758-8160 / Facsimile (410) 758-8168
www.earthdatainc.com

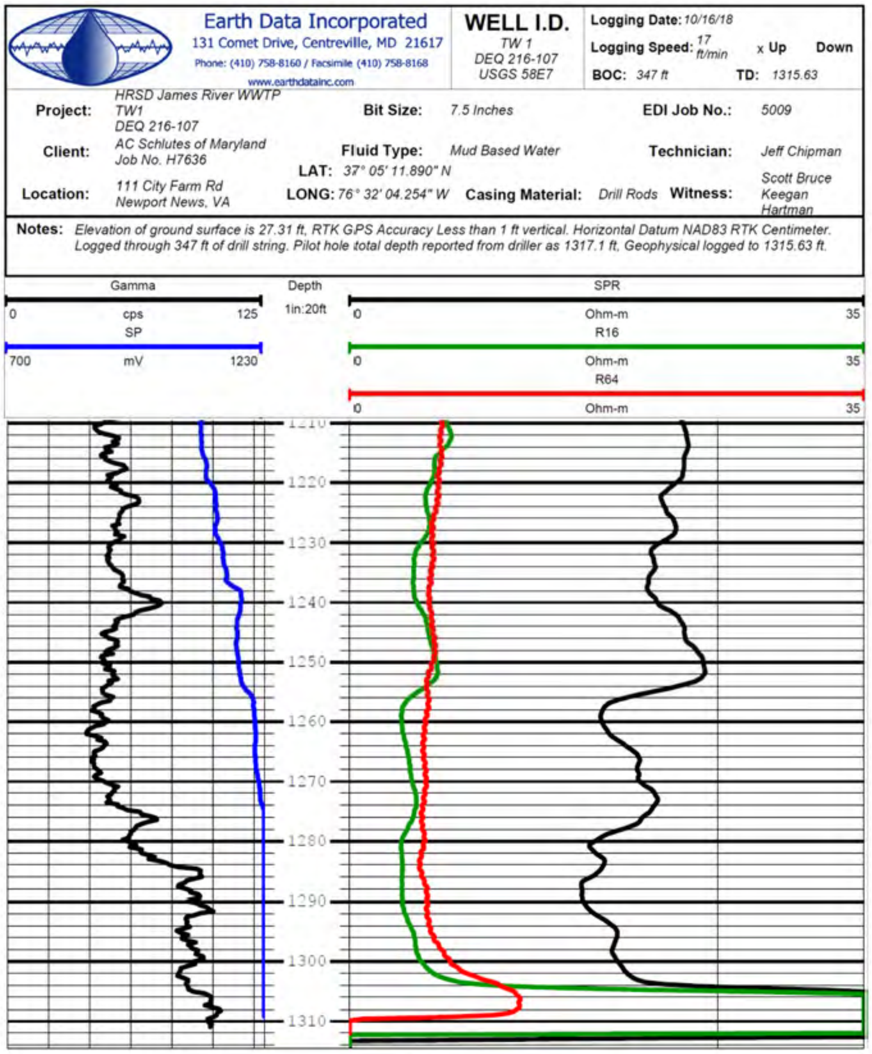
WELL I.D.
TW 1
DEQ 216-107
USGS 58E7

Logging Date: 10/16/18
Logging Speed: 17 ft/min x Up Down
BOC: 347 ft **TD:** 1315.63

Project:	HRSD James River WWTP TW1 DEQ 216-107	**Bit Size:**	7.5 Inches	**EDI Job No.:**	5009
Client:	AC Schlutes of Maryland Job No. H7636	**Fluid Type:**	Mud Based Water	**Technician:**	Jeff Chipman
Location:	111 City Farm Rd Newport News, VA	**LAT:** 37° 05' 11.890" N **LONG:** 76° 32' 04.254" W	**Casing Material:** Drill Rods	**Witness:**	Scott Bruce Keegan Hartman

Notes: Elevation of ground surface is 27.31 ft, RTK GPS Accuracy Less than 1 ft vertical. Horizontal Datum NAD83 RTK Centimeter. Logged through 347 ft of drill string. Pilot hole total depth reported from driller as 1317.1 ft, Geophysical logged to 1315.63 ft.





Earth Data Incorporated
131 Comet Drive, Centreville, MD 21617
Phone: (410) 758-8160 / Facsimile (410) 758-8168
www.earthdatainc.com

WELL I.D.
TW 1
DEQ 216-107
USGS 58E7

Logging Date: 10/16/18
Logging Speed: 17 ft/min x Up Down
BOC: 347 ft **TD:** 1315.63

Project: HRSD James River WWTP
TW1
DEQ 216-107
Bit Size: 7.5 Inches
EDI Job No.: 5009

Client: AC Schlutes of Maryland
Job No. H7636
Fluid Type: Mud Based Water
Technician: Jeff Chipman

LAT: 37° 05' 11.890" N
Location: 111 City Farm Rd
Newport News, VA
LONG: 76° 32' 04.254" W
Casing Material: Drill Rods
Witness: Scott Bruce
Keegan
Hartman

Notes: Elevation of ground surface is 27.31 ft, RTK GPS Accuracy Less than 1 ft vertical. Horizontal Datum NAD83 RTK Centimeter. Logged through 347 ft of drill string. Pilot hole total depth reported from driller as 1317.1 ft, Geophysical logged to 1315.63 ft.

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINE HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Total Nitrogen	Lab	mg/L	Calculation			
		Turbidity (SDWA PMCL)	Field	NTU	Hach 8195	Glass vial	None	Analyze Immediately
		TOC	Lab	mg/L	SM 5310B/C	250mL Amber Glass	pH<2, H_3PO_4, HCl, H_2SO_4 Cool to <6°C	28 D
		pH	Field		SM 4500-H^+B-2000	Flow-through Cell	None	Analyze Immediately
		TDS	Lab	mg/L	SM 2540C	1000mL HDPE or Glass	Cool to <6°C	7 D
		EPA Primary MCLs						
		- Microorganisms						
		Male-specific and Somatic Coliphage	Lab	PFU/100m	EPA 1642			
		Cryptosporidium	Lab	Oocysts/L	EPA 1623	10L Poly Cubitainer	1° C – 10° C	96 H
		Giardia lamblia	Lab	Oocysts/L	EPA 1623	10L Poly Cubitainer	1° C – 10° C	96 H
		Legionella	Lab	MPN/100 mL	IDEXX	Sterile Glass or Plastic	6°C – 18°C	30 H
		Total Coliform	Lab	MPN/100 mL	SM 9223B	Sterile Glass or Plastic	0.2mL 10% $Na_2S_2O_3$ Cool <6°C	30 H
		E. coli	Lab	MPN/100 mL	SM 9223B	Sterile Glass or Plastic	0.2mL 10% $Na_2S_2O_3$ Cool <6°C	30 H
		- Disinfection Byproducts						
		Bromate	Lab	µg/L	EPA 302.0/300.1	150mL Amber Plastic	EDA, Cool to <6°C	28 D
		Chlorite	Lab	mg/L	EPA 300.0	150mL Amber Plastic or Glass	EDA, Cool to <6°C	14 D
		Haloacetic acids (HAA5)	Lab	µg/L	EPA 552.2	60mL Amber Glass Vial	6mg NH_4Cl, Cool to <6°C	14 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINERS, PRESERVATION AND HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Total trihalomethanes	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2 drops of 1:1 HCl added in the field, Cool to <6ºC. If sodium thiosulfate is used to dechlorinate, acidification may be omitted.	14 D
		- Inorganic Chemicals						
		Antimony, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Arsenic, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Asbestos	Lab	MFL	EPA 100.2	1000mL Sonicated Polypropylene	Cool to <6ºC	48 H
		Barium, Total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Beryllium, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Cadmium, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Chromium VI	Lab	µg/L	SM3500 Cr D	200mL HDPE or Glass	Cool to <6ºC	24 H
		Chromium, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Copper, Total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Cyanide, Total	Lab	µg/L	10-204-00-1-X	250mL HDPE or Glass	Check interferences (Ascorbic acid if chlorinated), pH >12 + Sodium Hydroxide, Cool <6°C	14 D
		Fluoride	Lab	mg/L	EPA 300.0	250mL HDPE	None	28 D
		Lead, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6 M
		Mercury, Total	Lab	µg/L	EPA 245.1	500mL HDPE or Glass	pH <2, HNO_3	28 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAIN HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Nitrate (NO_3-N)	Lab	mg/L	Calculation			
		Nitrite-N	Lab	mg/L	10-107-04-1-C	250mL HDPE or Glass	Cool to <6°C	28 D
		Selenium, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6M
		Thallium, Total	Lab	µg/L	EPA 200.8	500mL HDPE or Glass	pH <2, HNO_3	6M
		- Organic Chemicals						
		Acrylamide	Lab	µg/L	MWH/LCMSM	125mL Amber Glass	Cool to <6°C	28 D
		Alachlor	Lab	µg/L	EPA 525.2	10000mL Amber Glass	2mL 6N HCl, Cool <6°C	Extract within 14 D. Analyze within 30 D after extraction
		Atrazine	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl, Cool <6°C	Extract within 14 D. Analyze within 30 D after extraction
		Benzene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Benzo(a)pyrene (PAHs)	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl	Extract within 14 D. Analyze within 30 D after extraction
		Carbofuran	Lab	µg/L	EPA 531.2	40mL Amber Glass Vial	0.37g KH_2Citrate + 6mg ThioSulfate	28 D
		Carbon Tetrachloride	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6^{oC}	14 D
		Chlordane	Lab	µg/L	EPA 505	40mL Amber Glass	1 drop Thio (8%) Cool to <6°C	14 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINE HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Chlorobenzene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		2,4-D	Lab	µg/L	EPA 515.4	60mL Amber Glass Vial	3mg NaSulfite, Cool to <6°C	14 D
		Dalapon	Lab	µg/L	EPA 515.4	60mL Amber Glass Vial	3mg NaSulfite, Cool to <6°C	14 D
		1,2-dibromo-3-chloropropane (DBCP)	Lab	µg/L	EPA 504.1	40mL Amber Glass Vial	3mg $Na_2S_2O_3$ Cool to <6°C	14 D
		1,2-Dichlorobenzene (o-dichlorobenzene)	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2 drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		1,4-Dichlorobenzene (p-dichlorobenzene)	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2 drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		1,2-Dichloroethane	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		1,1-Dichloroethylene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	cis-1,2-Dichloroethylene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6ºC	14 D
		trans-1,2-Dichloroethylene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6ºC	14 D
		Dichloromethane (Methylene chloride)	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6ºC	14 D
		1,2-Dichloropropane	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6ºC	14 D
		Di(2-ethylhexyl) adipate	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl	Extract within 14 D. Analyze within 30 D after extraction
		Di(2-ethylhexyl) phthalate	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl	Extract within 14 D. Analyze within 30 D after extraction
		Dinoseb	Lab	µg/L	EPA 515.4	60mL Amber Glass	3mg NaSulfite	14 D
		Dioxin (2,3,7,8-TCDD)	Lab	pg/L	EPA 1613	1000mL Amber Glass	1mL 8% Thiosulfate	40 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Diquat	Lab	µg/L	EPA 549.2	1000mL Amber Poly	Protect from light, Cool to <6°C	21 D
		Endothall	Lab	µg/L	EPA 548.1	250mL Amber Glass	Cool to <6°C	14 D
		Endrin	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Epichlorohydrin	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	Cool to <6°C	14 D
		Ethylbenzene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Ethylene dibromide (EDB)	Lab	µg/L	EPA 504.1	40mL Amber Glass Vial	3mg $Na_2S_2O_3$	14 D
		Glyphosate	Lab	µg/L	EPA 547	125mL Amber Glass	Cool to <6°C	14 D
		Heptachlor	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Heptachlor Epoxide	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Hexachlorobenzene	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl, Cool to <6°C	Extract within 14 D. Analyze within 30 D after extraction
		Hexachlorocyclopentadiene	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl, Cool to <6°C	Extract within 14 D. Analyze within 30 D after extraction

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINE HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Lindane (Gamma-BHC)	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Methoxychlor	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Oxamyl (Vydate)	Lab	µg/L	EPA 531.2	40mL Amber Glass Vial	0.37g KH_2Citrate + 6mg ThioSO_4 Cool to <6°C	28 D
		Polychlorinated biphenyls	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop Thio (8%) Cool to <6°C	14 D
		Pentachlorophenol	Lab	µg/L	EPA 515.4	60mL Amber Glass Vial	3mg NaSulfite Cool to <6°C	14 D
		Picloram	Lab	µg/L	EPA 515.4	60mL Amber Glass Vial	3mg NaSulfite Cool to <6°C	14 D
		Simazine	Lab	µg/L	EPA 525.2	1000mL Amber Glass	2mL 6N HCl, Cool to <6°C	Extract within 14 D. Analyze within 30 D after extraction
		Styrene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Tetrachloroethylene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Toluene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Toxaphene	Lab	µg/L	EPA 505	40mL Amber Glass Vial	1 drop 8% Thio Cool to <6°C	14 D
		2,4,5-TP (Silvex)	Lab	µg/L	EPA 515.4	60mL Amber Glass Vial	3mg NaSulfite Cool to <6°C	14 D
		1,2,4-Trichlorobenzene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		1,1,1-Trichloroethane	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		1,1,2-Trichloroethane	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Trichloroethylene	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINERS HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Vinyl Chloride	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		Xylene, Total	Lab	µg/L	EPA 524.2	40mL Amber Glass Vial	25mg Ascorbic Acid (precharged) + 2drops of 1:1 HCl added in the field, Cool to <6°C	14 D
		-Radionuclides						
		Alpha particles	Lab	pCi/L	EPA 900.0	500mL Polypropylene/125mL polypropylene unpreserved	2 ~~4~~mL 6°C 18% HNO_3 Cool to <6°C	180 D
		Beta particles and photon emitters	Lab	pCi/L	EPA 900.0	500mL Polypropylene/125mL polypropylene unpreserved	2 ~~4~~mL 6°C 18% HNO_3 Cool to <6°C	180 D
		Radium 226	Lab	pCi/L	GA Method	1000mL HDPE	4mL 6°C 18% HNO_3 Cool to <6°C	180 D
		Radium 228	Lab	pCi/L	GA Method	1000mL HDPE	4mL 6°C 18% HNO_3 Cool to <6°C	180 D
		Uranium	Lab	µg/L	EPA 200.8	500mL HDPE	HNO_3, pH<2	180 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINERS HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Regulatory Parameters	SDWA Primary MCLs and Related Regulatory Parameters	Strontium-90	Lab	pCi/L	EPA 905.0	1000mL Polypropylene preserved/125mL polypropylene unpreserved	4mL ~~6°C~~ 18% HNO_3 Cool to <6°C	180 D
		Tritium	Lab	pCi/L	EPA 906.0	500mL Amber Glass	Cool to <6°C	180 D
	Virginia Groundwater Standards	Aldrin/Dieldrin	Lab	ug/L	EPA 8081A	1000mL Amber Glass	Cool to <6°C	7 D
		DDT	Lab	ug/L	EPA 8081A	1000mL Amber Glass	Cool to <6°C	7 D
		Kepone	Lab	ug/L	EPA 8081	1000mL Amber Glass	Cool to <6°C	7 D
		Mirex	Lab	ug/L	EPA 8081A	1000mL Amber Glass	Cool to <6°C	7 D
		Phenols	Lab	mg/L	MWH420/SW9066	250mL Amber Glass	1mL H_2SO_4, Cool to <6°C	28 D
Compounds of Emerging Concern	**Performance Indicators**	***Performance Indicators***						
		Public Health Indicators						
		1,4-dioxane	Lab	µg/L	EPA 52~~1~~ 2 (GC-QQQ/SPE)	500mL Amber Glass	25mg Na_2SO_3+ 500mg $NaHSO_4$ Cool to <6°C	28 D
		17-β-estradiol	Lab	ng/L	EPA 539 (LC-ESI-MS-MS/SPE)	500mL Amber Glass	40mg NaThio + 33mg 2-mercaptopyr, Cool to <6°C	28 D
		DEET	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA) Cool <6°C	28 D
		Ethinyl estradiol	Lab	ng/L	EPA 539	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA) Cool <6°C	28 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Compounds of Emerging Concern	**Performance Indicators**	NDMA	Lab	ng/L	EPA 52~~2~~ 1 (GC-QQQ/SPE)	500mL Amber Glass	40-50 mg/ Na Thiosulfate /25mg Na_2SO_3+ 500mg $NaHSO_4$ Cool to <6°C	14 D
		Perchlorate	Lab	µg/L	EPA 331	125mL Polypropylene	Cool <6°C	28 D
		PFOA + PFOS	Lab	ng/L	EPA 537/533	275mL Polypropylene	EPA 537 – 1.4g Trisma. EPA 533 -Ammonium Acetate. Cool <6°C	28 D
		PFBA	Lab	ng/L	EPA 537/533	275mL Polypropylene	EPA 537 – 1.4g Trisma. EPA 533 -Ammonium Acetate. Cool <6°C	28 D
		PFHpA	Lab	ng/L	EPA 537/533	275mL Polypropylene	EPA 537 – 1.4g Trisma. EPA 533 -Ammonium Acetate. Cool <6°C	28 D
		PFHxS	Lab	ng/L	EPA 537/533	275mL Polypropylene	EPA 537 – 1.4g Trisma. EPA 533 -Ammonium Acetate. Cool <6°C	28 D
		PFNA	Lab	ng/L	EPA 537/533	275mL Polypropylene	EPA 537 – 1.4g Trisma. EPA 533 -Ammonium Acetate. Cool <6°C	28 D
		tris(2-carboxyethyl)phosphine (TCEP)	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA) Cool <6°C	28 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Compounds of Emerging Concern	**Performance Indicators**	***Treatment Efficacy Indicators***						
		Cotinine	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA) Cool <6°	28 D
		Primidone	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA)	28 D
		Phenytoin	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(1.04g/L NaOmadine + 4g/L AA) Cool <6°C	28 D
		Meprobamate	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D
		Atenolol	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D
		Carbamazepine	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D
		Estrone	Lab	ng/L	EPA 539	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D
		Sucralose	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D
		Triclosan	Lab	ng/L	LCMSMS	40mL Amber Glass Vial	0.5mL(100g/L NaAzide + 4g/L AA) Cool <6°C	28 D

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINE HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Non-regulatory Parameters	Aquifer Characteristics/ Compatibility	Dissolved Oxygen	Field	mg/L	ASTM Method D888-09 (C)	Flow-through cell	None	Analyze Immediately
		Temperature	Field	˚C	Standard Method2 2550 B-2000	Flow-through cell	None	Analyze Immediately
		Specific Conductivity	Field	ms/cm	Standard Method2 2510 B-1997	Flow-through cell	None	Analyze Immediately
		ORP	Field	mV	SM2580B	Flow-through cell	None	Analyze Immediately
		Sulfide	Field	mg/L	Hach 8051	40 mL Glass vial	None	Analyze Immediately
		Sulfate	Field	mg/L	Hach 8131	40 mL Glass vial	None	Analyze Immediately
		Iron, field (ferrous as Fe^{2+})	Field	mg/L	HACH 8146	Plastic intermediate	None	Analyze Immediately
		Iron, Total, field	Field	mg/L	HACH 10249	Plastic intermediate	None	Analyze Immediately
		Alkalinity as CaCO$_3$	Field	mg/L	Hach Cat 2444301	40 mL Glass vial	None	Analyze Immediately
		Aluminum, dissolved	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Aluminum, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Arsenic, dissolved	Lab	mg/L	EPA 200.8	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Iron, dissolved	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Iron, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Manganese, dissolved	Lab	mg/L	EPA 200.8 or EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Manganese, total	Lab	mg/L	EPA 200.8 or EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Magnesium, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO$_3$	6 M
		Methane	Lab	mg/L	EPA 3810	40 mL Glass vial	None	14 days

APPENDIX C: IDENTIFICATION OF ANALYTICAL PARAMETERS AND SUMMARY OF METHODS, CONTAINER HOLDING TIMES

		Parameter	Lab/Field Measurement	Unit	Method	Container	Preservation	Holding Time
Non-regulatory Parameters	Aquifer Characteristics/ Compatibility	Potassium, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO_3	6 M
		Sodium, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO_3	6 M
		Calcium, total	Lab	mg/L	EPA 200.7	500mL HDPE or Glass	pH<2 HNO_3	6 M
		Sulfate	Lab	mg/L	EPA 300.0	250mL HDPE or Glass	Cool to <6°C	28 D
		Chloride	Lab	mg/L	EPA 300.0	250mL HDPE or Glass	None	28 D
		Alkalinity	Lab	mg/L	For regulatory - SM 2320B. For non-regulatory 10-303-31-1-A	250mL HDPE or Glass	Cool to <6°C	14 D
		Total Kjeldahl Nitrogen	Lab	mg/L	10-107-06-2-I	500mL HDPE or Glass	pH <2 with H_2SO_4 Cool to <6°C	28 D
		Ammonia as N	Lab	mg/L	10-107-06-1-J	500mL HDPE or Glass	pH <2 with H_2SO_4 Cool to <6°C	28 D
		Total Phosphorus	Lab	mg/L	10-115-01-1-E	500mL HDPE or Glass	pH <2 with H_2SO_4 Cool to <6°C	28 D
		Orthophosphate as P	Lab	mg/L	10-115-01-1-A	250mL HDPE or Glass	Filtered in the field, Cool to <6°C	48 H
		Silica as SiO_2	Lab	mg/L	EPA 200.7	250mL HDPE	Cool to <6°C	28 D
		Dissolved Organic Carbon	Lab	mg/L	SM5310 B/C-2011	250mL Amber Glass	Filtered in the field. pH < 2 with H_3PO_4, HCl, H_2SO_4 Cool to <6°C	28 D
		Hardness, Total	Lab	mg/L	Calculation	500mL HDPE or Glass	pH <2, HNO_3	6 M

JACOBS

Geochemical Evaluation and Recommended Measures for the Sustainable Water Initiative for Tomorrow Proposed Managed Aquifer Recharge Program at the James River Wastewater Treatment Plant

Hampton Roads Sanitation District

Test Well Program at SWIFT-JR

October 2019

Client Reference

Project Name

Project No:	Project Number
Document Title:	Project Geochemical Evaluation and Recommended Measures for the Sustainable Water Initiative for Tomorrow Proposed Managed Aquifer Recharge Program at the James River Wastewater Treatment Plant
Document No.:	Document No.
Revision:	<revision>
Date:	August 2019
Client Name:	Hampton Roads Sanitation District
Client No:	Client Reference
Project Manager:	Project Manager
Author:	<prepared by>
File Name:	Document1

Jacobs Engineering Group Inc.

4350

www.jacobs.com

Limitation: This document has been prepared on behalf of, and for the exclusive use of Jacobs' client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this document by any third party.

Document history and status

Revision	Date	Description	By	Review	Approved

Contents

Appendix A. Additional Information

Tables

Figures

Acronyms and Abbreviations

ASR	aquifer storage and recovery
AWT	advanced water treatment
BAC	biologically activated carbon
CAS	clay-rich aquifer sands
CEC	cation exchange capacity
CRT	constant rate aquifer test
DO	dissolved oxygen
EDX	energy dispersive x-ray
fbg	feet below grade
ft/d	feet per day
$FeCO^3$	siderite
FeS^2	pyrite
gpm	gallons per minute
GSD	grain size distribution
HFO	hydrous ferric oxide
HRSD	Hampton Roads Sanitation District's
IS	ionic strength
LSI	Langlier Saturation Index
LPA	Lower Potomac Aquifers
MAR	managed aquifer recharge
MDLs	method detection limits
mg/L	milligrams per liter
µg/L	micrograms per liter
mgd	million gallons per day
MPA	Middle Potomac Aquifers
MW-SAT	monitor well facilitating depth discrete sampling
ng/L	nanograms per liter
NGW	native groundwater
ORP	oxidation-reduction potential
PAS	Potomac Aquifer System
pCi/L	picoCuries per liter
PHREEPLOT	Plotting program using PHREEQC
PHREEQC	Thermodynamic equilibrium geochemical) model
SDWA MCLs	Safe Drinking Water Act – maximum contaminant limits
SEM	Scanning Electron Microscopy

SI	saturation index
SWIFT	Sustainable Water Initiative for Tomorrow
SWIFT-JR	SWIFT-James River
TDS	total dissolved solids
TSS	total suspended solids
TW-3	MAR well
UPA	Upper Potomac Aquifers
USGS	United States Geological Survey
VIP	Virginia Initiative Plant
WWTP	wastewater treatment plants
XRD	x-ray diffraction

1. Introduction

The Hampton Roads Sanitation District (HRSD) has undertaken the Sustainable Water Initiative for Tomorrow SWIFT program, entailing the reuse of highly purified wastewater as a resource for aquifer replenishment. SWIFT will subject secondary-treated wastewater to advanced water treatment (AWT processes and then inject AWT effluent (recharge) injection into the region's groundwater aquifers. HRSD is presently testing the SWIFT concept at a research center located at their Nansemond Wastewater Treatment Plant (SWIFTRC).

1.1 Initiative Framework

The project was arranged in a six-phased framework. The conclusion of each phase represents a juncture where HRSD can decide if and how to proceed to the next phase. This approach provides a screening process where potential barriers are identified and addressed, if possible. The phases comprise the following:

Table 1-1. Summary Description of SWIFT Phases

Initiative Phase	Phase Description
Phase 1 – Concept Feasibility	Evaluates overall feasibility concepts regarding treatability using advanced water treatment (AWT processes, potential membrane process concentrate treatability, aquifer recharge hydraulic injectability and recharge water/aquifer geochemical compatibility. Conceptual costs are estimated at an AACE Class 5 level.
Phase 2 – Concept Development	Further refines and develops AWT and groundwater injection concepts and facility features/layouts. Pilot-scale process evaluations are conducted to assess and compare AWT concepts and in-situ performance.
Phase 3 – Concept Demonstration	Confirmation Testing is conducted on a demonstration scale (approximately 1 million gallons per day mgd) flow rate . The facility operation is demonstrated through continuous operation of the AWT process and simultaneous injection of the treated water into the Potomac aquifer system (PAS). HRSD is assessing process and operational parameters and adjusting them in response to operational issues experienced at the SWIFT research center.
Phase 4 – Facility Plan Development	Preliminary development facility layouts and implementation approaches are developed based on information obtained from the Phase 2 Pilot Plant and the Phase 3 Demonstration Facility. Further development of facility features, regulatory acceptance, public/stakeholder acceptance. Evaluation and development of financing and resources needs and schedule refinement.
Phase 5 – Implementation Plan Development	Define specific project packages and implementation schedule including delivery method(s , project packaging and sequencing. Final selection of plant sites and capacities for implementation and subsequent preparation of preliminary engineering documentation. Development of program management plan, regulatory approvals, and resource/capital improvement plan.
Phase 6 – Full-Scale Facility Implementation	Final facility design per selected delivery approach. Construction initiation, completion and operation of planned SWIFT facilities at each of the selected plant sites.

This phase of the project, Phase 5, focuses on developing facility-specific information based on previous pilot-scale testing, drilling investigations, aquifer testing, process evaluations, water quality testing and preliminary planning. The information will assist in confirming project direction through more detailed facility technical and cost information. The output from Phase 5 will support HRSD in preparing an overall implementation plan that guides full-scale implementation should the SWIFT program continue to benefit HRSD's mission.

1.2 Report Purpose

The evaluation involves characterizing the hydraulic characteristics of the Potomac Aquifer System PAS beneath HRSD's SWIFT-James River facility (SWIFT-JR), along with identifying key geochemical issues related to the following:

- Recharging purified wastewater (recharge water or recharge) in an injection-type well
- Mixing recharge with native groundwater (NGW from the PAS and,
- Reactions between recharge and minerals contained in the matrices of the PAS.

Investigating geochemical issues will promote the long-term sustainability of the managed aquifer recharge MAR) initiative, protect local water users, and maintain the functionality of the PAS. The report focuses on investigating hydraulic and geochemical issues at SWIFT-JR.

1.3 Report Structure

The report is divided into seven major sections:

Section 1 – Introduction: This section provides a project introduction, purpose and objectives, and the overall report organization.

Section 2 – Geochemical Compatibility Issues: Section 2 characterizes the geochemical compatibility of recharge, native groundwater and minerals composing the PAS beneath SWIFT-JR.

Section 3 – Evaluation Approach: Section 3 describes the methods employed in evaluating the hydraulic characteristics of test well TW-4, hydraulic coefficients in the PAS, and then water chemistry, mineralogy, and potential reactions during their interaction.

Section 4 – Data Collection: Section 4 characterizes the hydraulic characteristics of test well TW-4, hydraulic coefficients in the PAS, and geochemical characteristics displayed by the recharge, native groundwater, and minerals in the PAS.

Section 5 – Estimating Aquifer Hydraulic Coefficients : Section 5 describes the results of step drawdown, 24-hour constant rate aquifer test, and the packer testing across specific screen or groups of screens in TW-4.

Section 6 – Evaluating Geochemical Compatibility: Section 6 evaluates the geochemical compatibility of the recharge, native groundwater (NGW and aquifer minerals based on sampling and testing conducted at TW-4.

Section 7 – Recommended Pretreatment Measures Section 7 recommends aquifer conditioning and pretreatment measures required at SWIFT-JR to prevent clay dispersion and metals leaching. Geochemical Compatibility Issues

Section 2 describes the issues that affect the chemical compatibility between the recharge, NGW in the PAS, and minerals in the aquifers of the PAS.

1.4 Background

A critical portion of SWIFT entails providing water to safely and affordably recharge the PAS at SWIFT-JR. In supporting a MAR program at SWIFT-JR, HRSD will evaluate the physical and chemical viability of recharging highly purified water (recharge) into the PAS. During recharge, the chemical compatibility, if not addressed correctly, can create operational and environmental issues detrimental to the program. In addition to the geochemical issues discussed in this report, physical problems total suspended solids, temperature, pH, etc. can result in clogging MAR wells, potentially compromising operations at the facility.

This report addresses the chemistry of recharge that has passed through AWT at HRSD's SWIFT-JR. Like SWIFTRC, SWIFT-JR will employ biological activated carbon (BAC) to treat secondary wastewater. However, HRSD has not yet constructed or piloted a BAC-based AWT at SWIFT-JR. Thus, to complete this evaluation, recharge water chemistry originates from an engineer's estimate of AWT effluent, and pilot testing results from HRSD's nearby York River facility, circa 2016 through 2019. These data typified the recharge water at SWIFT-JR and were used in evaluating potential reactions between the recharge, NGW, and the aquifer matrix.

Once the chemical compatibility issues are characterized, they are addressed through pre-treating the recharge and/or conditioning of the aquifer to stabilize (passivate) reactive minerals in situ. This report describes the techniques applied in characterizing chemical compatibility between the recharge, NGW, and minerals residing in the matrices of the PAS. Mathematical modeling techniques, used in testing the viability of several pretreatment alternatives, are also discussed.

2. Geochemical Compatibility Issues

Geochemical compatibility issues relate to:

- Long-term well operability
- Regulatory compliance
- Aquifer stability and preservation
- Potential water uses

The following table summarizes general geochemical compatibility issues, effects and categories of parameters for measurement and evaluation.

Table 2-1. Summary of Geochemical Issues Considered in Compatibility Assessment

Potential Issue at Injection Point	Potential Effect	Key Parameters	Media Interaction Evaluated
Mineral dissolution	Water quality impairment and aquifer matrix clogging	Metal-bearing minerals, Saturation Index, Safe Drinking Water Act – maximum contaminant limits SDWA MCLs	1) Recharge / NGW – Aquifer Matrix 2) Recharge – Aquifer Matrix
Mineral precipitation	Aquifer and well clogging	Metal-bearing minerals, Saturation Index, Dissolved Oxygen (DO	1) Recharge/NGW – Aquifer Matrix 2) Recharge Water – Aquifer Matrix
Clay structure fragmentation	Well clogging, aquifer matrix clogging	Clay mineralogy, Cation Exchange Capacity, cation chemistry in recharge	Recharge – Aquifer Matrix
Clay particle dispersion	Well clogging, aquifer matrix clogging	Ionic strength (IS)	Recharge – Aquifer Matrix
Physical clogging	Well clogging due to solids in recharge water	Total Suspended Solids (TSS)	Recharge

The following describes the geochemical compatibility issues in further detail:

Mineral Dissolution, mobilization, and eventually precipitation

Reactions between the recharge water and aquifer matrices can dissolve minerals, releasing their elemental components to the groundwater (Stuyfzand, 1993). Dilute recharge water containing dissolved oxygen (DO injected into an anoxic aquifer will interact with common, reduced metal-bearing minerals like pyrite (FeS_2 and siderite ($FeCO_3$ through reactions (sulfide oxidation, mineral dissolution, pH reduction) that release iron and other metals like manganese that occupy sites in the mineral structure. Oxidation of arsenian pyrite can release arsenic, creating a water quality concern in the migrating recharge. Left unchecked, leaching metals degrade the quality of water stored in the aquifer, violating Safe Drinking Act regulations, while limiting the use of the stored water by the local population.

As the oxidation process continues, iron and manganese released by mineral dissolution are converted to more oxidized forms (Fe(II) to Fe(III); Mn(II) to Mn(III) and Mn(IV) and reprecipitate as oxide and hydroxide minerals. Increasing the recharge water pH hastens precipitating hydroxide mineral phases, buffering the dissolution of reduced iron-bearing minerals remaining in the matrix. The reaction precipitates hydrous ferric oxide (HFO on the surface of reactive minerals, isolating the mineral and reducing (passivating) its reactivity in the aquifer.

Precipitating metal hydroxides on mineral surfaces can occlude pore spaces in the aquifer, reducing permeability. However, metal-bearing minerals typically constitute less than one percent of the aquifer matrix, so significant effects of the precipitates are limited to areas immediately surrounding the wellbore. As surface areas in the aquifer increase geometrically away from the well, the concern for metal oxide/hydroxide precipitation declines rapidly with distance from the well.

- **Ionic Strength and Mineral Cation Exchange Capacity Potential between recharge and NGW**

Recharge exhibiting a significantly lower ionic strength fresher than the NGW reduces the mineral surface charge environment in the aquifer matrix, potentially damaging interstitial clay minerals attached to aquifer framework particles (formation damage), weakening inter-particle attachments, and even diminishing adhesive charges between individual clay layers. Formation damage also arises when recharge contains differing cations than those residing in the exchange positions in clay minerals (Langmuir, 1997).

Exchanging cations can disrupt a clay mineral’s atomic structure particularly when their atomic radius exceeds the radius of the replacedcation. During exchange, larger cations fragment the tabular structure of clays, shearing off the edges of the mineral.

All these factors cause clay mineral fragments to migrate through the pore spaces of the aquifer. The fragments eventually block pore throats, reducing the permeability of the aquifer around a MAR well, diminishing the well’s injection capacity. Clay minerals accumulating (brush piling) in pore throats has proven difficult to reverse through conventional well rehabilitation measures.

- **Solids loading in recharge water**

Even the cleanest recharge can contain small amounts of TSS. If left to accumulate in the wellbore, solids can clog the screen, filter pack, and aquifer proximal to the well, which reduces the well’s injectivity. Injectivity reduction increases draw-up and eventually lowers the well’s injection capacity (Pyne, 2005). TSS can originate from scale, dirt in piping, and most commonly, treatment residuals.

Once the physical and chemical compatibility issues are characterized, they are addressed through engineering measures comprising the pre-treatment of the recharge water and/or the conditioning of the aquifer to stabilize passivate) reactive clay and metal-bearing minerals in situ. The techniques applied in characterizing physical and chemical compatibility between the recharge water, NGW and minerals residing in the matrices of the PAS are described in the sections below.

3. Evaluation Approach

This section discusses the approach to characterizing hydraulic conditions at test well TW-4 and PAS aquifers along with evaluating the characteristics of the recharge, groundwater and aquifer minerology in the PAS. TW-4 represents the fourth test well installed for the SWIFT program. Installing TW-4 at SWIFT-JR was preceded by TW-1, TW-2, and TW-3 at HRSD's Nansemond, York River, and Williamsburg facilities, respectively. HRSD has drilled, installed, and developed TW-5 at the Virginia Initiative Plant (VIP), but has not yet completed testing.

The table below identified the media where the potential issue exists.

Table 3-1. Summary Geochemical Characterization and Evaluation Approaches

Potential Issue	Media to be Characterized	Evaluation Approaches
Mineral dissolution and precipitation	1) Recharge / Groundwater – Aquifer Matrix 2) Recharge Water – Aquifer Matrix	Geochemical modeling of interactions between native groundwater test well), recharge water (from pilot plants , aquifer matrix (test well)
Clay structure fragmentation	Recharge – Aquifer Matrix	Classify major cations of the native groundwater (test well), recharge water (from pilot plants), /compare aquifer matrix CEC (test well)
Clay particle dispersion	Recharge Water – Aquifer Matrix	Geochemical modeling of interactions between native groundwater (test well), recharge water from pilot plants , aquifer matrix (test well)
Physical clogging	Recharge Water	Filtration techniques on recharge water

Based on the above, the program must characterize the following media:

- Recharge
- NGW
- Aquifer Mineralogy

Characterizing the chemistry of recharge, NGW, and aquifer minerals supports assessing the interaction between media including the mixing of recharge and NGW, and water – rock reactions. Methods employed in evaluating these interactions comprised conventional geochemical analysis and geochemical modeling.

3.1 Recharge, Groundwater and Aquifer Mineral Characterization

This section discusses techniques applied in characterizing recharge, groundwater, and aquifer minerals.

3.1.1 Recharge Water Characterization

3.1.1.1 Physical Characterization

At MAR facilities, two testing techniques are used in quantifying the solids content of recharge. These techniques comprise membrane filter index (MFI) and bypass filter index (BFI) testing. MFI and BFI tests provide short- and long-term clogging rates, respectively. HRSD applies both techniques at their SWIFTRC facility at Nansemond. The following describes MFI and BFI testing and results from SWIFTRC.

River SWIFT Tes

MFI indices, elevated three orders of magnitude above previous test results, helped identify a change in recharge quality caused by elevated iron concentrations, corroding from the interior of treatment vessels.
MFI testing uses a portable device that an operator can attach to various points along a run of pipe, or at the wellhead, whereas the BFI device is permanently attached to the wellheader piping. BFI testing also employs a filter device to measure a bypass filter index, TSS concentrations, and ultimately clogging indices in the recharge water. An HRSD operator or other personnel can run one MFI test in 30 to 45 minutes.

BFI tests consist of water passing through a 10-centimeter long canister filter while measuring the flowrate and volume. To start a BFI test, an operator installs the filter, and then records the initial flowrate. Operations personnel then measure the flowrate daily as it declines to 20 percent of the original rate. The filter is then removed, dried, and weighed, at the same time a new filter is installed in the device, starting another BFI test.

With the greater surface areas on the canister filter, BFI tests run significantly longer, often for several weeks to months. At SWIFTRC to date, flowrates through the BFI filters have never declined to the termination criteria for ending a test, which is 20 percent of the original flowrate. Instead, filters were removed for filtrate analysis at four- to eight-week intervals. However, the white filter elements grow discolored after only several hours of testing. Colors observed to date include grayish brown to brick red, corresponding to manganese or iron comprising the prevailing metals in the recharge water, respectively.

MFI and BFI tests evaluate physical characteristics of the recharge water for injection compatibility. These techniques are employed **afte**r constructing and starting the AWT. Treatment chemicals, piping, treatment trains and other factors influence the TSS content of the recharge, thus, testing results correspond directly to the specific conditions present at each AWT facility.

3.1.1.2 Hydraulic Characterization

The aquifer test program conducted in the Potomac Aquifer System (PAS) at test well TW-4 consisted of three parts including the following:

- Step-drawdown test
- One 24-Hour constant rate aquifer test (CRT , consisting of drawdown and recovery periods
- Packer tests conducted at six depth intervals including drawdown and recovery periods.

The step-drawdown test and 24-hour CRT were conducted between July 17 and 20, 2019. Packer testing was conducted in six intervals distributed across the Upper UPA; three intervals , Middle (MPA; two intervals , and Lower LPA; one interval) aquifers between August 29 and September 17. Packer testing began in the deepest interval and proceeded upward as the Contractor removed the packer assembly from the wellbore.
No observation wells were employed during the step drawdown, 24-hour CRT, or packer testing. Thus, analysis involved single-well test analytical techniques. Because of instabilities associated with pumping data, analysis of the data was biased toward the recovery portions of the 24-hour CRT and packer tests.

The aquifer test program conducted in TW-4 was intended to evaluate the hydraulic characteristics of the new test well including production capacity, specific capacity, specific loss, and coefficients of well loss. Additionally, data was evaluated to estimate the transmissivity of the PAS and specific intervals isolated by the packer tests.

3.1.1.3 Chemical Characterization Approach

To characterize the chemistry of recharge, an engineer estimated the chemistry of AWT effluent based on the chemical characteristics of the secondary effluent discharged from the James River Wastewater Treatment Plant WWTP . The evaluation employed mathematical modeling techniques to simulate treating secondary effluent by the following techniques: flocculation/sedimentation, ozonation, biologically activated carbon (BAC), granulated activated carbon (GAC), and disinfection with ultraviolet radiation and chloramines. Also, water quality samples were collected from HRSD's AWT pilot system at the York River WWTP (Table 3-2).

The chemistry of the simulated James River WWTP and observed York River WWTP AWT effluents look similar, both featuring a circum-neutral pH, total dissolved solids concentrations ranging between 420 and 600 mg/L, classifying the water as fresh, and a sodium chloride water type.

Table 3-2. Analysis for Samples collected During AWT Pilot Testing at HRSD's York River facility–Carbon-Based Recharge

Constituent	Units	PMCL
pH	standard units	0.1
Eh (corrected)	mv	50
Specific Conductivity	emhos	10
Dissolved Oxygen	mg/L	0.01
Temperature	ºC	0.1
Turbidity	NTU	0.1
Chloride	mg/L	1
Arsenic dissolved	µg/L	0.001
Arsenic total	µg/L	0.001
Iron dissolved	mg/L	0.01
Iron total	mg/L	0.01
Manganese dissolved	mg/L	0.005
Manganese total	mg/L	0.005
Magnesium total	mg/L	1
Potassium total	mg/L	1
Sodium total	mg/L	1
Calcium total	mg/L	1
Sulfate	mg/L	1
Sulfide	mg/L	0.01
Chloride	mg/L	1
Alkalinity	mg/L	1
Nitrate as N	mg/L	0.01
Total Kjeldahl Nitrogen	mg/L	0.1
Total Nitrogen	mg/L	0.5
Nitrite as N	mg/L	0.5
Silica	mg/L	1
Silicon	mg/L	1
Total organic carbon	mg/L	0.5

Table 3-2. Analysis for Samples collected During AWT Pilot Testing at HRSD's York River facility–Carbon-Based Recharge

Constituent	Units	PMCL
Total phosphorus	mg/L	0.1
Ortho-phosphate	mg/L	1
Total dissolved solids	mg/L	10
Total suspended solids	mg/L	1
Ammonia	mg/L	0.1
Total THMs	µg/L	1
Chloroform	µg/L	1
Bromoform	µg/L	1
Bromodichloromethane	µg/L	1
Dibromochloromethane	µg/L	1
Total HAA	µg/L	0.1
Uranium	µg/L	1
Nitrosamines	ng/L	1
Contaminants of Emerging Concern	ng/L	1
Bromide	pCi/L	1
Boron	µg/L	
Strontium	µg/L	
Be, Sb, Cd, Cr, Cu, Pb, Se, Th[1]	µg/L	
Carbon oxygen demand	mg/L	1

Note:

[1] Be = Beryllium, Sb = Antimony, Cd = Cadmium, Cu = Copper, Cr = Chromium, Pb = Lead, Se = Selenium, Th = thallium

3.1.2 Groundwater Characterization

Characterizing the chemical composition of NGW forms an essential element of evaluating the overall compatibility of recharge relative to both the NGW and the aquifer mineral content. Collecting field data to assess the chemical compatibility of the NGW in the PAS beneath SWIFT-JR- obtaining samples from the UPA, MPA, and LPA during packer tests, and from a sample collected near the end of the 24-hour constant rate aquifer test in well TW-4. Packer intervals spanned from 40 to 160 feet in length, testing one or two intervals in each aquifer, and totaling six tests (Table 3-3). Packer testing encompassed all ten screen intervals installed in TW-4 (Table 3-4).

Table 3-3. Analysis for Groundwater Samples collected Study at SWIFT-JR

Constituent	Units	MDL
pH	standard units	0.1
Eh (corrected)	mv	50
Specific Conductivity	emhos	10
Dissolved Oxygen	mg/L	0.01
Temperature	ºC	0.1
Turbidity	NTU	0.1
Field Sulfate	mg/L	5
Field Iron (ferrous	mg/L	0.01
Field Iron (total)	mg/L	0.01
Field Manganese	mg/L	0.01
Arsenic	mg/L	0.001
Chloride	mg/L	1
Field CO_2	mg/L	1
Aluminum dissolved	mg/L	0.01
Aluminum total	mg/L	0.01
Arsenic dissolved	ug/L	0.001
Arsenic total	ug/L	0.001
Iron dissolved	mg/L	0.01
Iron total	mg/L	0.01
Manganese dissolved	mg/L	0.005
Manganese total	mg/L	0.005
Magnesium total	mg/L	1
Potassium total	mg/L	1
Sodium total	mg/L	1
Calcium total	mg/L	1
Sulfate	mg/L	1
Sulfide	mg/L	0.01
Chloride	mg/L	1
Alkalinity	mg/L	1
Nitrate as N	mg/L	0.01
Total Kjeldahl Nitrogen	mg/L	0.1
Fluoride	mg/L	0.01

Table 3-3. Analysis for Groundwater Samples collected Study at SWIFT-JR

Constituent	Units	MDL
Silica	mg/L	1
Total organic carbon	mg/L	0.5
Total phosphorus	mg/L	0.1
Ortho-phosphate	mg/L	1
Total dissolved solids	mg/L	10
Total suspended solids	mg/L	1
Hardness	mg/L	10
Ammonia	mg/L	0.1
Total THMs	µg/L	1
Chloroform	µg/L	1
Bromoform	µg/L	1
Bromodichloromethane	µg/L	1
Dibromochloromethane	µg/L	1
Total HAA	µg/L	0.1
Uranium	µg/L	1
Gross Alpha	pCi/L	1
Gross Beta	pCi/L	1
Ra 226	pCi/L	1
Ra 228	pCi/L	1

Table 3-4. Packer Testing Intervals

Interval No.	Interval (feet below grade)	Date Tested	Aquifer
1	398 to 524	05/02/2019	UPA
2	570 to 636	05/06/2019	UPA
3	735 to 790	05/08/2019	UPA
4	960 to 1000	05/10/2019	MPA
5	1048 to 1122	05/15/2019	MPA
6	1240 to 1280	05/20/2019	LPA
24 hr CRT		12/18/2018	All aquifers

3.1.3 Aquifer Mineral and Clay Matrix Characterization

During drilling of the TW-4, drill cuttings were collected at 10-foot intervals through the total depth of the well boring and used to characterize the lithology with particular attention to grain size, color, sorting, texture, and mineralogy. Drilling the pilot boring was terminated upon encountering bedrock which consisted of siltstone metamorphosed to greenschist facies overlying gneiss. Basement core displayed numerous mineralized fractures displaying steeply dipping to vertical fracture surfaces. Many, but not every fracture surface contained sub-vertically plunging slickenlines.

In addition to drilling cuttings, the drilling contractor also collected cores in the PAS. Collecting 298 feet of core across the 892 feet of PAS section, coring focused on obtaining samples of aquifer sands. The drilling contractor employed a customized wire-line coring system that allowed coring discrete intervals along with advancing the borehole through conventional rotary drilling, instead of continuous coring. The method allowed recovering 207 feet of core for a 70 percent recovery efficiency. Eleven cores, each approximately 2.5 feet long, were submitted to Mineralogy Inc., a laboratory based in Tulsa, Oklahoma specializing in mineralogical and petrophysical analysis Table 3-5).

In addition to the boring log, the geologist prepared a graphic log of the well, based on the visual and laboratory analysis of core data. The graphic log shows the thickness of aquifer units and confining beds, salient grain size, and distribution of minerals. Contacts on the graphic log were coordinated with the geophysical log run upon reaching the total depth of the borehole at 1,314 feet below grade (fbg). Results from the mineralogical lab's analysis of the samples were added to the graphic log.

In addition to the graphic log, grain size distribution analysis GSD) conducted by the laboratory was applied in estimating the screen slot size and filter-pack grade for permanent MAR wells at SWIFT-JR. GSD analysis from a single core interval describes the grain size, sorting, shape, and texture of a sand interval Masch and Denny, 1986), along with facilitating the estimation of the transmissivity for individual aquifer intervals through special analytical techniques Hazen, 1893; Masch and Denny, 1986;). The sample volumes in a single core sample do not provide the aquifer volume to assess bulk transmissivity. However, GSD analyses help confirm the viability of transmissivity estimates through more conventional pump and packer testing techniques.

3.1.3.1 Mineralogical Laboratory Analysis

Following the logging of cuttings and cores, intervals were selected for mineralogical analysis by a specialty laboratory. A total of 11 core samples were selected over the sandy intervals of the three aquifers, comprising four samples each from the UPA and LPA, and three samples from the MPA. Samples were analyzed by x-ray diffraction (XRD) and energy dispersive x-ray EDX techniques to determine their mineralogical and elemental composition, respectively. Other analyses were selected according to the composition and hydrologic significance (aquifer sands, confining bed clay, intra aquifer clay, etc. of the samples.

In addition to XRD and EDX, aquifer sands underwent the following analyses:

- Quantitative thin section petrography (300-point count, and pore-filling composition)
- Grain size distribution (GSD analysis by laser particle analysis
- Specific gravity
- Cation exchange capacity (CEC)
- Acid insoluble analysis

Samples originating from less sand-rich intervals were analyzed for the following (plus XRD and EDX :

- Qualitative thin section petrography
- Scanning electron microscopy (SEM)
- CEC

Table 3-5. Selected Core Intervals and Mineralogical Analyses

	Core interval (fbg)				Analysis							
Sample No.	Top	Bottom	Aquifer	Screen Interval (#)	X-Ray Diffraction & Clay Fraction	Energy dispersive X-Ray Analysis	Compositional Petrographic Modal Analysis	Cation Exchange capacity	Laser Particle Size- English	Specific Gravity	Acid Insoluble Residue	Interpretive Report
1	427.5	428.6	UPA	1	X	X	X	X	X	X	X	[redacted]
2	491	492.9	UPA	2	X	X	X	X	[redacted]	[redacted]	X	[redacted]
3	578	579.6	UPA	3	X	X	X	X	X	X	X	[redacted]
4	637.5	640	UPA	4	X	X	X	X	[redacted]	[redacted]	X	[redacted]
5	779	781.5	UPA	6	X	X	X	X	X	X	X	[redacted]
6	886.5	889	MPA	Between Screens 6 & 7	X	X	X	X	[redacted]	[redacted]	X	[redacted]
7	912.5	915	MPA	Between Screens 6 & 7	X	X	X	X	X	X	X	[redacted]
8	974	976.5	MPA	7	X	X	X	X	X	X	X	[redacted]
9	1056	1058.5	MPA	8	X	X	X	X	X	[redacted]	X	[redacted]
10	1120	1122.5	MPA	9	X	X	X	X	X	X	X	[redacted]
11	1178	1180.5	LPA	Between Screens 9 & 10	X	X	X	X	X	[redacted]	X	[redacted]
[redacted]												

Note:
Core collected at the request of Virginia Department of Environmental Quality

3.1.3.2 Aquifer Mineral and Clay Matrix Characterization Evaluation

Evaluating aquifer samples included the following steps:

- Characterizing aquifer sand types according to the Folk classification system (Folk, 1965)
- Identifying reactive minerals in the aquifer and confining units
- Plotting the mineralogy on the graphic log of the test well
- Normalizing the clay mineralogy for aquifer sands and confining beds
- Applying a representative CEC to clay mineral suites.

Because disrupting clays in the PAS can profoundly influence injection operations, the last two steps held the greatest significance for formation samples from the SWIFT-JR. The clay mineralogy and CEC results helped constrain the input and interpretation of geochemical modeling results.

Clay mineral suites were normalized to 100 percent in the aquifer and confining bed samples, and then the mineral content by percentage was averaged between the UPA, MPA, and LPA. In the UPA and MPA at SWIFT-JR, the interstitial clay mineral suite in aquifer sand intervals exhibited a bi-modal distribution, with sodium-montmorillonite representing the predominating clay mineral. Kaolinite typified the prevailing clay mineral in cores collected at depths greater than 1,120 fbg primarily LPA .

CEC results were normalized across the section to obtain mean values for each aquifer unit, establish a relationship between CEC and clay content, and to investigate relationships between the magnitude of CEC and mineralogy in a sample. The approach helped identify the clay mineral(s that most influence the CEC of a sample.

3.1.3.3 Conventional Geochemical Analysis

Conventional geochemical analysis was employed using statistical, graphing, and plotting techniques on the recharge and native groundwater chemistry:

- Techniques used in describing predominant ionic species and the relationship between samples included:
  - Piper diagrams
  - Stiff diagrams
- Evaluating the oxidation-reduction (Redox potential of water samples included:
  - Redox diagrams
  - Redox constituent analysis
- Assessing the stability of clays and metal-bearing minerals (iron, manganese, aluminum, arsenic, etc.) in the PAS comprised employing the following techniques:
  - Parametric statistics
  - Correlation coefficients
  - Regression analysis
  - Phase diagrams

Piper and Stiff diagrams plot cation and anion equivalent concentrations either as percentages (Piper or absolute values (Stiff , to graphically display the predominant ionic species and the relationship between samples.

Redox line diagrams and the Jurgens et al. (2009) redox constituent analysis help describe redox conditions in the aquifer based on aqueous analysis. These techniques become particularly important when considering for example) the mobility of metals in the aquifer under changing redox conditions caused by recharging oxygen-rich water into a confined aquifer under anoxic conditions. Under the circum-neutral pH conditions found at SWIFT-JR, redox conditions control the mobility of iron and arsenic and the adsorption characteristics of aquifer minerals that can hinder arsenic mobility.

Phase diagrams were developed in assessing the stability of clays and metal-bearing minerals in the aquifer matrix. The program PHREEPLOT Kinniburgh, 2011) was used in preparing various types of phase diagrams. Linked to the geochemical model software PHREEQC (Parkhurst, 1996), PHREEPLOT can plot predominance area, log activities, log solubilities, H+ affinity and other thermodynamic properties on a two-dimensional graph.

3.1.4 Geochemical Modeling

Geochemical modeling was used in combination with water quality and mineralogy to perform the following activities:

- Simulate reactions between recharge water, native groundwater, and aquifer mineralogy
- Simulate aquifer conditioning techniques to stabilize minerals or complexes in situ
- Simulate pretreatment of the recharge

In simulating these activities, the geochemical modeling performed the following functions:

- Speciating ions and complexes
- Developing saturation indices for potential mineral phases
- Calculating ionic strengths of aqueous samples
- Calculating activities of constituents for plotting phase diagrams and calculating saturation indices
- Estimating the ionic content and saturation indices of minerals in equilibrium with mixtures of recharge and NGW.

The precipitation or dissolution of minerals was assessed based on their saturation indices (SI) displayed in the mixed-water samples. The SI of a mineral (Langmuir, 1997) determines whether the mineral occurs in equilibrium (SI=0.0) with a mixed water chemistry; is undersaturated (SI<0.0) and should dissolve if present; or is supersaturated (SI>0.0) and should precipitate. Estimation of saturation indices are usually not exact, often varying over ±0.3 units, depending on the composition of the solution. Moreover, SI's exceeding +0.3 suggests the mineral, if present, will not dissolve during the time frame of interest in this project. SI values falling below -0.3 infers the mineral is absent from the aquifer matrix.

Geochemical modeling of SI's proved particularly useful in identifying the potential presence of minerals not detected in XRD or petrographic analysis, because of the mineral's lack of crystallinity (amorphous phases , or because sampling did cover every inch of the PAS section. Amorphous minerals often reside in the interstitial spaces of aquifer sands. They often display a high degree of reactivity and, thus, can control NGW chemistry. Due to a lack of ordered, crystalline structure, amorphous minerals are commonly not detected by XRD or petrographic analyses.

3.1.4.1 Modeling Software Summary Description

PHREEQC, PHREEPLOT, and MINTEQA2 (Allison, 1991) were used in performing the geochemical modeling simulations. PHREEQC (Parkhurst, 1996), developed by the United States Geological Survey USGS), utilizes extensive thermodynamic databases to perform speciation and mineral phase calculations from user-entered water chemistry data. These calculations are useful in describing the geochemistry and estimating the mineralogy that influences the water quality. PHREEQC also performed numerous useful functions for evaluating the interactions between recharge and native groundwater at SWIFT-JR, including transport, mixing, cation exchange, surface complexation, simple chemical reactions, speciation, and inverse modeling.

MINTEQA2 was developed by the United States Environmental Protection Agency to perform equilibrium calculations on metals contaminating groundwater at RCRA and CERCLA sites. The program does not display the extensive capabilities of PHREEQC, but MINTEQA2 offers several functions that proved useful for evaluating surface complexation of metals in the PAS, including modules supporting cation exchange, and a wide range of surface complexation models Langmuir, Freundlich, Diffuse Double-Layer, Triple Layer and Constance Capacitance).

3.1.4.2 Modeling Approach

Modeling was accomplished utilizing a three-phased approach:

Phase 1 – Evaluating Recharge and Groundwater

The first modeling simulations were run using the analytical results from recharge and NGW samples as input. The modeling involved reacting minerals identified in the aquifer samples with constituents in the recharge like DO, nitrate, dissolved iron and others. The simulations helped characterize the mobility of common trace metals in the PAS during MAR. By identifying the metals that display greater mobility, through modeling the analyst can test the effectiveness of in situ pretreatment schemes in stabilizing minerals containing these metals.

Phase 2 – Mitigating metals mobilization

The process involved adding agents to the recharge water to precipitate minerals containing the targeted trace metals. Surface complexation functions were also employed in assessing the adsorption capacity of metal oxide surfaces developed from precipitating minerals composed of trace metals. Adsorption often exhibits greater effectiveness in fixing trace metals or stabilizing reactive metal-bearing minerals in situ than precipitation reactions. The following sequence describes the stepped approach applied to the second phase of modeling:

- React constituents in recharge water with NGW mixing) in the presence of aquifer minerals
- Test pretreatment schemes to stabilize dissolved trace metals and reactive metal-bearing minerals.
- Assess the capacity of metal oxide minerals to adsorb trace metals in aquifer environment

Phase 3 – Stabilizing clay minerals

The third phase of modeling involved evaluating the stability of clay minerals. Geochemical modeling helped establish the native stability of clay minerals in the PAS before and after recharge, but modeling added little to determining how changing the ionic strength of the recharge affected the stability of interstitial clays. Consequently, this critical portion of the evaluation relied on studies performed at other recharge sites.
The following sequence describes the approach for testing ion exchange conditioning schemes to assess which produces the greatest clay stability:

- Determine the native clay stability
- Evaluate clay mineral stability after recharge
- Apply clay mineral suites and CEC emerging from aquifer lab analysis
- Evaluate conditioning schemes with trivalent salts

4. Data Collection

Properly evaluating the hydraulic capabilities of TW-4 and the PAS, along with compatibility between recharge, NGW, and aquifer mineralogy required running an aquifer test program, obtaining samples of the plant effluent recharge water , collecting samples of NGW from each aquifer unit screened by the MAR test well, and collecting core and samples from the pilot boring, As HRSD has not yet conducted a pilot test for AWT nor constructed a permanent AWTP at SWIFT-JR, a representative plant effluent was mathematically simulated by HRSD using secondary effluent and how the chemistry was modified by the expected treatment processes including flocculation & sedimentation, ozonation, BAC, GAC, and disinfection UV and chloramines .

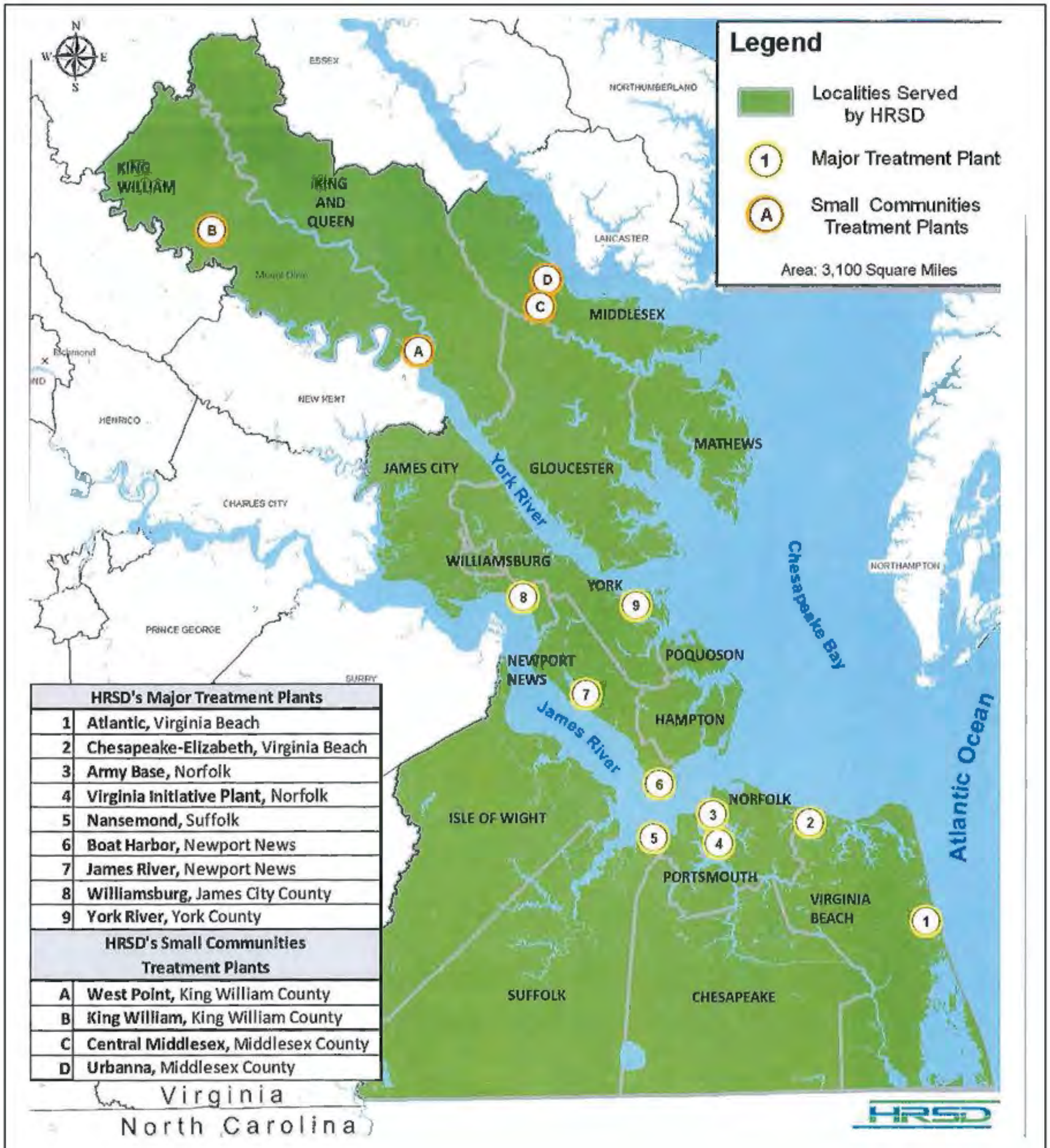
4.1 Test Well TW-4

A.C. Schultes, Inc. (Schultes of Waretown, Maryland drilled, installed, developed, and tested a MAR test well TW-4) at SWIFT-JR (Figure 4-1) between October and December 2018 Figure 4-2). TW-4 was installed to 1,290 fbg (Figure 4-3), fully penetrating the UPA, MPA, and LPA and encountering the bedrock basement. Excepting several thinner sand intervals that were not screened, screens fully penetrated the three aquifers and totaled 309 feet. Following development, TW-4 underwent a step-drawdown test, a 24-hour constant rate aquifer test, and packer testing at six depth intervals spanning the UPA 3), MPA (2), and LPA (1).

Schultes advanced the pilot boring, encountering competent bedrock at 1,314 fbg. Formation samples were collected as drill cuttings approximately every ten feet during drilling, while 298 feet of core was collected between 398 and 1,314 fbg. Schultes developed a wire line coring system specifically for the SWIFT program that allows drilling and coring at targeted intervals rather than the continuous coring usually employed in unconsolidated coastal plain sediments. Cores were collected exclusively from the Potomac Group formations.

To select accurate casing and screen elevations for TW-4, Schultes geophysically-logged the pilot borehole for natural gamma, spontaneous potential, short and long-normal resistivity, and single point resistance. TW-4 features single casing construction, consisting of 8-inch diameter black steel casing set to 398 fbg and then 309 feet of 8-inch diameter, 0.05-inch slot stainless steel, continuous wire wrap screen spanning the UPA 183 feet), MPA (86 feet) and LPA (40 feet), to 1,290 fbg. Eight-inch diameter, black steel blank casing separates the 10 screen intervals. Typical of sand intervals in the PAS, only one of the 10 exceeded 50 feet in thickness. The bottom of TW-4 contains a 10-foot long, 8-inch diameter, black steel sump. A US Silica Company Fil-Pro Grade Number 2 filter pack fills the annulus between the borehole wall and casing from 350 to 1,280 fbg.

TW-4 was developed using a combination of mechanical methods during December 2018. Schultes first applied a double-surge block in swabbing the well screens while airlift pumping to remove material brought into the well through swabbing. Starting from the deepest screen interval, they swabbed each 10 feet of screen for 30 minutes before moving up to the next interval. TW-4 was then pumped for several days at rates varying between 300 gpm and 700 gpm, before starting the pump testing program.



	HRSD's Major Treatment Plants
1	**Atlantic,** Virginia Beach
2	**Chesapeake-Elizabeth,** Virginia Beach
3	**Army Base,** Norfolk
4	**Virginia Initiative Plant,** Norfolk
5	**Nansemond,** Suffolk
6	**Boat Harbor,** Newport News
7	**James River,** Newport News
8	**Williamsburg,** James City County
9	**York River,** York County
	HRSD's Small Communities Treatment Plants
A	**West Point,** King William County
B	**King William,** King William County
C	**Central Middlesex,** Middlesex County
D	**Urbanna,** Middlesex County

Figure 4-1. HRSD Service Area Map
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f57_6X9315B.dgn

River SWIFT Tes

Figure 4-2. Site Map of SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f54_6X9315B.dgn

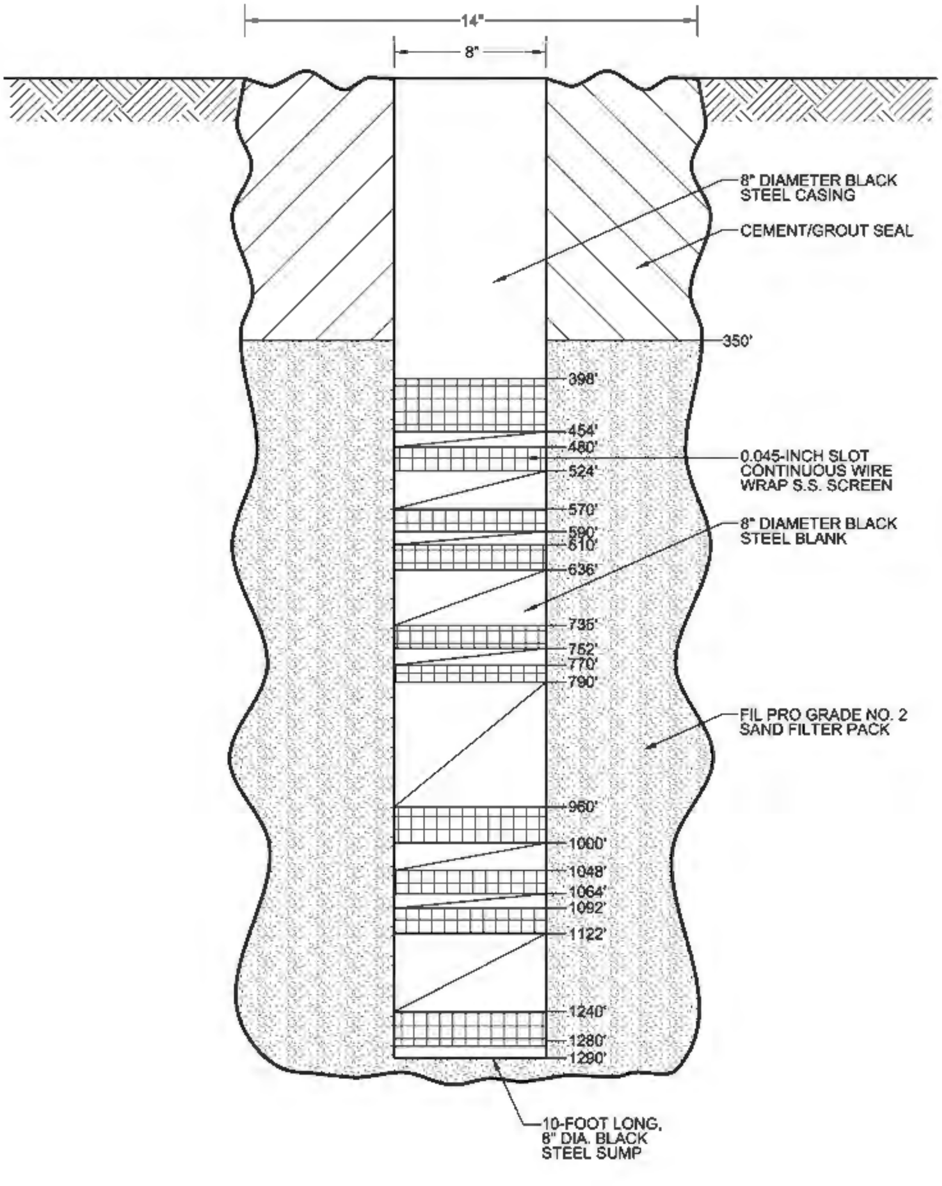


Figure 4-3. James River Test Well (TW-4) Design
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f55_6X9315B.dgn

4.2 Flow Rates during Aquifer Tests

TW-4 was equipped with a multiple stage, vertical turbine pump, installed to 300 feet below grade. The pump was driven with electrical power through a trailer-mounted portable generator. Pump and packer testing effluent was discharged to the head works of the SWIFT-JR. Field personnel measured pumping rates from a manometer tube mounted behind a 5 by 6-inch diameter orifice pipe and manually recorded the measurements. Also, pumping rates were measured from a McCrometer direct-read, propeller-style flowmeter.

4.3 Water Level Measurements

To measure water level fluctuations during each portion of the testing, a pressure transducer coupled to an automatic data logging unit was mounted in TW-4. Barometric pressure was measured with a pressure transducer mounted in the data logger. During pumping and recovery tests, the measurement frequencies and duration of the frequencies differed for each type of test. The drawdown portion of the step drawdown and packer tests were recorded at 1-minute intervals. Water level measurements during the drawdown portion of the 24-hour CRT and recovery intervals from the step drawdown, 24-hour CRT, and packer tests were recorded at a logarithmic frequency starting at ¼ second intervals and progressing to a 20-minute frequency by the end of the tests.

4.4 Step Drawdown Test

A four-interval step drawdown test was conducted on December 17, 2018. The test was run to establish baseline specific capacity and well losses at various flow rates and to determine the most efficient flow rate for the 24-hour, CRT test. The step drawdown test was run at four progressively increasing flow rates of 400, 500, 600, and 700 gpm for 60 minutes each.

During the step drawdown test, water level measurements were recorded at 1-minute intervals (linear format) for the drawdown portion of the test. Measurement frequency during the recovery portion of the step drawdown test involved a logarithmic format starting at ¼ second intervals and progressing to a 20-minute frequency by the end of the tests.

4.5 Constant Rate Aquifer Test

4.5.1 24-Hour CRT

The 24-hour CRT was conducted from December 18 to 19, 2018 and consisted of drawdown and recovery periods. During drawdown period, TW-4 was pumped at 600 gpm. Measurements were recorded at a logarithmic frequency during the drawdown and recovery portions of the 24-hour CRT. During the recovery period, water levels in TW-4 was recorded until water levels recovered to 95% of the static water level.

4.5.2 Packer Testing

Packer testing was conducted in six intervals in TW-4 between May 2 and 20, 2019 (Figure 4-4). Four of the six packer tests involved positioning and inflating two packers to isolate an individual interval. The deepest and shallowest zones were tested by inflating the top or bottom packers, respectively.

The drawdown portion of each test consisted of two segments. The first segment entailed running a step drawdown test consisting of 15-minute intervals conducted at incrementally increasing rates. Steps were performed at pumping rates of 10, 30, 50, 70, to 90 gpm. The pumping rate reached 90 gpm during the final step in all 6 testing intervals. After reaching the greatest pumping rate following five to six steps, the highest rate was maintained for two hours, and comprised the second portion of the test. After pumping at the highest achievable rate for two hours, the pump was turned off and recovering water levels were recorded. Recovering water levels were recorded at a logarithmic frequency, starting at 4 measurements per second and progressing to one measurement every 20 minutes. Recovering water levels were recorded overnight, before Schultes deflated the packers and positioned them at the next testing interval.

4.6 Recharge Water

In the absence of samples from a pilot or permanent AWT facility, the chemistry of recharge was estimated by HSRD through computer modeling of the treatment of secondary treated wastewater from the SWIFT-JR using carbon-based treatment. Simulated treatment processes comprised, in sequential order, sedimentation and flocculation, ozonation, BAC, granulated activated carbon (GAC), UV, and disinfection using mono-chloramine. HSRD analysts confirmed the accuracy of estimated chemistry by comparing the simulated results to BAC effluent observed during the pilot testing conducted at HRSD’s York River facility in 2016 (Table 4-1).

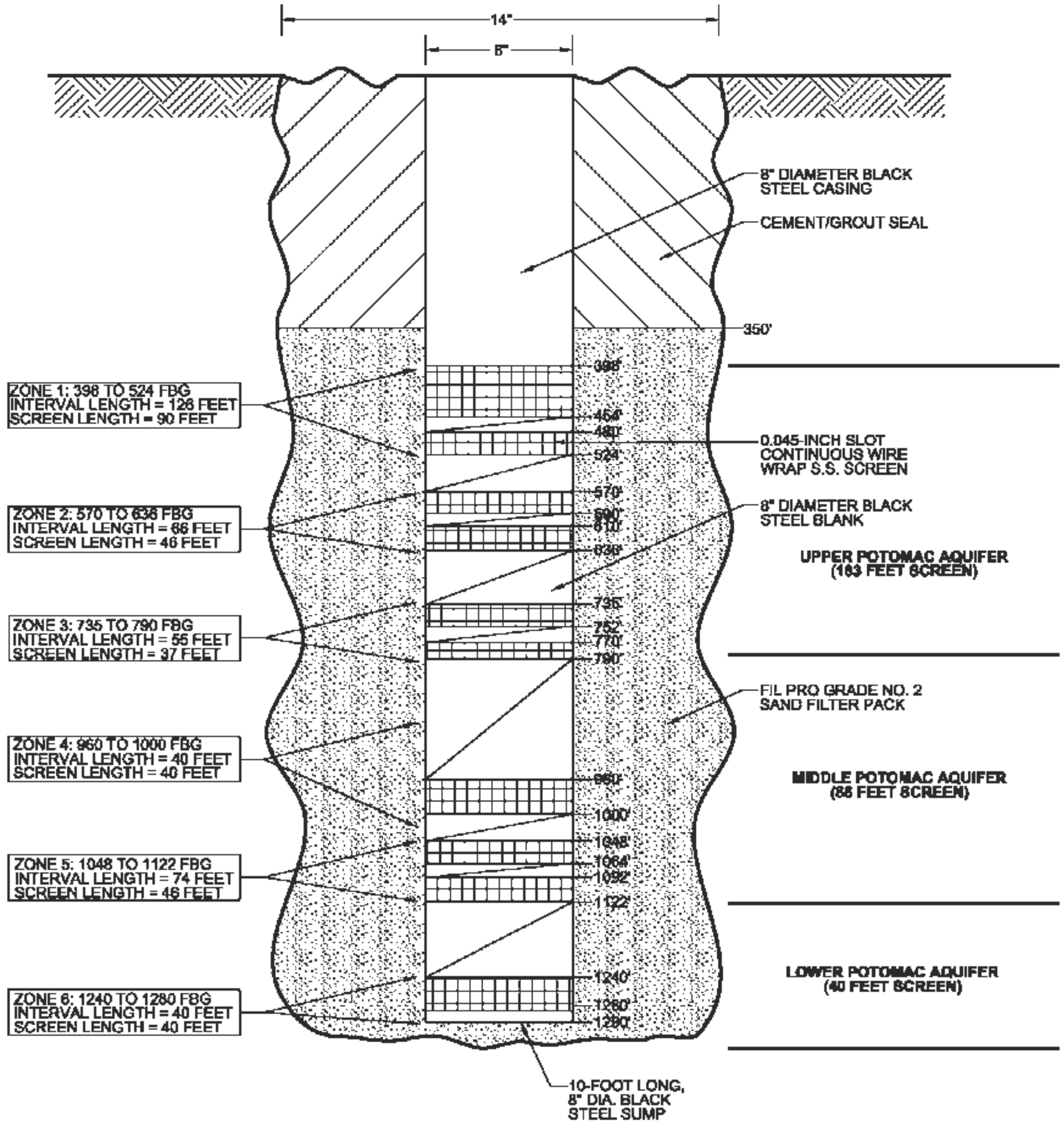
4.7 Groundwater Data

Six groundwater samples were collected at TW-4 during packer tests conducted in isolated intervals measuring from 40 to 126 feet in length. Screen lengths within the packer intervals ranged from 40 to 90 feet, while the remainder consisted of blank sections. A total of six intervals isolated by packers spanned the UPA three), MPA two), and LPA one).

In addition to the six water quality samples collected during the packer tests, one sample was collected at the end of the pumping period of the 24-hour CRT. The sample collected at the end of the CRT represented a mixture of NGW from the three aquifers, providing a useful check on the bulk chemistry from each aquifer, but does cannot substitute for the packer testing samples. HRSD analytical laboratory analyzed NGW samples from the 24-hour CRT and packer tests (Table 4-1).

4.8 Aquifer Mineral Data

While drilling the pilot boring for TW-4, the drilling crew collected cuttings at 10-foot intervals through the total depth of the well boring and 298 feet of core between 390 and 1,314 fbg. Ditch samples were cleaned, and then a 200-gram aliquot was spread across a paper sheet covering the ground surface to ease lithologic logging. Field personnel stored the remaining sample material in 1-quart jars. HQ-gauge core samples were processed in 2.5-foot lengths. Cores were laid in 3-inch diameter PVC pipe and covered with plastic wrap and then slid into thicker gauge plastic. Field personnel marked both coverings with the name of the boring, depths, date, and direction to the core top. A Jacobs geologist logged the lithology of the cuttings and core. Logging focused on the grain size, color of the sediments, sorting, and mineralogy.



TOTAL SCREEN LENGTH = 309 FT

Figure 4-4. James River Test Well (TW-4) Design Showing Packer Intervals
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DENT WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X3159 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | 	fig_6X3159.dgn

River SWIFT Tes

Table 4-1. Summary of Field, Laboratory, and Estimated Recharge and NGW Chemistry

Test Intervals Constituent	Units	72-HR CRT 12/19/2018	Packer Test #1 (398 to 524 fbg$^)$ 5/2/2019	Packer Test #2 (570 to 636 fbg) 5/6/19	Packer Test #3 (735 to790 fbg) 5/8/19	Packer Test #4 (960 to 1000 fbg) 5/10/19	Packer Test #5 (1048 to 1122 fbg) 5/15/19	Packer Test #6 (1240 to 1280 fbg) 5/20/19	Estimated Recharge Chemistry (BAC) 1/6/15	Pilot test at York River (BAC)	Primary Maximum Contaminant Limit
pH	standard units	6.32	6.76	7.71	6.14	7.22	7.26	7.62	7.8	6.96	6.5 o 8.5
ORP^3	mV	54.9	-133.8	-95	-70.3	-108	-103.2	-99.6	NA		
Eh corrected ^{4}	mV	254.9	66.2	105	129.7	92	96.8	100.4	NA	471	
Specific Conductivity	ms/cm	3.113	4635	4088	10120	6230	15370	16230	NA	21.580	
Dissolved Oxygen	mg/L	2.89	4.77	7.49	11.37	7.4	0.1	0.43	NA		
Temperature	ºC	20.27	25.97	23.57	26.77	25.87	25.8	26.59	22	28.4	
Turbidity	NTU	1.51	1.63	2.12	5.53	0.52	0.43	6.19	[illegible]	0.2	
Field Chloride	mg/L	NM	58	58	51	51	51		NA		
Field Carbon Dioxide	mg/L	NM	NM	NM	NM	NM	NM	NM	NA	21.8	
Field Sulfide as S	mg/L	0	0	0	0.04	0	0	0.01	NA	<0.1	
Field Sulfate as SO$_4$	mg/L	58	70	69	106	90	104	183	NA		
Field Iron (ferrous as Fe $^{2+}$	mg/L	0.22	2.35	2.31	1.35	1.34	2.07	2.22	NA		
Field Iron (total)	mg/L	0.91	2.04	2.01	1.7	1.79	2.22	3.14	NA		
Field Alkalinity as CaCO$_3$	mg/L	54	69	500?	105	880	920	820	NA	110	
LAB											
Aluminum dissolved	mg/L	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010	0	<0.04	0.1
Aluminum total	mg/L	0.063	<0.010	0.014	0.036	<0.010	<0.010	<0.010	NE	<0.04	0.1
Arsenic dissolved	mg/L	<1.00	0.25	<0.50	<0.50	<0.50	0.27	<0.50	0.7		0.01
Arsenic total	mg/L	<1.00	0.24	<0.50	<0.50	<0.50	0.27	<0.50	NE		0.01
Iron dissolved	mg/L	0.203	2.49	2.74	1.39	1.46	2.07	2.28	2	0.021	0.3
Iron total	mg/L	0.241	2.45	2.79	1.58	1.48	2.05	2.25	NE	0.0	0.3
Manganese dissolved	mg/L	0.0217	0.0518	0.0575	0.0527	0.0533	0.0829	0.142	NE	0.012	0.05
Manganese total	mg/L	0.0226	0.0504	0.0581	0.0539	0.0542	0.0852	0.142	NE	0.012	0.05
Magnesium total	mg/L	4.78	6.71	6.93	9.00	10.6	15.8	25.6	3.6	8.30	
Potassium total	mg/L	15.4	19.6	19.6	20.4	24.6	29	36.9	13	14.0	
Sodium total	mg/L	777	970	979	1060	1240	1500	1930	68	118.0	
Calcium total	mg/L	13.2	19.8	20.7	25.4	29.6	42.1	63.8	34	52	
Sulfate	mg/L	70.3	90.6	91.6	119	126	175	275	32	93	250
Chloride	mg/L	825	1460	1490	1770	1830	2290	3070	109	151.00	250
Alkalinity	mg/L	326	273	265	258	240	222	217	38	110	
Nitrate/Nitrite-N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.7	<0.01	
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.1	2.72	10
Total Kjeldahl Nitrogen	mg/L	0.52	0.69	0.66	0.78	0.79	0.92	1.03	2.6	1.19	
Fluoride	mg/L	2.16	0.913	0.920	0.863	0.793	0.601	<0.500	NE	0.57	4

Table 4-1. Summary of Field, Laboratory, and Estimated Recharge and NGW Chemistry

Test Intervals Constituent	Units	72-HR CRT 12/19/2018	Packer Test #1 (398 to 524 fbg) 5/2/2019	Packer Test #2 (570 to 636 fbg) 5/6/19	Packer Test #3 (735 to790 fbg) 5/8/19	Packer Test #4 (960 to 1000 fbg) 5/10/19	Packer Test #5 (1048 to 1122 fbg) 5/15/19	Packer Test #6 (1240 to 1280 fbg) 5/20/19	Estimated Recharge Chemistry (BAC) 1/6/15	Pilot test at York River (BAC)	Primary Maximum Contaminant Limit
Silica as SiO_2	mg/L	25.5	38.5	38.1	36.6	40.5	39.4	33.9	NE		
Silicon as Si	mg/L	11.9	18.0	17.8	17.1	18.9	18.4	15.8	NE		
Dissolved organic carbon	mg/L	0.16	0.13	0.11	<0.10	0.21	0.14	0.13	2	1.8	
Total organic carbon	mg/L	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	2	2.000	
Total phosphorus	mg/L	0.20	0.14	0.17	0.17	0.13	0.08	0.04	0.5	0.01	
Ortho-phosphate as P	mg/L	0.19	0.04	0.03	0.05	0.02	0.02	0.01	NE	0.05	
Total dissolved solids	mg/L	1880	2990	3060	3470	3590	4460	5800	420	525	
Total suspended solids	mg/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	0.05		
Hardness, Total	mg eq	52.6	77.1	80.2	100	118	170	265	99		
Ammonia as N	mg/L	0.44	0.56	0.54	0.60	0.61	0.86	0.91	0.52	<0.02	
BOD5	mg/L	<2	<2	<2	<2	<2	<2	<2	1		
COD	mg/L	<9.0	<12.0	<12.0	<12.0	<12.0	<15.0	<15.0	NE	7.2	
Gross Alpha	pCi/L	9.3	6.8	9.7	13	14	14	16	NE		15
Gross Beta	pCi/L	15	16	23	27	27	28	30	NE		
Ra 226 + Ra 228	pCi/L	1.1	ND	ND	1.4	1.6	4.8	8.8	NE		5
Uranium	ug/L	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.500	NE		30
Calculated species											
Ionic strength	mol/L	0.047	0.07475	0.0765	0.08675	0.08975	0.1115	0.145	0.0105	0.013125	
Ionic balance (Stuyfzand, 1993)	%	4.3	5.5	5.7	9.3	2.8	2.3	3.6	6.6	2.2	
Ca + Mg/Na + K	meq/L ratio	0.028	0.025	0.027	0.031	0.029	0.052	0.063	0.597	0.664	
Organic phosphorous	mg/L	0.137	0.127	0.160	0.153	0.123	0.073	0.037	NE	NE	
Organic nitrogen	mg/L	0.08	0.13	0.12	0.18	0.18	0.06	0.12	2.08	NE	

Notes:

[1] CRT = constant rate test
[2] fbg = feet below grade
[3] ORP = oxidation/reduction potential
[4] Eh = ORP + 200 mV
NA = Not applicable
NE = Not calculated for recharge water
NM = Not measured

In addition to the boring log, the geologist prepared a graphic log of the well boring showing the thickness of aquifer units, confining beds, salient grain size, and distribution of minerals (Figure 4-5). Contacts on the graphic log were coordinated with the geophysical log, which was run upon reaching the total depth of the borehole. Important minerals, identified by analysis of the samples selected for laboratory mineralogical analysis, were added to the graphic log.

Following the logging of cuttings, 11 intervals were selected for mineralogical analysis by Mineralogy, Inc., a laboratory specializing in mineralogical and petrophysical analysis located in Tulsa, Oklahoma. The laboratory analyzed all samples for bulk and clay fraction by x-ray diffraction (XRD) and energy dispersive x-ray EDX analysis in determining their mineralogical and elemental composition, respectively. Then samples underwent supporting analyses according to their composition and hydrologic significance (aquifer, confining bed, intra aquifer clay, etc.).

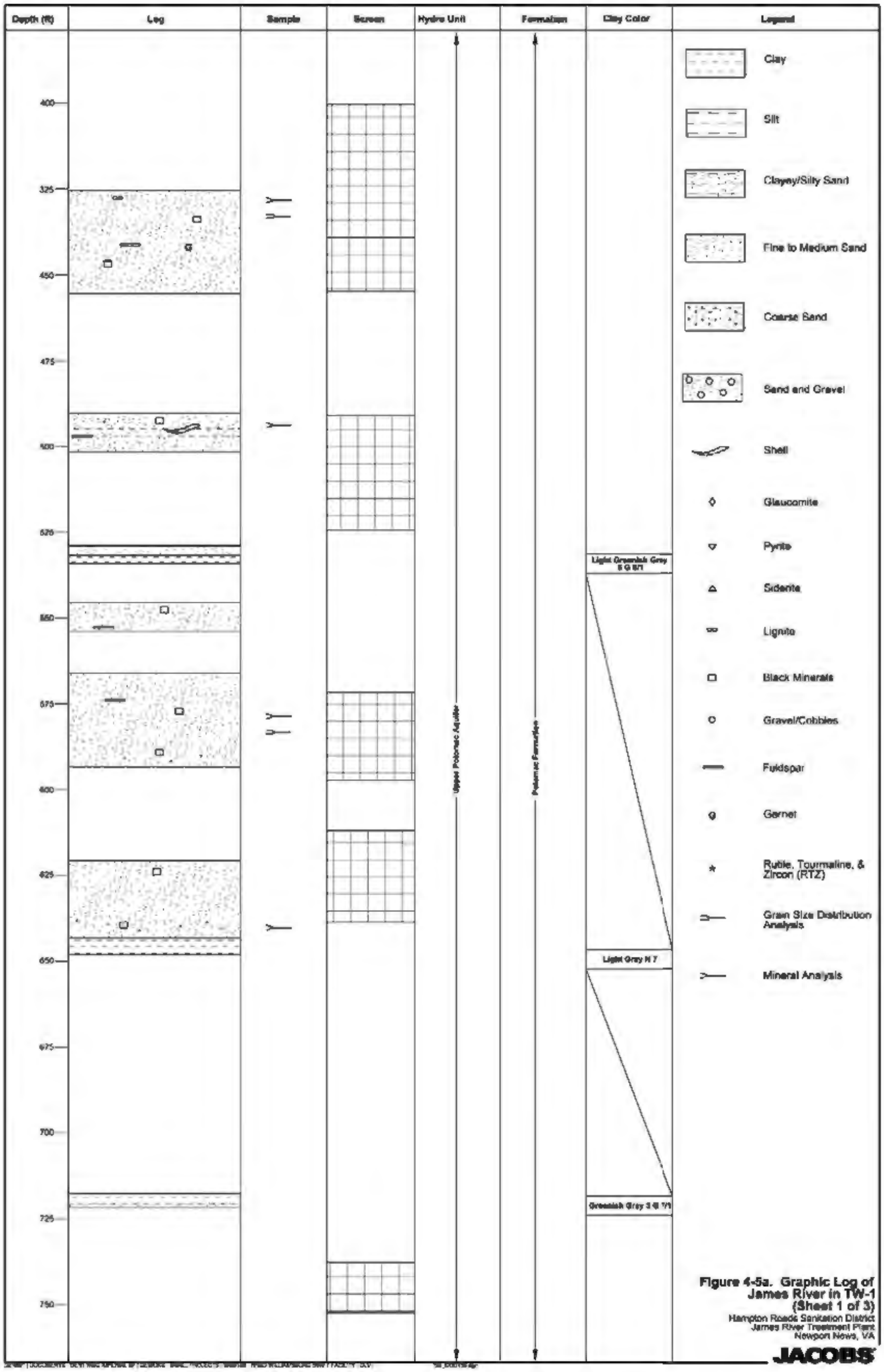


Figure 4-5a. Graphic Log of James River in TW-1 (Sheet 1 of 3)
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

River SWIFT Tes

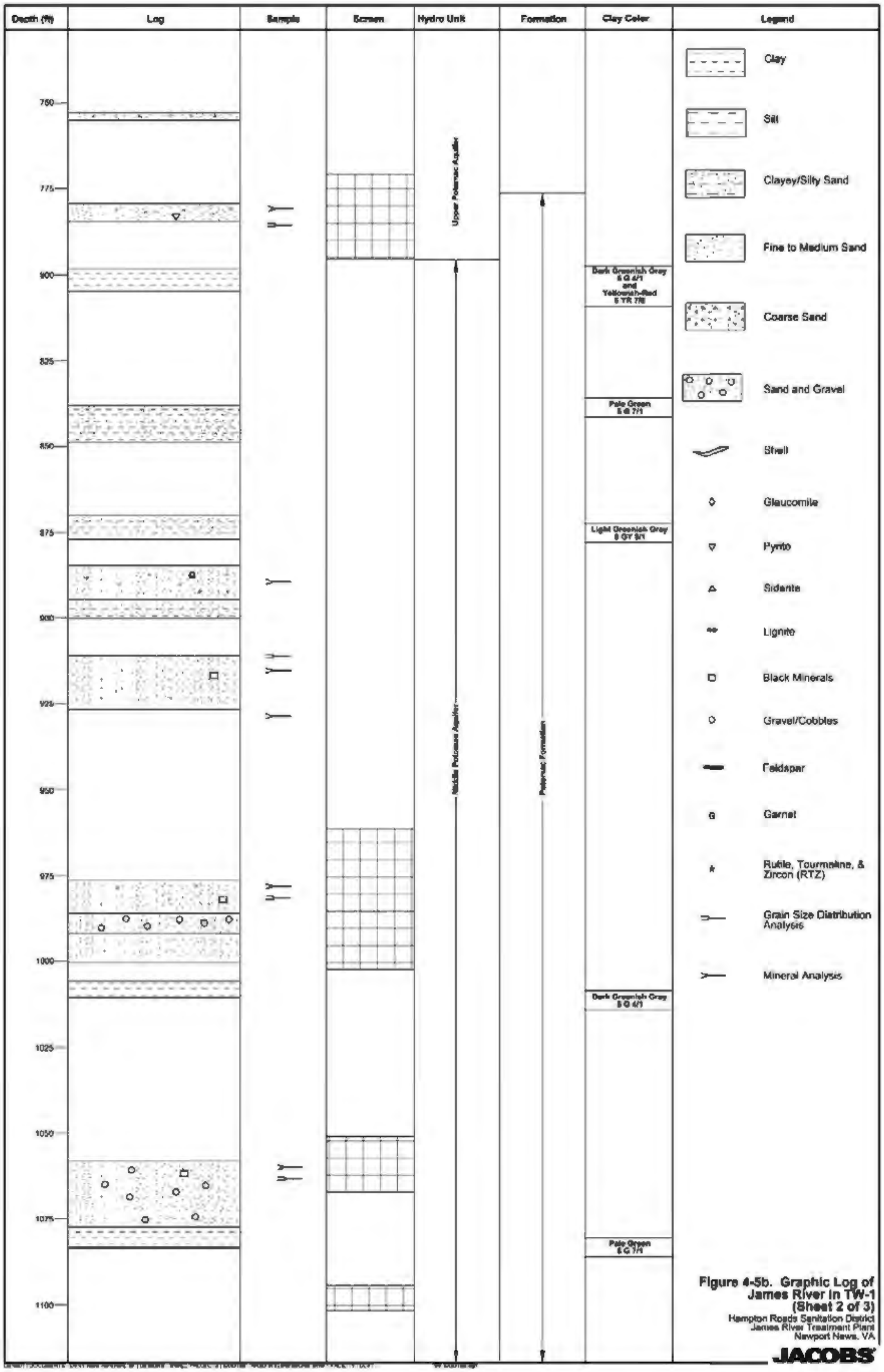


Figure 4-5b. Graphic Log of James River in TW-1 (Sheet 2 of 3)
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

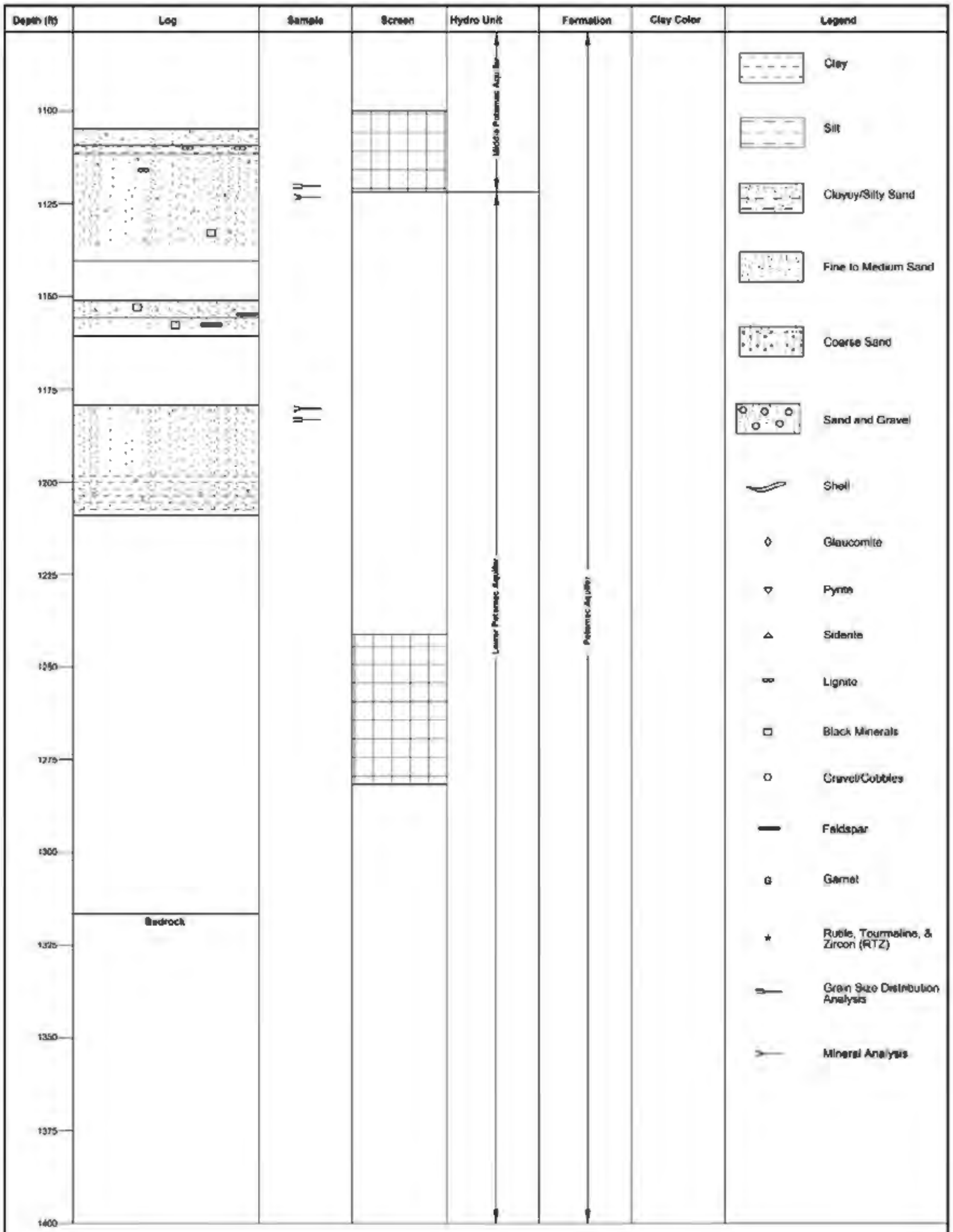


Figure 4-5c. Graphic Log of James River in TW-1 (Sheet 3 of 3)

Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

River SWIFT Tes

5. Estimating Aquifer Hydraulic Coefficients

5.1 Introduction

Section 5 describes the evaluation of data measured during the step drawdown, 24-hour CRT, and six packer tests. The tests were conducted to characterize baseline well parameters and hydraulic coefficients from the PAS and groups of sand intervals from the UPA, MPA, and LPA.

5.2 Step Drawdown Test

Step drawdown tests establish baseline hydraulic characteristics for a well while helping track long-term well performance. Thus, when operating a managed aquifer recharge (MAR) well, step drawdown tests support determining when invasive rehabilitation measures are required. Operators should run step drawdown tests at regular intervals to quantify well degradation over time, and subsequently develop measures to prevent or arrest declining well performance.

Important baseline well performance parameters include: specific capacity, specific discharge, well efficiency, well skin coefficient (well losses to laminar aquifer flow), and well loss losses to turbulent flow . Two methods help in estimating these characteristics. First, applying the Bierschenk (1964) method helped characterize specific capacity, specific discharge, well skin and well losses Figure 5-1). Second, well efficiency was determined by calculating theoretical drawdown values for TW-4 at each step using the Cooper Jacob 1946) equation and dividing by the observed drawdown for each step.

The specific capacity of a well represents its yield per unit of drawdown. Specific capacity depends on the transmissivity of the aquifer, pumping rate, pumping time, and efficiency of the well's design. To discriminate between the two indices, the specific capacity when during recharge is called injectivity in this report. In the Atlantic Coastal Plain aquifers injectivity falls to between 50 to 65 percent of the pumping specific capacity Pyne, 2005) when operating at identical flowrates and durations. As an example, when new, TW-1 at HRSD's SWIFTRC facility displayed specific capacity and injectivity values of 40 and 24 gpm/ft, respectively at 700 gpm, after 24 hours of continuous operation.

The baseline specific capacity of TW-4 determined from four steps averaged 12.1 gpm/ft (Table 5-1).
The specific capacity decreased as flow rate increased (each step) throughout the test, as expected from a properly developed, efficient production well. The specific capacity during the final step, conducted at 700 gpm, registered around 10.7 gpm/ft.

5.2.1 Bierschenk Analysis

Step drawdown test data are often evaluated using the Bierschenk method to graphically estimate head loss in the pumping well caused by laminar (skin coefficient) flow in the aquifer and turbulent flow in the well (well loss . Head loss from flow through the aquifer BQ is found by reading the Y intercept (B) of the line formed by an approximation of the plotted points from each step multiplied by the flow rate (Q). Well loss (CQ^2 describes the slope of the line (C) multiplied by the flow rate squared (Q^2 . Based on the assumptions of Bierschenk, total head loss s is governed by the following:

$$s = BQ+CQ^2 \text{ , or } s/Q \quad B+CQ$$

The Bierschenk analysis assumes that the BQ term is laminar and originates from the aquifer, whereas the CQ^2 term describes turbulent flow originating from the frictional head losses through the well screen. Occasionally, a highly efficient well may exhibit a high well loss (turbulent) coefficient, a misleading drawback inherent with Bierschenk analyses. The relationship between laminar flow in the aquifer and head loss in the well due to turbulence appears in skin and well loss coefficient values from TW-4 (Table 5-1). The laminar flow term for each step correlates with the well efficiency, and the loss to laminar flow decreases with each step, while well losses increase.

The Bieschenk method provides a technique for estimating hydraulic losses in a pumping or injection well from step drawdown test data. Applying the Bierschenk analysis, drawdown at the end of each step is divided by flow rate (s/Q . Then, s/Q in feet per gallons per minute (ft/gpm is plotted on the Y-axis against the flow rate (Q on the X-axis (Figure 5-1). With this plot, the slope of the regression line and the y-intercept determine the C and B terms from the equation above.

5.2.2 Projecting Step Testing Results to Operational MAR Wells

Hydraulic coefficients like specific capacity and specific injectivities obtained from an 8-inch diameter borehole drilled with mud typically increase by 2.5 to 3.0 times upon installing the full-size production or MAR well Driscoll, 2005). Thus, a 24-inch MAR well should display a specific capacity around 30 gpm/ft. Applying a ratio of 0.65, consistent the relationship between injectivity and specific capacity in MAR wells screened in the Atlantic Coastal Plain aquifers results in an injectivity of around 20 gpm/ft.

Operating at a recharge rate of 1,400 (2 MGD , the drawup should rise about 70 feet above the static water level of 114 fbg, yielding an injection level 44 fbg. Safe design practice requires maintaining a well's drawup/ drawdown values below 100 feet. Draw-up in operational MAR wells at SWIFT-JR should fall below the safety threshold.

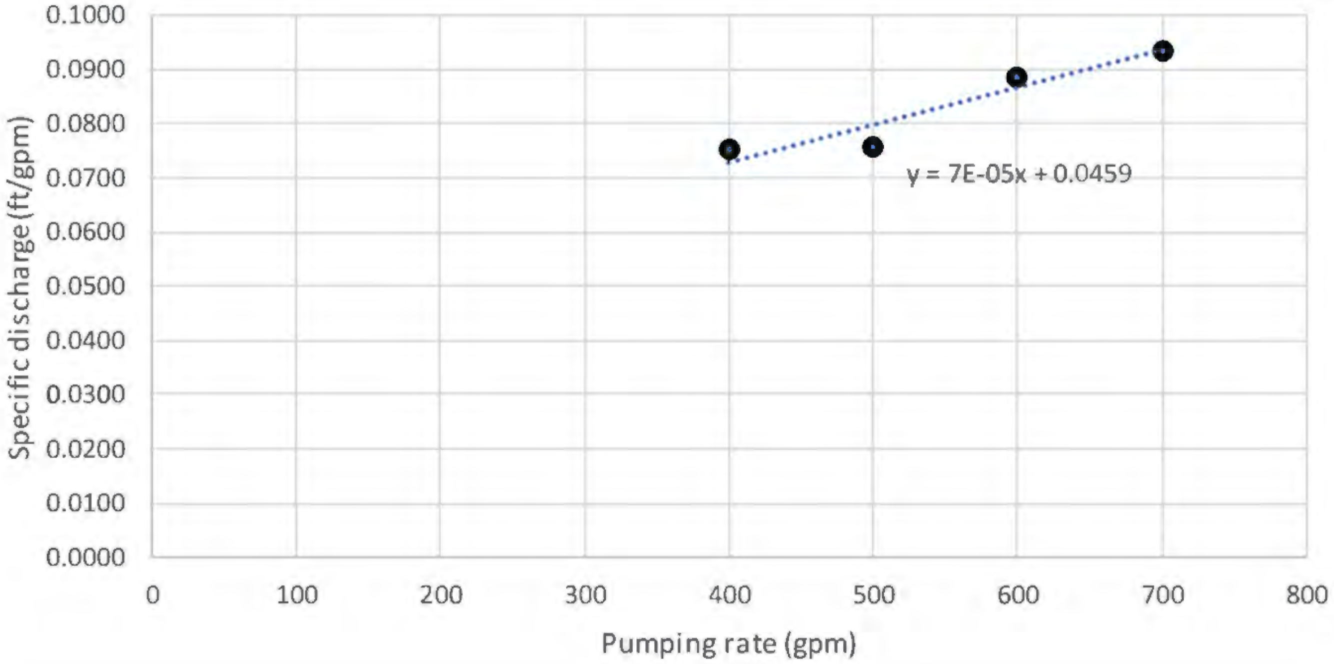


Figure 5-1. Bierschenk Analysis of Step Drawdown Test at TW-4

Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f51_6X9315B.dgn

Table 5-1. Summary of Step Drawdown Test Results

Static Water Level 114.16 feet below grade

Step No.	Pumping Rate (gpm)	Pumping Level (feet)	Drawdown (feet)	Specific Capacity (gpm/ft)	Specific Discharge (ft/gpm)	Skin Coefficient BQ (feet)	Well Loss CQ2 (feet)	Caused by Laminar Flow (%)
1	400	144.2099	30.0499	13.31	0.0751	18.36	11.20	61.10
2	500	152.1305	37.9705	13.17	0.0759	22.95	17.50	60.44
3	600	167.2759	53.1159	11.30	0.0885	27.54	25.20	51.85
4	700	179.68	65.52	10.68	0.0936	32.13	34.30	49.04
C	0.00007							
B	0.0459		average	12.11	gpm/ft			

5.3 Constant Rate Test

Data were evaluated from TW-4 from the drawdown and recovery periods of the 24-hour CRT to determine baseline aquifer hydraulic characteristics. The pumping rate during the 24-hour CRT ranged between 595 and 605 gpm. Water level data from the tests were analyzed by two methods:

- Cooper and Jacob (1946)
- Theis (1935) recovery method

The computer software AQTESOLV (Duffield, 2013) was applied to estimate hydraulic parameters from the 24-hour CRT field series data.

5.3.1 Results of Analyses

Transmissivity values calculated by the Cooper and Jacob straight-line, and Theis recovery methods for drawdown and recovery data for the 24-hour constant rate aquifer test ranged between 10,800 and 27,000 feet squared per day (ft^2/d). Because of the absence of well loss issues, recovery series data proves more useful for estimating transmissivity from single well tests. During the 24-hour CRT, the transmissivity estimated from recovery-series data averaged 26,000 ft^2/d (Table 5-2). The specific capacity in TW-4 at 600 gpm, near the end of the 24-hour pumping period, equaled 8.94 gpm/ft. Typical for drawdown and recovery data from pumping wells, the storage coefficients produced during the analysis ranged unrealistically and were not considered accurate. Assuming a sand thickness equivalent to the total screen length (309 ft), the PAS exhibits a hydraulic conductivity around 84 feet per day (ft/d).

Table 5-2. Estimates of aquifer transmissivity for 24-hour constant rate aquifer testing

Drawdown (ft^2/d)		Recovery (ft^2/d)		
Cooper-Jacob	Theis	Cooper-Jacob	Theis	Theis t/t'
12,260	10,780	26,480	26,480	25,000
Average of recovery analysis ft^2/d)		25,990		

5.4 Packer Testing

Specific capacity values calculated near the end of each packer test, ranged from 0.9 gpm/ft to 5 gpm/ft from zones screening the LPA and UPA, respectively. Pumping rates attained during each packer test ranged from 91 to 94 gpm.

Transmissivity of individual sand units was estimated using recovery data from each packer test. Considering individual intervals, the average transmissivity ranged from 400 ft^2/d in the LPA to 9000 ft^2/d in the shallow interval of the UPA (Table 5-3). When added together, transmissivities from each packer interval approximated the recovery-derived transmissivities determined from the 24-hour CRT. Hydraulic conductivities in the UPA, MPA, and LPA averaged 88, 74, and 10 ft/d, respectively.

Given the depth to the LPA at SWIFT-JR, its interbedded character featuring relatively thin sand units, and relatively low transmissivity, the LPA seems unsuitable as an effective MAR aquifer. Previous experiences in similar units have shown these low permeability units accept little recharge during MAR operations CH2M HILL, 1994, CH2M HILL, 1996, CH2M HILL, 2003). Considering these factors, permanent MAR wells a SWIFT-JR should screen only the UPA and MPA.

The absence of a viable LPA at SWIFT-JR should prompt a reduction in recharge rates from the 3 MGD originally assumed per each MAR well during planning studies. Projections based on the step testing results suggested that recharging at 1,400 gpm should reduce drawup below the 100- foot threshold usually applied to MAR wells in the Atlantic Coastal Plain aquifers.

Table 5-3. Hydraulic Results from Packer Testing at TW-4

									Transmissivity				
Packer Zone	Top (fbg)	Bottom (fbg)	Screen Zones	Zone Length (feet)	Screen Length (feet)	Aquifer Unit	Final Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Theis (ft2/day)	Cooper Jacob (ft2/day)	Theis t/t' (ft2/day)	Average per aquifer sand (ft2/day)	Hydraulic conductivity per aquifer (ft/day)
1	398	524	2	126	100	UPA	94	4.98	8012	8000	10900	9500	110
2	570	636	2	66	46	UPA	91	2.31	2900	1400	3700	2700	60
3	735	790	2	55	37	UPA	93	4.19	220	7400	7100	4900	130
4	960	1000	1	40	40	MPA	93	3.88	4500	4500	4500	4500	110
5	1048	1122	2	74	46	MPA	93	2.37	200	2400	3000	1900	40
6	1240	1280	1	40	40	LPA	93	0.92	100	430	530	400	10

Note:

Total transmissivity from Packer Tests ~ 19,400 ft^2/d.

5.5 Grain Size Distribution Analysis

Mineralogy Inc. measured the grain size distribution (GSD) in 6 of 11 cores using laser particle size analysis. Several methods estimate hydraulic conductivity using GSD analyses from undisturbed, unconsolidated samples. Using the GSD from cores at SWIFT-JR, the Hazen (1893) and Masch Denny (1966) methods were applied to estimate the hydraulic conductivity of sands contained in each core interval. Hydrogeologists commonly use these methods in the absence of aquifer testing (Eggleston and Rojstaczer, 2001) or other techniques. Practitioners of MAR in the Netherlands prefer using GSD techniques to derive hydraulic conductivity because they also reveal information on the average particle

Hazen’s method assumes the sample consists of medium sand and contains little gravel or finer particles. By contrast, Masch and Denny’s method accounts for a wide range of particle sizes. Thus, the Masch and Denny method accounts for the sorting of the sampling. Masch and Denny developed a set of curves based on Ó1. The D50 of the sample is compared against the curves to derive a hydraulic conductivity Table 5-4) in gallons per day per foot squared (gal/day-ft^2 and then converted to ft/d. d50 values in TW-4 for the cores ranged between a medium or coarse sand, a favorable characteristic for MAR operations.

Transmissivities estimated by the Hazen (31,100 ft^2/d) and Masch & Denny (36,600 ft^2/d) methods exceeded the average aquifer testing coefficient (26,000 ft^2/d) from the 24-hour constant rate pumping test by 5,000 to 10,000 ft^2/, respectively. Yet, the Hazen and Masch & Denny Methods represent empirical methods, relying on a small sample population that may not represent the bulk hydraulic conductivity of the aquifer. Core samples are often selected for analysis because they display visually favorable grain size and textural (sorting, fine content, sphericity, etc.) characteristics, further biasing results. Whereas, aquifer tests like the 24- hour CRT, and even packer tests stress a much greater volume of the aquifer.

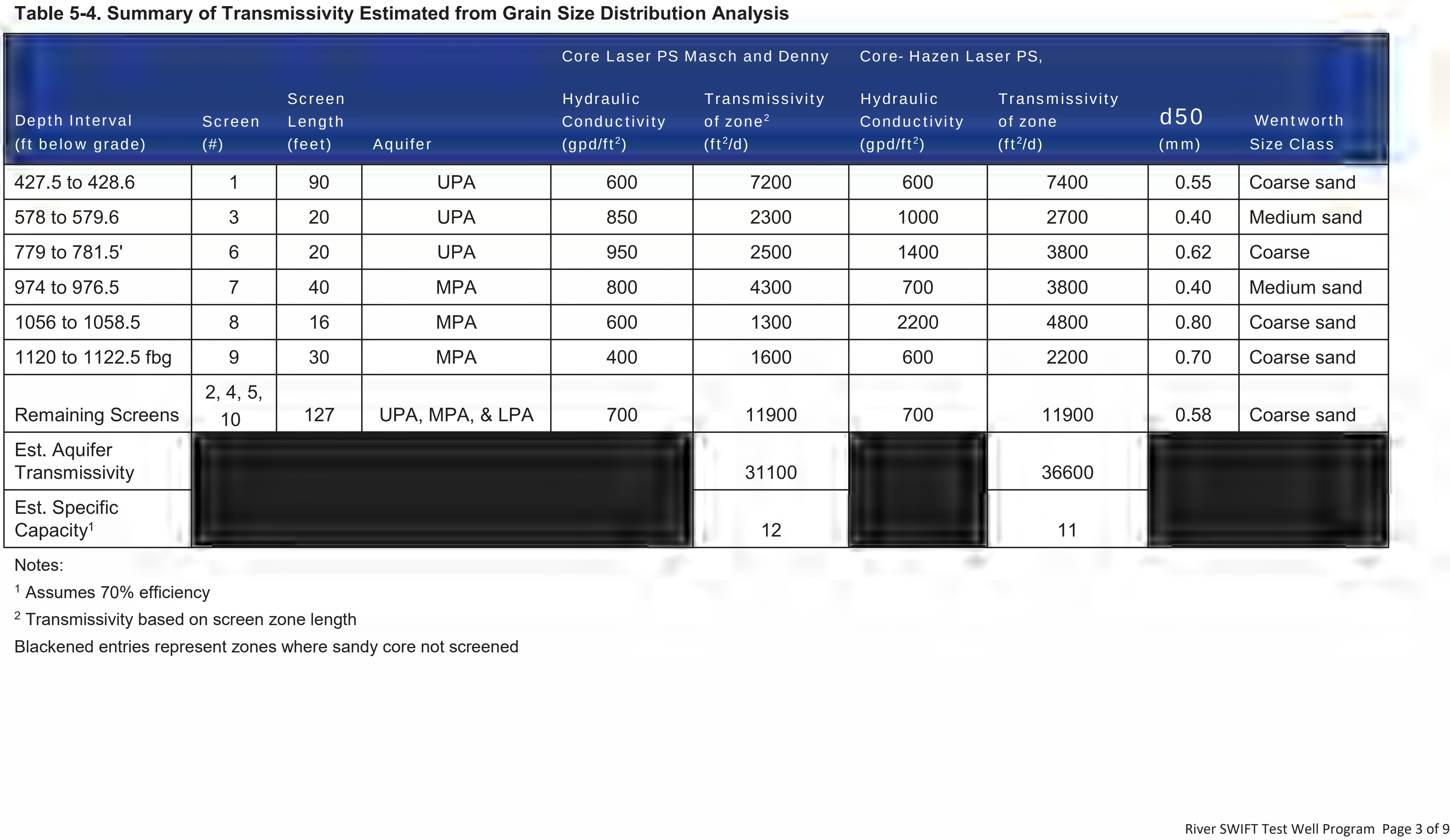


Table 5-4. Summary of Transmissivity Estimated from Grain Size Distribution Analysis

				Core Laser PS Masch and Denny		Core- Hazen Laser PS,			
Depth Interval (ft below grade)	Screen (#)	Screen Length (feet)	Aquifer	Hydraulic Conductivity (gpd/ft^2)	Transmissivity of zone[2] (ft^2/d)	Hydraulic Conductivity (gpd/ft^2)	Transmissivity of zone (ft^2/d)	d50 (mm)	Wentworth Size Class
427.5 to 428.6	1	90	UPA	600	7200	600	7400	0.55	Coarse sand
578 to 579.6	3	20	UPA	850	2300	1000	2700	0.40	Medium sand
779 to 781.5'	6	20	UPA	950	2500	1400	3800	0.62	Coarse
974 to 976.5	7	40	MPA	800	4300	700	3800	0.40	Medium sand
1056 to 1058.5	8	16	MPA	600	1300	2200	4800	0.80	Coarse sand
1120 to 1122.5 fbg	9	30	MPA	400	1600	600	2200	0.70	Coarse sand
Remaining Screens	2, 4, 5, 10	127	UPA, MPA, & LPA	700	11900	700	11900	0.58	Coarse sand
Est. Aquifer Transmissivity					31100		36600		
Est. Specific Capacity[1]					12		11		

Notes:

[1] Assumes 70% efficiency

[2] Transmissivity based on screen zone length

Blackened entries represent zones where sandy core not screened

6. Evaluating Geochemical Compatibility

This section characterizes the recharge water and NGW chemistry along with the framework and interstitial minerals composing the aquifers of the PAS. After characterizing the water quality and aquifer minerals, the section evaluates the following geochemical issues:

- Mineral dissolution
- Mineral precipitation
- Formation damage
- Damaging clays through cation exchange
- Dispersing clays caused by disparities in ionic strength

Based on the results of the evaluation, the section evaluates the effectiveness of potential mitigation approaches.

6.1 Water Quality Characterization

As described previously, in the absence of actual AWT effluent from SWIFT JR, two water chemistries were used for the Phase 5 evaluation. Recharge chemistry from SWIFT-JR was mathematically simulated assuming an AWTP treated secondary wastewater using sediment flocculation, ozonation, BAC, GAC, UV, and disinfection with chloramines. The second recharge chemistry relied on results of pilot testing treatment by BAC at SWIFT-YR.

By comparison, groundwater samples were obtained directly from TW-4, either from the entire wellbore during the 24-hour CRT,or from discrete screen intervals during the six packer tests. Important field chemistry parameters Table 4-1) were recorded throughout the pumping periods of each test. Upon obtaining stable field chemistry measurements parameters approaching the end of each pumping test field personnel filled bottles for analysis at HRSD's Laboratory in Virginia Beach.

In measuring pH, ORP, temperature, specific conductivity and DO, groundwater was passed through a sealed, Lucite box. Temperature, pH, and ORP were measured with an Orion Model 250 field meter or an Orion 3 Star Plus unit. ORP measurements collected with a silver chloride probe and adjusted to the standard hydrogen electrode (SH$_E$ using Zobell's standard reference solution.

Measurements of specific conductivity and DO were collected with YSI-manufactured meters. Field personnel used a Hach turbidity meter to measure turbidity of the samples. A Hach Model DR900 Colorimeter measured concentrations of total iron, ferrous iron, sulfide, and sulfate. Field measurements of dissolved carbon dioxide and alkalinity were performed using portable titration kits manufactured by LaMotte and Hach, respectively.

The integrity of the water quality data was assessed by balancing common cations calcium, magnesium, potassium, sodium, iron, nitrate) and anions (sulfate, chloride, and bicarbonate), and noting the difference. Analyses exceeding a 5-percent difference between cation and anion concentrations (in milli-equivalents per liter were discarded as unreliable, or if similar data proved unavailable, noted as exceeding the balancing criteria (Table 6-1).

Two thirds of balances displayed differences falling below 5 percent, with one third of the analyses displaying balances exceeding 5 percent. Balances exceeding 5 percent fell between 5 and 10 percent. The remaining balances fell between a difference of 5 and 10 percent. Two of the three analyses exceeding a 5 percent difference threshold exhibited elevated cations.

Table 6-1. Summary of Cation/Anion Balance Results for SWIFT-JR Analytical Results

Difference < 5	6	66.7	66.7
10 > Difference > 5	5	33.3	100
Difference > 10	0	0.0	100
Difference > 20	0	0.0	100
Total number of samples = 9			

6.1.1 Recharge Water

Recharge treated by the carbon-based process exhibited the following characteristics:

- A circum-neutral pH (6.96 to 7.8)
- Total dissolved solids (TDS concentrations (420 to 525 mg/L) indicative of fresh water (Hem, 1985).
- Ionic strength ranging from 0.011 to 0.013
- BAC-based recharge displayed a sodium chloride water type (Figure 6-1
- Dissolved iron concentrations equaled 0.021 and 2 mg/L in the York River and estimated analyses, respectively.
- Concentrations of dissolved manganese in samples from the pilot test at York River equaled 0.012 mg/L, but were not mathematically simulated for SWIFT-JR.
- Dissolved iron and manganese concentrations in recharge exceeding 0.1 mg/L and 0.02 mg/L, respectively, represent a potential source of precipitated particles that can clog a MAR well. Thus, dissolved iron concentrations in the estimated analyses represent a cause for concern.
- The AWT should contain processes that remove iron from the recharge water.
- Nitrate concentrations ranged from 2.7 to 3.1 mg/L in the York River and estimated analyses for SWIFT-JR, respectively.
- Partial denitrification of nitrate to nitrite created an interim issue at HRSD's SWIFTRC. Incomplete denitrification by ferrous iron created nitrite concentrations exceeding the Virginia PMCL of 1 mg/L migrating with the SWIFT recharge in the PAS.
- Passivating iron-bearing minerals using DO will produce ferrous iron upon dissolution of the host mineral that could potentially assist with denitrification if concentrations are high enough to complete the reaction, as shown with pyrite oxidation. $5FeS_2 + 14\ NO_3^- + 4H^+ \rightarrow 7N_2 + 10\ SO_4^{2-} + 5Fe^{2+} + 2H_2O$
- Concentrations of TOC (2 mg/L) slightly exceeded DOC (1.8 mg/L)
- DO concentrations in the York River samples ranged up to 16 mg/L and displayed an ORP falling in the oxic range at a pH of 7.0 (Figure 6-2).

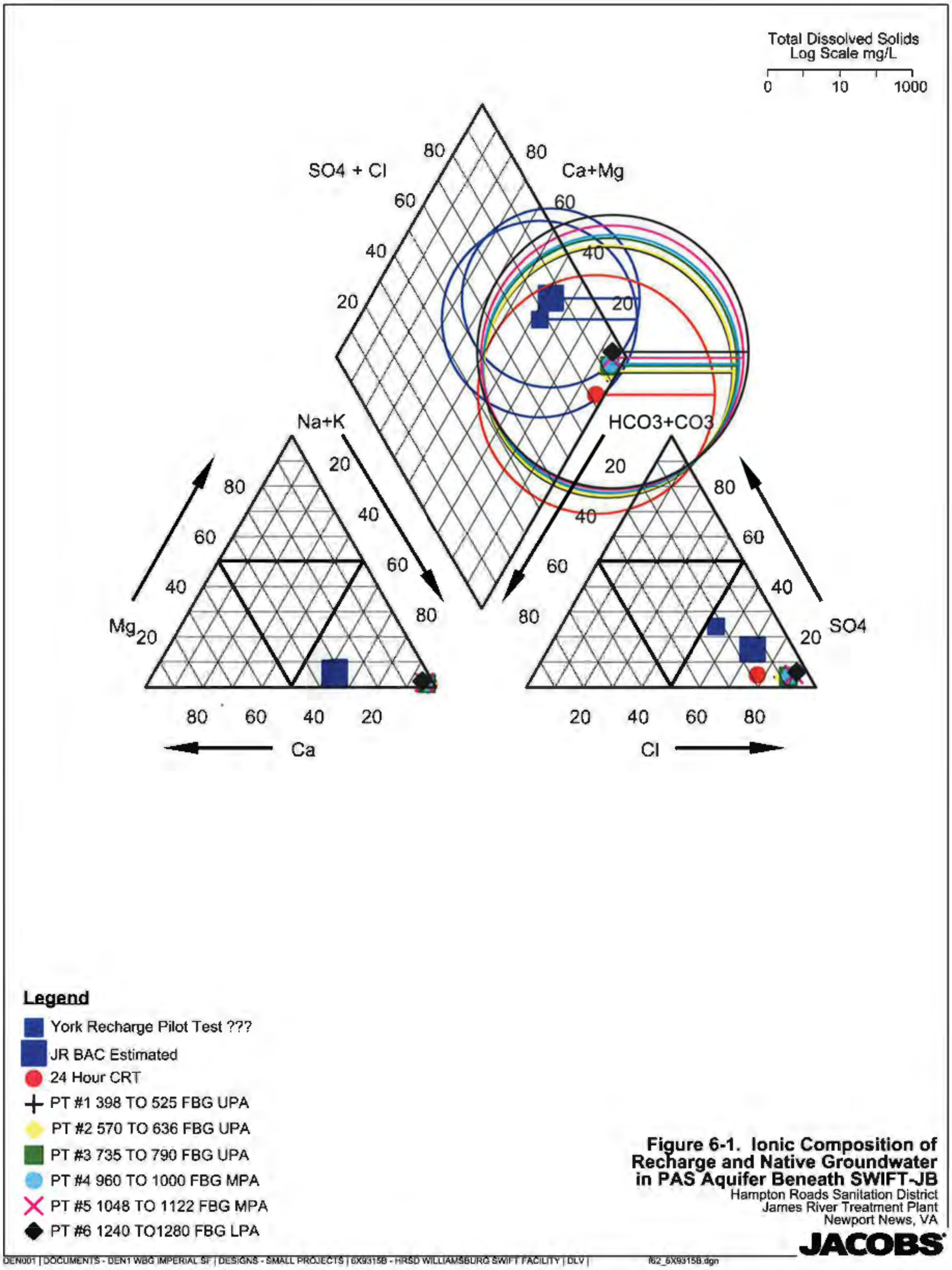


Figure 6-1. Ionic Composition of Recharge and Native Groundwater in PAS Aquifer Beneath SWIFT-JB
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

River SWIFT Tes

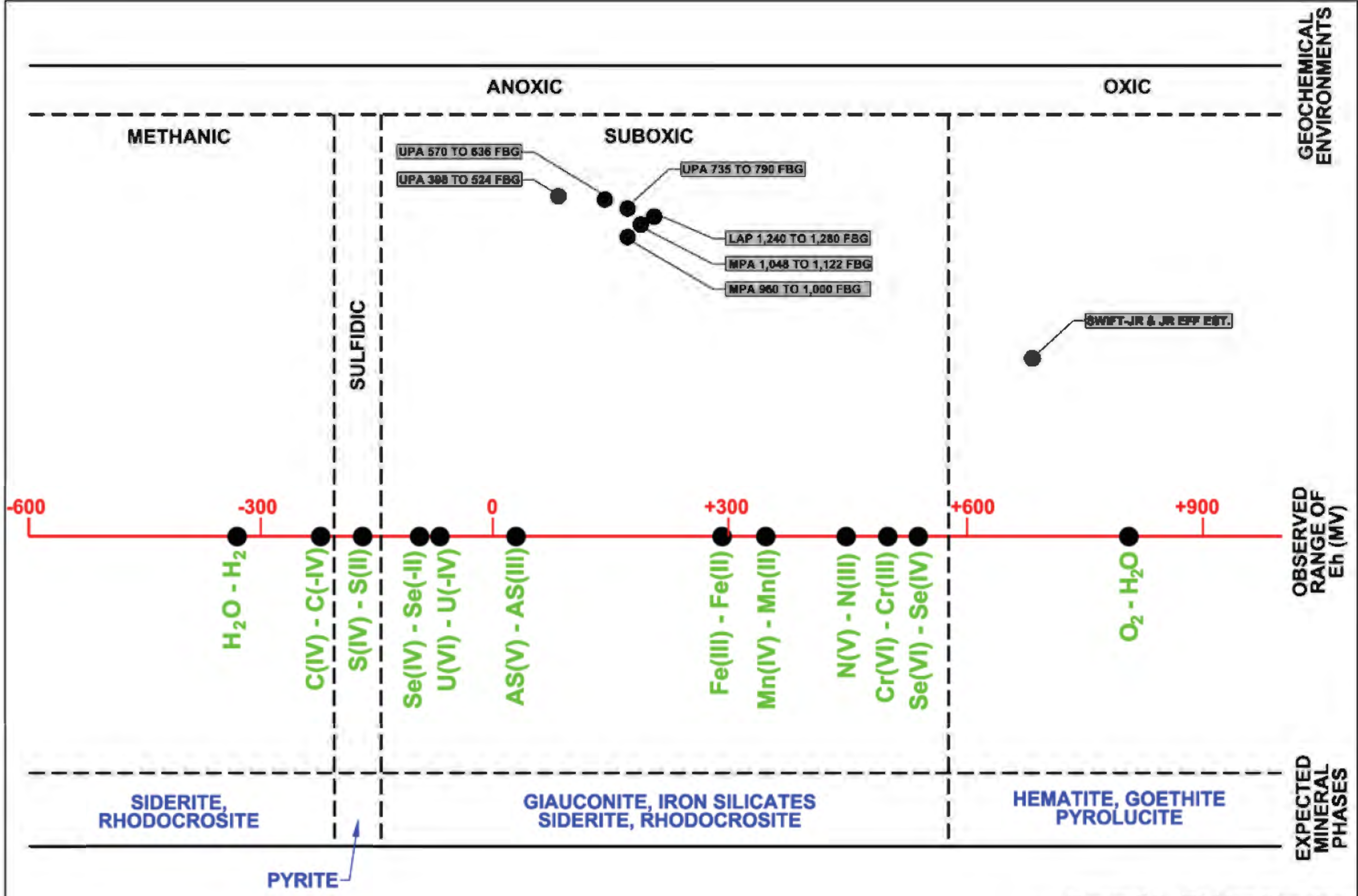


Figure 6-2. Eh Line Showing Recharge and NGW at SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

Note:
Height of plotted points hold no relevance.

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f03_6X93158.dgn

6.2 Groundwater Chemistry

The PAS contains the UPA, MPA, and LPA beneath SWIFT-JR. However, coring and packer testing revealed the LPA exhibited relatively thin, unsorted sand beds with corresponding poor hydraulic characteristics. Subsequently, the LPA was eliminated for further consideration as a receiving aquifer for SWIFT recharge. However, characteristics of NGW from the LPA are discussed briefly to support discussions regarding the chemistry of the NGW from the UPA and MPA.

Packer testing was conducted to collect water quality from intervals in the UPA and MPA. Except for single, 40-foot intervals found in the MPA (960 to 1000 fbg) and LPA 1240 to 1280 fbg), the remaining packer zones encompassed two sand intervals (Figure 4-4) in the UPA and MPA. The packer testing program tested all major sand zones in the PAS.

Groundwater samples collected from three packer intervals, spanning the UPA, exhibited similar chemistries, with increasing chloride, sodium and TDS/ionic strength with depth. The ionic strength ranged from 0.075 to 0.087 moles per liter (m/L) in the three tested zones (Packer Test #1 through #3). Chloride in the samples from the UPA exceeded concentrations in the recharge by over 10 times. Chloride typifies an inert constituent that migrates at the velocity of groundwater, thus making it an excellent tracer for tracking the movement of recharge in an aquifer. The disparity in concentrations between the recharge and NGW will enhance chloride's sensitivity in its application as a tracer constituent.

Concentrations of TDS and chloride in groundwater samples from the MPA increased across the two tested intervals (Packer Tests #4 and #5), and exceeded concentrations from the UPA. The ionic strength of samples from the MPA both equaled 0.089 and 0.11 m/L from Packer Tests #4 and #5, respectively. Groundwater samples from UPA and MPA displayed a sodium-chloride chemistry.

Iron concentrations fluctuated across the six intervals, ranging from 1.39 (UPA; Packer Test Zone #3) to 2.74 mg/L (UPA: Pack Test Zone #2) with concentrations from other intervals falling in between. Dissolved manganese concentrations from every NGW sample displayed concentrations exceeding the PMCL of 0.05 mg/L. Manganese concentrations increased from 0.051 to 0.142 mg/L in Packer test Zones #1 through 6.

Radionuclide activities exceeded the PMCL only in Packer Testing interval #6 (1240 to 1280 fbg), situated across the LPA. The sample displayed activities of Gross Alpha and total radium (^{226}Ra + ^{228}Ra equaling 16 and 8.8 pico Curies per liter (pCi/L), respectively.

The following sections describe NGW chemistry unique to the UPA and MPA.

6.2.1 UPA

Groundwater from the UPA was characterized by samples collected from Packer Tests #1 through #3 and exhibited the following chemistry:

- A circum-neutral pH ranging from 6.1 to 7.7.
- NGW sampled during packer testing of the UPA (Packer Tests #1 through #3 displayed total dissolved solids concentrations ranging from 2,990 to 3,470 mg/L, with ionic strengths ranging from 0.075 to 0.087 m/L.
- The ionic strength of samples from the UPA at 0.075 to 0.087 m/L, approach a difference of one order of magnitude compared to samples of the recharge water (0.0105 to 0.013 m/L).
- Dissolved iron and manganese concentrations fluctuated across the tested zones, reaching concentrations of 2.74 and 0.057 mg/L in Packer Test #2.
- A sodium chloride water type (Figure 6-1).

Fluoride concentrations in Packer Test Zones #1 through #3 fell below 1.0 mg/L, well below the PMCL of 4 mg/L.

- ORP measured during the packer tests and converted to Eh (Eh = ORP + 200 mV displayed values transitional between oxic and reducing (Figure 6-2). ORP, an electrical potential measurement, can offer mis-leading results if the system exhibits elements of disequilibrium.
- Evaluation of oxidation-reduction pairs (redox using a computer program developed by the USGS Jurgens, et. Al., 2009) showed anoxic conditions with reduction of ferric iron representing the prevailing redox process (Tables 6-1 and 6-2). Leaking tubing, or improperly calibrated metering equipment can falsely inflate DO measurements.
- Nutrient (TOC, DOC, ortho-phosphate, phosphorous, nitrate, total Kjhedahl Nitrogen) concentrations fall below or just slightly greater than method detection limits (MDLs .
- Gross Alpha and total radium ^{226}Ra + ^{228}Ra) (radionuclides activities remained below the PMCL of 15 and 5.0 pCi/L, respectively for Packer Tests #1 through #3.

6.2.2 MPA

NGW from the MPA was sampled during Packer Tests #4 and #5 corresponding to depth intervals at 960 to 1,000 fbg, and 1,048 to 1,122 fbg, respectively. NGW from these intervals exhibited the following characteristics:

- A circum-neutral pH ofaround 7.3
- TDS concentrations falling in the brackish category Hem, 1985) with concentrations ranging 3,600 to 4,500, and corresponding ionic strengths of 0.09 and 0.11 moles/L, roughly exceeding the ionic strength of the recharge by one order of magnitude.
- Both samples from the MPA displayed a sodium chloride water chemistry (Figure 6-1).
- Dissolved iron ranged from 1.5 to 2.1 mg/L between Packer Tests #4 and #5.
- Similarly, manganese concentrations jumped from 0.053 to 0.083 mg/L between the two intervals.
- Nutrient (TKN, nitrate, total phosphorus and ortho-phosphate) concentrations were at or below their respective MDLs
- Typical for NGW, TOC roughly equaled DOC concentrations with all concentrations less than 1.0 mg/L.
- Resembling samples collected during packer testing in the UPA, groundwater from the MPA displayed a transitional ORP (Figure 6-2).
- Samples fell within the anoxic redox category with ferric iron reduction constituting the prevailing redox process Tables 6-2 and 6-3).
- Samples for Packer Tests #4 and #5 displayed Gross Alpha activities around 14 p*Ci*/L, slightly less than the PMCL of 15 p*Ci*/L.
- Total radium (^{226}Ra + ^{228}Ra activities jumped from 1.6 to 4.8 p*Ci*/L between Packer Tests #4 and #5.

Table 6-2. Criteria and Threshold Concentrations for Identifying Redox Processes in Groundwater

[Table was modified from Jurgens, et al, 2009. Redox process: O_2, oxygen reduction; NO_3, nitrate reduction; Mn(IV), manganese reduction; Fe(III), iron reduction; SO_4, sulfate reduction; CH_4gen, methanogenesis. Chemical species: O_2, dissolved oxygen; NO_3-, dissolved nitrate; MnO_2(s), manganese oxide with manganese in 4+ oxidation state; $Fe(OH)_3$(s), iron hydroxide with iron in 3+ oxidation state; $FeOOH_3$(s), iron oxyhydroxide with iron in 3+ oxidation state; SO_4-^{2}, dissolved sulfate; CO_2(g), carbon dioxide gas; CH_4(g), methane gas. Abbreviations: mg/L, milligram per liter; —, criteria do not apply because the species concentration is not affected by the redox process; ≤, less than or equal to; ≥, greater than or equal to; <,
less than; >, greater than]

Redox category	Redox process	Electron acceptor (reduction) half reaction	Criteria for inferring process from water quality data					
			Dissolved oxygen (mg/L)	Nitrate, as nitrogen (mg/L)	Manganese (mg/L)	Iron (mg/L)	Sulfate (mg/L)	Iron/sulfide (mass ratio)
Oxic	O_2	$O_2 + 4H+ + 4e- \rightarrow 2H_2O$	≥0.5	—	<0.05	<0.1	—	
Suboxic	Suboxic	Low O2; additional data needed to define redox process	<0.5	<0.5	<0.05	<0.1	—	
Anoxic	NO_3^{-1}	$2NO_3- + 12H+ + 10e- \rightarrow N_{2g}$) + $6H_2O$; $NO_3- + 10H+ + 8e- \rightarrow NH_4+ + 3H_2O$	<0.5	≥0.5	<0.05	<0.1	—	
Anoxic	Mn(IV)	MnO_2 s + 4H+ + 2e- → $Mn_{2+} + 2H_2O$	<0.5	<0.5	≥0.05	<0.1	—	
Anoxic	Fe(III)/SO_4	Fe(III) and (or) SO42- reactions as described in individual element half reactions	<0.5	<0.5	—	≥0.1	≥0.5	no data
Anoxic	Fe(III)	Fe(OH)3(s + $3H^+ + e- \rightarrow Fe^{2+} + 3H_2O$; FeOOH(s) + $3H^+ + e- \rightarrow Fe^{2+} + 2H_2O$	<0.5	<0.5	—	≥0.1	≥0.5	>10
Mixed(anoxic	Fe(III)-SO_4	Fe(III) and SO_4^{2-} reactions as described in individual element half reactions	<0.5	<0.5	—	≥0.1	≥0.5	≥0.3, ≤10
Anoxic	SO_4	$SO_4^{2-} + 9H^+ + 8e- \rightarrow HS- + 4H_2O$	<0.5	<0.5	—	≥0.1	≥0.5	<0.3
Anoxic	CO_2	$CO_2(g) + 8H^+ + 8e- \rightarrow CH_4(g) + 2H_2O$	<0.5	<0.5	—	≥0.1	<0.5	

Table 6-3. Summary of REDOX Results

	Redox Variables Units	Dissolved O_2 (mg/L)	NO_3 (as Nitrogen) (mg/L)	Mn^{2+} (g/L)	Fe^{2+} (g/L)	SO_4^{2} (mg/L)	Sulfide (sum of H_2S, HS , S^{2-}) (mg/L)	Redox Assignment			
Sample ID	Threshold values	0.5	0.5	50	100	0.5	none	Num of Params	General Redox Category	Redox Process	Fe^{2+}/ Sulfide, ratio
24 Hour CRT	[redacted]	0.35	0.01	22.6	203	70.3	0.01	6	Anoxic	Fe(III)	20.3
PT# 1 398 to 524 fbg UPA	[redacted]	0.46	0.01	50.4	2490	90.6	0.01	6	Anoxic	Fe(III)	249
PT#2 570 to 636 fbg UPA	[redacted]	0.02	0.01	58.1	2740	91.6	0.01	6	Anoxic	Fe(III)	274
PT#3 735 to 790 fbg UPA	[redacted]	0.03	0.01	53.9	1390	119	0.03	6	Anoxic	Fe(III)	46.3
PT#4 960 to 1000 fbg MPA	[redacted]	0.01	0.01	54.2	1460	126	0.01	6	Anoxic	Fe(III)	146
PT#5 1048 to 1122 fbg MPA	[redacted]	0.03	0.01	85.6	2007	175	0.01	6	Anoxic	Fe(III)	200.7
PT#6 1240 to 1280 fbg LPA	[redacted]	0.03	0.01	142	2280	275	0.01	6	Anoxic	Fe(III)	228
Estimated SWIFT-JB Effluent	[redacted]	17	2.72	12	21	32	0.01	6	Oxic	O2	
York River Pilot Testing Effluent	[redacted]	5	0.47	12	21	93	0.01	6	Oxic	O2	

Note:

Developed using program from McMahon, et Al, 2009.

6.3 Lithology and Mineralogy of the PAS

This section describes the lithology and mineralogic composition of the UPA and MPA beneath SWIFT-JR. Field personnel purposely avoided selecting cores representing confining units for mineralogical analysis, instead focusing on aquifer sands. Eleven core samples (cores ranging in length from 0.7 to 2.5 feet, were shipped to Mineralogy Inc. for a list of lithologic, mineralogic, chemical, and petrophysical analysis Table 3-5). For brevity, individual core intervals are referenced by the depth to the top of the interval in this report.

As described previously, cores were analyzed using several lithological and mineralogic techniques. Composed of unconsolidated sand, cores were unsuited for conventional laboratory porosity and permeability testing. Instead, inter-granular porosity was estimated by quantitative thin section analysis using 300-point counts Table 6-4).

6.3.1 Aquifer sand lithology

Sands originating from the UPA and MPA fell into two lithological categories comprising:

- Aquifer sands quartz-rich)
- Clay-rich aquifer sands

The samples were separated into the categories based on their clay content. Aquifer sands displayed less than 10 percent clay, while the clay content of clay-rich aquifer sands (CAS) exceeded 10 percent. Four of the 11 cores were defined as aquifer sands, while remaining seven were classified as CAS. Screen intervals in TW-4 spanned across only three of the cores (427.5, 491, and 1120 fbg) described as CAS.

Aquifer sands displayed a grain-supported structure, and ranged across several classifications comprising arkose, sandy conglomerate and feldspathic sub-lithareanite (Table 6-4; Figure 6-3). CAS samples fell in the arkose, lithic arkose, and felspapthic litharenite, sand classifications.

The terms arkose and litharenite describe sand or sandstone containing proportionally high abundances of the feldspar mineral group, or rock fragments, respectively. Feldspar grains consisted mostly of microcline potassium-rich) with minor amounts of albite (Table 6-5). Rock fragments were composed predominantly of granite, with minor amounts of siltstone and shale. The same pattern in sand petrology was encountered in samples from HRSD's SWIFTRC York River, and Williamsburg's WWTP.

Aquifer sands exhibited coarse to medium grain size and were classified as moderately to very poorly sorted. Most individual framework grains appeared subangular in shape. Aquifer sands displayed an unconsolidated, grain-supported sedimentary fabric with either cross bedding, or cross-bedding disrupted by burrow mottling. CAS samples also displayed a grain supported structure, but contained significantly more pore filling matrix.

6.3.2 Porosity

Aquifer sands displayed an open framework, represented by well-connected pores separating aquifer framework grains. Pores observed in CAS intervals displayed larger amounts of pore filling and less connection between individual pores. The framework grains displayed point to point, or elongated contacts. Porosity in both aquifer sands and CAS lithologies consisted of primary intergranular porosity or secondary porosity. The morphology of secondary porosity consisted mostly of dissolving feldspar grains exhibiting varying amounts of micro-porosity. The feldspar grains in several cores (427.5, 578, 637.5, 779, 974, 1120, and 1178 fbg) displayed pervasive dissolution, significantly adding to the porosity of aquifer sand and CAS intervals. Porosity estimated using quantitative thin section techniques ranged from 12 to 25 percent, averaging 19 percent (Table 6-6). The estimates roughly coincide with the average porosity recommended by the United States Geological Survey Plume, 1996; 20 to 25 percent) for the Potomac Formation sands in modeling studies.

Table 6-4. Summary of Lithologic Characteristics from Cores

											Porosity			
Core Interval (fbg)	Screen Interval (#[1])	Aquifer	Mean Grain Diameter (mm)	Maximum Grain Diameter (mm)	Sand Size Classification	Aquifer Characterization	Lithologic Classification	Sorting	Roundness	Sedimentary fabric	Intergranular (%)	Secondary (%)	Moldic (%)	Total (%)
427.5 - 428.6	1	UPA	0.36	2.15	medium	Clay-rich aquifer sand[2]	Lithic Arkose	poorly	sub-angular	burrow mottled, matrix-rich, & unconsolidated	23	0	0	23
491 - 492.9	2	UPA	0.34	2.67	medium	Clay-rich aquifer sand	Lithic Arkose	poorly	sub-angular	burrow mottled, matrix-rich, unconsolidated	12	1	0	13
578 -579.6	3	UPA	0.3	4.16	very fine	Quartz-rich aquifer sand[3]	Arkose	poorly	sub-angular	burrow mottled, matrix-rich, & unconsolidated	13.3	2	0	15.3
637.5 - 640	4	UPA	0.52	3.19	coarse	Quartz-rich aquifer sand	Arkose	poorly	sub-angular	silty, matrix-rich, & unconsolidated	8.7	3.3	0	12
779 - 781.5	6	MPA	0.52	3.25	coarse	Quartz-rich aquifer sand	Lithic Arkose	poorly	sub-angular	unconsolidated	23.3	1.3	0	24.6
886.5 - 889	Between 6 and 7	MPA	0.85	3.51	coarse	Clay-rich aquifer sand	Feldspathic Litharenite	very poorly	sub-angular	matrix-rich &unconsolidated	21.3	1.7	0	23
912.5 - 915	Between 6 and 7	MPA	0.37	2.8	medium	Clay-rich aquifer sand	Lithic Arkose	moderately	sub-angular	burrow mottled, matrix-rich, & unconsolidated	22	2.7	0	24.7
974 - 976.5	7	LPA	0.37	0.98	medium	Quartz-rich aquifer sand	Arkose	moderately	sub-angular	burrow mottled, matrix-rich, &unconsolidated	16.3	6	0	22.3
1056 - 1058.5	8	LPA	0.72	6.24	coarse	Quartz-rich aquifer sand	Sandy conglomerate	very poorly	sub-angular	unconsolidated, pebble-rich, & feldspathic litharenitic	15.7	1.3	0	17
1120 - 1122.5	9	LPA	0.19	2.67	fine	Clay-rich aquifer sand	Arkose	very poorly	sub-angular	matrix-rich & unconsolidated	20.3	1.7	0	22
1178 - 1180.5	Between 9 and 10	LPA	0.49	4.94	medium	Clay-rich aquifer sand	Feldspathic Litharenite	very poorly	sub-angular	matrix-rich & unconsolidated	11.3	5	0	16

Notes:

[1] Screen number counting from shallowest to deepest - 10 total

19.3545

[2] Clay composition > 10%

[3] Clay composition < 10%

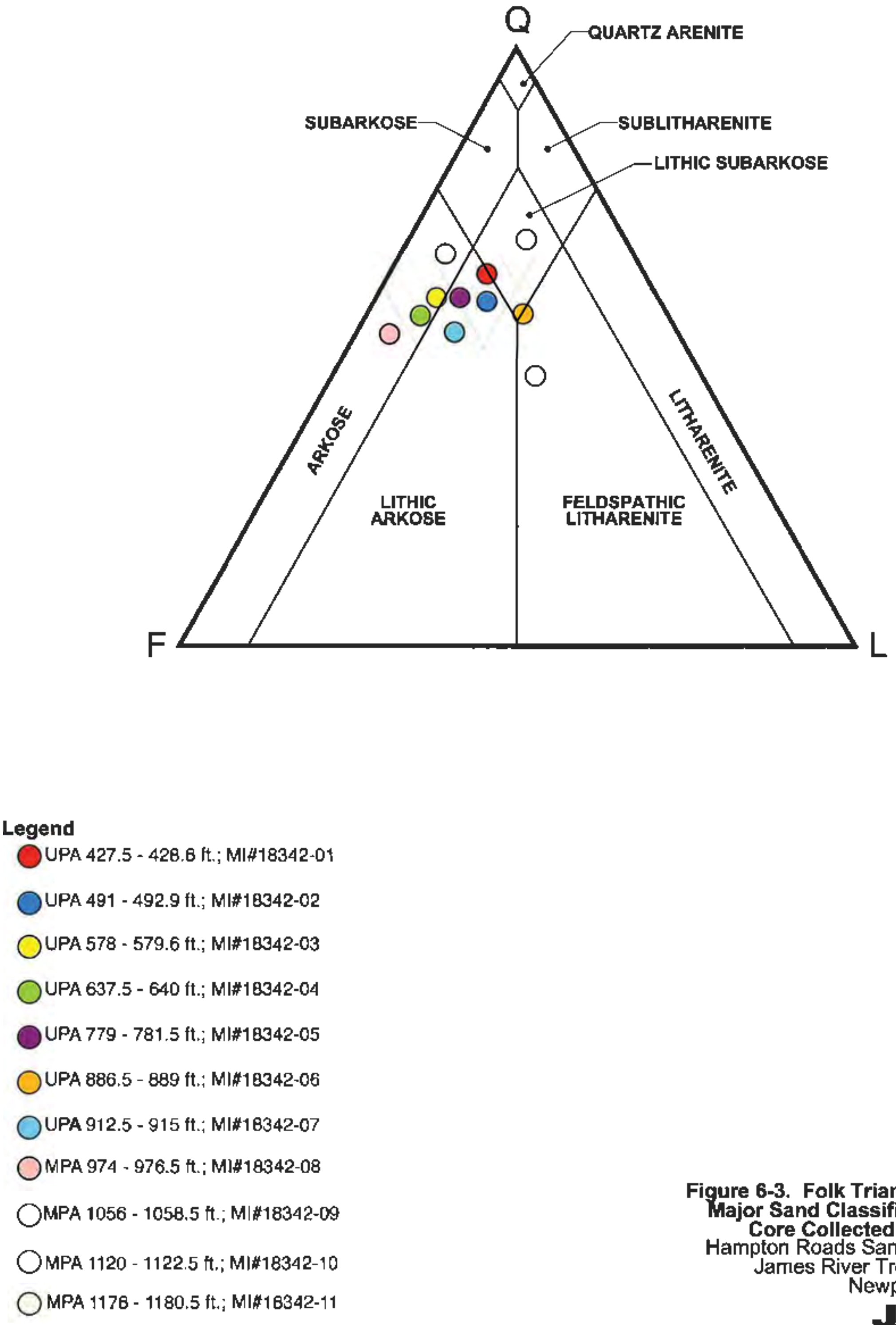


Figure 6-3. Folk Triangle Showing Major Sand Classifications from Core Collected at SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f54_6X9315B.dgn

Table 6-5. Summary of Minerals Identified in Cores by X-ray diffraction analysis

[redacted]	Sample Depth	427.5 to 428.6	491 to 492.9	578 to 579.6	637.5 to 640	779 to 781.5	886.5 to 889	912.5 to 915	974 to 976.5	1056 to 1058.5	1120 to 122.5	1178 to 1180.5
	Hydrostratigraphic Unit	UPA	UPA	UPA	UPA	UPA	MPA	MPA	MPA[1]	MPA[1]	MPA[1]	LPA
	Screen Interval in TW-4	1	2	3	4	6	Between 6 & 7	Between 6 & 7	7	8	9	Between 9 & 10
Mineral	Chemical Formula	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Quartz	SiO_2	66	60	73	85	78	63	70	75	70	61	67
Plagioclase Feldspar	Na, Ca) $AlSi_3O_8$	2	2	2	1	1.5	1	1.5	1	<0.5	0.5	<0.5
Microcline	$KAlSi_3O_8$	14	8	19	9	16	12	11	18	12	12	17
Quartz Feldspar	Total	*82*	*70*	*94*	*95*	*95.5*	*76*	*82.5*	*94*	*82*	*73.5*	*84*
Calcite	$CaCO_3$	1	0.5		0.5	0.5	1	0.5	0.5	0.5	0.5	1
Pyrite	FeS_2		1									
Magnetite	alpha Fe_3O_4	1	0.5		0.5		0.5	0.5	0.5	0.5		0.5
Kaolinite	$Al_2Si_2O_5OH)_4$	2	2	2	2	2	2	1	2.5	3	19	9.5
Chlorite	$(Mg, Al)_6\ Si, Al)_4O_{10}OH)_8$	<0.5	<0.5									
Illite/Mica	$KAl_2Si\ _3AlO_{10}OH)_2$	<0.5	2	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1	<0.5
Montmorillonite	$Na,K, Ca)_6(Si, Al\ _{36}O_{72}\ 2H_2O$	14	24	4	2	2	20.5	15.5	2.5	14	6	5
Clay	*Total %*	*16*	*28*	*6*	*4.5*	*4*	*22.5*	*16.5*	*5*	*17*	*26*	*14.5*
Total		100	100	100	100.5	100	100	100	100	100	100	100

Notes:

% Illite in layers ML I/S

[1] Sand interval not screened by TW-3

Table 6-6. Summary of Minerals Identified During Petrographic Modal Analysis (300 point count)

	Sample Depth	427.5 to 428.6	491 to 492.9	578 to 579.6	637.5 to 640	779 to 781.5	886.5 to 889	912.5 to 915	974 to 976.5	1056 to 1058.5	1120 to 122.5	1178 to 1180.5
	Hydrostratigraphic Unit	UPA	UPA	UPA	UPA	UPA	MPA	MPA	MPA1	MPA1	MPA1	LPA
	Screen Interval in TW-4	1	2	3	4	6	Between 6 & 7	Between 6 & 7	7	8	9	Between 9 & 10
Lithological classification		Lithic Arkose	Lithic Arkose	Arkose	Arkose	Lithic Arkose	Feldspathic Litharenite	Lithic Arkose	Arkose	Sandy Conglomerate	Arkose	Feldspathic Litharenite
Quartz/Feldspar/Lithic	%	61/25/14	59/26/15	59/32/09	56/37/07	58/30/12	57/21/22	62/35/13	51/43/06	69/13/18	65/29/06	44/25/31
Mean grain diameter	mm	0.36	0.34	0.3	0.52	0.52	0.85	0.37	0.37	0.72	0.19	0.49
Maximum grain diameter	mm	2.15	2.67	4.16	3.19	3.25	3.51	2.8	0.98	6.24	2.67	4.94
Hydrogeologic Classification	[redacted]	CAS	CAS	AQ	AQ	AQ	CAS	CAS	AQ	CAS	CAS	CAS
Sedimentary fabric		mU, ps, sa, BM, mr, uc	mU, ps, sa, BM, mr, uc	vfU, ps, sa, BM, mr, uc	cL, ps, sa, slt, mr, uc	cL, ps, sa, uc	cU, vps, sa, mr, uc	mU, ms, sa, BM, mr, uc	mU, ms, sa, BM, mr, uc	cL, vps, sa, uc, pr, FL	fU, vps, sa, mr, uc	mU, vps, sa, mr, uc
Framework Grains		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mono xstalline Quartz	%	33.7	25.5	44.3	39.3	34.7	18.3	34.3	31	36.3	31	30
Poly xstalline Quartz	%	4.7	3.5	2	4.3	5.7	14	3.3	1.3	7.7	8.7	2
Feldspar	%	15.7	12.5	25.3	29.3	21	11.7	21	27.3	8	17.7	18.3
Igneous rock fragments granite)	%	7	7	5.7	3	8	12.3	1.7	2.7	4	2.7	7.7
Glauconite	%	1										
Metaquartzite rock fragments	%		0.5	0.3	1.7						1.3	14
Siltstone rock fragments	%										5.7	
Calcareous skeletal rock fragments	%	0.3										
Mica	%				0.3					0.3		1.3
Magnetite	%	0.3		0.3	0.3	0.3		0.3	1			0.3
Other	%			0.3		0.3		0.3		0.3		
Matrix minerals	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pore-filling matrix	%	12	34.5	4	4.7	2	16	6.7	8.7	17.7	1	3
Authigenic clay matrix	%	1.7	3	2.7	5	3.3	4.7	7.7	5.7	1.3	15.7	8.3
Authigenic quartz overgrowth	%		0.5									
Siderite	%											
Pyrite	%											0.3
Intergranular porosity	%	23.7	12	13.3	8.7	23.3	21.3	22	16.3	15.7	20.3	11.3

Table 6-6. Summary of Minerals Identified During Petrographic Modal Analysis (300 point count)

	Sample Depth	427.5 to 428.6	491 to 492.9	578 to 579.6	637.5 to 640	779 to 781.5	886.5 to 889	912.5 to 915	974 to 976.5	1056 to 1058.5	1120 to 122.5	1178 to 1180.5
	Hydrostratigraphic Unit	UPA	UPA	UPA	UPA	UPA	MPA	MPA	MPA1	MPA1	MPA1	LPA
	Screen Interval in TW-4	1	2	3	4	6	Between 6 & 7	Between 6 & 7	7	8	9	Between 9 & 10
Secondary Intragranular porosity	%		1	2	3.3	1.3	1.7	2.7	6	1.3	1.7	5
Total		100.1	100	100.2	99.9	99.9	100	100	100	92.6	105.8	101.5

Notes:

Sedimentary Fabric Abbreviations

BM burrow mottled
cL = coarse-grained (Lower)
cU = coarse-grained (Upper)
Feld = Feldspathic
FL = feldspathic litharenite
mL = medium grained (Lower)
mr = matrix rich
ms moderately sorted
mU = medium-grained (Upper)

pr = pebble rich
ps = poorly sorted
sa = subangular
sdy sandy
sr = subrounded
uc = unconsolidate
vcL = very coarse grained (Lower)
vcU = very coarse grained (Upper)
vps very poorly sorted

6.3.3 Pore filling matrix and cement

Clay minerals were encountered in the pore spaces (interstitial of the aquifer sands and CAS as grain coatings, pore filling, or matrix separating individual framework grains. Detrital clay refers to clay particles deposited with the sands, while the term, authigenic describes clays that precipitate through chemical reactions following deposition.

Often detrital clay was mixed with organic silt and iron oxide crystals. Detrital clays displayed poorly-developed structures, while authigenic clays exhibited delicate book, box, and lamellar structures. In the PAS, authigenic clays typically form as a weathering product, precipitating following the dissolution of feldspars. In the four samples representing aquifer sands, authigenic clay comprised most of the interstitial clay composition. By comparison, detrital clay composed most of the interstitial clay in the CAS cores.

The clay content of the aquifer sands as determined from x-ray diffraction (XRD) ranged between 4.5 to 6 percent, while quantitative thin section analysis registered a clay content ranging from 2 to 8.7 percent of the 300-points counted on each thin section. Interstitial clay mineralogy in aquifer sands was dominated by montmorillonite, followed by subordinate amounts of kaolinite and illite mica (Tables 6-5 and 6-6; Figure 6-4) in core shallower than 1,100 fbg. At depths greater than 1,100 fbg, kaolinite dominated the clay composition.

The CAS cores 427.5, 491, 886.5, 912.5, 1056, 1120, and 1178 fbg) comprised a grain-supported matrix with pore spaces filled with detrital clays. The clay minerals in order of abundance comprised montmorillonite, kaolinite, and illite/mica in samples shallower than 1,100 fbg. Yet, cores deeper than 1,100 fbg displayed twice as much kaolinite, as montmorillonite.

The predominance of montmorillonite as an interstitial clay mineral in the aquifer sands of the PAS holds mixed implications for MAR operations. As the predominant cation in groundwater by far, sodium should represent the main cation in the atomic structure of the interstitial montmorillonite. Because of its multi-layer structure, sodium-montmorillonite suffers significant damage when exposed to recharge containing a significantly lower ionic strength. Also, the monovalent sodium ion will tend to exchange with other ions. Conversely, sodium-montmorillonite should prove easier to stabilize than other clay minerals through treatments with trivalent salt solutions.

6.3.4 Important Trace Minerals

Exclusive of the clay minerals, cores of the aquifer sands contained trace less than 10 percent) amounts of calcite, dolomite, magnetite, garnet, and amorphous iron oxide. The iron sulfide mineral pyrite (FeS_2 , a potential source of iron, manganese, and arsenic if reacting with elevated concentrations of DO contained in recharge, was encountered at concentrations equaling one percent of the whole rock matrix in a single sample and 0.3 percent in another. XRD identified pyrite in one core (491 fbg), while quantitative thin section analysis encountered pyrite in another 1,178 fbg). Both samples were classified as CAS. Thus, considering the two analytical techniques, pyrite appeared in zero and nearly 30 percent of the aquifer sand and CAS cores, respectively.

Pyrite appeared mixed with clay minerals or organic particles lining the interstitial areas of pores. Siderite, an iron carbonate ($FeCO_3$, can release large amounts of iron during dissolution and commonly occurs in the PAS and other local aquifers. Pyrite and siderite precipitate under reducing conditions in the presence of organic material. However, unlike HRSD's other SWIFT sites, siderite was not identified in aquifer sand or CAS cores analyzed using XRD or petrographic analysis at SWIFT-JR.

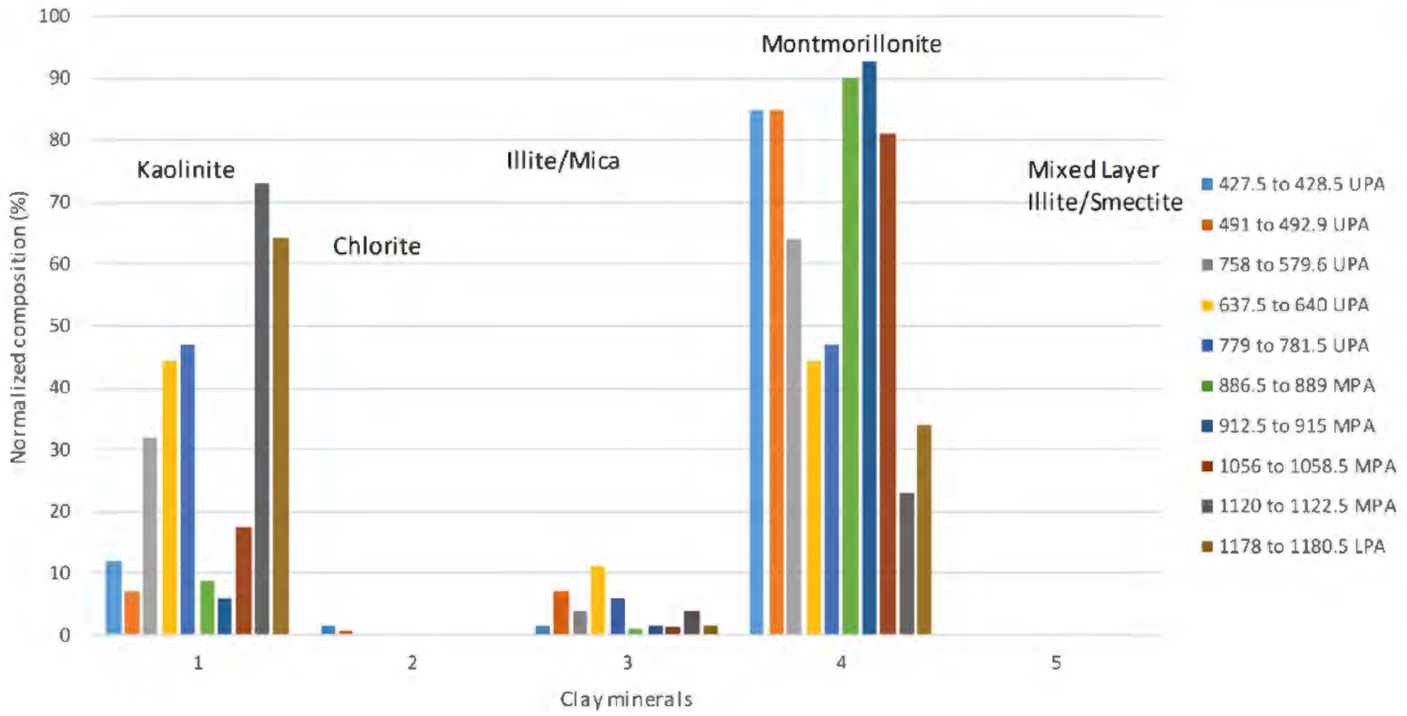


Figure 6-4. Clay Mineral Abundance Normalized to 100 Percent in Cores from SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f65_6X9315B.dgn

6.3.5 Summary of Lithological Information

In summary, PAS aquifer sands consisted of greater than 90 percent framework grains composed of quartz and potassium-rich feldspar. The porosity of aquifer sands ranged from 11 to 25 percent and averaged 20 percent. Interstitial clay minerals composed up to 10 percent of the whole rock matrix in aquifer sands, and up to 28 percent of the CAS cores. At depths shallower than 1,100 fbg, montmorillonite constituted the predominating clay mineral, followed in order by kaolinite, illite/mica, and chlorite. At depths exceeding 1,100 fbg kaolinite was the prevalent clay mineral followed by montmorillonite, illite, and chlorite.

Reactive metal-bearing minerals like pyrite were encountered in two of the seven CAS cores, but in none of the cores composed of aquifer sands. If relegated to only the finer grained portions of the aquifer, pyrite should not present a concern for injection operations. However, if present in the aquifer sands, pyrite can react with recharge water containing elevated DO. Siderite did not appear in aquifer sand nor CAS cores analyzed by XRD or petrographic analysis.

Cores submitted to the laboratory represent only a small portion of the aquifer section. Accordingly, in maintaining a conservative approach, an analyst must assume that siderite and pyrite can occur in aquifer sand or CAS intervals screened by an MAR well beneath SWIFT-JR.

PHREEQC simulated minerals in the six packer testing intervals using water quality analyses as input (Table 6-7). The presence of minerals was determined by assessing model derived saturation indices (SI's . Supplementary to the core results, SIs helped identify amorphous phases that may not emerge from the XRD or petrographic analysis. Typical of a quartz sand, SI's for quartz exceeded saturation in all samples. Consistent with petrographic and acid insoluble residue analysis calcite, aragonite, and dolomite displayed undersaturated SI's. Except for one interval (Packer Interval 3), siderite exhibited saturated SI's suggesting it should occur as a mineral in aquifer. However, siderite was not identified in any of the cores.

$FeOH_3$ a), a mineral identical to hydrous ferric oxide (HFO displayed saturated SI's in four of the six samples. HFO appeared as grain coating or pore filling in several petrographic slides. Aluminum oxide minerals like gibbsite, boehmite, and amorphous aluminum hydroxide ($AlOH_3$ displayed mostly undersaturated SI's indicating they should undergo dissolution from the aquifer sands. However, these minerals often appeared in petrographic slides as a pore filling precipitate co-located with dissolving feldspar grains. Clay minerals including kaolinite, illite, and several types of montmorillonite displayed consistently saturated SI's.

As a thermodynamic equilibrium model, PHREEQC simulates equilibrium conditions. Most SI results appeared consistent with the results of core analysis. Conflicts between the model results and mineralogic analysis suggest disequilibrium in the NGW/aquifer mineral system.

Table 6-7. Summary of Saturated Indices Estimated by PHREEQC Using NGW Quality from Packer Tests

Packer Intervals	Test interval (depth BG)	pH (S.U.)	pE (Volts)	Pyrite (FeS_2)	Mackinawite (FeS)	Siderite ($FeCO_3$)	Quartz (SiO_2)	$Al(OH)_3$(a) amorphous	Boehmite (AlOOH)	Gibbsite ($AlOH_3$)	Aragonite ($CaCO_3$)	Calcite ($CaCO_3$)	Dolomite ($CaMg(CO_3)_2$)	Chalcedony (SiO_2)	Cristobalite (SiO_2)	Anhydrite ($CaSO_4$)	Gypsum ($CaSO_4{:}2H_2O$)	Magnesite ($MgCO_3$)	Hydroxyapatite ($Ca_5(PO_4){:}3OH$)	Fluorapatite ($Ca_5(PO_4)$ 3F)	Rhodochrosite ($MnCO_3$)	Fe(OH)3(a) (amorphous)	Goethite (FeOOH)	Maghemite (Fe_2O_3)	Kaolinite ($Al_2Si_5O_5(OH)_4$)	Illite ($K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.55}O_{10}(OH)_2$)	Montmorillonite BelleFourche ($(HNaK)_{0.14}Mg_{0.4}Fe_{0.3}Al_{1.47}Si_{3.82}O_{10}(OH)_2$	Montmorillonite Aberdeen ($(HNaK)_{0.09}Mg_{0.29}Fe_{0.24}Al_{1.57}Si_{3.93}O_{10}(OH)_2$	Montmorillonite Ca $Ca_{0.16}Al_{2.3}Si_{3.67}O_{10}(OH)_2$	Kmica $KAl_3Si_3O_{10}(OH)_2$	Chlorite14A $Mg_5Al_2Si_3O_{10}(OH)_8$	Fluorite (CaF_2)
PT-1 UPA	398 to 524 fbg	6.75835	1.15	-50.2268	-33.2177	0.0261	0.7797	-2.3332	-0.1125	0.348	-1.4236	-1.2805	-2.6656	0.3536	0.3874	-2.692	-2.4771	-1.9685	-7.6831	-4.719	-1.4282	-1.2174	4.7087	0.9632	3.0842	0.8435	4.6109	3.4561	1.8289	6.4627	-12.6664	-1.8979
PT-2 UPA	570 to 636 fbg	7.69179	1.69	-71.956	-44.6672	0.9868	0.8075	-2.9877	-0.777	-0.2847	-0.426	-0.2812	-0.6995	0.3739	0.4123	-2.6818	-2.4576	-0.9959	-1.2889	0.8416	-0.4813	2.0425	7.8831	7.4831	1.8646	0.449	4.9019	4.51	0.7137	5.5283	-5.1932	-1.8462
PT-3 UPA	735 to 790 fbg	6.13997	2.18	-55.065	-36.776	-1.0887	0.747	-3.4688	-1.2446	-0.7951	-2.2028	-2.0604	-4.1968	0.3235	0.3557	-2.497	-2.2858	-2.7216	-9.0939	-5.5763	-2.285	-2.2645	3.6909	-1.1308	0.7362	-2.522	2.113	0.7372	-1.1247	2.3479	-20.4198	-1.8782
PT-4 MPA	960 to 1000 fbg	7.20847	1.55	-63.0305	-40.1534	0.1857	0.8052	-2.6118	-0.3917	0.0709	-0.8557	-0.7125	-1.5061	0.3786	0.4127	-2.4447	-2.2295	-1.3766	-3.1147	-0.6668	-1.0396	0.2655	6.1857	3.9294	2.5805	0.8831	5.0184	4.2488	1.446	6.245	-7.841	-1.8963
PT-5 MPA	1048 to 1122 fbg	7.25254	1.69	-65.36	-41.3953	0.3411	0.7952	-2.6593	-0.439	0.0235	-0.7008	-0.5576	-1.1747	0.3686	0.4027	-2.2153	-2.0004	-1.2001	-3.0109	-0.7373	-0.8448	0.6629	6.5833	4.7248	2.4657	0.8624	5.0887	4.4097	1.3343	6.1805	-6.7922	-2.0321
PT-6 LPA	1240 to 1280 fbg	7.60009	1.7	-71.0527	-44.2528	0.6835	0.7199	-3.0369	-0.813	-0.3613	-0.1942	-0.0516	-0.123	0.2958	0.3284	-1.9302	-1.7193	-0.6561	-1.718	-0.2213	-0.3175	1.7092	7.6578	6.8184	1.5493	0.2167	4.8756	4.5153	0.3175	5.2592	-3.2229	-2.6984

6.4 Mineral Dissolution/Precipitation Evaluation

6.4.1 Mixing Between Recharge Water and Native Groundwater

Mixing during MAR operations occurs when the recharge water contacts NGW from the receiving aquifer s . A mixing interface will form between the two water types, subsequently migrating away from the MAR well, growing thinner as the storage bubble expands (Figure 6-5). The position of the mixing interface will depend on several factors including how much recharge an individual screen interval accepts, the ambient hydraulic gradient, and the dispersion coefficient within the interval. A large dispersion coefficient increases the width of the mixing interface.

As described, mixing reactions around the MAR wellbore may cause operational challenges. One common reaction involves precipitating metal-oxide minerals when recharge containing DO contacts dissolved iron or manganese entrained in the recharge or native groundwater. Both recharge waters contained measurable concentrations of DO. Recharge chemistry estimated by modeling contained dissolved iron concentrations exceeding 1 mg/L. Conversely, NGW in the UPA and MPA exhibited anoxic concentrations of DO (DO < 1.0 mg/L) but concentrations of iron and manganese ranged between 1.4 to 2.7 mg/L and 0.05 to 0.08 mg/L, respectively. Minerals including, but not limited to calcite, aragonite, siderite, and gypsum can also precipitate during mixing.

6.4.1.1 Mixing Modeling

To evaluate mixing between the differing water types, estimated carbon-based recharge water and NGW from the UPA and MPA were blended at the following percentages of recharge using PHREEQC: 99, 98, 95 90, 85, 80, 70, 50, 30, 20, 10, 5, and 1. Two mixing simulations were run; the first involved mixing carbon-based recharge water with NGW from the shallowest interval that underwent packer testing in the UPA (398 to 524 fbg), while the second used water from the uppermost packer tested interval in the MPA (960 to 1,000 fbg).

As trace amounts of pyrite was encountered in the several samples, to impose conservative conditions on the modeling , PHREEQC simulated equilibrium between the mixed water and pyrite set at 1 percent, concentrations encountered in the core composed of clayey sand, collected at 491 fbg. In addition to pyrite, important reactions tracked during the mixing simulations included the potential precipitation of metal oxides, hydroxide, sulfate, and carbonate minerals along with dissolution of silicates, including clays.

Major ions including sodium, calcium and chloride tracked as expected from a mixing relationship (Figure 6-6). By comparison, iron and sulfate concentrations tracked higher than expected in mixed samples containing high percentages of recharge, reflecting modeled equilibrium between pyrite and DO. Iron concentrations reached 12 mg/L in samples of 99 percent recharge mixed with groundwater of the UPA and MPA, respectively. Sulfate concentrations in the mixed water from both aquifers approached 63 mg/L at a blend of 99 percent recharge, even though sulfate in the recharge was estimated at only 32 mg/L.

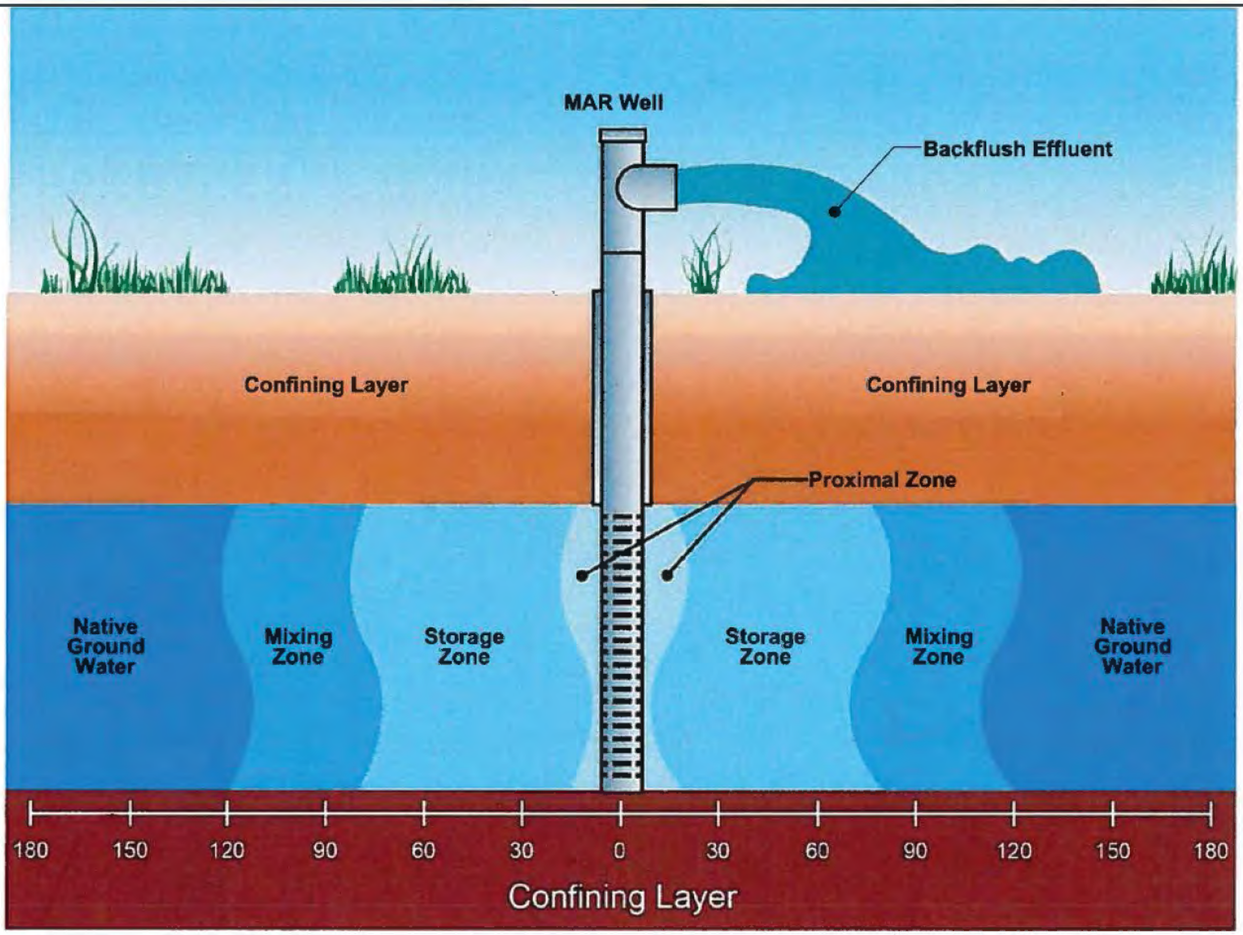


Figure 6-5. Conceptual Cross Section Showing Mixing Interface During MAR Operations
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

Source: Modified from Pyne, 2005

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f66_6X93158.dgn

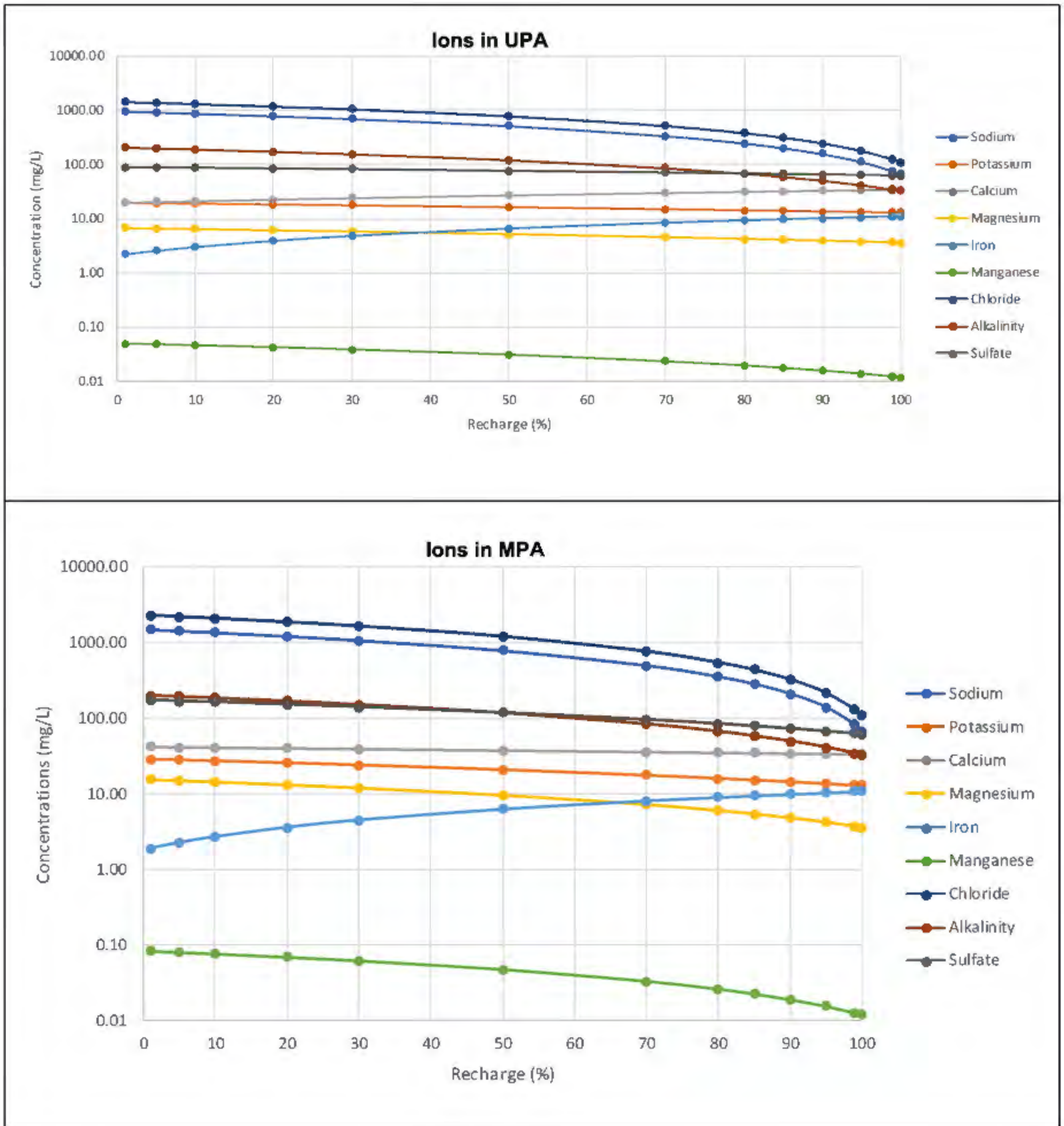


Figure 6-6. Ions in Simulated Mixed Water from UPA (398 to 524 fbg) and MPA (960 to 1000 fbg) at SWIFT-JR

Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f67_6X9315B.dgn

When examining potential reactions involving minerals, mixing simulations displayed similar results across the UPA and MPA. An explanation for saturation indices (SI's appears in Section 3.4. Hydrous ferric oxide (HFO , expressed in this modeling as $Fe(OH$ $_3$ a), an amorphous, iron-bearing mineral commonly found in groundwater environments, displayed strongly negative SI values centered around -3.00 (Figure 6-7), suggesting a tendency to dissolve in the mixed water.

Carbonate minerals, including calcite ($CaCO_3$), dolomite (CaMg CO_3 $_2$, magnesite ($MgCO_3$, and rhodochrosite ($MnCO_3$ displayed negative SI's, ranging between –1.0 and -4.0, suggesting a tendency to dissolve in mixed water. The negative SI range simulated for the minerals will not produce carbonate scaling on the screen or filter pack and thus, does not a potential source of clogging for the MAR well. Only the carbonate mineral, siderite, maintained a positive SI as the recharge mixture percentage increased in the simulations. Precipitating siderite removes iron from the mixed water. As long as the recharge drives the mixing interface away from the wellbore, and it never returns over the service life of the well, precipitating siderite should not present an aquifer plugging issue. Gypsum $CaSO_4 \cdot 2H_2O$ exhibited negative SI's in mixed samples across simulated UPA/MPA/ recharge mixing percentages.

The clay mineral kaolinite, along with gibbsite ($Al(OH$ $_3$, a weathering product of clays, displayed slightly positive SI's, indicating a tendency to precipitate. However, the precipitation of silicate minerals, including clays, happens slowly at temperatures encountered in groundwater environments (Barnes, et al., 1992 SEPM no. 47 , and accordingly should not influence MAR operations.

6.4.2 Evaluating Reactions Between Recharge Water and the Aquifer Matrix

An essential element of the geochemical compatibility analysis entails evaluating reactions between the recharge water and minerals residing in the aquifer matrix. The pH of the recharge and constituents like DO can react with metal-bearing minerals to precipitate oxides or mobilize undesirable constituents resulting in operational and/or water quality problems. In applying ozonation as treatment process, DO measured in the carbon-based effluent of the AWT at SWIFT-JR will exceed 5 mg/L.

Common reduced, metal- bearing minerals in the PAS aquifers include pyrite and siderite. Results of the XRD and petrographic analysis of formation samples from the pilot boring at TW-4 showed no evidence of pyrite in aquifer sands, but trace concentrations, 0.3 to 1 percent in CAS samples from the UPA and MPA.

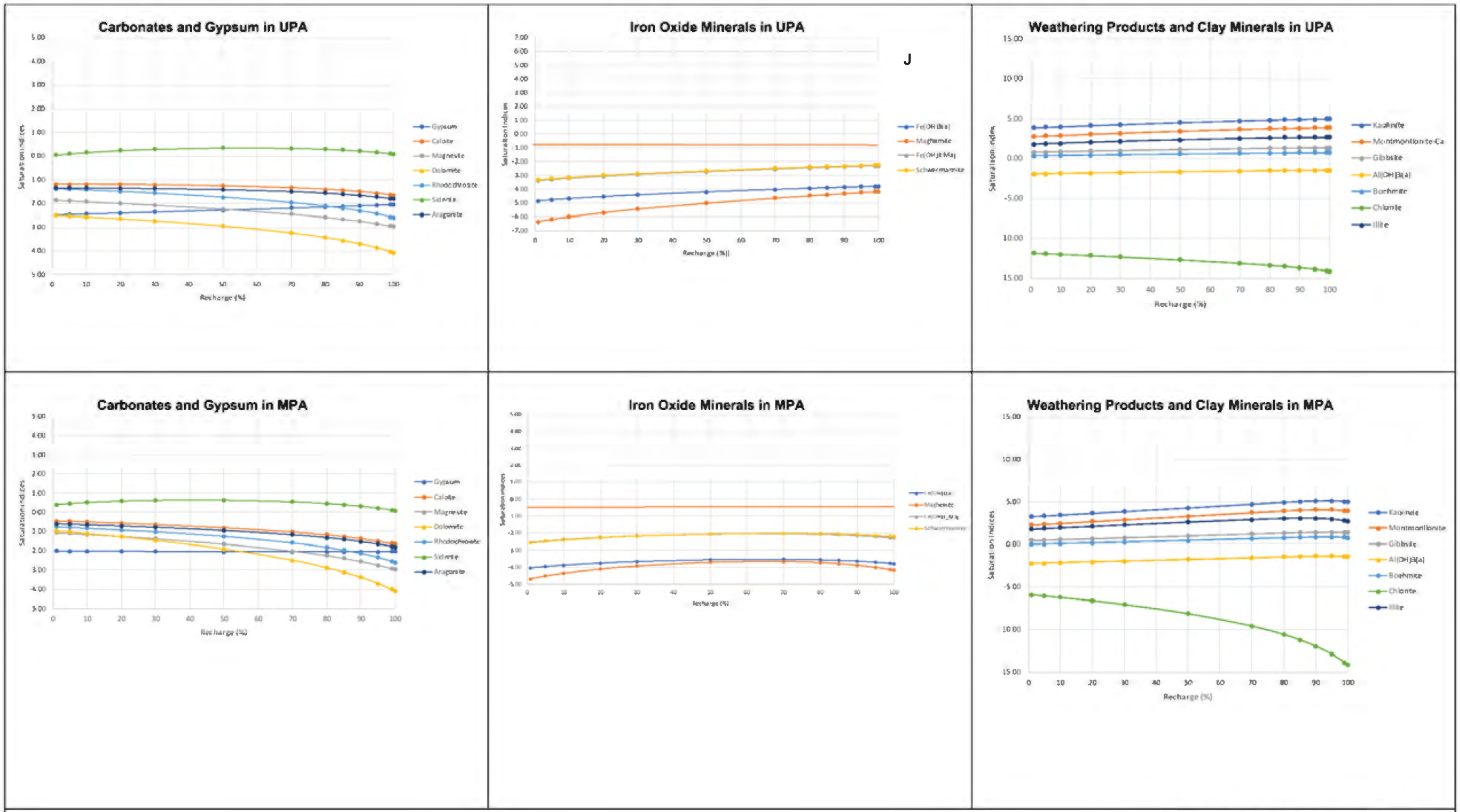


Figure 6-7. Saturation Indices in Simulated Mixed Water in UPA (398 to 524 fbg) and MPA (960 to 1000 fbg) at SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL 5F | DESIGNS - SMALL PROJECTS | 6X9315B - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f66_6X9315B.dgn

Although ferrous iron represents the primary metal in pyrite, manganese and cadmium can partially occupy the iron site in the atomic structure of both minerals (Deer, Howie, and Zussman, 1965 . Additionally, in the Cretaceous age sediments of the Atlantic Coastal Plain, pyrite occasionally contains varying amounts of arsenic Evangelou, 1995).

Arsenic Encountered at SWIFTRC

During testing at HRSD's SWIFTRC, arsenic appeared in samples collected at a monitor well (MW-SAT located 50 feet away from the MAR well. A FLUTe liner system installed in MW-SAT facilitated collecting depth discrete sampling from 11 sand intervals, comprising the UPA, MPA, and uppermost LPA, equivalent to the intervals screened in SWIFTRC's TW-1. Arsenic concentrations exceeding MDL's appeared in Screens 1, 2, 3, and 5 shortly after detecting SWIFT recharge migrating past MW-SAT during June and July 2018. Concentrations climbed up to 0.007 mg/L, but did not exceed the PMCL of 0.01 mg/L. During June 2019, arsenic concentrations in Screen 9 exceeded the PMCL of 10 ug/L, ranging up to 20 ug/L over three samples, collected daily.

Screen 9 represented the deepest and longest screen spanning the MPA (Figure 6-8). Despite its greater depth 1040 to 1,090 fbg placeholder , Screen 9 displayed the fastest arrival of recharge compared to much shallow screens. Moreover, during idle periods or extended pumping, samples from Screen 9 showed rapid incursions of NGW. The change in chemistry during these intervals more likely represents back diffusion or intra-aquifer circulation rather than NGW migrating back toward TW-1.

Except for Screen 9, the emergence of arsenic in depth discrete samples coincided with other evidence of chemical reactions including increasing iron and sulfate concentrations, inferring a relationship with pyrite oxidation. DO was not encountered in any samples, and was probably consumed in reactions with pyrite and other reduced minerals before recharge migrated past MW-SAT. With time, the pyrite oxidation signature elevated iron and sulfate) diminished, coincident with falling arsenic concentrations.

Unlike other screen intervals, arsenic concentrations appeared in Screen 9 significantly after the recharge front migrated beyond MW-SAT. The later appearance of arsenic in Screen 9 suggests a constituent attenuated during migration, but finally breaking through, and releasing arsenic. If the agent remained close to Screen 9, during the period when HRSD suspended recharge operations, between late November 2018 and April 2019, it could have arrived with the renewed recharge, causing the coinciding arsenic spike.

The lack of elevated ferrous iron in the data suggests competitive desorption of arsenic with a constituent like phosphate, carbonate, or other anionic constituents. Phosphate, in particular (Manning and Goldberg 1996) competes with arsenic on common oxide surfaces including HFO in aquifer environments Figure 6-9). Phosphate concentrations in the SWIFT recharge have ranged from 0.02 to 0.2 mg/L, enough present to release tens of ug/L arsenic. Competitive desorption does not stimulate strong indications of a chemical reaction other than elevated arsenic. An anionic agent like phosphate gets consumed during the reaction through adsorption, only appearing later as potential adsorption sites in the aquifer matrix become filled with phosphate.

Arsenic speciation (Table 6-8) analyses display As (V) as the predominating ion over most of the period of rising arsenic concentrations in Screen 9 with As (III) concentrations increasing later. The As V appears consistent with a competitive desorption of arsenic by another oxy-anion. As (V) adsorbs to HFO and other oxide surfaces more easily than As III), but is also more readily available for replacement. Later emerging As III) concentrations appears consistent with the exhaustion of As (V) and subsequent replacement of As III) through competitive adsorption.

Table 6-8. Summary of Arsenic Speciation Analyses in Screens 5 and 9 from MW-SAT At SWIFT-RC

Date	Screen #	As (III) (mg/L)	As(V) (mg/L)	As total (mg/L)	Comment
5/8/2019	9	0.001	0.019	0.02	Analyzed sample from period of greatest arsenic concentrations
7/2/2019	9	0.0022	0.0031	0.0053	Analyzed after concentrations dropped to 0.005 mg/L
7/2/2019	5	0.0035	ND	0.0035	Arsenic concentrations in Screen 5 increased up to 0.0045 mg/L in October 2018 coincident with pyrite oxidation signature (elevated iron & sulfate)

Note:

ND = Not detected

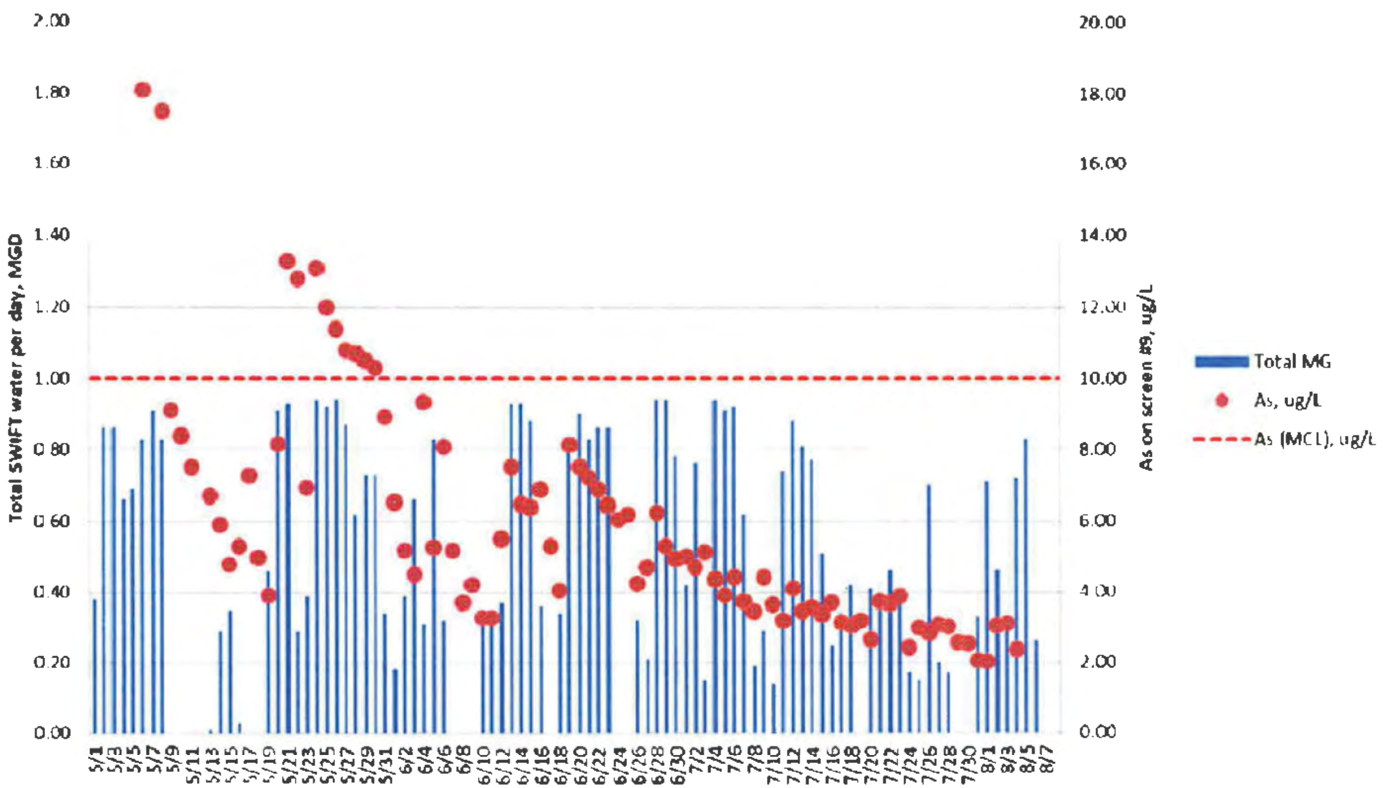


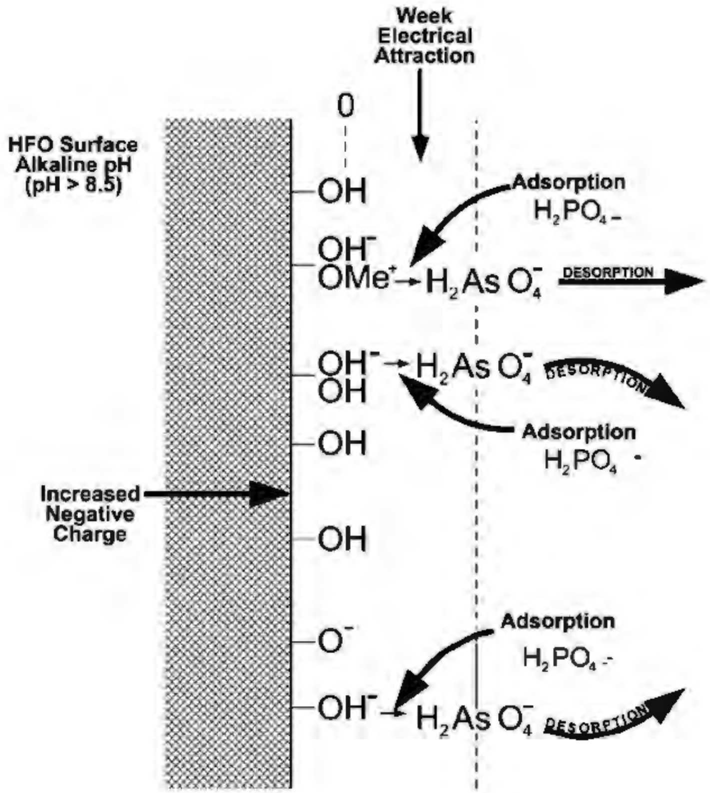
Figure 6-8. Arsenic Concentrations in Screen 9 of MW-SAT at HRSD SWIFTRC May 1 to August 7, 2019
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

Source: HRSD SWIFTRC (2019)

DEN00* | DOCUMENTS DENT WBG IMPERIAL SF | DESIGNS SMALL PROJECTS | 6X9315B HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f50_6X9315B.dgn

Appendix D: HRSD James River SWIFT Te



Legend

▨	HFO Surface
OH	Hydroxyl Coordinated with Iron
OMe^+	Adsorbed Metal
$H_2AsO_4^-$	Arsenate
$H_2PO_4^-$	

Figure 6-9. Conceptual Diagram of HFO Surfaces During Competitive Desorption Reactions
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

Mobilizing Metals from Pyrite Oxidation

Consistent with the maximum amount found during XRD analysis, pyrite at a concentration of 1.0 percent abundance was reacted with recharge water containing DO concentrations ranging from 1 to 20 mg/L. Reacting carbon-based recharge water with pyrite released Fe II and the bisulfide ion (Evangelou, 1995). Upon encountering DO, Fe II oxidized to the ferric (Fe III) ion which also acts as a strong oxidant, continuing the oxidation of pyrite (Figure 6-10). Fe (III) eventually precipitates as HFO, lowering the pH of the surrounding pore water. The bisulfide ion (S_2^{2-} further reacts with DO to form sulfuric acid (H_2SO_4 , also lowering the pH of the surrounding pore water (Figure 6-11).

Modeling results showed that Fe (II) concentrations increased from 11 to 21 mg/L at DO concentrations of 1 to 20 mg/L, respectively. The pH declined to 6.1 during the simulations between pyrite and carbon-based recharge water. If iron oxide precipitates during the reaction, the pH declines to 5.6. The estimated recharge chemistry exhibited alkalinity at 110 mg/L, a sufficiently elevated concentration to buffer the pyrite oxidation reaction. Simulations with recharge containing lower alkalinity concentrations, often result in pH falling below 5.0 CH2M HILL, 2016).

Mobilizing Arsenic from Pyrite Oxidation

Arsenic substitutes for sulfur in pyrite as an oxy-anion of As III). The overall reaction for oxidizing arsenian pyrite with DO is as follows:

$$FeS_2\text{-}H_2AsO_3^{-1} + 4O_2 + H_2O \rightarrow Fe^{2+} + 2)SO_4^{2-} + AsO_4^{3-} + 2H_2^{+}$$

The reaction liberates As III from pyrite, which eventually oxidizes to As V in most groundwater environments. Yet, the oxidation of As III) to As (V) usually occurs very slowly (Evangelou, 1995 .

Studies on the composition of pyrite have shown a wide range of arsenic substitution (Jones and Pichler, 2007; Kolker and Nordstrom, 2001). In cores from Florida, x-ray fluorescence analysis indicated that arsenic substituted for sulfur in 10 percent of the available sites Jones and Pichler, 2007). However, other studies revealed significantly lower amounts of substitution, ranging between 0.1 and 1% by mass of total pyrite. The formula for pyrite with 1% by mass of arsenic equals:

$FeS_{1.984}As_{0.016}$, and for 0.1% by mass is $FeS_{1.9984}As_{0.0016}$.

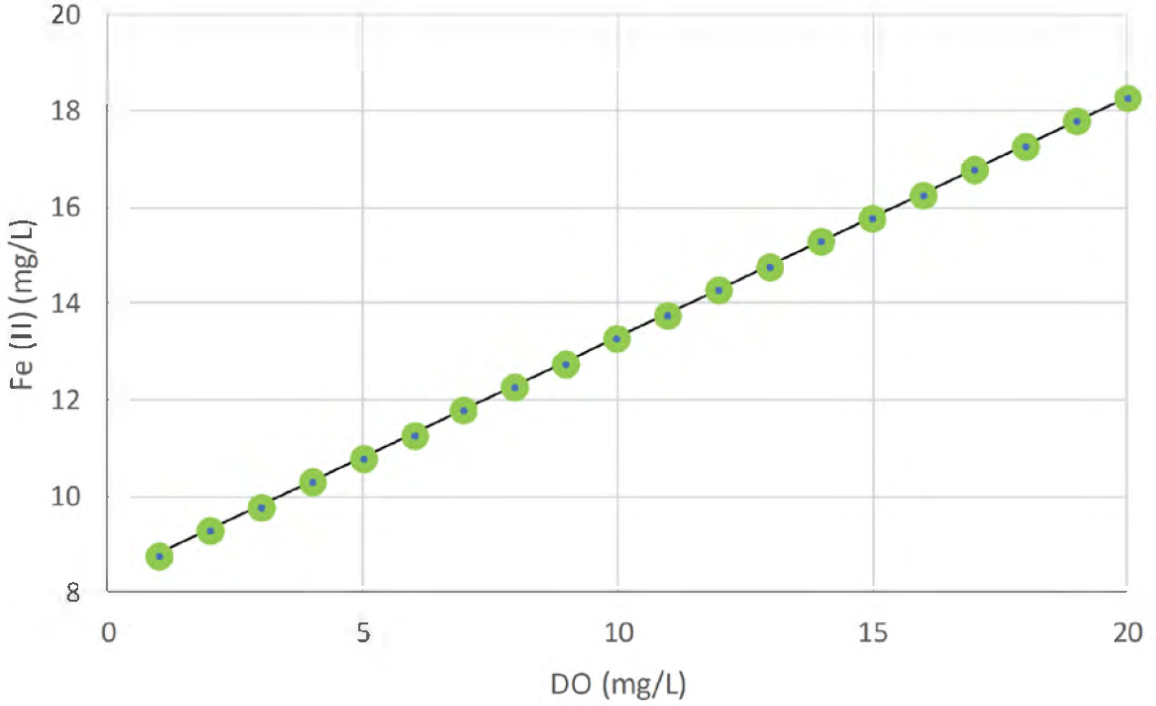


Figure 6-10. Iron Concentrations in Recharge Water During Pyrite Oxidation in UPA
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DENT WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | 170_6X93158.ogn

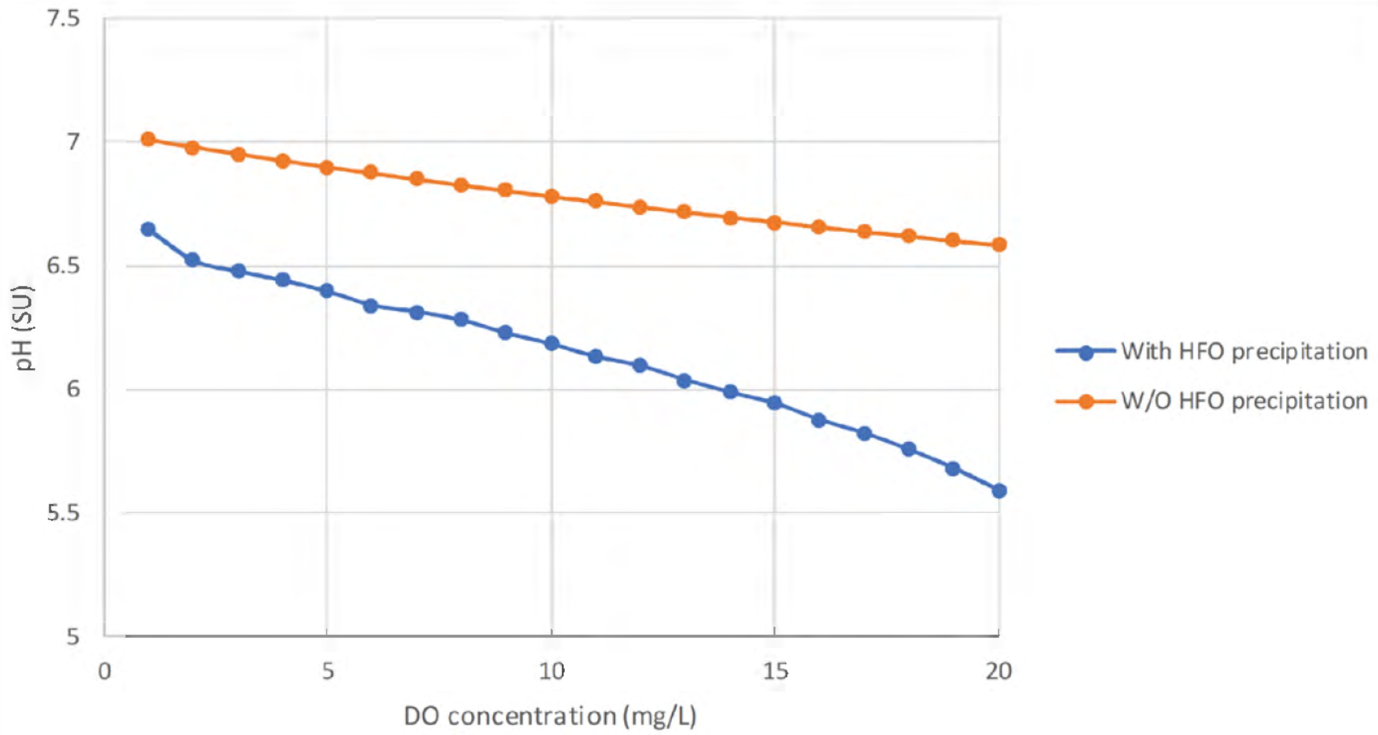


Figure 6-11. pH of Recharge Water During Pyrite Oxidation in UPA
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

DEN001 | DOCUMENTS - DENT WEG IMPERIAL_SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | 71_6X93158.dgn

The release of arsenic from pyrite was simulated with PHREEQC. In substituting for sulfur, arsenic concentrations were estimated as 1 percent by weight of the mass of pyrite. Then, pyrite was equilibrated with carbon-based recharge waters containing DO concentrations ranging from 1 to 20 mg/L. Applying this approach, arsenic concentrations increased from 0.7 to nearly 1.05 mg/L.

Arsenic concentrations in samples collected at MW-SAT at HRSD's SWIFTRC showed significantly lower concentrations than the modeling simulations. As described previously maximum arsenic concentration did not exceed 10 ug/L, when associated with other indicators of pyrite oxidation, including elevating iron and sulfate, and declining pH. Assuming no other mechanisms, except for pyrite oxidation, influencing its migration, arsenic percentages in pyrite probably fall several orders of magnitude less than 1 percent of the sulfur sites.

6.4.3 Assessing the Importance of Reactions Related to Dissolution and Precipitation

Based on the evaluation of mineral dissolution and precipitation reactions above the following impacts have been identified (Table 6-9):

Table 6-9. Identification of Impacts due to Mineral Dissolution and Precipitation

Geochemical interaction	Identified Potential Impact	Cause	Effect
Recharge Water/ Groundwater Mix with Aquifer Matrix	No identified impact	Not applicable	Not applicable
Recharge Water with Aquifer Matrix	Iron mobilization	DO in recharge water oxidizes pyrite, lowers pH and releases iron	Water quality impacts/aquifer degradation
Recharge Water with Aquifer Matrix	Arsenic mobilization	DO in recharge water oxidizes pyrite, lowers pH and releases arsenic	Water quality impacts/ aquifer degradation
Recharge Water with Aquifer Matrix	Lowering of pH	Oxidation reactions creates acid	Further mobilization of metal bearing minerals and destruction of HFO passivation coatings

6.4.4 Mitigating Mineral Dissolution and Precipitation

The modeling of the recharge water with the aquifer matrix indicates the potential for dissolving pyrite to release significant amounts of iron. Furthermore, if pyrite contains arsenic, it gets released in the same reactions. Pretreating the recharge water can prevent mobilizing these constituents.

6.4.4.1 Mitigating Iron Mobilization from Pyrite Oxidation

At other MAR facilities that recharge aquifers beneath the Atlantic Coastal Plain, such as aquifer storage and recovery (ASR) wells, siderite and pyrite dissolution is addressed by increasing the pH of the recharge by adding sodium hydroxide or potassium hydroxide. Increasing the pH raises the recharge above the solubility limit of these minerals, buffering their dissolution. Moreover, hydroxyl ions in sodium and potassium hydroxide will react with Fe (II) released from siderite or pyrite, precipitating HFO on the surface of these minerals, thus, reducing the reactivity of the mineral passivation). Elevating the pH by adding sodium or potassium hydroxide expedites oxidizing Fe(II) to Fe(III) at water temperatures over 10^{o}C. The reaction slows at lower temperatures.

In addition to passivating pyrite, HFO surfaces display excellent adsorption properties, adsorbing metals migrating in the aquifer environment including arsenic and Fe (II) (Figure 6-12). Iron adsorbs as a surface precipitate on HFO, while these surfaces exhibit an affinity for adsorbing arsenic at the pH values encountered in groundwater environments Dzomback and Morel, 1990).

Yet, the release of Fe(II) holds some other implications for SWIFT recharge operations. Fe(II) reduces nitrate and nitrite concentrations in SWIFT recharge. The reaction benefits operations if nitrate/nitrite gets reduced to harmless, nitrogen and oxygen, but can cause negative effects if the reaction does not proceed to completion and nitrite concentrations accumulate.

6.4.4.2 Mitigating Pyrite Oxidation (Arsenic Mobilization)

HFO surfaces in aquifer settings display a strong affinity for adsorbing the oxyanions of arsenic, comprising arsenite (As III) and arsenate (As V), and lowering its concentrations in groundwater. The program PHREEPLOT Kinniburgh, 2011) was applied to assess arsenic equilibria in relation to the HFO surfaces. PHREEPLOT combines the geochemical model, PHREEQC, with several plotting programs.

The phase diagrams developed using PHREEPLOT include diagrams of 1) arsenic with HFO and 2) the stability of iron. Recharge and native groundwater chemistries fall in the As V oxyanion fields which include $HAsO_4^{2-}$ and $NaAsO_4^{2-}$ at the pH of recharge in the PAS. Equilibrium relationships portrayed in the diagram suggest that if pyrite releases As (III), it should oxidize to As (V). The plot also implies that adsorbed arsenic (HFO complexes dominate the arsenic distribution at the pH and redox conditions present in the recharge/NGW mixing zone.

The simulation suggests that HRSD can protect water quality in the aquifer by developing HFO surfaces, and that these surfaces will adsorb arsenic migrating in groundwater the PAS. However, research shows that the kinetics of oxidizing As (III) to As (V) proceeds slowly in groundwater environments with only DO, a relatively weak oxidant, controlling the oxidation process Smedley and Kinniburgh, 2001). Figure 6-13 shows that HFO adsorbs As III) under a narrow range of reducing conditions that do not coincide with conditions expected in the PAS aquifers during MAR operations. Samples of recharge and native groundwater from the UPA and MPA appear in equilibrium with $Fe(OH)_3$ a) equivalent to HFO in the model).

As described by reactions encountered at the SWIFTRC, pyrite oxidation and migrating oxy-anions, like phosphate can complicate relationships between As V), As III), and HFO. HFO can buffer the release of arsenic into the migrating recharge, caused by pyrite oxidation, by adsorbing As V and As (III). While competing oxy-anions like phosphate can bring these ions back into solution.

Yet, creating HFO surfaces and subsequent adsorption appears to occur after several pore volumes of recharge passes through an aquifer interval. Thus, HFO is not generated at the leading edge of the recharge plume, but within the plume. So, the benefits of ions adsorbing to HFO are not realized near the plume's leading edge. Consequently, samples from a sentinel monitoring well can detect deleterious reactions between the recharge and aquifer that release undesired constituents into the migrating recharge.

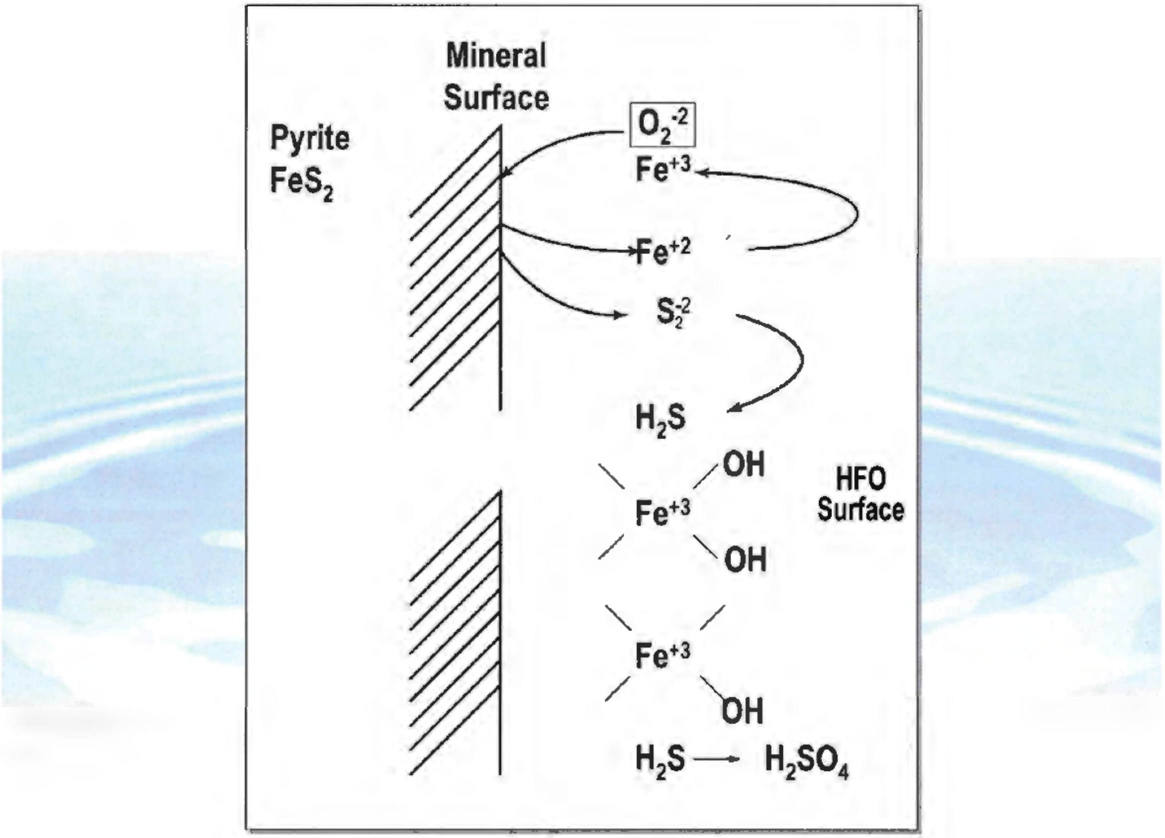


Figure 6-12. Conceptual Depiction of Pyrite Oxidation
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN! W8G IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93159 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | I72_6X93158.dgn

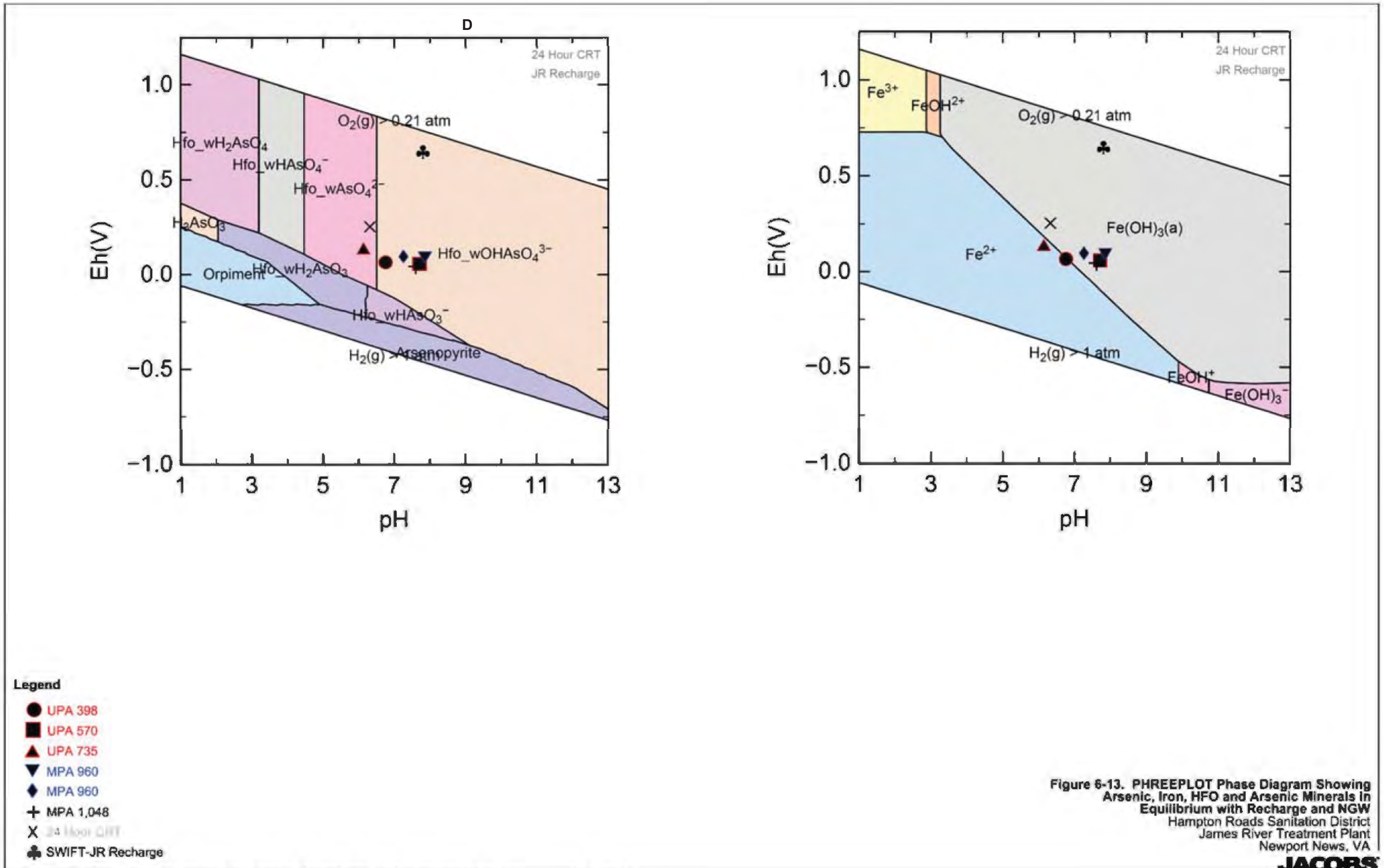


Figure 6-13. PHREEPLOT Phase Diagram Showing Arsenic, Iron, HFO and Arsenic Minerals in Equilibrium with Recharge and NGW
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA
JACOBS

6.4.4.3 Setting pH and Alkalinity Targets for Passivating Pyrite

To mitigate potential pyrite oxidation/dissolution caused by reactions when the recharge contacts these minerals in the PAS, HRSD should increase the pH of carbon-based recharge water using sodium hydroxide (NaOH). Thus, HRSD operators will need to control the pH and alkalinity of the recharge water. The following factors will constrain these important constituents:

- Adding NaOH to the recharge should provide enough hydroxyl ion to precipitate HFO and passivate reactive minerals.
- In the face of acid-producing reactions caused by pyrite oxidation, the recharge should contain alkalinity to buffer the pH in the aquifer, protecting HFO surfaces from dissolution.
- Manage the pH to avoid the precipitation of calcium carbonate ($CaCO_3$, a potential clogging agent in MAR wells.

PHREEQC was used to evaluate the relationship between recharge pH, alkalinity, NaOH dosage (at 100% solution strength), the saturation index (SI) of calcite ($CaCO_3$ and its isomorphs, and the SI of HFO surfaces Figure 6-14). Typically, an SI greater than +0.3 or less than -0.3 indicates that mineral will precipitate or dissolve, respectively.

Although HFO appears safe from dissolution at the pH values listed in the table, the SI of HFO reaches under-saturation at a pH of 6.7 and below. Accordingly, the modeling results suggest that maintaining a pH greater than 6.7 in the aquifer will prevent the dissolution of carefully developed HFO surfaces. Modeled redox conditions are not sufficiently oxidizing to form HFO under these conditions. However, HFO should not dissolve unless the pH drops below 6.7. Similarly, to prevent precipitating $CaCO_3$ in the recharge, LSI and SI values should not exceed +0.3. Accordingly, the recharge pH should not exceed 7.8.

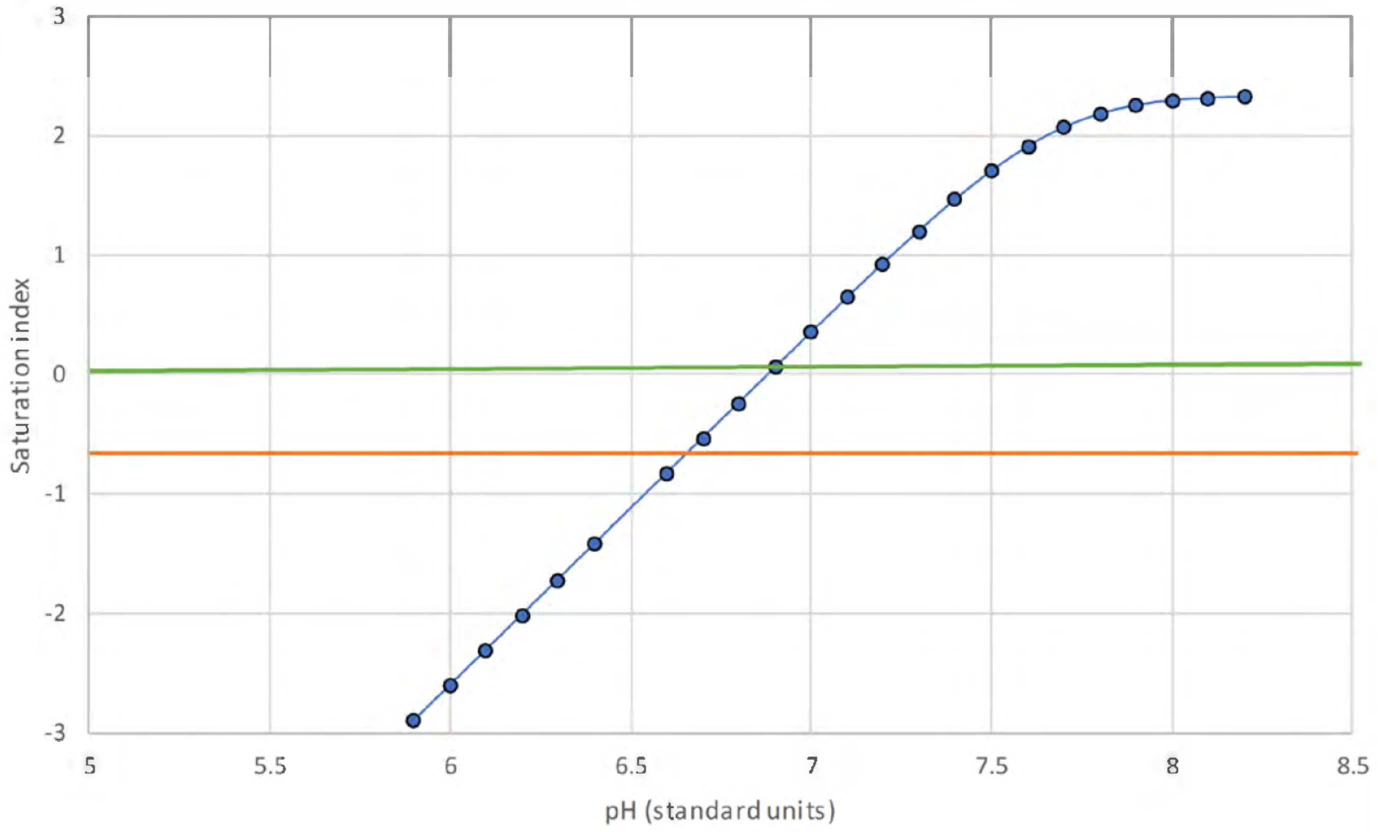


Figure 6-14. Saturation Indices in Recharge Water at Varying pH
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA
JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X03158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f14_6X03158.dgn

PHREEQC was also applied in determining the minimal alkalinity concentrations for buffering the pH of stored water after reactions between recharge containing variable amounts of DO and an aquifer matrix composed of reactive iron-bearing minerals. As shown by the modeled SI values for HFO, alkalinity concentrations in the carbon-based recharge should provide enough buffering to maintain a pH of 6.7 in the aquifer to protect HFO surfaces from dissolution (Figure 6-15).

In this set of simulations, pyrite was equilibrated with the expected recharge chemistry, comprising a pH of 7.8, and DO concentrations varying between 1 and 20 mg/L. As the proposed carbon-based recharge water for SWIFT-JR already assumes an alkalinity concentration of 110 mg/L, a hypothetical simulation was conducted at 60 mg/L to demonstrate the sensitivity of the geochemical system to broader changes in alkalinity. The alkalinity was also tested at 80, 100, 120, 140, 160, 180, 200, 220, and 240 mg/L. Oxidizing pyrite with DO creates sulfuric acid, a strong acid that completely disassociates in water, and so presents a conservative situation for testing the capacity of a buffering agent during reactions in a storage aquifer.

Simulation results indicated that a minimum alkalinity of 120 mg/L was required to maintain a pH of greater than 6.7 during reactions between pyrite and the recharge. The estimated 110 mg/L alkalinity of the recharge exceeds falls slightly less than the preferred threshold. Thus, the recharge may require additional alkalinity to maintain a pH of 6.7 in the PAS during pyrite oxidation. The estimated alkalinity in the recharge should maintain the pH around 7.0 after pyrite oxidation.

Simulations performed at other MAR sites in the Atlantic Coastal Plain where CO_2 is added to increase the alkalinity of the recharge show similar results, with an alkalinity in the recharge around 100 mg/L proving effective in maintaining the pH in the receiving aquifer.

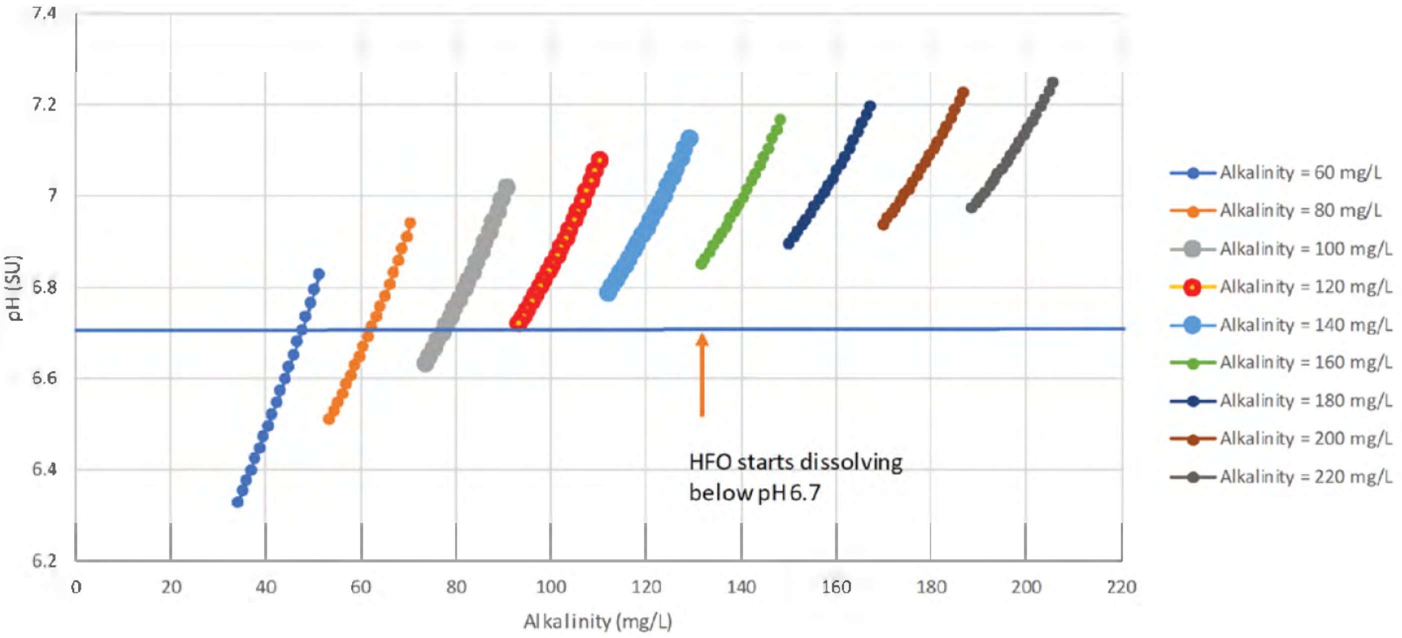


Figure 6-15. Graph Showing pH at Varying Alkalinity in Recharge Water During Pyrite Oxidation
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f75_6X93158.dgn

6.5 Clay Mineral Damage

As described above, MAR operations can damage clay minerals in the aquifer if the recharge is not compatible with the clay mineral chemistry. The two most common forms of damage occur when:

- Cations are exchanged between the recharge and clays residing in the interstitial spaces of the aquifer
- The ionic strength of the NGW exceeds the recharge by greater than one order of magnitude

Both reactions damage clays, releasing fragments that accumulate in interstices of sands, eventually reducing the permeability of the aquifer formation damage). Reactions in the sensitive areas immediately around the wellbore, where surface areas are small, promotes extensive formation damage through clogging. Surface area increases geometrically away from an MAR well. Thus, clogging of an individual pore throat at several feet away from the MAR well exerts minimal change on the bulk permeability of the aquifer.

Moreover, the velocity of recharging water progressively declines with distances from an MAR well. Although the cationic chemistry or ionic strength of a recharge water may weaken or expand a clay's mineral structure, the groundwater velocity needs to exceed the shear strength of the damaged mineral to mobilize mineral fragments, and deposit them in a pore throat, to incur formation damage. Subsequently, hydraulic mechanisms that lead to clogging are diminished at distances from the MAR wellbore, while the effects of clogging are widely dispersed and may not influence the bulk permeability of the aquifer.

6.5.1 Cation Exchange

Exchanging cations can disrupt the clay mineral structure particularly when their atomic radius exceeds the radius of the exchanged cation. The larger cation fragments the tabular structure, shearing off the edges of the mineral (Figure 6-16). Plate-like fragments break off the main mineral particle and migrate with flowing groundwater. Like the damage incurred by water of differing ionic strength, migrating clay fragments will accumulate in pore spaces, physically plugging passageways and reducing aquifer permeability. Unlike the accumulation of TSS in the wellbore, formation damage caused by migrating clays develops in the aquifer away from the wellbore, making its removal by backflushing or even invasive rehabilitation techniques very difficult. Consequently, the damage often proves irreversible.

Cation exchange describes the substitution of cations in solution for those held by a mineral. Cation exchange mechanisms are debated, but most agree are driven by a net negative surface charge on mineral surfaces. Samples of the aquifer sands and clay rich sands were submitted for cation exchange capacity CEC) analysis. CEC analysis involves determining the amount of a cation that the mineral could exchange with the surrounding solution, per unit mass of mineral.

6.5.1.1 Cation Exchange Capacity (CEC)

Cumulative CEC results obtained from interstitial clays in cores ranged from 3.2 to 21.8 milli-equivalents per 100 grams meq/100g) of sample (Table 6-10). Higher CEC values indicate a stronger tendency to exchange cations with the surrounding pore water.

To examine the relationship between CEC and clay content of a sample, CEC's were compiled from samples collected from the PAS at HRSD's Nansemond, York River, SWIFT-WB, SWIFT-JR, and the City of Chesapeake's ASR facility Figure 6-17). Samples displaying the largest CEC corresponded to the confining units which also contained the largest amounts of clay. Clay content and CEC exhibited a linear relationship that allowed calculation of CEC for samples containing lower amounts of clay, like the aquifer sands. According to the projections, the cumulative CEC values in aquifer sands containing around 5 percent interstitial clay should correspond to a CEC of approximately 8 meq/100g. Thus, the low CEC in aquifer sands suggests a relatively low probability for exchanging cations.

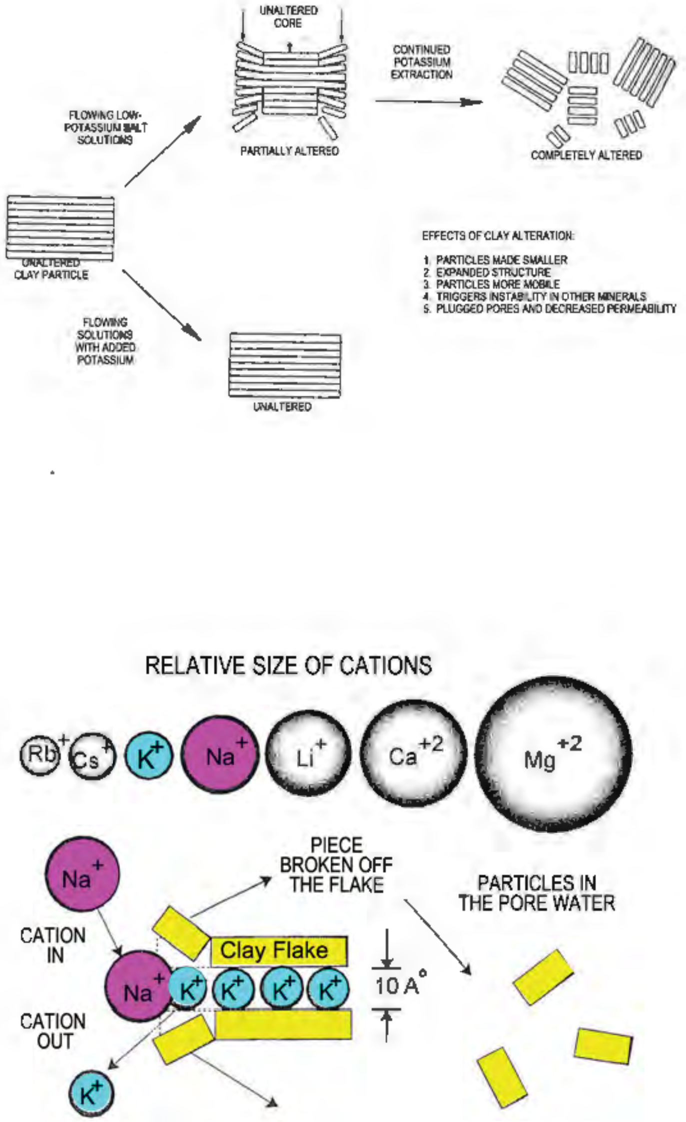


Figure 6-16. Mechanisms of Clay Particle Disaggregation and Migration During MAR Operations

Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

Source: Civan, 2000

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | f76_6X93158.dgn

Table 6-10. Summary of Cation Exchange Capacity

Sample No.	Depth (ft below grade)	Relation to Aquifer	Screen Interval in TW-4	Calcium (meq/100g)	Magnesium (meq/100g)	Sodium (meq/100g)	Potassium (meq/100g)	Cumulative CEC	Clay Content of Sample (%)	Selectivity Order
1	427.5 to 428.6	UPA	1	9.15	1.39	2.98	0.412	13.932	16	Ca>Na>Mg>K
2	491 to 492.9	UPA	2	12.2	3.53	4.74	1.29	21.76	28	Ca>Na>Mg>K
3	578 to 579.6	UPA	3	1.97	0.81	2.11	0.261	5.151	6	Na>Ca>Mg>K
4	637.5 to 640	UPA	4	1.47	0.4	1.03	0.27	3.17	4.5	Na>Ca>Mg>K
5	779 to 781.5	UPA	6	2.42	0.59	1.69	0.33	5.03	4	Ca>Na>Mg>K
6	886.5 to 889	MPA	Between 6 7	4.47	1.37	4.79	0.44	11.07	22.5	Na>Ca>Mg>K
7	912.5 to 915	MPA	Between 6 7	3.1	0.91	3.45	0.2	7.66	16.5	Na>Ca>Mg>K
8	974 to 976.5	MPA	7	3.45	1.02	2.42	0.36	7.25	5	Ca>Na>Mg>K
9	1056 to 1058.5	MPA	8	2.79	1.23	3.76	0.55	8.33	17	Na>Ca>Mg>K
10	1120 to 1122.5	MPA	9	2.2	0.79	2.87	0.26	6.12	26	Na>Ca>Mg>K
11	1178 to 1180.5	LPA	Between 9 10	2.27	0.79	2.68	0.47	6.21	14.5	Na>Ca>Mg>K
bulk density	2.65	kg/L					Correl coeffivient	0.670874219		
Porosity	0.37	fraction								

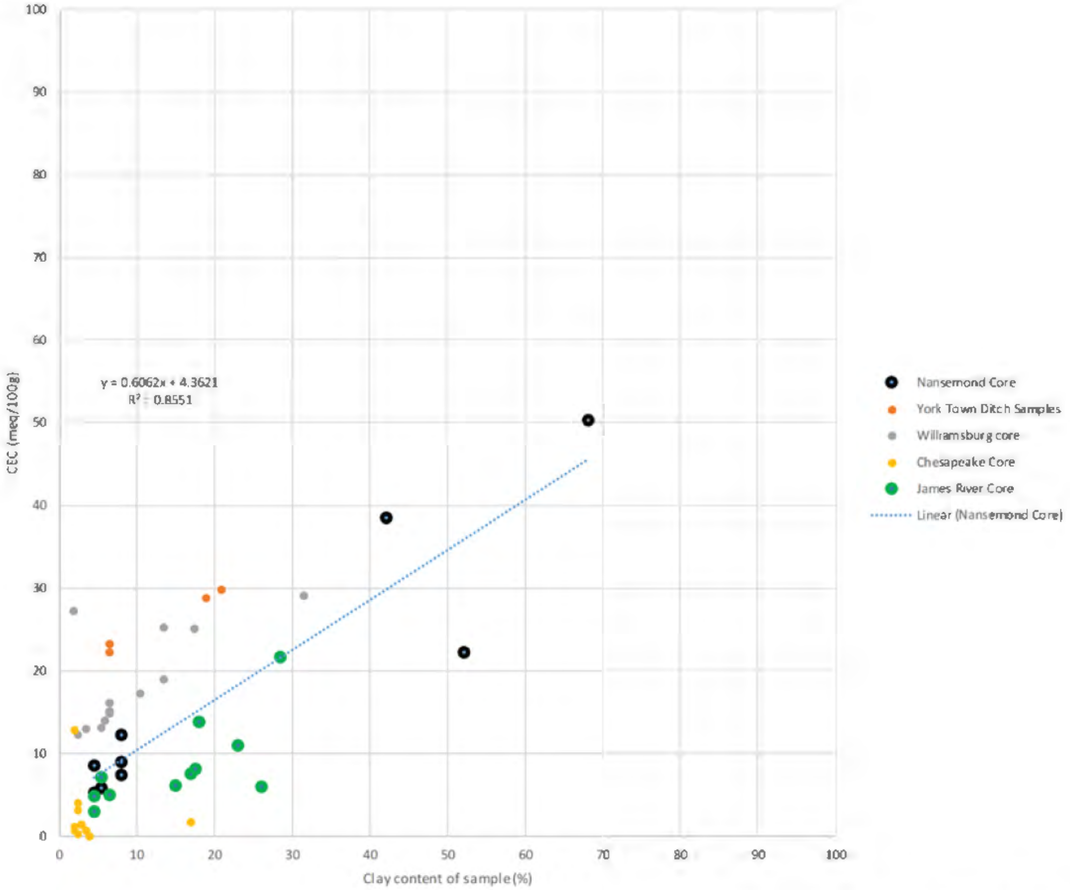


Figure 6-17. Graph Showing Relationship Between Clay Content of Sample and Cation Exchange Capacity
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

JACOBS

DEN001 | DOCUMENTS - DEN1 WBG IMPERIAL SF | DESIGNS - SMALL PROJECTS | 6X93158 - HRSD WILLIAMSBURG SWIFT FACILITY | DLV | 177_6X93158.dgn

CEC also involves a replacement sequence depending on the specific cations present. With four exceptions from the 11 cores, the hierarchy of exchangeable cations in core from SWIFT-JR were ordered as follows: sodium (Na)> calcium (Ca)> magnesium (Mg)> potassium (K). Three cores (427.5, 491, and 779 fbg) from the shallowest samples in the UPA and one sample from the MPA (974 fbg) displayed a slightly differing hierarchy following Ca>Na>Mg>K.

6.5.1.2 CEC Concerns at SWIFT-JR

NGW samples collected during the 24 hour CRT and packer testing at SWIFT-JR displayed a sodium chloride type water, matching the cation chemistry of the carbon-based recharge water. The calcium to sodium ratio varied only slightly between the recharge (0.51) and NGW in the UPA (0.025) and MPA (0.035). The similarity in the cations in the recharge and aquifer matrix and calcium to sodium ratio indicates that cation exchange should not present a problem during MAR operations.

6.5.2 Clay Particle Dispersion

In addition to cation exchange, formation damage can also arise through the dispersion of clay minerals when the recharge and native groundwater display differing ionic strengths, particularly when the ionic strength of the native groundwater exceeds the recharge by greater than one order of magnitude in moles per liter (moles/L). When displacing the brackish water in the diffuse-double layer between clay particles (Figure 6-18), binding positive charges, constituted by cations are displaced by fresh water containing a lower charge. Thus, the low ionic strength of the recharge can induce repulsive forces that disperse the particles, fragmenting the clay structure. Migrating clay fragments can eventually accumulate in smaller pores, physically plugging the pore space and reducing the permeability of the aquifer, described previously in discussing cation exchange.

Except for the shallowest interval tested in the UPA consisting of Screens 1 and 2, the ionic strength of the NGW exceeds the recharge water by greater than one half of one order of magnitude (Figure 6-19). A significant force causing both the structural expansion (swelling) and dispersion of clays results from the inherent negative charge on almost all clay mineral surfaces in solution at the circum-neutral pH encountered in the NGW and carbon-based recharge. In aquifers containing brackish NGW, positively charged cations surrounding the clay minerals neutralize the negative charge displayed by the mineral surface. Since a portion of the cations tend to disassociate from direct surface bonding, a positive ion swarm is established in the solution near the surface of the particle, while a negative charge occupies the inside of the particle. This condition describes the electrical double layer that surrounds clay and other mineral surfaces Reed, et al., 1972).

Particles displaying double layers tend to repel each other, causing dispersion. Since the strength of repulsion is related to the tendency of the adsorbed cations to disassociate, a greater proportion of more firmly attached cations will decrease the double layer thickness, thus reducing the particles' tendency to disperse. One of the most important factors influencing the dispersion of clay minerals involves a change in the double layer thickness of the clay particle.

When the concentrations of cations are large, as in brackish water, the double layer around the particle, or situated between the clay's structure layers gets compressed to a smaller thickness by the higher ionic strength. Compressing the double layer causes particles to coalesce, forming larger aggregates, in a process called clay flocculation. Conversely, when the ionic concentration of a fluid invading the aquifer is significantly lower than the native groundwater, the charge diminishes and the diffuse double layer expands, forcing clay particles and structural layers within clay minerals apart. The expansion prevents the clay particles from moving closer together and forming an aggregate.

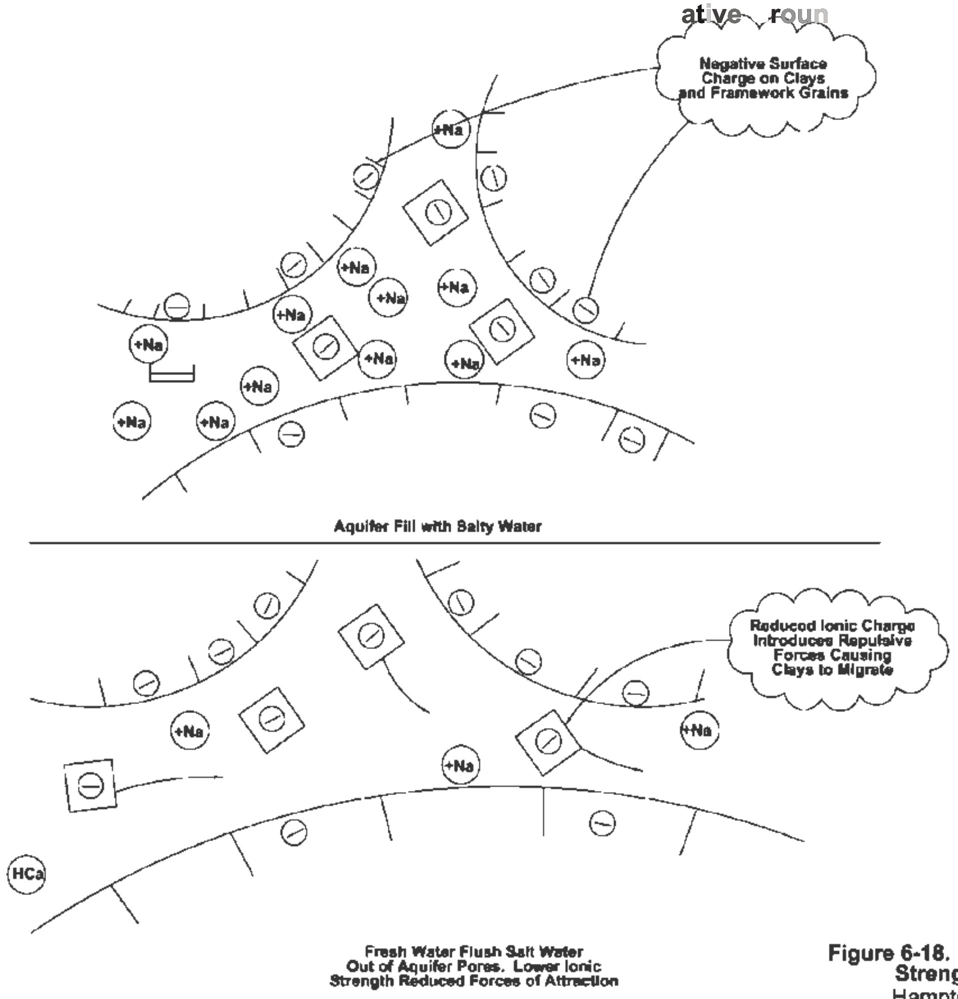


Figure 6-18. Effects of Changing Ionic Strength of Native Groundwater
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA

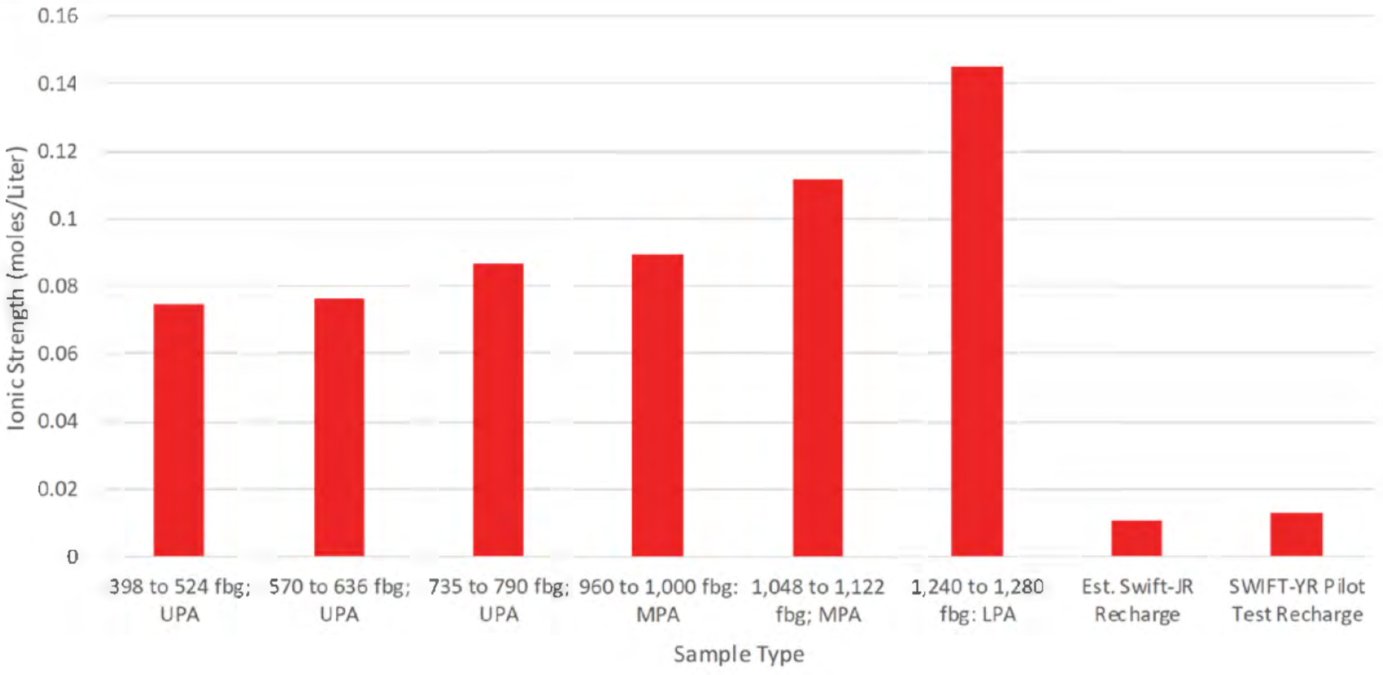


Figure 6-19. Ionic Strength of Recharge and NGW at SWIFT-JR
Hampton Roads Sanitation District
James River Treatment Plant
Newport News, VA
JACOBS

6.5.2.1 Effect on MAR Operations

Operationally, recharging the aquifer with treated water exhibiting a significantly lower ionic strength than the native groundwater can damage interstitial clay minerals attached to aquifer framework particles, weaken inter-particle attachments, and even diminish charges between individual clay layers. All these factors cause clay minerals and mineral fragments to disperse and then migrate through the pore spaces of the aquifer. The fragments eventually block pore throats, reducing the permeability of the aquifer around a MAR well, diminishing the well's injection capacity. Most literature sources Meade, 1964; Reed, 1972; Khilar and Fogler, 1984, and Gray and Rex, 1966) state that a disparity exceeding one of order of magnitude in ionic strength can cause formation damage. The disparity in ionic strength a SWIFT_JR exceeded one order of magnitude in sample collected from intervals screening the MPA and approached one order of magnitude in the UPA.

Therefore, recharge water, from the carbon-based treatment processes, could cause plugging of an MAR well and aquifer without some conditioning to the PAS before starting operations.

6.5.2.2 Regional Anecdotal Example

An ASR facility tested by United States Geological Survey USGS) in the 1970s at Norfolk, Virginia exhibited greater than 80 percent reduction in injectivity after only 150 minutes of starting injection operations (Brown and Silvey, 1977). The ASR well was installed in the UPA, screening nearly 85 feet of sand in the unit. Groundwater from the UPA displayed a TDS concentration around 3,000 mg/L (ionic strength = 0.08 moles/Liter (m/L), while recharge provided by the City of Norfolk exhibited concentrations around 100 mg/L (ionic strength = 0.003 m/L). The USGS employed nuclear, electrical, and mechanical geophysical logging techniques to evaluate the origin of the injectivity losses and discriminate between the causes of clogging documented at other sites, like TSS loading.

Injectivity losses caused by clogging from TSS loading typically occurs at discrete zones within the well screen. In contrast, geophysical logging of the ASR test well at Norfolk showed hydraulic conductivity losses distributed evenly across the entire screen. Also, in comparison to clogging by TSS, which responds positively to mechanical and chemical rehabilitations, the USGS could restore only a fraction of the well's original injectivity during invasive rehabilitation.

To arrest the declining injectivity, the USGS treated the wellbore and proximal aquifer with a concentrated calcium chloride ($CaCl_2$>1,000 mg/L) solution. As described above, the doubly charged, calcium cation forms a stronger particle and inter-layer bond than the monovalent cation, sodium. Using a concentrated solution ensures calcium exchanges for sodium at the maximum number of sites. After applying the treatment at Norfolk, the injectivity of the ASR test well remained stable (yet low over two more test cycles, before the project was ended.

Given the disparity in ionic strength between the recharge water and NGW from PAS at SWIFT-JR, to ensure successful MAR operations, HRSD should condition the PAS aquifers using trivalent salts to strengthen the attachments to aquifer framework grains by clay minerals, between clay particles, and interlayers of individual particles, prior to starting MAR operations. To date, HRSD has applied these measures at Nansemond SWIFT-NP) and York River (SWIFT-YR). Testing at Williamsburg (SWIFT-WB revealed that recharge water and NGW from the UPA and MPA displayed roughly similar ionic strengths, thus, conditioning interstitial clay minerals appeared unnecessary.

6.5.2.3 Treating the PAS at SWIFT-JR Using an Aluminum Chlorohydrate Flush

Aluminum salt solutions offer benefits for stabilizing clay minerals in the PAS. The trivalent aluminum ion forms a strong bond in the exchange position of clays. When added with a source of hydroxyl ion, a hydoxy-aluminum flush comprising a hydroxyl/aluminum atomic ratio of 2 creates molecules with a charge around +6. Yet hydroxy aluminum chloride solutions have proven difficult to prepare in the field and laboratory. Testing at SWIFT-NP resulted in precipitating $Al(OH)_3$, increasing the turbidity of the treatment solution and making injection difficult. A testing lab observed similar results with hydroxy-aluminum chloride mixtures. Commercial grade, aluminum chlorohydrate (ACH) combines $AlCl_3$ with the hydroxyl OH^- ion to form the +6 charge.

Laboratory testing conducted by Test America Laboratories in early 2019 with $AlCl_3$, hydroxy-aluminum chloride, and ACH solutions on clay minerals yielded interesting results. Clays from cores were treated with each solution and then underwent XRD analysis to examine the resulting atomic structural change in of the mineral. The three solutions formed bonds between clay particles, improved flocculation and strengthened clay mineral attachments. However, only ACH penetrated the inter-layer areas of the minerals changing the atomic structure of the minerals, strengthening the bonding between individual layers.

7. Recommended Pretreatment Measures

The following discusses measures required to ensure that the recharge chemistry when mixed with NGW or reacting with aquifer minerals does not compromise injection operations by damaging the permeability of the receiving aquifer, or create environmental issues by releasing undesirable constituents.

7.1 Summary of Mitigation Approach

Table 7-1 presents a summary of the mitigation approach.

Table 7-1. Summary of Mitigation Approach

Recharge Water/Aquifer Interaction			
Mitigation Issue	Mitigating Action	Mitigating Objective	Summary Description
Mineral dissolution/ precipitation	Adjust pH with NaOH to 7.8 or greater	Prevent mobilization of iron and arsenic,	Form and maintain HFO coating Maintain pH to counter acid formation due to iron oxidation effects
Aquifer Clay Matrix Stability			
Mitigation Issue	Mitigating Action	Mitigating Objective	Summary Description
Clay particle dispersion and fragmentation	Conditioning salt flush using aluminum chloro-hydrate	Prevent dispersion and disruption of clay particles and prevent clogging of the aquifer	Tighten the bonds between clay particles Tighten the bonds within the clay mineral structure

7.2 Aquifer Conditioning for Clays

Given the disparity in ionic strength between the recharge water and NGW, HRSD should condition interstitial clay minerals in the PAS using an ACH treatment solution. In addition to laboratory testing, ACH was successfully tested at SWIFT-YR in TW-2, during spring 2019. HRSD treated six zones extending from 720 to 1865 fbg with ACH. Following the treatment, HRSD conducted a 72-hour injection test using potable water, containing TDS concentrations around 100 mg/L and ionic strength around 0.03 m/L compared to TDS in the NGW, that reached 22,000 mg/L (ionic strength = 0.55 m/L).

The injection test volume exceeded approximately 500,000 gallons and extended roughly two times beyond volume of aquifer treated with ACH. The damaging effects of clay swelling, dispersion or migration were not observed in the hydraulic data from the injection test. The recharge head in TW-2 reached a stable level after three hours of commencing the test. Testing personnel maintained a stable recharge rate across the test period.

At SWIFT-JR's MAR wells, HRSD should treat zones encompassing the UPA and MPA. As described previously, the LPA displayed poor hydraulic characteristics during testing, and subsequently, was removed for further consideration as an MAR aquifer. Field personnel are presently administering a treatment and testing program using TW-4. The testing program will employ straddle packers to treat one to two screen zones at a time. Treatment volumes (Table 7-2) were based on the length of screen spanning each interval, a treatment radius of the aquifer of 12 feet, and a porosity of 19 percent, the average porosity determined during petrophysical analysis of core samples.

Table 7-2. Summary of Treatment Zones at James River & Treatment Volumes ACH 14 feet into Aquifer

Volume of 8-inch pipe 2.61 gal/ft
Volume of 2-inch pipe 0.16 gal/ft

Aquifer	Packed Zone Number	Screen Depths (fbg)	(fbg)	Total Length of screen (ft)	Treatment Radius (ft)	Volume treatment fluid (gallons)	Total length of zone (feet)	Volume of water to evacuate interval and piping (gallons)	Volume ACH (gallons)	(totes)
Upper Potomac	1	398 480	454 524	100	14	87,494	126	393	2459	10.2
	2	570 610	590 636	46	14	40,247	66	263	1131	4.7
	3	735 770	752 790	37	14	32,373	55	261	910	3.8
Middle Potomac	4	960	1000	40	14	34,998	40	258	984	4.1
	5	1048 1092	1064 1122	74	14	64,746	16	209	1820	7.6
	6	1240	1280	40	14	34,998	40	303	984	4.1

Notes:

Aluminum Chlorohydrate ACH)	0.1 M	29 gallon per 1,000 gallons H2O
Porosity (fraction)	0.19	

294855	Total Treatment fluid (gallons
8533	MINUS ACH volume (gallons)
286322	Treatment fluid minus ACH (gallons)
8286	ACH volume needed (gallons)
35	Totes
240	gallon/tote
29	gallons of ACH per 1,000 gallon solution

$AlCl_3$ or ACH treatment dosages at SWIFT-NP and SWIFT-YR, respectively, equaled 0.1 molar (M). However, laboratory testing associated to the SWIFT program has revealed that lower dosages of 0.01 or even 0.001 M work just as effectively as a solution strength of 0.1 M. The lower solution strength will require less careful handling upon removing the expended treatment solution.

The treatment program at SWIFT-JR's TW-4 will consist of the following steps:

- Conducting a step drawdown test to establish the baseline characteristics of TW-4.
- Treating the UPA and MPA with a 0.01 to 0.1 M strength ACH solution.
- Inject a volume of water to displace the treatment solution out of the piping and TW-4.
- Allow the solution to remain in the UPA and MPA for two weeks.
- Pump out the treatment solution from each treated zone.
- Perform a step drawdown test to determine the hydraulic effects of the treatment on TW-4.
- Conduct a 72 to 96- hour injection test at near operational rates with SWIFT or potable water.
- Conduct a step drawdown test to determine the hydraulic effects of injection testing with a dilute water on the MAR well.

At SWIFT-NP and SWIFT-YR the specific capacities of TW-1 and TW-2 improved between 5 and 20 percent following $AlCl_3$ or ACH treatments. Stabilizing interstitial clay minerals helps enlarge pore spaces while diminishing the tortuosity of flowpaths around the MAR well, improving the hydraulic characteristics of the MAR well.

8. References

Norfolk, Virginia, United States Geological Survey Professional Paper, 939, Washington, D.C., 1977

Barnes D.A., Girard, J.P., and Aronson, J.L., K-Ar Dating of Illite Diagenesis in the Middle Ordovician St. Peters Sandstone, Central Michigan Basin: Implications for Thermal History, in Origin, Diagenesis and Petrophysics of Clay Minerals in Sandstones, Housekecht, D.W., and Pittman, E.D. editors, Society for Sedimentary Geology, Special Publication No. 47, Tulsa, Oklahoma, 1992.

ChemSW, WATER!PRO™, Corrosion Control and Treatment Process Modeling Program, Schott Software, Munich, Germany, 1996.

Civan, F., *Reservoir Formation Damage; Fundamentals, Modeling, Assessment, and Mitigation*, Elsevier Publishing, Houston, TX, 2000.

Davies, C.W*.* *Ion Association*, Butterworths, Washington, D.C., 1962.

Debye, P., and E. Hückel, E. (1923). *"Zur Theorie der Elektrolyte. I. Gefrierpunktserniedrigung und verwandte Erscheinungen" [The theory of electrolytes. I. Lowering of freezing point and related phenomena]*. Physikalische Zeitschrift Vol, 24, 1923.

Drever, J.I., *The Geochemistry of Natural Water: Surface and Groundwater Environments.* Prentice-Hall, Inc., Upper Saddle River, New Jersey, 1982.

Dzomback, D.A. and F.M.M. Morel, *Surface Complexation Modeling: Hydrous Ferric Oxide*. John Wiley and Sons, New York, New York, 1990.

Eggleston, J., and Rojstaczer, S., The Value of Grain Size Conductivity Estimates; Comparison with High Resolution In Situ Field Hydraulic Conductivity, Geophysical Research Letter, Vol 28, New York, New York, 2001.

Evangelou, V.P., *Pyrite Oxidation and Its Control*, CRC Press, Boca Raton, Florida, 1995

FOLK, R.L, *Petrology of Sedimentary Rocks*, Hemphill Publishing, New York, New York, 1965.

Glaeser, J.D., Petrology and origins of Potomac and Magothy (cretaceous sediments, middle Atlantic Coastal Plain: Maryland Geological Survey, Baltimore, Maryland, 1969.

Gray, D.H., and R.W., Rex, *Formation Damage in Sandstones Caused by Clay Damage and Migration*, Proceedings of 14th National Conference on Clays and Clay Minerals, Pergamon Press, London, 1966.

Hazen, A., Some physical properties of sand and gravels, Massachusetts State Board of Health, 24th Annual Report, Boston, Massachusetts, 1893.

Hem, J. D., *Study and Interpretation of the Chemical Characteristics of Natural Water*, United States Geological Survey Water-Supply Paper 2254, Alexandria, Virginia, 1986.

Hewitt, C.H., *Analytical Techniques for Recognizing Water-Sensitive Reservoir Rocks*, Society of Professional Engineers, Denver, Colorado, 1963

Heywood, C.E. and Pope, J.P., *Simulation of Groundwater Flow in the Coastal Plain Aquifer System of Virginia*, United States Geological Survey, Scientific Investigations Report 2009-5039, Reston, Virginia, 2009.

Howard, J.J., Influence of Authigenic Clay Minerals on Permeability, in *Origin, Diagenesis, And Petrophysics of Clay Minerals in Sandstones*, D.W. Houseknecht, and E.D. Pittman editors, SEPM Publication No. 47, Oklahoma, 1992.

Jones, G.W., and Pichler, T., Relationship between pyrite stability and arsenic mobility during aquifer storage and recovery in southwest, central Florida, Environmental Science and Technology, Vol. 41, New York, NY, 2007.

Khilar, K.C. and Fogler, H.S., Mathematical Models for Permeability Reductions Due to Migration of Fines, in Migration of Fines in Porous Media, Springer, New York, New York, 1984.

Khilar, K.C. and Fogler, H.S., Reduction of Water Sensitivity in Sandstone, in Surface Phenomena In Enhanced Oil Recovery, Springer, New York, New York, 1984.

Langmuir, D., *Aqueous Environmental Geochemistry*, Prentice-Hall, Inc., Upper Saddle River, New Jersey, 1997.

Kolker, A., and Nordstrom, D.K., *Occurrence and microdistribution of arsenic in pyrite*, United States Geological Survey Workshop – Arsenic in the Environment, Denver, Colorado, 2009.

Manning, B.A. and Goldberg, S., *Modeling Competitive Adsorption of Arsenate with Phosphate and Molybdate on Oxide Minerals,* Soil Science Society of America Journal, Volume GO, no. 1, January-February 1996.

Masch, F.D., and Denny, K.J., Grain Size Distribution and Its Effect on the Permeability of Unconsolidated Sands, Water Resources Research, Volume 2, Dublin, Ohio, 1966.

McFarland, E.R., and Bruce, T.S., *The Virginian Coastal Plain Hydrogeologic Framework*, United States Geological Survey Professional Paper 1731, Reston, Virginia, 2006.

Meade, R.H., Removal of Water and Rearrangement of Particles During Compaction of Clayey Sediments-Review, Mechanics of Aquifer Systems, United Survey Professional Paper, 497-B, Washington, D.C., 1964.

Meng, A.A., and Harsh, J.F.*, Hydrogeologic Framework of the Virginia Coastal Plain*, Unites States Geological Survey Professional Paper 1404-C, Washington, D.C. 1988.

Postma, D., *Pyrite and Siderite Formation in Brackish and Freshwater Swamp Sediments*, American Journal of Science, V 282, P. 1151-1183, New York, New York, 1982.

Parkhurst, D.L., Users *Guide to PHREEQC – A Computer Program for Speciation, Reaction-Path, Advective-Transport, Inverse Geochemical Calculations*, U.S. Geological Survey Water Resources Investigation Report 95-4227, Lakewood, Colorado, 1996.

Plume, R.W., Hydrogeologic Framework of the Great Basin Region of Nevada, Utah and Adjacent States, United States Geological Survey, Professional Paper 1409D, Washington, D.C., 1996.

Pyne, D.G., *Aquifer Storage and Recovery: A Guide to Groundwater Recharge Through Wells.* ASR Press: Gainesville, Florida, 2005.

Reed, M.G., *Stabilization of Formation Clays with Hydroxy-Aluminum Solutions*, Journal of Petroleum Technology, July 1972, 860 to 864, Denver, Colorado.

Smedley, P.L., and Kinniburgh, D.G., A review of the source, behavior, and distribution of arsenic in natural waters, Applied Geochemistry, Vol. 17, Amsterdam, Netherlands, 2002.

Stuyfzand, P.J., *Hydrochemistry and Hydrology of the Coastal Dune area of the Western Netherlands*, KIWA, Niewegein, The Netherlands, 1993.

Stuyfzand, P.J., Putters, B., Hydrogeochemical patterns, processes and mass transfers during aquifer storage and recovery (ASR) in an anoxic, sandy aquifer, Applied Geochemistry, Elsevier, Vol. 27, Amsterdam, the Netherlands, 2012.

Stuyfzand, P.J., Antoniou, E.A., and van Breukelen, B.M., *Reactive transport modeling of an aquifer storage and recovery (ASR) pilot to assess long-term water quality improvement and potential solutions*, Applied Geochemistry, Vol. 28 Elsevier, Amsterdam, the Netherlands, 2013.

Theis, C.V., The lowering of the piezometric surface and the rate and discharge of a well using ground-water storage. Transactions, American Geophysical Union, Volume 16, Washington D.C., 1934.

Treifke, R.H., *Geologic Studies Coastal Plain of Virginia,* Bulletin 83, Virginia Division of Mineral Resources, Richmond, Virginia, 1973.

Truesdell, A.H. and Jones, B.F., *WATEQ, A Computer Program for Calculating Chemical Equilibrium of Natural Waters*, U.S. Geological Survey Journal of Research 2, 1974.

Virginia Department of Environmental Quality, Virginia Coastal Plain Model 2005 Withdrawals Simulation, Richmond, Virginia, 2006.

Warner, D.L., and Lehr, J.H., *Subsurface Wastewater Injection*, Premier Press, Berkeley, California

Attachment D: Injection Operation and Monitoring Program

D.1 Part I Facility Information

D.1.1 Flow Diagram of Fluid Flow through the Facility

A process flow diagram of the James River SWIFT treatment process is shown in Figure D.1. The full treatment process provides a multiple barrier approach to the control of contaminants and pathogens and produces a SWIFT Water which meets the Safe Drinking Water Act (SDWA) Primary Maximum Contaminant Levels (PMCLs). The SWIFT process consists of rapid mix with coagulant addition, flocculation and sedimentation, ozone oxidation, biologically active carbon filtration (BAF), GAC adsorption, and ultraviolet (UV) disinfection. This is the same treatment process that has been proven during pilot testing conducted in 2016-2017 and at the SWIFT Research Center (SRC) in 2018-2020. A more detailed description of the SWIFT process and the SWIFT Water regulatory requirements can be found in Appendix A, James River SWIFT Water Quality Targets.

A major upgrade to the existing JR Treatment Plant will be constructed concurrently with the SWIFT facilities. This will improve the quality and consistency of the secondary effluent that will in turn increase the quality and consistency of the SWIFT Water. Improvements include flow equalization in the interceptor system, new secondary clarifiers, and process upgrades for nitrogen treatment. The primary objectives of the improvements are to provide consistent flows and nutrient loads to SWIFT.

Following is a brief description of each treatment process with accompanying design criteria listed in Table D.1 for both JR SWIFT and the SRC:

- **Rapid Mix, Flocculation, Sedimentation:** Chemical coagulant and an organic polyelectrolyte will be added to the water to remove particles and dissolved organics through the formation and settling of chemical flocs and to prepare the water for effective filtration. The chemical coagulant is anticipated to be aluminum chlorohydrate (ACH) subject to change based on the results of bench-scale testing for this facility.
- **Ozone Oxidation:** Ozone will be added to oxidize high molecular weight organics for downstream removal in biofiltration and for direct oxidation of trace organics (e.g., contaminants of emerging concern such as pharmaceuticals and personal care products). Disinfection of pathogens will also be achieved with ozone addition though disinfection credit is not being claimed for this unit process. A hydrogen peroxide addition point will be added upstream of ozone injection such that ozone can be operated as an advanced oxidation process (AOP) for additional 1,4-dioxane removal.
- **Biofiltration (BAF):** Deep-bed granular media filters will provide biological removal of organic matter and particle and pathogen removal. Low filtered water turbidity (<0.15 nephelometric turbidity units [NTU]) will be targeted to ensure proper pathogen removal consistent with the design and operation of drinking water filters (see D.1.3.5 Critical Control Points below).
- **GAC Adsorption:** Granular activated carbon will provide removal of trace organics through biological and adsorption mechanisms. GAC media will be regenerated to meet the

proposed regulatory limit for total organic carbon (Table D.1) or per D.1.3.3 below, based on an assessment of the removal of non-regulatory performance indicators.

- **UV Disinfection:** UV irradiation will provide disinfection of the water before groundwater injection. A UV dose that is significantly higher than typically used for drinking water is being provided for JR SWIFT to allow for a minimum of 4-log virus removal (>186 mJ/cm2) and other treatment benefits, specifically NDMA photolysis during the startup and acclimation period prior to achieving necessary NDMA removal through BAF. Similar to ozone, a hydrogen peroxide addition point will be added upstream of UV and equipment will be selected to allow the UV system to be operated as an AOP for additional 1,4-dioxane removal.
- **pH & Alkalinity Adjustment for Aquifer Compatibility:** Sodium hydroxide will be used to adjust the final pH and alkalinity of the SWIFT Water prior to recharge at JR SWIFT, similar to the SRC. The pH target at the SRC is 7.6, and sodium hydroxide is added to raise the pH from nominally 7.0 (after UV). Raising the pH achieves two objectives: increasing the Langelier Saturation Index (LSI) to reduce the potential for corrosion in the recharge well and promoting the formation of hydrous ferric oxide (HFO) surfaces in the aquifer to limit metals mobilization. Many variables affect the pH target, including SWIFT Water alkalinity and dissolved oxygen and the aquifer oxidation-reduction potential (ORP), among otherss. HRSD is currently working on improving the understanding of both of these pH objectives at the SRC and will propose new pH and alkalinity targets prior to startup of JR SWIFT. It is likely that the pH target will be a function of the aquifer ORP and SWIFT Water alkalinity, and that it will decline over the course of operation.
- **Recharge Well Biofouling Control:** JR SWIFT will allow for the controlled addition of either free chlorine, preformed monochloramine, or hydrogen peroxide prior to the recharge well to prevent biological fouling of the well. Free chlorine will be utilized as needed to control nitrite during initial biofilter acclimation (i.e., prior to colonization of nitrite oxidizing bacteria during biofilter start-up). Free chlorine may also be used for an extended period of time to better manage biofouling in the well and coliform bacteria control. Hydrogen peroxide residual will only be used for biofouling control if UV advanced oxidation (UV + H_2O_2) is being performed for other water quality benefits, as this will likely result in an acceptable residual.

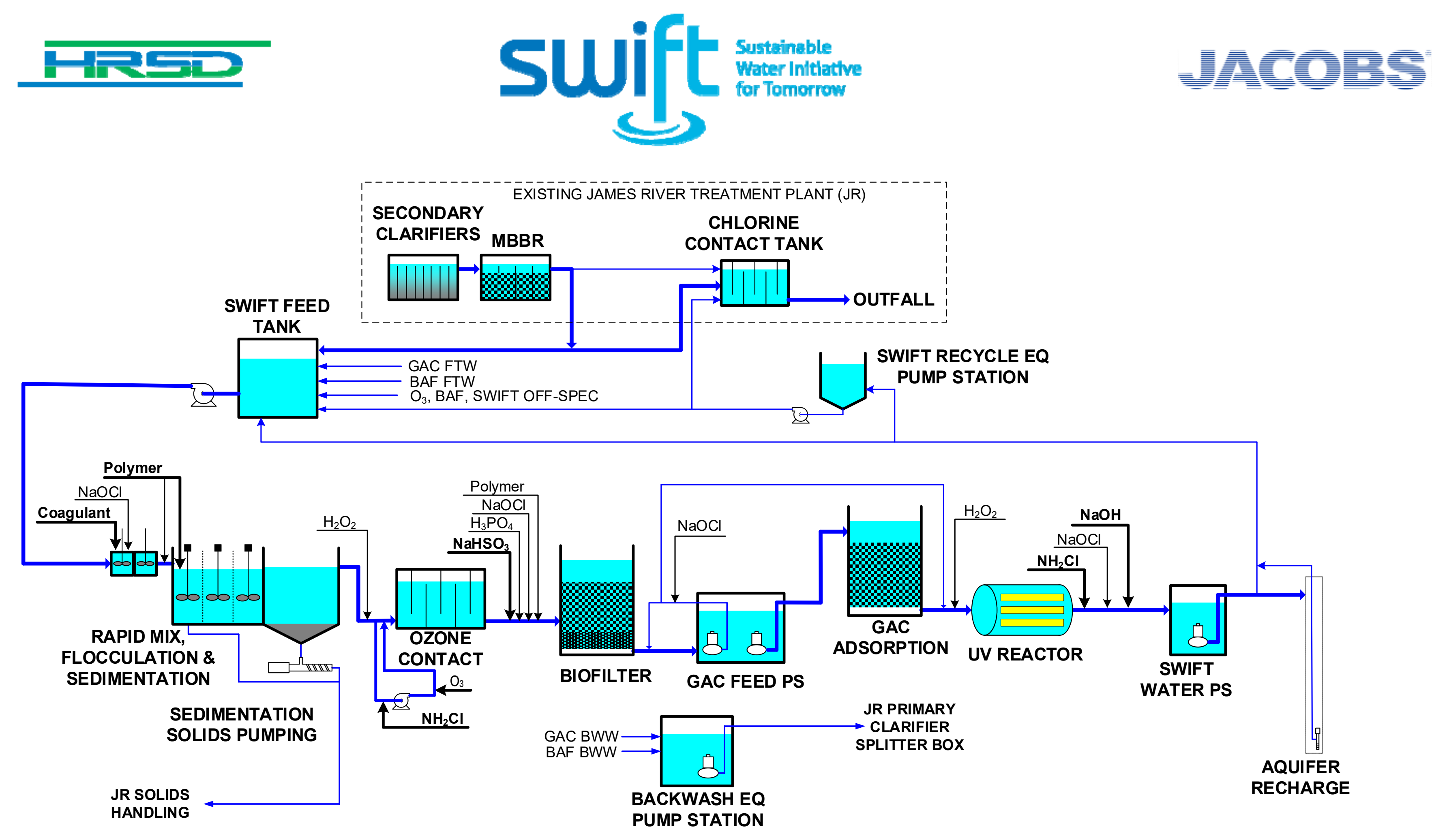


Figure D.1: JR SWIFT Process Flow Diagram

D.1.2 Contingency Plan

JR SWIFT Water will meet drinking water standards and will recharge the Potomac Aquifer System (PAS), identified as a potable water supply in Virginia. There is no contingency plan(s) to cope specifically with well failure as HRSD will maintain its Virginia Pollutant Discharge Elimination System (VPDES) permit which allows for discharge to surface waters. Automated Critical Control Points (CCPs) in the SWIFT Advanced Water Treatment facility (AWT) will prevent discharging effluent into the PAS that fails to meet PMCL's. HRSD has tied feedback from the CCP's into the AWT's Distributed Control System (DCS, HRSD's supervisory control automated data acquisition [SCADA] system. The DCS system automatically shuts down recharge flow to the MAR wells and diverts it to the outfall system should a water quality parameter or other index fall outside of programed limits. CCPs are described further in Section D.1.3.5 Monitoring Injection Fluids, below.

HRSD will monitor SWIFT Water recharge within the aquifer through the monitoring well nests. Appendix B, Aquifer Monitoring and Contingency Plan, describes the planned groundwater monitoring in detail. This document details a Contingency Plan should HRSD find that SWIFT Water that exceeded the PMCL was recharged to the aquifer or that an exceedance of the PMCL is observed in data collected from the monitoring wells. The plan includes notifying the agency, re-sampling, and providing additional information to the agency on measures taken to correct WQ issues.

JR SWIFT monitoring wells will be installed within the Area Boundary (shown in Attachment A, Figure A.1) at locations equidistant between two of the MAR wells; approximately 500 to 600 feet from a MAR well which equates to 1.5X total aquifer thickness is preferred for siting monitoring wells.

D.1.3 Drawing of the Surface Construction

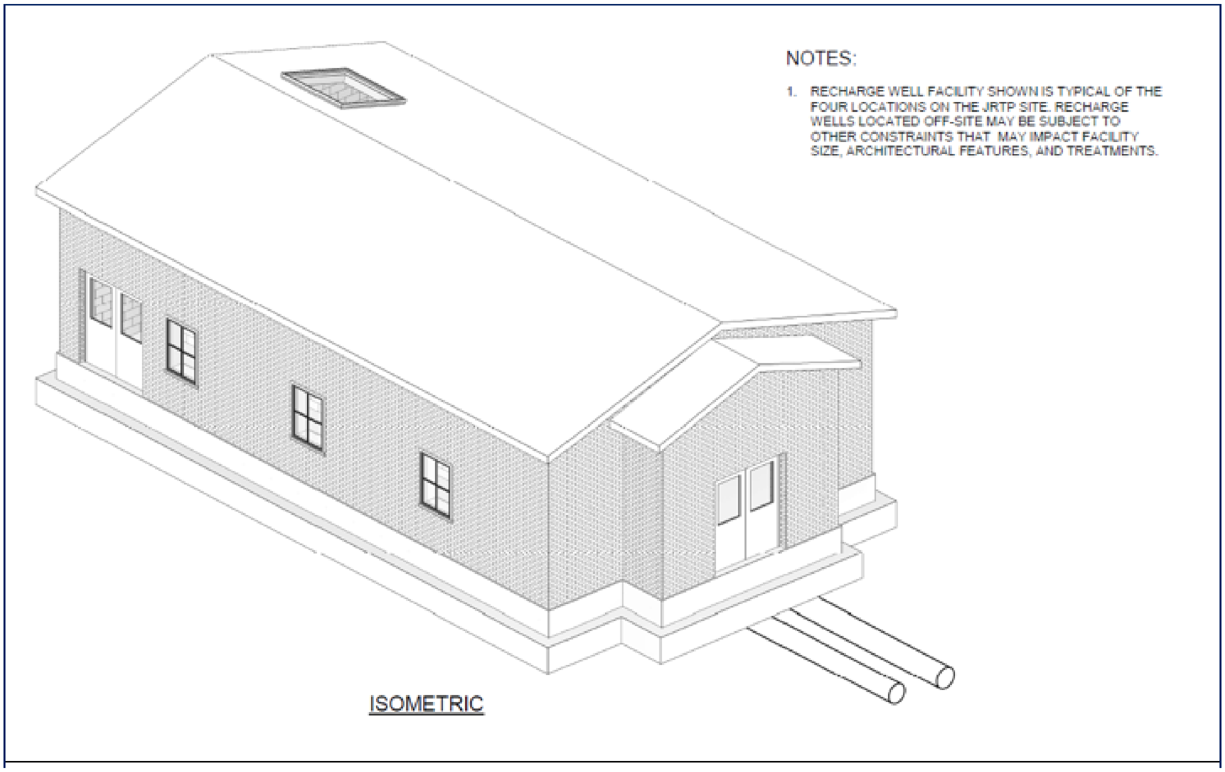
Figures D.2 through D.7 show the surface construction of the MAR Facilities, including:

- wellhead assembly
- location of flow meter, flow totalizers
- location of injection pressure and annulus pressure gauges.

Figures D.2 and D.5 depict the two MAR well house configurations: On-Site at JR SWIFT property, and Off-Site proximal to the JR SWIFT property. Off-site areas surrounding JR SWIFT consist of a municipal parks and playground operated by the City of Newport News. The footprint of those facilities located Off-Site is reduced to minimize the impact to recreational activities near those sites. See Attachment A for approximate locations of the MAR wells.

Figures D.3 and D.4 show the wellhead piping assembly, valves, flow meters/totalizers and indicates the location of pressure monitoring at the On-Site MAR well facilities.

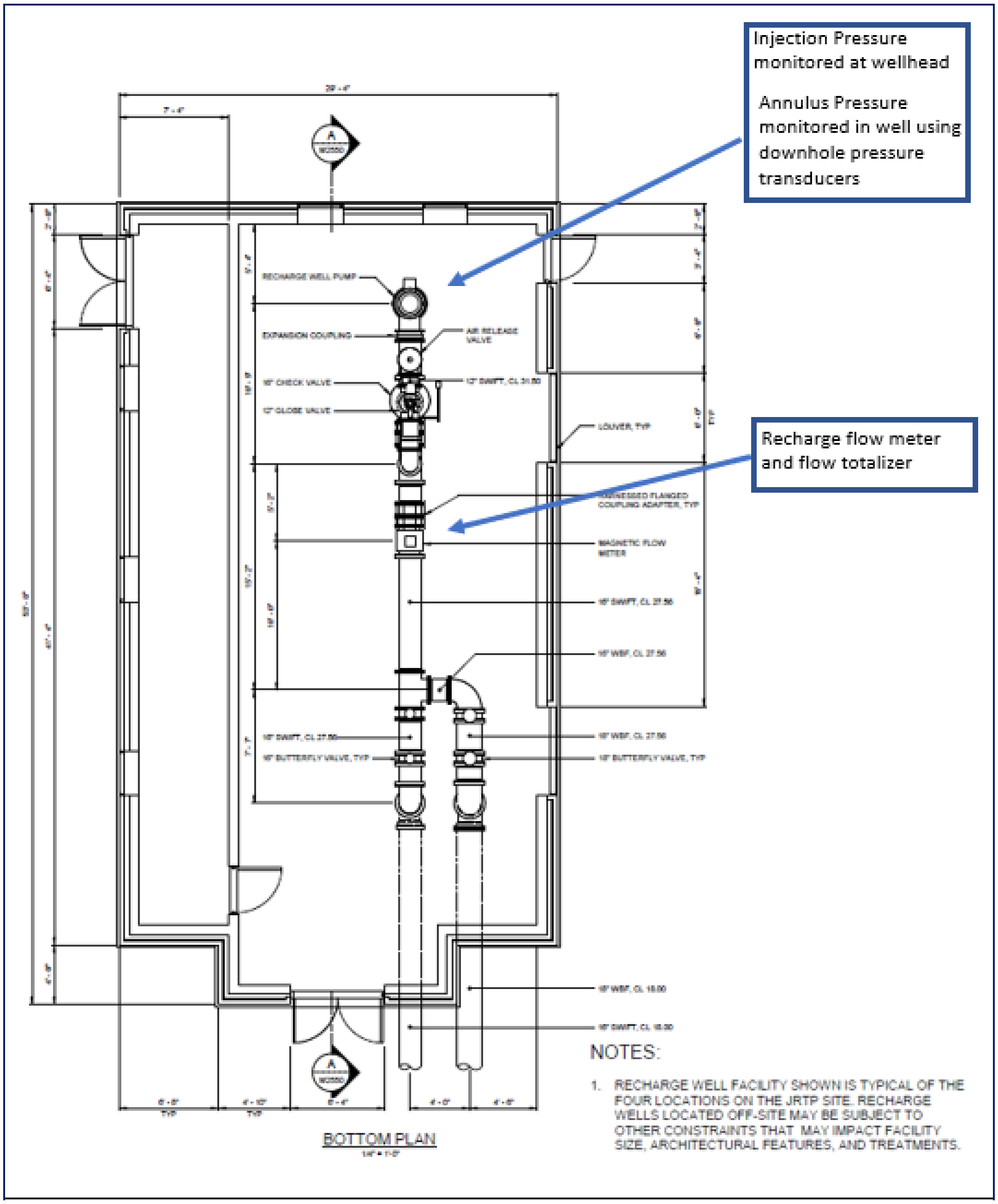
Figures D.6 and D.7 show the wellhead piping assembly, valves, flow meters/totalizers and indicate the location of pressure monitoring at the Off-Site MAR well facilities.



NOTES:

1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

Figure D.2: Surface construction around MAR wells on-site at the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.



Injection Pressure monitored at wellhead

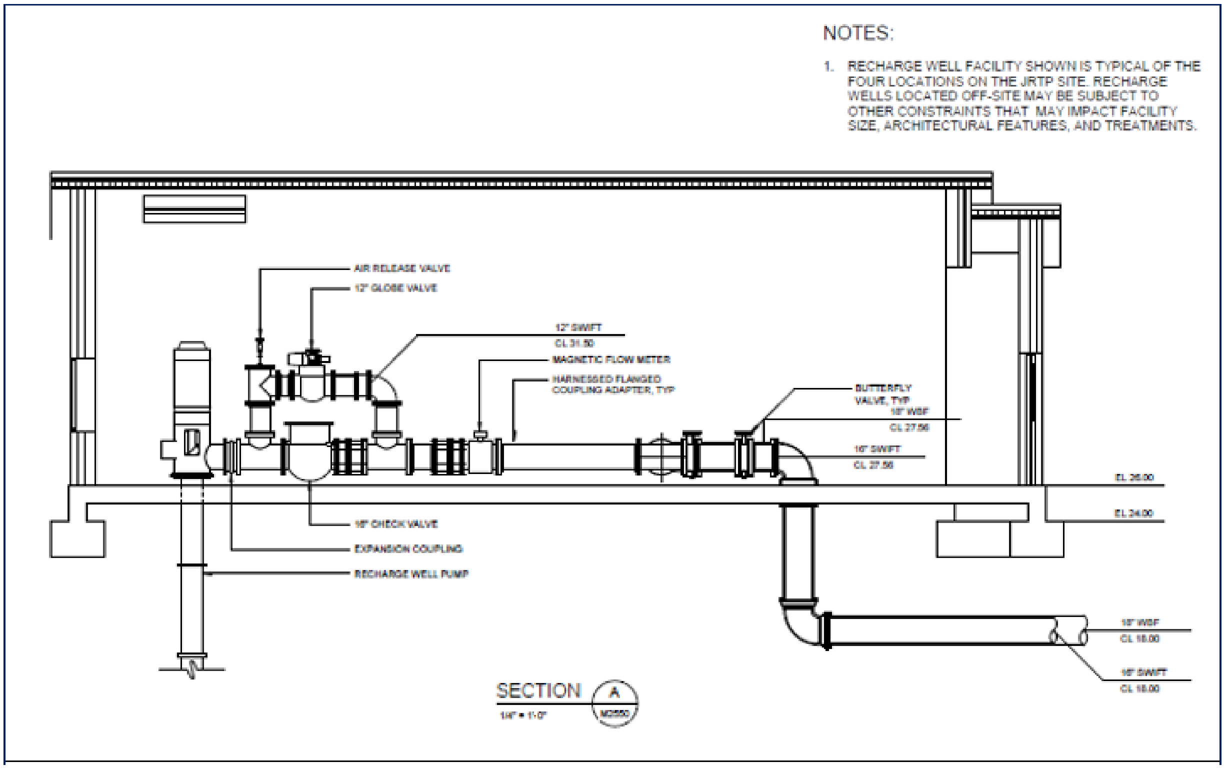
Annulus Pressure monitored in well using downhole pressure transducers

Recharge flow meter and flow totalizer

NOTES:

1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

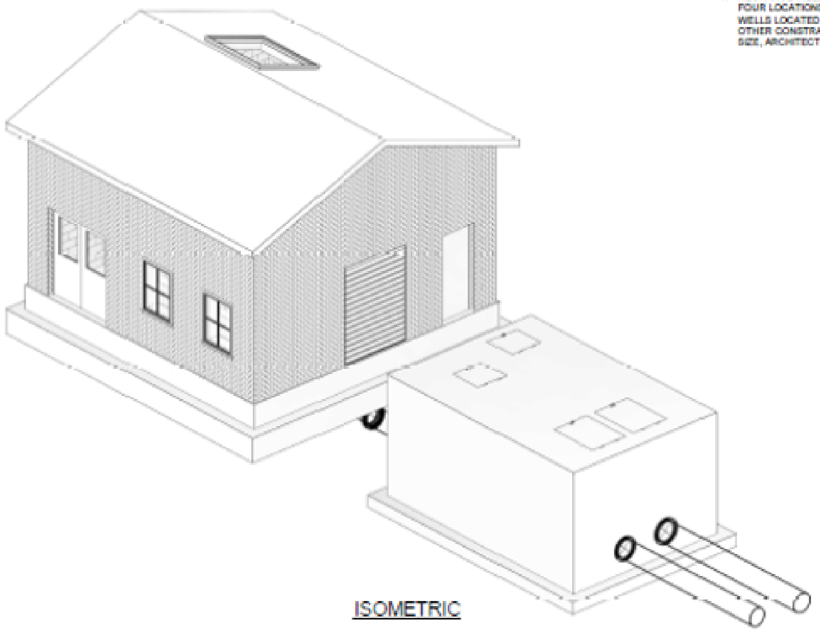
Figure D.3: Planview of surface construction around MAR wells on-site at the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.



NOTES:

1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

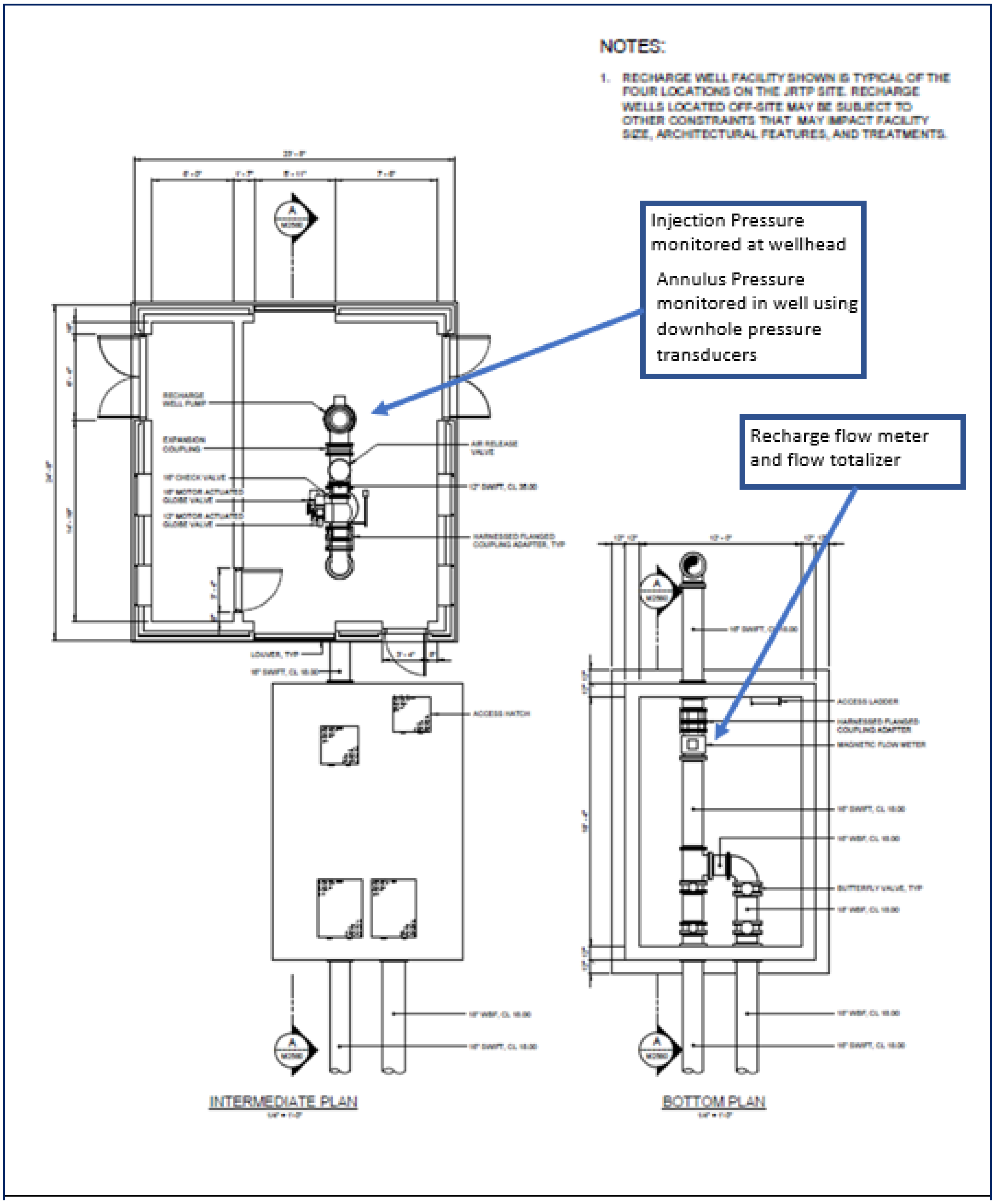
Figure D.4: Profile of surface construction around MAR wells on-site at the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.



NOTES:

1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

Figure D.5: Surface construction around MAR wells located off-site but proximal to the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.



NOTES:

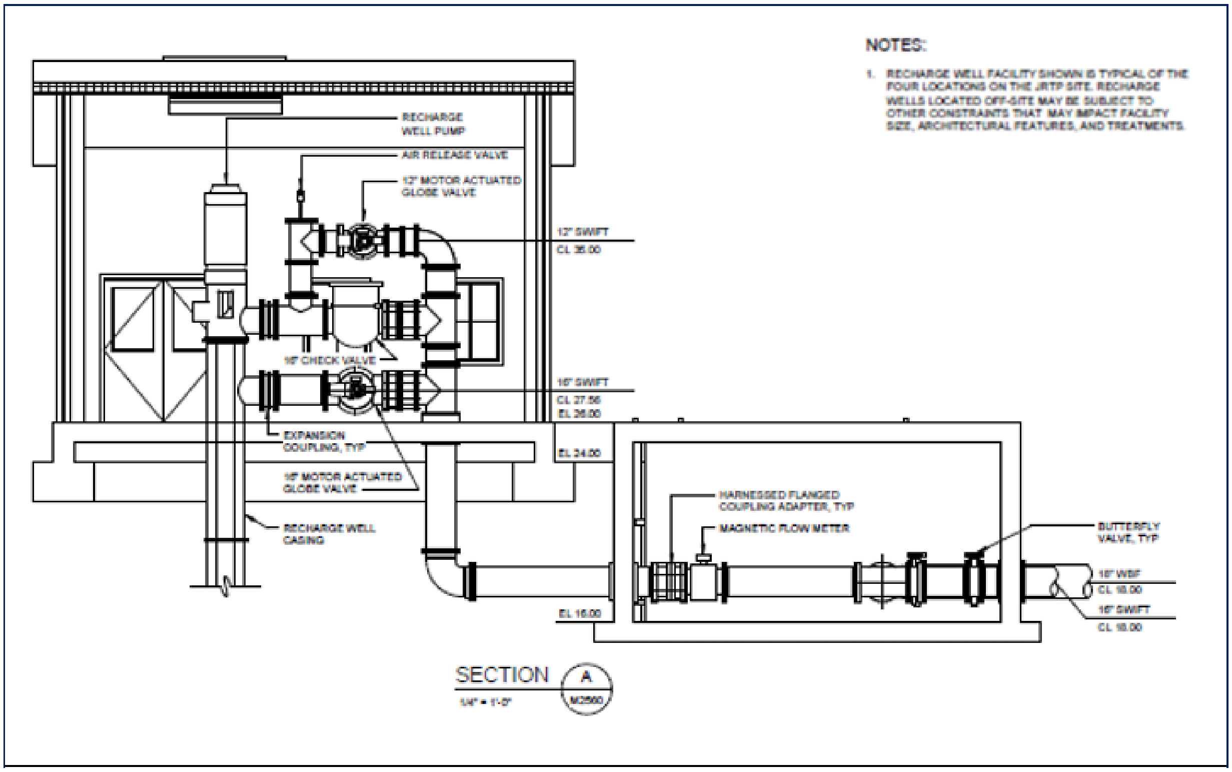
1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

Injection Pressure monitored at wellhead

Annulus Pressure monitored in well using downhole pressure transducers

Recharge flow meter and flow totalizer

Figure D.6: Planview of surface construction around MAR wells located off-site but proximal to the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.



NOTES:

1. RECHARGE WELL FACILITY SHOWN IS TYPICAL OF THE FOUR LOCATIONS ON THE JRTP SITE. RECHARGE WELLS LOCATED OFF-SITE MAY BE SUBJECT TO OTHER CONSTRAINTS THAT MAY IMPACT FACILITY SIZE, ARCHITECTURAL FEATURES, AND TREATMENTS.

Figure D.7: Profile of surface construction around MAR wells located off-site but proximal to the James River SWIFT Facility. Figure taken from bridging documents prepared by Hazen and Sawyer for James River SWIFT and Nutrient Upgrade.

D.1.3 Monitoring of Injection Fluids

D.1.3.1. JR SWIFT Regulatory Limits

SWIFT Water regulatory requirements are outlined in detail in Appendix A, James River SWIFT Water Quality Targets. Briefly, Table D.1 provides a list of the regulatory limits for JR SWIFT. Most parameters have a treatment goal in addition to the regulatory limit. The treatment goals will be supported by Critical Control Points identified in Table D.5. Table D.1 presents the complete list of regulatory requirements for JR SWIFT Water to recharge to the PAS. Quarterly reports detailing compliance with the regulatory limits will be provided to the U.S. Environmental Protection Agency (EPA) and the PAROC.

Table D.1: Regulatory Limits for SWIFT Water

Parameter	Regulatory Limit
EPA Drinking Water Primary Maximum Contaminant Levels (PMCLs)	Meet all PMCLs[1]
Total Nitrogen (TN)	5 mg/L Monthly Average; 8 mg/L Max Daily
Turbidity	Individual Filter Effluent (IFE) <0.15 NTU 95% of time and never >0.3 NTU in two consecutive 15-minute measurements
Total Organic Carbon (TOC)[2]	4 mg/L Monthly Average, 5 mg/L Maximum Instantaneous
Total Coliform[3]	<2 CFU/100 mL 95% of collected samples within one calendar month, applied as the 95th percentile
E. Coli	Non-Detect
TDS[4]	No Limit

[1] Refer to Table D.7 for proposed sampling frequency of PMCLs. Within 24 hours of notification from HRSD or contract laboratory of a potential PMCL exceedance as identified in Table D.2, SWIFT Water will be diverted to the wastewater treatment facility. A confirmation sample will be collected and submitted for analysis as soon as practical and no later than one week after receiving the initial sample results. If the confirmation sample does not confirm the result, recharge will resume. If the PMCL exceedance is confirmed, SWIFT Water will remain diverted until HRSD can complete an investigation as to the likely cause, take corrective action, and perform follow-up sampling to demonstrate that the corrective actions taken have been effective. HRSD will submit documentation describing the problem, the assessment, the corrective action taken, and the results of follow-up sampling within 14 days of resuming recharge.

[2] Regulatory limit applies to the TOC laboratory analysis which is collected at a frequency of 3 times per week.

[3] The TC monitoring requirement at the SRC included compliance with a geomean of 3 CFU/100 mL for 20 daily samples. The Virginia Department of Health (VDH) determined that the requirement to meet TC < 2 CFU/100 mL 95% of the time within a given month was protective of this geomean requirement and the application of both regulatory limits was not necessary.

[4] No limit for TDS as the primary driver is aquifer compatibility. Expected range for SWIFT Water at JR SWIFT is 300-700 mg/L.

D.1.3.2. Compliance Determination

The methodology for determining PMCL compliance varies depending on the specific parameter of interest. Consistent with Virginia Waterworks Regulation, 12VAC5-590-410, the constituents are categorized into groups, and for each constituent group PMCL compliance is determined by either a running annual average (RAA) or as a single-instance limit. Constituents regulated on a RAA basis are in violation when the RAA exceeds the numerical PMCL. Constituents regulated on a single-instance limit are in violation when the results of any single sample exceed the numerical PMCL. In all cases, compliance shall be determined by rounding off results to the same number of significant figures as the PMCL. Further details on compliance evaluations and calculations can be found in Appendix A, James River SWIFT Water Quality Targets.

Table D.2: JR SWIFT Primary Maximum Contaminant Level Compliance Determination

Analytes	SWIFT Water Monitoring Frequency[1]	Compliance Determination
Total coliform	5x/week	TC < 2 CFU/100 mL 95% of collected samples within one calendar month[2]
E coli	5x/week	Non-detect
Antimony, arsenic, barium, beryllium, cadmium, cyanide, chromium, fluoride, mercury, nickel, selenium, thallium	Monthly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Asbestos	Quarterly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Nitrate, Nitrite	5x/week	Compliance for these constituent groups is to be determined based on individual sample results. If any single sample is greater than the PMCL, the PMCL has been exceeded.
Organic chemicals	Monthly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Disinfection byproducts (TTHM and HAA5), Bromate, Chlorite	Monthly	Compliance with the PMCL is determined by a RAA of monthly data. If the average is greater than the PMCL, the PMCL has been exceeded.
Radionuclides	Monthly	Compliance for these constituent groups is to be determined based on individual sample results. If any single sample is greater than the PMCL, the PMCL has been exceeded.

[1] Minimum required monitoring frequency. All data collected during recharge operations and when the SWIFT facility is shut down due to a PMCL exceedance shall be reported and included in the compliance determination calculations. Data collected during a planned shutdown (such as a GAC contactor re-start) or during a pre-emptive shut down (such as when a CCP triggers a diversion of SWIFT water) are exempt from this requirement.

[2] If TC exceeds 2 CFU/100 mL > 95 % of samples (calculated by the 95th percentile) in one calendar month, HRSD will conduct an additional investigation (e.g., evaluating sample collection and training protocols, possible sample line contamination, etc.) A TC exceedance is not considered a PMCL exceedance unless E. coli is present. The results of the investigation will be included in the next quarterly report.

D.1.3.3. Performance Indicators

Table D.3 provides a list of performance indicators. These constituents are separated into those that are of public health interest and those that provide information on the effectiveness of treatment (*Final Report of an NWRI Independent Advisory Panel: Recommended DPR General Guidelines and Operational Requirements for New Mexico, 2016*). If the running annual average for any of the threshold values shown in Table D.3 is exceeded, an investigation will be conducted to determine the best action to address the issue. This could include sampling at the monitoring well to determine removal by soil aquifer treatment (SAT), source control, modifying wastewater treatment, modifying advanced treatment, no action, or an alternative approach.

HRSD is currently evaluating the occurrence of a broader suite of non-regulated parameters in order to develop an indicator list that reflects the characteristics of local wastewater sources. The collection and evaluation of this data is on-going, and an additional list of indicators will be developed prior to the start of JR SWIFT recharge operations and provided to the PAROC/PARML for review. The Hampton Roads-specific list of indicators will be evaluated in parallel with the indicators in Table D.3 to confirm the suitability of this new list for performance monitoring.

Table D.3: JR SWIFT Non-Regulatory Performance Indicators

Constituent	Category	Threshold Value	Unit	Notes
1,4-Dioxane	Public Health	1	µg/L	CCL4; CA Notification Limit
17-β-Estradiol	Public Health	0.9[1]	ng/L	CCL4
DEET	Public Health	200	µg/L	MN Health Guidance Value
Ethinyl Estradiol	Public Health	280[1]	ng/L	CCL4
NDMA	Public Health	10	ng/L	CCL4; CA Notification Limit
Perchlorate	Public Health	6	µg/L	CA Notification Limit
PFOA+PFOS[2]	Public Health	70	ng/L	CCL4; EPA Health Advisory
TCEP	Public Health	5	µg/L	MN Health Guidance Value
Cotinine	Treatment Effectiveness	1	µg/L	Surrogate for low molecular weight, partially charged cyclics
Primidone	Treatment Effectiveness	10	µg/L	
Phenytoin	Treatment Effectiveness	2	µg/L	
Meprobamate	Treatment Effectiveness	200	µg/L	High occurrence in wastewater treatment plant effluent
Atenolol	Treatment Effectiveness	4	µg/L	
Carbamazepine	Treatment Effectiveness	10	µg/L	Unique structure
Estrone	Treatment Effectiveness	320	ng/L	Surrogate for steroids
Sucralose	Treatment Effectiveness	150	mg/L	Surrogate for water soluble, uncharged chemicals with moderate molecular weight
Triclosan	Treatment Effectiveness	2,100	µg/L	Chemical of interest

[1] Threshold value identified in *Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water, Recommendations of a Science Advisory Panel, 2018; SCCWRP Technical Report 1032.*

[2] Though no thresholds have been established, monitoring and reporting will include PFBA, PFHpA, PFHxS and PFNA.

D.1.3.4. Design Pathogen Log Removal Value

JR SWIFT will be designed and operated (using CCPs) to achieve at least 12 log removal value (LRV) for viruses and 10 LRV for *Cryptosporidium* and *Giardia* through a combination of advanced treatment processes and soil aquifer treatment. Table D.4 provides a treatment process pathogen LRV summary for JR SWIFT. Monitoring at the SRC will be used to verify the claimed credits for each process unit. The following key design and operational considerations and regulatory references are provided for context for Table D.4:

- Two-log removal of viruses and 2.5-log *Giardia* removal is granted per the *Surface Water Treatment Rule Guidance Manual*, 1991 edition, section 5.5.2, for a well operated conventional filtration treatment plant.

- Three-log *Cryptosporidium* removal is granted per the *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual* section 1.4.1 if the combined filter effluent (CFE) is less than 0.3 NTU 95% of the time and never greater than 1.0 NTU. An additional 0.5-log credit is granted in section 7.2.1 for achieving individual filter effluent (IFE) of 0.15 NTU 95% of the time and having no two consecutive measurements 15 minutes apart greater than 0.3 NTU. One more additional 0.5-log credit is granted in section 7.2.1 for achieving CFE of 0.15 NTU 95% of the time. CCPs will be enacted to ensure that these turbidity requirements are met.
- The ozone system will not be operated specifically to achieve pathogen removal credit. It is anticipated that ozone operation to achieve oxidation of organics will also achieve very high levels of pathogen removal, but this will not be a programmed CCP or operational goal at JR SWIFT. If ozone is operated in AOP mode, there will be no ozone residual and no way to demonstrate pathogen log removal under the current EPA guidance, although research is being and will be conducted in the future to demonstrate removal using other verification methods.
- The design Ultraviolet “UV” dose of 186 mJ/cm^2 provides 4 LRV for viruses according to Table 1.4 of the *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule*. Significantly greater inactivation of *Cryptosporidium* and *Giardia* would be achieved at this design dose, though only 4-log removal is claimed in Table D.4. If UV is operated in AOP mode, significantly more pathogen removal credit could be achieved, but that is not claimed in Table D.4.
- At least 6-log credit for viruses, *Cryptosporidium*, and *Giardia* is expected through SAT based on the modeled travel time of the recharge water in the PAS. Literature has demonstrated additional treatment of recharge water as it moves through an aquifer system; the California Department of Health Regulations Related to Recycled Water section 60320.108 states that 1-log virus reduction credit is granted for every month the water is in the ground up to 6-log reduction. A minimum 6-log removal of *Cryptosporidium* and *Giardia* is expected when achieving 6-log virus reduction. HRSD’s soil column testing has confirmed this assumption.

Table D.4: JR SWIFT Design Pathogen LRV

Parameter	Floc/Sed (+BAF)	Ozone	BAF+GAC	UV	Cl2	SAT	Total
Enteric Viruses	2	0	0	4	0	6	12
Cryptosporidium	4	0	0	4	0	6	14
Giardia	2.5	0	0	4	0	6	12.5

D.1.3.5. Critical Control Points

JR SWIFT will incorporate CCPs and critical operating points (COPs) throughout the treatment process, similar to the SRC, to ensure public health protection and to verify that treatment goals are being met at each of the individual processes. A violation of any CCP means that JR SWIFT may not be producing water that meets the treatment goals and will trigger a diversion of the SWIFT Water so that it is not directed to the recharge wells. In most instances, JR SWIFT will continue to operate through the CCP violation, but the SWIFT Water will be diverted back to the JR chlorine contact tank and will not be recharged into the aquifer. CCPs specifically protect public health and ensure compliance with regulatory parameters while COPs can be adapted as needed to ensure proper treatment performance throughout the SWIFT process.

CCPs have alert values at which point the operator is expected to take action to correct the performance as well as alarm values at which point an automated response will trigger action and prevent flow from going to the recharge wells. Both the alert and alarm values will be measured for a specified duration or computed as a running average before action is taken so that blips in online analyzers do not trigger action. The specific values for the alert and alarm levels will be configured as adjustable set points in the Distributed Control System and optimized as needed to meet the water quality requirements.

Table D.5 provides the current, preliminary list of CCPs for JR SWIFT, which is largely the same as the current list for the SRC. During the first year of SRC operation, several CCPs have been adjusted (and documented with EPA) based on lessons learned during operation. It is anticipated that there will be additional changes to Table D.5 as the SRC continues in operation.

Table D.5: Critical Control Points for JR SWIFT

Parameter	Alert Value	Alarm Value	Unit	Type[1]	Action
Critical Control Points (CCPs)					
SWIFT Feed Turbidity	3.5	5	NTU	Latched	Place Biofilters in Filter To Waste
SWIFT Feed Conductivity	1,500	2,000	microSiemens per centimeter	Latched	Place Biofilters in Filter To Waste
SWIFT Feed Total Inorganic Nitrogen	4.0	5.0	mg/L-N	Latched	Place Biofilters in Filter To Waste
Preformed Chloramine Failure (if used for bromate suppression)	N/A	Failure	mg/L	Latched	Divert SWIFT Water
Total Chlorine Upstream of Ozone (if used for bromate suppression)	2.0	1.0	mg/L	Latched	Divert SWIFT Water
Monochloramine Upstream of Ozone (if used for bromate suppression)	2.0	1.0	mg/L	Latched	Divert SWIFT Water
Ozone Feed Failure	N/A	Failure	N/A	Latched	Open Biofilter Backwash Waste Valve
High Ozone Dose	7.0	8.0	mg/L	Latched	Place Biofilters in Filter To Waste
Biofilter Individual Effluent Turbidity	0.1	0.15	NTU	Running Average	Place Biofilter in Filter To Waste
Biofilter Combined Filter Effluent Turbidity	0.1	0.15	NTU	Running Average	Place Biofilters in Filter To Waste
GAC Combined Effluent TOC, Instantaneous Online Analyzer	4.0	5.0	mg/L	Latched	Divert SWIFT Water
GAC Combined Effluent Nitrite	0.25	0.5	mg/L-N	Latched	Divert SWIFT Water
GAC Combined Effluent Ammonia[2]	0.1	0.3	mg/L-N	Latched	Divert SWIFT Water
UV Reactor Dose	<120% of Dose Setpoint	<105% of Dose Setpoint	%	Latched	Divert SWIFT Water
SWIFT Water Total Nitrogen	4.5	5.0	mg/L-N	Latched	Divert SWIFT Water

[1] A latched CCP requires the measured value to be above/below the limit for a specified duration before alerting or alarming. A running average will generate an alert or alarm if the running average over a specified duration is above/below the limit. Running averages were implemented for specific CCPs to more conservatively protect against water quality requirements.

[2] Ammonia control of GAC CE is applicable only when using free chlorine post-UV for well biofoulant control. Refer to table D.7, footnote 9 for additional information.

The following CCPs were removed or adjusted from the current CCPs in use at the SRC:

- Ozone Contactor Calculated LRV – Virus (CCP): As JR SWIFT will not operate ozone to achieve disinfection credit, the LRV has been removed from the CCP list.
- Free Chlorine CT (CCP): As JR SWIFT will not add free chlorine for disinfection of SWIFT Water, the required CT has been removed from the CCP list. SWIFT Water Chlorine Residual remains a COP to prevent biofouling in the recharge wells.
- CCPs associated with the tasting system at the SRC have been removed as JR SWIFT will not be designed for tastings.

D.1.3.6 JR SWIFT Regulatory Sampling Plan

Sampling will be performed throughout the treatment process to verify treatment performance, online analyzer accuracy, and compliance with regulatory limits. A detailed sampling plan has been generated that addresses these purposes. Sampling will consist of a combination of onsite analysis, lab analysis performed by HRSD, and specialized analysis performed by outside contract labs. Table 4.1 provides the additional monitoring required to document compliance with the targeted LRV for the UV system. Table D.6. provides the sampling plan specific to the proposed regulatory limits and performance indicators including the location and frequency of each sample.

Table D.6: Additional Monitoring to Support UV LRV [1]

UV LRV
UV Intensity, each reactor
UVT, GAC Combined Effluent
Reactor Flow, each
Calculated Dose (validated), each reactor
Status, each

[1] All continuous measurements. Calculated dose and LRV will be reported as part of the quarterly monitoring reports. Calculations will be based on 15 min data.

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]

Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Total Nitrogen		Weekly				Monthly	Monthly	5x/week
Turbidity					Continuous[4]	Continuous[4]		
TOC		Weekly	3x/week			3x/week		3x/week
pH[5]								Continuous
TDS[5]								Monthly
Regulatory Parameters: EPA Primary MCLs								
Male-specific and somatic coliphages[5]		Quarterly						Quarterly
Cryptosporidium	Quarterly	Quarterly						Quarterly
Giardia lamblia	Quarterly	Quarterly						Quarterly
Legionella		Quarterly						Quarterly
Total Coliform		Weekly						5x/week
E. coli		Weekly						5x/week
Bromate				5x/week				Weekly
Chlorite	Quarterly	Monthly						Monthly
Haloacetic acids (HAA5)								Monthly
Total trihalomethanes								Monthly
Disinfectants[6]								
Chloramines (as Cl_2)								Continuous[7]
Chlorine (as Cl_2)								Continuous[7]

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1, 2, 3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Antimony, Total	Quarterly	Monthly						Monthly
Arsenic, Total	Quarterly	Monthly						Monthly
Asbestos		Quarterly						Quarterly
Barium, Total	Quarterly	Monthly						Monthly
Beryllium, Total	Quarterly	Monthly						Monthly
Cadmium, Total	Quarterly	Monthly						Monthly
Chromium, Total	Quarterly	Monthly						Monthly
Copper, Total	Quarterly	Monthly						Monthly
Cyanide, Total	Quarterly	Monthly						Monthly
Fluoride	Quarterly	Monthly						Monthly
Lead, Total	Quarterly	Monthly						Monthly
Mercury, Total	Quarterly	Monthly						Monthly
Nitrate -N		Weekly				Monthly	Monthly	5x/week
Nitrite-N		Weekly				Monthly	Monthly	5x/week
Selenium, Total	Quarterly	Monthly						Monthly
Thallium, Total	Quarterly	Monthly						Monthly
Acrylamide	Quarterly	Monthly						Monthly
Alachlor	Quarterly	Monthly						Monthly
Atrazine	Quarterly	Monthly						Monthly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Benzene	Quarterly	Monthly						Monthly
Benzo(a)pyrene (PAHs)	Quarterly	Monthly						Monthly
Carbofuran	Quarterly	Monthly						Monthly
Carbon Tetrachloride	Quarterly	Monthly						Monthly
Chlordane	Quarterly	Monthly						Monthly
Chlorobenzene	Quarterly	Monthly						Monthly
2,4-D	Quarterly	Monthly						Monthly
Dalapon	Quarterly	Monthly						Monthly
1,2-dibromo-3-chloropropane (DBCP)	Quarterly	Monthly						Monthly
1,2-Dichlorobenzene (o-dichlorobenzene)	Quarterly	Monthly						Monthly
1,4-Dichlorobenzene (p-dichlorobenzene)	Quarterly	Monthly						Monthly
1,2-Dichloroethane	Quarterly	Monthly						Monthly
1,1-Dichloroethylene	Quarterly	Monthly						Monthly
cis-1,2-Dichloroethylene	Quarterly	Monthly						Monthly
trans-1,2-Dichloroethylene	Quarterly	Monthly						Monthly
Dichloromethane (Methylene chloride)	Quarterly	Monthly						Monthly
1,2-Dichloropropane	Quarterly	Monthly						Monthly
Di(2-ethylhexyl) adipate	Quarterly	Monthly						Monthly
Di(2-ethylhexyl) phthalate	Quarterly	Monthly						Monthly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1, 2, 3]

Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Dinoseb	Quarterly	Monthly						Monthly
Dioxin (2,3,7,8-TCDD)	Quarterly	Monthly						Monthly
Diquat	Quarterly	Monthly						Monthly
Endothall	Quarterly	Monthly						Monthly
Endrin	Quarterly	Monthly						Monthly
Epichlorohydrin	Quarterly	Monthly						Monthly
Ethylbenzene	Quarterly	Monthly						Monthly
Ethylene dibromide (EDB)	Quarterly	Monthly						Monthly
Glyphosate	Quarterly	Monthly						Monthly
Heptachlor	Quarterly	Monthly						Monthly
Heptachlor Epoxide	Quarterly	Monthly						Monthly
Hexachlorobenzene	Quarterly	Monthly						Monthly
Hexachlorocyclopentadiene	Quarterly	Monthly						Monthly
Lindane (Gamma-BHC)	Quarterly	Monthly						Monthly
Methoxychlor	Quarterly	Monthly						Monthly
Oxamyl (Vydate)	Quarterly	Monthly						Monthly
Polychlorinated biphenyls	Quarterly	Monthly						Monthly
Arochlor (AR)1016	Quarterly	Monthly						Monthly
AR1221	Quarterly	Monthly						Monthly
AR1232	Quarterly	Monthly						Monthly
AR1242	Quarterly	Monthly						Monthly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
AR1248	Quarterly	Monthly						Monthly
AR1254	Quarterly	Monthly						Monthly
AR1260	Quarterly	Monthly						Monthly
Pentachlorophenol	Quarterly	Monthly						Monthly
Picloram	Quarterly	Monthly						Monthly
Simazine	Quarterly	Monthly						Monthly
Styrene	Quarterly	Monthly						Monthly
Tetrachloroethylene	Quarterly	Monthly						Monthly
Toluene	Quarterly	Monthly						Monthly
Toxaphene	Quarterly	Monthly						Monthly
2,4,5-TP (Silvex)	Quarterly	Monthly						Monthly
1,2,4-Trichlorobenzene	Quarterly	Monthly						Monthly
1,1,1-Trichloroethane	Quarterly	Monthly						Monthly
1,1,2-Trichloroethane	Quarterly	Monthly						Monthly
Trichloroethylene	Quarterly	Monthly						Monthly
Vinyl Chloride	Quarterly	Monthly						Monthly
Xylene, Total	Quarterly	Monthly						Monthly
Alpha particles		Monthly						Monthly
Beta particles and photon emitters		Monthly						Monthly
Radium 226		Monthly						Monthly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1, 2, 3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Radium 228		Monthly						Monthly
Uranium		Monthly						Monthly
Regulatory Parameters: Virginia Groundwater Standards[8]								
Aldrin/Dieldrin	Quarterly	Monthly						Monthly
DDT	Quarterly	Monthly						Monthly
Kepone	Quarterly	Monthly						Monthly
Mirex	Quarterly	Monthly						Monthly
Phenols	Quarterly	Monthly						Monthly
Strontium-90		Monthly						Monthly
Tritium		Monthly						Monthly
Non-regulatory Parameters: Performance Indicators								
Public Health Indicators								
1,4-dioxane	Quarterly	Quarterly						Quarterly
17-β-estradiol	Quarterly	Quarterly						Quarterly
DEET	Quarterly	Quarterly						Quarterly
Ethinyl estradiol	Quarterly	Quarterly						Quarterly
NDMA	Quarterly	Quarterly		Weekly		Weekly		Weekly[9]
Perchlorate	Quarterly	Quarterly						Quarterly
PFOA + PFOS	Quarterly	Quarterly						Quarterly
PFBA	Quarterly	Quarterly						Quarterly
PFHpA	Quarterly	Quarterly						Quarterly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
PFHxS	Quarterly	Quarterly						Quarterly
PFNA	Quarterly	Quarterly						Quarterly
tris(2-carboxyethyl)phosphine (TCEP)	Quarterly	Quarterly						Quarterly
Treatment Efficacy Indicators								
Cotinine	Quarterly	Quarterly						Quarterly
Primidone	Quarterly	Quarterly						Quarterly
Phenytoin	Quarterly	Quarterly						Quarterly
Meprobamate	Quarterly	Quarterly						Quarterly
Atenolol	Quarterly	Quarterly						Quarterly
Carbamazepine	Quarterly	Quarterly						Quarterly
Estrone	Quarterly	Quarterly						Quarterly
Sucralose	Quarterly	Quarterly						Quarterly
Triclosan	Quarterly	Quarterly						Quarterly
Non-regulatory Parameters: Aquifer Characteristics and/or Compatibility								
Unregulated Contaminant Monitoring Rule (UCMR)[10]								TBD[10]
Dissolved Oxygen								Monthly
Temperature								Monthly
Specific conductivity								Monthly
ORP								Monthly
Iron, Total								Continuous[11]

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1, 2, 3]								
Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Aluminum, dissolved								Monthly
Aluminum, total								Monthly
Arsenic, dissolved								Monthly
Iron, dissolved								Monthly
Manganese, dissolved								Monthly
Manganese, total								Monthly
Magnesium, total								Monthly
Potassium, total								Monthly
Sodium, total								Monthly
Calcium, total								Monthly
Sulfate								Monthly
Chloride								Monthly
Bromide		Weekly						
Alkalinity								Monthly
Total Kjeldahl Nitrogen		Weekly				Monthly		Weekly
Ammonia as N								Weekly
Total Phosphorus			Weekly			Weekly		Weekly
Orthophosphate as P			Weekly			Weekly		Weekly
Silica as SiO_2								Monthly
Hardness, Total								Monthly

Table D.7: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]

Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water

[1] Compliance samples are collected during periods of recharge. Point of compliance for all regulatory parameters is SWIFT Water with the exception of turbidity. Compliance point for turbidity monitoring is BAF Individual and Combined Filter Effluents (BAF IFE, BAF CFE).

[2] Non-compliance process monitoring may be modified based on operational needs.

[3] All samples are collected as grabs unless denoted as “Continuous”. 15-minute data will be reported for each continuous measurement.

[4] All in service turbidimeters will be verified with daily lab grabs. Only 15-min online turbidimeter data will be submitted for IFE and CFE. If a turbidimeter is out of service, unreliable or suspect, turbidity samples will be collected by grab for lab analysis every 4 hours, and those data will be submitted.

[5] Monitoring requirement with no limit imposed.

[6] ClO_2 not used for disinfection and therefore is not included in monitoring.

[7] Continuous measurements of chlorine and chloramines will be confirmed with a daily grab sample.

[8] Virginia Ground Water Standards (9VAC25-280-40) not included as a PMCL under the Safe Drinking Water Act (SDWA) and considered critical for inclusion by the Virginia Department of Health (VDH).

[9] In addition to monitoring NDMA concentration, NDMA Formation Potential (FP) tests will be as follows:

- when monochloramine is being added following UV disinfection the frequency shall be monthly for one year. NDMA FP frequency will be reduced in years 2 – 3 to quarterly, followed by annual testing for the duration of the permit, provided the contingencies for phased reduction continue to be met. Phased reduction is contingent upon (i) NDMA concentrations under agreed-upon conditions in FP testing remaining < 10 ng/L, and (ii) NDMA concentrations in the monitoring wells remaining < 10 ng/L. Exceedance of either of these conditions will “reset” the phased reduction schedule.
- when free chlorine is being added following UV disinfection, NDMA FP testing will be conducted monthly for three months and will be ceased if (i) NDMA concentrations under agreed-upon conditions in FP testing remain < 10 ng/L, and (ii) NDMA concentrations in the monitoring wells remain < 10 ng/L. NDMA FP is expected to be minimal when using free chlorine post-UV and HRSD will further mitigate this risk by incorporating ammonia monitoring of the GAC combined effluent with a CCP for SWIFT Water diversion (Table D.5).
- All NDMA FP data will be evaluated by PARML and PAROC to ensure concurrence with phased reductions.

[10] HRSD shall monitor currently effective UCMR parameters at the frequency required for large water systems.

[11] Continuous measurements of total iron will be confirmed with a weekly grab sample.

D.2 Well Information

D.2.1 Recharge Flows

Average and maximum MAR recharge flows are estimated as follows:

- Average day flow per well: 1.65 million gallons per day (MGD)
- Maximum day flow per well: 2.0 MGD
- Average aggregate flow for wellfield: 12.375 MGD (75% of capacity)
- Maximum aggregate flow for wellfield: 16.5 MGD

D.2.2 Source of the Injection Fluid

The source of the injection fluid for recharge consists of treated secondary effluent from HRSD's wastewater treatment facilities that pass through the JR SWIFT AWT and meets EPA SDWA PMCLs.

D.2.2 Proposed Annular Fluid

Not applicable, no annular fluid will be used in the JR SWIFT MAR wells

D.2.3 Analysis of chemical and physical characteristics of the injection fluid

Table D.8 describes the predicted chemical and physical characteristics of the injection (recharge) fluid. Table D.8 also displays native groundwater quality from the receiving aquifers beneath JR SWIFT. Effluent/recharge emerging from the AWT at JR SWIFT will meet all PMCLs. Monitoring and regulatory thresholds for the injection fluid are noted in Table D.7.

Table D.8: Native groundwater chemistry, test well at James River

Test Intervals		**72 HR CRT[1]**	**Packer Test 1 (398-524 fbg[2])**	**Packer Test 2 (570-636 fbg)**	**Packer Test 3 (735-790 fbg)**	**Packer Test 4 (960-1000 fbg)**	**Packer Test 5 (1048-1122 fbg)**	**Packer Test 6 (1240-1280 fbg)**	**Estimated Recharge Chemistry[3]**	**PMCL/ SMCL**
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
pH	standard units	6.32	6.76	7.71	6.14	7.20[6]	7.26	7.62	7.2 to 7.8	6.5 to 8.5
ORP[4]	mV	54.9	-133.8	-95	-70.3	-108	-103.2	-99.6	NA	
Eh (corrected)[5]	mV	254.9	66.2	105	129.7	92	96.8	100.4	NA	
Specific Conductivity	µs/cm	3113	4635	4088	5200[7]	6230	6690[7]	8700[7]	NA	
Temperature	ºC	20.27	25.97	23.57	26.77	25.87	25.8	26.59	15 to 26	
Turbidity	NTU	1.51	1.63	2.12	5.53	0.52	0.43	6.19		
Field Sulfide as S	mg/L	0	0	0	0.04	0	0	0.01	NA	
Field Sulfate as SO$_4$	mg/L	58	70	69	106	90	104	183	NA	
Field Iron (ferrous as Fe $^{2+}$)	mg/L	0.22	2.35	2.31	1.35	1.34	2.07	2.22	NA	
Field Iron (total)	mg/L	0.91	2.04	2.01	1.7	1.79	2.22	3.14	NA	
Aluminum, dissolved	mg/L	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010	<0.04	0.1
Aluminum, total	mg/L	0.063	<0.010	0.014	0.036	<0.010	<0.010	<0.010	<0.04	0.1
Arsenic, dissolved	µg/L	<1.00	0.25	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Arsenic, total	µg/L	<1.00	0.24	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Iron, dissolved	mg/L	0.203	2.49	2.74	1.39	1.46	2.07	2.28	0.07	0.3
Iron, total	mg/L	0.241	2.45	2.79	1.58	1.48	2.05	2.25	0.07	0.3
Manganese, dissolved	mg/L	0.0217	0.0518	0.0575	0.0527	0.0533	0.0829	0.142	0.01	0.05
Manganese, total	mg/L	0.0226	0.0504	0.0581	0.0539	0.0542	0.0852	0.142	0.01	0.05
Magnesium, total	mg/L	4.78	6.71	6.93	9.00	10.6	15.8	25.6	3.6	
Potassium, total	mg/L	15.4	19.6	19.6	20.4	24.6	29	36.9	13	
Sodium, total	mg/L	777	970	979	1060	1240	1500	1930	68	
Calcium, total	mg/L	13.2	19.8	20.7	25.4	29.6	42.1	63.8	34	
Sulfate	mg/L	70.3	90.6	91.6	119	126	175	275	53	250
Chloride	mg/L	825	1460	1490	1770	1830	2290	3070	106	250
Alkalinity	mg/L	326	273	265	258	240	222	217	38	
Nitrate/Nitrite-N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.7	
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.1	10
Total Kjeldahl Nitrogen	mg/L	0.52	0.69	0.66	0.78	0.79	0.92	1.03	2.6	
Fluoride	mg/L	2.16	0.913	0.920	0.863	0.793	0.601	<0.500	0.65	4
Silica as SiO$_2$	mg/L	25.5	38.5	38.1	36.6	40.5	39.4	33.9	NE	
Silicon as Si	mg/L	11.9	18.0	17.8	17.1	18.9	18.4	15.8	NE	

Table D.8: Native groundwater chemistry, test well at James River

Test Intervals		**72 HR CRT[1]**	**Packer Test 1 (398-524 fbg[2])**	**Packer Test 2 (570-636 fbg)**	**Packer Test 3 (735-790 fbg)**	**Packer Test 4 (960-1000 fbg)**	**Packer Test 5 (1048-1122 fbg)**	**Packer Test 6 (1240-1280 fbg)**	**Estimated Recharge Chemistry[3]**	**PMCL/ SMCL**
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
Dissolved organic carbon	mg/L	0.16	0.13	0.11	<0.10	0.21	0.14	0.13	4	
Total organic carbon	mg/L	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	4	
Total phosphorus	mg/L	0.20	0.14	0.17	0.17	0.13	0.08	0.04	0.02	
Orthophosphate as P	mg/L	0.19	0.04	0.03	0.05	0.02	0.02	0.01	0.01	
Total dissolved solids	mg/L	1880	2990	3060	3470	3590	4460	5800	420	
Total suspended solids	mg/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	0.05	
Hardness, Total	mg eq	52.6	77.1	80.2	100	118	170	265	99	
Ammonia as N	mg/L	0.44	0.56	0.54	0.60	0.61	0.86	0.91	0.52	
BOD5	mg/L	<2	<2	<2	<2	<2	<2	<2	1	
COD	mg/L	<9.0	<12.0	<12.0	<12.0	<12.0	<15.0	<15.0	<10	
Gross Alpha	pCi/L	9.3	6.8	9.7	13	14	14	16	NE	15
Gross Beta	pCi/L	15	16	23	27	27	28	30	NE	
Ra 226 + Ra 228	pCi/L	1.1	ND	ND	1.4	1.6	4.8	8.8	NE	5
Uranium	µg/L	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.500	NE	
Calculated species										
Ionic strength	mol/L	0.047	0.07475	0.0765	0.08675	0.08975	0.1115	0.145	0.0105	
Ionic balance (Stuyfzand, 1993)	%	4.3	5.5	5.7	9.3	2.8	2.3	3.6	6.6	
Ca + Mg/Na + K	meq/L ratio	0.028	0.025	0.027	0.031	0.029	0.052	0.063	0.597	
Organic phosphorous	mg/L	0.137	0.127	0.160	0.153	0.123	0.073	0.037	0.01	
Organic nitrogen	mg/L	0.08	0.13	0.12	0.18	0.18	0.06	0.12	2.08	

Notes:

[1] CRT - constant rate test

[2] fbg - feet below grade

[3] Estimated Recharge Chemistry based on JRTP effluent sampling in January 2015 and 2019 and mathematical modeling to estimate chemistry of JR SWIFT Water.

[4] ORP - oxidation/reduction potential

[5] Eh = ORP + 200 mV

[6] Instrument issue, pH estimated using PHREEQC

[7] Instrument issue, specific conductivity estimated by 1.5 x TDS

NA - Not applicable
ND – Non-detect
NM – Not measured
NE – Not estimated

Attachment E: Plugging and Abandonment Plan

No plugs will be used for abandonment. JR SWIFT Wells are constructed with casing, screens and gravel pack filter in unconsolidated clastic sediments of the Virginia Coastal Plain.

E.1 Plugging and Abandonment Procedures and Cost Estimate

Type of cement and method of abandonment is described below for both a typical SWIFT MAR well and typical monitoring well.

<u>MAR Wells (Figure F.1)</u>

Item #1 Includes all work associated with mobilization, demobilization of the drilling rig and supporting equipment for the work.

- Mobilize/demobilize drill rig, “kill” and remove wellhead **$16,000.**

Item #2 Remove pump and column from 250 to 350 feet below grade (fbg).

- Removal of injection and pump column: **$10,000.**

Item #3 Conduct a caliper log of the 18-inch, 20-inch and 30-inch diameter casings and screen from the base of the sump (1,175 fbg) to land surface.

- Caliper log **$3,000**.

Item #4 Place ASTM C150 Type I/II neat cement grout, via tremie pipe:

- 18-inch diameter from the base of the stainless-steel sump (1,175’) to 370 fbg = 805 LF.
  - 805 LF = 1,425 ft3 of cement grout
- 20-inch diameter stainless steel casing from 310’ to 370’ fbg = 60 LF
  - 60 LF = 135 ft3 of cement grout
- 30-inch diameter stainless steel casing from ground surface to 310’ fbg = 310 LF
  - 310 LF = 1,525 ft3 of cement grout
- Total estimated volume of cement grout = 3,085 ft3
- 3,085 ft3 @ $22/ft3 = **$67,870**.

MAR-1:	Estimated $96,870.00 per well x 10 wells:	$968,700
	Misc. & contingency (5%):	$48,435
	Total Estimated Cost to Abandon 10 wells:	**<u>$1,017,135</u>**

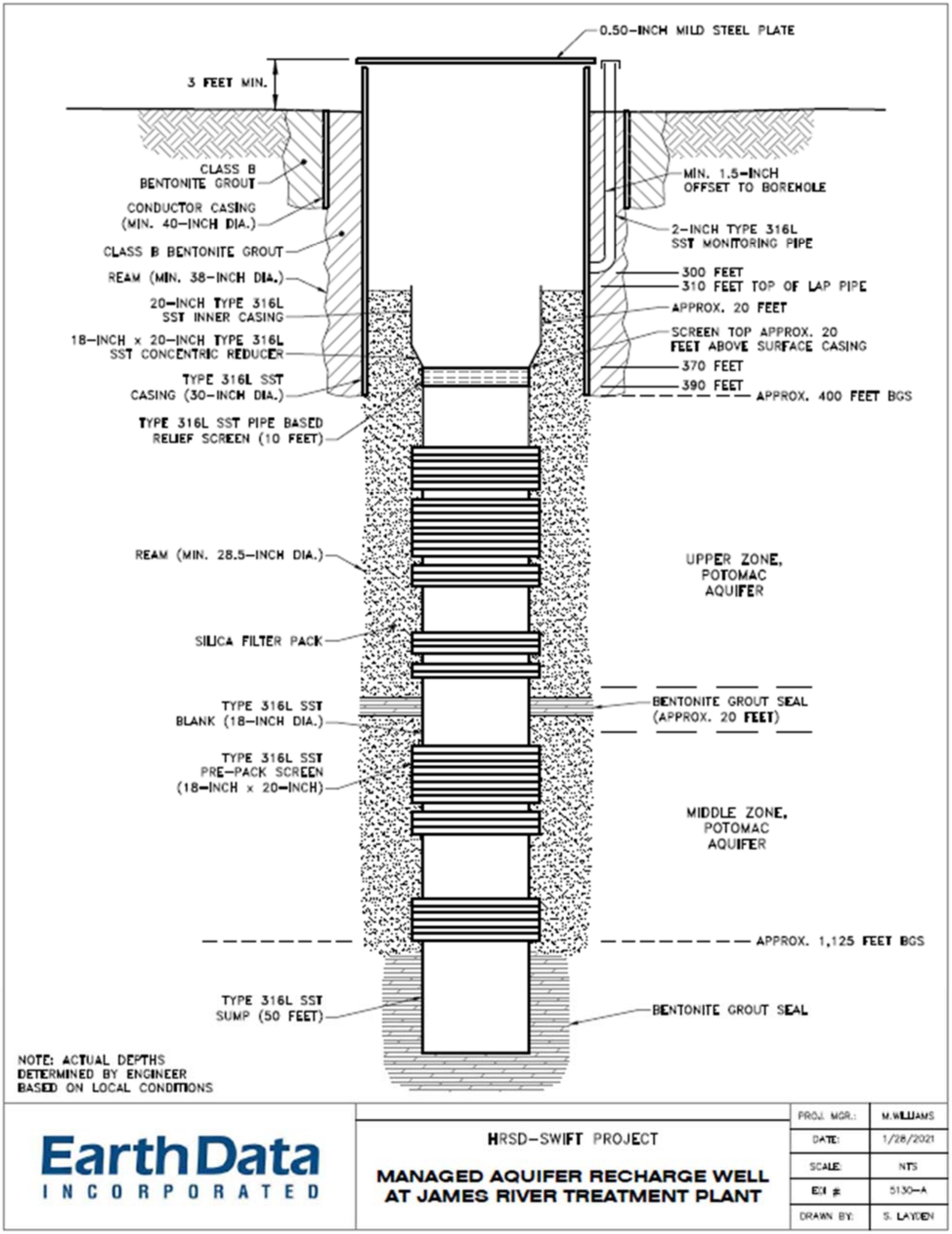


Figure F.1: Proposed Managed Aquifer Recharge Well at JR SWIFT. Elevations and materials of construction may change according to site specific conditions.

Monitoring Wells (Figures F.2, F.3, F.4)

- Six, upper zone of Potomac Aquifer System (UPA) = two at 450', two at 640' and two at 795' to base of sump
- Two, middle zone of Potomac Aquifer System (MPA) = 1,125 to base of sump

Item #1 Includes all work associated with mobilization, demobilization of the drilling rig and supporting equipment for the work.

- Mobilize/demobilize drill rig, remove wellhead, and pull sampling pump **$5,000 per well or cluster (if all abandoned at once)**

Item #2 Remove pump and column from 250 to 350 feet below grade (fbg).

- Remove pump and piping **$6000 per well**

Item #3 Conduct a caliper log of the 4.5-inch diameter inner casing and well screen.

- MPA well x 1,125 fbg.
    - Caliper log 2 @ $2,500.00 **= $5,000**
- UPA well x 450, 640 and 795 fbg.
    - Caliper log, 6 @ $2,000 **= $12,000**
- Total estimated cost for caliper logging: **$17,000 (8 wells)**

Item #4 Place ASTM C150 Type I/II neat cement grout via tremie:

- MPA wells: 4.5" casing from base of sump (1,125 fbg) to ground surface = 1,125 LF
    - 1,125 LF = 200 ft^3 of cement grout per well x 2 wells = 400 ft^3 of cement grout
    - 400 ft^3 cement grout @ $22/$ft^3$ = **$8,800**
- UPA wells: 4.5" casing from base of sump (450, 640 and 795 fbg) to ground surface = 1,885 LF
    - 1,885 LF = 833 ft^3 of cement grout per cluster x 2 clusters = 1,666 ft^3 of cement grout
    - 1,666 ft^3 neat cement grout @ $22 = **$36,652**

UPA:	Estimated $47,326 per cluster x 2 clusters:	$94,652
MPA:	Estimated $17,400 per well x 2 wells:	$34,800
	Subtotal:	$129,452
	Misc. & Contingency (5%):	$3,497
	Total Estimated Cost to Abandon:	**$132,949**

Abandonment Cost Summary:

Estimated cost to abandon 10 MAR Wells:	**$1,017,135**
Estimated cost to abandon 8 monitoring wells:	**$132,949**
Total estimated cost to abandon:	**$1,223,521**

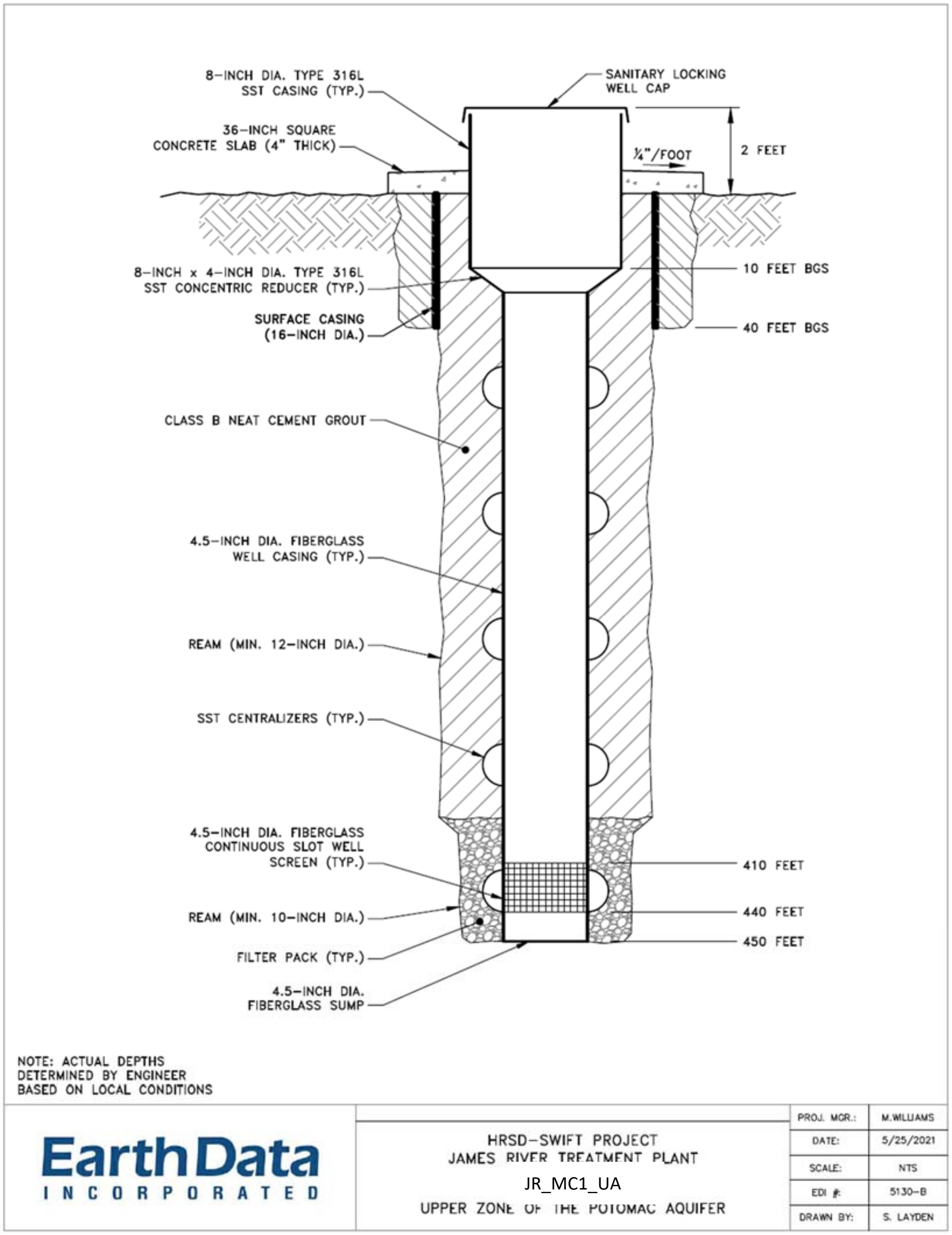


Figure F.2: Typical Shallowest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations and materials of construction may change according to site specific conditions.

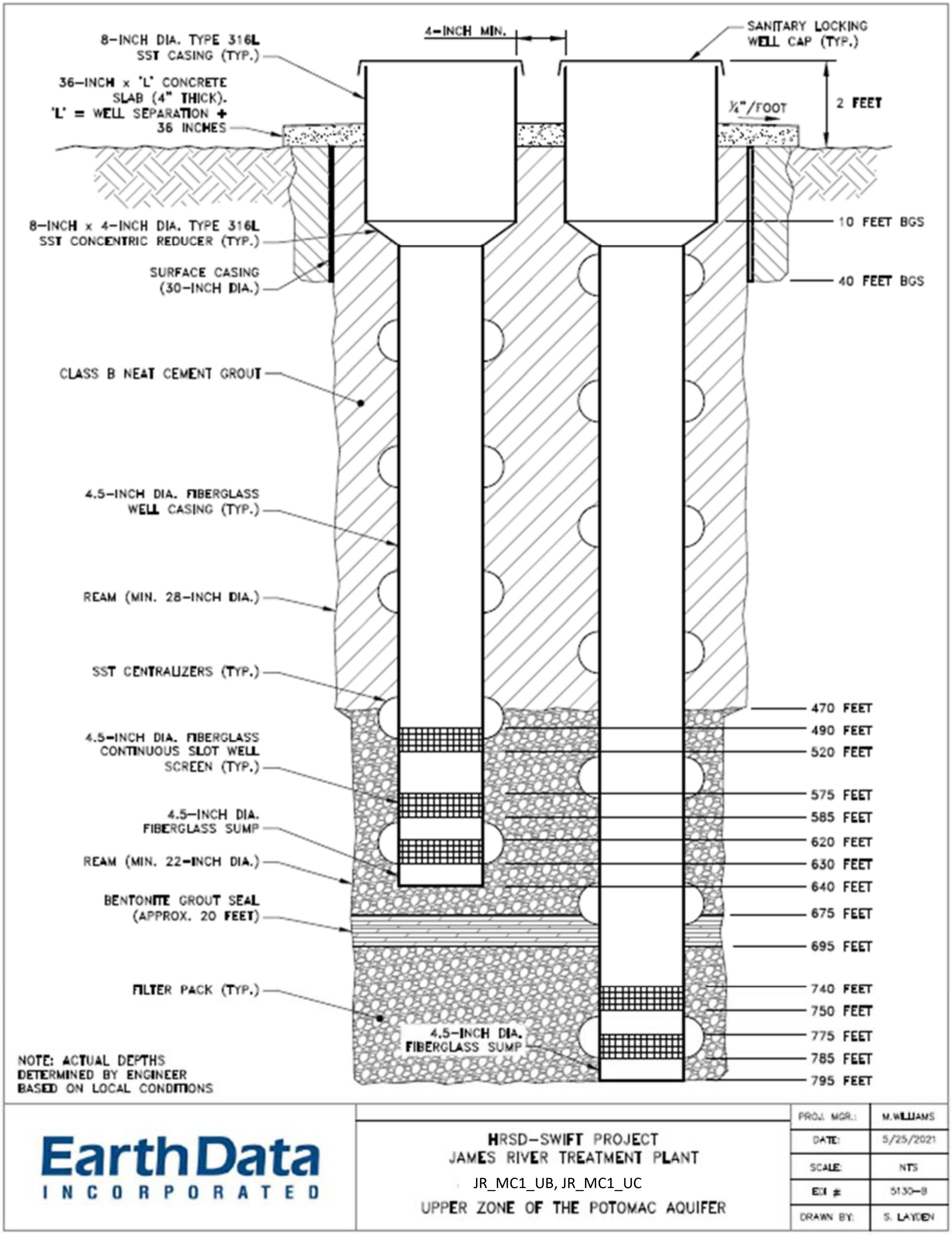


Figure E.3: Typical deeper Upper Zone Nest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

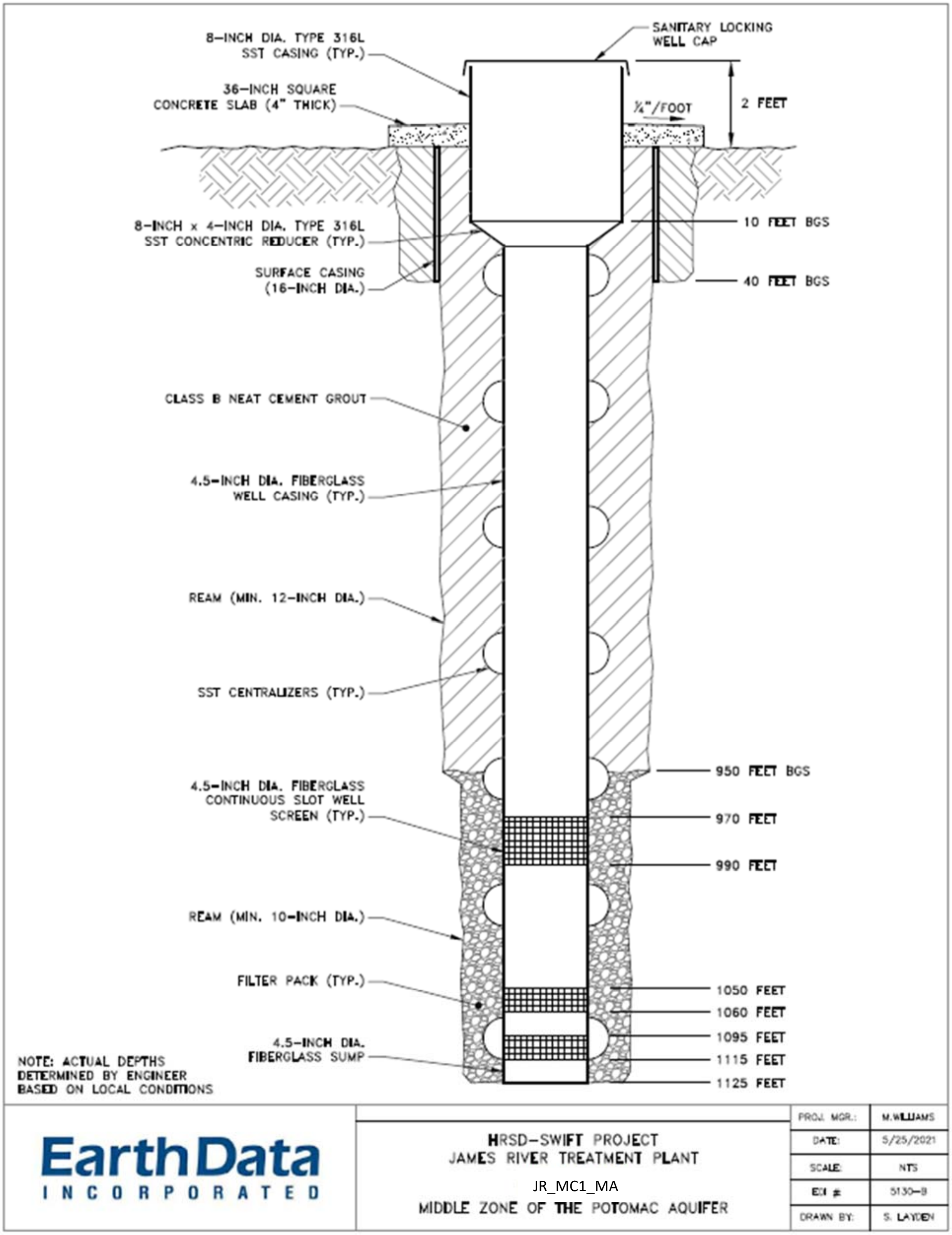


Figure E.4 Typical Middle Zone Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

OMB No. 2040-0042 Approval Expires 4/30/2022

United States Environmental Protection Agency

EPA

WELL REWORK RECORD, PLUGGING AND ABANDONMENT PLAN, OR PLUGGING AND ABANDONMENT AFFIDAVIT

Name and Address, Phone Number and/or Email of Permittee

Hampton Roads Sanitation District
James River SWIFT Wastewater Treatment Plant
111 City Farm Road
Newport News, Virginia 23602

Permit or EPA ID Number VAS5B170028617	**API Number** N/A	**Full Well Name** JR SWIFT Injection/Monitoring Wells

State Virginia	**County** City of Newport News

Locate well in two directions from nearest lines of quarter section and drilling unit

Latitude 37 05 04.8 N

Longitude 76 31 47.1 W

Surface Location

☐ 1/4 of ☐ 1/4 of Section ☐ Township ☐ Range ☐

☐ ft. from (N/S) ☐ Line of quarter section
☐ ft. from (E/W) ☐ Line of quarter section.

Well Class	Timing of Action (pick one)	Type of Action (pick one)
☐ Class I ☐ Class II ☐ Class III ☑ Class V	☐ Notice Prior to Work Date Expected to Commence ☐ Report After Work Date Work Ended	☐ Well Rework ☑ Plugging and Abandonment ☐ Conversion to a Non-Injection Well

Provide a narrative description of the work planned to be performed, or that was performed. Use additional pages as necessary. See instructions.

SEE ATTACHED

Certification

I certify under the penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. (Ref. 40 CFR § 144.32)

Name and Official Title *(Please type or print)* EDWARD HENIFIN, GENERAL MANAGER	**Signature**	**Date Signed** 11/3/2021

EPA Form 7520-19 (Rev. 4-19)

HRSD
Cleaning wastewater every day for a better Bay.

June 14, 2021

RE: Financial Responsibility for Class V Well at the James River Treatment Plant

In conjunction with HRSD's application for a Class V Well at the James River Treatment Plant, HRSD is pleased to submit financial information demonstrating evidence of HRSD's financial resources available necessary for a third party to close, plug, or abandon the well in the event HRSD, the owner or operator, is unable to do so. The monetary amount is based on the P&A plan cost estimate of $1,224,000 provided in Attachment E.

Attachment F-1 provides summary information showing Current Assets in excess of Current Liabilities in the amount of $103.9 million and $33.7 million for the fiscal years ended June 30, 2019 and June 30, 2018, respectively; and Total Assets in excess of Total Liabilities in the amount of $769.7 million and $688.5 million for the fiscal years ended June 30, 2019 and June 30, 2018, respectively.

Attachment F-2 provides summary information showing Total Cash, Cash Equivalents, and Investments in the amount of $326.9 million and $285.2 million for the fiscal years ended June 30, 2019 and June 30, 2018, respectively, of which $284.0 million and $190.2 million are unrestricted.

The HRSD Comprehensive Annual Financial Report for the Fiscal Years Ended June 30, 2019 and 2018 (the CAFR) is available on the HRSD website at the link below. The Financial Statements have been audited by Cherry Bekaert, LLP, and has received an unqualified audit report, included on pages 9 and 10 in the CAFR. We believe the summary information provided on Attachments F-1 and F-2 and the audited CAFR provide sufficient support to show HRSD's ability to pay a third party to close, plug, or abandon the well in the event HRSD is unable to do so.

If you have additional questions regarding our submission, please feel free to contact me directly at 757-460-7215 or lacors@hrsd.com.

Sincerely,

Carroll L. (Lee) Acors
Chief of Accounting

https://www.hrsd.com/sites/default/files/assets/Documents/pdfs/finance/FY2019_CAFR.pdf

Water Quality Department • PO Box 5911, Virginia Beach, VA 23471-0911 • 757.460.7004

www.hrsd.com

HAMPTON ROADS SANITATION DISTRICT
SUMMARY STATEMENTS OF NET POSITION
AS OF JUNE 30, 2019 AND 2018

ASSETS AND LIABILITIES (in thousands)

		2019	2018
A	**CURRENT ASSETS**	$ 244,423	$ 173,604
B	**NON-CURRENT ASSETS**	1,513,744	1,505,739
C=A+B	**TOTAL ASSETS**	1,758,167	1,679,343
	DEFERRED OUTFLOWS OF RESOURCES	21,442	20,762
		$ 1,779,609	$ 1,700,105
D	**CURRENT LIABILITIES**	$ 140,564	$ 139,914
E	**LONG-TERM LIABILITIES**	847,928	850,928
F=D+E	**TOTAL LIABILITIES**	988,492	990,842
	DEFERRED INFLOWS OF RESOURCES	9,412	11,634
	NET POSITION		
	Net investment in capital assets	494,779	512,398
	Restricted for debt service	28,553	27,799
	Unrestricted	258,373	157,432
	TOTAL NET POSITION	781,705	697,629
	TOTAL LIABILITIES, DEFERRED INFLOWS OF RESOURCES AND NET POSITION	$ 1,779,609	$ 1,700,105
G=A-D	**CURRENT ASSETS less CURRENT LIABILITIES**	$ 103,859	$ 33,690
H=B-E	**TOTAL ASSETS less TOTAL LIABILITIES**	$ 769,675	$ 688,501

SOURCE: **HRSD Comprehensive Annual Financial Report for the Fiscal Years Ended June 30, 2019 and 2018 pages 16 & 17**

Attachment F-2

HAMPTON ROADS SANITATION DISTRICT
SUMMARY OF CASH AND INVESTMENTS
AS OF JUNE 30, 2019 AND 2018

CASH AND INVESTMENTS (in thousands)

		2019	2018
	CURRENT ASSETS		
J	Cash and cash equivalents	$ 155,453	$ 66,078
K	Cash and cash equivalents - Restricted	42,888	44,718
L	Investments	-	17,871
		$ 198,341	$ 128,667
	NON-CURRENT ASSETS		
M	Cash and cash equivalents	$ 128,530	$ -
N	Cash and cash equivalents - Restricted	-	50,359
P	Investments	-	106,219
		$ 128,530	$ 156,578
	TOTAL		
Q=J+M	Cash and cash equivalents	$ 283,983	$ 66,078
R=K+N	Cash and cash equivalents - Restricted	42,888	95,077
S=L+P	Investments	-	124,090
	Cash, Cash Equivalents, and Investments	$ 326,871	$ 285,245
	Unrestricted Cash, Cash Equivalents, and Investments	$ 283,983	$ 190,168

SOURCE: **HRSD Comprehensive Annual Financial Report for the Fiscal Years Ended June 30, 2019 and 2018 pages 16 & 17**

Attachment G: Site Security (Commercial Wells Only)

G.1 Site Security

Though the James River SWIFT is not a commercial facility, note that the HRSD James River SWIFT Advanced Water Treatment (AWT) Facility will be co-located with the HRSD James River Treatment Plant. The site is surrounded by a perimeter fence and access to the site is controlled through a locked entrance gate. Managed Aquifer Recharge (MAR) and monitoring wells located off-site will be housed within locked buildings depicted in Attachment D, Figures D.2. and D.5.

Attachment H: Aquifer Exemptions

Not applicable. HRSD is not requesting an exemption.

Attachment I: Existing EPA Permits

Permitting Authority	Permit/Registration Number	Type
Virginia DEQ, State Water Control Board	VA0081272	VPDES Permit
VADEQ, State Water Control Board	VAN040090	Nutrient General Permit
VADEQ, State Air Pollution Control Board	#60996	State Operating Permit, Stationary Source
RCRA Registration	000800813	Hazardous Waste

Attachment J: Description of Business

HRSD is a regional wastewater entity serving 18 cities and counties located primarily in Hampton Roads in southeast Virginia. With a combined treatment capacity just under 250 MGD, HRSD provides wastewater treatment to approximately 1.7 million people. As a political subdivision of the Commonwealth of Virginia, HRSD is overseen by an 8-member board of Governor appointed Commissioners.

HRSD's Sustainable Water Initiative for Tomorrow (SWIFT) is a managed aquifer recharge program, adding multiple advanced water treatment processes to select HRSD wastewater treatment facilities to produce a highly treated water (SWIFT Water) that meets drinking water standards and is compatible with the receiving aquifer. Secondary effluent from up to seven of HRSD's existing treatment facilities will be treated at SWIFT facilities and SWIFT Water will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. At full-scale, HRSD will have the capacity to recharge approximately 100 million gallons per day of SWIFT Water that will significantly reduce the nutrient load to the sensitive Chesapeake Bay and provide significant benefit to the region by limiting saltwater intrusion, reducing land subsidence, and providing a sustainable source of groundwater, a necessity for continued economic expansion in the region.

This permit application is for HRSD's first full-scale facility to be located at HRSD's James River Treatment Plant (Newport News, VA). Since 2018, HRSD has been operating a demonstration scale 1 MGD advanced water treatment and recharge facility at the SWIFT Research Center located at its Nansemond Treatment Plant in Suffolk, Virginia. As of October 28, 2020, this SWIFT Research Center has successfully recharged 400 million gallons to the PAS.

Attachment K: Optional Additional Project Information

In conjunction with the application for a Water Infrastructure Finance and Information Act (WIFIA) loan, HRSD submitted the following information that may be relevant to the federal laws below.

K.1. The Wild and Scenic Rivers Act

There are no known wild and scenic rivers located within the Area of Review.

K.2. The National Historic Preservation Act of 1966

Table K.1. Potential project impacts to historical resources.

	IMPACT ANTICIPATED		
CULTURAL RESOURCES:	**NO IMPACT**	**LESS THAN SIGNIFICANT IMPACT**	**POTENTIALLY SIGNIFICANT IMPACT**
1. Changes to historical resources, including archaeological and cultural resources as defined in 36 CFR part 800.	☐	☒	☐
2. Modification of unique paleontological resources or site or unique geologic features.	☐	☒	☐
3. Disturbance of human remains, including those interred outside of formal cemeteries.	☒	☐	☐

A review of the Virginia Cultural Resources Information System (VCRIS) maintained by the Virginia Department of Historic Resources (VDHR), the Virginia Archaeological Site Survey Records, the Virginia Historic Inventory Property Forms, and the National Register of Historic Places (NRHP) was conducted as part of a cultural resources desktop survey of the project area. Immediately to the southeast of the James River Water Treatment Plant, along the bank of the Warwick River, is the location of the Colonial settlement of Warwicktowne, which served as the county seat of Warwick County (now the City of Newport News) (Gray and Pape 2020). The project area, therefore, is located in an area of high archaeological potential.

VCRIS shows three previously conducted cultural resource surveys in the project area, dating from 1976 to 1992, of both aboveground and belowground resources. There are three previously identified aboveground properties close to the Limit of Disturbance (LOD) – the Battle of Yorktown (VDHR ID #099-5283), Farmstead (VDHR ID #121-0103), and Newport News

City Prison Farm (VDHR ID #121-0104). There are nine previously identified archaeological sites close to the LOD, and two that fall within the LOD (Gray and Pape 2020).

AECOM conducted a Phase I archaeological survey in March 2020 of areas of proposed ground disturbance (i.e, area of potential effect, APE) in support of the proposed project and pursuant to Section 106 of the NHPA of 1966, as amended, the Advisory Council on Historic Preservation's (ACHP) "Protection of Historic and Cultural Properties" and the DHR Guidelines for Conducting Historic Resources Survey in Virginia (AECOM 2020b). A copy of the Phase I archaeological survey report was submitted with the WIFIA application and can be provided on request. AECOM conducted a second Phase I archaeological survey in October 2020 of the construction staging area and the proposed relocation of an access road (AECOM 2020c). AECOM conducted a third Phase I archaeological survey in May 2021 to incorporate additional areas of proposed ground disturbance associated with the recharge and monitoring wells (AECOM 2021). Copies of these two Phase I archaeological survey reports can be provided on request.

The three Phase I archaeological surveys of the JRTP APE resulted in the documentation of two new archaeological sites within the APE, 44NN0359 and 44NN0360, as well as the relocation within the APE of a portion of 44NN0281; no evidence of previously recorded sites 44NN0068, 44NN0069, 44NN0278, 44NN0281, and 44NN0282 was encountered.

While site 44NN0281 has been determined eligible for listing in the NRHP, it has been determined in consultation with VDHR, which serves as the Virginia State Historic Preservation Office (SHPO) that the archaeological deposits associated with 44NN0281 within the APE do not have the potential to yield significant information about the historic occupation of the APE and do not contribute to the NRHP eligibility of 44NN0281 as a whole. The archaeological deposits of two newly recorded sites, 44NN0359 and 44NN0360, likewise do not have the potential to yield significant information about the historic occupation of the APE, and the sites were determined not eligible for the NRHP by DHR. Therefore, the recommendation of the Phase I archaeological survey report is that the proposed project be allowed to proceed without concern for impacts to significant archaeological sites. Adherence with the Code of Virginia (e.g., §18.2-126, 127) is required should unanticipated graves or human remains be encountered during construction activities.

Effects to cultural resources could include encroachment, displacement or destroying or diminishing the historic integrity of NRHP listed or eligible properties; however, as described in the Phase I archeological survey report, no impacts to significant cultural resources are anticipated. Practicable mitigation measures include consultation with the SHPO and/ or Tribal Historic Preservation Office (THPO), minimization of adverse effects and development of an unanticipated discoveries plan. The location and extent of known cultural resources in the project vicinity would be considered during project design. If impacts to significant cultural resources cannot be fully avoided, HRSD would work with VDHR to determine appropriate measures to protect and reduce impacts to architectural and archaeological resources.

K.3. The Endangered Species Act

Table K.2. Potential project impacts to biological resources.

	IMPACT ANTICIPATED		
BIOLOGICAL RESOURCES:	**NO IMPACT**	**LESS THAN SIGNIFICANT IMPACT**	**POTENTIALLY SIGNIFICANT IMPACT**
1. Jeopardizing the continued existence of any threatened or endangered species identified in local or regional plans, policies, or regulations, or by the U.S. Fish and Wildlife Service or National Marines Fisheries Service.	☐	☒	☐
2. Modification, fragmentation, or degradation of critical habitat identified in local or regional plans, policies, or regulations, or by the U.S. Fish and Wildlife Service or National Marines Fisheries Service.	☐	☒	☐
3. Harm to fauna, including mammals, birds, reptiles, amphibians, fish, and invertebrates.	☐	☒	☐
4. Changes in vegetation type (native to the region), particularly if the vegetation type in the region is already highly fragmented because of human activity.	☐	☒	☐
5. Modification, fragmentation, or degradation of biological sensitive areas other than those mentioned above.	☐	☒	☐
6. Disturbances to marine mammals protected by the Marine Mammal Protection Act as defined under 16 U.S.C 1361-1407.	☒	☐	☐
7. Disturbances to Bald or Golden Eagles as defined under 16 U.S.C. 68 et seq.	☒	☐	☐
8. Disturbances to migratory birds as defined under 16 U.S.C. 703-712 as amended.	☐	☒	☐
9. Conflicts with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, state, or federal habitat conservation plan.	☒	☐	☐
10. Introduction or spread of invasive species as identified under Executive Order 13112.	☐	☒	☐

During construction, it would be expected that some vegetation cover would be lost due to direct impacts from clearing, trenching, excavation, soil compaction, and general activity on the site. Given the relatively small footprint of water and wastewater projects, this impact would be minimal and not likely cause disturbance to vegetation beyond site boundaries.

Likewise, minor, short-term effects on wildlife could occur as they would likely be deterred by construction activities, vehicles, and equipment. Minor, long-term effects on some wildlife are anticipated due to displacement. Less mobile wildlife species may not be able to relocate outside of the construction area. One federally-listed rare, threatened, or endangered species was identified by U.S. Fish and Wildlife Service (USFWS) during a review of the project vicinity via the Information for Planning and Consultation (IPaC) tool: the northern long-eared bat (NLEB) (*Myotis septentrionalis*) (threatened) (USFWS 2019a). Potentially suitable summer roosting habitat has been observed in the project area for the NLEB. According to the Virginia Department of Wildlife Resources (VDWR) NLEB Winter Habitat and Roost Tree Application, the nearest known maternity roost for the NLEB is approximately 35 miles southeast of the proposed project area (VDWR 2020). There are no documented maternity roosts or hibernacula within 150 feet and 0.25 miles of the project area, respectively; therefore, incidental take from tree removal is not prohibited. Voluntary conservation measures such as a time of year restriction (June 1 – July 31) and minimizing light pollution through adjusting light angles downward will be implemented where practical. Results of the IPaC database search and the NLEB Habitat and Roost Tree Map as well as a USFWS Self-Certification Letter, noting a “may affect, not likely to adversely affect” determination for the NLEB were submitted with the WIFIA application and can be provided on request. Prior to commencement of the project, coordination with USFWS would be conducted regarding the limits and timing of vegetation removal, in order to ensure compliance with the Endangered Species Act.

The Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act confer protection to the bald eagle (*Haliaeetus leucocephalus*) (USFWS 2019b). The southern portion of the peninsula separating the James and Warwick rivers near the mouth of the Warwick River has been documented as containing bald eagle nests that are historic, and nests that may currently be in use. The project area is located beyond the restricted radius of the documented bald eagle nests. No nests in use by a bald eagle has been observed within the project vicinity, and no bald eagles were observed flying over or in the vicinity of the project area during the onsite investigations. The Center for Conservation Biology (CCB) Mapping Portal identified the nearest documented bald eagle nest approximately 1,950 feet southeast of the project area boundary (CCB 2020). The USFWS Virginia Field Office’s Bald Eagle Map Tool identified one bald eagle concentration area intersecting the project area along the southwestern edge of the project boundary (USFWS 2020a). The CCB Map and the USFWS Virginia Field Office’s Bald Eagle Concentration Map are included in Appendix B. Due to the distance from the project construction activities (greater than 660 feet from the documented nest and inland from the shoreline), no impacts to the bald eagle concentration or nests are anticipated.

The Virginia Department of Game and Inland Fisheries maintains records of species known or likely to occur throughout the Commonwealth of Virginia in the Fish and Wildlife Information Service (FWIS) database. Review of the FWIS database identified eight federally endangered or threatened species with the potential to occur within a two-mile radius of the project area (FWIS 2020). The FWIS Project Report was submitted with the WIFIA application and can be provided on request. Of the eight species identified, there is one documented occurrence - the loggerhead sea turtle (*Caretta caretta*, federal listed threatened), which only occurs in open waters. Since there are no in-water activities associated with the project, no impacts to the loggerhead sea turtle are anticipated.

The FWIS habitat prediction model also identifies four species with the potential to occur within a two-mile radius of the project area: the federal proposed/state listed endangered eastern black rail (*Laterallus jamaicensis jamaicensis*); the state listed endangered canebrake rattlesnake (*Crotalus horridus*, southestern population); the state listed threatened Henslow’s sparrow (*Centronyx henslowii*); and the state listed threatened Mabee’s salamander (*Ambystoma mabeii*).

USFWS indicates that eastern black rail habitat consists of impounded and unimpounded salt and brackish marshes (USFWS 2020b). Wetlands within the project area are categorized as PFO and no positive observations have occurred within a two-mile radius of the project area; therefore, no effect is anticipated to the eastern black rail. Canebrake rattlesnake habitat consists of mature hardwood, mixed hardwood-pine forests, forested cane thickets, and ridges adjacent to swampy areas (VDWR 2011). A 100-foot RPA buffer is being placed on most wetlands within the project area which will not be disturbed by project activities. Swampy areas in the project area outside of the RPA appear to be heavily disturbed by past and current land use and no positive observations have been made within a two-mile radius of the project area. Therefore, no effect is anticipated to the canebrake rattlesnake. Henslow’s sparrow habitat is described as hayfields, pastures, wet meadows, undisturbed protected grasslands, upland portions of salt marshes, and old fields (USFWS 2012). While some areas within the project area are upland grass fields, these areas are mowed turf grasses and are not allowed to grow as a hay field or meadow. Therefore, no effect is anticipated to the Henslow’s sparrow. Habitat for Mabee’s salamander is described as savannas on the edges of bogs or ponds, low wet woods and swamps, and adjacent to ditches and pools (VHS 2020). A 100-foot RPA buffer has been placed on all wetlands within the project area including low wet woods. The majority of uplands within 200 feet of wetlands in the project area, not covered by the RPA buffer, are heavily industrialized or managed turf grass. Therefore, no effect is anticipated to the Mabee’s salamander.

Based on the land cover of the project area, mitigation measures, and proposed activities, the project is expected to have "no effect" on the federally listed threatened and/or endangered species.

No significant impacts to biological resources would be expected to result from the proposed SWIFT project. Potential effects could include reduced vegetative cover, soil compaction, erosion or sedimentation, habitat fragmentation, introduction of invasive species, changes in water availability, and disturbance from construction noise and dust. Practicable mitigation measures include implementation of avoidance and minimization measures and BMPs, implementation of recommendations from relevant governmental wildlife agencies, prevention of spills and leaks from vehicles and equipment, and implementation of measures to minimize soil compaction and the transportation of noxious, invasive and pest species. Protective measures would be identified in coordination with the U.S. Fish and Wildlife Service and state wildlife agencies, as applicable, to protect federally threatened or endangered species that may inhabit or otherwise utilize the project area. Protective measures may include time-of-year restrictions, lighting alterations, and/or design modifications, among others.

K.4. The Coastal Zone Management Act

Table K.3. Potential project impacts to water resources.

	IMPACT ANTICIPATED		
WATER RESOURCES:	**NO IMPACT**	**LESS THAN SIGNIFICANT IMPACT**	**POTENTIALLY SIGNIFICANT IMPACT**
1. Violations of any water quality standards or waste discharge requirements, including degradation of water quality.	☒	☐	☐
2. Depletion or contamination of groundwater supplies (including sole-source aquifers) or negatively interfere with groundwater recharge.	☒	☐	☐
3. Alteration of the drainage pattern of a water resource that would result in an increase in erosion or flooding on- or off-site.	☐	☒	☐
4. Soil erosion or stormwater runoff that increases sediment, pollutants, or contaminates into streams, rivers, or other water resources.	☐	☒	☐
5. Floodplain modification, development within, or redirection, as defined by executive order 11988.	☒	☐	☐

	IMPACT ANTICIPATED		
WATER RESOURCES:	**NO IMPACT**	**LESS THAN SIGNIFICANT IMPACT**	**POTENTIALLY SIGNIFICANT IMPACT**
6. Increase in flood risk affecting loss on human safety, health, and welfare.	☐	☒	☐
7. Loss, degradation, or destruction of wetlands and waterbodies through direct removal, filling, hydrological interruption, or other means.	☐	☒	☐
8. Alteration of wild and scenic rivers as defined by the Wild and Scenic River Act 16 U.S.C. 1271 et seq.	☒	☐	☐
9. Conflicts with the Rivers and Harbors Act, 33 U.S.C. 403.	☒	☐	☐
10. Conflicts with the Coastal Barrier Resources Act, 16 U.S.C. 3501 et seq.	☒	☐	☐
11. Conflicts with the Coastal Zone Management Act, 16 U.S.C. 1451 et seq.	☐	☒	☐

The project would have an overall long-term benefit on flood risk, aquifers, and the groundwater supply by reducing aquifer-related land subsidence in coastal Virginia and allowing additional time to adapt to sea level rise and protect valuable coastal wetlands for decades longer than currently projected.

A wetlands delineation was conducted in January 2020 to determine the extent of jurisdictional waters of the U.S. (WOUS) within and adjacent to the project area. In May 2020, AECOM conducted further wetlands investigations to confirm and expand upon the May 2020 findings (AECOM 2020a). A copy of the January 2020 Wetlands Delineation Report was submitted with the WIFIA application and can be provided on request.

The wetland field investigations identified five non-tidal wetlands and one non-tidal stream within the project area, identified as wetlands WA, WB, WD, WE, and WF, and stream SA. Wetlands WA and WF consist of both tidal and non-tidal wetlands, but only the non-tidal portions of these wetlands occur within the project boundary. The extent of wetland WD was expanded during the May 2020 field investigation by approximately 0.02 acres. The non-tidal portion of wetland WA, wetlands WB, WC, WD, WE, WF, and WG were field-verified by AECOM as palustrine forested (PFO) wetlands. The tidal portion of wetland WA, portions of wetlands WB, WD, WE, WF, and wetland WC and WG are located outside the project boundary.

Two of the wetlands (wetlands WB and WD) are located in previously disturbed areas within the fenced portion of the James River Treatment Plant property. Wetland WA is located in the forested area at the southern edge of the project area. The remaining wetland (WF) and stream SA are located in forested areas along the west and southwest project boundary adjacent to an unnamed tidal tributary to the Warwick River. The approximate location and extent of the jurisdictional features identified in the field are depicted on Figure K.1 and WOUS located within the project area are summarized in Table K.4. Appropriate federal, state, and local wetland permits would be secured prior to commencement of the project.

Table K.4. Summary of WOUS within Project Area

Wetland/Stream	Tidal	Cowardin Classification*	Area (Acres)
WA	Non-tidal	PFO	0.14
WB	Non-tidal	PFO	0.04
WD	Non-tidal	PFO	0.17
WE	Non-tidal	PFO	0.36
WF	Non-tidal	PFO	1.75
SA	Non-tidal	N/A	125 Linear Feet
Total			2.46

* Cowardin classification based on information from USFWS-NWI mapper (USFWS NWI 2020)

The City of Newport News administers and enforces the Chesapeake Bay Preservation Act (CBPA) within the city limits via the City's Chesapeake Bay Preservation Act Ordinance (CBPO). Under the CBPO, Resource Protection Areas (RPAs) incorporate tidal wetlands, tidal shores, nontidal wetlands connected by surface flow and contiguous to tidal wetlands or waterbodies with perennial flow, and a 100-foot wide buffer surrounding the aforementioned features, as well as along waterbodies with perennial flow. Consistent with the CBPA and CBPO, a potential 100-foot RPA has been mapped along wetlands and streams that continue off-site where it is assumed that they are connected by surface water flow and contiguous to tidal wetlands or water bodies with perennial flow. The RPA includes portions of the parcel associated with the existing HRSD treatment plant; however, the proposed project and site layout largely avoids disturbance of the RPA. Should the selected contractor determine encroachment into the RPA may be necessary, a detailed field delineation of the RPA would be conducted, and proper approvals would be obtained from the City of Newport News and VDEQ, as appropriate.

According to the most recent Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM), the proposed project improvements are located outside the 100-year and 500-year floodplains, as depicted on Figure K.2. Floodplains to the south and southwest do occur within the project boundary; however, the proposed site layout avoids encroachment into or disturbance of the floodplain. The nearby floodplains are associated with James River, Warwick River, and the unnamed tributary to the Warwick River located along the western parcel boundary of the treatment plant.

Effects could include ground and soil-disturbing activities, direct impacts to surface water or wetlands, new or expanded outfalls and discharges of effluent to water resources. Practicable mitigation measures include use of erosion and sediment control measures and BMPs, compliance with permit requirements, effective site selection and design, consistency with Executive Order 11990 and the Clean Water Act Section 404(b)(1) guidelines, water efficiency, coordination with Regional utilities, and planning for extreme weather. Minimization and avoidance of impacts to jurisdictional waters of the U.S. would occur during site design. Erosion and sediment control measures would be implemented during construction to protect surface waters from sediment and nutrient transport and deposition. Treatment processes would be identified to ensure protection of groundwater resources and water quality. Compensatory mitigation would be secured, if needed, to ensure no more than minimal impacts to jurisdictional waters of the U.S. result from the project.

Note: This map is for reference only; NAD83 State Plane Virginia South; Aerial Image Source: ESRI, 2019; January 2020 wetland delineation by: Hazen and Sawyer; updated 05/28/2020 by AECOM; Approximate Waters of the U.S. field flagged and GPS-recorded but have not been confirmed by USACE; Wetlands WE, WF, and WG extend beyond the extent shown

Figure K.1: James River Treatment Plant Site Wetlands Map

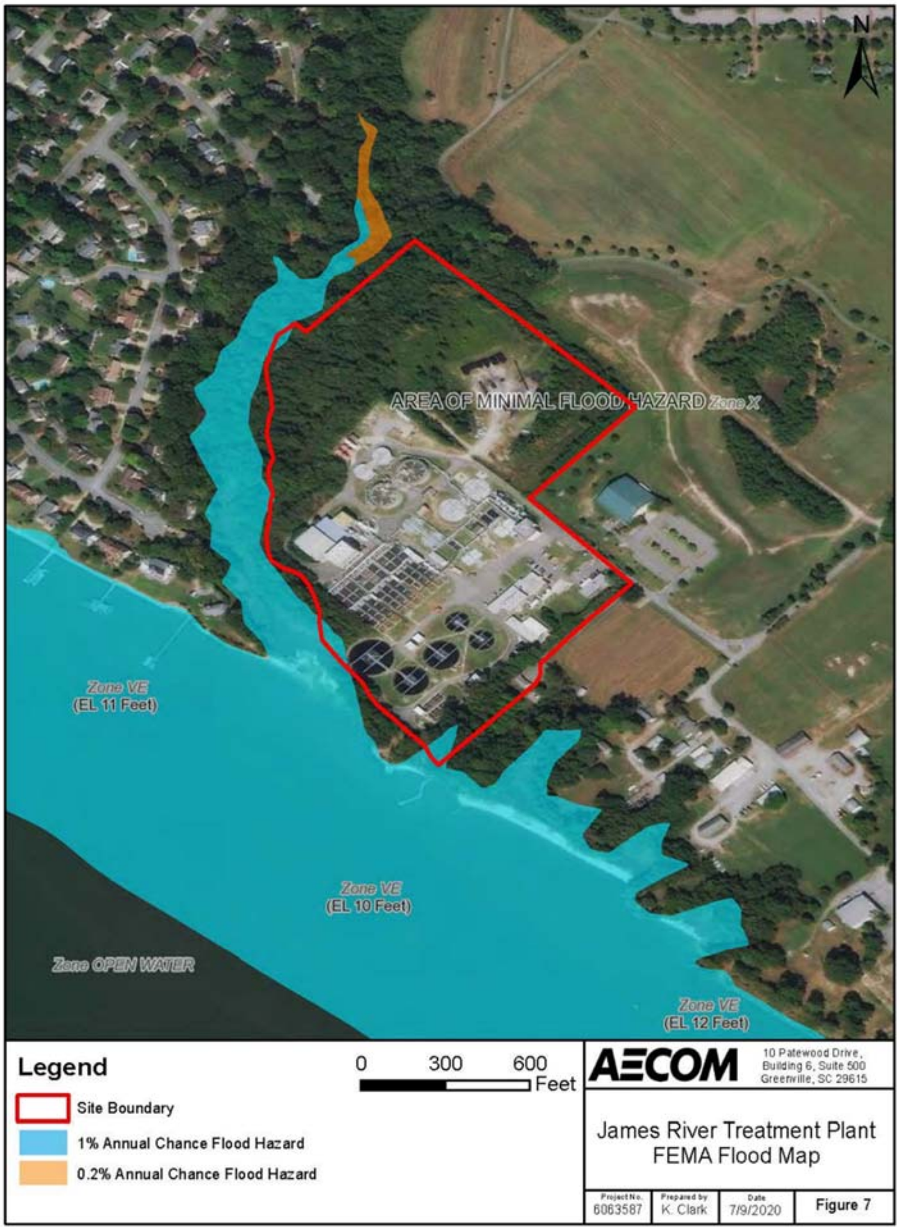


Figure K.2: James River Treatment Plant FEMA Flood Map

The most significant change to water resources proposed by the project would be the pumping of large volumes of water into the deepwater Potomac Aquifer. However, the project's net impact would be beneficial, as the recharge water would be treated to drinking water standards prior to being returned to the aquifer.

It is anticipated that higher quality discharge waters would result in improvements in downstream waters and aquatic habitats. The project would utilize advanced water treatment (AWT) processes to treat secondary wastewater treatment plant effluent to drinking water standards. The SWIFT water would subsequently be used to recharge the Potomac Aquifer system to counter depleting aquifer levels and provide additional environment benefits (HRSD 2019). Analytical groundwater flow and geochemical modeling using various treatment and recharge techniques has been conducted to determine the optimal treatment and recharge methods (HRSD 2019). The modeling represented the VDEQ preferred metric for determining the beneficial impacts of proposed pumping/recharge on the Potomac Aquifer. The AWT is expected to improve drinking water sources, i.e., the Potomac Aquifer, by treating and reducing contamination and removing disease-causing agents (HRSD 2019). The project would provide a sustainable source of groundwater to the Potomac Aquifer, increase the hydrostatic pressure within the aquifer, prevent saltwater intrusion into the aquifer, and slow land subsidence related to aquifer withdrawals. The project is intended to have an overall beneficial effect on water resources; therefore, no significant adverse impact anticipated.

References

AECOM. 2020a. Wetlands and Waters Delineation Report. Prepared for the James River HRSD SWIFT Project. City of Newport News, Virginia. July 2020

AECOM. 2020b. Phase I Archaeological Survey of the Sustainable Water Initiative For Tomorrow Improvements to the James River Treatment Plant. Prepared for HRSD. May 2020.

AECOM. 2020c. Phase I Archaeological Survey of the Sustainable Water Initiative For Tomorrow Improvements to the James River Treatment Plant, Section 3 Addition. Prepared for HRSD. October 2020.

AECOM. 2021. Phase I Archaeological Survey of the Sustainable Water Initiative For Tomorrow James River Treatment Plant Recharge Wells. Prepared for HRSD. May 2021.

Center for Conservation Biology (CCB) 2020. CCB Mapping Portal. https://www.ccbbirds.org/maps.php. Accessed May 21, 2020.

Fish and Wildlife Information Service (FWIS). 2020 Virginia Department of Wildlife Resources (formerly Game and Inland Fisheries), Fish and Wildlife Information Service. Accessed May 20, 2020. https://vafwis.dgif.virginia.gov/fwis/

Gray and Pape. 2020. Results of Additional Cultural Resources Investigation for the Hampton Roads Sanitation District SWIFT Project, James River Treatment Plant, Newport News, Virginia. February 10, 2020.

HRSD. 2019. HRSD SWIFT Water Infrastructure Finance and Innovation Act. Letter of Interest. June 2019.

U.S. Fish and Wildlife Service (USFWS). 2012. Status Assessment and Conservation Plan for the Henslow's Sparrow (*Ammodramus henslowii*. Accessed July 14, 2020. https://www.fws.gov/migratorybirds/pdf/management/focal-species/HenslowsSparrow.pdf

USFWS 2019a. Information for Planning and Consultation (IPAC) tool. Accessed April 15, 2019. https://ecos.fws.gov/ipac/

USFWS. 2019b. Migratory Bird Treaty Act Protected Species Accessed April 15, 2019. https://www.fws.gov/birds/management/managed-species/migratory-bird-treaty-act-protected-species.php

USFWS. 2020a. Virginia Field Office's Bald Eagle Map Tool. Accessed May 20, 2020. https://www.fws.gov/northeast/virginiafield/endangered/projectreviews _step6b.html

USFWS. 2020b. Eastern black rail Laterallus jamaicensis jamaicensis. Accessed July 14, 2020. https://www.fws.gov/southeast/wildlife/birds/eastern-black-rail/#habitat-section

USFWS National Wetlands Inventory (NWI) 2020. NWI Wetlands Data Mapper. Accessed May 20, 2020. https://www.fws.gov/wetlands/data/mapper.html

Virginia Department of Wildlife Resources (VDWR). 2011. Canebrake Rattlesnake Conservation Plan. Accessed July 14, 2020. https://dwr.virginia.gov/wp-content/uploads/canebrake-rattlesnake-conservation-plan.pdf

VDWR. 2020. NLEB Winter Habitat and Roost Trees. Accessed May 20, 2020. https://www.dgif.virginia.gov/wildlife/bats/northern-long-eared-bat-application/

Virginia Herpetological Society (VHS). 2020. Mabee's Salamander *Ambystoma mabeei*. Accessed July 14, 2020. https://www.virginiaherpetologicalsociety.com/amphibians/salamanders/mabees-salamander/mabees_salamander.php

Appendix A: James River SWIFT Water Quality Targets

1.0 Introduction

The Hampton Roads Sanitation District (HRSD) Sustainable Water Initiative for Tomorrow (SWIFT) is a managed aquifer recharge program located in southeast Virginia. The SWIFT program will add multiple advanced water treatment processes to select HRSD wastewater treatment facilities to produce a highly treated water (SWIFT Water) that meets drinking water standards and is compatible with the receiving aquifer. Secondary effluent from up to seven of HRSD's existing treatment facilities will be treated at SWIFT facilities and SWIFT Water will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. At full-scale, HRSD will have the capacity to recharge approximately 100 million gallons per day of SWIFT Water that will significantly reduce the nutrient load to the sensitive Chesapeake Bay and provide significant benefit to the region by limiting saltwater intrusion, reducing land subsidence, and providing a sustainable source of groundwater, a necessity for continued economic expansion in the region.

HRSD's James River Treatment Plant (JR; Newport News, VA) will be the site of a full-scale SWIFT facility. The purpose of this document is to define the SWIFT water quality targets for JR SWIFT and demonstrate how the targets will be achieved. The intent is to build upon the targets established for the SWIFT Research Center (SRC) and leverage data and lessons learned from SRC operation to establish the JR SWIFT targets. As the SWIFT program evolves, the water quality targets are also expected to change so that appropriate targets are identified for each project. The SWIFT Water Quality Targets document is a detailed supplement to HRSD's Class V Underground Injection Control (UIC) permit application for James River SWIFT.

The SRC, located in Suffolk, VA, houses a demonstration-scale, 1 million gallon per day (MGD) Advanced Water Treatment (AWT) facility and recharge well. The facility and recharge well went on-line in the spring of 2018. More than 18 months of operational data has demonstrated at a meaningful scale that the SWIFT AWT can successfully meet the SWIFT Water Quality targets proposed below.

In addition to the 1 MGD demonstration-scale facility, the SRC houses a pilot ozone-biofiltration treatment train as well as soil columns used to evaluate the availability of soil aquifer treatment across multiple time scales (3-day, 1 month, and 6 month). As such, the SRC has proven invaluable in investigating a wide variety of questions common in the potable reuse arena. Much of this research focuses on the management of constituents of emerging concern (CECs) and optimizing treatment performance. Current research areas at pilot and/or demonstration scale include:

- The management of organic compounds (e.g., disinfection by-products and CECs) and understanding the potential for associated public health risk. This involves research in optimizing the performance of various unit processes in order to better control for compounds such as 1,4-dioxane, disinfection by-products (DBPs: e.g. bromate, NDMA, haloacetonitriles and haloacetaldehydes), per-and polyfluoroalkyl substances, and low molecular weight aldehydes. Acknowledging limitations in parameter-specific chemical analyses that cannot detect every known and unknown compound, HRSD is also working with researchers to conduct a variety of bioanalytical screening techniques (e.g., estrogen receptor assay, aryl hydrocarbon assay, and larval zebrafish assay) in an attempt to better understand the utility of these tools in providing an additional layer of public health protection in potable reuse frameworks.

- Microbiological studies which include understanding the occurrence of antibiotic resistance genes, antibiotic resistant bacteria, and a wide variety of pathogens and pathogen indicators in potable reuse scenarios. The pathogen monitoring has combined culture- and molecular-based methods for indicator and pathogen quantification. For early pilot work, HRSD analyzed male-specific and somatic coliphages by culture methods. Human polyomavirus, human adenovirus 40/41, enterovirus, norovirus, pepper mild mottle virus, enterococcus spp. Human specific Bacteroides spp., *E. coli* O157:H7, and Legionella pneumophila were enumerated by molecular methods. At the SRC, HRSD is analyzing male-specific and somatic coliphages by culture methods. *Campylobacter coli*, *Campylobacter jejuni*, human adenovirus 40/41, norovirus, rotavirus, enterovirus, and pepper mild mottle virus are being enumerated by molecular methods.
- Understanding the potential for additional soil aquifer treatment. This involves a series of columns containing soils obtained from test well drilling at the SRC. The columns are set up to simulate 3-day, 1 month, and 6 month travel times through the aquifer and have been used to evaluate the removal of total organic carbon, CECs, DBPs, and pathogen indicators.
- Aquifer studies to include modeling flow distribution and solute transport through the aquifer system.

Research and optimization studies regarding the control of chemical or microbial contaminants will evolve over the coming years as new questions arise or new technologies become available and will continue to inform design of other future full-scale SWIFT facilities.

1.1 General Description

The JR SWIFT facility will be designed to accept secondary effluent from the existing JR treatment plant. Average daily flows at JR are between 12 and 13 MGD and secondary effluent flow will be directed to the SWIFT Feed Tank, diverting flow away from the existing outfall. Planned interceptor system improvements will increase the average JR influent flow up to 16 MGD by diverting flow from other parts of the HRSD service area and will equalize the dry weather flows to JR. JR SWIFT is being designed to treat a nominal flow of 16 MGD through the Advanced Water Treatment (AWT) process. Ten recharge wells will be designed to receive the SWIFT Water for recharge into the Potomac Aquifer System (PAS). HRSD will maintain its Virginia Pollutant Discharge Elimination System (VPDES) permit and the use of its permitted outfall to allow for the discharge of flows as necessary (e.g., flows that exceed the capacity of the AWT, discharging SWIFT Water that doesn't meet the water quality specifications, or for other operational purposes).

The treatment process for JR SWIFT is described in this document and consists of the same advanced treatment technologies as the SRC. Where design criteria differ from the SRC, justification is provided. Performance data for the SRC is not provided in this document as it is assumed that the Quarterly Reports that have been submitted to EPA and available at https://www.hrsd.com/swift/quality sufficiently document the SRC performance to date.

JR SWIFT will differ from the SRC in that it will not be designed to offer tasting events to the public. The only end use for JR SWIFT water will be to recharge the PAS. As such, the primary compliance point for JR SWIFT will be after the SWIFT Water Pump Station, prior to recharge. Sampling will be conducted at this location to confirm compliance with all SWIFT Water quality targets. Online analyzers throughout the treatment process will confirm that the treatment performance is sufficient and critical control points (CCPs) will initiate action. CCP failures will result in action that prevents inadequately treated water from recharging the aquifer (see Table 3-1). The selection of these CCPs reflects thoughtful consideration of critical points in process control necessary for the protection of public health with regard to both microbial and chemical contamination.

A network of groundwater monitoring wells around the recharge wells will be used to monitor water quality as the recharge front migrates through the PAS. The purpose of these wells is detailed in the Aquifer Monitoring and Contingency Plan (Appendix B). Note that all of the proposed regulatory limits in this document are intended to be met at the SWIFT Water Pump Station.

An independent SWIFT oversight structure, similar to the Occoquan Watershed Monitoring Program formed to provide oversight of indirect potable reuse in northern Virginia, has been enabled through legislative action. The Potomac Aquifer Recharge Oversight Committee (PAROC) and the Potomac Aquifer Recharge Monitoring Laboratory (PARML) will serve to provide independent oversight and monitoring of the SWIFT treatment processes, observe the aquifer response to the recharge, and confirm compliance with SWIFT program performance targets.

1.2 Process Design Summary

A process flow diagram of the JR SWIFT treatment process is shown in Figure 1.1. The full treatment process consists of rapid mix with coagulant addition, flocculation and sedimentation, ozone oxidation, biologically active carbon filtration (BAF), GAC adsorption, and ultraviolet (UV) disinfection. This is the same treatment process that has been proven during pilot testing conducted in 2016-2017 and at the SRC in 2018-2020.

A major upgrade to the existing JR Treatment Plant will be constructed concurrently with the SWIFT facilities. This will improve the quality and consistency of the secondary effluent that will in turn increase the quality and consistency of the SWIFT Water. Improvements include flow equalization in the interceptor system, new secondary clarifiers, and process upgrades for nitrogen treatment. The primary objectives of the improvements are to provide consistent flows and nutrient loads to SWIFT.

Following is a brief description of each treatment process with accompanying design criteria listed in Table 1.1 for both JR SWIFT and the SRC:

- **Rapid Mix, Flocculation, Sedimentation:** Chemical coagulant and an organic polyelectrolyte will be added to the water to remove particles and dissolved organics through the formation and settling of chemical flocs and to prepare the water for effective filtration. The chemical coagulant is anticipated to be aluminum chlorohydrate (ACH) subject to change based on the results of bench-scale testing for this facility.
- **Ozone Oxidation:** Ozone will be added to oxidize high molecular weight organics for downstream removal in biofiltration and for direct oxidation of trace organics (e.g.,

contaminants of emerging concern such as pharmaceuticals and personal care products). Disinfection of pathogens will also be achieved with ozone addition though disinfection credit is not being claimed for this unit process. A hydrogen peroxide addition point will be added upstream of ozone injection such that ozone can be operated as an advanced oxidation process (AOP) for additional 1,4-dioxane removal.

- **Biofiltration (BAF):** Deep-bed granular media filters will provide biological removal of organic matter and particle and pathogen removal. Low filtered water turbidity (<0.15 nephelometric turbidity units [NTU]) will be targeted to ensure proper pathogen removal consistent with the design and operation of drinking water filters (see Critical Control Point section).
- **GAC Adsorption:** Granular activated carbon will provide removal of trace organics through biological and adsorption mechanisms. GAC media will be regenerated to meet the proposed regulatory limit for total organic carbon (see Regulatory Limits section) or per Section 2.1 below, based on an assessment of the removal of non-regulatory performance indicators.
- **UV Disinfection:** UV irradiation will provide disinfection of the water before groundwater injection. A UV dose that is significantly higher than typically used for drinking water is being provided for JR SWIFT to allow for a minimum of 4-log virus removal (>186 mJ/cm2) and other treatment benefits, specifically NDMA photolysis during the startup and acclimation period prior to achieving necessary NDMA removal through BAF. Similar to ozone, a hydrogen peroxide addition point will be added upstream of UV and equipment will be selected to allow the UV system to be operated as an AOP for additional 1,4-dioxane removal.
- **pH & Alkalinity Adjustment for Aquifer Compatibility:** Sodium hydroxide will be used to adjust the final pH and alkalinity of the SWIFT Water prior to recharge at JR SWIFT, similar to the SRC. The pH target at the SRC is 7.6, and sodium hydroxide is added to raise the pH from nominally 7.0 (after UV). Raising the pH achieves two objectives: increasing the Langelier Saturation Index (LSI) to reduce the potential for corrosion in the recharge well and promoting the formation of hydrous ferric oxide (HFO) surfaces in the aquifer to limit metals mobilization. Many variables affect the pH target, including SWIFT Water alkalinity and dissolved oxygen and the aquifer oxidation-reduction potential (ORP), among otherss. HRSD is currently working on improving the understanding of both of these pH objectives at the SRC and will propose new pH and alkalinity targets prior to startup of JR SWIFT. It is likely that the pH target will be a function of the aquifer ORP and SWIFT Water alkalinity, and that it will decline over the course of operation.
- **Recharge Well Biofouling Control:** JR SWIFT will allow for the controlled addition of either free chlorine, preformed monochloramine, or hydrogen peroxide prior to the recharge well to prevent biological fouling of the well. Free chlorine will be utilized as needed to control nitrite during initial biofilter acclimation (i.e., prior to colonization of nitrite oxidizing bacteria during biofilter start-up). Free chlorine may also be used for an extended period of time to better manage biofouling in the well and coliform bacteria control. Hydrogen peroxide residual will only be used for biofouling control if UV advanced oxidation (UV + H_2O_2) is being performed for other water quality benefits, as this will likely result in an acceptable residual.

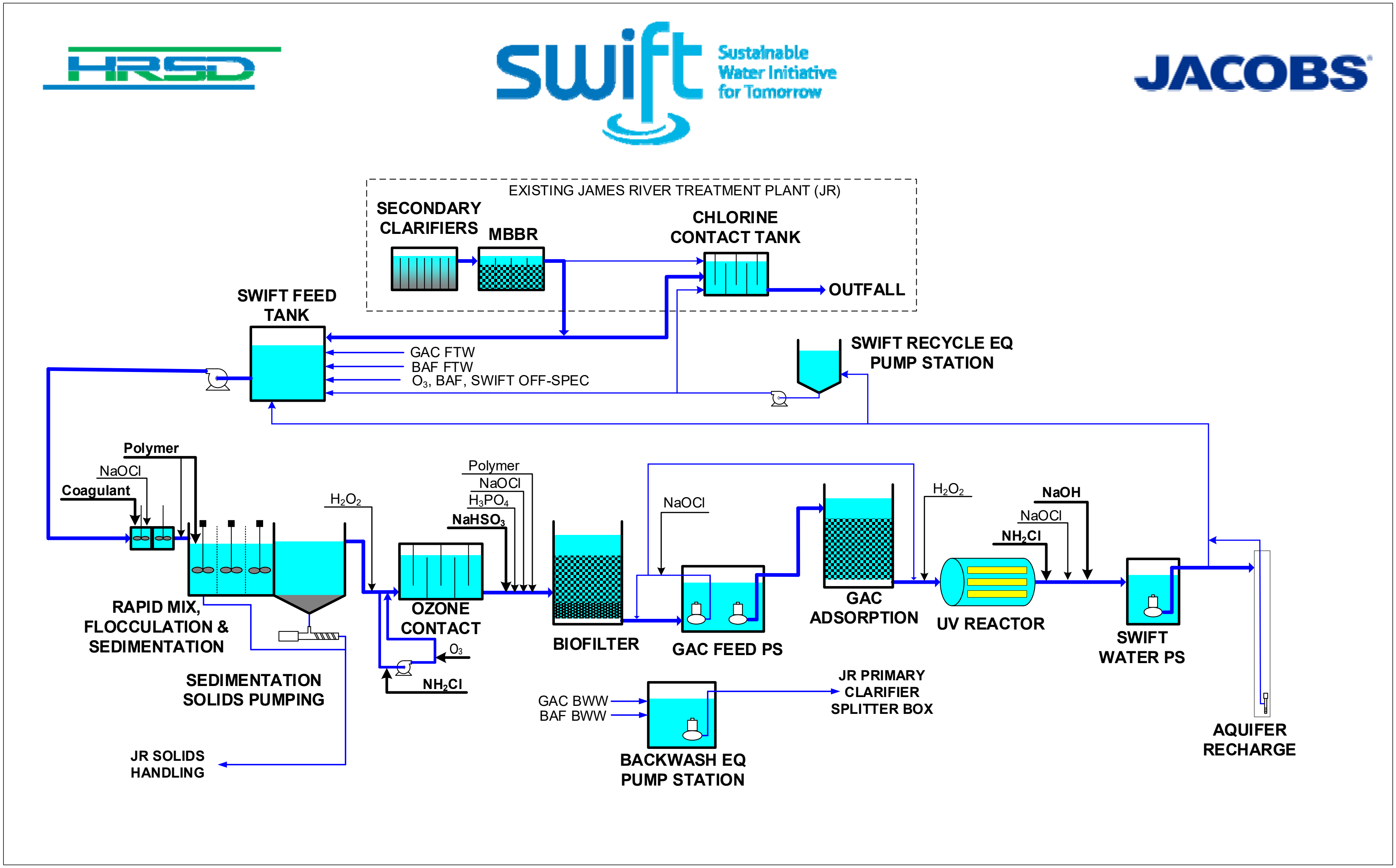


Figure 1.1: JR SWIFT Process Flow Diagram

Table 1.1: JR SWIFT and SRC Treatment Process Design Criteria

Process/Criteria	JR SWIFT Value	SWIFTRC Value	Units
Rapid Mix Velocity Gradient	1,000	1,000	s-1
Number of Flocculation Stages	3	3	#
Flocculation Stage Residence Time, each, all in service	10	15	Min
Design Sedimentation Projected Loading Rate, all in service	0.28	0.20	gpm/sf
Maximum Ozone Dose	10	20	mg/L
Ozone Contactor Hydraulic Residence Time	5	8	Min
Number of Biofilters	7	4	#
BAF Loading Rate, each, one filter out of service	3.6	4	gpm/sf
BAF Empty Bed Contact Time, one filter out of service	10.4	9.3	Min
BAF Carbon Media Depth	5	5	Ft
BAF Sand Media Depth	1	1	Ft
Number of GAC Adsorbers	7	2	#
GAC Empty Bed Contact Time, one adsorber out of service	20.9	15	Min
Design UV Virus Log Removal Value	4	4	LRV
Design UV Dose	186	186	mJ/cm2
Minimum UVT	89	85	%
Minimum UV Lamp Age & Lamp Fouling Factor, each	90	90	%

LRV = Log Removal Value
mJ/cm2 = milijoules per square centimeter
UVT =ultraviolet transmittance
Gpm/sf=gallons per minute per square foot

The following design criteria have been adjusted from the SRC design:

- Flocculation Stage Residence Time: total flocculation residence time was reduced from 45 min at the SRC to 30 min at JR SWIFT. This is still within typical hydraulic residence times for flocculation.
- Maximum Ozone Dose: the design maximum ozone dose has been reduced from 20 mg/L at the SRC to 10 mg/L at JR SWIFT based on sampling at the SRC and pilot testing of the JR secondary effluent. The maximum ozone dose that can be applied is limited by bromate formation and testing has shown that ozone doses above 10 mg/L result in bromate concentrations that exceed the regulatory limit.
- Ozone Contactor Hydraulic Residence Time: a shorter residence time for ozone contact is included in the JR SWIFT design as the longer contact time is not necessary.

- Biofilter Loading Rate: the design biofilter loading rate has been decreased from 4 gpm/sf at the SRC to 3.6 gpm/sf in order to provide a longer empty bed contact time for improved treatment performance.
- GAC Empty Bed Contact Time (EBCT): The GAC EBCT with one adsorber out of service has been increased from 15 min at the SRC to 20.9 min.
- Minimum UVT: the design UVT for the UV reactors has been increased from 85% at the SRC to 89% as pilot testing and SRC operation have demonstrated that a UVT of 88-90% corresponds to a TOC around 4.0 mg/L. Operating at a lower UVT (~85%) would thus result in a violation of the 4.0 mg/L TOC regulatory target, so the design minimum has been increased to 89%.

It is important to acknowledge the role of the aquifer in providing additional treatment of the SWIFT Water. HRSD soil column testing and preliminary results from the SRC suggest there is significant removal of both pathogens and organics in the PAS. HRSD will continue to monitor the results of ongoing soil column testing and the SRC monitoring wells to determine if operational strategies or design criteria for future full-scale facilities should be adjusted.

2.0 Regulatory Limits and Performance Indicators

The proposed JR SWIFT water quality targets are similar to the water quality targets established for the SRC. Based on feedback from the Virginia Department of Health (VDH), the Total coliform regulatory limit was modified as described in Table 2-1. No other changes have been proposed as there has not yet been sufficient data collected from the SRC to justify or necessitate a change. As operation of the SRC progresses, HRSD intends to consider if the water quality targets can be adjusted based on the data collected.

The SWIFT Water quality targets have been separated into two groups: regulatory parameters and performance indicators. Regulatory parameters must be achieved in order to continue the recharge flow to the PAS and will be supported by the CCPs. Performance indicators provide additional input on the performance of the treatment process and can help inform treatment or process decisions.

2.1 JR SWIFT Regulatory Limits

Table 2.1 provides a list of the regulatory limits for JR SWIFT. Most parameters have a treatment goal in addition to the regulatory limit. The treatment goals will be supported by the CCPs. Table 2.1 presents the complete list of regulatory requirements for JR SWIFT Water to recharge to the PAS. Similar to the SRC, quarterly reports detailing compliance with the regulatory limits will be provided to the U.S. Environmental Protection Agency (EPA) and the PAROC.

Table 2.1: Regulatory Limits for SWIFT Water

Parameter	Regulatory Limit
EPA Drinking Water Primary Maximum Contaminant Levels (PMCLs)	Meet all PMCLs[1]
Total Nitrogen (TN)	5 mg/L Monthly Average; 8 mg/L Max Daily
Turbidity	Individual Filter Effluent (IFE) <0.15 NTU 95% of time and never >0.3 NTU in two consecutive 15-minute measurements
Total Organic Carbon (TOC)[2]	4 mg/L Monthly Average, 5 mg/L Maximum Instantaneous
Total Coliform[3]	<2 CFU/100 mL 95% of collected samples within one calendar month, applied as the 95th percentile
E. Coli	Non-Detect
TDS[4]	No Limit

[1] Refer to Table 4.2 for proposed sampling frequency of PMCLs. Within 24 hours of notification from HRSD or contract laboratory of a potential PMCL exceedance as identified in Table 2.2, SWIFT Water will be diverted to the wastewater treatment facility. A confirmation sample will be collected and submitted for analysis as soon as practical and no later than one week after receiving the initial sample results. If the confirmation sample does not confirm the result, recharge will resume. If the PMCL exceedance is confirmed, SWIFT Water will remain diverted until HRSD can complete an investigation as to the likely cause, take corrective action, and perform follow-up sampling to demonstrate that the corrective actions taken have been effective. HRSD will submit documentation describing the problem, the assessment, the corrective action taken, and the results of follow-up sampling within 14 days of resuming recharge.

[2] Regulatory limit applies to the TOC laboratory analysis which is collected at a frequency of 3 times per week.

[3] The TC monitoring requirement at the SRC included compliance with a geomean of 3 CFU/100 mL for 20 daily samples. The Virginia Department of Health (VDH) determined that the requirement to meet TC < 2 CFU/100 mL 95% of the time within a given month was protective of this geomean requirement and the application of both regulatory limits was not necessary.

[4] No limit for TDS as the primary driver is aquifer compatibility. Expected range for SWIFT Water at JR SWIFT is 300-700 mg/L.

2.1.1. Compliance Determination

The methodology for determining PMCL compliance varies depending on the specific parameter of interest. Consistent with Virginia Waterworks Regulation, 12VAC5-590-410, the constituents are categorized into groups, and for each constituent group PMCL compliance is determined by either a running annual average (RAA) or as a single-instance limit. Constituents regulated on a RAA basis are in violation when the RAA exceeds the numerical PMCL. Constituents regulated on a single-instance limit are in violation when the results of any single sample exceed the numerical PMCL. In all cases, compliance shall be determined by rounding off results to the same number of significant figures as the PMCL.

Table 2-2: JR SWIFT Primary Maximum Contaminant Level Compliance Determination

Analytes	SWIFT Water Monitoring Frequency[1]	Compliance Determination
Total coliform	5x/week	TC < 2 CFU/100 mL 95% of collected samples within one calendar month[2]
E coli	5x/week	Non-detect
Antimony, arsenic, barium, beryllium, cadmium, cyanide, chromium, fluoride, mercury, nickel, selenium, thallium	Monthly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Asbestos	Quarterly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Nitrate, Nitrite	5x/week	Compliance for these constituent groups is to be determined based on individual sample results. If any single sample is greater than the PMCL, the PMCL has been exceeded.
Organic chemicals	Monthly	Compliance with the PMCL is determined by a Running Annual Average (RAA). If the average is greater than the PMCL, the PMCL has been exceeded.
Disinfection byproducts (TTHM and HAA5), Bromate, Chlorite	Monthly	Compliance with the PMCL is determined by a RAA of monthly data. If the average is greater than the PMCL, the PMCL has been exceeded.
Radionuclides	Monthly	Compliance for these constituent groups is to be determined based on individual sample results. If any single sample is greater than the PMCL, the PMCL has been exceeded.

[1] Minimum required monitoring frequency. All data collected during recharge operations and when the SWIFT facility is shut down due to a PMCL exceedance shall be reported and included in the compliance determination calculations. Data collected during a planned shutdown (such as a GAC contactor re-start) or during a pre-emptive shut down (such as when a CCP triggers a diversion of SWIFT water) are exempt from this requirement.

[2] If TC exceeds 2 CFU/100 mL > 95 % of samples (calculated by the 95th percentile) in one calendar month, HRSD will conduct an additional investigation (e.g., evaluating sample collection and training protocols, possible sample line contamination, etc.) A TC exceedance is not considered a PMCL exceedance unless E. coli is present. The results of the investigation will be included in the next quarterly report.

2.1.1.1. Constituents Regulated on a RAA basis

This category includes the following constituent groups: inorganic chemicals (antimony, arsenic, barium, beryllium, cadmium, chromium, fluoride, mercury, nickel, selenium, and thallium), asbestos, organic chemicals, and disinfection byproducts. A RAA will be used to determine PMCL compliance for these constituent groups.

The RAA will be calculated as an average of single values that correspond to the minimum sampling frequency period defined in Table 2.2. When the average of multiple samples is calculated to evaluate compliance, any values less than the quantitation limit will be calculated as zero for the purposes of averaging.

- For constituent groups with a minimum sampling frequency period of “Monthly”, the RAA will consist of an average of 12 equally-weighted “single monthly values”, with each single monthly value representing the average of all data points collected during the corresponding calendar month.
- For constituent groups with a minimum sampling frequency period of “Quarterly”, the RAA will consist of an average of 4 equally-weighted “single quarterly values”, with each single quarterly value representing the average of all data points collected during the corresponding quarter. For the sake of brevity, this document will describe the method of calculating the RAA for “Monthly” groups only. RAAs for Quarterly constituent groups will be calculated in the same way, but with “quarter” substituted for “month”.

The RAA will be calculated as an average of the single monthly value of the current calendar month and the single monthly values of the last 11 calendar months.

Each time a sample is collected and measured, the single monthly value for the current calendar month will be re-calculated to include the new measurement, and the RAA will subsequently be re-calculated using the updated current single monthly value.

If, after measuring a sample and re-calculating the RAA, the PMCL is exceeded, the facility is in violation of the PMCL and recharge must cease.

Once a PMCL violation has occurred and SWIFT water has been diverted, HRSD may collect follow-up samples no more frequently than once per day. Each time a sample is measured, the single monthly value and RAA will be re-calculated as described above. Once the RAA is reduced to below the PMCL, the facility is no longer in violation and may resume recharge. Note that data collected during the PMCL shutdown is not to be omitted from future compliance calculations.

2.1.1.2. Constituents Regulated on a Single Instance Basis

This category includes the following constituent groups: nitrate and nitrite, radionuclides.

Compliance for these constituent groups is to be determined based on individual sample results. If any single sample exceeds the numerical PMCL, the facility is in violation and must stop recharging.

Once a PMCL exceedance has occurred and SWIFT Water has been diverted, HRSD may collect follow-up samples no more frequently than once per day. Each time a follow-up sample is collected, the results of the initial sample that triggered the exceedance and all follow-up samples will be averaged. If this average is below the PMCL, the facility is no longer in violation and may resume recharge.

2.2 Performance Indicators

Table 2.3 provides a list of performance indicators. These constituents are separated into those that are of public health interest and those that provide information on the effectiveness of treatment (*Final Report of an NWRI Independent Advisory Panel: Recommended DPR General Guidelines and Operational Requirements for New Mexico, 2016*). Table 2.3 provides information on where the criteria for each public health constituent was developed (many from the EPA contaminant candidate list [CCL4]) and the type of performance indicator. If the running annual average for any of the threshold values shown in Table 2.3 is exceeded, an investigation will be conducted to determine the best action to address the issue. This could include sampling at the monitoring well to determine removal by soil aquifer treatment (SAT), source control, modifying wastewater treatment, modifying advanced treatment, no action, or an alternative approach.

HRSD is currently evaluating the occurrence of a broader suite of non-regulated parameters in order to develop an indicator list that reflects the characteristics of local wastewater sources. The collection and evaluation of this data is on-going, and an additional list of indicators will be developed prior to the start of JR SWIFT recharge operations and provided to the PAROC/PARML for review. The Hampton Roads-specific list of indicators will be evaluated in parallel with the indicators in Table 2.3 to confirm the suitability of this new list for performance monitoring.

Table 2.3: JR SWIFT Non-Regulatory Performance Indicators

Constituent	Category	Threshold Value	Unit	Notes
1,4-Dioxane	Public Health	1	µg/L	CCL4; CA Notification Limit
17-β-Estradiol	Public Health	0.9[1]	ng/L	CCL4
DEET	Public Health	200	µg/L	MN Health Guidance Value
Ethinyl Estradiol	Public Health	280[1]	ng/L	CCL4
NDMA	Public Health	10	ng/L	CCL4; CA Notification Limit
Perchlorate	Public Health	6	µg/L	CA Notification Limit
PFOA+PFOS[2]	Public Health	70	ng/L	CCL4; EPA Health Advisory
TCEP	Public Health	5	µg/L	MN Health Guidance Value
Cotinine	Treatment Effectiveness	1	µg/L	Surrogate for low molecular weight, partially charged cyclics
Primidone	Treatment Effectiveness	10	µg/L	
Phenytoin	Treatment Effectiveness	2	µg/L	
Meprobamate	Treatment Effectiveness	200	µg/L	High occurrence in wastewater treatment plant effluent
Atenolol	Treatment Effectiveness	4	µg/L	
Carbamazepine	Treatment Effectiveness	10	µg/L	Unique structure
Estrone	Treatment Effectiveness	320	ng/L	Surrogate for steroids
Sucralose	Treatment Effectiveness	150	mg/L	Surrogate for water soluble, uncharged chemicals with moderate molecular weight
Triclosan	Treatment Effectiveness	2,100	µg/L	Chemical of interest

[1] Threshold value identified in *Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water, Recommendations of a Science Advisory Panel, 2018; SCCWRP Technical Report 1032.*

[2] Though no thresholds have been established, monitoring and reporting will include PFBA, PFHpA, PFHxS and PFNA.

2.3 Design Pathogen Log Removal Value

JR SWIFT will be designed and operated (using CCPs) to achieve at least 12 log removal value (LRV) for viruses and 10 LRV for *Cryptosporidium* and *Giardia* through a combination of advanced treatment processes and soil aquifer treatment. Table 2.4 provides a treatment process pathogen LRV summary for JR SWIFT. Monitoring at the SRC will be used to verify the claimed credits for each process unit. The following key design and operational considerations and regulatory references are provided for context for Table 2.4:

- Two-log removal of viruses and 2.5-log *Giardia* removal is granted per the *Surface Water Treatment Rule Guidance Manual*, 1991 edition, section 5.5.2, for a well operated conventional filtration treatment plant.
- Three-log *Cryptosporidium* removal is granted per the *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual* section 1.4.1 if the combined filter effluent (CFE) is less than 0.3 NTU 95% of the time and never greater than 1.0 NTU. An additional 0.5-log credit is granted in section 7.2.1 for achieving individual filter effluent (IFE) of 0.15 NTU 95% of the time and having no two consecutive measurements 15 minutes apart greater than 0.3 NTU. One more additional 0.5-log credit is granted in section 7.2.1 for achieving CFE of 0.15 NTU 95% of the time. CCPs will be enacted to ensure that these turbidity requirements are met.
- The ozone system will not be operated specifically to achieve pathogen removal credit. It is anticipated that ozone operation to achieve oxidation of organics will also achieve very high levels of pathogen removal, but this will not be a programmed CCP or operational goal at JR SWIFT. If ozone is operated in AOP mode, there will be no ozone residual and no way to demonstrate pathogen log removal under the current EPA guidance, although research is being and will be conducted in the future to demonstrate removal using other verification methods.
- The design Ultraviolet “UV” dose of 186 mJ/cm2 provides 4 LRV for viruses according to Table 1.4 of the *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule*. Significantly greater inactivation of *Cryptosporidium* and *Giardia* would be achieved at this design dose, though only 4-log removal is claimed in Table 2.4. If UV is operated in AOP mode, significantly more pathogen removal credit could be achieved, but that is not claimed in Table 2.4.
- At least 6-log credit for viruses, *Cryptosporidium*, and *Giardia* is expected through SAT based on the modeled travel time of the recharge water in the PAS. Literature has demonstrated additional treatment of recharge water as it moves through an aquifer system; the California Department of Health Regulations Related to Recycled Water section 60320.108 states that 1-log virus reduction credit is granted for every month the water is in the ground up to 6-log reduction. A minimum 6-log removal of *Cryptosporidium* and *Giardia* is expected when achieving 6-log virus reduction. HRSD’s soil column testing has confirmed this assumption.

Table 2.4: JR SWIFT Design Pathogen LRV

Parameter	Floc/Sed (+BAF)	Ozone	BAF+GAC	UV	Cl2	SAT	Total
Enteric Viruses	2	0	0	4	0	6	12
Cryptosporidium	4	0	0	4	0	6	14
Giardia	2.5	0	0	4	0	6	12.5

2.4 Future SWIFT Facility Considerations

The SRC and the soil column testing will continue to provide significant operational data on the performance of the advanced treatment processes with respect to both microbial and chemical contaminant controls while JR SWIFT is being designed and constructed. Prior to design of other full-scale facilities and prior to operation of JR SWIFT, AWT design and operational parameters will be reevaluated. For example, if significant reduction of organics is demonstrated at the SRC monitoring wells or by soil column testing, HRSD may seek credit for Total Organic Carbon (TOC) reduction through SAT and modify the SWIFT Water TOC regulatory limit accordingly assuming concurrence from the PAROC. It is intended that all water quality targets will be treated with this adaptive management approach.

3.0 Critical Control Points

JR SWIFT will incorporate CCPs and critical operating points (COPs) throughout the treatment process, similar to the SRC, to ensure public health protection and to verify that treatment goals are being met at each of the individual processes. A violation of any CCP means that JR SWIFT may not be producing water that meets the treatment goals and will trigger a diversion of the SWIFT Water so that it is not directed to the recharge wells. In most instances, JR SWIFT will continue to operate through the CCP violation, but the SWIFT Water will be diverted back to the JR chlorine contact tank and will not be recharged into the aquifer. CCPs specifically protect public health and ensure compliance with regulatory parameters while COPs can be adapted as needed to ensure proper treatment performance throughout the SWIFT process.

CCPs have alert values at which point the operator is expected to take action to correct the performance as well as alarm values at which point an automated response will trigger action and prevent flow from going to the recharge wells. Both the alert and alarm values will be measured for a specified duration or computed as a running average before action is taken so that blips in online analyzers do not trigger action. The specific values for the alert and alarm levels will be configured as adjustable set points in the Distributed Control System and optimized as needed to meet the water quality requirements.

Table 3.1 provides the current, preliminary list of CCPs for JR SWIFT, which is largely the same as the current list for the SRC. During the first year of SRC operation, several CCPs have been adjusted (and documented with EPA) based on lessons learned during operation. It is anticipated that there will be additional changes to Table 3.1 as the SRC continues in operation.

Table 3.1: Critical Control Points for JR SWIFT

Parameter	Alert Value	Alarm Value	Unit	Type[1]	Action
Critical Control Points (CCPs)					
SWIFT Feed Turbidity	3.5	5	NTU	Latched	Place Biofilters in Filter To Waste
SWIFT Feed Conductivity	1,500	2,000	microSiemens per centimeter	Latched	Place Biofilters in Filter To Waste
SWIFT Feed Total Inorganic Nitrogen	4.0	5.0	mg/L-N	Latched	Place Biofilters in Filter To Waste
Preformed Chloramine Failure (if used for bromate suppression)	N/A	Failure	mg/L	Latched	Divert SWIFT Water
Total Chlorine Upstream of Ozone (if used for bromate suppression)	2.0	1.0	mg/L	Latched	Divert SWIFT Water
Monochloramine Upstream of Ozone (if used for bromate suppression)	2.0	1.0	mg/L	Latched	Divert SWIFT Water
Ozone Feed Failure	N/A	Failure	N/A	Latched	Open Biofilter Backwash Waste Valve
High Ozone Dose	7.0	8.0	mg/L	Latched	Place Biofilters in Filter To Waste
Biofilter Individual Effluent Turbidity	0.1	0.15	NTU	Running Average	Place Biofilter in Filter To Waste
Biofilter Combined Filter Effluent Turbidity	0.1	0.15	NTU	Running Average	Place Biofilters in Filter To Waste
GAC Combined Effluent TOC, Instantaneous Online Analyzer	4.0	5.0	mg/L	Latched	Divert SWIFT Water
GAC Combined Effluent Nitrite	0.25	0.5	mg/L-N	Latched	Divert SWIFT Water
GAC Combined Effluent Ammonia[2]	0.1	0.3	mg/L-N	Latched	Divert SWIFT Water
UV Reactor Dose	<120% of Dose Setpoint	<105% of Dose Setpoint	%	Latched	Divert SWIFT Water
SWIFT Water Total Nitrogen	4.5	5.0	mg/L-N	Latched	Divert SWIFT Water

[1] A latched CCP requires the measured value to be above/below the limit for a specified duration before alerting or alarming. A running average will generate an alert or alarm if the running average over a specified duration is above/below the limit. Running averages were implemented for specific CCPs to more conservatively protect against water quality requirements.

[2] Ammonia control of GAC CE is applicable only when using free chlorine post-UV for well biofoulant control. Refer to table 4.2, footnote 9 for additional information.

The following CCPs were removed or adjusted from the current CCPs in use at the SRC:

- Ozone Contactor Calculated LRV – Virus (CCP): As JR SWIFT will not operate ozone to achieve disinfection credit, the LRV has been removed from the CCP list.
- Free Chlorine CT (CCP): As JR SWIFT will not add free chlorine for disinfection of SWIFT Water, the required CT has been removed from the CCP list. SWIFT Water Chlorine Residual remains a COP to prevent biofouling in the recharge wells.
- CCPs associated with the tasting system at the SRC have been removed as JR SWIFT will not be designed for tastings.

4.0 JR SWIFT Regulatory Sampling Plan

Sampling will be performed throughout the treatment process to verify treatment performance, online analyzer accuracy, and compliance with regulatory limits. A detailed sampling plan has been generated that addresses these purposes. Sampling will consist of a combination of onsite analysis, lab analysis performed by HRSD, and specialized analysis performed by outside contract labs. Table 4.1 provides the additional monitoring required to document compliance with the targeted LRV for the UV system. Table 4.2 provides the sampling plan specific to the proposed regulatory limits and performance indicators including the location and frequency of each sample.

Table 4.1: Additional Monitoring to Support UV LRV [1]

UV LRV
UV Intensity, each reactor
UVT, GAC Combined Effluent
Reactor Flow, each
Calculated Dose (validated), each reactor
Status, each

[1] All continuous measurements. Calculated dose and LRV will be reported as part of the quarterly monitoring reports. Calculations will be based on 15 min data.

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2, 3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Total Nitrogen		Weekly				Monthly	Monthly	5x/week
Turbidity					Continuous[4]	Continuous[4]		
TOC		Weekly	3x/week			3x/week		3x/week
pH[5]								Continuous
TDS[5]								Monthly
Male-specific and somatic coliphages[5]		Quarterly						Quarterly
Cryptosporidium	Quarterly	Quarterly						Quarterly
Giardia lamblia	Quarterly	Quarterly						Quarterly
Legionella		Quarterly						Quarterly
Total Coliform		Weekly						5x/week
E. coli		Weekly						5x/week
Bromate				5x/week				Weekly
Chlorite	Quarterly	Monthly						Monthly
Haloacetic acids (HAA5)								Monthly
Total trihalomethanes								Monthly
Chloramines (as Cl_2)								Continuous[7]
Chlorine (as Cl_2)								Continuous[7]

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2, 3]								
Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Antimony, Total	Quarterly	Monthly						Monthly
Arsenic, Total	Quarterly	Monthly						Monthly
Asbestos		Quarterly						Quarterly
Barium, Total	Quarterly	Monthly						Monthly
Beryllium, Total	Quarterly	Monthly						Monthly
Cadmium, Total	Quarterly	Monthly						Monthly
Chromium VI	Quarterly	Monthly						Monthly
Chromium, Total	Quarterly	Monthly						Monthly
Copper, Total	Quarterly	Monthly						Monthly
Cyanide, Total	Quarterly	Monthly						Monthly
Fluoride	Quarterly	Monthly						Monthly
Lead, Total	Quarterly	Monthly						Monthly
Mercury, Total	Quarterly	Monthly						Monthly
Nitrate -N		Weekly				Monthly	Monthly	5x/week
Nitrite-N		Weekly				Monthly	Monthly	5x/week
Selenium, Total	Quarterly	Monthly						Monthly
Thallium, Total	Quarterly	Monthly						Monthly
Acrylamide	Quarterly	Monthly						Monthly
Alachlor	Quarterly	Monthly						Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2, 3]								
Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Atrazine	Quarterly	Monthly						Monthly
Benzene	Quarterly	Monthly						Monthly
Benzo(a)pyrene (PAHs)	Quarterly	Monthly						Monthly
Carbofuran	Quarterly	Monthly						Monthly
Carbon Tetrachloride	Quarterly	Monthly						Monthly
Chlordane	Quarterly	Monthly						Monthly
Chlorobenzene	Quarterly	Monthly						Monthly
2,4-D	Quarterly	Monthly						Monthly
Dalapon	Quarterly	Monthly						Monthly
1,2-dibromo-3-chloropropane (DBCP)	Quarterly	Monthly						Monthly
1,2-Dichlorobenzene (o-dichlorobenzene)	Quarterly	Monthly						Monthly
1,4-Dichlorobenzene (p-dichlorobenzene)	Quarterly	Monthly						Monthly
1,2-Dichloroethane	Quarterly	Monthly						Monthly
1,1-Dichloroethylene	Quarterly	Monthly						Monthly
cis-1,2-Dichloroethylene	Quarterly	Monthly						Monthly
trans-1,2-Dichloroethylene	Quarterly	Monthly						Monthly
Dichloromethane (Methylene chloride)	Quarterly	Monthly						Monthly
1,2-Dichloropropane	Quarterly	Monthly						Monthly
Di(2-ethylhexyl) adipate	Quarterly	Monthly						Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]

Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
Di(2-ethylhexyl) phthalate	Quarterly	Monthly						Monthly
Dinoseb	Quarterly	Monthly						Monthly
Dioxin (2,3,7,8-TCDD)	Quarterly	Monthly						Monthly
Diquat	Quarterly	Monthly						Monthly
Endothall	Quarterly	Monthly						Monthly
Endrin	Quarterly	Monthly						Monthly
Epichlorohydrin	Quarterly	Monthly						Monthly
Ethylbenzene	Quarterly	Monthly						Monthly
Ethylene dibromide (EDB)	Quarterly	Monthly						Monthly
Glyphosate	Quarterly	Monthly						Monthly
Heptachlor	Quarterly	Monthly						Monthly
Heptachlor Epoxide	Quarterly	Monthly						Monthly
Hexachlorobenzene	Quarterly	Monthly						Monthly
Hexachlorocyclopentadiene	Quarterly	Monthly						Monthly
Lindane (Gamma-BHC)	Quarterly	Monthly						Monthly
Methoxychlor	Quarterly	Monthly						Monthly
Oxamyl (Vydate)	Quarterly	Monthly						Monthly
Polychlorinated biphenyls	Quarterly	Monthly						Monthly
Arochlor (AR)1016	Quarterly	Monthly						Monthly
AR1221	Quarterly	Monthly						Monthly
AR1232	Quarterly	Monthly						Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
AR1242	Quarterly	Monthly						Monthly
AR1248	Quarterly	Monthly						Monthly
AR1254	Quarterly	Monthly						Monthly
AR1260	Quarterly	Monthly						Monthly
Pentachlorophenol	Quarterly	Monthly						Monthly
Picloram	Quarterly	Monthly						Monthly
Simazine	Quarterly	Monthly						Monthly
Styrene	Quarterly	Monthly						Monthly
Tetrachloroethylene	Quarterly	Monthly						Monthly
Toluene	Quarterly	Monthly						Monthly
Toxaphene	Quarterly	Monthly						Monthly
2,4,5-TP (Silvex)	Quarterly	Monthly						Monthly
1,2,4-Trichlorobenzene	Quarterly	Monthly						Monthly
1,1,1-Trichloroethane	Quarterly	Monthly						Monthly
1,1,2-Trichloroethane	Quarterly	Monthly						Monthly
Trichloroethylene	Quarterly	Monthly						Monthly
Vinyl Chloride	Quarterly	Monthly						Monthly
Xylene, Total	Quarterly	Monthly						Monthly
Radionuclides								
Alpha particles		Monthly						Monthly
Beta particles and photon emitters		Monthly						Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2, 3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Radium 226		Monthly						Monthly
Radium 228		Monthly						Monthly
Uranium		Monthly						Monthly
Aldrin/Dieldrin	Quarterly	Monthly						Monthly
DDT	Quarterly	Monthly						Monthly
Kepone	Quarterly	Monthly						Monthly
Mirex	Quarterly	Monthly						Monthly
Phenols	Quarterly	Monthly						Monthly
Strontium-90		Monthly						Monthly
Tritium		Monthly						Monthly
1,4-dioxane	Quarterly	Quarterly						Quarterly
17-β-estradiol	Quarterly	Quarterly						Quarterly
DEET	Quarterly	Quarterly						Quarterly
Ethinyl estradiol	Quarterly	Quarterly						Quarterly
NDMA	Quarterly	Quarterly		Weekly		Weekly		Weekly[9]
Perchlorate	Quarterly	Quarterly						Quarterly
PFOA + PFOS	Quarterly	Quarterly						Quarterly
PFBA	Quarterly	Quarterly						Quarterly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1, 2, 3]

Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water
PFHpA	Quarterly	Quarterly						Quarterly
PFHxS	Quarterly	Quarterly						Quarterly
PFNA	Quarterly	Quarterly						Quarterly
tris(2-carboxyethyl)phosphine (TCEP)	Quarterly	Quarterly						Quarterly
Cotinine	Quarterly	Quarterly						Quarterly
Primidone	Quarterly	Quarterly						Quarterly
Phenytoin	Quarterly	Quarterly						Quarterly
Meprobamate	Quarterly	Quarterly						Quarterly
Atenolol	Quarterly	Quarterly						Quarterly
Carbamazepine	Quarterly	Quarterly						Quarterly
Estrone	Quarterly	Quarterly						Quarterly
Sucralose	Quarterly	Quarterly						Quarterly
Triclosan	Quarterly	Quarterly						Quarterly
Unregulated Contaminant Monitoring Rule (UCMR)[10]								TBD[10]
Dissolved Oxygen								Monthly
Temperature								Monthly
Specific conductivity								Continuous
ORP								Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2,3]								
Parameter	**JR Influent**	**SWIFT Feed**	**Floc/Sed Effluent**	**Ozone Effluent**	**BAF IFE**	**BAF CFE**	**GAC CE**	**SWIFT Water**
Iron, Total								Continuous[11]
Aluminum, dissolved								Monthly
Aluminum, total								Monthly
Arsenic, dissolved								Monthly
Iron, dissolved								Monthly
Manganese, dissolved								Monthly
Manganese, total								Monthly
Magnesium, total								Monthly
Potassium, total								Monthly
Sodium, total								Monthly
Calcium, total								Monthly
Sulfate								Monthly
Chloride								Monthly
Bromide		Weekly						
Alkalinity								Monthly
Total Kjeldahl Nitrogen		Weekly				Monthly		Weekly
Ammonia as N								Weekly
Total Phosphorus			Weekly			Weekly		Weekly
Orthophosphate as P			Weekly			Weekly		Weekly
Silica as SiO_2								Monthly
Hardness, Total								Monthly

Table 4.2: JR SWIFT Regulatory and Process Monitoring Plan, Sample Location and Minimum Monitoring Frequency

HRSD JR SWIFT Regulatory and Process Monitoring Plan[1,2, 3]								
Parameter	JR Influent	SWIFT Feed	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	SWIFT Water

[1] Compliance samples are collected during periods of recharge. Point of compliance for all regulatory parameters is SWIFT Water with the exception of turbidity. Compliance point for turbidity monitoring is BAF Individual and Combined Filter Effluents (BAF IFE, BAF CFE).

[2] Non-compliance process monitoring may be modified based on operational needs.

[3] All samples are collected as grabs unless denoted as “Continuous”. 15-minute data will be reported for each continuous measurement.

[4] All in service turbidimeters will be verified with daily lab grabs. Only 15-min online turbidimeter data will be submitted for IFE and CFE. If a turbidimeter is out of service, unreliable or suspect, turbidity samples will be collected by grab for lab analysis every 4 hours, and those data will be submitted.

[5] Monitoring requirement with no limit imposed.

[6] ClO_2 not used for disinfection and therefore is not included in monitoring.

[7] Continuous measurements of chlorine and chloramines will be confirmed with a daily grab sample.

[8] Virginia Ground Water Standards (9VAC25-280-40) not included as a PMCL under the Safe Drinking Water Act (SDWA) and considered critical for inclusion by the Virginia Department of Health (VDH).

[9] In addition to monitoring NDMA concentration, NDMA Formation Potential (FP) tests will be as follows:

- when monochloramine is being added following UV disinfection the frequency shall be monthly for one year. NDMA FP frequency will be reduced in years 2 – 3 to quarterly, followed by annual testing for the duration of the permit, provided the contingencies for phased reduction continue to be met. Phased reduction is contingent upon (i) NDMA concentrations under agreed-upon conditions in FP testing remaining < 10 ng/L, and (ii) NDMA concentrations in the monitoring wells remaining < 10 ng/L. Exceedance of either of these conditions will “reset” the phased reduction schedule.
- when free chlorine is being added following UV disinfection, NDMA FP testing will be conducted monthly for three months and will be ceased if (i) NDMA concentrations under agreed-upon conditions in FP testing remain < 10 ng/L, and (ii) NDMA concentrations in the monitoring wells remain < 10 ng/L. NDMA FP is expected to be minimal when using free chlorine post-UV and HRSD will further mitigate this risk by incorporating ammonia monitoring of the GAC combined effluent with a CCP for SWIFT Water diversion (Table 3.1).
- All NDMA FP data will be evaluated by PARML and PAROC to ensure concurrence with phased reductions.

[10] HRSD shall monitor currently effective UCMR parameters at the frequency required for large water systems.

[11] Continuous measurements of total iron will be confirmed with a weekly grab sample.

Appendix B: James River SWIFT Aquifer Monitoring and Contingency Plan

1.0 Introduction

HRSD’s James River Treatment Plant (JR; Newport News, VA) will be the site of a full-scale SWIFT facility. This document describes the monitoring and contingency plans for evaluating the hydraulic and water quality response of the Potomac Aquifer System (PAS) to recharging SWIFT Water. The Aquifer Monitoring and Contingency Plan (“Monitoring Plan”) is a detailed supplement to HRSD’s Class V Underground Injection Control (UIC) permit application for James River SWIFT (JR SWIFT).

1.1 General Description

The JR SWIFT facility will accept secondary effluent from the existing JR treatment plant and send it through the Advanced Water Treatment process (AWT). Ten managed aquifer recharge (MAR) wells will receive a nominal flow of 16 MGD of SWIFT Water for recharge into the PAS. Construction of managed aquifer recharge (MAR) wells and the AWT should commence in 2021 and 2022, respectively.

Key topics presented in the Monitoring Plan include the following:

1) HRSD will recharge SWIFT Water from the JR SWIFT facility into the upper (UPA) and middle (MPA) zones of the PAS through ten (10) MAR wells. Proposed locations are identified on Figure 1.1.
2) HRSD will monitor water levels and water quality during MAR operations through two clusters of monitoring wells, each located approximately 500 feet from a MAR (Figure 1.1).
3) The monitoring well clusters will each consist of four wells, screened within the UPA and MPA. The UPA and MPA contain six and three discrete sand intervals, respectively at the test well installed at JR. Screens in monitoring wells will, to the extent practical, match the closest MAR wells. Thus, screens in the monitoring wells will likely fully represent the UPA and MPA at each cluster. Samples collected from individual monitoring wells located in clusters JR_MC1 and JR_MC2 will represent groundwater chemistry or migrating recharge water in the UPA or MPA. If a water quality issue arises, HRSD may decide to collect depth discrete samples from individual sand intervals in the UPA or MPA by removing the affected well’s sampling pump and conducting packer testing.
4) Once the baseline groundwater chemistry in the UPA and MPA is established, HRSD will sample the monitoring wells in the JR_MC1 and JR_MC2 clusters at a routine frequency (See Table 3.1). Each of the eight monitoring wells will contain a permanent sampling pump, facilitating the purging and collection of representative groundwater samples.
5) HRSD will analyze samples of the SWIFT Water for a comprehensive list of analytes on a regular basis to evaluate its compatibility with the UPA and MPA (See Table 4.2 of JR SWIFT Water Quality Targets for list of SWIFT Water monitoring).
6) HRSD will monitor water levels in the MAR and monitoring wells, facilitating the tracking of specific capacity during recharge (injectivity), backflushing, and changes in aquifer transmissivity and storage coefficients.
7) Depending on the final chemistry of SWIFT Water at JR SWIFT relative to the native groundwater (NGW) at a specific monitoring well, chloride, specific conductivity, sulfate, or fluoride may serve

as a non-reactive or minimally-reactive tracer for tracking SWIFT r monitoring wells. A tracer in the SWIFT Water should not react with minerals in the PAS while displaying concentrations that differ sufficiently from constituent concentrations in the NGW.

Figure 1.1: Proposed locations of Managed Aquifer Recharge (MAR) Wells for JR SWIFT and monitoring wells. MAR and monitoring well locations may be adjusted based on site specific conditions but will lie within the area of the wellfield denoted by the blue boundary. Private wells are identified in blue and red. The three private wells that have been constructed within the AOR are less than 50 feet deep and screen the surficial Columbia Aquifer. All existing and potential future wells based on available permit applications are classified as non-potable and each of these private well users is connected to the public water supply for potable water use (Newport News Waterworks). The brackish groundwater quality contained in the UPA and MPA makes using these aquifers for potable, irrigation, commercial, or industrial supplies impractical. Note well features are not to scale.

2.0 James River SWIFT Well Facilities

The facilities associated with MAR activities (Figure 1.1) at JR SWIFT include the MAR wells (MAR 1-10), and eight conventional monitoring wells clustered in two nests. Monitoring wells in both nests (JR_MC1 and JR_MC2), will screen the UPA and MPA. The ten MAR wells will each screen across the UPA and MPA. To the extent practical, screen intervals in monitoring wells located at monitoring nests JR_MC1 and JR_MC2 will match intervals in the closest MAR wells. Thus, screens in the monitoring wells will likely fully represent the available sand intervals (productive zones) in the UPA and MPA.

A test program at JR SWIFT, comprising drilling, aquifer testing, coring, mineralogic analysis, and water quality sampling indicated that the Lower Zone of the Potomac aquifer (LPA) was unsuitable for MAR applications. The LPA displayed a relatively small (40 feet) effective sand thickness, while packer testing conducted in the LPA yielded relatively low permeability. Accordingly, HRSD will not use the LPA for MAR operations at JR SWIFT.

To discriminate between monitoring associated with the SWIFT AWT processes and monitoring the aquifer response to MAR, this plan describes water exiting the AWT as “SWIFT Water”, and describes water injected into the MAR wells as “recharge water”.

Water level monitoring instrumentation installed in the MAR and monitoring wells will record the hydraulic water level and display the levels on the JR Distributed Control System (DCS).

2.1 Managed Aquifer Recharge Wells

The following section describes MAR and monitoring wells, including designated locations and construction details.

2.1.1 Recharge Well – location and construction

HRSD plans to install ten MAR wells distributed across the JR SWIFT site (Figure 1.1). Eight MAR wells will recharge the UPA and MPA at rates approaching 2 MGD each, while HRSD will bring the other two wells into service as needed. Alternatively, HRSD could use all wells simultaneously, at a lower recharge rate. Either approach should facilitate removing one well from service for maintenance at any time. Considering more routine maintenance, the JR SWIFT facility design will accommodate backflushing at frequencies of up to once daily for each MAR well in service, although a less frequent backflushing schedule of several times weekly is more likely.

To preclude excessive hydraulic interference, HRSD will maintain an approximate 1,000-ft spacing between MAR wells. A small 20 by 40-foot building will protect each MAR well, wellhead, and equipment. HRSD will control recharge rates at JR SWIFT using a foot valve connected to the base of each vertical turbine pump. The foot valve backs recharge water up the pump column preventing recharging under a vacuum and entraining air in the recharge water. Foot valves for MAR wells contain orifice holes drilled in the valve face that facilitate recharge around a narrow range of rates. Thus, foot valves at JR SWIFT will contain orifices designed for 2 MGD. The valves slide along a center shaft and slide upward when the pump is running, allowing water to pass.

Each MAR well will consist of 30-inch diameter 2205 duplex or Type 316L stainless steel casing (Figure 2.1 MAR well) that extends to the top of the UPA, encountered around 400 feet below grade (fbg). A 20-inch inner casing and screen assembly will screen across the UPA and MPA, extending to around 1,125 fbg, and comprising around 270 feet of screen, including 180 and 90 feet screening the UPA and MPA respectively. The screen assembly will consist of 18-inch x 20-inch diameter, pre-packed, dual-wall screen separated by stainless steel blanks and ending in a 50-foot long, stainless steel sump. The material for the pre-pack well screen, blank sections and sump will consist of 2205 duplex or Type 316L stainless steel. Estimated screen length and depths are based upon data gathered at the James River test well and will be adjusted depending on highly localized conditions of each MAR.

Test drilling at JR SWIFT revealed that no single, sand interval exceeded 65 feet in thickness and most ranged between 20 and 30 feet, restricting screen lengths and increasing the number of blanks separating individual screen intervals. The total number of screen intervals could range between 7 and 9. At the request of the Virginia Department of Environmental Quality (VDEQ), in each MAR well

HRSD will install a minimum 20-foot thick bentonite grout seal adjacent to a blank section between the UPA and MPA to isolate the two aquifer zones.

Each MAR well will include a 20-inch diameter inner casing that will extend approximately 60 above the top of a 20-foot length of pipe-based relief screen. The inner casing and relief screen material will be 2205 duplex or 316L stainless steel with site-specific requirements for corrosion resistivity as the determining factor for selecting the final material.

Employing a pre-packed screen may enable HRSD to recharge at higher injection pressures as water levels rebound and injection level elevations exceed the ground surface. With a conventional well screen and filter pack, high injection pressures combined with a clogging well screen can promote micro-channel formation in the filter pack, ultimately connecting the screen with formation. Micro channel formation allows fine, well sorted sands to enter the MAR well during backflushing. Eventually, catastrophic sand pumping can bury the well screen up to the elevation of the sand source. The situation requires removing the pumping equipment and rehabilitating the MAR well. Often the situation grows repetitive as the well ages, typically requiring reductions in the injection rate.

Because of its dual wall construction and tightly packed, artificial filter pack, a pre-packed screen prevents channel formation. Additionally, extensive testing in MAR wells across the United States has shown the pre-packed to be more resilient under higher injection pressures. Also, the compartmental nature of a pre-packed screen allows customizing the filter pack and screen slot size to discrete sand intervals, rather than sizing the filter pack and screen openings to the smallest grain size distribution encountered in the aquifer as in wells equipped with a conventional screen and filter pack.

HRSD will equip each MAR well with a pump capable of backflushing at rates approaching approximately 2,800 gallons per minute (gpm), approximately two times the anticipated injection rate. Backflushing removes total suspended solids (TSS) that accumulate in the well screen and filter pack during MAR operations. MAR wells screening the sandy Atlantic Coastal Plain aquifer typically require backflushing twice weekly, or more. Backflushing frequency depends on the injection rate and TSS concentrations in recharge water (TSS loading), while well depth, well diameter and pumping rate determine the duration of each backflushing event. HRSD currently backflushes the test well (TW-1) at the SWIFT Research Center (SRC) at a daily frequency.

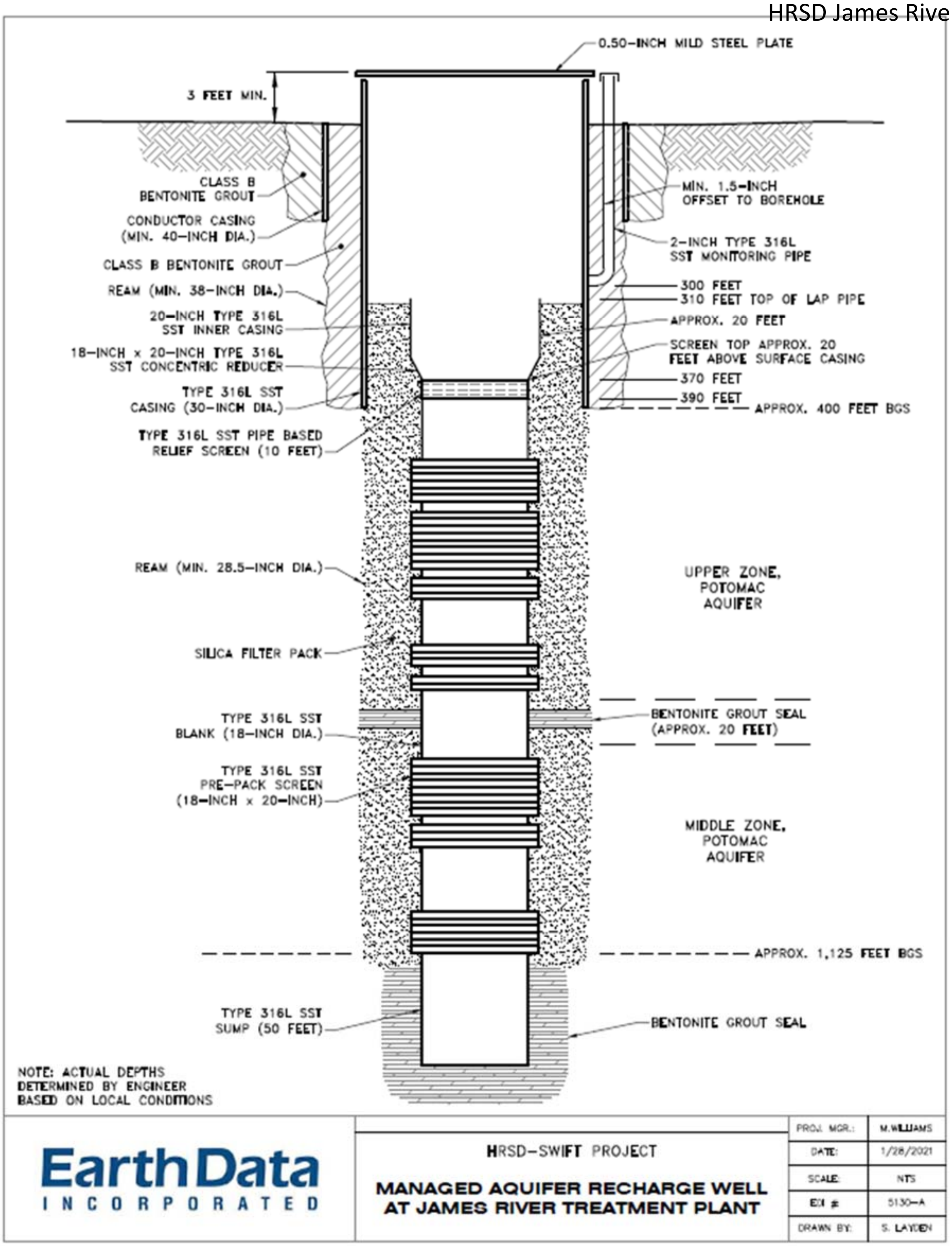


Figure 2.1: Proposed Managed Aquifer Recharge Well at JR SWIFT. Elevations and materials of construction may change according to site specific conditions.

2.1.2 Pre-Recharge Aquifer Conditioning around MARs

The United States Geological Survey has described extensive formation damage during MAR operations in the PAS of southeastern Virginia (Brown and Silvey, 1977). USGS conducted test cycles at a pilot aquifer storage and recovery (ASR) facility in Norfolk, Virginia during the early 1970s. Recharge exhibiting an ionic strength of 0.0001 moles per liter (mol/L) was injected into a test well screening the UPA and MPA, where the ionic strength of the native groundwater equaled 0.01 mol/L.

The specific capacity (injectivity) of the test well declined by nearly 80 percent in the first 90 minutes after commencing recharge, reducing the capacity of the ASR well by a similar amount, and effectively ending the viability of the facility. The project continued for several years, but injectivity and injection capacity losses proved irreversible.

Pre-recharge aquifer conditioning was successfully employed at HRSD's SRC at the Nansemond Treatment Plant where the ionic strengths of the SWIFT Water and the NGW differed by one order of magnitude or more. The difference in the ionic strengths of the recharge at JR SWIFT (0.02 moles per liter (mol/L) compared to NGW in the UPA (0.081 mol/L) and MPA (0.1 mol/L), both fall close to or greater than one order of magnitude. Therefore, the UPA and MPA at JR SWIFT will require conditioning with aluminum salts prior to starting MAR operations. Local native groundwater characteristics were determined through test well monitoring at the James River site and are detailed in Table 2.1.

2.2. Conventional Monitoring Wells

HRSD plans to install eight monitoring wells at JR SWIFT in two clusters. Each cluster will include four monitoring wells, three screened in the UPA and one in the MPA; two of the wells in the UPA will be nested in one borehole, their screen zones separated by a minimum 20-foot long bentonite grout seal. These wells may lie up to 50 feet apart to preclude interference during drilling. HRSD will locate well cluster JR_MC1 on the boundary of the JR SWIFT facility approximately 500 ft from the nearest recharge well. Likewise, JR_MC2 will lie approximately 500 feet (1.5 aquifer thicknesses) away from any MAR well. Moreover, with their locations within the Area of Review (AOR), samples from JR_MC1 and JR_MC2 should provide representative water quality of recharge water chemistry exiting the AOR in the UPA and MPA. Considering a distance equaling around 500 feet, an aquifer thickness totaling 270 feet and recharge rate approaching 2 MGD, it has previously been determined that recharge water should not reach JR_MC1 and JR_MC2 for approximately 0.9 years in the absence of dispersion and 0.7 years considering dispersion typical in sand aquifers.

The monitoring well network design captures conditions equidistant between two operating MAR wells and at MAR wells located both inside and outside the area housing the JR SWIFT AWT. The ambient hydraulic gradient determined from a synoptic survey map developed by USGS runs around 0.00001 ft/ft. Analytical modeling (CAPZONE and GWPATH) performed to predict recharge levels at the MAR wells produced a gradient of approximately 0.02 ft/ft at individual MAR wells after 50 years of operation.

Scenarios performed using the VDEQ regional model demonstrate the groundwater flow direction with and without SWIFT. The modeling indicates that local to JR, within the monitoring well network, the gradient will be controlled by SWIFT recharge. The recharge at JR MAR wells will produce a mound of pressure in a radial morphology, everywhere away from the MAR well will be

Table 2.1: Native groundwater chemistry, test well at James River

Test Intervals		**72 HR CRT[1]**	**Packer Test 1 (398-524 fbg[2])**	**Packer Test 2 (570-636 fbg)**	**Packer Test 3 (735-790 fbg)**	**Packer Test 4 (960-1000 fbg)**	**Packer Test 5 (1048-1122 fbg)**	**Packer Test 6 (1240-1280 fbg)**	**Estimated Recharge Chemistry[3]**	**PMCL/ SMCL**
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
pH	standard units	6.32	6.76	7.71	6.14	7.20[6]	7.26	7.62	7.2 to 7.8	6.5 to 8.5
ORP[4]	mV	54.9	-133.8	-95	-70.3	-108	-103.2	-99.6	NA	
Eh (corrected)[5]	mV	254.9	66.2	105	129.7	92	96.8	100.4	NA	
Specific Conductivity	µs/cm	3113	4635	4088	5200[7]	6230	6690[7]	8700[7]	NA	
Temperature	ºC	20.27	25.97	23.57	26.77	25.87	25.8	26.59	15 to 26	
Turbidity	NTU	1.51	1.63	2.12	5.53	0.52	0.43	6.19		
Field Sulfide as S	mg/L	0	0	0	0.04	0	0	0.01	NA	
Field Sulfate as SO_4	mg/L	58	70	69	106	90	104	183	NA	
Field Iron (ferrous as Fe^{2+})	mg/L	0.22	2.35	2.31	1.35	1.34	2.07	2.22	NA	
Field Iron (total)	mg/L	0.91	2.04	2.01	1.7	1.79	2.22	3.14	NA	
Aluminum, dissolved	mg/L	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010	<0.04	0.1
Aluminum, total	mg/L	0.063	<0.010	0.014	0.036	<0.010	<0.010	<0.010	<0.04	0.1
Arsenic, dissolved	µg/L	<1.00	0.25	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Arsenic, total	µg/L	<1.00	0.24	<0.50	<0.50	<0.50	0.27	<0.50	0.7	10
Iron, dissolved	mg/L	0.203	2.49	2.74	1.39	1.46	2.07	2.28	0.07	0.3
Iron, total	mg/L	0.241	2.45	2.79	1.58	1.48	2.05	2.25	0.07	0.3
Manganese, dissolved	mg/L	0.0217	0.0518	0.0575	0.0527	0.0533	0.0829	0.142	0.01	0.05
Manganese, total	mg/L	0.0226	0.0504	0.0581	0.0539	0.0542	0.0852	0.142	0.01	0.05
Magnesium, total	mg/L	4.78	6.71	6.93	9.00	10.6	15.8	25.6	3.6	
Potassium, total	mg/L	15.4	19.6	19.6	20.4	24.6	29	36.9	13	
Sodium, total	mg/L	777	970	979	1060	1240	1500	1930	68	
Calcium, total	mg/L	13.2	19.8	20.7	25.4	29.6	42.1	63.8	34	
Sulfate	mg/L	70.3	90.6	91.6	119	126	175	275	53	250
Chloride	mg/L	825	1460	1490	1770	1830	2290	3070	106	250
Alkalinity	mg/L	326	273	265	258	240	222	217	38	
Nitrate/Nitrite-N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.7	
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.1	10
Total Kjeldahl Nitrogen	mg/L	0.52	0.69	0.66	0.78	0.79	0.92	1.03	2.6	
Fluoride	mg/L	2.16	0.913	0.920	0.863	0.793	0.601	<0.500	0.65	4
Silica as SiO_2	mg/L	25.5	38.5	38.1	36.6	40.5	39.4	33.9	NE	
Silicon as Si	mg/L	11.9	18.0	17.8	17.1	18.9	18.4	15.8	NE	
Dissolved organic carbon	mg/L	0.16	0.13	0.11	<0.10	0.21	0.14	0.13	4	
Total organic carbon	mg/L	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	4	

Table 2.1: Native groundwater chemistry, test well at James River

Test Intervals		**72 HR CRT[1]**	**Packer Test 1 (398-524 fbg[2])**	**Packer Test 2 (570-636 fbg)**	**Packer Test 3 (735-790 fbg)**	**Packer Test 4 (960-1000 fbg)**	**Packer Test 5 (1048-1122 fbg)**	**Packer Test 6 (1240-1280 fbg)**	**Estimated Recharge Chemistry[3]**	**PMCL/ SMCL**
Analyte	**Units**	**12/19/18**	**5/2/19**	**5/6/19**	**5/8/19**	**5/10/19**	**5/15/19**	**5/20/19**	**1/6/15**	
Total phosphorus	mg/L	0.20	0.14	0.17	0.17	0.13	0.08	0.04	0.02	
Orthophosphate as P	mg/L	0.19	0.04	0.03	0.05	0.02	0.02	0.01	0.01	
Total dissolved solids	mg/L	1880	2990	3060	3470	3590	4460	5800	420	
Total suspended solids	mg/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	0.05	
Hardness, Total	mg eq	52.6	77.1	80.2	100	118	170	265	99	
Ammonia as N	mg/L	0.44	0.56	0.54	0.60	0.61	0.86	0.91	0.52	
BOD5	mg/L	<2	<2	<2	<2	<2	<2	<2	1	
COD	mg/L	<9.0	<12.0	<12.0	<12.0	<12.0	<15.0	<15.0	<10	
Gross Alpha	pCi/L	9.3	6.8	9.7	13	14	14	16	NE	15
Gross Beta	pCi/L	15	16	23	27	27	28	30	NE	
Ra 226 + Ra 228	pCi/L	1.1	ND	ND	1.4	1.6	4.8	8.8	NE	5
Uranium	µg/L	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.500	NE	
Calculated species										
Ionic strength	mol/L	0.047	0.07475	0.0765	0.08675	0.08975	0.1115	0.145	0.0105	
Ionic balance (Stuyfzand, 1993)	%	4.3	5.5	5.7	9.3	2.8	2.3	3.6	6.6	
Ca + Mg/Na + K	meq/L ratio	0.028	0.025	0.027	0.031	0.029	0.052	0.063	0.597	
Organic phosphorous	mg/L	0.137	0.127	0.160	0.153	0.123	0.073	0.037	0.01	
Organic nitrogen	mg/L	0.08	0.13	0.12	0.18	0.18	0.06	0.12	2.08	

Notes:

[1] CRT - constant rate test

[2] fbg - feet below grade

[3] Estimated Recharge Chemistry based on JRTP effluent sampling in January 2015 and 2019 and mathematical modeling to estimate chemistry of JR SWIFT Water.

[4] ORP - oxidation/reduction potential

[5] Eh = ORP + 200 mV

[6] Instrument issue, pH estimated using PHREEQC

[7] Instrument issue, specific conductivity estimated by 1.5 x TDS

NA - Not applicable

ND – Non-detect

NM – Not measured

NE – Not estimated

downgradient. Therefore, this placement of the monitoring well clusters equidistant between two MAR wells will represent downgradient conditions of those two wells. The eight monitoring wells will feature a single-cased design (Figures 2.2, 2.3 and 2.4) with an 8-inch diameter stainless steel upper casing installed to a depth of 10 fbg and a 4.5-inch diameter carbon steel or fiberglass reinforced plastic (FRP) casing extending to the top screen. The screen and blank assembly will match the recharge intervals in the closest MAR wells. Screens will either be Type 316L stainless steel wire wrap or fiberglass reinforced continuous slot well screen surrounded by U.S. Silica (or equivalent) filter pack. Each well will include a minimum 10-foot long sump at the base of the deepest well screen

The 4.5-inch diameter monitoring well casings will accommodate a permanently installed, sampling pump, set to around 200 fbg each well. The sampling pumps will deliver a steady purging rate of 10 gpm against a total dynamic head (TDH) of 275 feet. As water levels rebound in the UPA and MPA, purging rates should increase as the TDH declines. In addition to the sampling pump, each monitoring well will be equipped with a pressure transducer that will record water levels to the plant’s DCS.

Should water quality issues emerge in samples collected from a monitoring well, HRSD may elect to collect depth discrete samples from individual sand intervals through packer testing. A water quality issue could represent the following situations:

- A constituent contained in migrating SWIFT recharge water.
- A constituent released during a reaction related to mixing between native groundwater and SWIFT recharge water.
- Reactions between SWIFT recharge water and aquifer releasing metals or other potentially harmful constituents.

HRSD will remove the sampling pump and install a packer testing assembly to sample individual screens in the affected monitoring well. At JR SWIFT test well TW-4 (DEQ: 2161-07; USGS: 58E7), the UPA and MPA contained six and three sand intervals, respectively.

The wells will be completed with a sanitary seal and housed in a secure, locked structure. The structure will be large enough to accommodate sample pumps, wellhead assembly and any necessary monitoring equipment. The protective structure is not included in the typical construction schematics below.

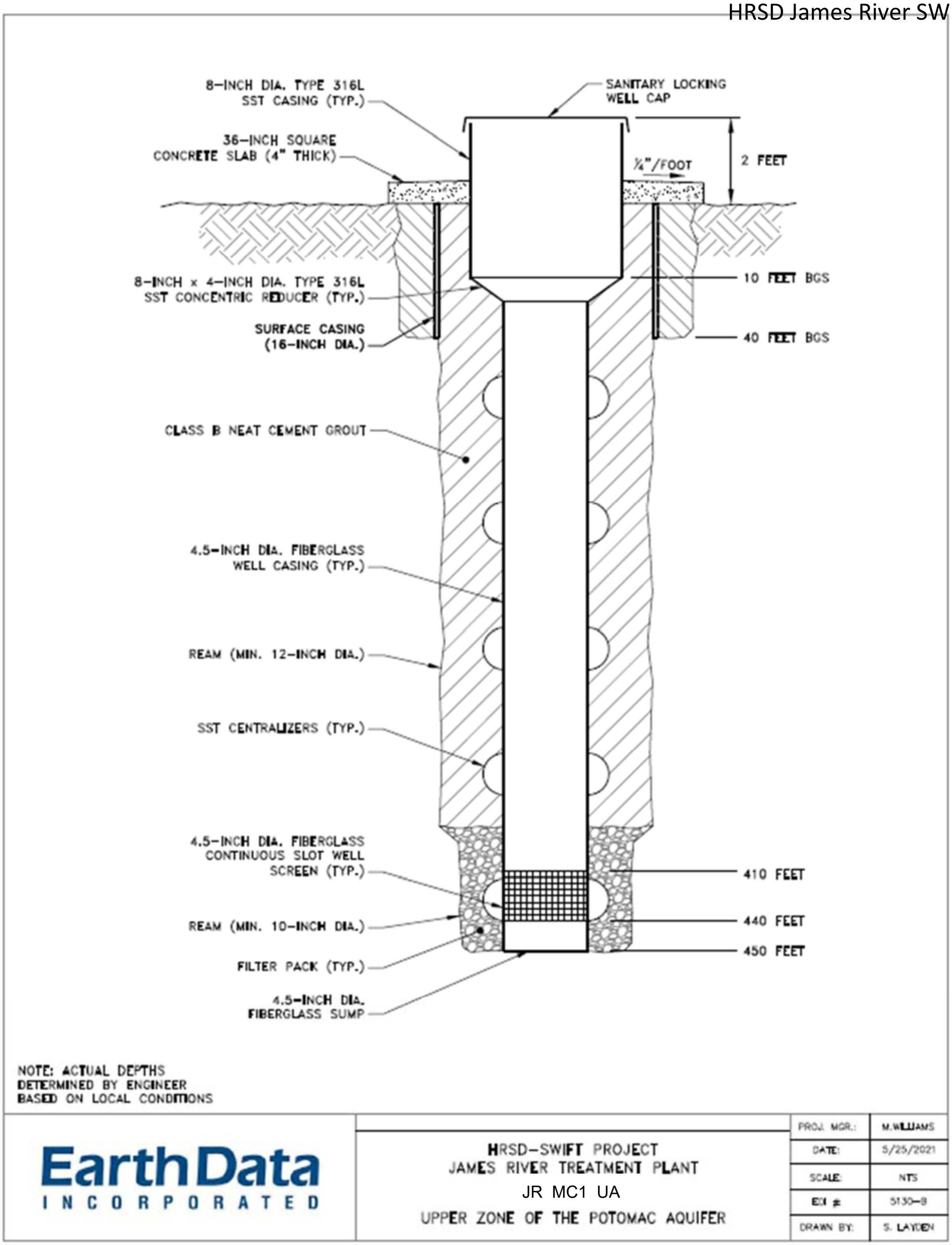


Figure 2.2: Typical Shallowest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

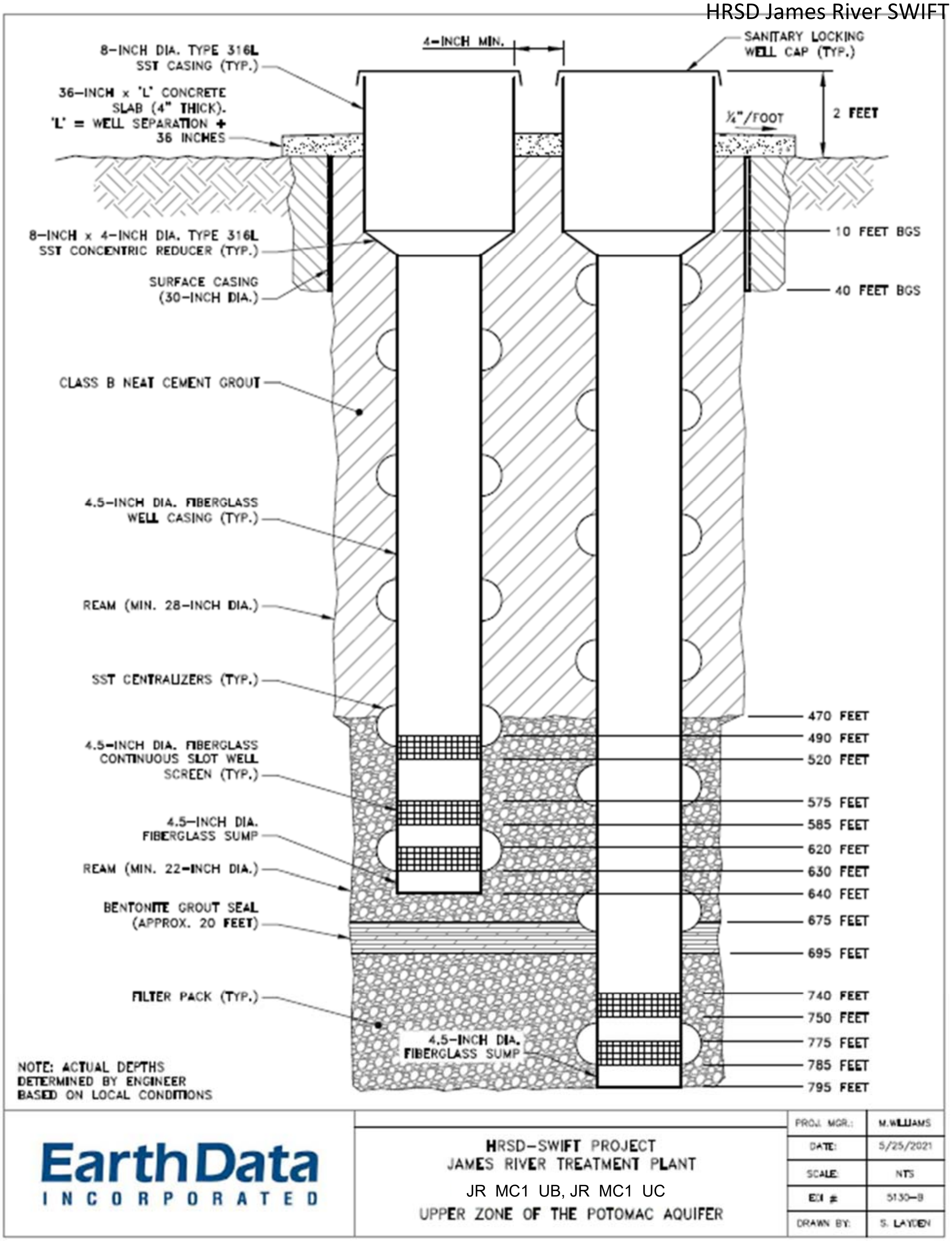


Figure 2.3: Typical deeper Upper Zone Nest Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

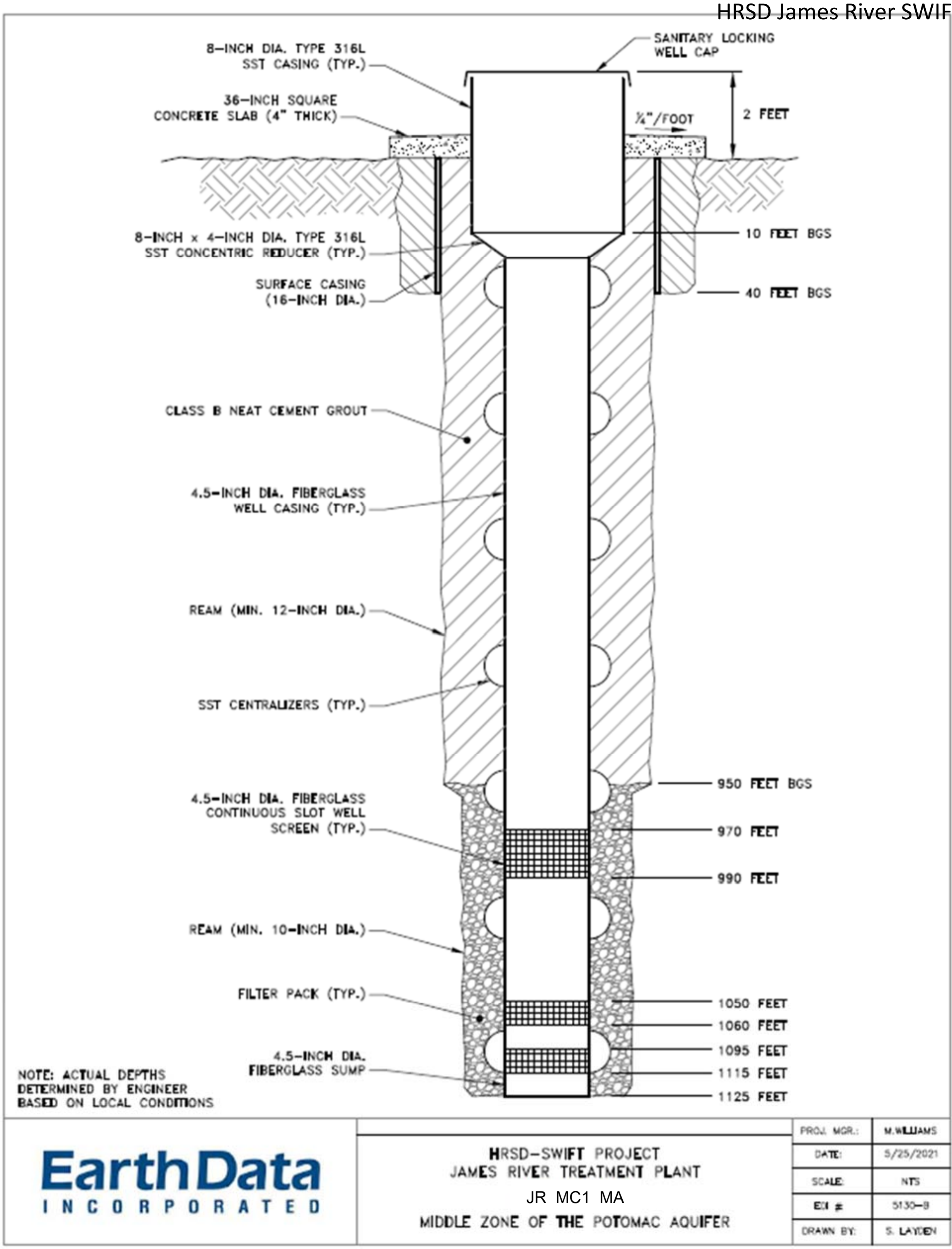


Figure 2.4 Typical Middle Zone Well Construction Diagram for James River SWIFT monitoring well clusters (JR_MC1 and JR_MC2). Elevations may change according to site specific conditions.

3.0 Monitoring Plan

This section describes the hydraulic and water quality monitoring plan for the JR SWIFT MARs. Table 3.1 identifies the monitoring analytes. Quarterly monitoring is identified for disinfection by-products (DBPs), indicator compounds and regulated parameters frequently detected in SWIFT Water in addition to other parameters of interest (e.g., iron, manganese, etc.). Quarterly monitoring of all regulatory and indicator compounds is targeted in the uppermost zone of the Potomac Aquifer System as it represents the zone of the PAS most likely used for potable water supply. The groundwater monitoring plan may be modified during the term of the permit based upon input from the Potomac Aquifer Recharge Oversight Committee. Laboratory analyses will be conducted by a Virginia Environmental Laboratory Accreditation Program (VELAP) accredited laboratory. Accredited laboratories will utilize EPA-approved test methods for all regulatory parameters. Non-regulatory analytes will be analyzed utilizing the same approach when approved test methods are available and appropriate for the groundwater matrix.

Table 3.1: Groundwater Monitoring Plan. Baseline (B), Quarterly (Q) and Annual (A) monitored analytes are identified in the table below.

Parameter	JR_MC_UA	JR_MC_UB	JR_MC_UC	JR_MC_MA
Regulatory Parameters				
Total Nitrogen	B, Q	B, Q	B, Q	B, Q
Turbidity	B, Q	B, A	B, A	B, A
TOC	B, Q	B, Q	B, Q	B, Q
TDS	B, Q	B, Q	B, Q	B, Q
Regulatory Parameters: EPA Primary MCLs				
Microorganisms				
Male-specific and somatic coliphages	B, Q	B, A	B, A	B, A
Cryptosporidium	B, Q	B, A	B, A	B, A
Giardia lamblia	B, Q	B, A	B, A	B, A
Legionella	B, Q	B, A	B, A	B, A
Total Coliform	B, Q	B, A	B, A	B, A
E. coli	B, Q	B, A	B, A	B, A
Disinfection Byproducts				
Bromate	B, Q	B, A	B, A	B, A
Chlorite	B, Q	B, A	B, A	B, A
Haloacetic acids (HAA5)	B, Q	B, Q	B, Q	B, Q
Total trihalomethanes	B, Q	B, Q	B, Q	B, Q
Inorganic Chemicals				
Antimony, Total	B, Q	B, A	B, A	B, A
Arsenic, Total	B, Q	B, Q	B, Q	B, Q
Asbestos	B, Q	B, A	B, A	B, A
Barium, Total	B, Q	B, A	B, A	B, A
Beryllium, Total	B, Q	B, A	B, A	B, A
Cadmium, Total	B, Q	B, A	B, A	B, A

Parameter	JR_MC_UA	JR_MC_UB	JR_MC_UC	JR_MC_MA
Chromium VI	B, Q	B, A	B, A	B, A
Chromium, Total	B, Q	B, A	B, A	B, A
Copper, Total	B, Q	B, A	B, A	B, A
Cyanide, Total	B, Q	B, A	B, A	B, A
Fluoride	B, Q	B, Q	B, Q	B, Q
Lead, Total	B, Q	B, A	B, A	B, A
Mercury, Total	B, Q	B, A	B, A	B, A
Nitrate -N	B, Q	B, Q	B, Q	B, Q
Nitrite-N	B, Q	B, Q	B, Q	B, Q
Selenium, Total	B, Q	B, A	B, A	B, A
Thallium, Total	B, Q	B, A	B, A	B, A
Organic Chemicals				
Acrylamide	B, Q	B, A	B, A	B, A
Alachlor	B, Q	B, A	B, A	B, A
Atrazine	B, Q	B, A	B, A	B, A
Benzene	B, Q	B, A	B, A	B, A
Benzo(a)pyrene (PAHs)	B, Q	B, A	B, A	B, A
Carbofuran	B, Q	B, A	B, A	B, A
Carbon Tetrachloride	B, Q	B, A	B, A	B, A
Chlordane	B, Q	B, A	B, A	B, A
Chlorobenzene	B, Q	B, A	B, A	B, A
2,4-D	B, Q	B, A	B, A	B, A
Dalapon	B, Q	B, A	B, A	B, A
1,2-dibromo-3-chloropropane (DBCP)	B, Q	B, A	B, A	B, A
1,2-Dichlorobenzene (o- dichlorobenzene)	B, Q	B, A	B, A	B, A
1,4-Dichlorobenzene (p- dichlorobenzene)	B, Q	B, A	B, A	B, A
1,2-Dichloroethane	B, Q	B, A	B, A	B, A
1,1-Dichloroethylene	B, Q	B, A	B, A	B, A
cis-1,2-Dichloroethylene	B, Q	B, A	B, A	B, A
trans-1,2-Dichloroethylene	B, Q	B, A	B, A	B, A
Dichloromethane (Methylene chloride)	B, Q	B, A	B, A	B, A
1,2-Dichloropropane	B, Q	B, A	B, A	B, A
Di(2-ethylhexyl) adipate	B, Q	B, A	B, A	B, A
Di(2-ethylhexyl) phthalate	B, Q	B, A	B, A	B, A
Dinoseb	B, Q	B, A	B, A	B, A
Dioxin (2,3,7,8-TCDD)	B, Q	B, A	B, A	B, A
Diquat	B, Q	B, A	B, A	B, A

Parameter	JR_MC_UA	JR_MC_UB	JR_MC_UC	JR_MC_MA
Endothall	B, Q	B, A	B, A	B, A
Endrin	B, Q	B, A	B, A	B, A
Epichlorohydrin	B, Q	B, A	B, A	B, A
Ethylbenzene	B, Q	B, A	B, A	B, A
Ethylene dibromide (EDB)	B, Q	B, A	B, A	B, A
Glyphosate	B, Q	B, A	B, A	B, A
Heptachlor	B, Q	B, A	B, A	B, A
Heptachlor Epoxide	B, Q	B, A	B, A	B, A
Hexachlorobenzene	B, Q	B, A	B, A	B, A
Hexachlorocyclopentadiene	B, Q	B, A	B, A	B, A
Lindane (Gamma-BHC)	B, Q	B, A	B, A	B, A
Methoxychlor	B, Q	B, A	B, A	B, A
Oxamyl (Vydate)	B, Q	B, A	B, A	B, A
Polychlorinated biphenyls	B, Q	B, A	B, A	B, A
Arochlor (AR)1016	B, Q	B, A	B, A	B, A
AR1221	B, Q	B, A	B, A	B, A
AR1232	B, Q	B, A	B, A	B, A
AR1242	B, Q	B, A	B, A	B, A
AR1248	B, Q	B, A	B, A	B, A
AR1254	B, Q	B, A	B, A	B, A
AR1260	B, Q	B, A	B, A	B, A
Pentachlorophenol	B, Q	B, A	B, A	B, A
Picloram	B, Q	B, A	B, A	B, A
Simazine	B, Q	B, A	B, A	B, A
Styrene	B, Q	B, A	B, A	B, A
Tetrachloroethylene	B, Q	B, A	B, A	B, A
Toluene	B, Q	B, A	B, A	B, A
Toxaphene	B, Q	B, A	B, A	B, A
2,4,5-TP (Silvex)	B, Q	B, A	B, A	B, A
1,2,4-Trichlorobenzene	B, Q	B, A	B, A	B, A
1,1,1-Trichloroethane	B, Q	B, A	B, A	B, A
1,1,2-Trichloroethane	B, Q	B, A	B, A	B, A
Trichloroethylene	B, Q	B, A	B, A	B, A
Vinyl Chloride	B, Q	B, A	B, A	B, A
Xylene, Total	B, Q	B, A	B, A	B, A
Radionuclides				

Parameter	JR_MC_UA	JR_MC_UB	JR_MC_UC	JR_MC_MA
Alpha particles	B, Q	B, A	B, A	B, A
Beta particles and photon emitters	B, Q	B, A	B, A	B, A
Radium 226	B, Q	B, A	B, A	B, A
Radium 228	B, Q	B, A	B, A	B, A
Uranium	B, Q	B, A	B, A	B, A
Regulatory Parameters: Virginia Groundwater Standards				
Aldrin/Dieldrin	B, Q	B, A	B, A	B, A
DDT	B, Q	B, A	B, A	B, A
Kepone	B, Q	B, A	B, A	B, A
Mirex	B, Q	B, A	B, A	B, A
Phenols	B, Q	B, A	B, A	B, A
Strontium-90	B, Q	B, A	B, A	B, A
Tritium	B, Q	B, A	B, A	B, A
Non-regulatory Parameters: Performance Indicators				
Public Health Indicators				
1,4-dioxane	B, Q	B, Q	B, Q	B, Q
17-β-estradiol	B, Q	B, Q	B, Q	B, Q
DEET	B, Q	B, Q	B, Q	B, Q
Ethinyl estradiol	B, Q	B, Q	B, Q	B, Q
NDMA	B, Q	B, Q	B, Q	B, Q
Perchlorate	B, Q	B, Q	B, Q	B, Q
PFOA + PFOS	B, Q	B, Q	B, Q	B, Q
PFBA	B, Q	B, Q	B, Q	B, Q
PFHpA	B, Q	B, Q	B, Q	B, Q
PFHxS	B, Q	B, Q	B, Q	B, Q
PFNA	B, Q	B, Q	B, Q	B, Q
tris(2-carboxyethyl)phosphine (TCEP)	B, Q	B, Q	B, Q	B, Q
Treatment Efficacy Indicators				
Cotinine	B, Q	B, Q	B, Q	B, Q
Primidone	B, Q	B, Q	B, Q	B, Q
Phenytoin	B, Q	B, Q	B, Q	B, Q
Meprobamate	B, Q	B, Q	B, Q	B, Q
Atenolol	B, Q	B, Q	B, Q	B, Q
Carbamazepine	B, Q	B, Q	B, Q	B, Q
Estrone	B, Q	B, Q	B, Q	B, Q
Sucralose	B, Q	B, Q	B, Q	B, Q

Parameter	JR_MC_UA	JR_MC_UB	JR_MC_UC	JR_MC_MA
Triclosan	B, Q	B, Q	B, Q	B, Q
Non-regulatory Parameters: Aquifer Characteristics and/or Compatibility				
Dissolved Oxygen	B, Q	B, A	B, A	B, A
Temperature	B, Q	B, A	B, A	B, A
pH	B, Q	B, A	B, A	B, A
Specific conductivity	B, Q	B, A	B, A	B, A
ORP	B, Q	B, A	B, A	B, A
Aluminum, dissolved	B, A	B, A	B, A	B, A
Aluminum, total	B, A	B, A	B, A	B, A
Arsenic, dissolved	B, A	B, A	B, A	B, A
Iron, dissolved	B, A	B, A	B, A	B, A
Iron, Total	B, Q	B, Q	B, Q	B, Q
Manganese, dissolved	B, A	B, A	B, A	B, A
Manganese, total	B, Q	B, Q	B, Q	B, Q
Magnesium, total	B, A	B, A	B, A	B, A
Potassium, total	B, A	B, A	B, A	B, A
Sodium, total	B, A	B, A	B, A	B, A
Calcium, total	B, A	B, A	B, A	B, A
Sulfate	B, A	B, A	B, A	B, A
Chloride	B, A	B, A	B, A	B, A
Bromide	B, A	B, A	B, A	B, A
Alkalinity	B, A	B, A	B, A	B, A
Total Kjeldahl Nitrogen	B, Q	B, Q	B, Q	B, Q
Ammonia as N	B, Q	B, Q	B, Q	B, Q
Total Phosphorus	B, A	B, A	B, A	B, A
Orthophosphate as P	B, A	B, A	B, A	B, A
Silica as SiO_2	B, A	B, A	B, A	B, A
Hardness, Total	B, A	B, A	B, A	B, A

3.1. Managed Aquifer Recharge Wells

This section describes water quality sample collection and water level monitoring and recording for each of the MAR wells (1-10).

3.1.1. Water Quality Monitoring

Water quality monitoring for each MAR will occur prior to start-up of recharge well operations at JR SWIFT and will consist of baseline monitoring (Table 3.1). HRSD will collect a single sample from each of the MAR wells (MAR 1-10) prior to initiating MAR operations. Analytical results will represent the native groundwater chemistry at each MAR well. Results of this analysis will be reviewed prior to initiating recharge to allow for an assessment of variability and collection of additional samples if warranted.

3.2 Monitoring Wells

This section describes water quality sample collection and water level monitoring and recording from the two clusters of monitoring wells, JR_MC1 and JR_MC2. Each cluster will include four conventional monitoring wells screened in the UPA and MPA. Screen intervals in each monitoring well will to the extent practical match screens in the closest MAR wells. Thus, screens in each monitoring well will likely fully penetrate the UPA or MPA.

Samples collected from individual monitoring wells at JR_MC1 or JR_MC2 will represent native groundwater or migrating SWIFT recharge in the UPA or MPA. Should a water quality issue emerge at any monitoring well, HRSD could elect to collect samples from individual sand intervals through packer testing. A water quality issue could represent the following situations:

- A constituent contained in migrating SWIFT recharge.
- A constituent released during a reaction related to mixing between native groundwater and SWIFT-recharge.
- Reactions between SWIFT recharge and aquifer releasing metals or other potentially harmful constituents.

Exploration conducted at JR SWIFT TW-4 (DEQ: 2161-07; USGS: 58E7), revealed the UPA and MPA contained six and three sand intervals, respectively. The 4.5-inch diameter casing and screen assemblies used in the monitoring wells will accommodate packer testing assemblies from most commercial manufacturers.

3.2.1 Water Quality Monitoring

HRSD will conduct baseline and ongoing monitoring at the clustered monitoring wells (Refer to Table 3.1 for a summary of planned baseline, quarterly and annual monitoring). The baseline monitoring will entail collecting samples over four quarters prior to initiating MAR operations to establish the baseline water chemistry in the UPA and MPA aquifers. Field chemistry and lab results from 32 samples will characterize the groundwater chemistry in the UPA and MPA. This baseline sampling will begin at least one - two years prior to initiating MAR operations.

Once MAR operations commence, HRSD will conduct on-going monitoring at each of the eight monitoring wells as described in Table 3.1 to evaluate any changes in water quality that may result from mixing between the recharge water and the native groundwater as well as reactions between the recharge water and aquifer minerals.

3.2.2 Hydraulic Monitoring

HRSD will install pressure transducers in each of the eight monitoring wells, enabling the tracking of water levels during MAR operations. The water levels will represent potentiometric head in the UPA and MPA and will likely climb toward the ground surface during MAR operations as potentiometric head in the aquifers rebound. These data also provide a platform for comparing the draw-up in the UPA and MPA aquifers with draw-up in the MAR wells. Differences in the two values represent head losses due to well effects, helping to evaluate well clogging and the required frequency for backflushing.

3.2.3. Tracer Selection

Evaluating advection, dispersion, diffusion, and the mixing between recharge water and native groundwater in the screened intervals of each monitoring well requires tracking the migration of a conservative constituent, or tracer. Several analytes at JR SWIFT could serve as a tracer including fluoride, sulfate, chloride, and specific conductance. The use of a tracer(s) will allow HRSD to monitor the migration of recharge water past the monitoring well locations, distinguishing between groundwater and recharge water at each monitoring well location.

A tracer should exhibit the following two important characteristics:

- Non-reactive behavior between water types and minerals in the aquifer
- Significantly differing concentrations in the recharge water and NGW.

Because it displays elevated concentrations in NGW from the UPA and MPA, fluoride behaves conservatively in the aquifer environment, while exhibiting low concentrations in treated water, studies often use fluoride as a tracer during groundwater projects performed in the Virginia Coastal Plain. Data collected from the James River test well indicated that the fluoride concentrations in groundwater from the UPA and MPA range from 1.23 to 2.93 mg/L, compared to 0.57 mg/L in the projected recharge water chemistry (Table 2.1). In addition to fluoride, chloride, a relatively inert ion, displays differing concentrations (14 times) between the projected recharge water (106 mg/L) and groundwater produced from the UPA and MPA (1,460 to 2,290 mg/L).

Sulfate has worked as an effective tracer at HRSD's SRC, where sulfate concentrations provided a well-defined breakthrough curve at a monitoring well screening the UPA, located over 250 feet from the test MAR well. However, reactive sulfide minerals elevate sulfate during oxidation reactions with oxygenated recharge water, usually creating sulfate at twice the concentrations found in the SWIFT recharge water. Zones screening the MPA at the SRC produced the recognizable sulfide oxidation signature.

Compared to chloride, sulfate concentrations in the recharge water (53 mg/L) are predicted to be approximately 30 to 60 percent of concentrations encountered in the NGW of the MPA and UPA, respectively. Thus, elevated concentrations of sulfate, from sulfide oxidation reactions, might obscure the leading edge of the SWIFT recharge migrating past a monitoring well screening the UPA or MPA. Pyrite, the most common sulfide mineral found in the PAS, appeared in cores samples collected from the UPA and MPA.

Specific conductance displays a similar relationship, projecting around 900 µS/cm in the recharge water and from 4,088 to 8,700 µS/cm in NGW from UPA and MPA. Moreover, other researchers have pointed to the correlation between specific conductivity and chloride concentrations in a water sample (Hem, 1985). Often chloride concentrations make up 20 percent of a specific conductivity measurement. Consistent with this relationship, the SWIFT Water and NGW are expected to exhibit markedly differing specific conductivity measurements. Yet, a specific conductivity measurement involves ions other than chloride that can react in the aquifer environment. Thus, a specific conductivity measurement may not qualify as an acceptably inert tracer but, with its relative ease of measurement could serve as a screening indicator of chloride concentrations.

As JR_MC1 and JR_MC2 will serve as long-term monitoring locations for JR SWIFT, the timing when recharge water first passes the monitoring wells will register minimal influence on the monitoring schedule.

4.0 Contingency Plan

The contingency plan describes measures for responding to non-routine situations arising during MAR operations. Obvious situations might involve recharging compromised water quality into the PAS or encountering a constituent that exceeds Safe Drinking Water Act (SDWA) Primary Maximum Contaminant Levels (PMCL) in one of the monitoring wells. Operational contingency plans to address well performance, such as declining injectivity, will be outlined in HRSD's Operations and Maintenance (O&M) manual.

As MAR operations progress at JR SWIFT, HRSD personnel may amend this plan to add situations not covered in this version of the Contingency Plan.

4.1. Water Quality

The regulatory monitoring and the critical control point protocols are intended to prevent exceedances of any PMCLs within the PAS resulting from recharging SWIFT Water. If PMCL exceedances are confirmed in the SWIFT Water prior to injection, HRSD will divert SWIFT Water to the JRTP until compliance with the PMCL is demonstrated (refer to SWIFT Water Quality Targets, Table 2.2 for PMCL exceedance determination). Similarly, exceeding certain critical control point action values will result in a diversion of water away from the AWT or away from the MAR wells.

HRSD will monitor the quality of recharge water migrating in the PAS at monitoring well nests JR_MC1 and JR_MC2 as identified in Table 3.1. After the recharge front has migrated past any of the monitoring wells, if any of the regulated parameters are elevated above the PMCL in groundwater samples, HRSD will enact the following contingencies.

- HRSD will collect and submit a confirmation sample for analysis as soon as practical and no later than one week after receiving the initial sample results. If the results appear related to sampling error or other factors, HRSD will provide an explanation in a report submitted to EPA. Depending on the parameter of concern, data turnaround after sample submission can range from 2 – 4 weeks.
- If results are confirmed, HRSD will contact the EPA Region III 's UIC Case Manager and the Potomac Aquifer Recharge Oversight Committee (PAROC) within 24 hours of confirmation to provide notification and will provide a report to EPA and the PAROC within 14 days of confirmation describing in detail the potential cause and any corrective measures that may be implemented to mitigate the issue.
- In the case of an exceedance, HRSD will make all efforts to track the source of a potential contaminant.
- If necessary, HRSD may adjust the treatment process to reduce the reactivity (passivate) of minerals in the PAS in situ. HRSD will increase the sampling frequency at monitoring the wells, as appropriate, to track concentrations of the potential contaminant. HRSD will work with the PAROC and EPA to determine what additional measures may be needed including halting recharge operations until an alternative solution is developed.

- As described above, HRSD may decide to conduct packer testing in an affected monitoring well to determine if the constituent originates from a discrete sand interval or from the entire UPA or MPA.

5.0 References

Hem, J.D. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Edition, US Geological Survey Water-Supply Paper 2254, University of Virginia, Charlottesville, 1985.