FIU-DOE Research Review

FIU Applied Research Center

Tues, March 31	Wed, April 1	Thurs, April 2	Fri, April 3
10:00 AM - 12:00 PM *Presentation- Env. Remediation Technologies (FIU Project 3)* Discussion of research area in support of EM **1:00 - 3:00 PM** *Presentation- Env. Remediation Technologies (FIU Project 2)* Discussion of research area in support of EM	**10:00 AM - 12:00PM** *Presentation- Workforce Development and Training (FIU Project 5)* Discussion of research area in support of EM **1:00 - 3:00 PM** *Presentation- D&D and Env. Mgmt IT Research (FIU Project 4)* Discussion of research area in support of EM	**1:00 - 3:00 PM** *Presentation- High Level Waste/Waste Processing Research (FIU Project 1)* Discussion of research area in support of EM	**10:00 AM - 12:00 PM** *Wrap-up - Discussion of DOE-FIU Cooperative Agreement*

Project 3
Environmental Remediation Technologies

Presenters:
Dr. Ravi Gudavalli
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Dr. Mehrnoosh Mahmoudi
Dr. David Roelant
Dr. Shimelis Setegn

Florida International University

Project Staff and Students

- Dr. Ravi Gudavalli – Research Analyst
- Angelique Lawrence – Research Analyst
- Dr. Mehrnoosh Mahmoudi – Post Doctoral Fellow
- Dr. David Roelant – Associate Director of Research
- Dr. Shimelis Setegn – Water Resources Program Lead
- Natalia Duque – DOE Fellow (Graduate, MS Water Resources Eng.)
- Kiara Pazan – DOE Fellow (Undergrad, BS Environmental Eng.)
- Yoel Rotterman – DOE Fellow (Undergrad, BS Mechanical Eng.)

Project Clients and Collaborators

FIU Applied Research Center

- DOE EM-12
  - Patricia Lee – FIU Project Liaison
  - Latrincy Bates – SRNL Project Liaison
- DOE EM-13
  - Albes Gaona – Project Liaison & Sustainable Remediation Task Lead
  - Andrew Szilagyi – Director of D&D Operations
- SRNL
  - Carol Eddy-Dilek – Project Liaison
  - Miles Denham – Task 1 Lead
  - Brian Looney – Task 2 Lead
  - Ralph Nichols – Task 3 Lead

Project Description

Background/History

- Integrated surface/subsurface flow & contaminant transport models of ORR watersheds (East Fork Poplar Creek, Upper EFPC (Y-12 NSC Area) and White Oak Creek).
- Expt'l studies to obtain kinetic/equilibrium data parameters related to Hg transport, speciation and methylation/demethylation kinetics within EFPC watershed.
- GIS technology for storage and geoprocessing of spatial/temporal model data.

New scope (FY13 – Year 4):

- Level 2 (semi-quantitative) Green & Sustainable Remediation (GSR) analysis at DOE sites.
- Analysis of the baseline, optimization studies and development of system improvement plan for A/M Area groundwater remediation system at SRS.

Transition from ORR to SRS (FY14 – Year 5):

- Experimental studies, modeling efforts and sustainability studies now focused at SRS.

Project Description

FIU Year 4 Carryover Work Scope

- Task 1: EFPC Model Update, Calibration and Uncertainty Analysis – Tech. Rpt
- Task 2: Simulation of NPDES- and TMDL-Regulated Discharges from Non-Point Sources for the EFPC and Y-12 NSC – Technical Report
- Task 3: Sustainable Remediation and Optimization: Cost Savings, Footprint Reductions, and Sustainability Benchmarked at EM Sites – Technical Report
- Task 4: Geodatabase Development for Hydrological Modeling Support – Technical Report

FIU Year 5 New Work Scope

- Task 1: Modeling of the Migration and Distribution of Natural Organic Matter Injected into Subsurface Systems
- Task 2: Surface Water Modeling of Tims Branch
- Task 3: Sustainability Plan for A/M Area Groundwater Remediation System

DOE-FIU Cooperative Agreement

Project 3 Accomplishments

Florida International University

Project-Wide Major Accomplishments

Completion of FIU Year 4 Carryover Work Scope

- Task 1 Final Technical Report: "EFPC Model Update, Calibration, and Uncertainty Analysis"
  - Submitted July 31, 2014.
- Task 2 Final Technical Report: "Simulation of NPDES- and TMDL-Regulated Discharges from Non-Point Sources for the EFPC and Y-12 NSC"
  - Submitted July 31, 2014.
- Task 3 Final Technical Report: "Green and Sustainable Remediation Practices, Tools and their Application at DOE Office of Environmental Management Sites"
  - Submitted September 26, 2014.
- Task 4 Final Technical Report: "Geodatabase Development for Hydrological Modeling Support"
  - Submitted June 30, 2014.

Task 1: Description

Task 1: EFPC Model Update, Calibration, and Uncertainty Analysis (Yr 4 Carryover)

- Subtask 1.1: Review of the existing Hg thermodynamic database and update for EFPC environmental conditions.
- Subtask 1.2: Integration of the Hg thermodynamic database into the existing EFPC model.
- Subtask 1.3: Provide a series of simulations using the EFPC model and the thermodynamic and kinetic interactions.

Carryover Work Scope: Task 1

Objective

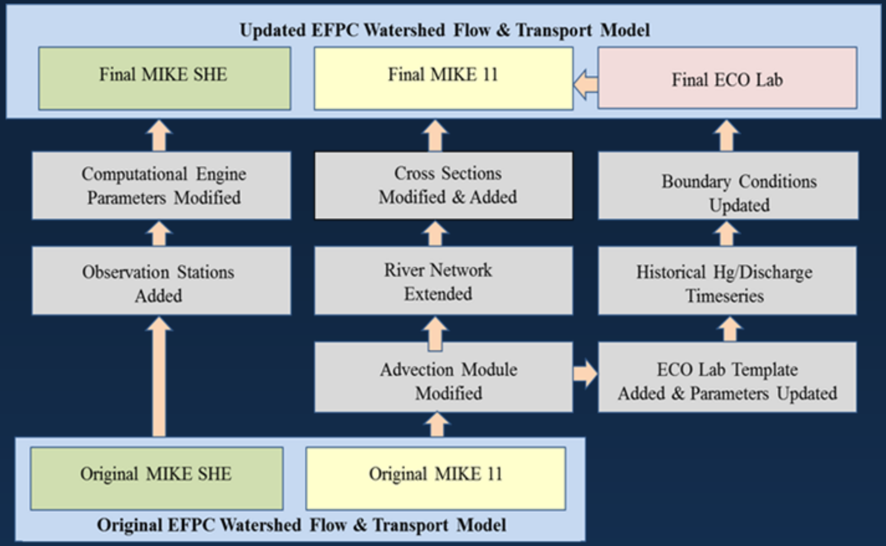
Analysis of coupling between hydrology and Hg transport within context of decreasing risk of D&D activities.

Benefits

- Conventional hydrologic and remediation analytical tools (accepted by EPA, USACE, and USGS) in combination with latest scientific software (2D/3D numerical flow and transport models integrated with reaction kinetics and thermodynamic software) provides integrated solution for understanding mobility and impacts of contaminants at DOE sites.
- Provides state-of-the-practice tools for analysis of sustainable and green remediation alternatives (developed for DOD sites) needed to address long term sustainability in terms of reduced environmental and energy footprints of remedial actions.

Carryover Work Scope Task 1 Accomplishments

- Developed & calibrated numerical model for hydrology, sediment & Hg transport in UEFPC (1996 to present).
- Reconfigured model to incorporate sedimentation module and extended it to include 52 additional outfalls covering entire EFPC and Bear Creek.
- Performed simulations using range of Manning's numbers, threshold run-off water depths, and drainage coefficients to calibrate flow from 2000 – 2008. MATLAB scripts were used for statistical analysis of observed and computed data.
- Provided DOE with assessment reports on effectiveness of 8 remedial scenarios.



Carryover Work Scope Task 1 Accomplishments

- Reviewed and updated existing Hg thermodynamic database specific to EFPC environmental conditions & integrated it into flow and transport models already developed for the site.
- Implemented equations in the kinetic solver (ECOLAB) which provides distribution between total-Hg and methyl-Hg species based on observed distribution coefficients (as fraction).
- Conducted preliminary tests to calibrate model using observed ratios of total-Hg and methyl-Hg concs. Initial results showed template predicts ratio between total-Hg and Me-Hg concs.

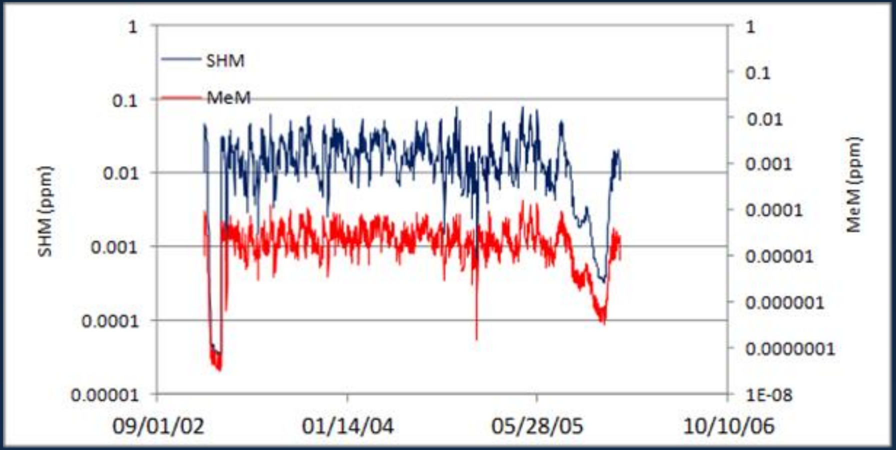


Figure showing nearly proportional distribution between dissolved mercury (SHM) and methylmercury species (MeM) based on the ECOLAB kinetic model.

Task 2: Description

Task 2: Simulation of NPDES- and TMDL-Regulated Discharges from Non-Point Sources for the EFPC and Y-12 NSC (Yr 4 Carryover)

- Subtask 2.1: Use of the observed outfall discharges to provide simulations of the entire EFPC watershed and the load discharge at Station 17 using the EFPC model previously developed with MIKE SHE and 11.

Carryover Work Scope: Task 2

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Objective

Use of EFPC model for numerical analysis of contaminant flow and transport within EFPC watershed to determine impact of model parameters on TMDL.

- Ecosystem responses to variations in contaminant loading (changes in external & internal loading in time and space).
- Effect of ecosystem restoration on existing contaminant pools.

Benefits

- Modeling supports development of TMDLs to estimate source loading and evaluate loading capacities that meet WQ standards.
  - *EFPC identified on Final 2008 303(d) List by TDEC as impaired waterbody not supporting designated uses due to contamination by mercury, PCBs, nitrates, and phosphates.*
- TMDL may be used to develop controls for reducing pollution from point and nonpoint sources to restore and maintain WQ.

Carryover Work Scope Task 2 Accomplishments

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- Update of EFPC database with:
  - Surface and GW levels
  - Water flow
  - Spatiotemporal distribution of pollutants in soil, water, and sediments
  - Bioassessment data
- Spatial and temporal analyses conducted to:
  - Identify spatial variations of Hg in EFPC water, shallow/deep soil layers, stream bank/streambed sediments
  - Evaluate timing of impairment, potential source loading, other conditions contributing to impairment
  - Investigate effect of rainfall and runoff on Hg conc. in EFPC

Carryover Work Scope Task 2 Accomplishments

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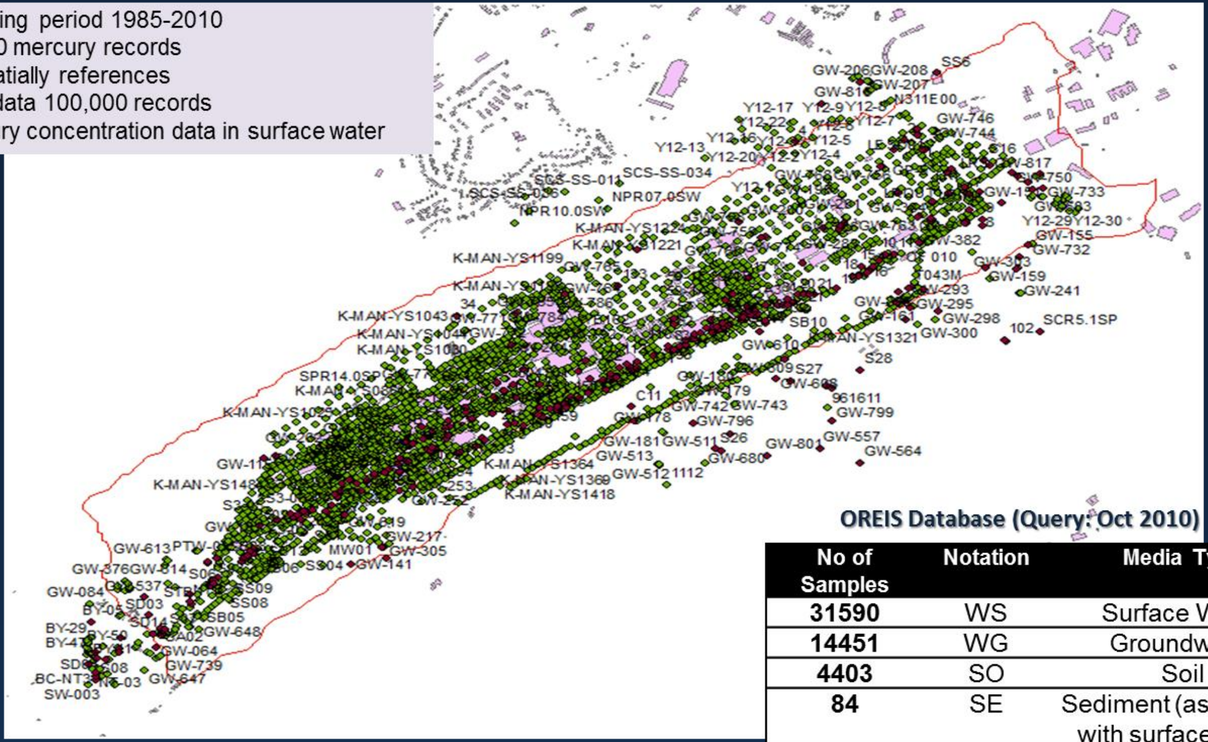
- Sampling period 1985-2010
- 54,000 mercury records
- All spatially references
- Flow data 100,000 records
- Mercury concentration data in surface water



Mercury Concentrations in Soil in the Watershed Model Domain

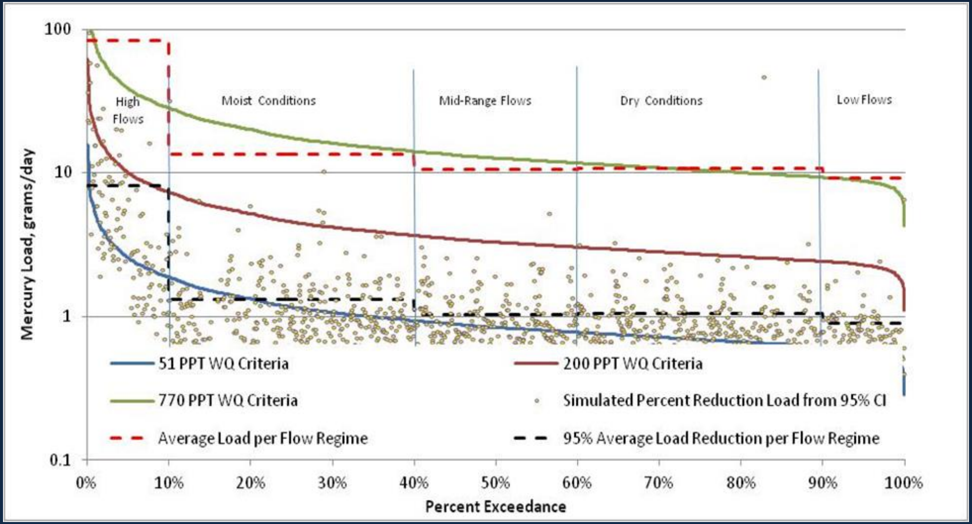
OREIS Database (Query: Oct 2010)

No of Samples	Notation	Media Type
31590	WS	Surface Water
14451	WG	Groundwater
4403	SO	Soil
84	SE	Sediment (associated with surface water)

- Data (up to 2013) for all 57 outfalls along EFPC obtained from OREIS and formatted for input into model and boundary conditions (rainfall, evapotranspiration, timeseries of outfalls, rivers and canals) updated to extend simulations to 2012.

Carryover Work Scope Task 2 Accomplishments

- Comprehensive review of TMDL requirements for EFPC established by EPA & TDEC
  – Target Hg conc. for EFPC = 51 ppt for recreational use (TDEC regulations for surface waters), from which "Loading Capacity" duration curve was developed.
- Several target load-duration curves developed for EFPC
  – Hg target concs. of 51, 200, and 770 ppt applied to each ranked flow to generate flow duration curve.
  – Target load reduction criteria developed using % reduction.



- Model used with newly developed ECOLAB template.
- Incorporates MeHg into kinetic & thermodynamic eqns.

Carryover Work Scope Task 2 Accomplishments

- Report containing:
  - WQ criteria and TMDL target
  - WQ assessment and deviation from TMDL target
  - WQ data analysis and source identification
  - Development of flow and load duration curves
  - Load allocation analysis

Task 3: Description

Task 3: Sustainable Remediation and Optimization: Cost Savings, Footprint Reductions, and Sustainability Benchmarked at EM Sites (Yr 4 Carryover)

- Subtask 3.1: Benchmarking of current methodology using SITEWISE™
- Subtask 3.2: Implementation of a SITEWISE™ module for sustainable analysis and optimization of monitoring programs.
- Subtask 3.3: Calibration and Verification of the SITEWISE™ monitoring program module.

Carryover Work Scope: Task 3

Objectives

Task focused on EM pilot studies and software to:

- Evaluate benefit of sustainable remediation practices.
- Quantify environmental footprint of remedial and other alternatives.
- Develop sustainable optimization module for monitoring program analysis on EM sites.

Benefits

- Building block approach will reduce redundancy in sustainability evaluation and facilitate identification of specific activities with greatest environmental footprint.
- The methodology employed will provide a decision matrix for remedy selection, design, or implementation and allows for a remedy optimization stage as well.

Carryover Work Scope Task 3 Accomplishments

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- Review of geostatistical software including MAROS or GTS.
  - Software used to downsize a compliance monitoring program (i.e., remove wells, analytes, or frequencies).
- Tests conducted with SITEWISE™ monitoring module and results used to calculate the following using MS Excel:
  - Reduction in emissions
  - Energy and water usage
  - Waste generation
  - Accident risk over the program total life cycle
- Initial simulations conducted, data gaps identified.

SITEWISE site info sheet.

Carryover Work Scope Task 3 Accomplishments

- Review to determine factors which may significantly impact the GSR metrics, including:
  - Excessive number of monitoring locations
  - Inefficient chemical injection strategy
  - Excess quantity of chemicals used
  - Inefficient power usage by over-sized equipment
  - Installing less energy efficient equipment
  - Unnecessary continuously running equipment
  - Unnecessary unit operations
- Development of optimization strategies for integrated surface and GW models capable of predicting contaminant F & T within site domain to achieve the following:
  - Reduction of the number of monitoring locations
  - Improvement of the chemical injection strategy
  - Reduction of the quantity of chemicals used

Task 4: Description

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(Carryover) Task 4: Geodatabase Development for Hydrological Modeling Support

- Subtask 4.1: Update of existing EFPC geodatabase.
- Subtask 4.2: Development of customized Python scripts to enhance database querying capabilities.
- Subtask 4.3: Use the existing geodatabase structure developed for the EFPC modeling work at OR to create similar databases.

Carryover Work Scope: Task 4

Objectives

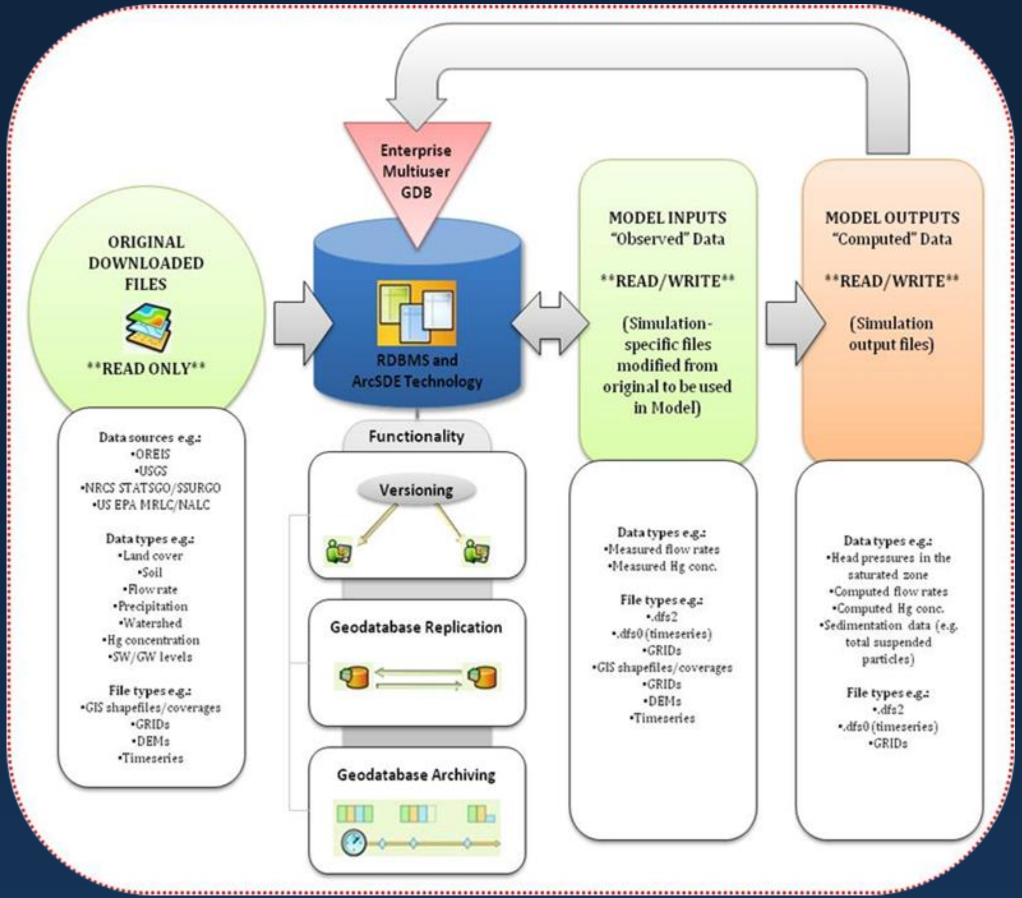
- Development of an ArcSDE Geodatabase.
- Pre- and post-processing of hydrological model data using ArcMap and ArcToolbox.
- Use of ArcGIS ModelBuilder & Python scripting to:
  - Automate repetitive geoprocessing tasks.
  - Perform statistical calculations.
  - Generate maps and reports.
- Use of ArcGIS Geodatabase Diagrammer to create, edit or analyze geodatabase schema.

Benefits

- Centralized data management for storage, concurrent editing and import/export of model-specific data.
- Pre-processing and integration of data derived from multiple sources into a single manageable system.
- Automation and simplified retrieval of stored GIS and timeseries data resulting in faster and more complex analyses of field test data. Toolbox created is a scalable and reusable application that can be implemented at other DOE sites.
- Visualization of model-derived research results via maps, graphs and reports.
- Database structure enables linkage with scalable hydrologic modeling applications.
- XML-based GIS data exchange system facilitates import/export of preconfigured data as XML files which can contain both the data definition and the data itself.

Carryover Work Scope Task 4 Accomplishments

Development of enterprise geodatabase to store, process and manage hydrological modeling data derived from FIU's work at ORR.



ORR Geodatabase Architecture

Carryover Work Scope Task 4 Accomplishments

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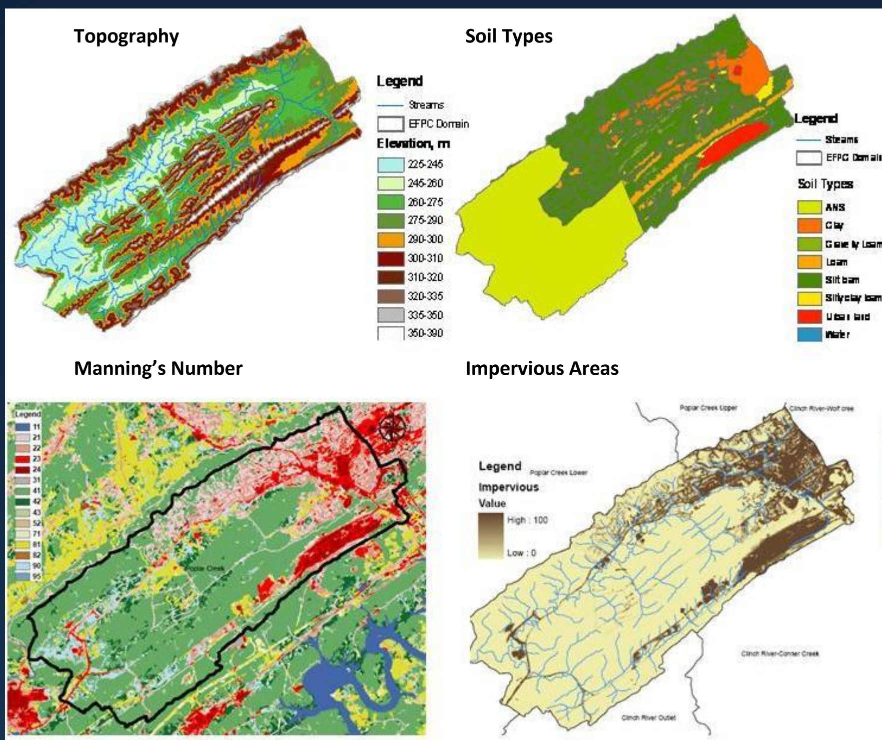
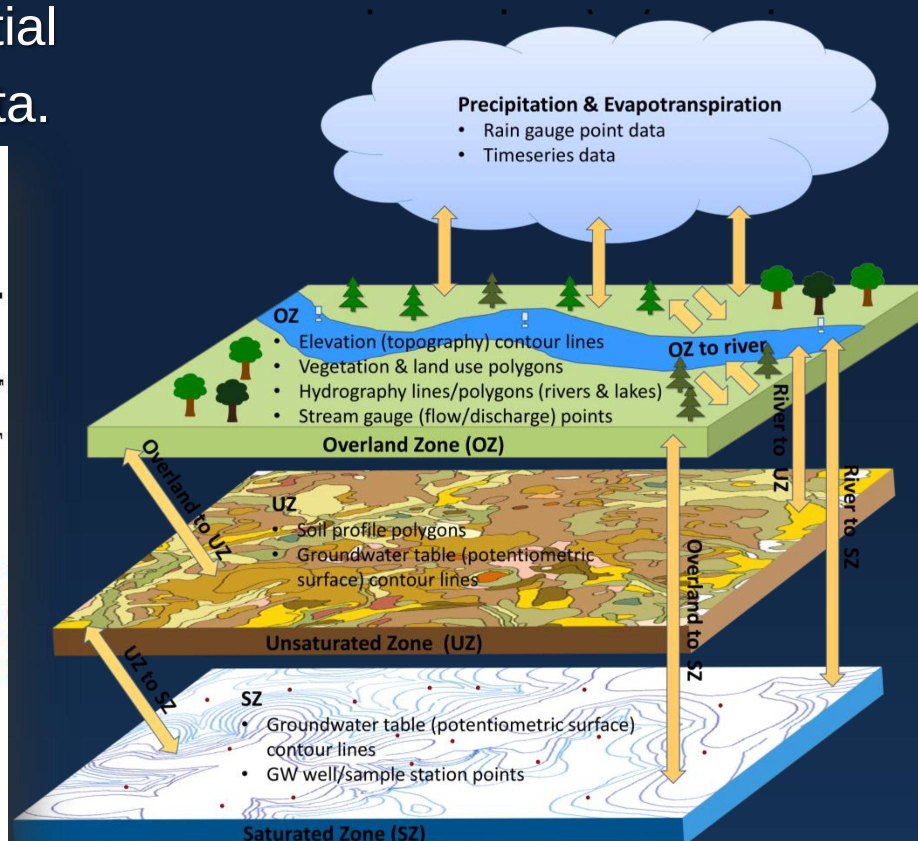
Pre- and post-processing of spatial and temporal hydrological model data.



GIS-based Model Grid Files



MIKE SHE Model Spatiotemporal (GIS) Data Inputs

Carryover Work Scope Task 4 Accomplishments

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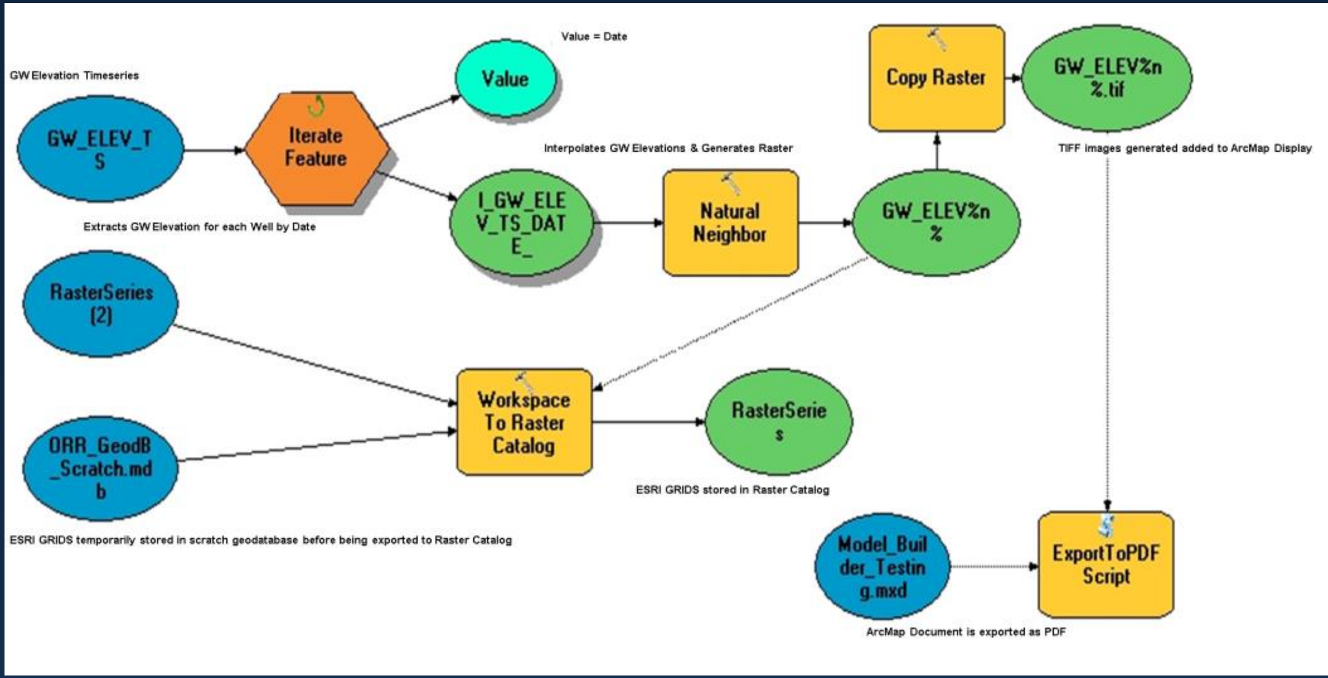

ArcGIS ModelBuilder Process Workflow Diagram

Development of process flow models & customized Python scripts to automate repetitive querying and geoprocessing of data, generation of maps and reports, and statistical analyses.

Project-Wide Major Accomplishments

FIU Year 5 Work Scope

Milestone No.	Milestone Description	Status
2014-P3-M1	Completion of work plan for experimental column studies (Subtask 1.1)	Completed 9/30/14
2014-P3-M2	Completion of literature review (Subtask 2.2)	Completed 03/31/15
2014-P3-M3	Development of preliminary site conceptual model of Tims Branch (Subtask 2.2)	Completed 03/31/15
2014-P3-M4	Completion of Baseline Analysis (Subtask 3.1)	Completed 2/27/15
2014-P3-M5	SRS site visit and meeting	FIU visited SRS 8/5/14
2014-P3-M6	Meeting and presentation of project progress at SRS	Due 3/18/15, Planned 4/13/15

Project-Wide Major Accomplishments

FIU Year 5 Work Scope

No.	Client Deliverables	Status
1	Draft Project Technical Plan	Submitted 6/18/14
2	Work plan for experimental column studies (Subtask 1.1)	Submitted 9/30/14
3	Literature review summary (Subtask 2.2)	Submitted 3/31/15
4	Baseline analysis summary (Subtask 3.1)	Submitted 2/27/15
5	Two (2) abstract submissions to WM 2015 Symposium	Submitted 8/15/14
6	Presentation overview to DOE HQ/SRNL of the project progress and accomplishments (Mid-Year Review)	3/31/15

Task 1: Description

New Task 1: Modeling of the migration and distribution of natural organic matter injected into subsurface systems

- Batch & column expts. to determine transport parameters for modeling migration/distribution of humic acid (HA) injected into subsurface.
- Modeling coupled to column studies to address complexities not currently addressed in available models (i.e., spatial and temporal changes in pH and organic properties).
  - Subtask 1.1: Work plan for experimental column studies.
  - Subtask 1.2: Column testing of migration/distribution of HA injected into subsurface systems.
  - Subtask 1.3: Development of subsurface flow, fate and transport model of HA.

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Task 1: Description

Background:

- SRS – a major DOE facility for plutonium production during Cold War
- F-Area seepage basins received ~1.8 billion gal. low-level waste
  - Nitric acid, various radionuclides and dissolved metals
- U(VI) and other radionuclides above MCLs
- Humic substances (HS)
  - Account for 50-80% of organic carbon in soil/sediment
  - Excellent binding capacity for metals makes HS strong candidate for remediation efforts to reduce U(VI) mobility in the subsurface

Huma-K

Task 1: Description

Objectives:

- Assemble, integrate and develop a practical and implementable approach to quantify and model potential natural organic matter
- Understand sorption behavior of HA at varied pH
  - Analyze the mobility of HA injections
  - Predict migration and distribution of humate injected into subsurface systems during deployment for in situ treatment

Project 3 - Task 1 Accomplishments

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Completed Subtask 1.1: Work plan for experimental column studies.

Stage 1

- Estimation of flow rates and concentration of humic acid
- Soil Characterization

Stage 2

- Bromide Tracer Test
- Preconditioning of columns w/ pH 3.5, 5, 6 and 7 solutions
- Sorption with Huma-K injection at pH 9
- Desorption with pH 3.5, 5, 6 and 7 solutions

Project 3 - Task 1 Accomplishments

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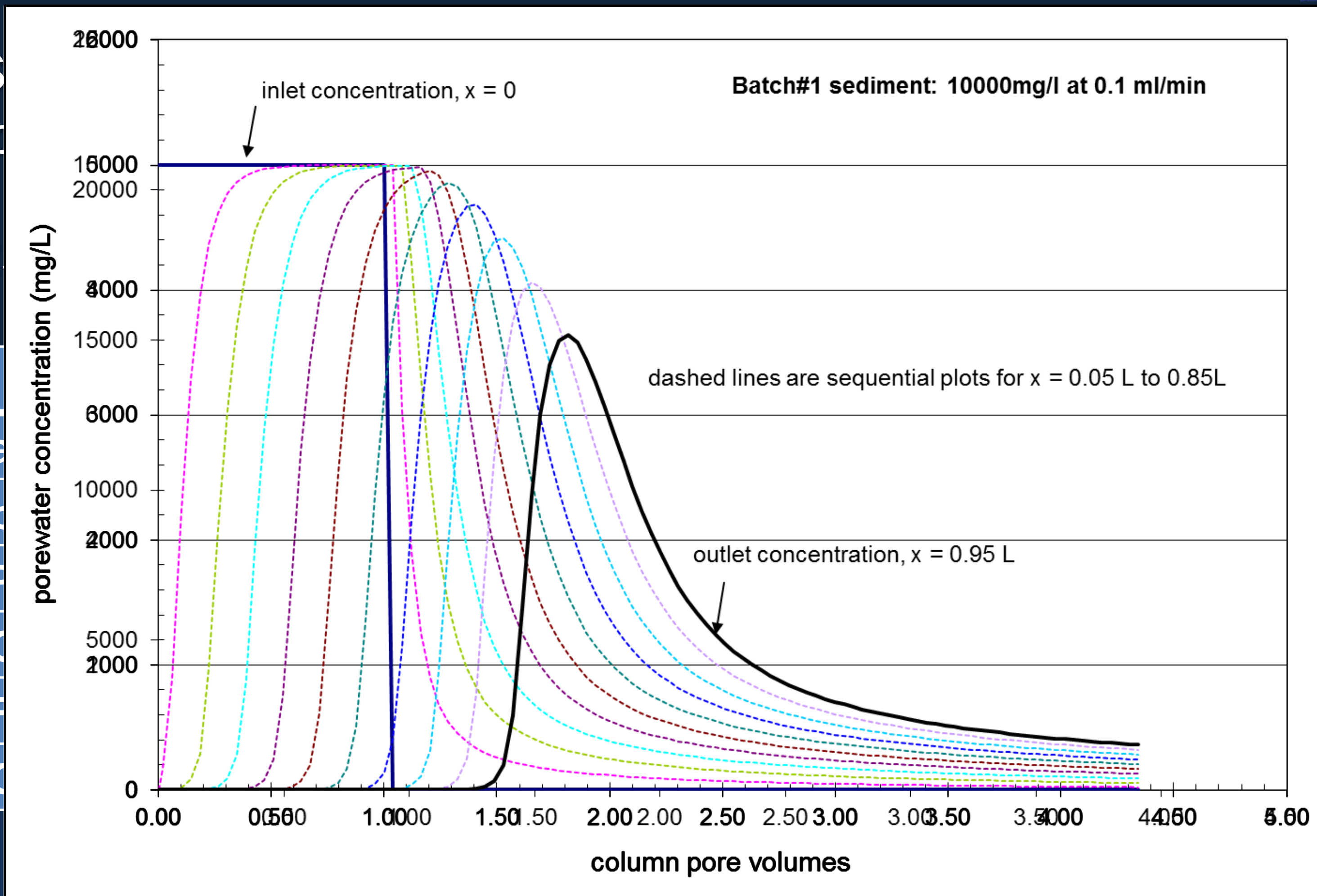
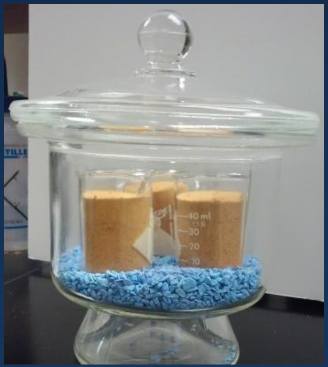


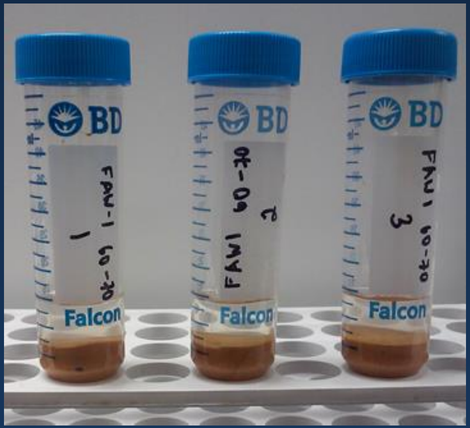
Assumed based on literature

Project 3 - Task 1 Accomplishments

Stage 1: Soil Characterization

- Characterized FAW-1: 60’-70’ SRS soil to obtain bulk density, particle density, porosity and pH
  - Bulk density = 1.33 g/cm³
  - Particle density = 2.65 g/cm³
  - Porosity = 0.50
  - pH = 4.06





Project 3 - Task 1 Accomplishments

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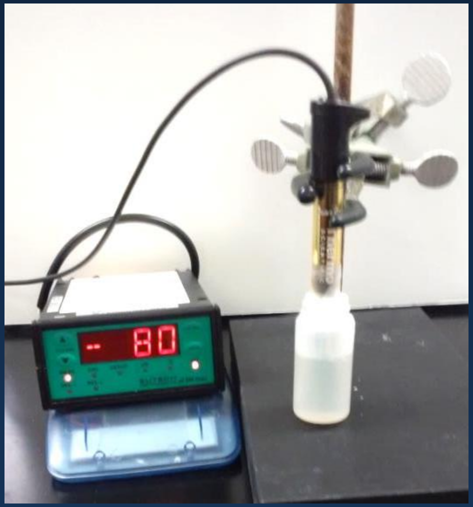
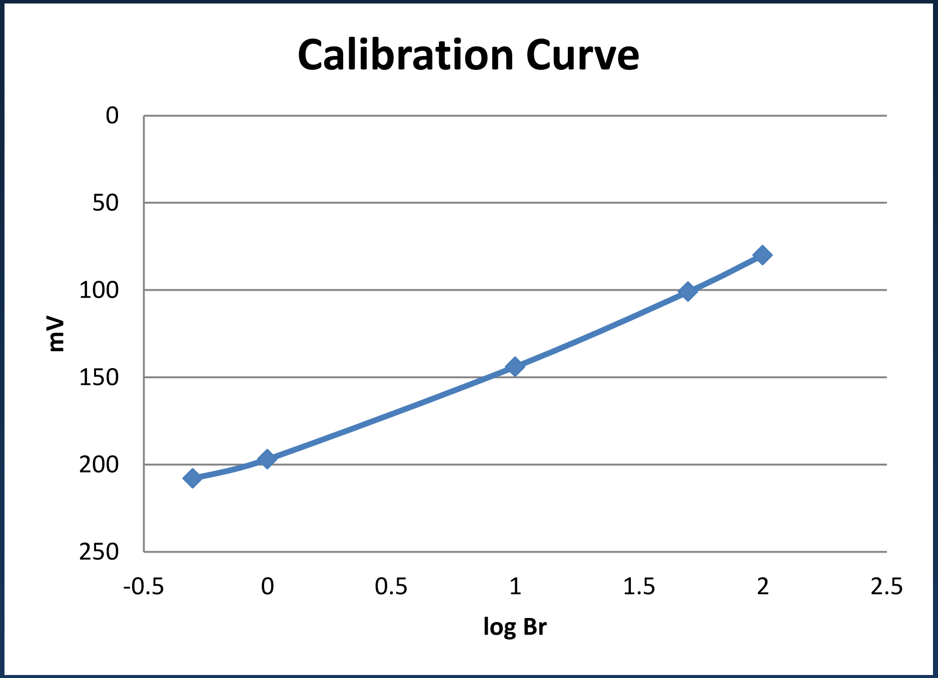
Stage 2: Bromide Tracer Test (Calibration of Bromide Electrode)

- A set of calibration standards in the range of 0.5 to 100 ppm were prepared using DI water and bromide in 20 mL bottles
- Ensures reliability of readings for bromide tracer tests





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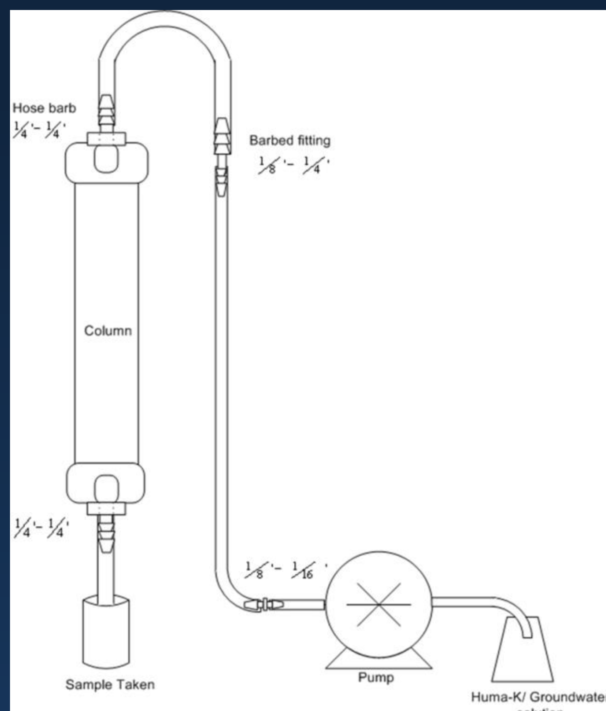
Project 3 - Task 1 Accomplishments

Stage 2: Designed column set-up/configuration to run humate injection experiments

- Identified tubing and adapters for pump to achieve required flow rates



Project 3 - Task 1 Accomplishments

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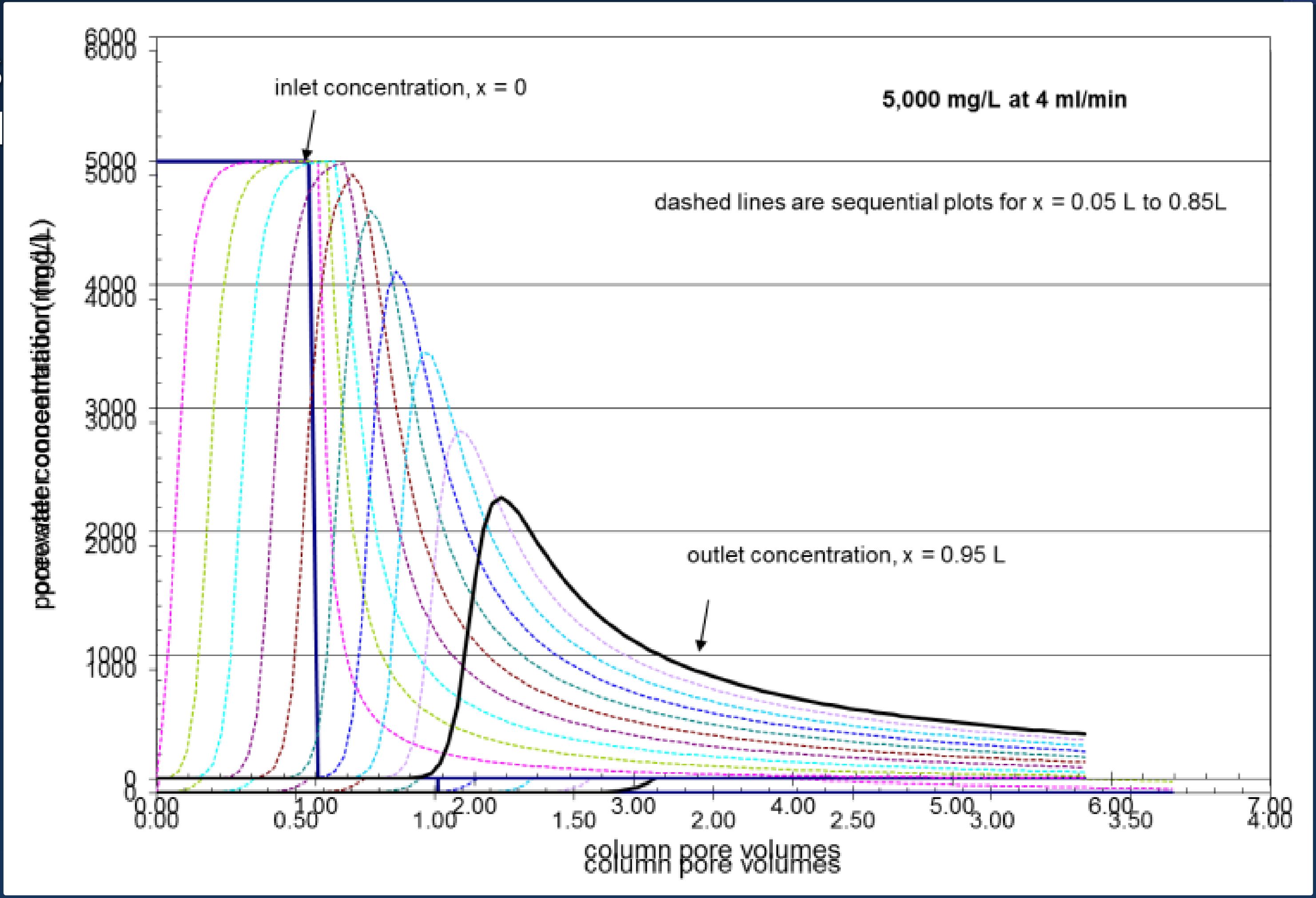


Task 1: Future Work – FY14 (Year 5)

- Complete Subtask 1.2: Column testing of migration/distribution of HA injected into subsurface systems.
  - Finish column experiments to determine sorption and desorption properties
  - Determine HA concentration using UV-Vis, iron and silica concentration using ICP-OES
  - Determine transport parameters for modeling migration and distribution of HA injected into subsurface
- Complete Subtask 1.3: Development of subsurface flow, fate and transport model of HA.

CLIENT DELIVERABLES	DUE DATE
Technical Report for Task 1: Modeling of the migration and distribution of natural organic matter injected into subsurface systems	6/3/15

Task 2: Description

[New] Task 2: Surface Water Modeling of Tims Branch

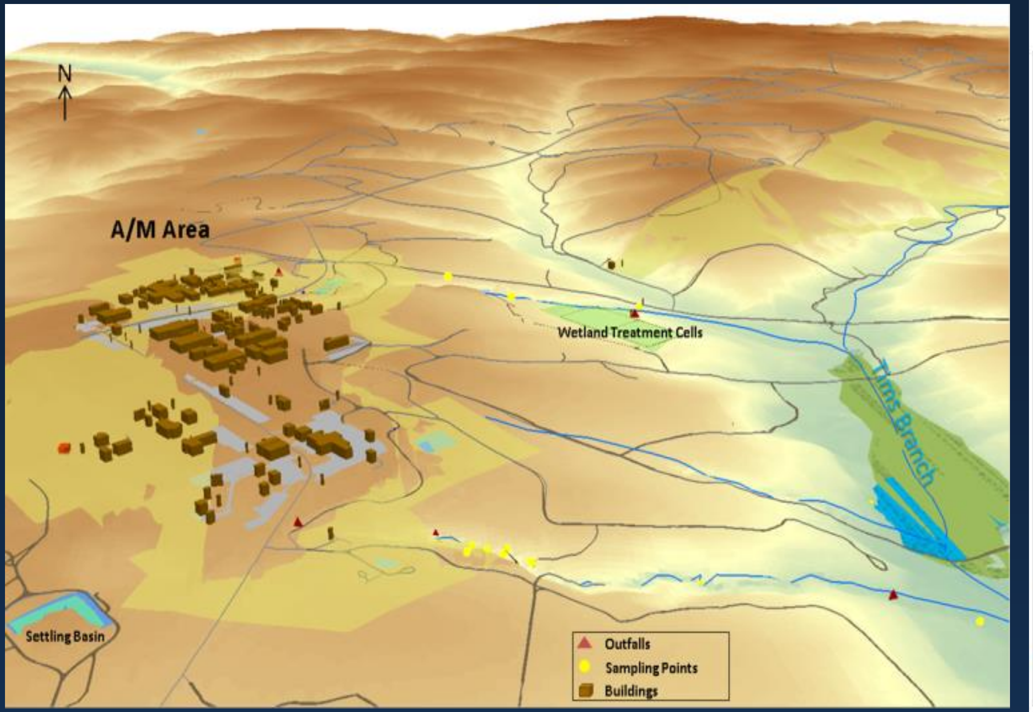
- Tims Branch impacted by 60 yrs of anthropogenic events associated with discharges from process and laboratory facilities.
- Application of GIS & stream/ecosystem modeling tools to examine response of Tims Branch to historical discharges and Environmental Management remediation actions.
- Hydrological modeling of Tims Branch (water, sediment, Hg & Sn)
  - Subtask 2.1: Development of a detailed GIS-based representation of the Tims Branch ecosystem.
  - Subtask 2.2: Modeling of surface water and sediment transport in the Tims Branch system.

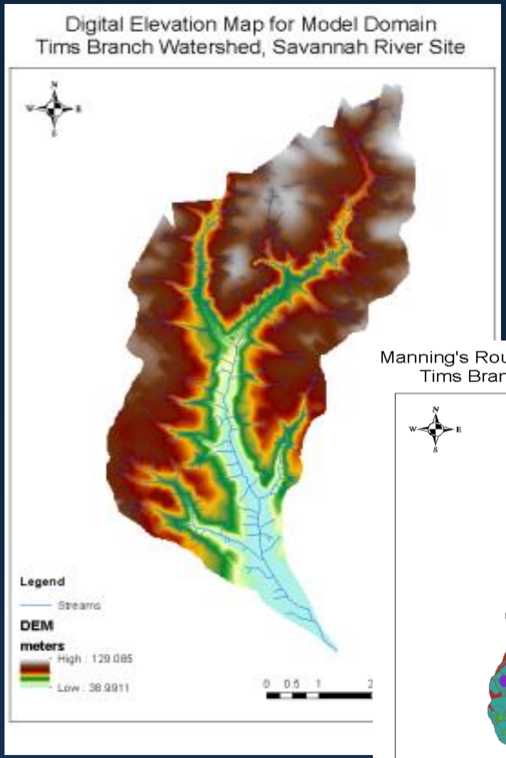
Project 3 - Task 2 Accomplishments

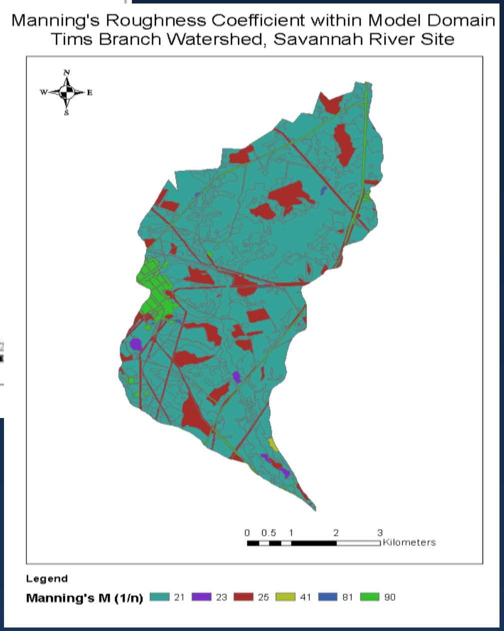
Subtask 2.1: Development of a detailed GIS-based representation of the Tims Branch ecosystem.

- Developed process flow models using ArcGIS ModelBuilder to:
  - Clip GIS data provided by SRNL to model domain.
  - Project data into same coordinate system.
- Developed 2D & 3D GIS-based representations of SRS A/M Area:
  - Tims Branch, major tributaries, water bodies, watershed boundary, SRS boundary, outfalls, sampling/monitoring points, control structures, buildings, roads, topography DEM, elevation contours, soils, etc.
- Developed grid files for MIKE SHE model input from existing GIS data and literature review data:
  - Manning's Roughness coefficient, paved runoff coefficient, infiltration, etc.

Project 3 - Task 2 Accomplishments







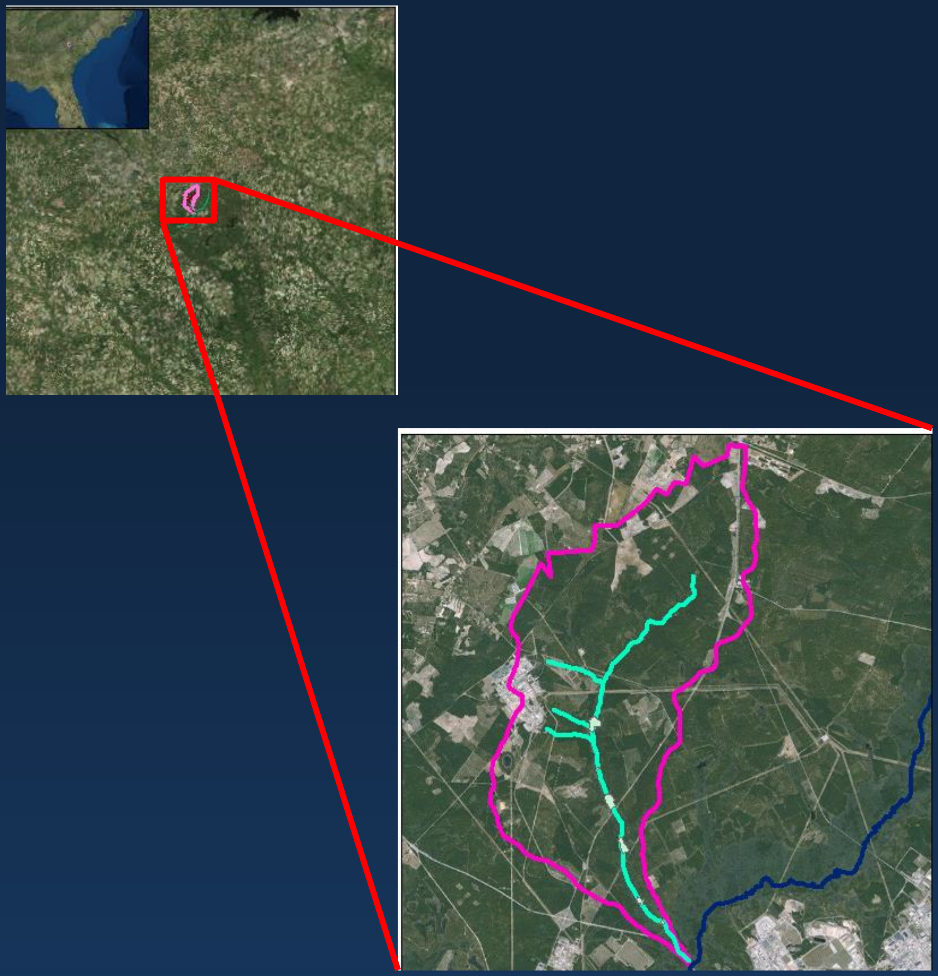
3D Map of SRS A/M Area and Tims Branch (left), Digital elevation model (center) and Manning's roughness coefficient (right) grid files used in MIKE SHE model.

Project 3 - Task 2 Accomplishments

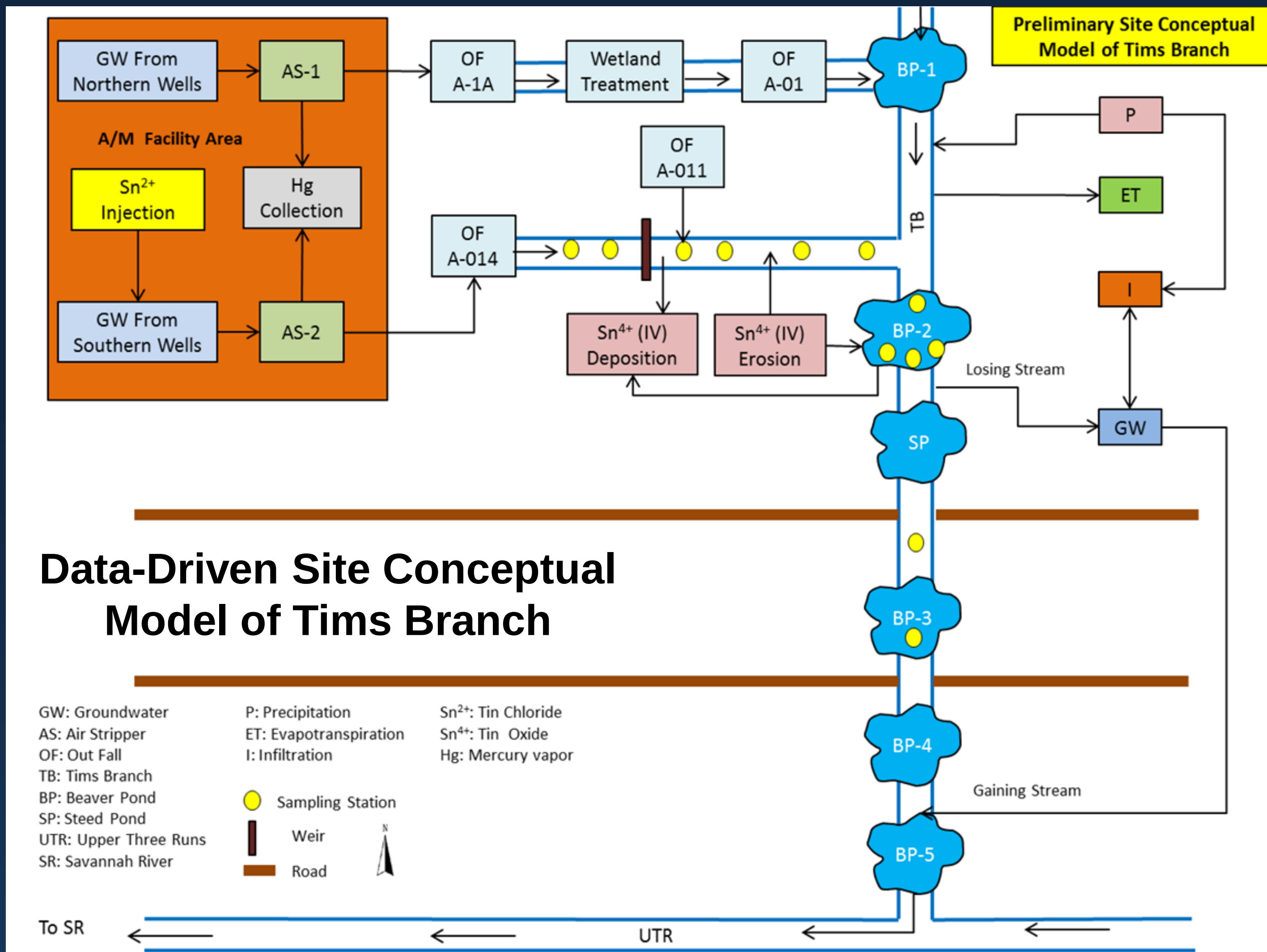
- Subtask 2.2: Modeling of surface water and sediment transport in the Tims Branch system.
  - Completed Literature Review and submitted Summary Report 3/31/15.
    - Reviewed SRS-DOE reports and published journals provided by SRS.
    - More than 30 reports and 100 journal articles reviewed.
    - Total of 10 specific reports found significant were included in the literature review summary report.
    - Specific reports by Brian Looney (2010, 2012) and Betancourt (2011) were among the most addressed in the literature review.
    - Total of 40 journal articles were found relevant to the study.
    - Additional literature review was performed to explicitly address previous hydrological modeling efforts conducted for Tims Branch. Very few studies were conducted in hydrological model development.

Project 3 - Task 2 Accomplishments

- Developed data-driven conceptual model of Tims Branch.
- Developed a process-based conceptual model.
- Conducted preliminary data review and collection for model setup using MIKE SHE.
- Began preliminary development of a 1-D stream/river hydrology model using MIKE 11.
- Finishing the literature review for the hydrological modeling and experimental work.

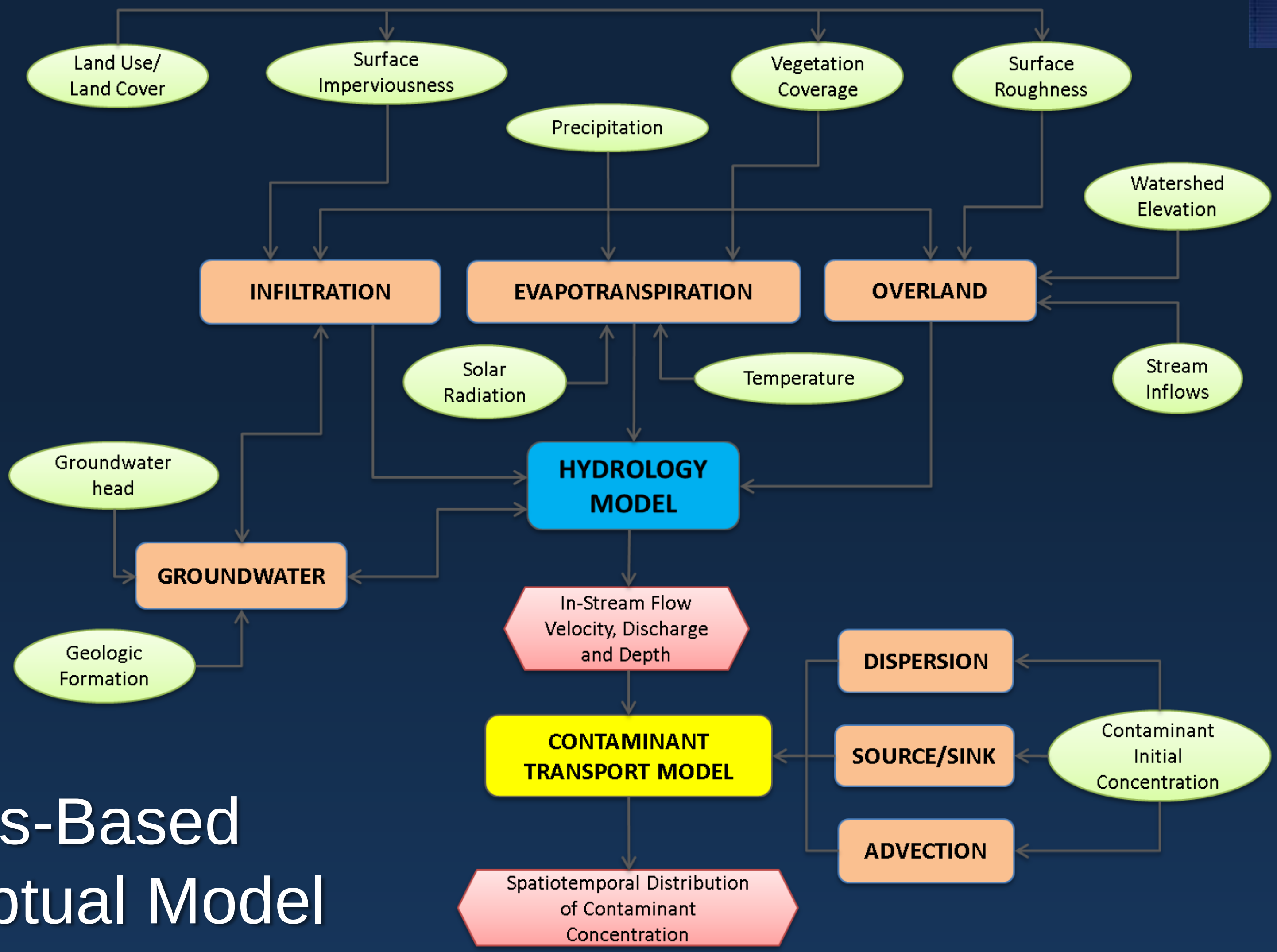


Project 3 - Task 2 Accomplishments



Project 3 - Task 2 Accomplishments

FIU Applied Research Center



Process-Based Conceptual Model

Task 2: Future Work – FY14 (Year 5)

- Complete Subtask 2.1: Development of detailed GIS-based representation of Tims Branch ecosystem.
- Complete Subtask 2.2: Modeling of surface water and sediment transport in the Tims Branch system.

CLIENT DELIVERABLES	DUE DATE
Technical Report for Task 2: Surface Water Modeling of Tims Branch	6/10/15

Task 3: Description

[New] Task 3: Sustainability Plan for the A/M Area Groundwater Remediation System

- Supports EM-13 in developing proposed actions for the A/M Area groundwater remediation system infrastructure that will reduce the system's environmental burden.
- Applies analysis and state-of-the-art modeling tools to enable DOE-EM to incorporate sustainability metrics in environmental management decisions.
- Applies to subsurface/surface contamination and supplements traditional risk paradigms to help develop interim and final remediation end-states.
  - Subtask 3.1: Analyze Baseline.
  - Subtask 3.2: Energy Efficiency.
  - Subtask 3.3: Mechanical Design and Operations Modifications for Sustainable Remediation (while controlling contaminant migration)

Task 3: Background

- SRS produced materials for production of nuclear weapons from 1950s-1980s.
- Trichloroethylene (TCE) and tetrachloroethylene (PCE) were main solvents used in degreasing and other industrial operations: Categorized as dense non-aqueous phase liquids (DNAPLs), semi-volatile, and hazardous chemicals.
- 1,600 metric tons of TCE, PCE and 1,1,1-trichloroethane were released into the environment at multiple locations.

SRS A/M Area

- Located in northern part of SRS within lower reaches of Tims Branch watershed (topographic elevation from ~420 ft to ~118 ft).
- Consists of facilities that fabricated reactor fuel and target assemblies (M-Area), and administrative and support facilities (A-Area).

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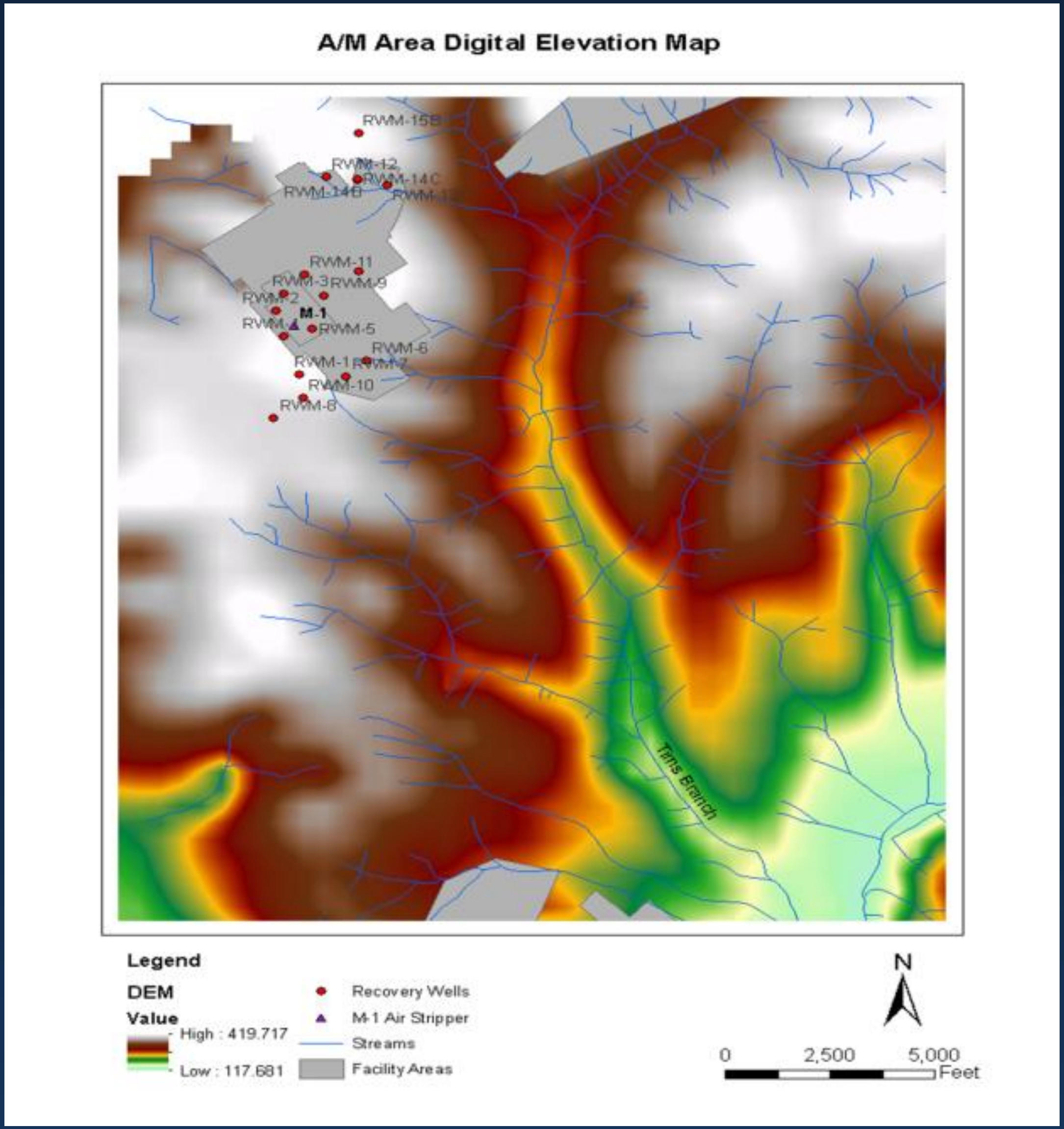


Task 3: Background

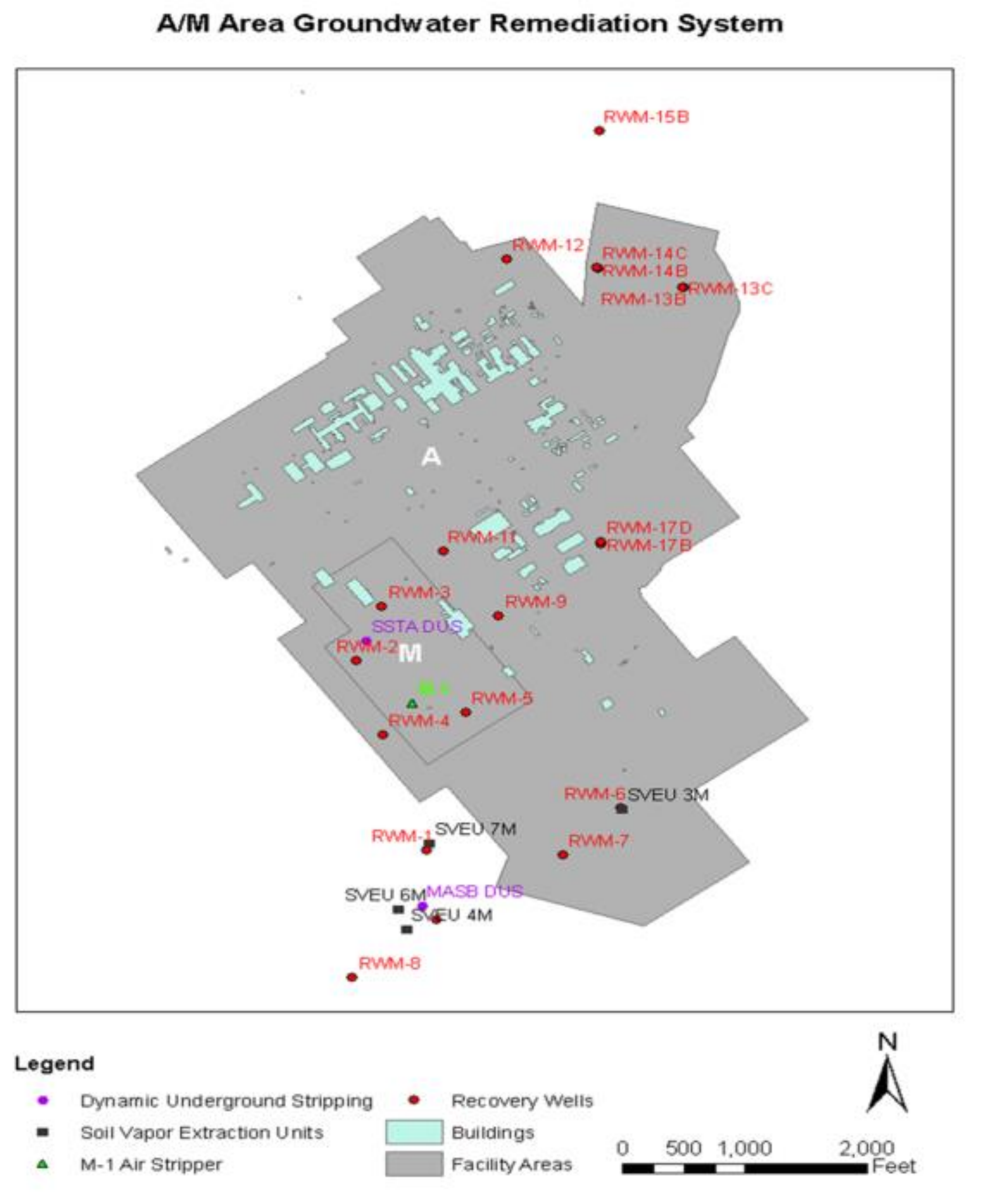
FIU Applied Research Center

M-1 Air Stripper Performance

- M-1 air stripper and well network operating continuously since 1985 at average electrical load of 150 kW and flow rate of 420 gpm.
- Influent TCE concentration to the air stripper decreased greatly from 25,200 ug/L in 1986 to 2,230 ug/L by end of 2012, with same energy consumption and water pumping rate.

M-1 Air Stripper and Recovery Well Network

- Installed in 1985 to treat groundwater to reduce chlorinated solvent concentrations.
- 17 recovery wells installed over the years. Currently recovery wells 1-12 feed the M1 air stripper.
- Treated groundwater is discharged to a stream in Tims Branch.


A/M Area Groundwater Remediation System
RWM-15B
RWM-12
RWM-14C
RWM-14B
RWM-13C
RWM-13B
A
RWM-11
RWM-17D
RWM-17B
RWM-3
RWM-9
SSTA DUS
RWM-2
M
RWM-5
RWM-4
RWM-6
SVEU 3M
RWM-1
SVEU 7M
RWM-7
SVEU 6M
MASB DUS
SVEU 4M
RWM-8
Legend
Dynamic Underground Stripping
Soil Vapor Extraction Units
M-1 Air Stripper
Recovery Wells
Buildings
Facility Areas
N
0 500 1,000 2,000
Feet

Task 3: Results

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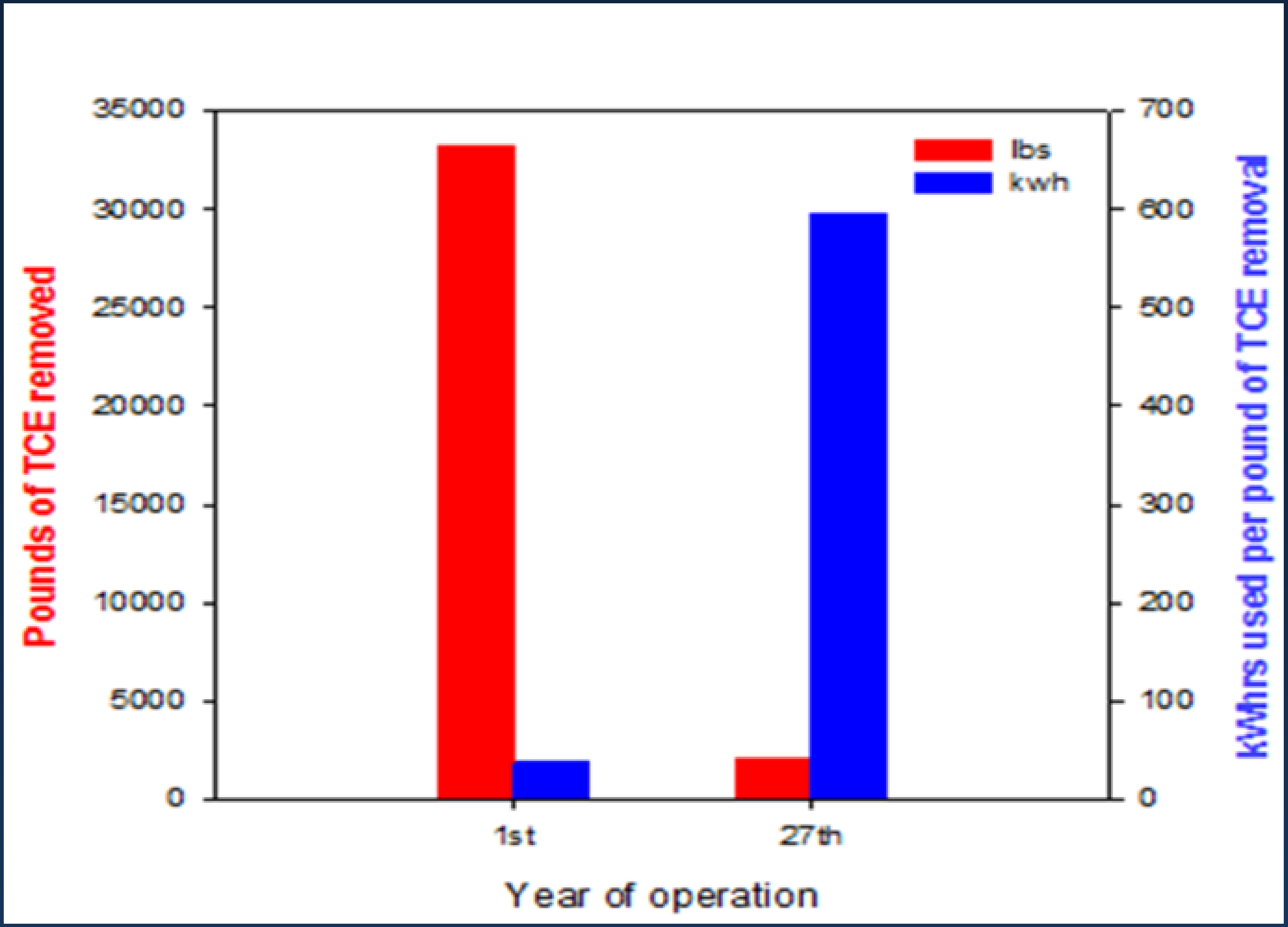
TCE Recovery 1^{st} & 27^{th} Years of Operation



Task 3: Results

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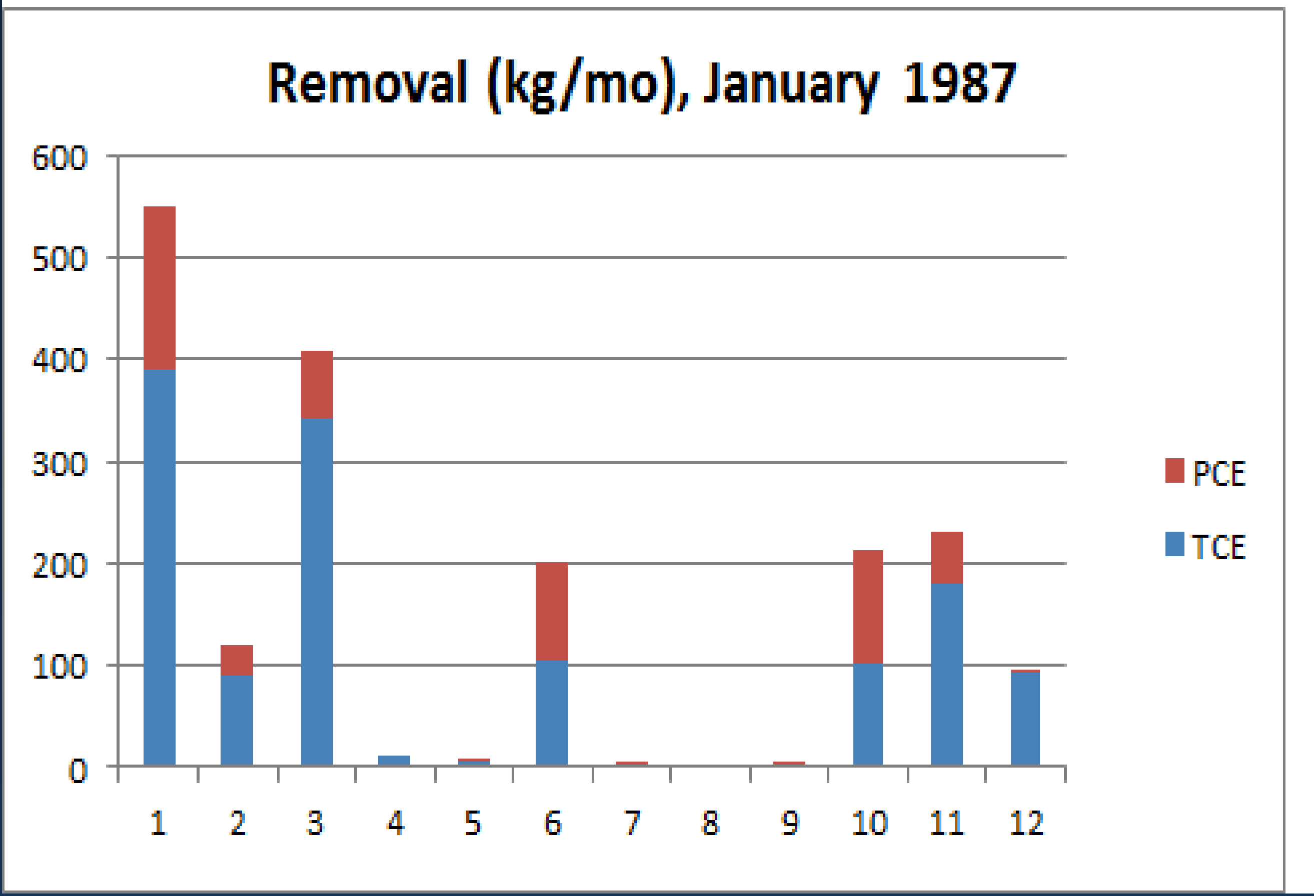
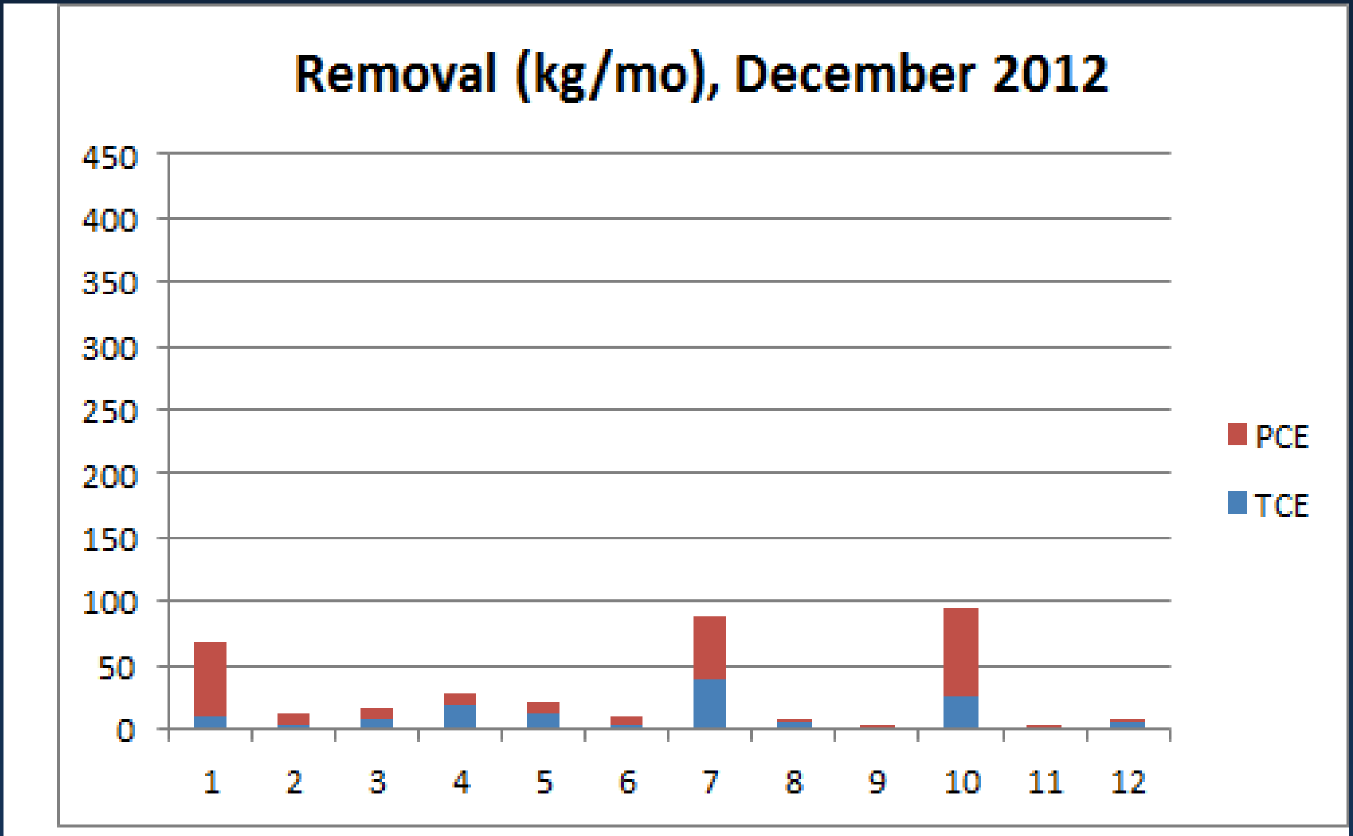
TCE & PCE Removal January 1987

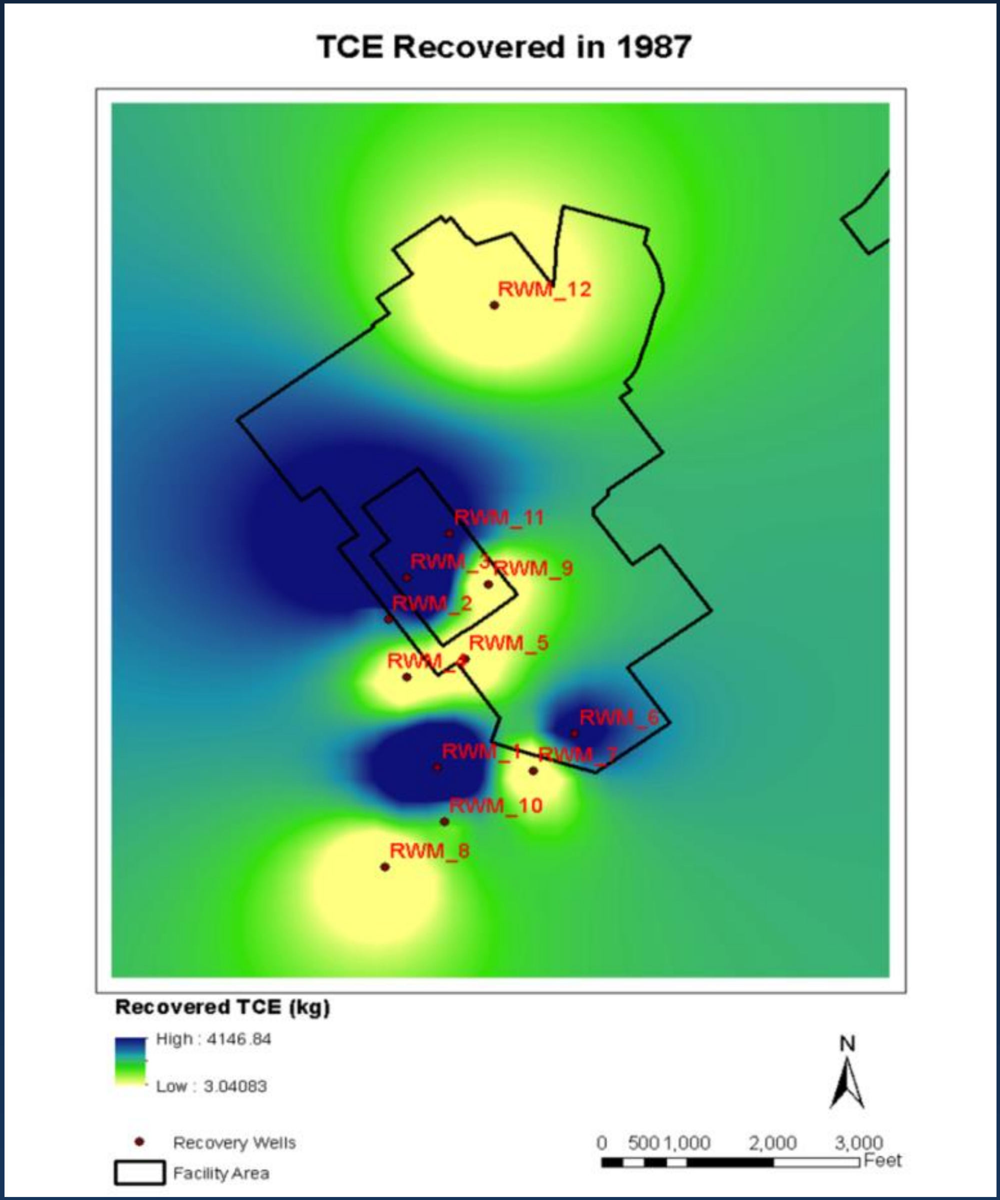


Task 3: Results

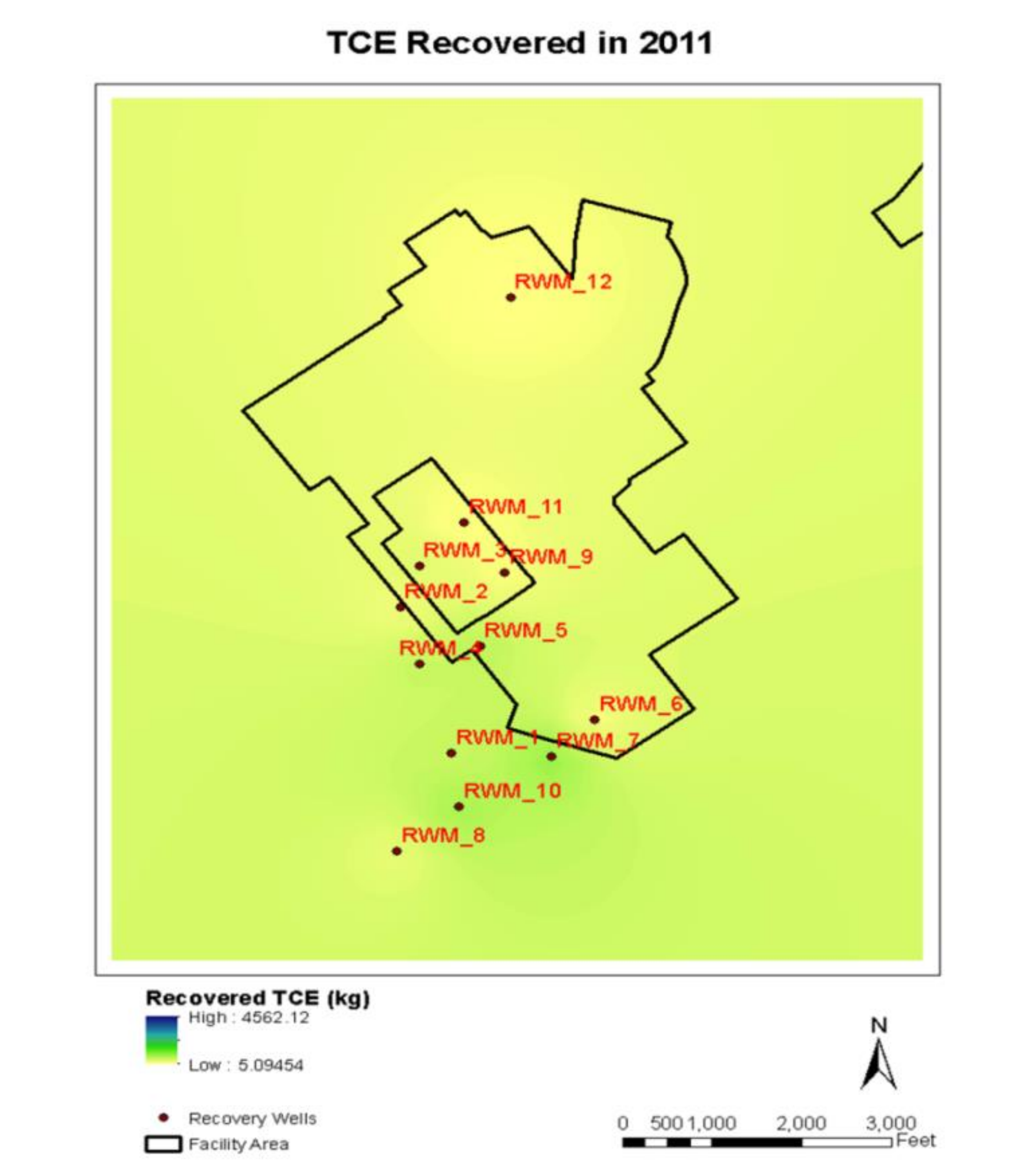
FIU Applied Research Center

TCE & PCE Removal December 2012





TCE Recovery in 1987



TCE Recovery in 2011

Task 3: Results

Collection of per Well Data

- Major effort in 2014 was identification of missing data per well on TCE & PCE recovery.
- Site had detailed info on water going to stripper from all wells combined.
- Site had a detailed database with 90% of the per well data.
- Site supplied dozens of reports from which FIU located most of the missing per well data to allow for per well analyses.

Results per Well

- Monthly removal rate and cumulative mass removed for TCE and PCE in the 12 recovery wells were analyzed for 1987-2012.
- 7 of 12 recovery wells have transitioned to more PCE than TCE removed. This is an expected result since TCE was initially used and then replaced by PCE.
- Rate of recovery in some wells affected by Dynamic Underground Stripping (DUS) process.
- 7 wells exhibit exponential decay in contaminant removal, 5 exhibit steady concentrations, and 2 exhibit linear decreases.

Task 3: Results

FIU Applied Research Center

DUS still affecting remediation today

- Dynamic Underground Stripping (DUS) process injected steam into the ground and enhanced recovery of VOCs that is ongoing today.
- Steam injection occurred August 2005 – 2009.
- Steam was applied to the deep vadose zone first, then to the aquifer zone, and then to the mid-vadose zone.
- Soil vapor extraction is ongoing, residual temperatures in the deep low permeability zones still exceeding 65.6°C (150°F).
- To date >204 metric tons (450,000 lb) of VOCs removed.

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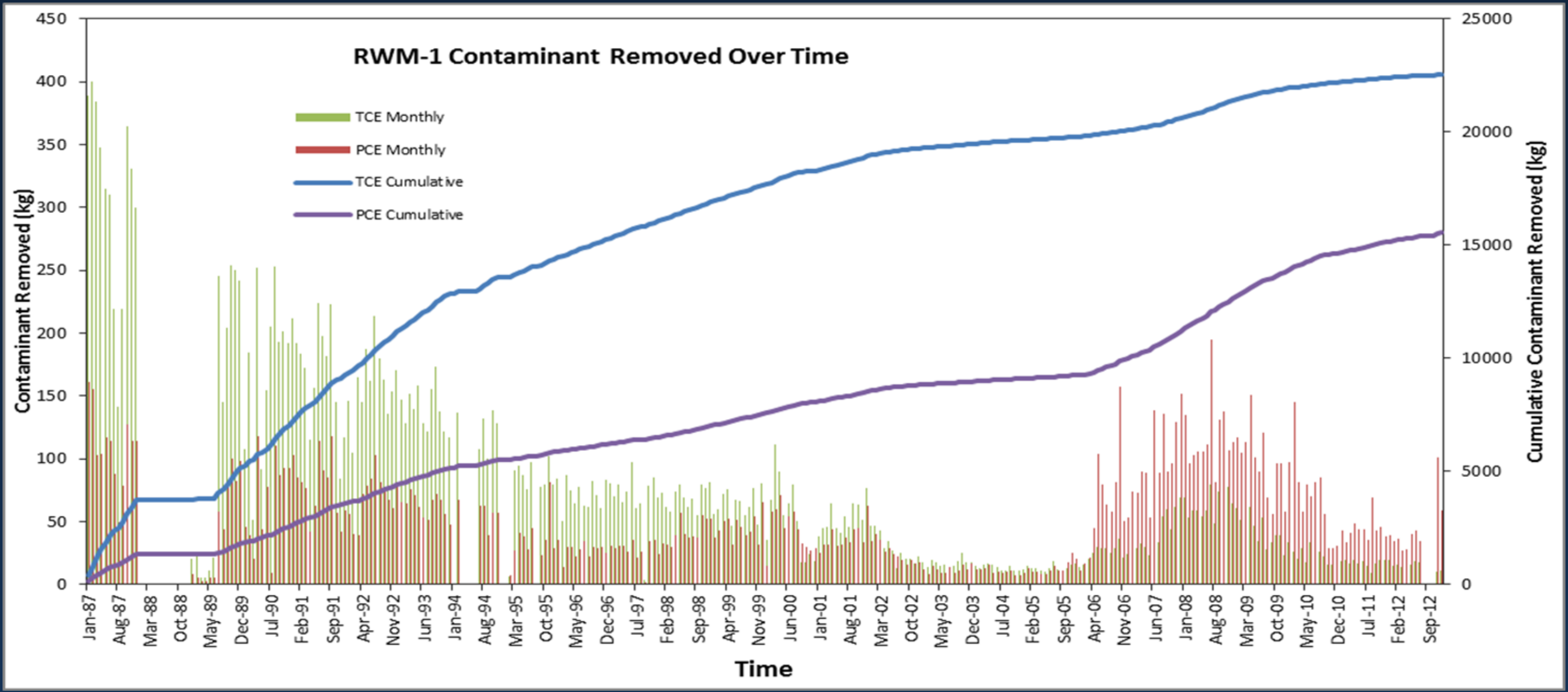
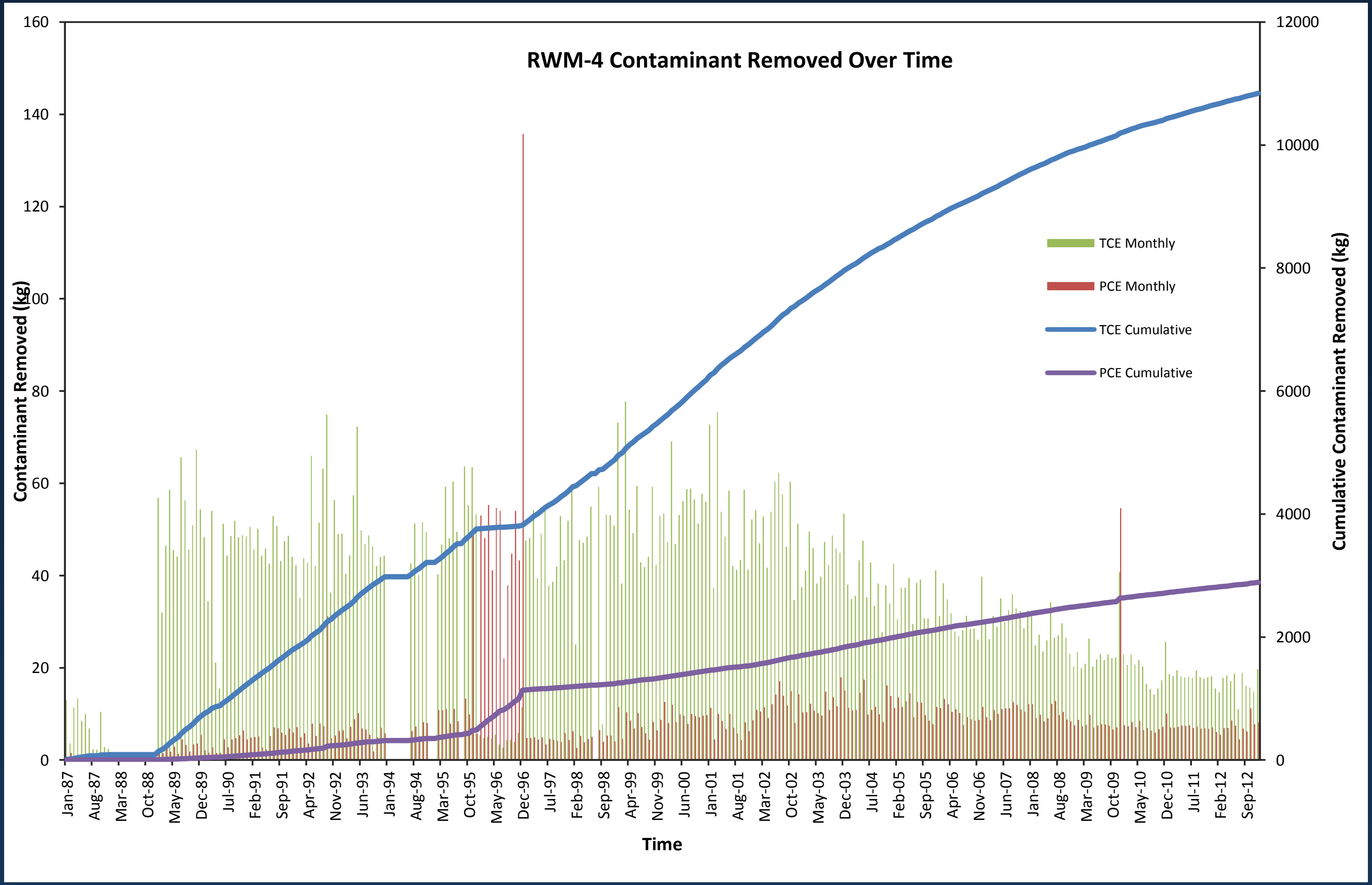
Task 3: Results

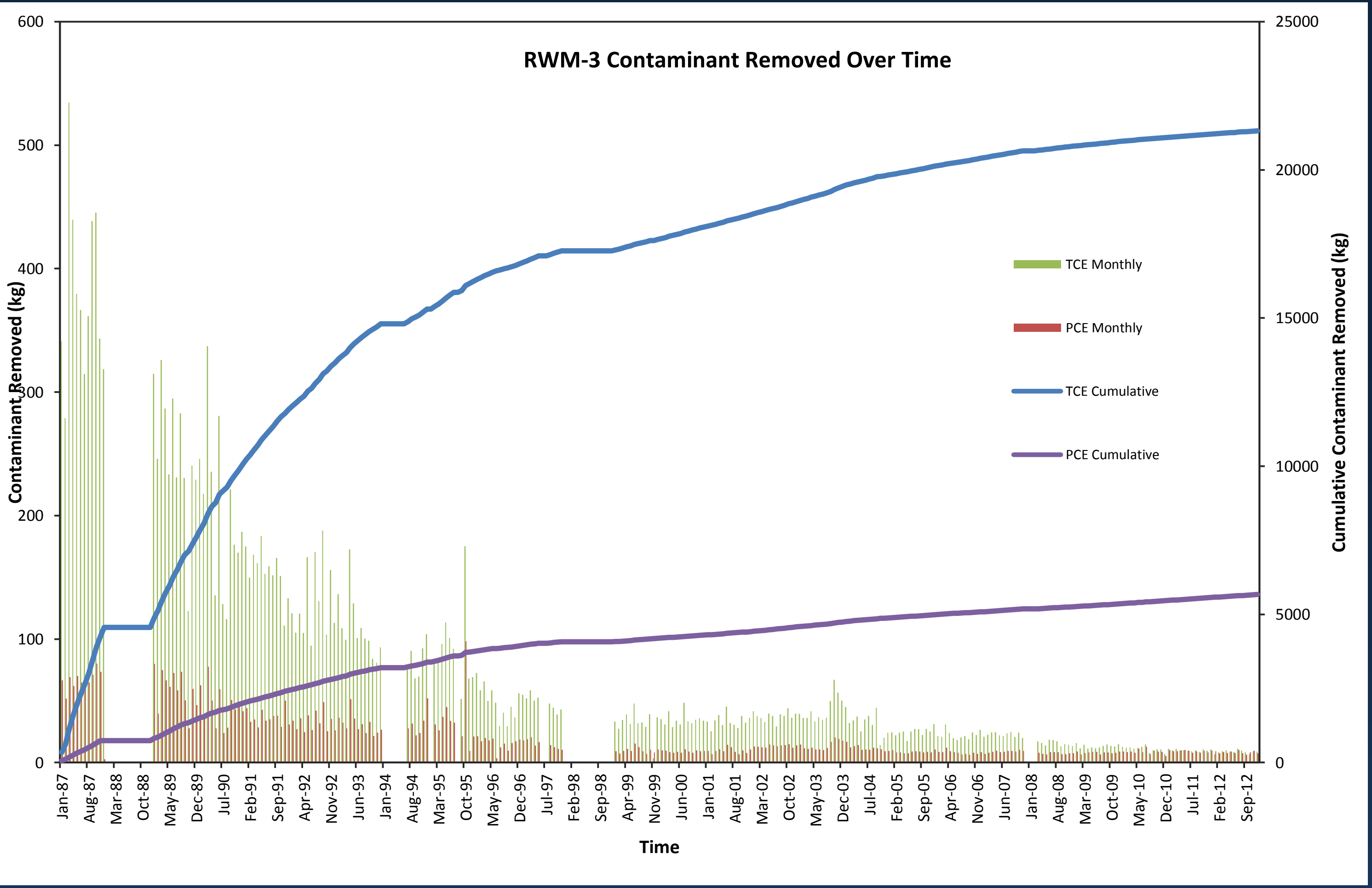


Task 3: Results



Florida International University

Task 3: Results



Task 3: Results

Source: SRNL

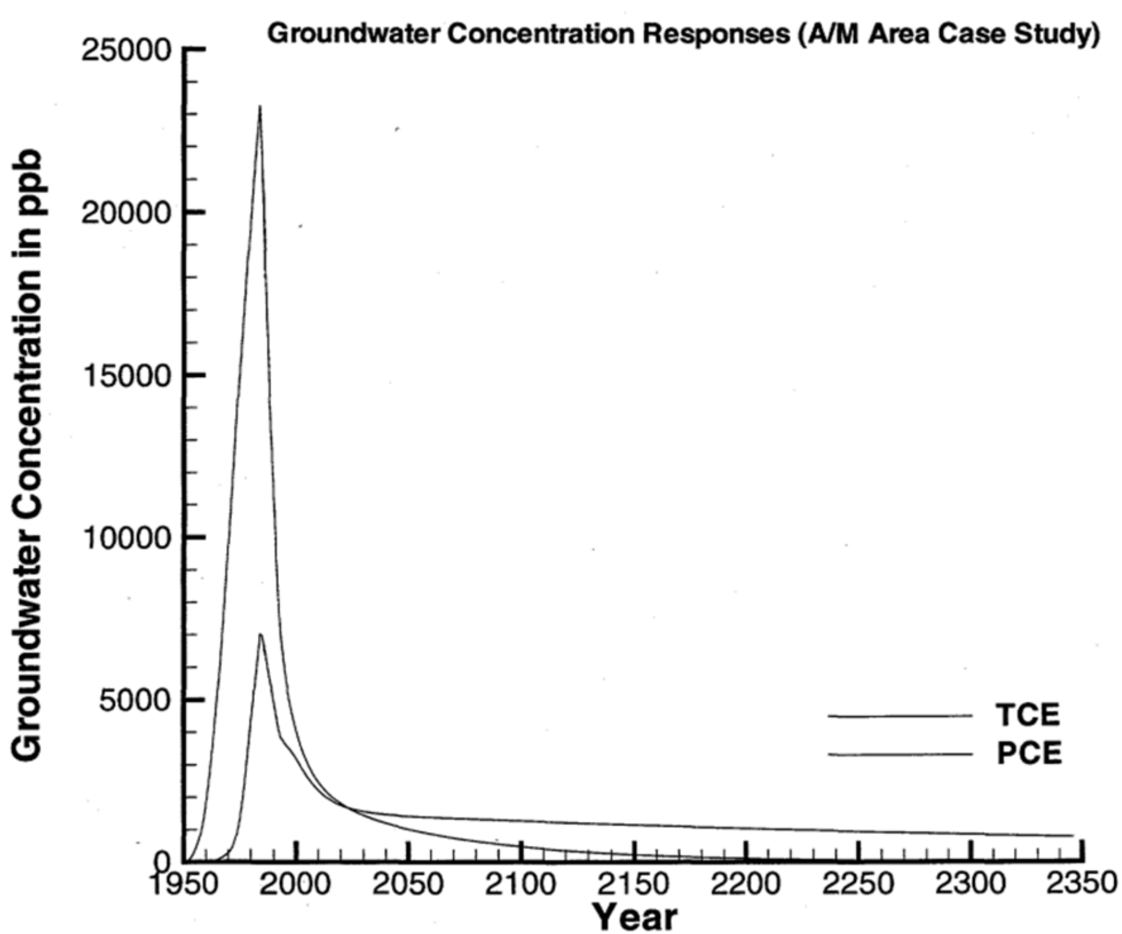


Figure 50: Response of Bulk Groundwater Concentrations to the A/M Area Corrective Action Program.

Project 3 - Task 3 Accomplishments

- Completed and submitted two major Sustainable Remediation reports:
  - "Green and Sustainable Remediation Practices, Tools and their Application at DOE Office of Environmental Management Sites".
  - "Baseline Summary Report for Sustainable Remediation Options for the M1 Air Stripper at DOE SRS" (Subtask 3.1: Analyze Baseline).

M1 Air Stripper at SRS A/M Area

Task 3: Future Work – FY14 (Year 5)

- Identify opportunities to improve efficiencies related to electrical energy, water usage, and the use of other resources, beginning with mechanical design modifications.
- Investigate operational strategies to increase system performance by optimizing the hydraulic loads, pumping rates, contaminant mass flow rates and well drawdown levels.
- Determine a set of metrics which will correlate the pumping rates, the cone of depression, and the interaction between the wells with the contaminant mass flow rates.

CLIENT DELIVERABLES	DUE DATE
Technical Report for Task 3: Sustainability Plan for the A/M Area Groundwater Remediation System	6/17/15

Project-wide: Future Work – FY14 (Year 5)

FIU Applied Research Center

CLIENT DELIVERABLES	DUE DATE
Presentation overview to DOE HQ/SRNL of the project progress and accomplishments (Year End Review)	6/30/15**
Draft Year End Report	6/30/15*

**Final documents will be submitted to DOE within 30 days of the receipt of comments on the draft documents.*

***Completion of this deliverable depends on availability of DOE-HQ official(s)*

Future Work (2015-2020)

Experimental studies and development/testing of sampling/monitoring technologies for better understanding of long-term behavior of subsurface contaminants and potential effects of remediation technologies.

Proposed research includes:

- Laboratory experiments on soil and contaminants in SRS F/H Area including:
  - Batch and column experiments to estimate adsorption/desorption and transport parameters to better predict and apply remediation technologies.
  - Laboratory analyses of aqueous chemistry of metals (uranium and other radioactive contaminants) in soils and surface water.

Future Work (2015-2020)

Targeted study of contaminants and recovery of Tims Branch may include:

- Biota/biofilm sampling in Tims Branch for contaminants and effects of remediation strategies.
- Laboratory analyses of aqueous chemistry of metals in biota, biofilms, sediments and surface water in Tims Branch including:
  - Laboratory measurements of contaminant concentrations and controlling geochemical parameters (pH, pe, ionic strength, organic carbon, mineralogy, etc.)
  - Measurement of the methylation of tin and mercury in sediments representing the range of conditions present in the SE US.
  - Calculation of chemical thermodynamic coefficients and rates of Hg and Sn methylation in stream and pond sediments.

Future Work (2015-2020)

Development/refinement of surface water models of Tims Branch ecosystem to simulate surface movement, sorption/desorption & transport of contaminants.

- Intercompartmental transfers of contaminants (including water, biota, sediment, biofilm, etc.).
- Sediment trapping of contaminants & associated transport during stormflow.
- Impact geo- and hydro-morphology have on the system and contaminant transport.
- Implementation of transport module to simulate behavior & transport of contaminants in Steed Pond.
- Simulation of current tin (Sn) deposition in stream sediments & future deposition, conc. & transport.
- Modeling of reactive transport of metals (Sn, Hg).

- *NOTE: Tims Branch ecosystem is an important applied science opportunity due to significant past research by SREL and SRNL. This collaborative effort is specifically focused on improving conceptual and quantitative modeling of a real-world ecosystem impacted by DOE operations for 50 years and is now recovering. Recently, innovative EM developed treatment technologies that have eliminated anthropogenic mercury sources from this watershed and introduced a known quantity of relatively inert tin oxide tracer.*

Future Work (2015-2020)

- Green Sustainable Remediation assessment of the Groundwater Remediation System (GWRS) at A/M Area & other remediation systems/strategies at SRS including:
  - Develop baseline for SRS sustainability performance (water resources, electricity, emissions, etc.) for A/M Area GWRS and propose alternative processes or new technologies to improve sustainability.
  - Work with SRS on follow up studies to facilitate implementation of improved processes/technologies on A/M GWRS.
  - Review additional site remediation systems at SRS, develop baseline, identify improvements with modeling to show impacts and support implementation (one remediation system at a time).

Future Work (2015-2020)

- FIU staff and students will support DOE Office of Soil and Groundwater in the testing and evaluation of ASCEM community released code.

- Based on the DOE Fellow summer internship experience during summer 2014, FIU proposes to involve other DOE Fellows and students in the testing and evaluation of ASCEM code.

Masters & PhDs

- Natalia Duque (DOE Fellow)
  - MS Water Resources Engineering
  - Expected Graduation Date: Fall 2016

Internships

- Summer 2014
  - Natalia Duque (DOE Fellow)
  - Location: DOE HQ (EM-13), Washington, D.C.
  - Mentor: Albes Gaona, Lead Sustainability Specialist, Office of Deactivation and Decommissioning and Facility Engineering (D&D/FE) (EM-13)
    - Assisted EM with sustainability related projects
    - Developed a Sustainable Remediation Technologies Catalog
    - Researched sustainable approaches to environmental remediation
  - Report Title: "Sustainable Remediation and Literature Review for Savannah River Site A/M Area Groundwater Remediation System"

Conferences & Presentations

2015 Waste Management Symposium

- Professional Paper/Poster
  - "Utilization of GIS Technology to Support Development of Flow and Contaminant Fate and Transport Models at US DOE Sites" – Angelique Lawrence, Georgio Tachiev.
- Professional Paper/Presentation
  - "Modeling and Quantitative Assessment of Green and Sustainable Remediation Options for the M1 Air Stripper System at DOE SRS" – David Roelant, Ralph Nichols, Natalia Duque.
- Student Paper/Poster
  - "Column Testing of the Migration and Distribution of Humate Injected into Subsurface Systems at Savannah River Site's F/H Area" – Kiara Pazan (DOE Fellow), Ravi Gudavalli.
  - "Quantitative Assessment of Sustainable Remediation Options for the M-1 Air Stripper System at SRS" – Natalia Duque (DOE Fellow), David Roelant.

Utilization of GIS Technology to Support Development of Flow and Contaminant Fate and Transport Models at US DOE Sites

Angelique Lawrence and Dr. Georgio Tachiev
Applied Research Center, Florida International University

FIU Applied Research Center

BACKGROUND

The Applied Research Center (ARC) at Florida International University (FIU) has supported the remediation efforts of the U.S. Department of Energy's Oak Ridge Reservation (ORR) in Tennessee through hydrological modelling of the fate and transport of inorganic and organic pollutants of concern with a focus on mercury (Hg).

Integrated surface and subsurface flow, fate and transport models were developed for several watersheds including East Fork Poplar Creek (EFPC), Upper EFPC in the Y-12 National Security Complex (Y-12 NSC) and White Oak Creek (WOC), to provide analysis of contaminant patterns within each watershed. More than a hundred simulations were completed to calibrate the models, derive model uncertainties, and to provide analysis of remediation scenarios, resulting in gigabytes of computed spatial and temporal simulation data for each computation node.

An advanced spatial data structure was needed to address the management, processing, and analysis of spatial and temporal numerical modelling data derived from multiple sources. Geographic Information Systems (GIS) technology was employed to support the hydrological modelling work through storage and geoprocessing of spatial and temporal data required by the models and to produce hydrogeological maps for visualization. An *ArcSDE geodatabase* was developed which facilitates centralized storage and management of experimental and computed model data, putting it into a structured, coherent, and logical computer-supported system. Its capabilities were extended over the years using tools such as *ArcGIS ModelBuilder* combined with *Python* scripting to automate repetitive tasks, perform statistical analyses and generate maps and reports. GIS data processing and automation enabled faster and hence more complex analyses of field test data.

Fig. 1. East Fork Poplar Creek

METHOD

1. **Development of an ArcSDE Geodatabase.**
2. **Pre- and post-processing of hydrological model data using ArcMap and ArcToolbox.**
3. **Use of ArcGIS ModelBuilder & Python scripting to:**
   - Automate repetitive geoprocessing tasks.
   - Perform statistical calculations.
   - Generate maps and reports.
4. **Use of ArcGIS Geodatabase Diagrammer to create, edit or analyze geodatabase schema.**

Development of an ArcSDE Geodatabase

Fig. 2. ORR Geodatabase System Architecture

The ORR Geodatabase (Fig. 2):

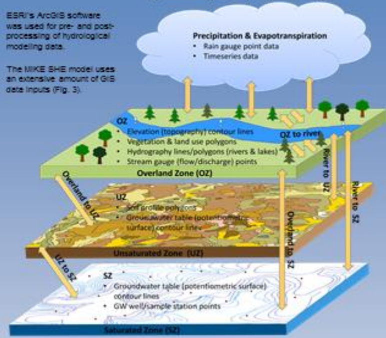
- A multiuser relational database management system (RDBMS) deployed on advanced Windows server using ArcGIS for Server.
- Based on ArcHydro and ArcGIS Base Map data models which had several input data types in common with ORR Geodatabase.
- ArcHydro has tools to support water resources applications within the ArcGIS environment.
- Modifications were then made for project specific input parameters.

- Serves as a centralized data management system.
- Provides access to data generated from simulations of contaminant fate and transport to all users.
- Facilitates storage, concurrent editing and import/export of model configuration and output data specific to the hydrologic and transport models being used.
- Structured to be replicable for application at other DOE sites.

Pre- and Post-Processing of Model Data using ArcGIS

- ESRI's ArcGIS software was used for pre- and post-processing of hydrological modelling data.
- The MIKE SHE model uses an extensive amount of GIS data inputs (Fig. 3).

Fig. 3. MIKE SHE Model Spatiotemporal (GIS) Data Inputs



- Development of hydrological models requires data that may include thousands of groundwater monitoring wells, boreholes, stream reaches with gauges, weather stations, land cover, vegetation, soil type, topography, geology, water quality and satellite imagery (Fig. 4).
- GIS enables hydrologists to pre-process and integrate data derived from multiple sources that are usually in different coordinate systems, have different spatial references, are at different scales, and are from different time periods, into a single manageable system.
- GIS-based approaches in hydrological modelling can provide the benefit of combining different layers of geographic data to create new integrated information which can be quite useful for creating dependent or independent hydrological variables.
- GIS can also serve as a useful tool in visually displaying research results via maps, graphs and reports which help to enhance the understanding and interpretation of model-derived data and to obtain a perception closer to reality.

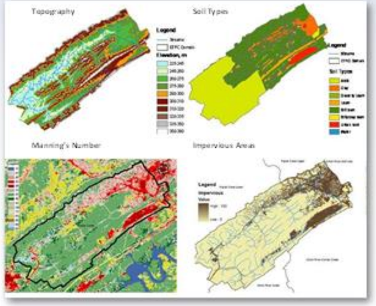


Fig. 4. Gridded input data files used for model development

ArcGIS ModelBuilder & Python

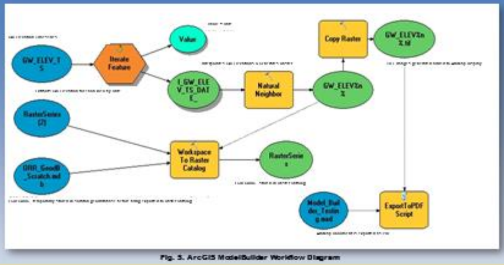


Fig. 5. ArcGIS ModelBuilder Workflow Diagram

Geoprocessing Automation

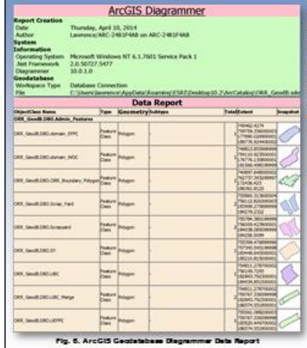
- Python scripts were used to customize built-in ArcGIS tools to automate repetitive model-specific geoprocessing tasks using ArcGIS ModelBuilder.
- A toolbox was developed for use with the EFPC model, but is scalable and reusable with geodatabases containing data relevant to other DOE sites.
- Customized tools and scripts automate the query and retrieval of timeseries data and contaminant flow and transport parameters from the ORR geodatabase.
- The ArcGIS data model iterates through selected features and exports the results in tabular format.
- The toolbox has capabilities to:
  - Add GIS files to ArcMap and create layer files.
  - Select features within a specified area (e.g. the study domain) and zoom to selected features.
  - Clip/extract selected features and create a new layer file of selected subset.
  - Export clipped feature in format to be used by MIKE SHE/11 model.
  - Export attributes of clipped feature in MS Excel or text format for statistical analysis and generation of graphs and reports.
  - Export map extent in various formats (e.g. JPEG, TIFF or PDF) for development of reports.
  - Interpolate timeseries data collected at various monitoring points, generate gridded surfaces, and create and export mapped results.
- ArcGIS ModelBuilder generates model workflow diagrams (Fig. 5) to document and visually represent tools and scripts incorporated in the data model.

Statistical Analysis

- Customized Python scripts were also developed to perform statistical analyses on model output data.
- A library of scripts was implemented and coupled with other existing libraries used for mathematics, science, and engineering such as NumPy and SciPy.
- The goal was to create scripts to calculate model performance statistics for a subset of existing flow and contaminant monitoring stations.
- Data for the selected stations are available, in most cases, on an hourly basis and for some stations on a daily basis only.
- The following lists some of the parameters for which scripts were developed.
  - **ME:** Mean error .
  - **MAE:** Mean absolute error .
  - **RMSE:** Root mean square error.
  - **STD:** Standard deviation.
  - **CoVar:** Covariance.
  - **Cor:** Correlation.
  - **PEV:** Percent explained variance.
  - **NS:** The Nash-Sutcliffe model efficiency coefficient.

ArcGIS Geodatabase Diagrammer

- Details of the ORR geodatabase data and schema were generated using the ArcGIS Geodatabase Diagrammer utility for ArcGIS 10.2.
- ArcGIS Diagrammer is essentially a productivity tool used to create, edit or analyze geodatabase schema.
- It generates reports (Fig. 6) and diagrams (Fig. 7) in the form of editable graphics and serves as a visual editor which accepts XML workspace documents that are created from ESRI's ArcMap or ArcCatalog.
- Reports generated depict the ORR geodatabase data structure and details of the features, rasters and tables used during hydrological model development, as well as any existing relationships and spatial references.


ArcGIS Diagrammer

Report Creation
Date: Thursday, April 10, 2014
Author: Lawrence/ARC-2481F4A8 on ARC-2481F4A8
System Information
Operating System: Microsoft Windows NT 6.1.7601 Service Pack 1
.Net Framework: 2.0.50727.5477
Diagrammer: 10.0.1.0

Fig. 6. ArcGIS Geodatabase Diagrammer Data Report

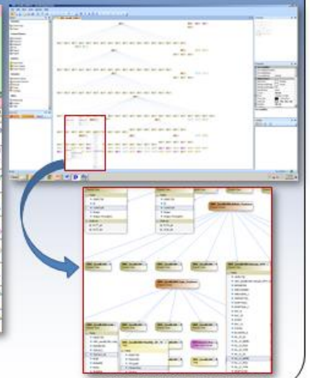


Fig. 7. ORR Geodatabase Schema Diagram

BENEFITS & CONTRIBUTIONS

- GIS-based hydrologic models can provide a spatial element that other hydrologic models lack.
- GIS enables hydrologists to pre-process and integrate data derived from multiple sources into a single manageable system.
- GIS-based approaches in hydrological modelling can be used to combine different layers of geographic data to create new integrated variables.
- GIS can be used for visualization of model-derived research results via maps, graphs and reports.
- GIS technology has proven useful in supporting the hydrological modeling work performed by FIU-ARC at the Oak Ridge Reservation (ORR) through development of a geodatabase which has provided an advanced spatial data structure for management, processing, and analysis of spatial and temporal numerical modelling data derived from multiple sources.
- ArcGIS ModelBuilder coupled with Python scripting enabled the automation of many of the repetitive geoprocessing tasks required for pre- and post-processing of hydrological modelling data. GIS data processing and automation facilitated faster and hence more complex analyses of field test data. The toolbox created is a scalable and reusable application that can be implemented at other DOE sites.
- Finally, a web-based GIS application can facilitate sharing of project derived data with stakeholders including DOE personnel and ORR site contractors.

ACKNOWLEDGEMENTS

This research is sponsored by the U.S. Department of Energy
Office of Environmental Management
under cooperative agreement # DE-EM0000598.

Quantitative Assessment of Sustainable Remediation Options for the M-1 Air Stripper System at SRS

Introduction

The US Department of Energy (DOE) Savannah River Site (SRS) covers 310 sq. miles and is located south of Aiken, SC. The site produced materials used in the production of nuclear weapons from the 1950s to the 1980s.

Trichloroethylene (TCE) and tetrachloroethylene (PCE) were the main solvents used in degreasing and other industrial operations. These solvents are categorized as dense non-aqueous phase liquids (DNAPLs), semi-volatile, and hazardous chemical compounds.

In the 1980's, operations were initiated to remediate the contaminated soil and groundwater which continues today.

Problem Statement

The M-1 air stripper and well network has operated continuously since 1985 at an average electrical load of 150 kW and flow rate of 420 gpm. The influent TCE concentration to the air stripper has decreased exponentially from 25,200 ug/L in 1986 to 2,230 ug/L by the end of 2012, with the same energy consumption and water pumping rate.

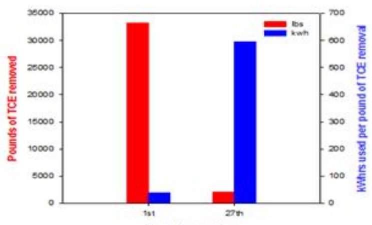


Figure 1: M-1 Stripper TCE removal During 1st and 27th Year of Operation

Purpose

To analyze the operation of the SRS A/M Area groundwater remediation system using state-of-the-art modeling tools to provide suggested engineering and operational improvements to expend less resources while still containing the contaminant plume.

Implementation of improvements will help DOE-EM apply sustainable remediation at its sites and help DOE achieve DOE-wide sustainability performance metrics.

A/M Area

- Located in the northern part of SRS within the lower reaches of the Tims Branch watershed (topographic elevation from ~420 ft to ~ 118 ft).
- Consists of facilities that fabricated reactor fuel and target assemblies (M-Area), and administrative and support facilities (A-Area).

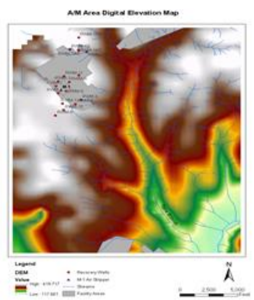


Figure 2: SRS A/M Area Digital Elevation Map

M-1 Air Stripper & Recovery Well Network

- Installed in 1985 to treat groundwater in order to reduce chlorinated solvent concentrations.
- 17 recovery wells have been installed over the years. Currently recovery wells 1-12 feed the M1 air stripper.
- The treated groundwater is discharged to a stream in Tims Branch.

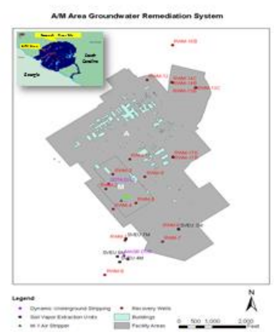


Figure 3: SRS A/M Area Remediation Network

Preliminary Results

The monthly removal rate and the cumulative mass removed for TCE and PCE in the 12 recovery wells was analyzed for 1985-2012. Removal from well RWM-1 is plotted below.

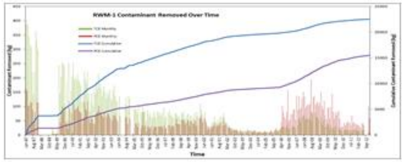


Figure 4: RWM-1 Cumulative and Monthly TCE and PCE Mass Removed

- 7 of 12 recovery wells have transitioned to more PCE than TCE removed. This is an expected result since TCE was initially used and then replaced by PCE.
- The rate of recovery in some wells was affected by the Dynamic Underground Stripping process.
- 7 wells exhibit exponential decay in contaminant removal while 5 exhibit steady concentrations, and 2 exhibit linear decreases.

Table 1: Comparison of Contaminant Removal 1987 to 2012

Comparison of Contaminant Removal 1987 to 2012

Well ID RWM	TCE Jan. '87 removal (kg/mo.)	TCE Dec. '12 removal (kg/mo.)	TCE Jan. '87 H_2O Intensity, kg/Mgal	TCE Dec. '12 H_2O Intensity, kg/Mgal	PCE Jan. '87 removal (kg/mo.)	PCE Dec. '12 removal (kg/mo.)	PCE Jan. '87 H_2O Intensity, kg/Mgal	PCE Dec. '12 H_2O Intensity, kg/Mgal
1	389.00	10.57	243	26.9	161.35	58.76	101	149
2	89.09	3.00	98.2	3.24	29.43	8.68	32.4	9.39
3	341.37	8.94	116	3.89	66.55	7.53	22.7	3.27
11	180.52	2.18	69.6	.931	49.59	0.16	19.1	0.0665
4	12.96	19.64	23.1	10.0	0.00	8.13	0.00783	4.15
5	5.29	13.35	5.32	6.57	1.43	8.26	1.44	4.07
7	3.48	40.15	7.32	23.8	2.90	48.72	6.10	28.9
8	0.09	5.20	0.129	2.66	0.22	3.67	0.305	1.88
10	101.16	24.89	52.0	18.5	111.05	70.67	57.1	52.4
6	105.00	2.90	73.7	2.70	95.94	7.58	67.3	7.04
12	91.76	6.39	39.3	3.11	0.05	0.06	0.0196	0.03.13
9	3.77	1.73	3.23	9.08E-07	0.67	0.53	.571	.278

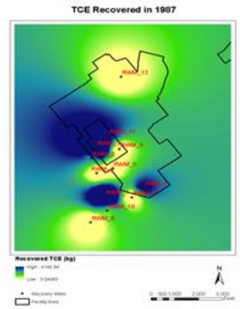


Figure 5: TCE (kg) Recovered per Well in 1987.

Figure 6: TCE (kg) Recovered per Well in 2011.

Future Work

- Identify opportunities to improve efficiencies related to electrical energy, water usage, and the use of other resources, beginning with mechanical design modifications.
- Investigate operational strategies to increase system performance by optimizing the hydraulic loads, pumping rates, contaminant mass flow rates and well drawdown levels.
- Determine a set of metrics which will correlate the pumping rates, the cone of depression, and the interaction between the wells with the contaminant mass flow rates.

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Column Testing of the Migration and Distribution of Humate Injected into Subsurface Systems at Savannah River Site's F/H Area

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Abstract

The F-Area seepage basins at Savannah River Site (SRS) have received approximately 1.8 billion gallons of low-level waste solutions, containing nitric acid, radionudides and dissolved metals due to plutonium separation operations from 1955 to 1988. The waste solutions became a source of contamination for groundwater and soil at the site, with U(VI) and other radionuclides above their maximum contaminant levels (MCLs). For remediation, humic acid (HA) technology has shown to be a potential approach for controlling mobility of radionuclides. Because sorbed HA and uranium develop a strong bond at slightly acidic pH, the mobility of the contaminant molecules should decrease with flushing of SRS groundwater. Column experiments are planned using SRS soil from the F/H Area to examine the sorption and desorption properties of HA in SRS soil. The data from these experiments will then be used to perform modeling of the migration and distribution of HA injected into the subsurface.

Background

- F-Area seepage basins at Savannah River Site (SRS) have received large amounts of low level waste solutions.
- Uranium and various radionuclides are above maximum contaminant levels.
- Remediation by humic acid (HA) has shown to be a potential approach for controlling mobility of contaminants.

Fig 1. Area seepage basins (from Millings et al., 2013).

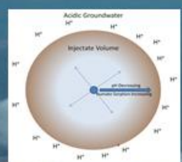

Fig 2. Conceptual Behavior of Humate Injected

Objectives

- Study the migration and distribution of HA injected in to subsurface systems by column experiments in support of uranium remediation.
  - Obtain sorption and desorption parameters and understand sorption under different levels of pH

Methodology

- Characterization of F-area soil.
- Perform column flow through bromide tracer tests.
- Preparation of artificial groundwater to mimic SRS groundwater.
- Preconditioning of columns to bring pH of soil to field conditions.
  - pH of 3.5, 5.0, 6.0, 7.0 will be attained.
- Injection of Huma-K into column and study the sorption by analyzing the effluent via UV-Vis spectrophotometer.
- Perform desorption for 3.5, 5, 6, and 7 pH solutions.

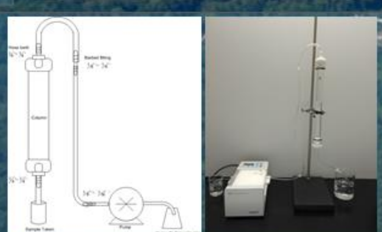

Fig 3-4. Experimental Column Setup

Results

- The preliminary data for column experiments have been found, including the properties of SRS soil and concentration of Huma-K needed.
- Soil Characterization: FAW-1 60'-70'
  - Bulk density: 1.334 g/cm^3
  - Particle density: 2.645 g/cm^3
  - Porosity: 0.496
  - pHw: 4.06
- Humate Injection scenarios are used to predict the sorption of HA on sediment and determine optimum concentration of Huma-K and flow rate, as well as to compare to experimental breakthrough curves.
- Injection Scenarios
  - a: 2082 mg/kg
  - b: 0.0025 L/mg
  - Cell pore vol/time step: 0.4
  - Huma-K Concn: 5000 mg/L

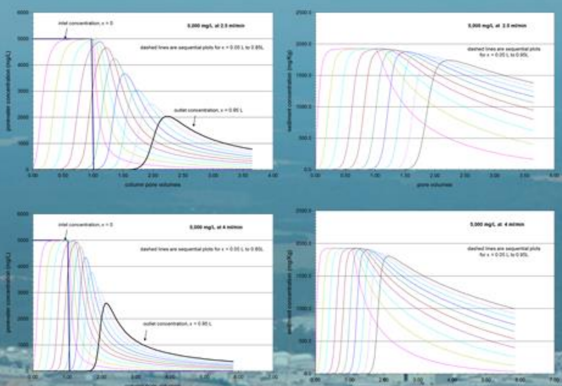

Fig 5-8 Simple conceptual models of humate injection using Langmuir isotherm.

Discussion

- The injected Huma-K at high pH is expected to decrease the mobility of organic molecules as pH decreases, as it interacts with the soil and flushing of artificial groundwater.
- The expected results should demonstrate that humate sorbed to soil should bind with uranium at acidic pH.
- The modeled injection scenarios suggests the optimal Huma-K concentration and flow for columns should be 5000 mg/L at 2.5 ml/min, avoiding over saturation and best amount of sorption to sediment.
- The results from previously conducted humate injection tests will be used to compare the properties of humic acid.

Future Work

- Continue column experiments to determine sorption and desorption properties to use for actual field deployment
- In addition to uranium, ICP tests will be performed for iron and silica.
- Data from this experiment will be used to develop a subsurface flow, rate, and transport model of distribution of humic acid for in situ treatment

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QUESTIONS