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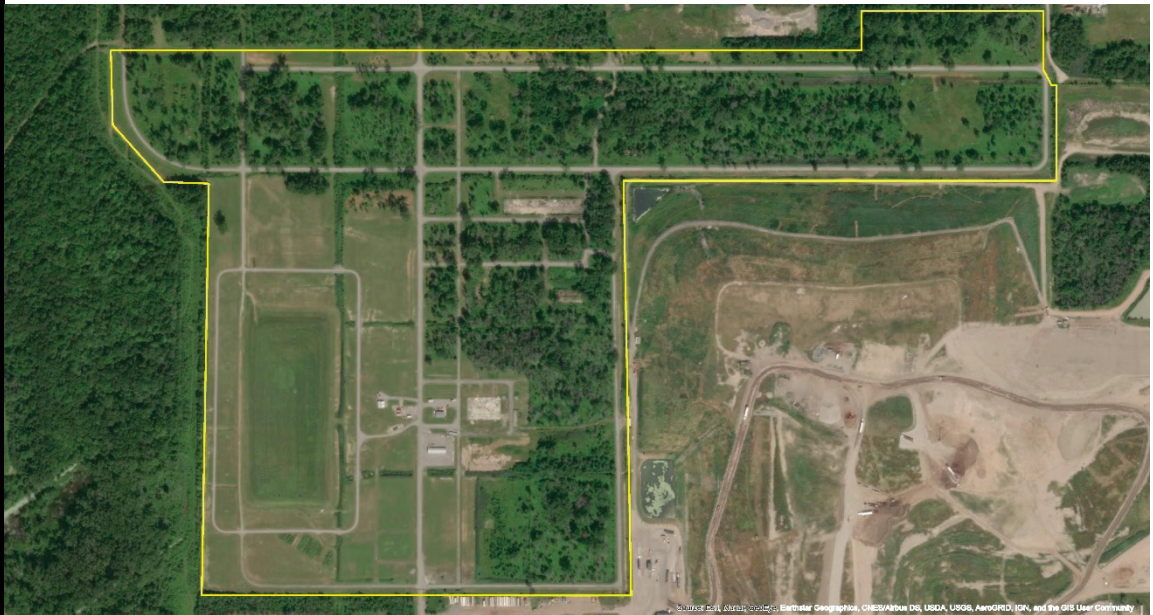


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Phytomanagement of Soil and Groundwater at the Niagara Falls Storage Site (NFSS) Using Hybridized Trees

Afrachanna D. Butler, Catherine C. Thomas,
Nathan R. Beane, Anthony J. Bednar,
and William T. Frederick

September 2021



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Phytomanagement of Soil and Groundwater at the Niagara Falls Storage Site (NFSS) Using Hybridized Trees

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Abstract

The Manhattan Engineer District previously used the 191-acre Niagara Falls Storage Site (NFSS) in Niagara County, New York, to store radioactive residues and wastes from uranium (U) ore processing. At present, management practices will determine whether enhanced evapotranspiration rates produced by hybridized shrub willow cuttings planted in 2016 will affect groundwater hydrology. Two shrub willow varieties were planted in an approximately one-half acre area to examine growth performance along a U impacted sanitary sewer line. Additionally, control plots will compare the effectiveness of shrub willows to unplanted areas.

Observations of the planted area after 18 months showed success of shrub willow growth with increasing biomass. Chemical analysis from tree tissue samples of the field study showed no significant uptake of U or thorium (Th) to date. A greenhouse study conducted in parallel to the field study tested the willows under controlled greenhouse conditions and evaluated their ability to grow and accumulate contaminants under controlled conditions. Results from the greenhouse study demonstrated that U accumulation was minimal. Thus, this study demonstrates that the shrub willows are not accumulators of U or Th, an advantageous characteristic that implies stabilized contaminants in the soil and no translocation of U into the aboveground biomass.

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Preface

The work reported herein was conducted at the Niagara Falls Storage Site (NFSS), Buffalo, NY, and the US Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS, under Funding Account Code H542953; AMSCO Code 081323. Funding was provided by the Formerly Utilized Sites Remedial Action Program (FUSRAP), under the NFSS operations and maintenance budget for the project. The Buffalo District partnered with the ERDC under the Engineering with Nature® (EWN) initiative to implement innovative groundwater management techniques at the NFSS.

This project was performed under the direct leadership of Dr. Afrachanna Butler, who coordinated all efforts including oversight, experimental designs, and activities related to ERDC's roles. Dr. Catherine Thomas co- led greenhouse activities and oversaw laboratory procedures for ERDC- and NFSS-collected samples. Chemical analyses were performed by Dr. Anthony Bednar of ERDC-EL's Environmental Chemistry Branch. Dr. Nathan Beane of the Wetlands and Coastal Ecology Branch selected shrub willow varieties and led field efforts for planting and establishing trees on-site. Drs. Butler and Thomas prepared this report. The report was reviewed by Mr. William T. Frederick, USACE–Buffalo District (LRB).

This study was conducted under the supervision of Mr. William T. Frederick, and under the general supervision of Jeffery Rowley, NFSS Project Manager for the FUSRAP at LRB.

Mr. Justin Heavey and Mr. Karl Hallen, both Senior Research Support Specialists at SUNY College of Environmental Science and Forestry in Syracuse, New York, contributed their knowledge and expertise on shrub willow plantings design, growth, and coppicing.

This report documents results of the phytomanagement field demonstration at the NFSS, as well as supporting investigations conducted at the ERDC-EL. At the time of publication, Dr. Michael Rowland was Chief of the Environmental Engineering Branch, and Mr. Warren Lorentz was Division Chief of the Environmental Processes and Engineering Division. The Deputy Director of ERDC-EL was Dr. Jack Davis, and the Director was Dr. Edmond J. Russo.

COL Teresa A. Schlosser was the Commander of ERDC, and Dr. David Pittman was the Director.

1 Introduction

Background

The Niagara Falls Storage Site (NFSS) and associated vicinity properties occupy approximately 1,500 ac (607 ha) of the original 7,500 ac (3,035 ha) Lake Ontario Ordnance Works (LOOW) (Bednar et al. 2004). The NFSS stored radioactive materials, residues, and waste from uranium (U)¹ ore processing between 1944 and 1952 (USACE 2011). To date, the US Army Corps of Engineers (USACE) is responsible for environmental response activities at NFSS until two years after remedial action is complete, at which time the US Department of Energy (DOE) assumes responsibility for long-term surveillance and maintenance (Clayton et al. 2012). This study implemented a field pilot investigation to evaluate hybridized trees' ability to address hydrologic conditions impacting contaminant migration at the NFSS.

Disturbed areas, in which soil was excavated for installation of sanitary sewer lines, demonstrated greater hydraulic conductivity, since the backfilled media was less compacted relative to the surrounding undisturbed soil. As a result, soil in the areas along the sanitary sewer lines presents an increased risk for migration of the radionuclides. Therefore, the research team explored an experimental strategy to augment the natural attenuation of contaminants: planting shrub willow trees along sewer line areas to transpire high volumes of water and minimize contaminant diffusion along the sewer line. The research team selected the willow tree species because of its ability to transpire high volumes of water and its poor capacity to accumulate and translocate heavy metals. This report discusses characterization, planting, and evaluation of the field test area.

Purpose

This effort supported the USACE Buffalo, New York, district (LRB) in the evaluation of dendroremediation as a phytomanagement strategy to

1. For a full list of the spelled-out forms of the chemical elements used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 265, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

passively contain contaminants in soil and groundwater, which have relevance to the Formerly Utilized Sites Remedial Action Program (FUSRAP) mission.

Goals and objectives

This field pilot investigation sought to mitigate potential migration of radionuclides, U and thorium (Th), by way of hydraulic control.

Specifically, the team sought to

- determine the ability of hybridized shrub willows to dewater areas with poorly compacted, backfilled soil along buried, sanitary sewer line;
- determine the ability of the shrub willows to withstand and uptake elevated levels of U and Th; and
- assess growth characteristics of shrub willows in controlled, greenhouse, and in situ conditions.

2 Materials and Methods

Background soil and plant characterizations

During the initial visit to the NFSS (April 2015), the team collected soil (surface and subsurface), plants (particularly grasses), and tree bole samples from various site locations (Table 1). In August 2015, common reed (*Phragmites australis*) phragmites and dogwood (*Cornus* sp.) samples were collected from a vegetated swale near manhole (MH) #7, and tree-core samples from eastern cottonwood (*Populus deltoides*), pin oak (*Quercus palustris*), northern red oak (*Quercus rubra*), green ash (*Fraxinus pennsylvanica*), and black locust (*Robinia pseudoacacia*) trees were collected in areas EU 3 and 4. These samples were collected to analyze the occurrence of radionuclide contamination in the soil and assess its potential bioavailability to the native trees and plants. Several tree-core samples were obtained in areas where only groundwater was contaminated with U and Th. Background characterizations of soil and tree samples were conducted at the US Army Engineer Research and Development Center's (ERDC) Environmental Laboratory (EL). Chemical analyses were performed by the Environmental Chemistry Branch Analytical Geochemistry Team. Soil parameter measurements included total metals, pH, cation exchange capacity, and total Nitrogen. Soil and plant tissue samples were collected from various locations near groundwater monitoring wells (MW) and Man Hole (MH) at the NFSS. Soils and tree tissues were digested using the United States Environmental Protection Agency (USEPA) method 3051A (USEPA 2007), which was 0.5 soil or tree tissue + 10mL¹ nitric acid completed to final volume of 100mL with Deionized (DI) water. Soil concentrations (mg/kg) were determined by the digestion concentration (mg/L), final volume (L), and soil mass (kg). Inductively Coupled Plasma Mass Spectrometry (ICP-MS) USEPA method 6020 was used to analyze both U and Th (USEPA 1994). Table 1 shows the types of samples collected from each sample location at the NFSS.

1. For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

Table 1. Site locations of soil and grass samples collected at the Niagara Falls Storage Site (NFSS).

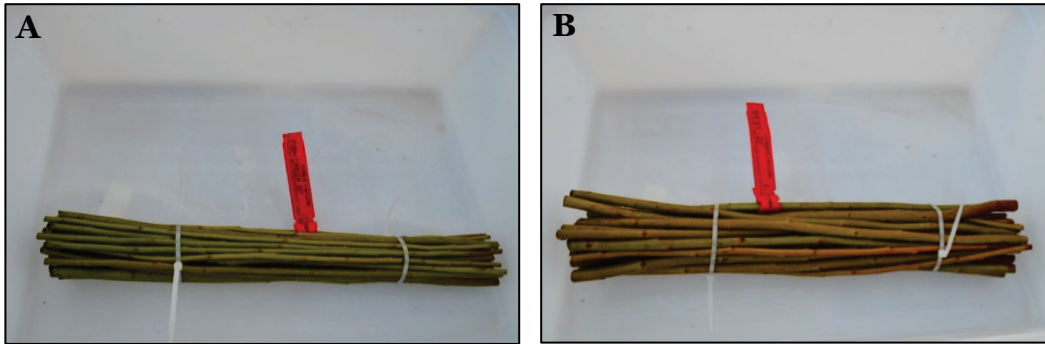
Sample location	Sample type
EU 11	Grass roots and shoots, surface and subsurface soils
MW 30	Surface soil
MW 415	Tree boles
MW 415A	Grass roots and shoots, surface soil
MW 930	Subsurface soil
“R” ST	Grass roots and shoots, surface and subsurface soils

Field demonstration study

For the field demonstration, two shrub willow species were planted as cuttings in May 2016 to evaluate their ability to control hydrology with efforts to dewater areas adjacent to sewer lines and those encompassing two MW locations (Figure 1). The planting location was situated atop contaminated sewer line locations. This location was identified using sampling data from nearby MH #6 and #9, with shrub varieties stratified across the area available for planting. Two control plots were also established within the study area (Figure 2).

All trees were planted on an approximate 6 ft spacing between rows and 18 in between individual trees within a given row. This is a tree planting density of 4,480 trees per acre. Tree cuttings used for this effort were 10 in in length and planted in loosened, disked soil approximately 9 in deep, with 1 in left above ground level. The soil around each cutting was packed by foot for each tree planted. Since the initial planting, two coppicing events have occurred (Dec 2016 and Jan 2018). Field piezometers were installed in October 2017 by LRB personnel to monitor changes in groundwater level. Radionuclide concentrations in subsurface water were also monitored by the LRB team from samples collected from MW. Plant tissues and soil cores were collected from the test plot in a randomized fashion and shipped to the ERDC’s EL for analyses to determine the levels of radionuclides detected in plant tissues and soil. The LRB team will carry out continuous monitoring of radionuclide concentrations in tree leaves to determine whether the trees will translocate contaminants from the soil at various growth and life-cycle stages.

Figure 3. 20 in Fish Creek (A) and SX61 (B) cuttings soaking in water until planting.



Soil collection

Soil samples were collected from various locations at the NFSS and shipped to ERDC in a 55-gal drum. The soil samples were collected near MW 958, MH06, MH09, and MW505 (see Figure 1 for MW and MH locations). Each sample was separated in plastic bags by lower and upper layers, sealed, and placed inside the 55-gal drums. The lower soil layers were collected from NFSS at depths between 6 and 16 in, and upper soil layer were collected at depths between 0 and 6 in. Soils were removed from the drums and placed in 36 in diameter polyethylene pools at a depth of 10 in to air-dry at room temperature (Figure 4). After drying, the soils were homogenized with shovels and rakes. Following soil homogenization, subsamples were collected, and geochemical analyses (for example, total metals, U and Th concentrations, pH, cation exchange capacity, and total organic carbon) were performed using standard USEPA methods 9045 and 9081 (pH and CEC, respectively) and modified USEPA methods 3051 A SW-846 and 6020 (U and Th) (USEPA 2000; USEPA 1986; USEPA 2007; USEPA 1994).

Figure 4. Soil drying process, (A) wet and (B) dry, after removal from 55 gal drums.

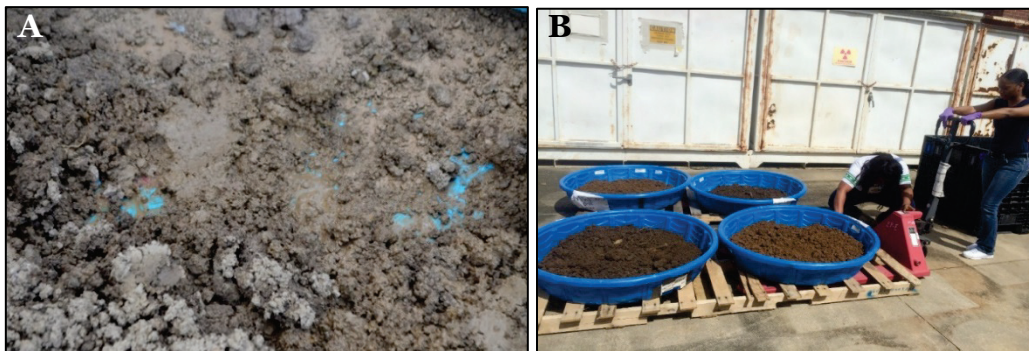


Table 2. Sampled soil locations at NFSS.

Sample location	Top soil (in)	Subsoil and native glacial till (in)
MW958	0-2	2-4
MH06	0-4	4-7
MH09	0-4	4-12
MW505	6-12	12-16

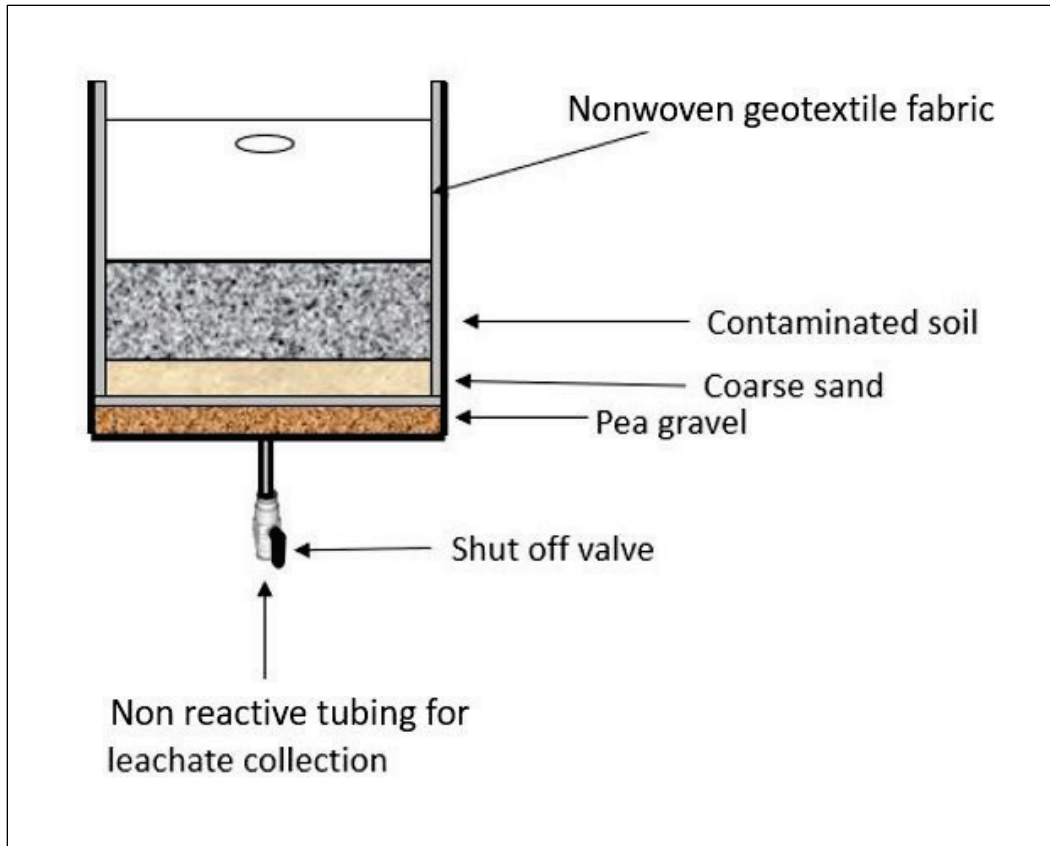
Greenhouse growth conditions and measurements

The greenhouse experiment included 12×12×12 in containerized high-density polyethylene boxes (Figure 5), which were layered with pea gravel, sand, and soil (Figure 6). A 3 in (7.62 cm) layer of pea gravel was placed at the bottom of the growth chamber to prevent sediment from clogging the drainage holes throughout the leachate collection. A layer of nonwoven geotextile was placed atop the pea gravel and draped around the inside of the growth chambers. A 3 in (7.62 cm) layer of coarse sand was placed on top of the geotextile and compacted before the contaminated soils were added. A 6 in (15.24 cm) layer of soil was placed over the sand layer and compacted to form a sediment layer approximately 12 in deep. The containers are designed to use a nonreactive tubing and shut-off valves to allow for the collection of leachate and were placed on fabricated iron stands.

Figure 5. 12×12×12 in black containerized greenhouse growth containers.



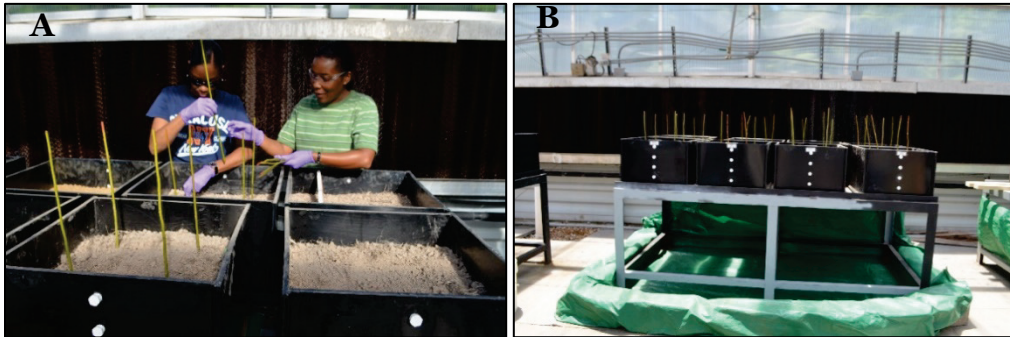
Figure 6. Schematic of containerized growth chamber.



On the basis of available soil volume, 12 growth chambers were employed in this study, eight for the planted containers and four smaller containers for the controls. Experimental chambers consisted of two growth containers for each soil location, with either Fish Creek or SX61. For the control chambers, there was one container for each soil. In the planted chambers, four of the 20 in Fish Creek and SX61 cuttings were planted in the contaminated NFSS soil and irrigated using DI (Figures 7A and B). The greenhouse setup was located at an ERDC greenhouse in Vicksburg, Mississippi, with ambient conditions ranging between 32 ± 5 °C during the day and 21.1 ± 5 °C at night and a natural photoperiod of 12h:12h light:dark cycle. ONSET HOBO data loggers monitored the relative humidity, temperature, and lighting. The plants were manually irrigated weekly with DI water as needed. The soil moisture content was monitored to maintain soil field capacity. Weekly growth assessments included measurement of tree height:the vertical distance from the top of the soil surface, which is the base of the shrub, to the top of the highest branch on the shrub. Plant growth and U and Th accumulation in tree stems, leaves, and roots were determined at the termination of the study. Soils removed

from each growth chamber were homogenized before geochemical analysis, since delineating upper and lower soil layers would be difficult because of the limited height of placed soil.

Figure 7. (A) Planting of Fish Creek and SX61 cuttings and (B) eight growth containers with planted cuttings.



3 Results and Discussion

Background soil and plant characterizations

The site was characterized in part by investigating pH and total U and Th in soils and plant material. Table 3 provides the pHs for NFSS soils, and Table 4 provides the radionuclide concentrations for soils and plants.

Table 3. Average pH measurements of soils collected at the NFSS.

Sample #	Sample ID	pH
1	EU11 1-2"	7.97
2	EU11 (Sewer Line) 4-6"	8.70
3	"R"ST 1-2"	7.92
4	"R"ST 4-6"	8.02
5	MW 30 1-2"	7.91
6	MW 415A 1-2"	7.92
7	MW 930 4-6"	8.14
8	EWN.OBA.RAD.1-Surface	8.01
9	EWN.OBA.RAD.1-SubSurface	7.94

Table 4. Thorium (Th) and uranium (U) concentrations measured in grass and soils samples collected at NFSS (April 2015).

	Sample ID	Th (mg/kg)	U (mg/kg)
Plant tissue	MW 415A Grass Roots	1.3	0.9
	MW 415A Grass Shoots	1.5	0.5
	EU11 Grass Roots	2.3	6.2
	EU11 Grass Shoots	1.2	4.0
	"R"ST Grass Roots	0.6	1.9
	"R"ST Grass Shoots	0.6	1.1
	Tree Bark (near MW 415)	0.1	0.0
Soil	EU11 1-2"	3.4	8.7
	EU11 (Sewer Line) 4-6"	4.2	26.7
	"R"ST 1-2"	3.8	2.5
	"R"ST 4-6"	4.0	2.1
	MW 30 1-2"	3.1	0.8
	MW 415A 1-2"	3.0	1.0
	MW 930 4-6"	2.9	0.7
	EWN.OBA.RAD.1-Surface	3.3	2.6
	EWN.OBA.RAD.1-SubSurface	3.5	1.8

Uranium and Th levels detected in soil and grass samples were between 0.6 and 4.2 mg/kg for Th and 0.5 and 2.6 mg/kg for U, except for samples collected near sanitary sewer lines in area EU 11. This outcome was expected for U, as high concentrations of the radionuclide have been detected near sanitary sewer areas during previous site characterizations and monitoring events, when samples were collected from adjacent soils and MW. Elevated levels of Th were also expected in soils near sanitary sewer areas but appeared to be relatively constant across the site. The constant concentrations of Th are likely due to its anionic, insoluble nature as well as its association with natural organic matter (NOM) (Bednar et al. 2004). However, Kumar et al. (2015) reports a reduction in U soil sorption as organic matter increases. There are several factors affecting U mobility in soil, including organic matter, pH, Eh and CO_3^{2-} , and speciation. Ahmed, Young, and Shaw (2012) reports U to be significantly more mobile than Th in mildly acidic to slightly alkaline soils (pH 5.8–7.5) and Th as most soluble in acidic (pH 3.6–4.7) soils. Thus, the pH of the soils collected at the NFSS (Table 3) could account for the trends observed in radionuclide concentrations shown in Table 4. However, the behavior of U in the test soils is not well understood.

In phragmites and dogwood samples collected from a vegetated swale near MH#7, little to no U or Th was detected in the samples (Table 5). In tree core samples collected from the site, U and Th was below detectable levels, indicating that the legacy radionuclides have not been translocated into tree tissues.

Table 5. Levels of U and Th detected in plant samples collected on a vegetated swale near MH#7 (ND—not detected).

Sample ID	U (mg/kg)	Th (mg/kg)
Phragmites flowers	0.01	ND
Phragmites leaves	ND	ND
Phragmites stems	ND	ND
Dogwood leaves	ND	ND
Dogwood stems	ND	ND
Dogwood fruit	ND	ND

Field demonstration study

After shrub willow cuttings were planted at the site, the trees were maintained and monitored by LRB personnel for growth response relative to temperature and other environmental factors.

Photos of the shrub willows documented growth and rate of biomass increases. After planting the willow tree cuttings (May 2016), the trees grew for eight months and coppiced (January 2017) to promote higher biomass yields for the upcoming spring (Figure 8). No soil or plant tissue samples were collected for the first year of planting to avoid any damage or unnecessary disturbance to the site. One year after planting, shrub willows had reached heights up to 7 ft (Figure 9). After sixteen months, the shrub willow plot exhibited good biomass growth (Figure 10). Four months later, in January 2018, the willow shrubs reached dormancy during the winter/snow season (Figure 11.)

Figure 8. Shrub willows growth 11 months after initial planting and eight months following initial coppicing (April 2017).



Figure 9. Shrub willows one year after initial planting (June 2017).



Figure 10. Shrub willow plot nine months after initial coppicing and 16 months after initial planting (September 2017).



Figure 11. Test plot after coppicing of the shrub willows (Jan 2018).



In shrub willow tissue samples collected from the NFSS field plot 18 months after the initial planting, little to no U was detected in either shrub hybrid. The greatest concentration of U measured in Fishcreek and SX61 shrubs were 0.08 and 0.12 mg/kg, respectively (Table 6). As observed in

the greenhouse study, overall biomasses of the SX61 hybrid were comparatively greater than that of the Fishcreek hybrid. Table 7 lists biomasses of each field sample collected from the test plot.

Table 6. Uranium concentrations in field plants (ND—not detected).

ID	U (mg/kg)	ID	U (mg/kg)
SX-1	ND	FC-1	ND
SX-2	0.12	FC-2	ND
SX-3	0.10	FC-3	0.08
SX-4	ND	FC-4	ND
SX-5	ND	-	-

Table 7. Average biomasses of field plant samples collected from the NFSS.

Field Sample ID	Dry Wt. (g)
SX 61 - 1	11.173
SX 61 - 2	13.140
SX 61 - 3	35.806
SX 61 - 4	13.406
SX 61 - 5	6.584
Fishcreek - 1	11.620
Fishcreek - 2	12.004
Fishcreek - 3	14.313
Fishcreek - 4	12.434

Exploratory greenhouse study

Initial U and Th soil concentrations

Table 8 provides initial U soil concentrations. Soil concentrations of U were highest in soil samples collected near MH06 at 4–7 in, averaging 17.365 mg/kg, and at 0–4 in, averaging 8.913 mg/kg. Soil samples collected near MH 09 at 0–4 in and 4–6 in averaged 1.77 mg/kg and 1.63 mg/kg, respectively. The soil samples collected near the MW 505 and 958 were lower compared to MH06. MW 505 samples resulted soil concentrations at depths 0–12 in and 12–16 in were 1.77 mg/kg and 3.95 mg/kg, respectively. Uranium soil concentrations collected near MW958 at 0–2 in and 2–4 in were 2.61 mg/kg and 4.33 mg/kg, respectively.

Soil concentrations for Th were relatively similar across all samples, ranging 3.2–4.6 mg/kg. Soil samples collected near MH 06 at 0–4 in and 4–7 in were 4.65 mg/kg and 3.25 mg/kg, respectively. MH 09 soil samples collected at depths 0–4 in and 4–6 in resulted 3.73 mg/kg and 4.19 mg/kg, respectively. MW 505 samples resulted soil concentrations at depths 0–12

in. and 12–16 in. were 3.79 mg/kg and 3.63, respectively. Soil concentrations of Th collected near MW958 at 0–2 in and 2–4 in were 3.63 mg/kg and 4.39 mg/kg, respectively.

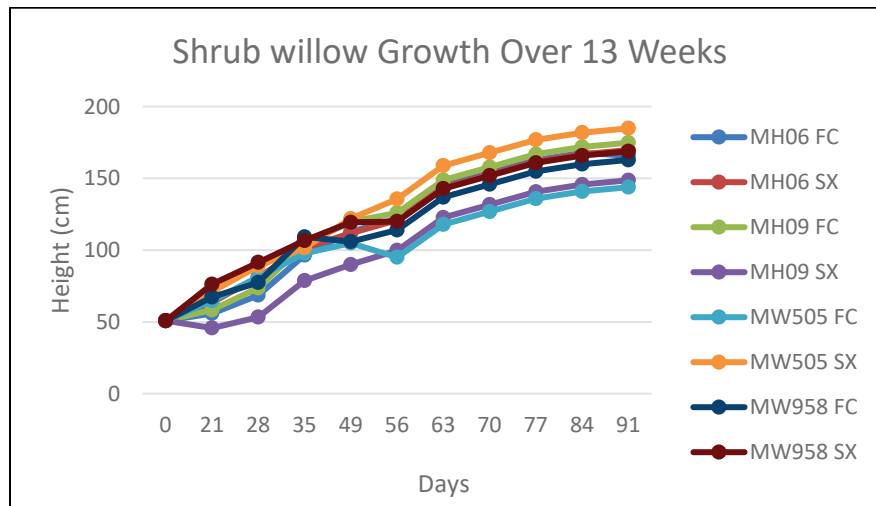
Table 8. Initial U concentrations (mg/kg) in NFSS soils MH06, MH09, MH505, and MH 958.

Sample ID	U (mg/kg)	Th (mg/kg)
MW06 0-4	8.9	4.6
MW06 4-7	17.3	3.2
MW09 0-4	1.7	3.7
MW09 4-6	1.6	4.1
MW505 0-12	1.7	3.7
MW505 12-16	3.9	3.6
MW958 0-2	2.6	3.6
MW958 2-4	4.3	4.3

Growth observations

Both shrub willows grew rapidly during the greenhouse study. The stem heights of both species grown in all eight soils went from 50.8 cm to an average of 164.93 cm after 13 weeks (Figure 12). Stems developed in just seven days (Figure 13). In one month, there were yellowing of leaves observed in SX61, likely resulting from a lack of nutrients, particularly N (Figure 15) (USEPA 1986). Brown spots were observed on some of the leaves around day 56 (Figure 16), usually an indication of leaf disease caused by pathogens (that is, bacteria or fungi) (Uchida 2000).

Figure 12. Fish Creek and SX61 shrub willow growth over 13 weeks (up to 91 days).



Plant growth photos over 91 days

Figure 13. SX61 shrub willow at day seven (front row left) and at day 14 (front row right) grown in MH06 area soils.

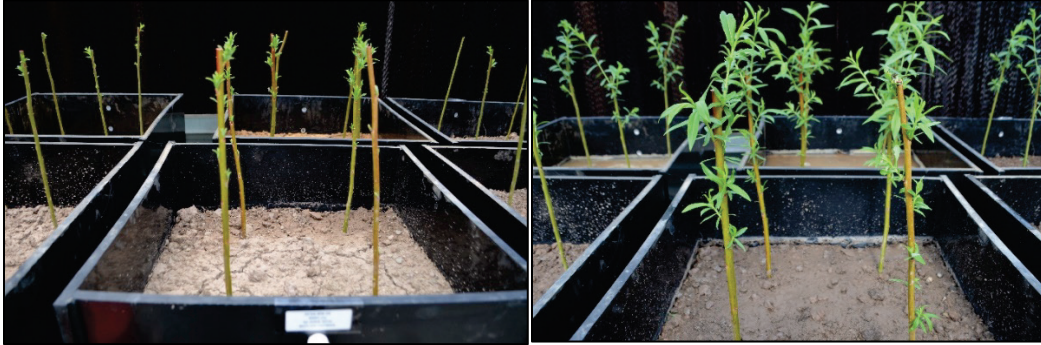


Figure 14. SX61 shrub willows grown in MH06 area soils at day 21 (front row left) and at day 28 (front row right) grown in MH06.

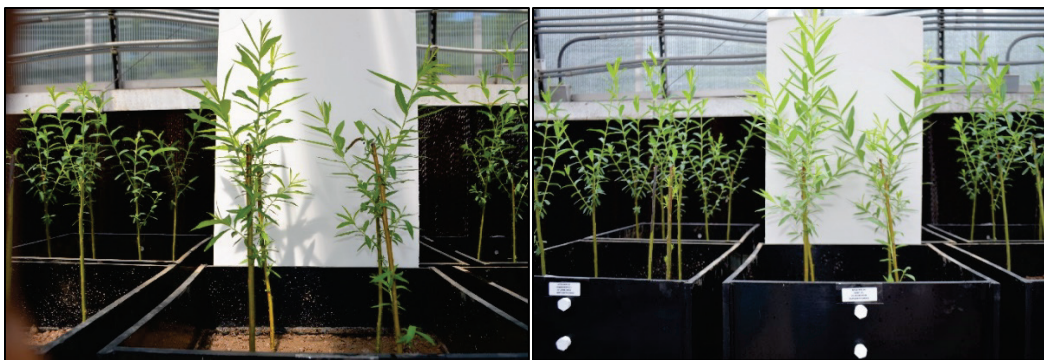


Figure 15. SX61 shrub willow grown in MW505 area soils at day 28 showing yellowing of leaves.



Figure 16. SX61 shrub willow grown in MW505 area soils at day 35 showing leaf brown spots.



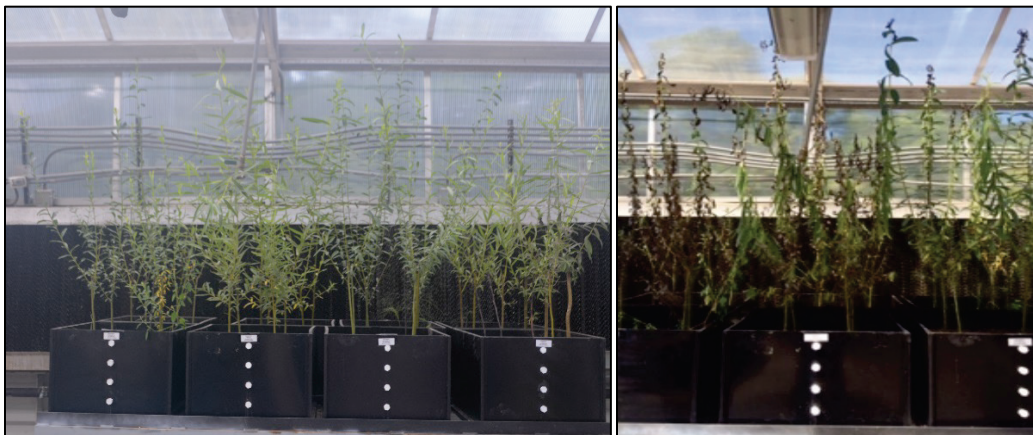
Shrub willow SX61 attained an overall greater biomass relative to Fishcreek, with a general trend of greater stem lengths (Figure 17). However, this outcome was expected, as SX61 cuttings were notably larger than Fischcreek cuttings (Figure 18). Comparing soil types and effects on plant growth, it appears the largest plants for both willow hybrids were observed in MW09 and MW958 soils. This observation is likely attributed to the higher Total Kjeldahl Nitrogen (TKN) concentrations present in the

soils. The lowest biomass was reported in MW505 soil, which also had the lowest TKN measurement.

Figure 17. SX61 shrub willow grown in MW06 area soils at day 56.



Figure 18. All eight containerized growth chambers at day 63 (left) and SX61 grown in MH06 area soils at day 91 (right).



Final soil U concentrations

The concentration of U measured in soils after 91 days of growing shrub willow cuttings was less in all soils, particularly MW 06 soils. As no leachate was lost from the bottom of the containers, this variation and decrease in concentration is likely due to the migration of the U into lower

layers of the lysimeter cell. This phenomenon would create a heterogeneous distribution of U in the soil mixture, resulting in the lack of U mass balance observed in the composite soil and plant tissue concentrations. Table 4 lists the initial concentrations of U in soils planted with each shrub willow hybrid. Approximately 97% and 99% total U recovery was observed in final MW 09 and MW 505 soils, respectively. Concentrations of U were notably less in final MW 06 and MW 958 soils (Table 9) relative to the initial soil concentrations (Table 8), since only 14% and 57%, respectively, of the U was recovered between soil and plant concentrations.

Table 9. Final U concentrations in greenhouse study soils.

Plant ID	Soil ID	U (mg/kg)	Plant ID	Soil ID	U (mg/kg)
FC	MW 06	1.733	SX	MW 06	1.467
	MW 09	1.295		MW 09	1.321
	MW 505	0.934		MW 505	1.626
	MW 958	1.954		MW 958	1.121

Uranium sorption by shrub willow roots

In addition to having a larger biomass, shrub willow hybrid SX61 accumulated higher concentrations of U in roots compared to the Fishcreek hybrid, although the total amount of accumulated U was still quantitatively minuscule (approximately 0.1%). This trend was observed for each of the four soil types. According to background measurements of the tested soils, a correlation between TKN and U sorption to Fishcreek and SX61 plant roots was observed, as sorption increased TKN concentrations were elevated (Table 10). However, the general mechanism of U uptake in plant roots is poorly understood, and it is therefore unclear if microbial activity influenced U sorption by plant roots. No correlation between cation exchange capacity (CEC) and U sorption or translocation was observed for either shrub willow hybrid. Uranium sorption and translocation data are shown in Figures 19 and 20, respectively.

Table 10. Initial and final soil background measurements (TKN—Total Kjeldahl Nitrogen).

Soil ID		Initial TKN (mg/kg)		Initial CEC (meq/100 g)	
MW 06		1800		19.85	
MW 09		2700		24.11	
MW 505		1400		11.07	
MW 958		2200		9.231	
Final TKN (mg/kg)					
FC	Soil ID	TKN	SX	Soil ID	TKN

	MW 06	1700		MW 06	1400
	MW 09	1700		MW 09	2000
	MW 505	1300		MW 505	1600
	MW 958	1900		MW 958	1700

Figure 19. Bar graph showing concentration of U in shrub willow roots.

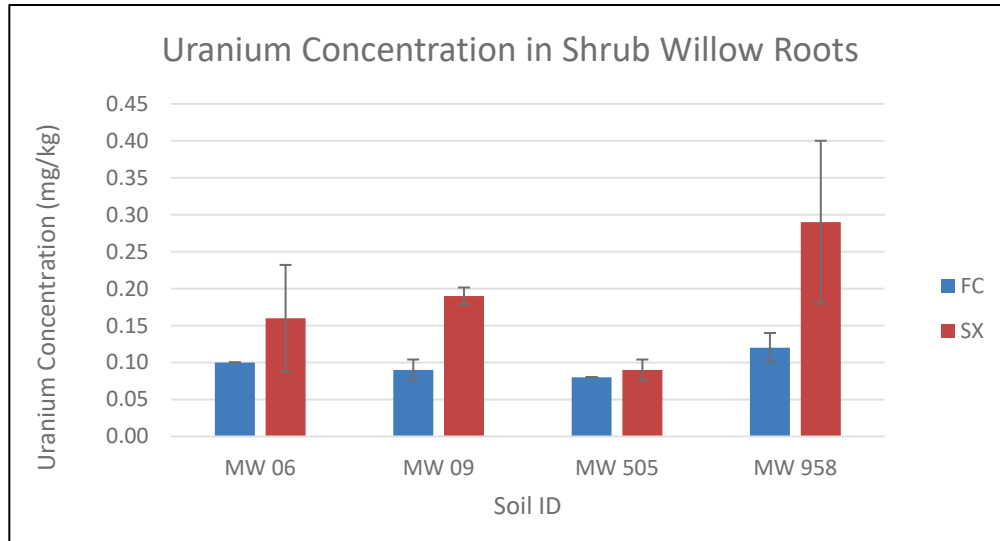


Table 11. Shrub willow root biomasses.

Plant ID	Soil ID	Dry Wt. (g)	Plant ID	Soil ID	Dry Wt. (g)
FC	MW 06	6.2	SX	MW 06	8.6
	MW 09	8.8		MW 09	9.1
	MW 505	2.0		MW 505	8.0
	MW 958	8.9		MW 958	16.7

Uranium translocation in shrub willow plants

Uranium uptake and translocation in shrub willow hybrids Fishcreek and SX61 were modest in magnitude, with an average accumulation in leaves of both hybrid types approximately 0.1% relative to soil concentrations. Soil background measurements, plant biomasses, and U concentrations reported in test soils and plant tissues are detailed in Figure 20 and Tables 11–14.

Figure 20. Bar graph showing U translocation into Fishcreek and SX61 leaves.

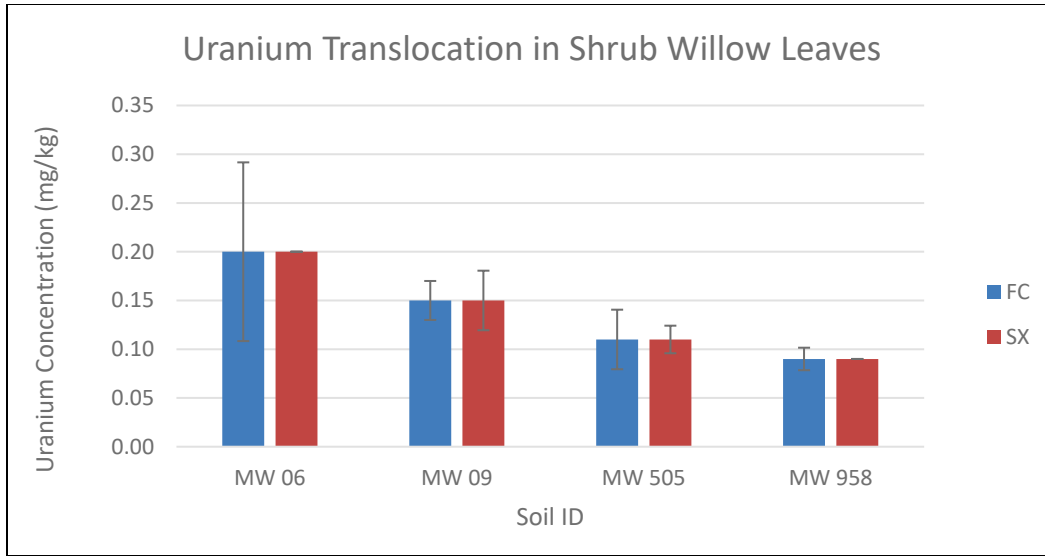


Table 12. Biomasses of shrub willow leaves.

Plant ID	Soil ID	Dry Wt. (g)	Plant ID	Soil ID	Dry Wt. (g)
FC	MW 06	46.8	SX	MW 06	45.0
	MW 09	16.5		MW 09	25.7
	MW 505	10.3		MW 505	32.2
	MW 958	29.6		MW 958	63.8

Table 13. Biomasses of shrub willow cuttings and stems.

Plant ID	Soil ID	Dry Wt. (g)	Length (cm)	Plant ID	Soil ID	Dry Wt. (g)	Length (cm)
FC	MW 06	60.9	137	SX	MW 06	70.2	143
	MW 09	98.9	152		MW 09	90.4	162
	MW 505	56.4	134		MW 505	68.0	138
	MW 958	62.8	148		MW 958	102.4	136

Table 14. Uranium concentrations in plant stems.

Plant ID	Soil ID	U (mg/kg)	Plant ID	Soil ID	U (mg/kg)
FC	MW 06	0.24	SX	MW 06	0.20
	MW 09	0.14		MW 09	0.15
	MW 505	0.11		MW 505	0.11
	MW 958	0.00		MW 958	0.09

Uranium concentration data for shrub leaves and stems indicated that hybrid willow SX61 translocated equivalent U concentrations relative to Fishcreek in each of the four soils (Figure 20). Fishcreek and SX61 hybrid types accumulated approximately 0.02%, 0.007%, 0.006%, and 0.008% U from MW 06, MW 09, MW 505, and MW 958 soils, respectively. Very little to no U was detected in the stem tissues of either plant.

4 Conclusions

Although hybrid willow SX61 grew to a greater mass compared to the Fishcreek hybrid, the potential of the two plants to translocate U and Th are comparable. Hybrid willow SX61 appears to have a greater capacity to stabilize U in the soil, as higher concentrations of the uranium were sorbed to the roots. This capacity is a promising characteristic for phytomanagement, as contaminant stabilization can be achieved using plants with a low translocation potential. Overall, U translocation ability for both Fishcreek and SX61 are low. Unlike translocation characteristics demonstrated by Fishcreek and SX61 hybrids in the greenhouse study, an established trend for translocation ability was not observed in field plants due to the low concentrations of U detected in each plant.

Overall, this investigation demonstrated that both Fishcreek and SX61 shrub willow hybrids are poor accumulators of the radionuclides U and Th because of the relatively small quantities of the elements measured in plant tissues. This similar characteristic ensures the two species are favorable for contaminant stabilization via subsurface dewatering from evapotranspiration, yet they will not create an exposure risk to fauna that browse the plants.

References

- Ahmed, H., Young, S., Shaw, G. 2012. Solubility and Mobility of Thorium and Uranium in Soils: The effect of soil properties on TH and U concentrations in soil solution. Geophysical Research Abstracts. Vol. 14.
- Bednar, A., Gent, D., Gilmore, J., Sturgis, T., Larson, S. 2004. Mechanisms of Thorium Migration in a Semiarid Soil. *Journal of Environmental Quality*. 33:2070–2077.
- Clayton, C., Kothari, V., Starr, K., Widdop, M., Gillespie, J. 2012. Evaluation of final radiological conditions at areas of the Niagara Falls Storage Site remediated under the Formerly Utilized Sites Remedial Action Program (FUSRAP). WM2012 Conference, Phoenix, Az, USA.
- Kumar, A., Rout, S., Mishra, M., Karpe, R., Ravi, P., Tripathi, R. 2015. Impact of particle size, temperature and humic acid on sorption of uranium in agricultural soils of Punjab. *Springerplus*. 4:262-270.
- Shimshi, D. Leaf Chlorosis and Stomatal Aperture. 1967. *New Phytologist*. 66 (3): 455-461.
- Uchida, R. 2000. Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms in “Plant Nutrient Management in Hawaii’s Soils: Approaches for Tropical and Subtropical Agriculture”, J. A. Silva and R. Uchida, eds., pp 31-55. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.
- USACE. 2011. NFSS remedial investigation report addendum. <http://www.lrb.usace.army.mil/Missions/HTRW/FUSRAP/NiagaraFallsStorageSite.aspx>.
- USEPA (US Environmental Protection Agency). 1986. Method 9081 Cation-Exchange Capacity of Soils (Sodium Acetate). Revision 0. Washington, DC: US Environmental Protection Agency. <https://www.epa.gov/sites/production/files/2015-12/documents/9081.pdf>.
- USEPA. 1994. Method 6020: Inductively Coupled Plasma—Mass Spectrometry. Revision 0. Washington, DC: US Environmental Protection Agency. <https://www.epa.gov/sites/production/files/documents/6020.pdf>.
- USEPA. 2000. pH in Liquid and Soil SW-846 Method 9040 (Liquid) and SW-846 Method 9045 (Soil). Revision January 21, 2000. Washington, DC: US Environmental Protection Agency. https://19january2017snapshot.epa.gov/sites/production/files/2015-06/documents/9045_1crf.pdf.
- USEPA. 2007. “Method 3051A (SW-846): Microwave Assisted Acid Digestion of Sediments, Sludges, and Oils.” Revision 1. In *Selected Analytical Methods for Environmental Remediation and Recovery (SAM)*. Washington, DC: US Environmental Protection Agency. <https://www.epa.gov/esam/us-epa-method-3051a-microwave-assisted-acid-digestion-sediments-sludges-and-oils>.

REPORT DOCUMENTATION PAGE

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14. ABSTRACT The Manhattan Engineer District previously used the 191-acre Niagara Falls Storage Site (NFSS) in Niagara County, New York, to store radioactive residues and wastes from uranium (U) ore processing. At present, management practices will determine whether enhanced evapotranspiration rates produced by hybridized shrub willow cuttings planted in 2016 will affect groundwater hydrology. Two shrub willow varieties were planted in an approximately one-half acre area to examine growth performance along a U impacted sanitary sewer line. Additionally, control plots will compare the effectiveness of shrub willows to unplanted areas. Observations of the planted area after 18 months showed success of shrub willow growth with increasing biomass. Chemical analysis from tree tissue samples of the field study showed no significant uptake of U or thorium (Th) to date. A greenhouse study conducted in parallel to the field study tested the willows under controlled greenhouse conditions and evaluated their ability to grow and accumulate contaminants under controlled conditions. Results from the greenhouse study demonstrated that U accumulation was minimal. Thus, this study demonstrates that the shrub willows are not accumulators of U or Th, an advantageous characteristic that implies stabilized contaminants in the soil and no translocation of U into the aboveground biomass.					
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