Evaluation and Application of Phytoremediation at FUSRAP Projects - 16275

Michelle Barker[1], John Busse[1], William Frederick[1], Karen Keil[1], Mathew Masset[1], Jane Staten[1] and Neil Miller[1]**,** Afrachanna Butler[2], Catherine Thomas[2], Nathan Beane[2], and Joseph Kreitinger[2]
[1]U.S. Army Corps of Engineers, Buffalo District, Buffalo, NY
[2]U.S. Army Corps of Engineers, Engineer Research and Design Center, Vicksburg, MS

ABSTRACT

The Niagara Falls Storage Site (NFSS) and associated vicinity properties (VPs) occupy approximately 607 hectares (1,500 acres) of the original 3,035-hectare (7,500-acre) Lake Ontario Ordnance Works (LOOW). The NFSS was used to store radioactive materials, residues and waste from uranium ore processing between 1944 and1952. A field-study is currently underway to evaluate the potential use of hybridized trees to stabilize radionuclides, mainly uranium, and chlorinated solvents derived from trichloroethylene degradation in groundwater at the NFSS. The purpose of this effort is to support the USACE-Buffalo District in the evaluation and implementation of phytoremediation approaches to contain groundwater impacts on the site. This demonstration project is considered a site maintenance action and will have relevance to the Formerly Utilized Sites Remedial Action Program (FUSRAP) mission.

The demonstration is designed to determine the ability of trees to withstand and uptake Uranium (U), and to a lesser extent Trichloroethylenes (TCEs), and hydraulically control groundwater where historical practices produced a series of disconnect plumes. Although the groundwater at the NFSS is naturally high in total dissolved solids that preclude untreated consumption, the groundwater contaminant levels are very high in some areas and may limit the options for future site re-use.

Active groundwater remediation is impractical due to the clayey site soils and low risk of transport. The phytoremediative approach is a passive action to lessen the groundwater impacts during the project's life cycle and property re-use planning. The target contaminant sources and plumes occur near the property boundaries, along legacy sanitary sewer lines, and near on-site surface-water courses. The demonstration includes soil characteristic determinations, the testing of optimal hybrid tree species, field implementation at target sites, and soil moisture and groundwater monitoring during the long-term evaluation phase. The final disposition of the trees will be included in future site decision and maintenance documents.

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) Buffalo District is evaluating dendroremediative techniques as a phytomanagement strategy to control contaminants in groundwater that may impact uncontaminated soils at the NFSS. This interim site-management effort has relevance to the Formerly Utilized Sites Remedial Action Program (FUSRAP) goal for the site (i.e., risk mitigation) [1, 2, 3]. Shrub and tree species are being evaluated as a means for 1) hydrologic control in areas of higher groundwater concentrations and 2) the potential translocation of uranium from groundwater to the plant structure. The characterization of metals and radionuclides in soils and native flora within the NFSS is also being performed. This effort aligns with the Corps' Engineering with Nature Initiative, which encourages aesthetic vegetation that can 1) create a new habitat for wildlife while phytomanaging soil and groundwater contaminants and 2) provide collaboration with research stakeholders (local universities).

Figure 1 shows the uranium impacts in groundwater and the areas of phytomanagement evaluation (i.e., sanitary sewer traces and organic compound impacts) [1, 2].

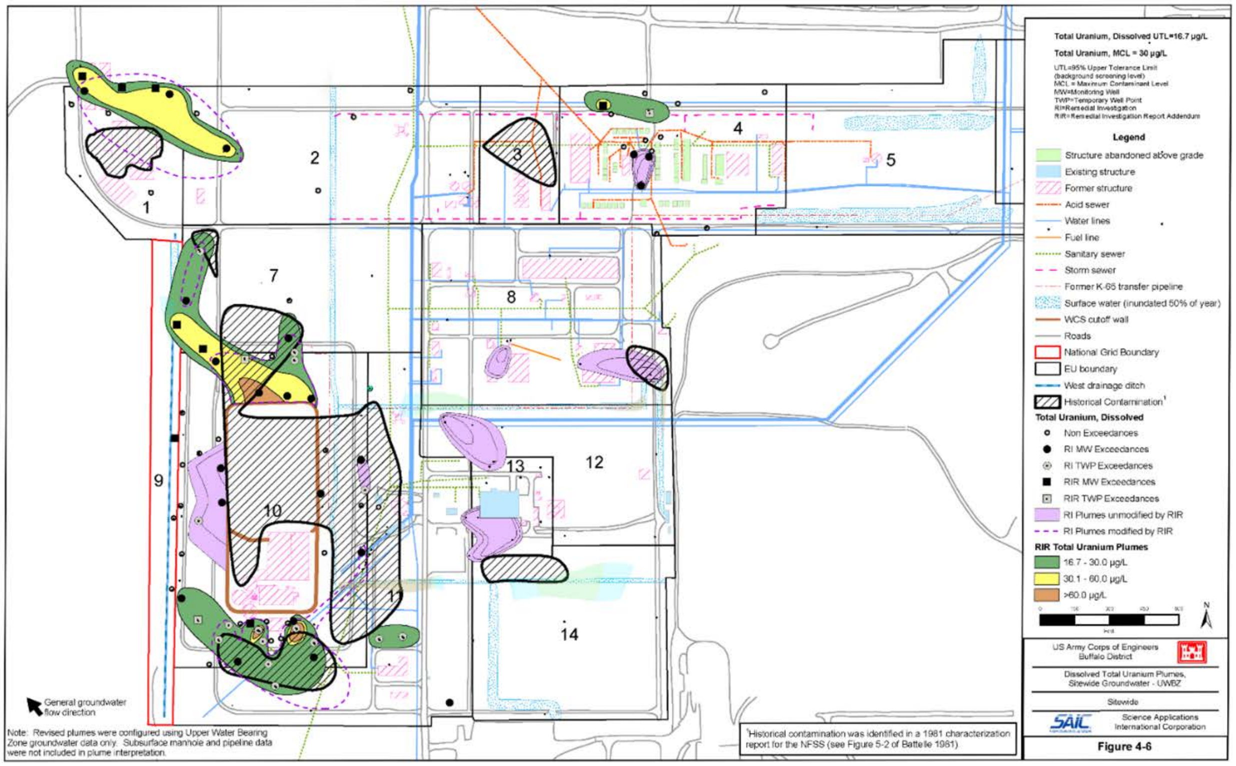

Figure 1. Uranium Contamination in the Upper Water-bearing Zone

METHOD

Site hydrogeology

The surficial geology is composed of a Brown Clay Till that consists of a clayey silt and silty clay groundmass containing non-contiguous sand and gravel lenses, which together comprise the upper water-bearing zone (UWBZ). A geostatistical analysis of these coarse grained lenses show a vertically and horizontally discontinuous distribution that varies considerably in thickness, color, texture, extent, and saturation. The lenses are not horizontally continuous over distances greater than 4.6 to 6.1 meters (m) (15 to 20 feet [ft]) and vertical distances of 1.2 to 1.8 m (4 to 6 f) [1,3,6]. As a result, the occurrence of groundwater in the UWBZ varies across the site; proximate wells may have noticeably different water levels depending on sand lens presence and evapotranspirational stress [1, 3]. The UWBZ overlies a Gray Lacustrine Clay aquitard that hydraulically separates the underlying lower water bearing zone (LWBZ), which is composed of an Alluvial Sand and Gravel, Red Lodgment Till, and Queenston Shale bedrock.

The interpretation of regional groundwater flow in the UWBZ is to the northwest towards the Niagara River and Lake Ontario. The average horizontal gradients typically range between 0.0012 and 0.0074 m/m, which reflects the flat lake plain environment surrounding the site (Figure 3). Groundwater seasonally fluctuates and average of 2.4 feet (2012) and is most pronounced in wells with no sand lenses, which is normal for fine-grained lithologies [1, 2].

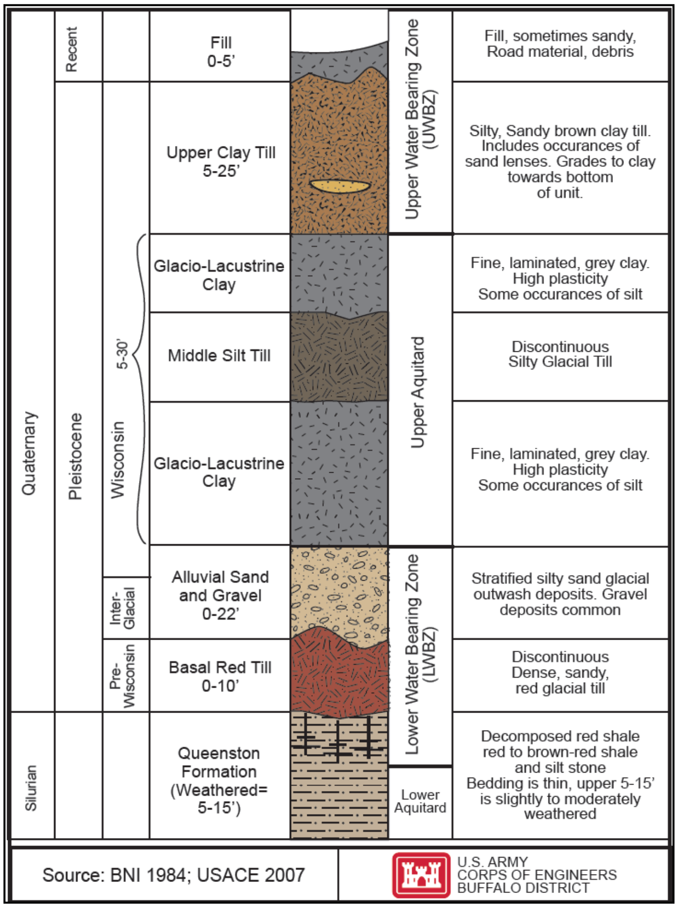

Figure 2. Hydrostratigraphy at NFSS

Site contamination

The groundwater sampling history at the NFSS spans nearly 30 years [1]. Summary analyses confirm that groundwater in the NFSS area is naturally poor in quality due to high salinity and mineralization [2, 3, 4]. The water quality in the UWBZ is indicative of low recharge to a hydraulically slow flow system, which produces mineralized (saline) groundwater containing high total dissolved solids (TDS) and calcium/magnesium sulfates derived from the glacial sediments. The water quality in the LWBZ is relatively higher in salinity, total dissolved solids, sulfate species, and several metals without drinking water standards (e.g., calcium, magnesium, potassium, sodium) due to the mineralization in this zone.

This natural condition was degraded by radionuclide and organic compound handling and storage that produced soil contamination and associated uranium impacts in the UWBZ (Figure 1). Remedial actions throughout the 1970s and 1980s focused on soil and sediment consolidation on the NFSS, although some operational areas still exhibit residual soil contamination [5]. Soil-based constituents of concern identified during the Baseline Risk Assessment (BRA) [1] include the uranium-238 and -235 series, arsenic, boron, cadmium, antimony, methylene chloride, and trichlororethylene (TCE) and associated byproducts. The widest impacts to groundwater appear from total uranium, thus the majority of groundwater monitoring is focused on uranium radionuclides. The phytomanagment of the site

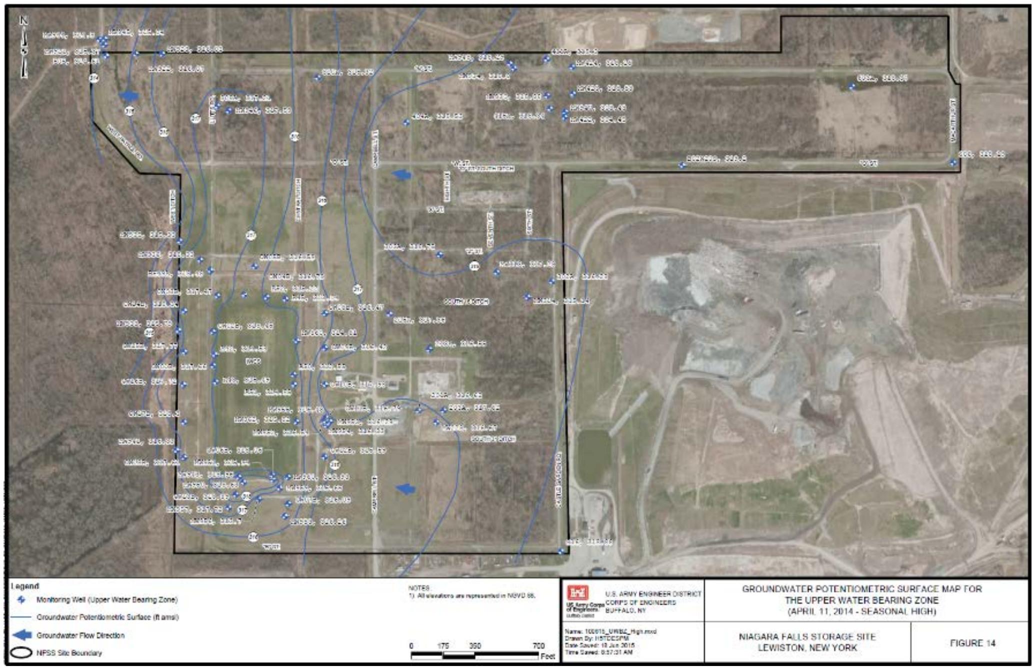

Figure 3. NFSS UWBZ Potentiometry

contamination will be focused on select areas where high concentrations of uranium is evident in groundwater or soils.

RESULTS

Storage areas and sewer-line impacts

Legacy storage and waste handling areas south and east of the Interim Waste Containment Building (IWCS) were investigated for radiologic constituents in soil that would be a source for local groundwater contamination. Soil borings, test pits, and monitoring wells were installed and sampling data indicate low-concentration uranium impacts in soil, but higher than expected uranium concentrations in groundwater. The sanitary sewer lines south and east of the IWCS were partially excavated, exposed, sampled (interior material and exterior soil and groundwater), and plugged were needed (Figure 4). Manhole #6 (MH06) was removed and revealed that the sanitary sewer line is partially filled with a black crystalline material containing approximately 610 milligrams per kilogram (mg/kg) of uranium. This sewer line is a 2.5- to 3-m (8- to 10-ft) deep, 45-cm (18-inch) round clay pipe with an 1.3-m (4-ft) square concrete form poured on top; this encasement probably was installed to support truck and rail-cars crossing the line. The line deepens to the north towards a legacy sewerage treatment facility that served historic explosive-manufacturing facilities [1].

Several well arrays and investigation excavations were clustered or aligned to best define contaminant migration potential near this line-source. The uranium concentrations in groundwater were greatest in the excavation water surrounding the sewer line (~7,000 migrograms per liter (µg/L); the groundwater concentrations declined to 85 µg/L about 8 meters (25 ft) downgradient. Such concentrations are evident elsewhere along this utility near the IWCS, so the uranium-containing crystalline material in the pipe is considered a linear source to groundwater collecting in the legacy utility trenches that were loosely backfilled during site construction, as evidenced on historic aerial photographs [1].

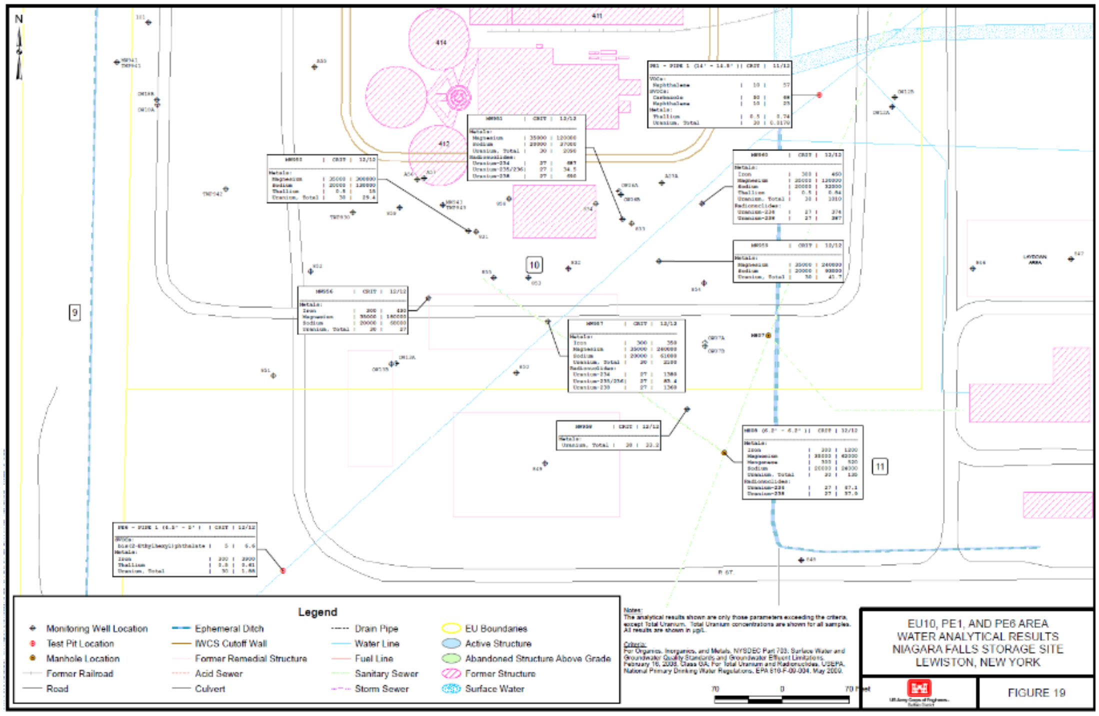

Figure 4. Storage and Utility Area Groundwater Impacts

The linearity of the utilities posed an opportunity for the management of this groundwater source by using phytoremediative techniques to manage the impacted groundwater during the decision-making process for the site [6]. This site management strategy is discussed below.

Phytomanagment of groundwater sources

The phytoremediative techniques planned at the NFSS will focus on the extraction of uranium and organic compounds from groundwater, as a long-term site management component. The intent is to ensure that site re-use options are not limited by uranium in groundwater derived from impacted utilities. A literature review determined that hybrid willow shrub and tree species were candidates for uranium uptake studies in a greenhouse setting, which began in the fall of 2015. Soil samples were analyzed for biologic support constituents, such as soil texture and biogeochemical indicators (e.g., total metals concentrations, pH, cation exchange capacity, total organic carbon, and total nitrogen). A series of existing vegetative samples, including tree cores, bark samples, roots and leaves, were analyzed for uranium, radium, and thorium isotopes. The data indicate that current site species are not bioaccumulating uranium, thorium, or radium isotopes.

A 2016 field study using selected willow or hybrid cultivars will occur after the greenhouse studies and be focused on 1) the transpiration of groundwater along contaminated sanitary sewer lines and 2) the potential for translocation of contaminants (or up-take) into the plant. The greenhouse studies monitored containerized plantings in high-clay soils to emulate NFSS conditions. Selected containers were experimentally spiked with uranium to examine cultivar variance of bioaccumulation and rates of translocation.

In the spring of 2016, a planting corridor along the most impacted site utilities will be defined and the soil prepared for installation of biotechnical features. Soil samples will be collected to provide estimates of fertilizer levels or soil amendments that are needed during tillage. The test plots above the sewer lines will cover about 0.8 hectares (2 acres) (Figure 5). The area will be divided into planted versus unplanted (i.e., control) test plots. Four, fast growing, cultivars are expected to emerge from the greenhouse study and will be planted on site in 2016. Field lysimeters and/or piezometers will be installed beneath the ground surface to monitor changes in subsurface water levels and dissolved uranium within and near the various species plots.

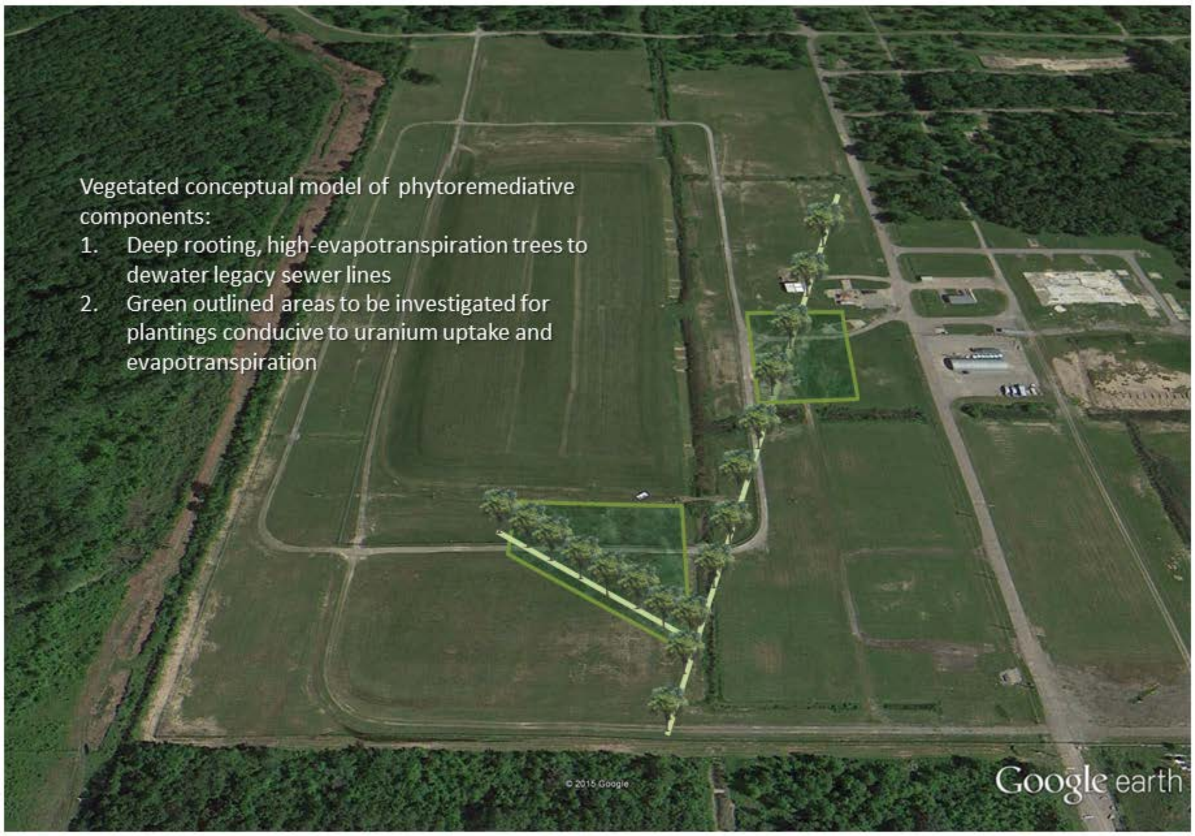

Figure 5. Proposed Phytomanagment Areas at NFSS

In addition to shrub and smaller tress species, select segments of the sewer line surrounded by high concentration groundwater may be planted with a hybrid poplar tree that will firstly control groundwater movement via evapotranspiration and secondly promote translocation of uranium from groundwater. The hybrid poplar trees may be planted using a “tree-well” system similar to patented EnPhySys to promote aggressive root development and to increase the phytomanagement potential of the trees. The Army Corps team will monitor the success of the shrub willow and hybrid poplar trees by measuring the health and growth characteristics (i.e., height and trunk circumference). Vegetation (i.e., leaves and pruned tree parts) samples will be collected to monitor plant bioavailability and uptake of site-related radionuclides. Coincidentally, the subsurface hydrogeologic conditions will be assessed for groundwater extraction characteristics and geochemical changes derived from the presence of the vegetation.

CONCLUSION

Groundwater contamination near legacy radioactive-residue storage areas and along impacted sanitary sewer lines provide an opportunity to test phytoremeditive technologies as part of the NFSS operation and management program. Since site remediation may be over 10 years away, the interim management of contaminant sources for groundwater will ensure that adjacent soils do not become contaminated by the diffusion of high-concentration groundwater evident near a sanitary sewer line. The groundwater is not considered a consumptive resource due to naturally high salinity and poor quality, thus this phytomanagment program is designed to minimize soil impacts from groundwater contamination (i.e., volumetric growth of soil impacts).

The analysis of site soils and greenhouse studies of uranium uptake will indicate the optimal shrub and tree species that would promote uranium scavenging from site groundwater and possibly soils. Program actuation will include planting scenarios and techniques to dewater the utilities, minimize uranium in groundwater, and have low maintenance. This work also will provide species and techniques that can be widely applied to groundwater impacts throughout the NFSS. Groundwater quality and hydrology within and around the plantings will be monitored routinely to document the effects on soil moisture. The phytomanagement success metrics will be 1) source management via hydraulic control, 2) uranium removal from groundwater, and 3) promotion of geochemical conditions that lower uranium solubility in groundwater (reductive conditions). This program work will continue through 2019, when the viability of the phytomanagement techniques at the NFSS will be evaluated for maintenance or expansion pending the hydrogeologic and contaminant-distribution responses.

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