

Publication No. 03-129-185

WATER QUALITY INVESTIGATION OF IN-SITU TAILING SAND DEPOSITS UNDER NATURAL ENVIRONMENTAL CONDITIONS

Prepared by
Schreuder, Inc.

under a grant sponsored by



July 2002

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WATER QUALITY INVESTIGATION OF IN-SITU TAILING SAND DEPOSITS
UNDER NATURAL ENVIRONMENTAL CONDITIONS

FINAL REPORT

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July 2002

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PERSPECTIVE

Demand for water in central Florida is increasing while the availability of groundwater is dwindling. Saltwater intrusion is threatening the Floridan Aquifer in coastal areas, while lowered aquifer levels are of concern in more inland areas. The Southwest Florida Water Management District (SWFWMD) is proposing to cut back on the permitted quantities of water pumped from the Floridan Aquifer in the Southern Water Use Caution Area (SWUCA) so as to be closer to sustainable yield levels. This will have a significant impact on current, and especially future, water users. To meet the growing demands of development, alternative sources of water must be sought. Possible sources are reclaimed wastewater, the capture of storm water, the capture of "excess" surface water, development of the surficial aquifer, and desalinization of seawater.

This project is part of an effort to examine the feasibility of storing wastewater or excess surface water in reservoirs on mined lands, purifying the water with wetland treatment and sand tailing filtration, and then injecting the treated water into the Floridan Aquifer. This project examines water quality in several sand tailings deposits in the field and provides additional validation of earlier laboratory leaching tests on the effects of sand tailings filtration on water quality.

Other FIPR-funded projects on this topic include:

- Potential Use of Phosphate Mining Tailing Sand for Water Filtration: Leaching Tests (FIPR Publication No. 03-113-154). This report addresses the leaching of sand tailings in barrels as a first step in determining the effects of sand tailing filtration on water quality.
- An Investigation of the Capacity of Tailing Sand to Remove Microorganisms from Surficial Waters (FIPR Publication No. 03-124-153). This is a laboratory column leaching study to examine microorganism removal by sand tailing filtration.
- Feasibility of Natural Treatment and Aquifer Recharge of Wastewater and Surface Waters Using Mined Phosphate Lands: A concept to Expand Regional Water Resource Availability (FIPR Project No. 94-03-113). This project examines the feasibility, including costs, of several potential real world possibilities for water treatment and storage on mined lands.
- Pilot Project to Test Natural Water Treatment Capacity of Wetland and Tailing Sand Filtration Concept (FIPR Project 98-03-136). This is a larger field demonstration of wetland treatment and sand tailing filtration on the quality of storm water and waste water.

Steven G. Richardson
FIPR Reclamation Research Director

ABSTRACT

Tailing sands are abundant by-products of the phosphate ore beneficiation process, which are deposited as piles on undisturbed land, as piles over waste clay settling areas, and as fill in mine cuts. Tailing sand deposits from twelve locations, six each from pile and fill deposits, were identified and explored with geotechnical borings. At each location, a temporary monitoring well was installed and a sample of the ground water from the tailing sand deposit was obtained. Each sample was analyzed for primary and secondary drinking water standards. The water quality profiles of the fill and pile samples were compared.

Ground water samples from tailing sand deposits met EPA and State of Florida primary and secondary drinking water standards for all but a few parameters. The main parameters that exceeded drinking water standards were iron and manganese, cations that commonly occur in natural ground water at concentrations exceeding secondary drinking water standards. In a few samples, aluminum, antimony and cadmium exceeded drinking water standards, although the occurrence of these parameters was likely due to suspended clay in the samples. Ground water samples from tailing sand fill deposits had fewer exceedances of drinking water standards than samples from pile deposits (several of the piles were deposited over waste clay). Water quality differences among sites did not appear to be related to the age of the tailing sand deposits.

ACKNOWLEDGMENTS

The initial proposal entitled “Water Quality Investigation of *In-situ* Tailing-sand Deposits Under Natural Environmental Conditions” was submitted to the Florida Institute of Phosphate Research (FIPR) with the encouragement of the Executive Director, Paul Clifford, Ph.D. in September of 1997. After the proposal was reviewed under FIPR’s guidelines and under the direction of Steven Richardson, Ph.D., FIPR’s Reclamation Research Director, the Board approved FIPR Contract # 97-03-129, effective September 1, 1998. The members of the Board were B. Bandyopadhyay, Richard L. Coleman, A.L. “Judge” Holmes, M. Jack Ohanian, and Sam Zamani.

The members of the research team that worked on the project were: Peter J. Schreuder, C.P.G., the principal investigator, John M. Dumeyer, P.E., P.G., the project manager, H. Cliff Harrison, P.G., the senior hydrogeologist, and Samantha D. Andrews and Holly L. Barnette, the project hydrogeologists. Lee Cawley, of IMC Phosphates Company, and Thomas E. Myers II, P.E., of Cargill Fertilizer, Inc., provided valuable knowledge of the nature and history of various tailing sand deposits, as well as access to the sampling sites.

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EXECUTIVE SUMMARY

This report describes work performed as part of an ongoing Florida Institute of Phosphate Research (FIPR) project to investigate the possible use of mined phosphate lands as a tool in regional water-resource management. The overall study addresses the feasibility of temporarily storing excess surface water, followed by wetland treatment by biological processes and then filtering in a tailing sand filter bed. A previous bench test suggested that a tailing-sand filtrate poses little concern with respect to the radionuclide parameters evaluated. It was important to validate this bench test data using sands that are in place and are under natural hydrological conditions. This study was the next step to ensure that filtering surface water through tailing sands does not adversely affect the water quality of the filtrate. It was the intent of this investigation to validate the results of the bench test by investigating *in-situ* tailing sands with respect to age and location. Further, the test's analytical parameters were increased to include additional inorganics, nutrients, and organic compounds regulated by the EPA and State of Florida primary and secondary drinking water standards (Environmental Protection Agency 2000).

The use of tailing sands as a filter medium provides the opportunity to purify excess surface water, storm water, and wastewater to meet drinking water standards. Meeting these standards may allow and encourage recharging of filtered surface water to the Floridan Aquifer. The Southwest Florida Water Management District has found the Floridan Aquifer to be significantly stressed by over-pumping in the Southern Water Use Caution Area (SWUCA). Since the majority of phosphate mining is located in the SWUCA, recharge of the Floridan Aquifer would be a significant benefit to the area.

Twelve tailing sand sites were selected. Out of the total twelve sites, six were in above ground piles or piles over clay, and six were in sands deposited below grade in mine pits (fill). At two locations, paired sets of tailing-sand sites were selected from the same general mine area. The paired sites had similar sands but differed in how they were deposited (one example each of pile and fill sites). An additional criterion in the selection of tailing sand sites was the relative processing ages of the sands, the goal being to determine whether the processing age of tailing sands is related to the chemical profile of the ground water contained in them. Wells were constructed at each site and water samples were collected for analyses.

This project has shown that ground water contained within tailing sand deposits meets EPA and State of Florida primary and secondary drinking water standards for all but a few parameters. The most common exceedances of drinking water standards that were observed were for iron (nine out of twelve samples) and manganese (seven out of twelve samples), both secondary standards. Iron and manganese are common constituents of ground water in the region and can easily be eliminated with post-filtration treatment. Water quality differences among sites did not appear to be related to the age of the tailing sand deposits. However, the study indicated that ground water in tailing sands deposited over waste clays was slightly more likely to exceed drinking water standards for a few parameters, such as iron and manganese, than ground water in tailing sands deposited as fill in mine cuts (not in contact with waste clay).

INTRODUCTION

BACKGROUND

This report describes work performed as part of an ongoing Florida Institute of Phosphate Research (FIPR) project to investigate the possible use of mined phosphate lands as a tool in regional water-resource management. The overall study addresses the feasibility of temporarily storing excess surface water, wastewater, or storm water in a reservoir, prior to release to a manmade wetland area for treatment by biological processes. From the wetlands, the water will filter through approximately 20 feet of tailing sand deposits. The sand filtration step in the surficial water treatment is intended to further reduce total suspended solids and microorganisms and improve the water quality to drinking water standards. After treatment, this water can either be stored in the Floridan Aquifer for future use or pumped directly for consumer use. A schematic diagram of the process is included as Figure 1. The use of sand dunes to improve the quality of the Rhine River has been used in The Netherlands for over a century and currently produces high quality drinking water to that densely populated area.

DESCRIPTION OF PREVIOUS PROJECTS

The key to the successful implementation of the concept of natural purification of surficial water is the ability of the proposed system, including tailing-sand filtration, to produce water that meets state-mandated drinking water standards. Tailing sands contain small quantities of the phosphatic minerals that naturally contain unstable isotopes such as uranium and some of its progeny. Because the drinking water standards contain limits on certain radionuclide parameters, the possible impact of radionuclides liberated from the phosphate minerals into surface water filtered through tailing sands needs to be evaluated. Schreuder, Inc. (SI) performed a bench test to determine the degree that radionuclides associated with the tailing sands could leach into the surface water (Schreuder and Dumeyer 1998) (FIPR Project 94-03-113). The bench-test project included the analyses of 123 water samples and several soil samples. The results of that project showed that water in contact with tailing sands for up to 225 days generally met the EPA and State of Florida drinking water standards for radionuclides.

Another drinking water standard applies to the concentration of certain microorganisms (total coliform and *E. coli*) in the filtrate. It was important in the evaluation of the tailing sand filtration concept that the capacity of the tailing sands to remove microorganisms from surficial waters be investigated. SI recently teamed with the Department of Health to conduct a microorganism bench test funded by FIPR (Schreuder and others 1998) (FIPR Project 96-03-124R). That study's goal was to evaluate and quantify the capacity of tailing sand filtration to remove microorganisms from waters applied onto the tailing sands. The study indicated that tailing sand filtration with an unsaturated zone can remove microorganisms from the water.

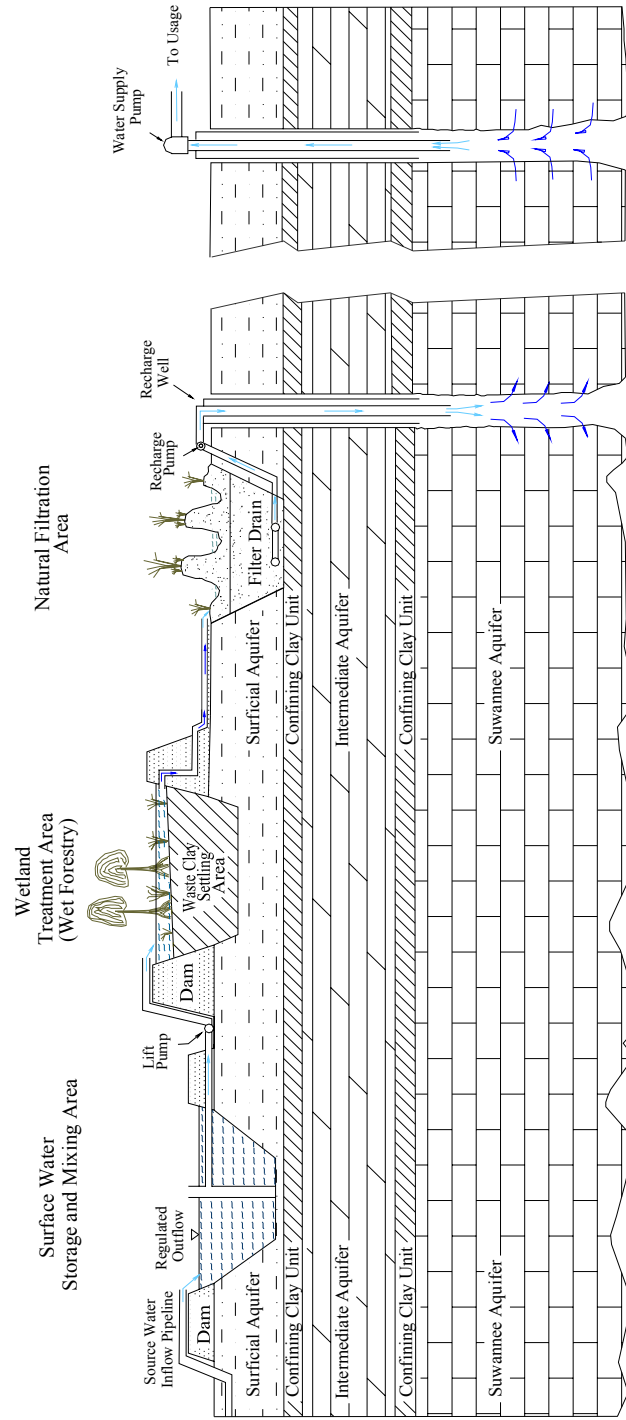


Figure 1. Cross-Section View of Natural Treatment and Aquifer Storage and Recovery Concept.

PURPOSE OF CURRENT INVESTIGATION

The previous radionuclide bench test suggested that a tailing-sand filtrate poses little concern with respect to the radionuclide parameters evaluated. It is important, though, to validate this test data using sands that are in place and are under natural hydrological conditions. This study is the next step to ensure that filtering surface water through tailing sands does not adversely affect water quality of the filtrate. It was the intent of this investigation to validate the results of the radionuclide bench test by investigating *in-situ* tailing sands with respect to age and location. Further, the test's analytical parameters were increased to include additional inorganics, nutrients, and organic compounds regulated by the EPA and State of Florida primary and secondary drinking water standards.

Certain natural factors could not be reproduced during the bench test. These factors, such as ground water flow conditions, rainfall, or variations with respect to tailing sands deposited above grade (in a pile) or within mine cuts, were not addressed. To describe tailing sand leaching and develop a quantifiable set of design criteria for a filtration basin, these factors must be evaluated *in situ* with respect to chemical characteristics under natural environmental conditions.

The use of tailing sands as a filter medium provides the opportunity to repurify excess surface water, storm water, and wastewater to meet drinking water standards. Meeting these standards may allow and encourage recharging of filtered surface water to the Floridan Aquifer. The Southwest Florida Water Management District (SWFWMD) has found the Floridan Aquifer to be significantly stressed by over-pumping in the Southern Water Use Caution Area (SWUCA). Since the majority of phosphate mining is located in the SWUCA, recharge of the Floridan Aquifer would be a significant benefit to the area.

Currently, tailing sands are considered a mining byproduct, used primarily in the phosphate mining industry's reclamation programs. The potential to repurify surface water, via tailing sand filtration, may likely increase the value of tailing sands to the community. As such, tailing sand filtration would enable the SWFWMD and the phosphate mining industry to initiate water reclamation policies and methods to reduce future water supply shortages at a low cost. Further, if proven successful, the overall project will provide an alternative source of sediment-free surface water for mining operations, thus reducing the need for pumpage from the Floridan Aquifer by the mining industry. This study also provides a basis for design criteria of the tailing sand filtration basin development.

REVIEW OF PERTINENT LITERATURE

Information on radionuclide concentrations from phosphatic tailing sands in the Bone Valley Phosphate District (Figure 2) is limited. Most previous studies involving tailing sands have focused on uranium-238 and radium-226. As indicated in Table 1,

reported radium-226 activities for tailing sands range from 1.68 pCi/g to 12.2 pCi/g. Guimond (1976) determined uranium-238 and radium-226 activities in tailing sands at 5.3 pCi/g and 7.5 pCi/g, respectively. These radionuclide activities commonly exist at levels less than that of the natural overburden without a leach zone (10 pCi/g, Texas Instruments, Inc. 1977). The leach zone is the upper portion of the phosphate deposit where downward movement of infiltration has removed soluble compounds. This region also coincides with increases in radionuclide activities of the sediment. Uranium-238 activities for the leach zone approach 10 pCi/g (Texas Instruments, Inc. 1977), while radium-226 activities approach 40 pCi/g (Kaufmann and Bliss 1977). The phosphate matrix underlies this zone with a radium-226 activity that generally exceeds that of the leach zone (see Table 1). Table 1 also shows radium-226 activities for natural soils, ranging from 0.5 to 1.5 pCi/g. These studies reveal a general increase in both uranium-238 and radium-226 activities with depth, where maximum activities occur in the leach zone and the phosphate matrix.

Mining of the phosphate matrix requires the excavation of all the overlying sediments. After removal of the matrix, an open mine cut remains. Since the leach zone and matrix are both removed in this process, the greatest sources of radionuclides are also removed. A comparison of uranium-238 and radium-226 concentrations between tailing sands and the natural sediments indicates that a mine cut filled with sand tailings should present a substantially smaller source of radionuclides to mobilization by percolating ground water. At present, no known study exists that addresses this situation, though several studies on radionuclide mobilization have been performed.

Upchurch and others (1991) performed a study on ground water radiochemistry, focusing on the uranium series isotopes. They indicated a low mobilization of uranium-238 and radium-226 occurring within apatite by natural ground waters. The study indicates that radium-226 activities exceed uranium-238 in pore water, but are commonly less than 5 pCi/l. As an inert gas, radon-222 readily disassociates from apatite during formation. The presence of both micro-fractures/pores within apatite and the effective porosity of the media are controlling factors in radon-222's capacity to migrate (Rama and Moore 1984) (Upchurch and others 1991). Lead-210, a daughter product of radon-222 decay, was shown as an unlikely source of radionuclide contamination. This is due to adsorption of lead-210 by clays and reaction with sulfide, sulfate, and carbonate to form low soluble compounds. Oural and others (1986) suggest that polonium-210 is the main source of alpha emission, particularly in the surficial aquifer, though a detailed understanding of its pore water activities is limited. This makes the characterization of polonium-210 within tailing sands important as a source of radionuclide contamination of pore water. In general, radionuclides appear to mobilize under oxidizing and low pH conditions.

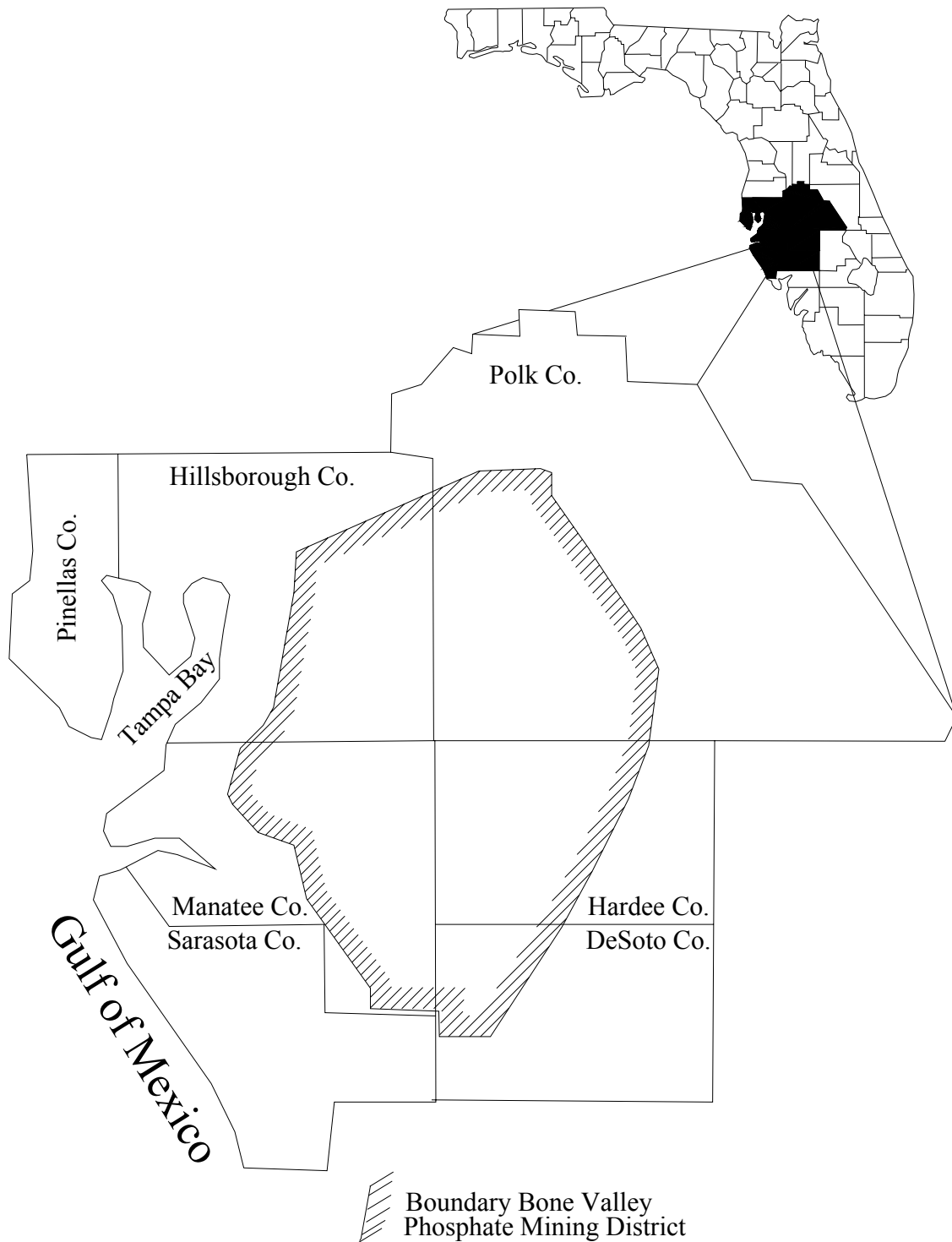


Figure 2. Location and Extent of the Bone Valley Phosphate Mining District, West-Central Florida.

Table 1. Summary of Reported Radium-226 Activities in Tailing Sands.

Average (pCi/g)	Range (pCi/g)	Reference	Location
<u>Sand Tailings:</u>			
--	6.2-8.8	Florida Department of HRS (1975)	
7.5	---	Guimond (1976)	
7.5	---	Kaufmann & Bliss (1977)	Central Florida
2.7	2.0-3.3	Roessler and others (1979)	North Florida
5	---	Roessler and others (1979)	Central Florida
5.2	1.7-12.2	Roessler and others (1980)	
4.28	2.92-5.16	FIPR, unpublished data	Central Florida, old
2.94	1.35-4.42	FIPR, unpublished data	Central Florida, fresh
5.05	3.30-6.80	FIPR, unpublished data	North Florida, old
1.68	1.05-2.30	FIPR, unpublished data	North Florida, fresh
<u>Soil:</u>			
1.5	---	EPA, unpublished data	
0.5	0.2-3.8	Roessler and others (1980)	
<u>Overburden:</u>			
10	---	Kaufmann & Bliss (1977)	Central Florida
2.5	0.2-30.6	Roessler and others (1980)	
13	---	EPA (1978)	
<u>Leach Zone:</u>			
40	---	Kaufmann & Bliss (1977)	Central Florida
<u>Matrix:</u>			
40	---	Florida Department of HRS (1975)	
60	---	Guimond & Windham (1975)	
85	---	Roessler and others (1979)	
25.9	6.0-137.0	Roessler and others (1980)	

A study by Burnett and others (1987) suggests a correlation between radionuclide activities and the degree of phosphatic rock weathering. They show a general increase in radionuclide activities of “weathered samples” relative to “unweathered samples.” Further, a shift in activities between the unweathered and weathered samples suggests a distribution relationship relative to grain size. The activities of the unweathered samples roughly parallel the mass distribution of the phosphatic component, while in the weathered samples it concentrates in the finest and coarsest phosphatic components. They suggest that this fractionation, relative to grain size, is explained by a surface area effect related to an increase in the phosphatic surface area of the fine components and radionuclide concentration by recrystallization in the coarse fraction. It may be argued that the difference in activities between the older weathered and younger unweathered tailing sands is primarily a factor of improvements in the beneficiation process. The unweathered (younger) tailing sands have less phosphatic material, and thus, lower activities. Data from an unpublished study by the Florida Institute of Phosphate Research indicates an increase in radium-226 activities of older tailing sands relative to fresh tailing sands (Table 1). The old tailing sands range in age since processing from 10 to 20 years and the fresh tailing sands only range from days to weeks in age.

Another aspect of the Burnett study led to the investigation of leaching characteristics of radionuclides from phosphatic rock. Natural ground water conditions were simulated in the laboratory and placed in association with powdered phosphatic rock. Humic acid (as Suwannee River water) leached uranium-238 from both unweathered and weathered samples, while leaching radium-226 from primarily weathered samples. Ammonium chloride and ammonium carbonate solutions and double-deionized water were also found to leach radium-226. Polonium-210 showed no leaching preference associated with any of these solutions.

A study by El-Shall and Bogan (1994) describes a general north-south variation in the phosphate matrix through the Central Florida region. The variation in the matrix is generally related to upper and lower zones within the Bone Valley and Hawthorn formations. Further, a decrease in ore grade is demonstrated from north to south in the southern extension of the Central Florida mining district.

METHODOLOGY

SELECTION OF SITES

The selection of the tailing sand sites was originally to be based on two main criteria: sands that were deposited above ground (in piles) and sands deposited below grade in mine pits. This division reflected a primary goal of the project: to compare the water quality in tailing sand deposits that receive their recharge strictly from precipitation to the water quality in tailing sands that are in direct connection with the regional ground water. This concept was modified slightly to take into account the nature of existing deposits. Areas of fill that were deposited in clay settling areas (CSAs) rather than in mine pits were classified as piles over clay, to distinguish the fact that these deposits are isolated from regional ground water by the aquitard-like nature of the residual clay slime. A schematic figure of the three types of deposits is provided in Figure 3.

In the process of selecting a preliminary target list of sites, the following sources of data were reviewed:

1. Several available sites on mined land were reviewed that were originally surveyed during the tailing-sand selection for the radionuclide bench test;
2. Maps of old and more recently mined lands were obtained from the Bureau of Mine Reclamation and from industry personnel;
3. Aerial photos and topographic maps of mining areas were collected and reviewed;
4. Interviews were conducted with individuals having knowledge of tailing sand deposits;
5. Finally, site visits were made to assess the current nature of the sites, including accessibility, current use, and recent reclamation activities.

The site selection process led to the selection of twelve tailing sand sites, two of which were “paired sites”. At these locations, a paired set of tailing-sand sites were selected from the same general mine area. The paired sites have similar sands but differ in how they were deposited (one example each of pile and fill samples). Out of the total twelve sites, six were in above ground piles or piles over clay, and six were in sands deposited below grade in mine pits (fill). An additional criterion in the selection of tailing sand sites was the relative processing ages of the sands, the goal being to determine whether the processing age of tailing sands is related to the chemical profile of the ground water contained in them.

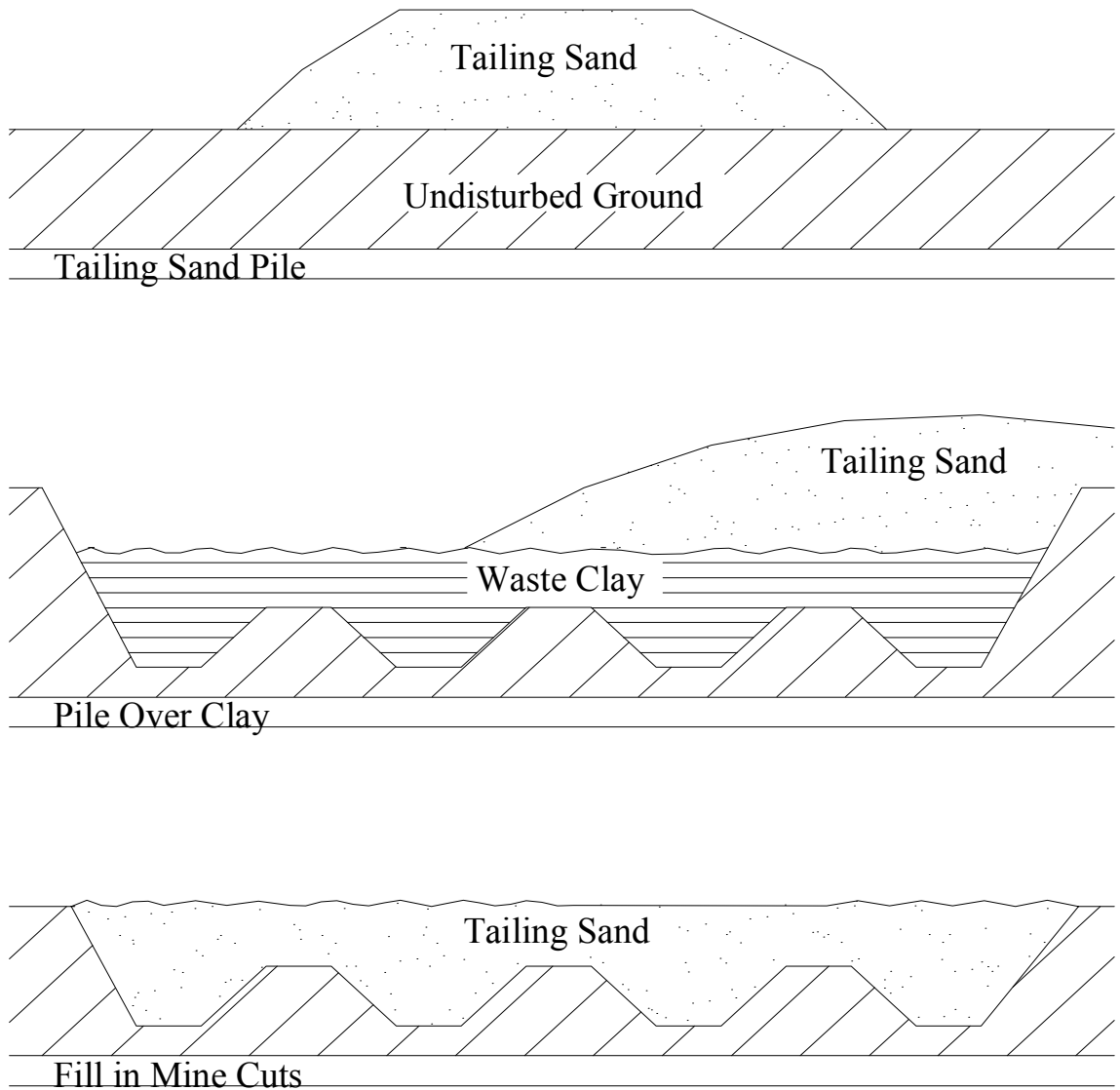


Figure 3. Idealized Cross-Sections of Tailing Sand Pile, Pile Over Clay, and Fill in Mine Cuts.

Ten mining sites were chosen as potential drilling locations. These included Big Four, Clear Springs, Fort Green, Fort Lonesome, Fort Meade, Hookers Prairie, Hopewell, Kingsford, Noralyn, and Payne Creek (Figure 4). At each site, the locations of any existing above grade piles and below grade fills were determined by speaking with phosphate industry representatives with knowledge of the mining history at each site. Additionally, aerial photographs of these areas from pre- and post- mining conditions were analyzed for potential locations; older aerials for each site were difficult to obtain, however. The sites were visited and potential boring locations were selected using topographic maps and global positioning satellite (GPS) equipment. Some sites had limited accessibility, while others had been totally changed by reclamation and re-processing activities. At sites that were accessible, the GPS coordinates were mapped and compared to recent and historical aerial photographs to ensure that possible drilling locations were located in the correct deposits.

To determine the general location of the well installations, SI reviewed aerial photographs and topographic maps to identify the orientation of the mine cuts, spoil piles, and the tailing sand deposits. Once this information was known, exploratory drilling with two-inch diameter solid-stem augers was performed along a line perpendicular to the trends of the tailing sand deposits. This permitted the assessment of the local extent of the tailing sands and their association with any underlying spoil piles or cast overburden. At each potential location, test borings were completed to either natural grade or until the auger met refusal. Care was taken to ensure that the auger flights were advanced into the ground at the same rate as the rotation of the augers, preventing the advancement of cuttings up the auger, a situation that could result in erroneous placement of the depth of occurrence of the sediments. The test-boring samples were described on a continuous basis as auger flights were withdrawn from the ground.

An important requirement for the sampling wells was that they be located as far as possible away from any subsurface spoil piles or cast overburden to minimize the influence of the disturbed sediments on the water chemistry. Another requirement was that there be at least 10 feet of pure tailing sands within the water table in order for a site to be selected for the installation of a well. Once the borings were completed, and the best location for the monitor well was selected, the monitoring wells were installed using a six-inch inside diameter hollow stem auger.

WELL INSTALLATION

Construction of the sampling wells between January 4 and February 11, 2000, was performed inside the six-inch hollow-stem auger, following the advancement of the auger to the total depth. The bases of the two-inch diameter well screens were set at least 10 feet into the water table, with the total depth determined at the time of installation based on site-specific lithology. The annular space around the well screen from the bottom of the bore hole to a level three feet above the screen was backfilled with clean 20/30 grade sand to create a filter pack around the 10 feet of 0.020-inch slotted well

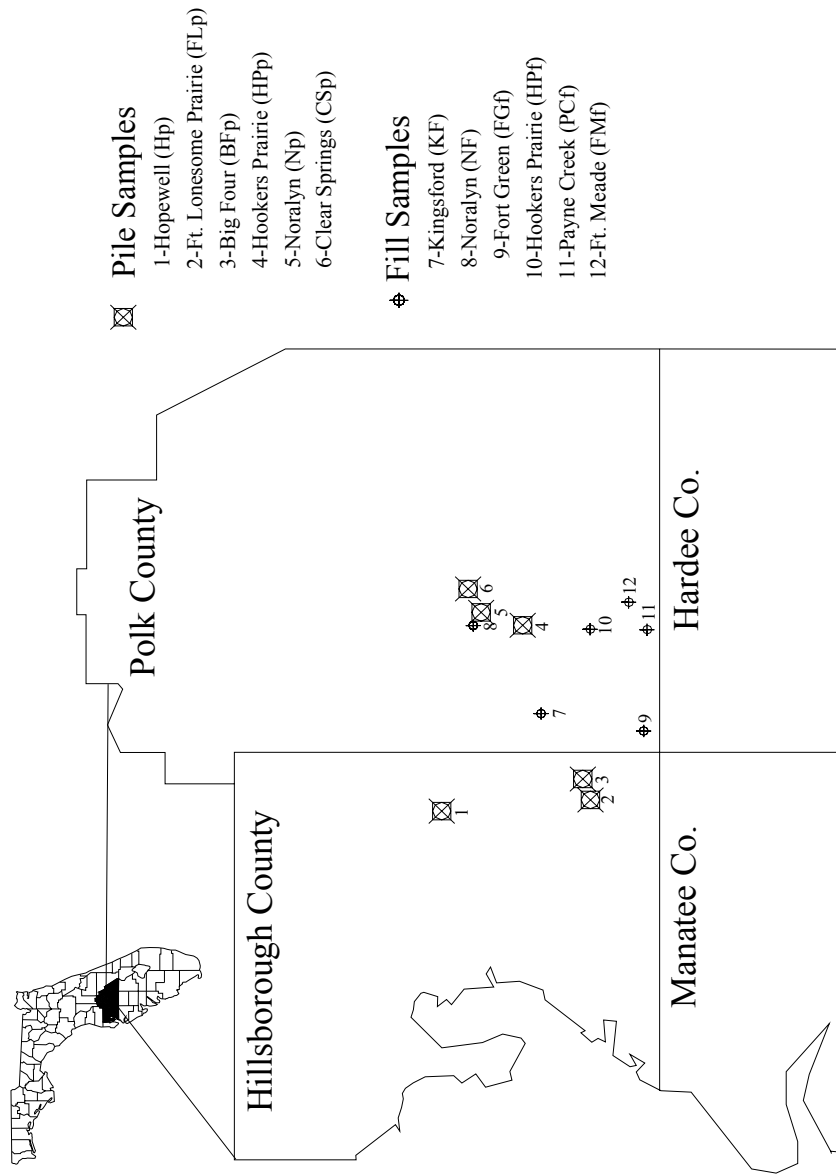


Figure 4. Sample Locations.

screen. The remaining annular space was filled with a mixture of drill cuttings and bentonite chips to maintain a seal around the casing and to prevent surface water from migrating directly down the casing and bypassing the natural filtration by the tailing sands around the borings. The filter pack and the bentonite/cuttings mixture were poured down the annulus as the auger was removed to ensure the well was properly sealed from the surface. The wells were developed by pumping at the time of the installation to produce clean ground water samples. All of these wells were temporary monitor wells; therefore, no well construction permits were required. The general construction details of the monitoring wells are shown in Figure 5.

The proposed work plan called for the sites to be sampled in pairs. One site from each pair was to have been representative of tailing sand deposited above grade, or over a clay pond, thereby isolating the ground water in the tailing sand deposit from the regional ground water. The second site in each pair was to have been in tailing sands generated by the same mine and beneficiation process as the first, differing only in the depositional scenario (below grade, in a mine cut, and therefore in direct contact with the regional ground water).

Unfortunately, as mentioned previously, some potential test sites were inaccessible or had been disturbed by reclamation activities, and so were not available for inclusion in this study. Additionally, at some locations the subsurface data did not prove favorable for the installation of a monitor well (too deep to water table or the tailing sand interval was too thin). Therefore, based on actual field conditions, it was not possible to group the wells into six pairs of sites.

A total of 12 wells (11 new, one existing) were sampled during this project. A concerted effort was given to locate the monitor wells in locations which met the project goals of areal distribution and pairing of wells; 52 exploratory borings were drilled, resulting in the installation of nine new monitor wells on property owned by IMC Phosphates Company. Two of these wells, at sites associated with the Noralyn Mine, were paired as described above. Additionally, access was granted to three sites on Cargill Fertilizer, Inc. property. Two paired wells were installed in tailing sands from the Hookers Prairie Mine (one well was installed in a pile, while the other was installed below grade in a filled mine cut), and an existing monitor well at the Fort Meade Mine (Section 29) rounded out the list of sampling points. A summary of the locations and construction details of the wells is presented in Table 2.

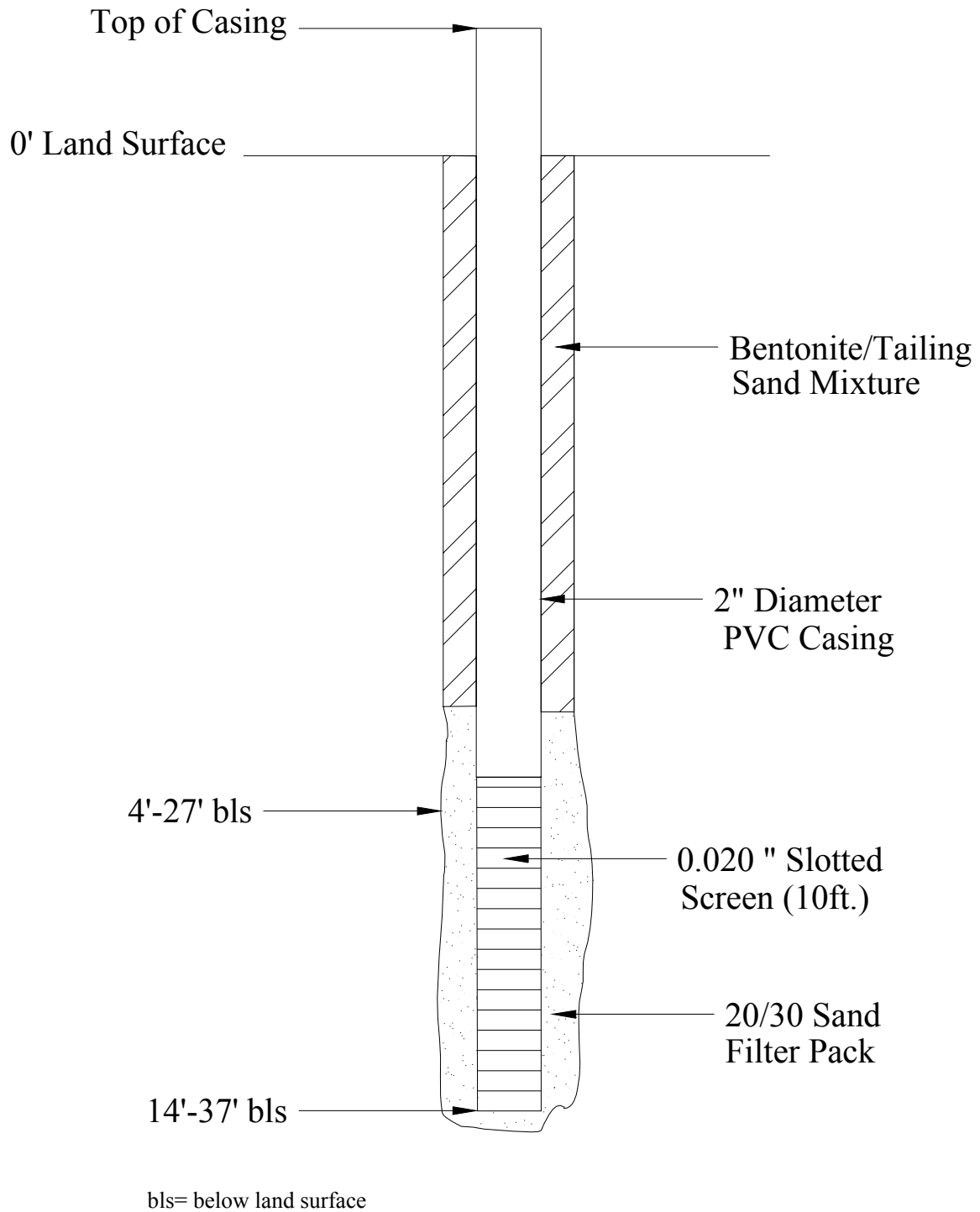


Figure 5. Construction Details of Ground Water Monitoring Wells.

Table 2. Well Locations and Construction Details.

Mine Location and Well S/T/R	Type of Site	Well ID	In Contact With Regional Ground Water?	Approximate Age (Years)	Depth to Water (Ft)	Tailing Sand Interval (Ft)	Total Well Depth (Ft)*
IMC Phosphates Company Sites							
Big Four 26/31S/22E	Pile over Clay	BFp	N	23	14	3-30**	27
Clear Springs 23/30S/25E	Pile over Clay	CSp	N	11 – 16	5	5-16**	14
Fort Green 28/32S/23E	Fill in Cut	FGf	Y	21 - 22	6	0-19	17
Fort Lonesome 33/31S/22E	Pile on Natural Grade	FLp	N	24 - 25	25	0-41	37
Hopewell 32/29S/22E	Pile on Natural Grade	Hp	N	> 25	20	0-33	31
Kingsford 11/31S/23E	Fill in Cut	Kf	Y	4	5	0-20	18
Noralyn 26/30S/24E	Fill in Cut	Nf	Y	12 - 13	12	0-23	22
Noralyn 29/30S/25E	Pile over Clay	Np	N	18	16	0-35	30
Payne Creek 35/32S/24E	Fill in Cut	PCf	Y	4 - 7	7	0-24	20
Cargill Fertilizer, Inc. Sites							
Fort Meade Section 29 29/32S/25E	Fill in Cut	FMf	Y	12 - 15	14	0-15	15
Hookers Prairie 33/31S/24E	Fill in Cut	HPf	Y	5 - 8	7	0-25	22
Hookers Prairie 10/31S/24E	Pile over Clay	HPp	N	15 - 20	12	0-40	35

*Screened Interval is bottom 10 feet of well.

** Surface layer is silty sand overburden

SAMPLE COLLECTION

After well construction was complete, SI personnel purged each well and collected one sample from each between January 18 and February 16, 2000. The wells were purged of at least 3 well volumes, and purging continued until the field parameters of pH, specific electrical conductance, and temperature were constant (within 10% over three consecutive readings, five minutes apart). The samples were collected using a decontaminated Teflon[®] bailer for the polynuclear aromatic hydrocarbons (USEPA Method 610) or with a peristaltic pump and clean tubing for the metals and radionuclide samples. The samples were placed into containers with the appropriate preservative for each analyte, stored on ice, and transported to Thornton Laboratories in Tampa, Florida the same day as they were collected.

SAMPLE ANALYSES

Thornton Laboratories analyzed each sample for the presence of the parameters presented in Table 3. Visual examination of the initial sample collected from the Fort Lonesome pile revealed unusually high turbidity, possibly due to a high concentration of silt or clay in the tailing sand. Upon receipt of the analytical results from this sample and others with noticeable turbidity, it was noted that the concentrations of parameters that are commonly associated with clay-size minerals (aluminum, fluoride, iron, gross alpha, radium 226, and uranium) were higher than expected in the turbid samples. To more accurately assess the true nature of the ground water, a pair of filtered and unfiltered samples was collected from each well and analyzed for the metals and radionuclide groups. The results of the analyses of both the unfiltered and the filtered samples are included in Tables 4 and 5.

Table 3. Water-Quality Parameters Analyzed from Groundwater Samples.

Cations	Anions	Polynuclear Aromatic Hydrocarbons
<i>Aluminum</i>	Arsenic	Acenaphthene
Antimony	Cyanide	Acenaphthylene
Barium	Fluoride	Anthracene
Beryllium	Selenium	Benzo (A) Anthracene
Cadmium	<i>Sulfate</i>	Benzo (A) Pyrene
Chromium	Total Phosphorus	Benzo (B) Fluoranthene
Copper		Benzo (GHI) Perylene
<i>Iron</i>	Radionuclides	Benzo (K) Fluoranthene
Lead	Gross Alpha	Chrysene
<i>Manganese</i>	Radium-226	Dibenzo (A, H) Anthracene
Mercury	Thallium	Fluoranthene
<i>Nickel</i>	Total Uranium	Fluorene
<i>Silver</i>		Indeno (1, 2, 3-CD) Pyrene
Zinc	Other Parameters	1-Methylnaphthalene
	<i>pH</i>	2-Methylnaphthalene
	Specific Conductance	Naphthalene
		Phenanthrene
		Pyrene

* Primary drinking water standards are listed in normal type. Secondary drinking water standards are listed in *italics*.

RESULTS

INITIAL ASSESSMENT

The analytical results of the ground water from the fill and pile samples are presented in Tables 4 and 5, respectively. This grouping reflects the fundamental difference between the two sets of samples; ground water in tailing sand fill deposits is believed to be in contact with the surrounding regional ground water, while the ground water found in piles (over clay or undisturbed ground) originates solely from precipitation and is located above the regional ground water.

This study focused on collecting *in-situ* samples from tailing sand deposits with a two-fold purpose. The initial goal was to determine whether ground water contained within tailing sand deposits meets primary and secondary drinking water standards. By knowing this, a baseline may be defined which will be used in conjunction with water quality data from water flowing into the proposed filter system to predict the quality of the filtered water produced by the system. The secondary goal, although almost equal in importance, was to determine if there is any significant difference in the quality of ground water found in piles as compared to fill in mine cuts. This has great importance in the final design of the proposed filter system, as sources of tailing sand are finite in number, with many deposits existing in areas that are infeasible for construction of a filter system. General conclusions that can be made regarding differences in the tailing sand in the two types of deposits will greatly aid in the selection of construction sites and methods.

ANALYTICAL RESULTS

The results of the laboratory analyses presented in Tables 4 and 5 are grouped by type of water quality parameters (cations, anions, polynuclear aromatic hydrocarbons or PAHs, radionuclides, and pH and Specific Electrical Conductance). The results from both the filtered and unfiltered samples are shown, but as mentioned previously, the filtered samples represent the actual ground water which does not carry any suspended material in flow through porous media. The turbid water in the unfiltered samples are caused by the movement of the bailer in the well. Any results that are in exceedance of either primary or secondary drinking water standards are highlighted with bold text.

Fill Samples

The overwhelming majority (93 percent) of the chemical parameters that were analyzed for in the fill samples (Table 4) were either not detected or were below primary and secondary drinking water standards. The secondary drinking water standards of iron and manganese were the only parameters in exceedance, being detected in four and three samples, respectively. Aluminum (also a secondary standard) exceeded the standard in

one fill sample. Natural ground water in the Surficial and Floridan Aquifers frequently exceeds the secondary drinking water standards for iron and manganese, and these parameters are easily dealt with in a post-filter treatment, if necessary. The remainder of the cations and all of the anions, PAHs, radionuclides, and pH were all either not detected or were found at levels below the primary and secondary drinking water standards.

Pile Samples

As in the fill samples, the majority (91 percent) of the chemical parameters analyzed in the pile samples were either not detected or were found at levels below the primary and secondary drinking water standards. The secondary drinking water standards for iron and manganese were exceeded in five and four samples, respectively. The secondary standard for aluminum was exceeded in two samples, while the primary drinking water standards for antimony and cadmium were exceeded in one sample each. The remainder of the cations and all of the anions, PAHs, radionuclides, and pH were all either not detected or were found at levels below the primary and secondary drinking water standards.

Table 4. Fill Samples - Analytical Results.

Fill Samples	ID >>> Standards	FMf	HPf	FGf	PCf	Nf	Kf	High	Low
Cations									
<i>Aluminum (mg/l)</i>	0.2	ND	ND	0.1	ND	0.2	0.3	0.3	ND
Unfiltered		ND	0.5	2	2.1	0.2	4.1		
Antimony (mg/l)	0.006	0.002	ND	ND	ND	ND	0.002	0.002	ND
Barium (mg/l)	2.0	ND	ND	0.04	0.04	ND	ND	0.04	ND
Beryllium (mg/l)	0.004	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	ND	ND	ND	ND	0.00025		
Cadmium (mg/l)	0.005	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	ND	ND	0.0002	ND	0.0001		
Chromium (mg/l)	0.10	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	0.001	0.004	0.005	0.001	0.011		
Copper (mg/l)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	ND	ND	ND	ND	ND		
<i>Iron (mg/l)</i>	0.3	0.19	6.4	0.18	3.9	2.8	1.0	6.4	0.18
Unfiltered		0.29	6.8	0.37	5.1	2.5	0.29		
Lead (mg/l)	0.015	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	0.001	0.001	0.002	ND	0.004		
<i>Manganese (mg/l)</i>	0.050	0.012	0.093	0.012	0.061	0.062	0.024	0.093	0.012
Unfiltered		0.008	0.097	0.014	0.059	0.051	0.029		
Mercury (mg/l)	0.002	ND	ND	ND	ND	ND	ND	ND	ND
<i>Nickel (mg/l)</i>	0.10	ND	0.005	ND	ND	ND	ND	0.005	ND
<i>Silver (mg/l)</i>	0.10	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/l)	5.0	ND	0.015	0.008	0.015	0.013	ND	0.015	ND

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in italic type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

Table 4 (Cont.). Fill Samples – Analytical Results.

Anions	ID >>>	FMf	HPf	FGf	PCf	Nf	Kf	High	Low
	Standards								
Arsenic (mg/l)	0.05	ND	ND	ND	ND	ND	ND	ND	ND
Cyanide (mg/l)	0.2	ND	ND	ND	ND	ND	ND	ND	ND
Fluoride (mg/l)	4.0	2.5	1.1	1.0	1.0	2.3	1.4	2.5	1.0
	Unfiltered	3.0	1.0	0.84	1.2	2.9	1.8		
Selenium (mg/l)	0.05	ND	ND	ND	ND	ND	ND	ND	ND
<i>Sulfate (mg/l)</i>	250	22	ND	53	77	11	12	77	ND
Total Phosphorus (mg/l)	NA	ND	0.23	ND	0.24	ND	0.16	0.24	ND
	Unfiltered	ND	ND	0.24	1.30	0.88	1.10		
Polynuclear Aromatic Hydrocarbons	ID >>>	FMf	HPf	FGf	PCf	Nf	Kf	High	Low
	Standards								
Acenaphthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (A) Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (A) Pyrene (µg/l)	0.2	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (B) Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (GHI) Perylene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (K) Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Dibenzo (A, H) Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Indeno (1, 2, 3-CD) Pyrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylnaphthalene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Pyrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in italic type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

Table 4 (Cont.). Fill Samples - Analytical Results.

	ID >>>	FMf	HPf	FGf	PCf	Nf	Kf	High	Low
Radionuclides									
Gross Alpha (pCi/l)	15	3.2	2.9	3.0	3.0	2.5	3.2	3.2	2.5
Unfiltered		3.5	7.6	9.3	18.6	6.4	8.0		
Radium 226 (pCi/l)	20	0.8	0.9	1.2	0.9	0.7	0.9	1.2	0.7
Unfiltered		1.0	1.2	1.1	3.4	1.3	2.9		
Thallium (mg/l)	0.002	ND	ND	ND	ND	ND	ND	ND	ND
Total Uranium (pCi/l)	13.8	0.8	1.7	2.4	1.8	0.8	0.9	2.4	0.8
Unfiltered		0.7	1.7	2.9	6.5	0.7	3.4		
Other Parameters									
<i>pH</i>	6.5-8.5	7.4	6.3	6.9	6.7	7.1	6.9	7.4	6.3
Specific Conductance (µmhos/cm)	NA	309	302	462	458	245	396	462	245

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in italic type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

Table 5. Pile Samples - Analytical Results.

File Samples	ID >>> Standards	HPp	CSp	Np	BFp	FLp	Hp	High	Low
Cations									
<i>Aluminum (mg/l)</i>	0.2	0.5	ND	ND	ND	6.6	0.1	6.6	ND
Unfiltered		ND	5.5	1.6	1.3	146	0.3		
Antimony (mg/l)	0.006	ND	0.002	ND	0.009	0.001	0.002	0.009	ND
Barium (mg/l)	2.0	ND	0.04	ND	ND	0.47	ND	0.47	ND
Beryllium (mg/l)	0.004	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	0.0005	ND	ND	0.004	ND		
Cadmium (mg/l)	0.005	ND	ND	ND	ND	0.30	ND	0.300	ND
Unfiltered			0.0005	0.0002	0.0001	0.0034	0.0003		
Chromium (mg/l)	0.1	ND	ND	ND	ND	0.008	ND	0.008	ND
Unfiltered		ND	0.017	0.007	0.003	0.016	0.003		
Copper (mg/l)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Unfiltered		ND	ND	ND	ND	ND	ND		
<i>Iron (mg/l)</i>	0.3	7.8	7.4	17.0	0.19	4.7	8.3	17.0	0.190
Unfiltered		9.8	10	20.	0.73	52.	9.7		
Lead (mg/l)	0.015	ND	ND	ND	ND	0.003	ND	0.003	ND
Unfiltered		ND	0.005	0.003	ND	0.058	ND		
<i>Manganese (mg/l)</i>	0.05	0.22	0.13	0.18	0.017	0.02	0.12	0.22	0.017
Unfiltered		0.28	0.12	0.15	0.022	0.12	0.12		
Mercury (mg/l)	0.002	ND	ND	ND	ND	ND	ND	ND	ND
<i>Nickel (mg/l)</i>	0.10	ND	ND	ND	ND	0.038	ND	0.038	ND
<i>Silver (mg/l)</i>	0.10	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/l)	5.0	ND	0.037	0.029	ND	0.110	ND	0.110	ND

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in *italic* type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

Table 5 (Cont.). Pile Samples – Analytical Results.

	ID >>> Standards	HPp	CSp	Np	BFp	FLp	Hp	High	Low
Anions									
Arsenic (mg/l)	0.05	ND	ND	0.011	ND	0.018	ND	0.018	ND
Cyanide (mg/l)	0.2	ND	ND	ND	ND	ND	ND	ND	ND
Fluoride (mg/l)	4.0	0.9	0.82	2.2	1.1	0.82	1.200	2.2	0.82
Unfiltered		2.0	2.4	3.1	1.1	9.3	1.100		
Selenium (mg/l)	0.05	ND	ND	ND	ND	ND	ND	ND	ND
<i>Sulfate (mg/l)</i>	250	39	ND	ND	16	6.0	ND	39	ND
Total Phosphorus (mg/l)	NA	ND	0.14	ND	ND	1.7	ND	1.7	ND
Unfiltered		ND	9.3	4.9	3.6	32	0.79		

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in *italic* type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

Table 5 (Cont.). Pile Samples – Analytical Results.

Polynuclear Aromatic Hydrocarbons	Std	HPp	CSp	Np	BFp	FLp	Hp	High	Low
Acenaphthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (A) Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (A) Pyrene (µg/l)	0.2	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (B) Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (GHI) Perylene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (K) Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Dibenzo (A, H) Anthracene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Indeno (1, 2, 3-CD) Pyrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene (µg/l)	NA	ND	40	ND	ND	ND	ND	40	ND
2-Methylnaphthalene (µg/l)	NA	ND	42	11	ND	ND	ND	42	ND
Naphthalene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND
Pyrene (µg/l)	NA	ND	ND	ND	ND	ND	ND	ND	ND

Table 5 (Cont.). Pile Samples – Analytical Results.

Radionuclides	Std	HPp	CSp	Np	BFp	FLp	Hp	High	Low	
Gross Alpha (pCi/l)	15	3	3.3	3.5	2.4	8.5	2.5	8.5	2.4	
Unfiltered		4.7	62	19	16.6	755	9.0			
Radium 226 (pCi/l)	20	1.0	1.3	0.9	0.8	1.6	0.90	1.6	0.8	
Unfiltered		1.2	8.9	5.7	2.9	51	3.0			
Thallium (mg/l)	0.002	ND	ND	ND	ND	ND	ND	ND	ND	
Total Uranium (pCi/l)	13.8	1.6	0.6	0.8	1.3	3.1	0.8	3.1	0.6	
Unfiltered		1.1	7.5	3.3	3.8	66	2.8			
Other Parameters										
<i>pH</i>	6.5-8.5	6.6	6.5	6.6	6.5	6.7	6.4	6.58	6.7	6.4
Specific Conductance (µmhos/cm)	NA	585	714	383	225	190	117	369	714	117

Note: Unfiltered results are on second line; filtered values exceeding drinking water standards are shown in bold type; secondary drinking water standards are in *italic* type. Filtered and unfiltered samples are discrete samples, so variability can be expected.

DISCUSSION AND CONCLUSIONS

DRINKING WATER STANDARDS

As presented in Tables 4 and 5, and described in the previous section, the ground water found in the tailing sand deposits meets the overwhelming majority of primary and secondary drinking water standards. The most common exceedances of drinking water standards were for iron and manganese, cations that pose little health hazard and are commonly found at elevated concentrations in naturally occurring ground water. These minerals can easily be dealt with in a post-filter treatment system, or exemptions to the standards may be obtained prior to use or subsurface injection. Antimony and cadmium were found in only one sample each; these occurrences are likely the result of extremely fine clay and apatite particles suspended in the sample rather than actually being dissolved in the ground water. Aluminum is slightly more common, being found in one fill and two pile samples, but is also commonly associated with clay minerals.

COMPARISON OF FILL AND PILE SAMPLES

The major difference between the two groups of samples is whether the ground water in the tailing sand deposits is in contact with the regional surficial aquifer (fill samples) or not (pile samples). This basic difference can be extended to certain logical assumptions about the ground water in the tailing sands. For instance, the precipitation falling on a tailing sand pile, being unsaturated with respect to the constituents of the tailing sands, migrates downward through an unsaturated zone, building up a perched water table within the sand deposit. The primary control over the flow velocity of the ground water in the downward and outward directions is the nature of the underlying sediments. Ground water in a tailing sand pile will either infiltrate into the surficial aquifer below the pile in the instance of a pile over undisturbed ground, or it will discharge laterally out of the base of the pile in the instance of a pile over waste clay.

In either scenario, the tailing sand will be exposed to the leaching action of moving ground water, without the buffering action of the surrounding regional ground water. The initial effects of unsaturated water on tailing sands are fairly aggressive, as was shown in the bench test study "Potential Use of Phosphate Mining Tailing Sand for Water Filtration: Leaching Tests" (Schreuder and Dumeyer 1998). The leaching action of natural precipitation, therefore, should increase the concentrations of dissolved chemicals in the ground water as soluble minerals in the unsaturated zone are transported into the water table within the tailing sand pile. As there is no flushing of the saturated zone by the regional surficial aquifer, the input of precipitation is the only mechanism for the flushing of the dissolved constituents. The apparent trend in the results is that pile samples are higher in average phosphorus, gross alpha, iron, manganese and average pH, while sulfate is lower in pile samples. Conductivity is about the same in both pile and fill.

Conversely, precipitation falling on tailing sand fill in mine cuts without waste clay can freely discharge in the direction of regional ground water flow. Ground water in

the surrounding surficial aquifer, which is in equilibrium with the constituents of the sediments through which it travels, is constantly flushing the water table within the tailing sand deposits, buffering, diluting, and flushing chemical species that were leached from the unsaturated upper zones of the tailing sand deposit. In the leaching test study, concentrations of dissolved constituents such as uranium and sulfate, while elevated during the first few days of leaching, drop off to concentrations below drinking water standards with a flushing of as few as two pore volumes of water. It is therefore expected that there will be lower concentrations of dissolved chemicals in the ground water contained within tailing sand fill deposits than in piles or piles over waste clay.

WATER QUALITY

To evaluate the multitude of data regarding drinking water standards and to better analyze the differences between pile and fill samples, Table 6 provides a visual presentation of the analytical data. Intervals were defined to classify data into five groups: not detected (ND), meeting drinking water standards (DWS), 1 to 2 times drinking water standards (1-2), 2 to 10 times drinking water standards (2-10), and greater than 10 times drinking water standards (> 10). These values were calculated by subtracting the drinking water standard from the reported value and then dividing the difference by the standard.

Evaluation of Table 6 clarifies the water quality trends that were noticed in the initial assessment of the data. The most noticeable pattern is the overwhelming abundance of parameters that were not detected or were below drinking water standards. Ninety-seven percent of the fill and 95% of the pile samples were at this level. The fill and pile samples showed similar distributions between these two classes; an average of 74% of the parameters in the fill samples and 73% of those in the pile samples were not detected, while an average of 23% of the parameters in the fill samples and 22% of the parameters in the pile samples were detected at levels below the drinking water standards. The true distinction between the fill and pile samples is in the high range of the parameters that exceed the drinking water standards. While only two of the fill samples exceeded any drinking water standards by more than 10 times, seven of the pile samples met this level of exceedance.

Table 6. Relationship of Chemical Constituents of Ground Water in Tailing Sand Deposits to Drinking Water Standards.

ID and Age of Deposit	CSp (16 yrs)					Hp (>25 yrs)					Np (18 yrs)					Nf (13 yrs)				
	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10
Cations																				
Aluminum																				
Antimony																				
Barium																				
Beryllium																				
Cadmium																				
Chromium																				
Copper																				
Iron																				
Lead																				
Manganese																				
Mercury																				
Nickel																				
Silver																				
Zinc																				
Anions																				
Arsenic																				
Cyanide																				
Fluoride																				
Selenium																				
Sulfate																				
Total Phosphorus																				
Radionuclides																				
Gross Alpha																				
Ra-226																				
Thallium																				
Total Uranium																				

Table 6. Relationship of Chemical Constituents of Ground Water in Tailing Sand Deposits to Drinking Water Standards (Cont.).

ID and Age of Deposit	FLp (25 yrs)					BFp (23 yrs)					HPp (20 yrs)					HPf (8 yrs)				
	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10
Cations																				
Aluminum					■	■							■			■				
Antimony		■						■			■					■				
Barium		■				■					■					■				
Beryllium	■					■					■					■				
Cadmium					■						■					■				
Chromium		■				■					■					■				
Copper	■					■					■					■				
Iron					■		■								■					■
Lead		■				■					■					■				
Manganese		■					■							■				■		
Mercury	■					■					■					■				
Nickel		■									■						■			
Silver	■					■					■					■				
Zinc		■				■					■						■			
Anions																				
Arsenic		■				■					■					■				
Cyanide	■											■					■			
Fluoride		■					■					■					■			
Selenium	■					■					■					■				
Sulfate		■					■					■				■				
Total Phosphorus						■					■									
Radionuclides																				
Gross Alpha		■					■					■					■			
Ra-226		■					■					■					■			
Thallium	■					■					■					■				
Total Uranium		■					■					■					■			

Table 6. Relationship of Chemical Constituents of Ground Water in Tailing Sand Deposits to Drinking Water Standards (Cont.).

ID and Age of Deposit	Kf (4 yrs)					FGf (22 yrs)					PCf (7 yrs)					FMf (15 yrs)				
	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10	ND	DWS	1-2	2-10	>10
Cations																				
Aluminum																				
Antimony																				
Barium																				
Beryllium																				
Cadmium																				
Chromium																				
Copper																				
Iron																				
Lead																				
Manganese																				
Mercury																				
Nickel																				
Silver																				
Zinc																				
Anions																				
Arsenic																				
Cyanide																				
Fluoride																				
Selenium																				
Sulfate																				
Total Phosphorus																				
Radionuclides																				
Gross Alpha																				
Ra-226																				
Thallium																				
Total Uranium																				

ND: Parameter not detected. DWS: Drinking Water Standard (primary in normal text, secondary in *italics*). NA: Not Applicable – no drinking water standard established for this parameter. 0-100: Concentration = 0-100% over DWS. 100-1000: Concentration = 100%-1000% over DWS. > 1000: Concentration = more than 1000% over DWS.

Type of Deposit and Influence of Regional Ground Water

After determining whether ground water in tailing sand deposits can be generally expected to meet drinking water standards, the secondary goal of this study was to determine if there is any relationship between the ground water quality within tailing sand deposits that had been placed in differing environments; either isolated from regional ground water (pile or pile over clay deposits) or in direct contact with regional ground water (fill in mine cuts). The type of deposit appears to have a general bearing on the relative distribution of the parameters of concern in the water sample. As shown in Table 6, the range of concentrations for each parameter that exceeds a drinking water standard seems to be greater for the pile samples than for the fill samples. These observations suggest that the pile samples, which receive ground water recharge from rainfall alone, are more likely to contain elevated concentrations of the parameters of concern than are the fill samples, which are buffered and flushed by the regional surficial aquifer.

Age of Deposit

No general relationship between the age of the deposit and the concentrations of the parameters of concern could be noted in the samples examined for this study. Specific parameters showed general trends that may or may not be related to the age of the deposits. For instance, manganese concentrations are generally less with older deposits as compared to younger ones; this relationship is more marked in the fill samples than in the pile samples. Similarly, iron concentrations (with a few exceptions) are generally lower in the older fill samples than in the younger ones. The relationship of iron to age in the pile samples, however, is not well defined; younger samples plot near the middle of the range of data, while older samples were found to contain both high and low concentrations of iron. The most important aspect of these relationships is that they are not absolute; factors such as the source material or the efficiency of the beneficiation process may also influence the ground water quality.

VALIDATION OF PREVIOUS WORK

The tailing sand leaching tests previously performed (Schreuder and Dumeyer 1998) demonstrated that tailing sands tested have a relatively low capacity to leach radionuclides into pore waters. No other parameters (except sulfate, in tailing sand from one particular source) were detected in levels exceeding primary or secondary drinking water standards after 225 days of contact between the test water and the tailing sand samples. The concentrations of all parameters detected in the leaching test declined over time, suggesting that the flushing of multiple pore volumes of ground water could reduce the concentrations of parameters that exceed the drinking water standards to acceptable levels. This conclusion is validated by the observation in this study that the fill samples have fewer than half the number of drinking water exceedances greater than 10 times the drinking water standard than do the pile samples. The premise that the ground water in

the tailing sand fill deposits is buffered and flushed by the regional surficial aquifer, as opposed to the isolated nature of the ground water in the pile deposits, supports this conclusion.

CONCLUSIONS

This project has shown that ground water contained within tailing sand deposits meets EPA and State of Florida primary and secondary drinking water standards for all but a few parameters. The most common exceedances of drinking water standards that were observed were for iron and manganese, two constituents of ground water that can easily be eliminated with post-filtration treatment. Equally important, this study has identified a relationship between the nature of the tailing sand deposit and the likelihood of encountering concentrations of certain chemical constituents that exceed drinking water standards. It is evident from this study that tailing sands deposited in mine cuts that have not previously been used as waste clay settling areas are more likely to contain ground water that meets these standards. The conclusions reached as part of this study will be valuable in the selection of the source of sand for future tailing sand filtration projects.

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