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ON-REFUGE INVESTIGATIONS SUB-ACTIVITY

MO - Implications of Wetland Management on Mercury Bioavailability and Exposure to Resident Waterfowl, Fish, and Macrobenthic Invertebrate Populations at Mingo National Wildlife Refuge

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ABSTRACT

Mingo National Wildlife Refuge (MNWR) is a 21,592 acre, Mississippi delta swamp/marsh/ forest complex in southeast Missouri, which provides important habitat for waterfowl, fish, amphibians, and reptiles. However, threats to fish and wildlife have been documented due to exposure to mercury (Hg) and potentially selenium (Se), suspected to be from anthropogenic sources of aerial deposition and/or erosion/runoff from upgradient agricultural areas (Wood, 2007; Bruland, 1997; and Charboneau and Nash, 1993). Mercury and other heavy metal loading sources, wetland management affects, and exposure to biota were investigated by analyzing surface water, sediment, dredge spoils, and tissues of macroinvertebrates, fish, and duck eggs. Biotic and abiotic sample results did not confirm earlier reports of elevated Se. However, risks, including potential population effects from mercury, especially to hooded merganser, and other piscivorous birds were confirmed. Concentrations in upper trophic level fish (bowfin, large-mouthed bass, and bullhead exceeded 0.3 to 0.4 mg/kg (ppm) wet weight (WW) (1.2 mg/kg dry weight (DW)), which is both the U.S. EPA (2001) human health consumption advisory and Lowest Observed Adverse Effect Level (LOAEL) to waterfowl documented by Barr (1986) and Scheuhammer et al. (2007). Mercury concentrations in hooded merganser eggs ranged from 1.61 to 7.02 and averaged 3.25 µg/g DW, compared to wood duck eggs, which ranged from 0.046 to 0.30 µg/g DW and averaged 0.13 µg/g DW. This difference in concentration is expected due to trophic differences in diet between the two duck species and the tendency of Hg to biomagnify. Mean concentrations of total mercury in hooded merganser (but not wood duck) eggs exceed a LOAEL of 0.5 µg/g WW (2.5 µg/g DW) established by Fimreite (1971). Consequently, it can be assumed that some degree of toxicity is occurring to hooded merganser hatchlings, which may contribute to decreased reproductive success. Wood (2007) evaluated 117 hooded merganser eggs at MNWR and characterized only 10% of them as successful. These findings corroborate assertions of impaired reproduction of this species at MNWR.

Key Words: Mingo National Wildlife Refuge, Mercury, Fish, Waterfowl, Sediments, Abiotic, Bioaccumulation

Preface

This report provides documentation of environmental contaminants in soils, sediments, water, benthic macroinvertebrates, fish, and duck eggs collected from Mingo National Wildlife Refuge, Missouri. A portion of the analytical chemistry results are in U.S. Fish and Wildlife Service Analytical Control Facility catalog number 3040029 for the 2007 data and catalog number 3040030 and 3040031 for the 2008 data.

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should be directed to:

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Mingo National Wildlife Refuge (MNWR) is located in Southeast Missouri, in the portion of the State commonly known as the Missouri Bootheel. The refuge consists of 21,592 acres (approximately 34 square miles) straddling two counties, Stoddard and Wayne, with nearly half of the refuge's acreage situated within each county. Puxico, a small town, is the refuge's nearest neighbor and is located approximately one mile to the south of the refuge's Visitor Center. The western border of MNWR occurs along the "foothill of the Ozarks", while the majority of the core land mass of the refuge falls within the boundaries of the Advance Lowlands landform, and Ozark Escarpment forms the eastern border (McCrea, 1972). The Advance Lowlands are part of the northernmost extension of the Mississippi Embayment or Mississippi alluvial wetland system.

MNWR's primary purpose is for use as a sanctuary for migratory birds, the preservation of wilderness character, and the conservation of endangered or threatened species. MNWR serves as a critical wetland habitat in Southeast Missouri and contains the largest remaining tract of bottomland hardwood forest in the state. Missouri's Bootheel once contained 2.5 million acres of bottomland hardwood forest. Due to its diversity of habitats and the ample supply of water, amphibians and reptiles abound at MNWR. More than 65 species have been documented, including frogs, toads, salamanders, lizards, turtles, and snakes. Several species of reptiles and amphibians that occur on MNWR are considered rare at the state level including the three-toed amphiuma (*Amphiuma tridactylum*) and the alligator snapping turtle (*Macrochelys temmincii*).

The refuge contains approximately 15,000 acres of bottomland hardwoods, 506 acres of cropland, 704 acres of moist soil units, 474 acres of grasslands, and 3,300 acres of marsh and 200 acres of open water habitat. There are 7 natural areas on the refuge and 7,730 acres designated as a Class I Wilderness Area.

1.1 Contaminant Threat

Mingo National Wildlife Refuge recently underwent a Contaminant Assessment Process (Coffey, 2005) that concluded that mercury (Hg) and selenium (Se) concentrations are elevated in water and in fish on the refuge. The CAP report is part of FWS Biomonitoring of Environmental Status and Trends Program and recommended investigations to document the severity of heavy metal contamination in the sediments and biota, specifically Hg and Se. The principle basis for this conclusion is past investigations of contaminant concentrations in the fishes and other biota of MNWR that have shown dangerously high levels of Hg.

The most recent MNWR tissue data comes from a 2006 study that documented mean Hg concentrations in wood duck (*Aix sponsa*) and hooded merganser (*Lophodytes cucullatus*) eggs in the range of 5.0 to 6.0 milligrams per kilogram (mg/kg) wet weight (Wood, 2007). The same study showed mean Se concentrations in the eggs of the abovementioned species to range from 30 to 40 mg/kg wet weight (Wood, 2007). Se concentrations reported by Wood (2007) were well above the Toxicity Effects Threshold (TET) of 7 mg/kg dry weight reported by Lemly (2002). Other recent biotic studies include a 1997 study where Hg in fish tissues were determined to range from 0.9 to 2.5 mg/kg wet weight (Bruland, 1997). Charboneau and Nash

(1993) showed concentrations in bowfin (*Amia calva*) to be as high as 5.51 mg/kg dry weight and red-eared slider (*Trachemys scripta*) liver tissue samples to be as highs as 7.46 mg/kg dry weight. These concentrations exceed the recommended Hg concentrations for fish established by EPA of 200-300 *u*g/kg wet weight. Concentrations of Se in two out of ten fish collected in 1987 (Charbonneau and Nash, 1993) are slightly elevated compared to the geometric mean of the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990), but do not exceed toxicity bench marks.

1.2 Sources of Contamination

Atmospheric deposition from industrial coal combustion is thought to be the main source of input for Hg (Zhang et. al, 2001). The Missouri Department of Natural Resources (MDNR) monitors Hg and other pollutants such as Se on-site using a wet deposition sampling system that collects rainwater for analysis as part of the National Atmospheric Deposition Program. Data generated from this sampling effort indicates that atmospheric deposition is a large contributor to the Hg and Se concentrations on the refuge. Rainfall from March 26, 2002 to March 21, 2005 deposited 38,172 ng/m² of Hg on the refuge (Air Quality Branch, FWS, 2004). This computes to an estimated 67.57 kilograms (148.8 lbs) of Hg deposited over the refuge in three years. If a constant deposition rate is assumed, it is estimated that in 30 years, over 675 kilograms (1,488 lbs) of Hg will be deposited on MNWR via precipitation. The form of Hg deposited from the atmosphere is likely ionic Hg. Ionic Hg is not a highly bioavailable form of Hg, meaning it is not highly toxic or not easily accumulated by biota. However, there are an abundance of organisms present in a swamp and other wetlands that transform elemental or ionic Hg into methyl mercury (MeHg) (Jones, et al, 1996). Methyl mercury is highly bioavailable and is responsible for most of the toxic effect and bioaccumulation associated with Hg contamination. In addition, the diversity of hydraulic regimes (wetting and drying cycles) may further accelerate and exacerbate the Hg methylation process. Thus the rate of bioaccumulation in MNWR, which is dominated by swamps and other wetlands with frequently fluctuating water levels, is likely to be increased and the seriousness of the problem compounded.

In 1964, Congress passed the Wilderness Act. This Act designated that a certain portion of lands be set aside in a "natural and unspoiled state for future generations," (Hendee and Dawson, 2002). The western portion of the refuge (7,730 acres) was designated in as a Class I Wilderness Area in 1976 as shown in Figure 2. The area is mandated by law to be protected from anthropogenic influence and is also subject to the provisions outlined in the Clean Air Act of 1977.

Figure 1. The Location of Mingo National Wildlife Refuge

Image Credit: Mingo NWR Comprehensive Conservation Plan

Figure 2. Hydrologic Features at Mingo NWR

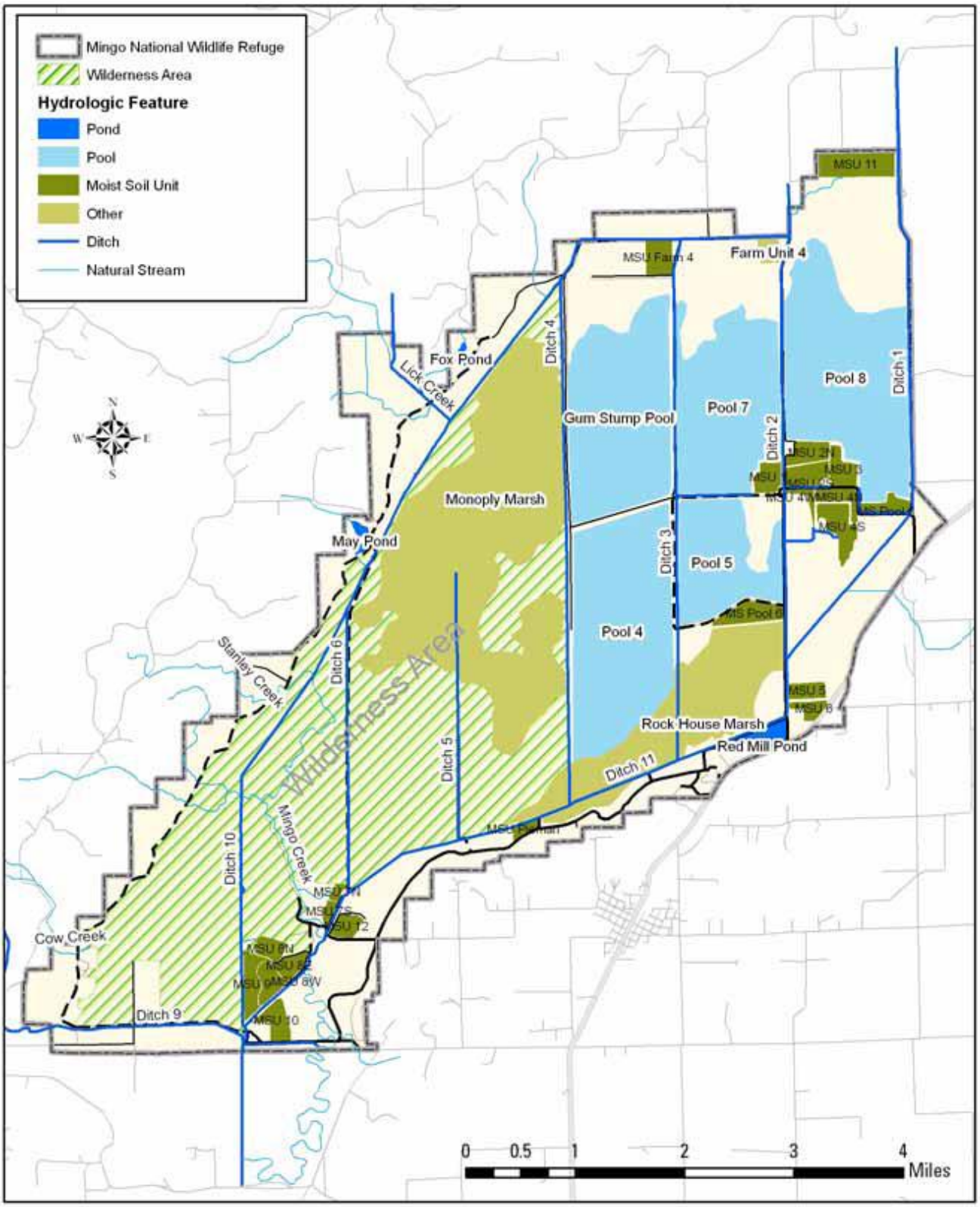
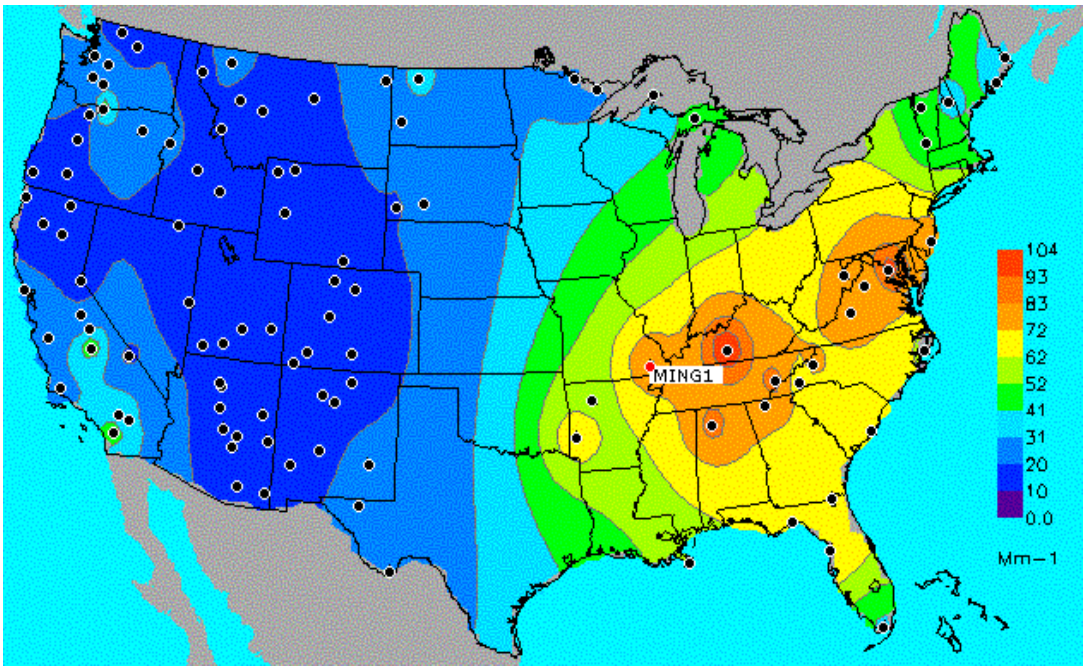


Image Credit: Mingo NWR Comprehensive Conservation Plan

Figure 3. Mercury Deposition Rates Across the Continental United States



As shown in Figure 3, MNWR is subjected to the greatest amount of air pollution of the twenty-one Class I Areas that the FWS manages (Air Quality Branch, FWS, 2004). The FWS recently issued an adverse impact statement regarding a permit application for the proposed Prairie State Generating Station (PSGS). The proposed PSGS would be located 140 km northeast of the refuge and would substantially increase levels of numerous pollutants in the atmosphere, including Hg.

1.3 Mercury effects on Biota

Atmospheric pollutants can drastically affect the biota of an area, especially fish and amphibians, which are directly impacted by the build-up of pollutants in aquatic environments. Hg and chemical compounds containing Hg have no known role in biological processes and serve no function in any forms of life (USFWS, 1987). Once mercurial contaminants are deposited into aquatic systems, there are two main sources of entry into the food chain. First, elemental Hg binds to suspended sediments or dissolved organic carbon in the water column and/or benthic sediments and is ingested. Secondly, direct processing by zooplankton and other microorganisms can methylate Hg thereby increasing its bioavailability (Nishimura and Kumagai, 1983). Once Hg has contaminated the lowest trophic levels it will bioaccumulate exponentially in the upper trophic levels. In wetlands areas, Hg bioaccumulation has been defined as a serious threat to wildlife, with the highest risks posed to piscivorous predators, (Snodgrass et al., 2000; Gariboldi et al., 1998; Wolfe et al., 1998). Thus the pathways can be traced from atmospheric deposition, to water and sediment, to microorganisms and zooplankton, to invertebrates, fish, birds, reptiles and amphibians, to the highest trophic level predators. Hg is considered to be a hazardous substance to every form of life (USFWS, 1987).

The effects of Hg contamination on fish and wildlife are varied and are generally different for different species. Each species and even some individuals will have differing tolerances. However, it is a well accepted and documented fact that Hg can affect populations through severe toxicity or by modification of biological, physiological and behavioral systems which can reduce survivorship, fecundity, and overall reproductive success while increasing mortality. Mercury exposure has been shown to effect hormonal development that may affect nest attendance and incubation behavior (Heath and Frederick, 2005).

MNWR is critical to the survival of certain species such as rare, threatened and endangered species. Protection of the habitats of these species from adverse impacts due to Hg deposition is also imperative to prevent further losses to these imperiled populations. Key species on MNWR include but are not limited to the bald eagle (*Haliaeetus leucocephalus*), taillight shiner (*Notropis maculates,)* cypress darter (*Etheostoma proeliare*), bantam sunfish (*Lepomis symmetricus),* banded pygmy sunfish (*Elassoma zonatum*), dollar sunfish (*Lepomis marginatus*), snowy egret (*Egretta thula*), least bittern (*Ixobrychus exilus*), alligator snapping turtle (*Macrochelys temmincii*), and the three-toed amphiuma (*Amphiuma tridactylum*).

1.4 Waterfowl

Mercury contamination of wildlife, especially avian species, can seriously impact reproduction, behavior, and mortality in aquatic systems (Scheuhammer, 1987); (Barr, 1986). Several studies indicate that birds can store up to 40% of their body Hg load in eggs and feathers (Lewis,1991; Fimreite et al, 1974) and therefore it may be possible to correlate Hg concentrations in wood duck eggs and/or feathers with body concentrations. The avian egg has been found to be an excellent metric to conduct biomonitoring of Hg (Henny and Herron, 1989; Burger, 1995; Hughes et al., 1997; Wolfe et al, 1998), especially in situations where nest boxes can be utilized to obtain samples easily and without much expense (Kennamer et al., 2005). Egg Hg concentrations can also be associated with hatch failure of the egg, not associated with adult behavior (Fenreite, 1971; Borg et al, 1969). Mercury concentrations associated with this decline in hatch success ranged from 1.3 to 2.0 mg/kg wet weight in mallards (Borg et al, 1969). Waterfowl are often used in contaminant studies of wetlands because of their extensive use of such areas (Kennamer, 2005; Johnson et al., 1971).

The diets of waterfowl vary among species and seasons. Through food habit studies it has been determined that laying female wood ducks selectively forage for invertebrates mostly Coleoptera, Diptera, and Isopoda species. The protein needed by female wood ducks for reproduction is mainly derived from the diet and not from endogenous sources (Drobney and Fredrickson, 1979). This selective foraging translates into an inference that contaminant levels of invertebrates should be correlated with the levels in albumen and yolk, where most of the protein from food sources is deposited during the laying phase. Hooded mergansers will also eat invertebrates although their diet chiefly consists of fish (Fredrickson, 2006). Consequently, this study selected the contaminant content of wood duck and hooded merganser eggs as an analytical endpoint for both waterfowl health and reproduction as well as invertebrate community contamination.

A total of 100 nest boxes are located throughout the refuge. Ducks are exposed to multiple environments, but concentrate on moist soil units, Monopoly Marsh, and other wetland areas. Wood ducks and hooded mergansers were selected because they are largely resident populations and they represent different feeding patterns. Wood ducks feed heavily on macrobenthic invertebrates associated with ditches and shallow water, and the mergansers feed primarily on fish in ditches and deeper water. Wood ducks typically restrict their daily activities to an area around their nest site. Fluctuating water levels may cause an increase in home range, however, stable water levels and readily available food will restrict breeding ranges. These stable water levels during the breeding season and abundant food resources exist in the nesting territories of wood ducks on MNWR. Several studies report home ranges varying from within 1 kilometer (0.62 mile) of the nest site in Minnesota (Gilmer et al. 1978) and at Muscatatuck NWR in southern Indiana ranges averaged 0.8 kilometer (0.5 mile) from the nest site (Robb 1986). Wood ducks on MNWR are expected to have similar ranges to those reported by Gilmer and Robb. Following incubation, broods may travel up to 5 miles from their nest site to raise their young in portions of the MNWR and especially Monopoly Marsh (Blum, 2006) personnel communication).

1.5 Amphibians

Worldwide declines have been observed in amphibian populations (Houlahan et al., 2000; Wake, 1991; Blaustein, 1994) and this is of important concern to any area that has the level of diversity that is found at MNWR. There are several causes that have been linked to these declines including pesticides, pollutants, and diseases (Daszak et al., 2000). Amphibians are especially sensitive to changes in their environment and thus declines can be indicative of potential problems. Amphibians are tied closely to water throughout their life cycle. Aquatic amphibian skin is extremely absorptive and the organisms feed almost exclusively on aquatic animals and plants. Also many amphibians undergo a metamorphosis from larval aquatic life-stage into aquatic or semi-aquatic adulthood. This transformation process presents an unusual (for vertebrates) physiological event for toxic exposure to manifest a toxic effect. For these reasons Hg in water and sediment has multiple routes of exposure and mechanisms to significantly reduce overall diversity and abundance of amphibians.

1.6 Human Health Impacts

Mercury contamination does not only pose an adverse threat to fish and wildlife populations. Due to several public use activities popular at MNWR, humans are also at an increased risk of contamination. Annually, MNWR has over 110,000 visits. Of the total visits each year, approximately 2,400 visits are from individuals who are fishing at the refuge. During the fishing season, the diets of many local visitors include substantial quantities of fish caught from MNWR even though the refuge is under an existing fish consumption advisory. In 2001, a fish advisory was placed on MNWR due to Hg levels exceeding ten times, the action levels of 200-300 ppb established by the EPA (MDC. 2005). Human exposure to MeHg has been linked with several severe neurological disorders. According to the EPA, impacts on cognitive thinking, memory, attention, language, and fine motor and visual spatial skills have been seen in children exposed to MeHg in the womb (EPA, 2006). In addition to these subtle impairments, symptoms of MeHg poisoning may include impairment of the peripheral vision; disturbances in sensations ("pins and

needles" feelings, usually in the hands, feet, and around the mouth); lack of coordination of movements; impairment of speech, hearing, walking; and muscle weakness (EPA, 2006).

The MNWR area serves as an important resting and feeding area for migratory birds along the Mississippi Flyway. Although peak waterfowl populations are estimated at 125,000 individuals annually, the total number of waterfowl that rest, nest, or simply pass through the refuge annually significantly exceeds that estimation. Waterfowl utilize food sources at MNWR during migration periods, and as a wintering area, and resident species utilize the refuge year-round for food, nesting, and resting. Due to the high waterfowl usage of the refuge and surrounding areas, waterfowl hunting is a popular public use activity. Each year approximately 300 ducks are harvested on MNWR In addition to the waterfowl harvested on MNWR there are several nearby private wetlands and Missouri Department of Conservation's Duck Creek Conservation Area that provide hunting opportunities for waterfowl. The birds utilizing these adjacent lands often feed and rest at MNWR. In order to understand the bioaccumulation of Hg in waterfowl species at MNWR, body burdens of Hg were investigated in fish and invertebrate-feeding waterfowl consumed by humans that utilize the refuge.

2. SCIENTIFIC OBJECTIVES

The goals of the 2007-2009 investigation were to: better understand bioaccumulation of Hg in key species at MNWR; better document threats to refuge users through ingestion of fish and waterfowl; and to understand how management actions at the refuge may affect exposure to trust resources at the refuge.

While biological effects of exposure to Hg are well documented and past research at MNWR has shown accumulation of Hg in biota, the impacts of changes in hydrology and sediment management that likely impact the bioavailability and exposure regimes of Hg to fish and wildlife has never been investigated.

There is evidence provided by a refuge aerial deposition sampler that Hg contamination at the refuge is primarily aerial, from ionic Hg in rainwater. As such, initial deposition and contamination in a small geographic area would be expected to be relatively homogeneous. However, differences in topography, drainage patterns, vegetation coverage, and soil and sediment chemistry, among other things, greatly influence heavy metal concentration distribution over a landscape. MNWR is a local sink for nutrients and water flow. This location within the landscape may also make MNWR a sink for heavy metal accumulation, including Hg, despite the presumed initial homogeneous aerial deposition. In addition, fluctuating water levels, changing oxidation states, and biological activity influence Hg bioavailability.

The objectives of this study are:

Objective #1 – Evaluate geographic heavy metal distribution and loading sources.

> ***Null Hypothesis:*** Mercury and other sub-aerially deposited metals distribution are relatively homogeneously distributed across the refuge.

Soil, water, and sediment samples were collected in a variety of upland and lowland locations to determine metal distribution over a two-year period. The sampling was designed to monitor metal sources in water and sediment from ditches entering and leaving the refuge and from ponds and wetlands that have small drainage basins. Soil sampling occurred over time adjacent to an existing air Hg monitor to provide a correlation with air deposition data.

Objective #2- Evaluate how changes in hydrology influence Hg distribution and bioavailability.

Null Hypothesis: Changes in wetland hydrology will not significantly effect Hg distribution or bioavailability.

Total Hg and MeHg were analyzed in samples of sediment or soil collected twice a year during wet and dry cycles for two years. Total sulfate was also analyzed at these locations for the initial sample, since sulfate is an important component needed for the bacterial reduction process that drives Hg methylation. Samples were collected from ditches, a creek, a marsh, a moist soil unit, and an upland pond that have different drainage basins and flow regimes. Total and dissolved metals, dissolved organic carbon, pH, dissolved oxygen, oxidation-reduction potential, and specific conductance were analyzed in water samples collected from these same locations.

Objective #3- Evaluate how changes in sediment management influence Hg distribution and bioavailability.

Null Hypothesis: Ditch dredging will not significantly effect Hg distribution or bioavailability.

Total Hg and MeHg Hg were analyzed in samples of sediment and soil collected twice a year during wet and dry cycles for two years. Samples were collected from ditches that have been dredged over different periods of time and one ditch that has not been dredged. Total and dissolved metals, dissolved organic carbon, pH, and specific conductance were also analyzed in water samples collected from these same locations.

Objective #4- Evaluate whether Hg biomagnification processes are occurring by evaluating concentrations in different feeding guilds and trophic levels.

Null Hypothesis: Hg concentrations will not differ significantly between feeding guilds of similar species at MNWR.

Total Hg concentrations were measured in macrobenthic invertebrates, three different fish guilds: top predators including bowfin (*Amia calva*) and largemouth bass (*Micropterus salmoides*), micropredators including bluegill (*Lepomis macrochirus*) and

white crappie (*Poxomis annularis*), and omnivores including black bullhead *(Ameiurus melas*) and channel catfish (*Ictalurus* punctatus).

Concentrations of Hg and Se were also measured in wood duck (*Ais sponsa*) and hooded merganser (*Mergus cucullatus*) eggs, representing different feeding guilds.

Objective #5- Evaluate whether elevated Hg and Se concentrations in duck tissues (as measured in eggs) could result in a toxic effect, as compared to international thresholds for avian toxicology.

Null Hypothesis: Concentrations of Hg and Se in duck eggs will not exceed international toxicity thresholds.

Wood duck and hooded merganser eggs were sampled for Hg and Se to determine if concentrations of either element exceeded internationally developed standards for avian toxicology.

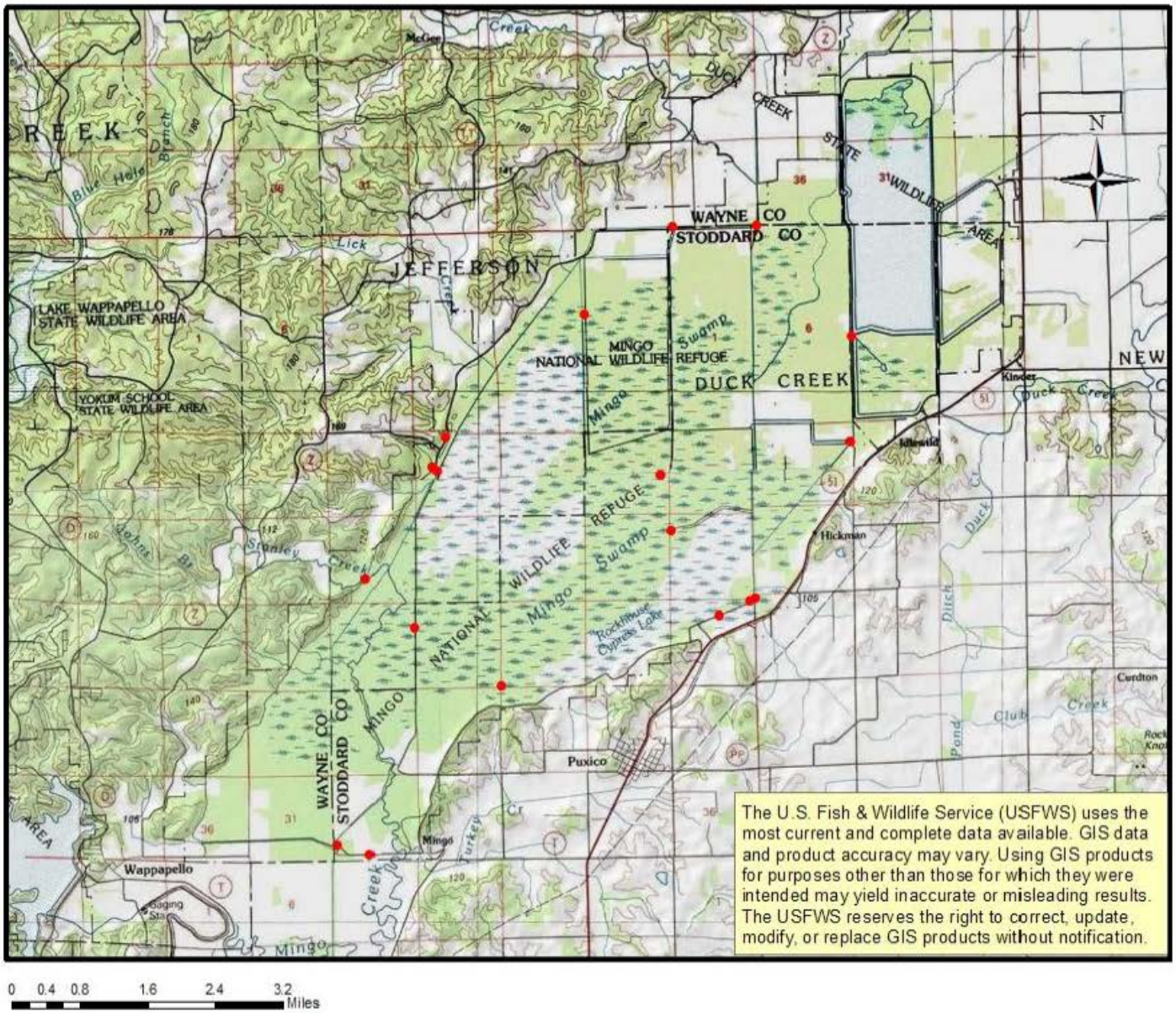
3. METHODS

3.1. Study Parameters

MNWR is a large and complex refuge involving three drainage sub-basins and multiple pools and moist soil units controlled by an extensive drainage system and 50 water control structures, in addition to a number of upland ponds that are disconnected from the regional drainage system. As discussed in Section II, refuge samples consisted of ditch, creek, marsh, and pond sediment; soil from moist soil units and upland locations; water from ditches, creeks, and ponds; macrobenthic invertebrates from ditches, creeks, and ponds; fish from ditches, creeks, and ponds; and duck eggs from nest boxes located on moist soil units, marshes and swamps.

Sediment/soil sampling was conducted at nineteen sample locations described in Table 1 and located on Figure 4. Sample locations were selected to give a diversity of hydraulic regimes (wet and dry cycles), hydrologic inputs (differing drainage basins), differing sediment management regimes (dredging at different times or not at all), and to reflect background conditions. Background, in this case, was identified as locations that are not influenced by flow through the main influent drainage basins. In addition, to analyses of Hg; Se, which is also an air emission by product of coal-burning boilers; and other heavy metals that are associated with mining in the St. Francis River basin (which has been known to flow into MNWR during flooding) were also analyzed to determine whether there are compounding factors contributing to the contaminant load at MNWR. These sample locations were designed to meet the requirements of Objective #1. A subset of these locations had additional analyses performed for methyl Hg and sulfate to address Objective #2. This information is contained in Table 2.

Figure 4. Abiotic Sampling Locations at Mingo



Water sampling and fish sampling were co-located with ditch sampling locations to the extent possible. Water samples also included analysis for other heavy metals to determine whether other contaminants besides Hg are contributing to the contaminant load and potential toxic impacts at MNWR. Fish, macrobenthos, and water sampling locations and a justification for these locations are given in Table 3.

Collection and heavy metal analysis of aquatic macrobenthic invertebrates provides information on metal concentration of prey species for both fish and duck species that are evaluated in this proposal. Aquatic invertebrates also give a better representation of differential contaminant loading sources, since they are generally less mobile and have a more restricted home range. Heavy metal concentrations in their tissue are likely to be more directly attributable to the metal concentrations in the sediment or water within a particular ditch or pond in which they are living, as opposed to fish or ducks who potentially feed from a number of ditches, ponds or wetland areas. A summary of all the sampling numbers and analytes are given in Table 4.

3.2. Collection Methods

General Site Data
The investigators completed a qualitative description of each site including the current weather, site conditions, site location, number and ID of samples collected, and collaborators on site. A GPS reading and one or more photographs were taken at every sample location. The GPS reading was stored internally on the Garmin GPSMap device and recorded in a log book.

Sediments
ASTM Method E 1391-03 was used in the collection of sediments. Sediment samples were collected using methods appropriate to the depth of water in the habitat. Composite samples of approximately the top five centimeters of sediment from ditches were collected using a Ponar dredge and other discreet mechanical sampling device in saturated areas. Five aliquots per sample were collected within a 50 meter stretch of ditch, or 50 square meter area of non-linear habitat features. Composite soil samples were collected from the top three centimeters using new plastic serving spoons. Samples were homogenized in a stainless steel or plastic mixing bowls, with a plastic spoon, placed in laboratory-prepared glass jars, and placed on ice. Samples were given a unique sample number and recorded on field logs and a chain of custody. Samples were secured in a cooler until delivery to the laboratory for analysis. Soil and sediment samples collected for MeHg analysis were frozen at the refuge and shipped frozen on dry ice to the analytical facility to protect from degradation.

Water
Water samples were collected and preserved according to U.S. EPA guidance (U.S. EPA, 1983). Unfiltered water samples were collected by submerging the laboratory-prepared glass jars directly in the water body. Water samples were collected from approximately the middle of the water column of the water body. Filtered water samples for dissolved metals were collected using a GeoTech DisposaFilter, 0.45 μm high capacity capsule filter. Metal samples were preserved to a pH <2 using ultrapure nitric acid following delivery to the analytical facility. Field parameters were collected prior to laboratory samples and recorded in the field log and chain of custody. Site physical properties including dissolved oxygen, pH, conductivity, and

temperature were determined using a YSI 556 Multiparameter Water Quality Instrument (YSI Incorporated, Yellow Springs, Ohio) calibrated at each collection site. The furthest downgradient samples were collected first, proceeding to the most upgradient location. Samples were secured in a cooler on ice until delivery to the laboratory for analysis.

Invertebrates

Invertebrates were collected using either dip nets or mechanical grabs, depending on flow, depth and substrate conditions at each sampling location. Field and laboratory personnel followed Standard Operating Procedures (SOP) P 578 established by the USGS CERC. Aquatic insect larvae were collected by scooping detritus from the stream bottom and gently wash away the sediment by rocking the net back and forth in the water, or by placing the mouth of the net on the stream bottom at a perpendicular angle approximately 12-cm downstream from the object (rock or log) harboring these organisms. The object and surrounding benthos was then disturbed with the feet while holding the net firmly in place. Organisms were swept into the net where they were hand-picked from debris with a pair of polyethylene tweezers.

Fish

Fish sampling occurred at 6 geographic locations at MNWR using collection techniques, including but not limited to electroshocking. Sampling took place at each predetermined sampling location in the late summer. The sampling locations included Ditch 1, Ditch 2, Ditch 11, Stanley Creek, Mingo River, and May Pond. Sampling locations were determined by hydrologic flow and site accessibility. At each of the 6 sites, at least 10 fish of each of the three feeding guilds will be pursued. Whole body samples will be collected and analyzed to determine total Hg contamination in relation to top level predators, such as eagles or osprey that nest on refuge. Site physical properties including dissolved oxygen, pH, conductivity, and temperature were determined using a YSI 556 Multiparameter Water Quality Meter.

Duck Eggs

A total of 100 nest boxes are managed on MNWR. Samples of eggs were taken from these nest boxes. The first egg of each clutch was targeted for collection, as previous studies have shown that contaminant levels are higher in the first eggs and declines with each additional egg in a clutch (Kennamer, 2005). This method of sampling reduces bias related to laying order. 42 hooded merganser eggs and 31 wood duck eggs were collected in the spring of 2008. All eggs were stored with a label indicating nest box identification, date, time, permit numbers etc., and stored in egg cartons inside of a cooler and then transported to a refrigerator until all samples were acquired. Eggs were processed using the EPA method 3050b (USEPA, 1996) to prepare and digest samples for chemical analysis.

Sampling Quality Assurance/Quality Control

All field samples included a duplicate sample collected at a rate of 10% of all media sampled. Field blanks were collected if non-dedicated samples are collected.

3.3 Chemical Analysis

3.3.1. Sample Preparation

Sediment
Sediment samples designated for metal analysis were lyophilized in their original containers using a Genesis 35EL lyophilizer. Percent moisture was determined in conjunction with the lyophilization process. Sediments were relatively fine-grained; therefore, mechanical grinding was not deemed necessary to produce samples suitable for analysis. Instead, dried sediment was transferred into a Ziploc bag which was then sealed and placed on a flat surface. A rolling pin was used to flatten the bag by rolling the pin from the bottom of the bag to the top until a uniform material was produced. Once reduced in this manner, a part was transferred to a glass vial and stored at room temperature in a dessicator before further preparation.

Fish
The larger (> 300g) and more bony frozen fish samples (bowfin, bullhead, bass, and channel catfish) were cut into 1-2 inch blocks using a Hobart food service band saw. The frozen blocks were then fed into a 0.25HP Hobart food service meat grinder to produce a hamburger-consistency product. Ground material was fed through the meat grinder a second time, collected in a plastic bag, then hand-kneaded to a final product. Fish samples < 300g (crappie and bluegill) were chopped into pieces using a titanium meat cleaver. The pieces were then fed through a Kitchenaid benchtop meat grinder equipped with a titanium blade and extrusion plate. The ground material was placed back through the meat grinder a second time, collected in a plastic bag, and hand kneaded. For all ground fish, a part of this wet ground material was placed in a crystallizing dish and lyophilized with a Genesis 35EL lyophilizer with percent moisture determined as part of the lyophilization process. After drying, the sample was placed in a plastic bag and hand-kneaded to a final coarse product, which was transferred to a 40 mL glass vial and stored at room temperature in a dessicator.

Invertebrates
Invertebrate samples were <0.5 g wet weight as received and lyophilized intact, then placed in small glass vials and stored in a dessicator at room temperature.

Duck Eggs
Collectors were instructed to wash off the outside of intact eggs with a dilute soapy water and then freeze. When eggs were received by USGS personnel, each egg was submerged under a flowing stream of deionized water for 5 to 10 seconds, which served to thaw the shell from the inner egg contents then the shell was removed rapidly. Frozen egg contents were then rinsed with deionized water for 2 to 3 seconds, then placed in a 2 ounce (oz) glass jar and lyophilized. After lyophilization, dried eggs were homogenized with a glass rod, transferred to 40 mL glass vials, and stored in a dessicator at room temperature.

3.3.2. Chemical Preparation

Water and Sediment
All water samples were acidified upon receipt by USGS personnel. Water samples designated for metals were acidified with Ultrex® HNO_3 to 1% weight/volume (w/v) and those designated for Se

were acifidied with sub-boiled HCl (1% w/v). Following acidification, water samples for metals were stored at room temperature, whereas water samples for Se were stored in the dark at 4 degrees Celsius (^{0}C). Non-filtered water samples collected for metals were digested for subsequent analysis by inductively coupled plasma-mass spectrometry (ICP-MS) by placing 5 mL of sample into a 50 mL quartz reaction vessel, adding 1 mL HNO_3, and heating the sealed high pressure vessel assembly in a Perkin-Elmer Multiwave Digestion System according to specifications in a pre-programmed method. After cooling, digestates were transferred to a storage container and diluted to a final volume of 50 mL. Final acid matrix was 2 percent HNO_3. For sediment, approximately 0.2 g of dried sediment was placed in a 100 mL Type M Teflon lined ceramic reaction vessel to 5.5mL of HNO_3 and 0.5 mL HCl was added. After processing through the Multiwave Digestion System, cooled digestates were transferred to a storage container and diluted to a 100 mL final volume. Final acid matrix was 5.5 percent HNO_3, 0.5 percent HCl.

To prepare digestates suitable for the quantitative determination of Se by hydride generation flow injection atomic absorption spectroscopy (HGFIAAS), 20 mL of each filtered and non-filtered water sample was subjected to a HNO_3-$Mg(NO_3)_2$ dry ashing procedure. The procedure consisted of three steps: boiling with HNO_3 for solubilization and partial oxidation, 500 ^{o}C ashing with $Mg(NO_3)_2$ for completion of oxidation and decomposition of remaining organic matter, and heating with 6 Molar (M) or 50 percent HCl to dissolve the ash and reduce Se from Se^{+6} to Se^{+4}. Following the HCl dissolution, digestates were diluted to ~100 mL with deionized water, yielding a 10 percent HCl final acid matrix. Sediment, fish, and duck eggs were dry-ashed using the same procedure, but with a starting material of ~0.5 g dry weight.
For the Hg determination in sediment, fish, invertebrates, and duck egg samples, there was no chemical preparation (digestion), because the dried sample was decomposed thermally during instrumental analysis (see below).

3.3.3. Instrumental Analysis

Metals
Digested water and sediment samples were analyzed by ICP-MS using the quantitative analysis mode. The instrument employed was a Perkin-Elmer Sciex Elan DRCe ICP-MS. Internal standards were rhodium [Rh; 10 nanograms per milliliter (ng/mL)] and bismuth (Bi; 10 ng/mL). Calibration curves were as follows: Cr,Co,Ni,As,Pb - 5, 10, 20, 40 ng/mL; Zn - 75, 150, 300 ng/mL; Ag – 1.5, 3, 6, 12 ng/mL. For the analysis, any sample or digestate over the upper calibration standard automatically was diluted 10 times, via a Cetac ASD-500 autodiluter in a serial fashion, until concentrations were within the confines of the standard line. Masses monitored included ^{52}Cr and ^{53}Cr; ^{59}Co, ^{60}Ni and ^{62}Ni; ^{66}Zn and ^{68}Zn; ^{75}As, ^{107}Ag and ^{109}Ag, ^{111}Cd and ^{114}Cd; ^{206}Pb, ^{207}Pb, ^{208}Pb. Where multiple masses were monitored, masses were selected for reporting based on least interferences. Lead was reported as the sum of three masses (^{206}Pb+^{207}Pb+^{208}Pb).

Selenium
The determination of Se was accomplished by HGFIAAS. In this procedure, the digestate is mixed with a HCl carrier solution and then reduced by $NaBH_4$, which has been stabilized with NaOH. The resulting volatile AsH_3 or H_2Se is transferred with argon carrier gas into a heated quartz cell, which is mounted on an atomic absorption spectrophotometer for decomposition and measurement.

Mercury in Soils and Sediment
Mercury was determined with a direct mercury analyzer by thermal combustion gold amalgamation atomic absorption spectrophotometry (TCGAAAS). With this method, a dried sample [40-60 milligrams (mg)] was combusted in a stream of oxygen. All Hg in the sample was volatilized and trapped by amalgamation on a gold substrate, thermally desorbed, and quantitated by atomic absorption spectrophotometry (USEPA, 2003). The entire sequence was conducted with a Milestone DMA-80 analyzer equipped with an automated sample carousel.

Mercury in Water
Total mercury was determined in water by oxidation with BrCl followed by reduction of Hg (II) to Hg(0) with $SnCl_2$. Hg(0)g is purged from the aqueous sample with argon and trapped on a gold column. The trapped Hg is released by heating and then analyzed by atomic fluorescence.

Methyl Mercury in Soils and Sediments
Determination of methyl mercury in soils and sediments was performed by distillation, ethylation, trapping, gas chromatography, and atomic fluorescence. Methyl mercury was distilled to separate it from interfering species and then ethylated with sodium tetraethyl borate. Methyl ethyl mercury is trapped on a Tenax column and then separated on an isothermal GC column. Following pyrolysis of the separated species, Hg is detected by atomic fluorescence.

DOC
DOC in water was performed by Engineering Surveys and Services Testing Laboratories (ESS) of Columbia, MO, following Method 5310B, High *Temperature Combustion Method* in "Standard Methods for the Examination of Water and Wastewater," 20th edition (Clesceri and others, 1998). The sample was acidified to convert inorganic carbonates to CO_2, followed by purging to remove the CO_2. A part of the sample, which subsequently contained only nonpurgable organic carbon, was injected into a heated reaction chamber containing an oxidative catalyst. The water was vaporized and the organic carbon oxidized into CO_2 and H_2O. The CO_2 from the oxidation of organic carbon was transported by carrier gas into a nondispersive infrared analyzer for measurement.

Sulfate
The determination of sulfate in water was performed by EES following Method 4500-SO_4^{-2}, *Turbidimetric Method* in "Standard Methods for the Examination of Water and Wastewater," 20th edition (Clesceri and others, 1998). Sulfate ion (SO_4^{-2}) was precipitated in an acetic acid medium with barium chloride to form barium sulfate crystals of uniform size. Light absorbance of the $BaSO_4$ suspension was measured by a photometer. The SO_4^{-2} concentration was determined by comparing the reading with a standard curve made by carrying SO_4^{-2} standards in the 0 to 40 mg/L SO_4^{-2} range through the entire procedure.

Water Hardness
Water hardness as milligrams per liter (mg/L) $CaCO_3$ was determined by the ethylenediaminetetraacetic acid (EDTA) titrimetric method. Approximately 100 mL of water was mixed with 2 mL of a $NH_4OH{\cdot}NH_4Cl$ buffer solution and one micro-spatula of Eriochrome Black T indicator. This mixture was titrated with

0.01 M disodium ethylenediaminetetraacetate dehydrate until the solution color changed from red to purple then blue.

Cation Exchange Capacity (CEC)
CEC of sediments was performed by the University of Missouri's Soil Testing and Plant Diagnostic Service Laboratory using the summation method of estimating CEC. The sediment or soil was dried and then extracted with 1 Normal (N) ammonium acetate (NH_4OAc) at pH 7 to extract exchangeable basic cations [e.g., potassium (K), calcium (Ca), magnesium (Mg)), with each cation expressed as milliequivalent (meq)/100 g sample. A second aliquot of the sediment or soil was used to determine neutralizable acidity (NA) by the New Woodruff Buffer Method. In this procedure, 5 g of sediment or soil was mixed with 5 mL of 0.01 $CaCl_2$ solution and 5 mL of Woodruff Buffer solution (acetate hydroxide at pH 7). The pH of the mixture was determined after 30 minutes. A depression of 0.1 pH equals 1 meq of neutralizable acidity per 100 g of sample. The calculated CEC was the sum of the three basic cations expressed as meq/100g of sample, plus the quantity of NA.

Total Organic Carbon (TOC)
TOC of sediments was performed by ESS following ASTM Method D-2974-00 "Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils" (ASTM, 2003). Approximately 50 g of wet sediment was heated to a constant weight at 105 ^{o}C in a convectional drying oven. After recording of the dry sediment weight, the sample was ashed in a muffle furnace overnight at 440 ^{0}C. The ashed sample was weighed, wet with a small amount of deionized water, dried overnight again at 105^{0}C, then weighed**.** This allows an estimate of ashed sediment grams minus water of hydration. The organic matter (OM) content was calculated as the difference between the dried sediment weight and this adjusted ashed weight. The percent OM was calculated as: g OM ÷ g dry sediment x 100. The percent TOC was calculated as percent OM x 0.58, following recommendations of Shumacher and others (2002). The percent TOC of organic matter varies between 40 to 58 percent depending on soil composition.

3.4. Quality Control

For digestion of unfiltered water and sediment samples, quality control included digestion blanks, a reference solution, sample replicates, and sample spikes. Quality control for hardness included a reference solution and replicates; for sulfate and DOC, spikes and replicates; and for TOC, replicates. For ICP-MS quantitative analysis, quality-control parameters included repeated analysis of calibration blanks and standards throughout the run, laboratory control samples, analytical duplicate, analytical spike, interference check solution, and a check of dilution percent difference. For samples analyzed by atomic absorption (Hg and Se), pre-digestion quality control included digestion blanks, replicates, spikes, and reference solutions/materials. Analytical quality control for Se included calibration verification solutions and analysis spikes, whereas for Hg included calibration verification reference tissues.

3.5. Data Analysis

Data was statistically analyzed to determine relationships between possible contamination in relation to species with various feeding techniques. Since Hg concentrations in the fauna of an

aquatic ecosystem are strongly linked to position in the food web (Nichols, 2002). Contamination data was also compared in relation to the geographic locale of the five sample sites. Since the different sampling sites represent different hydrological input areas and are connected to various land usage schemes, data was analyzed to show any variation in contamination among particular sites within the refuge.

3.6 Final Project Schedule

A comprehensive project schedule is given in Table 5.

4. RESULTS

4.1 Total Mercury in Water

Concentrations of total mercury in water under varying flow regimes during 2007 and 2008 at MNWR are presented in Table 6. Concentrations of total mercury in water ranged from 0.00160 µg/L at Stanley Creek under 2007 low flow conditions to a maximum of 0.00717 µg/L at Ditch 5 during 2007 low flow conditions. Mean concentrations of total mercury in water were highest during 2008 low flow conditions (0.00428 µg/L) and lowest during 2007 low flow conditions (0.00290 µg/L).[1] Given the variability in the data set and lack of significant differences among the data sets, there does not appear to be a difference in the loading of total mercury in water during different water flow conditions on the refuge.

4.2. Low Flow Water Conditions 2007

Other Metals in Water
Concentrations of elements in filtered and unfiltered water from MNWR from the low-flow 2007 sampling are indicated in Table 7. Among the unfiltered water samples, all elemental concentrations were greatest in water from the Ditch 5 site. Concentration (ng/mL)(ppb) ranges for each element in unfiltered water were as follows: Cr, < 2.0 to 9.0; Co, < 0.14 to 2.84; Ni, < 0.63 to 7.14; Zn, < 4.3 to 21.2; As, < 0.87 to 5.57; Ag, < 0.23 to 0.44; and Pb, 0.11 to 10.9.[2] Concentration (ng/mL) ranges for each element in filtered water were as follows: Cr, 0.6 to 1.2; Co, 0.17 to 1.34; Ni, 0.20 to 1.46; Zn, < 0.4 to 5.2; As, 1.05 to 3.48; Ag, < 0.03; and Pb, < 0.03 to 0.21.

Concentrations of Se in Mingo water are presented in Table 8. Water from the Ditch 5 site had the only Se concentration (0.42 ng/mL) that was above the method detection limit of 0.35 ng/mL.

Metals in Sediment and Soil
Percent moisture and concentrations of elements in MNWR sediment from the 2007 low flow sampling are presented in Table 9. Concentration (µg/g dry weight) ranges for each element were as follows: Cr, 15.1 to 44.9; Co, 3.47 to 22; Ni, 9.77 to 31; Zn, 33.5 to 117; As, 2.12 to 16.9; Se,

[1] µg/L is substantially the same as parts per billion (ppb).
[2] ng/mL is also substantially the same as ppb.

0.16 to 1.30; Ag, 0.033 to 0.19; Hg, 0.018 to 0.12; and Pb, 9.27 to 128. [3]For elements with established Consensus-Based Probable Effect Concentrations (PECs; Cr,Ni,Zn,As,Hg,Pb; Ingersoll and others, 2000), the greatest concentration in sediment was less than the respective PEC for that element (µg/g (ppm) dry weight; Cr, 111; Ni, 48.6; Zn, 459; As, 33; Hg, 1.06; and Pb, 128) for all except Pb, for which the greatest sediment concentration (site SR-1, Shaw's Ridge) was equal to the Pb PEC. Se concentrations were less than the 2 µg/g dry weight toxic effects threshold reported by Lemly (2002).

Highest concentrations of Hg were observed at the Rockhouse Marsh (0.10 µg/g dry weight), Shaw's Ridge (0.12 µg/g dry weight), and Monopoly Marsh (0.099 µg/g dry weight). Lowest concentrations of Hg were observed at the dredged portion of Ditch 11 (0.018 µg/g dry weight) and at the Sandblow (0.024 µg/g dry weight). The average concentration of Hg in dredged areas during 2007 low flow conditions was 0.033 µg/g dry weight. The average concentration of Hg in undredged soil and sediments (including terrestrial soil samples) was 0.063 µg/g dry weight, nearly twice the mean for undredged areas.

Hardness, Sulfate, and DOC
Hardness expressed as mg/L $CaCO_3$ in MNWR waters is indicated in Table 10, above, and ranged from 40 to 118 mg/L. Sulfate in MNWR waters was < 5.0 mg/L (Table 11), and DOC ranged from 3.1 to 8.6 mg/L (Table 12).

TOC and CEC
Percent TOC and CEC for MNWR sediments are presented in Table 13. TOC was relatively high (15.3, 19.4, and 25.1 percent) in sediments from three sites (Shaw's Ridge, Monopoly Marsh, Rock House Marsh), and at all other sites < 10 percent. CEC was also greatest in sediments from Shaw's Ridge and Rock House Marsh (20.2 and 21.4 meq/100g) and at other sites ranged from 6.9 to 17.1 meq/100g.

4.3. Low Flow Water Conditions 2008

Metals in Water
Concentrations of elements in unfiltered and filtered water from the fall 2008 low-flow sampling are indicated in Table 14. Among unfiltered water samples, all elemental concentrations were greatest in water from the Ditch 2 site, with the exception of As and Ag. Concentration (ng/mL) ranges for each element in unfiltered water were as follows: Cr, <0.35 to 2.79; Co, 0.13 to 1.21; Ni, 0.75 to 3.43; Zn, <3.9 to 4.8; As, 1.20 to 2.73; Ag, <0.037; and Pb, <0.072 to 2.19. Generally, concentrations of elements in unfiltered water were higher than concentrations in filtered water from the same sites. Concentration (ng/mL) ranges for each element in filtered water were as follows: Cr, <0.29; Co, 0.19 to 0.80; Ni, <0.17 to 1.63; Zn, <1.3 to 13.8; As, 0.98 to 1.82; Ag, <0.011 to 0.026; and Pb, 0.019 to 0.21.

Concentrations of Se in water for the low flow 2008 sampling are presented in Table 15. Water from Ditch 11 and Ditch 2 sites had the only Se concentrations (0.32, 0.21 and 0.17 ng/mL) that were above the method detection limits of 0.19 and 0.15 ng/mL.

[3] µg/g is substantially the same as parts per million (ppm).

Metals in Sediment and Soil
Percent moisture and concentrations of elements in MNWR sediment are presented in Table 16. For sediments collected as part of the fall 2008 low-flow sampling event, concentration (µg/g dry weight) ranges for each element were as follows: Cr, 8.3 to 52.1; Co, 2.60 to 17.8; Ni, 7.92 to 26.4; Zn, 15.1 to 147; As, 1.85 to 10.8; Se, 0.096 to 1.21; Ag, <0.078 to 0.25; Hg, <0.015 to 0.098; and Pb, 3.99 to 76.8. For elements with established Consensus-Based Probable Effect Concentrations for sediment toxicity (PECs; Cr, Ni, Zn, As, Hg, Pb; Ingersoll and others, 2000), the greatest elemental concentration in sediment was less than the respective PEC for that element (µg/g dry weight; Cr, 111; Ni, 48.6; Zn, 459; As, 33; Hg, 1.06; and Pb, 128).

Highest concentrations of Hg were observed at Pool 8 (0.098 µg/g dry weight), Shaw's Ridge (0.098 µg/g dry weight), and Monopoly Marsh (0.096 µg/g dry weight). Lowest concentrations of Hg were observed at the dredged portion of Ditch 1 (<0.015 µg/g dry weight) and the dredged portion of Ditch 3 (<0.015 µg/g dry weight). The average concentration of Hg in dredged areas during 2008 low flow conditions was 0.026 µg/g dry weight. The average concentration of Hg in undredged soil and sediments (including terrestrial soil samples) was 0.055 µg/g dry weight, more than twice the mean for undredged areas.

Se concentrations were less than the 2 µg/g dry weight toxic effects threshold reported by Lemly (2002).

4.4. High Water Flow Conditions 2008

Metals in Water
Concentrations of elements in unfiltered and filtered water from the spring high-flow sampling are presented in Table 17. Concentrations of elements in reagent blanks were at or less than method detection limits. Concentration (ng/mL) ranges for each element in unfiltered water were as follows: Cr, <0.23 to 1.88; Co, 0.21 to 2.22; Ni, 0.76 to 3.16; Zn, 5.8 to 23.7; As, <0.44 to 2.51; Ag, <0.052; and Pb, 0.17 to 1.60. Generally, concentrations of elements in unfiltered water were higher than concentrations in filtered water from the same sites. Concentration (ng/mL) ranges for each element in filtered water were as follows: Cr, 1.09 to 2.0; Co, 0.32 to 2.06; Ni, 0.61 to 2.13; Zn, 1.4 to 3.8; As, <0.44 to 2.14; Ag,<0.014; and Pb, 0.029 to 0.53.

Metals in Sediment and Soil
Percent moisture and concentrations of elements in MNWR sediment are presented in Table 18. For sediments collected as part of the spring high-flow sampling event, concentration (µg/g dry weight) ranges for each element were as follows: Cr, 14.3 to 49.6; Co, 6.72 to 16.8; Ni, 11.3 to 29.8; Zn, 33.9 to 150; As, 1.50 to 12.1; Se, 0.16 to 1.12; Ag, <0.10 to 0.29; Hg, 0.021 to 0.094; and Pb, 14.0 to 107. For elements with established Consensus-Based Probable Effect Concentrations for sediment toxicity (PECs; Cr, Ni, Zn, As, Hg, Pb; Ingersoll and others, 2000), the greatest elemental concentration in sediment was less than the respective PEC for that element (µg/g dry weight; Cr, 111; Ni, 48.6; Zn, 459; As, 33; Hg, 1.06; and Pb, 128). Se concentrations were less than the 2 µg/g dry weight toxic effects threshold reported by Lemly (2002).

Highest concentrations of Hg were observed at Shaw's Ridge (0.094 µg/g dry weight), and the Ozark Escarpment (0.094 µg/g DW). Lowest concentrations of Hg were observed at the dredged

portion of Ditch 1 (0.028 µg/g DW) and at the Sandblow (0.021 µg/g DW). The average concentration of Hg in dredged areas during 2008 high flow conditions was 0.039 µg/g DW. The average concentration of Hg in undredged soil and sediments (including terrestrial soil samples) was 0.056 µg/g DW.

4.5. Mercury and Selenium in Fish Tissues

Percent moisture and concentrations of Hg and Se in fish collected from MNWR in 2007 and 2008 are presented in Table 19. Selenium concentrations ranged from 0.45 to 1.80 ug/g dry weight (DW). Mercury concentrations in whole-body fish ranged from 0.066 to 2.18 ug/g DW.

4.6. Mercury and Selenium in Duck Eggs

Percent moisture and concentrations of Hg and Se in eggs of hooded mergansers and wood ducks are presented in Table 20. Selenium concentrations in hooded merganser eggs ranged from 1.14 to 2.28 micrograms per gram (µg/g) DW and averaged 1.81 µg/g dry weight. In wood duck eggs, selenium levels ranged from 0.77 to 1.86 µg/g DW and averaged 1.20 µg/g DW. Mercury concentrations in hooded merganser eggs ranged from 1.61 to 7.02 and averaged 3.25 µg/g DW. Total Hg concentrations in wood ducks ranged from 0.046 to 0.30 µg/g DW and averaged 0.13 µg/g DW.

4.7. Methyl Mercury in Soils and Sediments

Concentrations of MeHg in undredged, dredged, and dredge spoil areas of MNWR are presented in Table 21. Concentrations of MeHg in soils and sediments of undredged areas ranged from 0.00028 mg/kg (ppm) DW at the undredged portion of Ditch 1 during 2007, low flow conditions to 0.00380 mg/kg DW at the undredged portion of Ditch 3 during 2008 high flow conditions.[4] Mean concentration of undredged areas regardless of hydraulic flow regime was 0.00112 mg/kg DW. Concentrations of MeHg in soils and sediments of areas that had been recently dredged ranged from 0.00012 mg/kg DW at the dredged portion of Ditch 1 during 2008 low flow conditions to 0.00074 mg/kg DW at the dredged portion of Ditch 3 during 2007 low flow conditions. Mean concentration of MeHg in dredged areas regardless of hydraulic flow regime was 0.00041 mg/kg DW. Concentrations of MeHg in dredge spoils, the materials excavated from dredged areas, ranged from 0.00015 mg/kg DW at the spoils of Ditch 11 during 2008 low flow conditions to 0.00054 mg/kg DW at the spoils of Ditch 11 during the 2007 low flow conditions. Mean concentration of MeHg in dredge spoils regardless of hydraulic flow regime was 0.000315 mg/kg DW.

5. DISCUSSION

5.1 Metals in Water

The data suggest that the waters of MNWR are not significant sources of metals, including Hg and Se, to refuge biota. Concentrations of elements in unfiltered water generally were higher than concentrations in filtered water from the same sites, which is fairly typical of surface water

[4] mg/kg is substantially the same as ppm.

with moderate or greater levels of turbidity. Hardness concentrations ranged from 40 to 118 mg/L. During all three sampling events (low flow 2007, low flow 2008, and high flow 2008) priority pollutant elements (USEPA, 2008) concentrations in filtered and unfiltered water were well below Criterion Continuous Concentrations (CCC; ng/mL): As, 150; Cr (III), 74; Cr (VI), 11; Pb, 2.5; Ni, 52; and Zn, 120. Concentrations of all elements in filtered and unfiltered water were also below the Criterion Maximum Concentrations (ng/mL): As, 340; Cr (III), 570; Cr (VI), 15; Pb, 65; Ni, 470; Ag, 3.4; and Zn, 120.

During the low flow 2007 sampling event, water from the Ditch 5 site had the only Se concentration (0.42 ng/mL) that was above the method detection limit of 0.35 ng/mL, a value well below the Se CCC of 5 ng/mL and the published toxic effects thresholds (TETs) for water (2 and >2 ng/mL) (May and others, 2008). During the low flow 2008 sampling event, water from Ditch 11 and Ditch 2 sites had the only Se concentrations (0.32, 0.21 and 0.17 ng/mL) that were above the method detection limits of 0.19 and 0.15 ng/mL, values well below the Se CCC of 5 ng/mL and the TETs for water (May and others, 2008).

Mean concentrations of total mercury in water were highest during 2008 low flow conditions (0.00428 µg/L) and lowest during 2007 low flow conditions (0.00290 µg/L). Significant differences in total mercury concentrations were not observed during the three sampling events.

5.2 Metals in Sediment and Soil

Results from all three sampling events during 2007 and 2008 did not indicate exceedances of established Consensus-Based Probable Effect Concentrations for sediment toxicity (PECs; Cr, Ni, Zn, As, Hg, Pb; Ingersoll and others, 2000). The greatest elemental concentration in sediments were always less than the respective PEC for that element (µg/g dry weight; Cr, 111; Ni, 48.6; Zn, 459; As, 33; Hg, 1.06; and Pb, 128) save for one instance during low flow conditions in 2007 where the concentration of Pb was equal to the PEC at Shaw's Ridge. Se concentrations were less than the 2 µg/g dry weight toxic effects threshold reported by Lemly (2002) during all sampling events, suggesting that Se toxicity is probably not occurring at MNWR.

Total Hg concentrations in soils and sediments were consistently elevated in undredged areas of the refuge, especially at Shaw's Ridge, Rockhouse Marsh, and Monopoly Marsh. Elevated concentrations of total Hg in these areas correspond well to elevated levels of TOC and commensurate high CEC associated with these sites. These data suggest that areas of the refuge that are accumulating large quantities of organic materials are trapping Hg.

5.3 Metal Loading Sources

An evaluation of the sediment, soil, and water metals data indicates that runoff from agricultural areas upstream in the watershed is not a major loading source of mercury and other metals to MNWR. In fact, some of the highest metal concentrations were found in soil at May Pond and at Shaw Ridge, both areas that do not receive runoff from the main ditches and agricultural areas of the watershed.

The major mercury loading sources are likely from aerial/rainfall deposition. The Missouri Department of Natural Resources operates a Mercury Concentration and Deposition monitor through the National Atmospheric Deposition Program. The monitors evaluate mercury deposition in meteoric water continuously through weekly sampling. Aerial deposition data was inspected that was collected from July 31, 2007 through October 27, 2008, a period roughly synchronous with the sampling effort contained in this report. Total cumulative deposition of Hg over this time period was 20.59 *u*g/m^2 (ppb). Surface soil data was collected from the field adjacent to the deposition monitor to provide a relationship between aerial deposition and soil concentrations. Mercury concentrations were measured at 0.051 and 0.029 *u*g/g (ppm) in 2007 and 2008, which were just under the mean concentrations of all sites for those sampling periods.

5.4 Methyl Mercury in Soils and Sediment

Table 22 and 23 present a means comparison for dredged, undredged, and dredge spoil areas under varying hydraulic flow regimes. The highest mean concentration of MeHg (0.00128 mg/kg DW) was observed during high flow conditions in undredged areas. The lowest mean concentration of MeHg (0.000318 mg/kg DW) was observed from dredge spoils during low flow conditions. Areas of the MNWR that had been dredged had similar values of MeHg for low flow (0.000440 mg/kg DW) and for high flow regimes (0.00044 mg/kg DW). The data suggest that MeHg concentrations are greatest across the refuge in undredged areas during periods of high water flow and least in dredge spoil materials that have been removed from the ditches, allowed to weather, and exposed to drying during low flow conditions. The data confirms the general understanding that the Hg methylation process is enhanced by the organic-rich, eutrophic, shallow-water hydraulic regime prevalent in ditches and wetlands at MNWR. Dredging of ditches has altered some of the conditions that leads to methylation of Hg.

5.5 Selenium and Mercury in Fish Tissue

Selenium concentrations ranged from 0.45 to 1.80 ug/g dry weight (DW). All Se values were less than published Se TET concentrations for whole-body fish, which range from 4 to 7.9 ug/g DW (May and others, 2008).

Levels of Hg in all bluegill, crappie, channel catfish, and invertebrate samples were less than the current USEPA consumption advisory (USEPA, 2001) for edible fish portions of 1.2 µg/g (ppm) DW (0.3 µg/g wet weight, assuming a 75 percent moisture content). However, one bullhead sample, 63 percent of bowfin samples (n=12), and 75 percent of the bass samples (n=3) had Hg concentrations exceeding the 1.2 µg/g DW consumption advisory.

Fish tissue concentrations do not indicate risks directly to the fish as compared with sublethal toxicity data indicating adverse affects from 5-10 mg/kg wet weight from Hoffman (2003). However, concentrations in fish considered as prey species and dietary intake do appear to be over concentrations associated with toxicity to waterfowl of 0.3 to 0.4 mg/kg (ppm) WW (Barr, 1986) and Scheuhammer et al. 2007).

5.6 Selenium and Mercury in Duck Eggs

Selenium concentrations in hooded merganser eggs ranged from 1.14 to 2.28 micrograms per gram (µg/g) DW and averaged 1.81 µg/g dry weight. In wood duck eggs, selenium levels ranged from 0.77 to 1.86 µg/g DW and averaged 1.20 µg/g DW. Selenium concentrations in all duck eggs were well below the Se TET for aquatic bird eggs of 7 µg/g DW reported by Lemly (2002).

Selenium concentrations in wood duck and hooded merganser eggs from MNWR were also measured by Wood (2007) as part of a master's thesis. Concentrations measured were extremely elevated. Means were calculated for different egg fate categories including: successful, dead, infertile and abandoned (calculated for mergansers only). Se concentration means for wood ducks were 40.3, 17.3, and 38.7 *u*g/g for successful, dead, and infertile eggs, respectively. Se concentration means for hooded mergansers were 35.9, 29.6, 30.1, and 30.8 *u*g/g for successful, dead, infertile, and abandoned eggs, respectively. It is presumed all data is reported by Wood (2007) as wet weight, since no mention of drying is found in the methods. Due to the lack of elevated Se found across all media analyzed in this (USFWS 2007-2009) investigation, it is suspected that these extremely high concentrations in eggs reported by Wood (2007) are due to problems in the analytical methods and not real concentrations found at MNWR.

Mercury concentrations in hooded merganser eggs ranged from 1.61 to 7.02 and averaged 3.25 µg/g DW. Total mercury concentrations in wood ducks ranged from 0.046 to 0.30 µg/g DW and averaged 0.13 µg/g DW. The greater Hg concentrations in merganser eggs compared to wood duck are presumably because of differences in diet. Hooded merganser diet includes fish, crayfish, frogs, clams, aquatic insects, and insect larvae (Birdweb, 2008). A wood duck's diet consists of about 90 percent aquatic plant material, such as floating aquatic plants, seeds, acorns, nuts and berries (Schultz, 1997).

Wood (2007) also analyzed Hg concentrations in duck eggs at MNWR. Hg concentration means for wood ducks were 5.5, 5.8, and 7.3 *u*g/g for successful, dead, and infertile eggs, respectively. Hg concentration means for hooded mergansers were 5.3, 5.8, 5.7, 5.6 *u*g/g for successful, dead, infertile, and abandoned eggs, respectively. No significant differences in Hg concentrations were found between species or between egg fates.

Considerable mercury concentrations in hooded merganser eggs found in this investigation indicate Hg bioaccumulation in the aquatic food chain. Fimreite (1971) documented a commonly cited Lowest Observed Adverse Effect Level (LOAEL) of 0.5 µg/g wet weight, or approximately 2.5 µg/g dry weight. Mean concentrations of total mercury in hooded merganser eggs exceed this LOAEL. Consequently, it can be assumed that some degree of toxicity is occurring to hooded merganser hatchlings, which may contribute to decreased reproductive success. This same conclusion cannot be made regarding wood ducks at MNWR at this point. Laboratory studies have indicated a decline in hatching success of pheasant eggs containing Hg residues from 1.3 to 2 µg/g wet weight (approximately 6.5 to 10 µg/g DW); however, there currently is much uncertainty regarding threshold concentrations of Hg in avian maternal diet and eggs that elicits reproductive problems (Wiener et al., 2002).

Another finding of Wood (2007) is that of 117 hooded merganser eggs evaluated only 12 (10%) hatched successfully, compared to 45% successful hatch rate in 38 wood duck eggs evaluated. Eighty (80) hooded merganser eggs were abandoned versus no abandonment observed amongst wood ducks. Elevated Hg concentrations have been linked to reduced clutch success and abandonment behavior in mergansers, other waterfowl and wading birds (Scheuhammer, 1987); (Barr, 1986); (Fenreite, 1971; Borg et al, 1969). The findings of this study related to differences in Hg concentrations in eggs between hooded mergansers and wood ducks could explain poor hatch success in hooded mergansers observed by Wood (2007).

5.7 Other Fauna of Concern

The staff of MNWR has documented mass mortality events and subsequent decline of several key species of turtles and snakes including red-eared sliders (*Trachemys scripta elegans*) and water moccasin (*Agkistrodon piscivores*). Based on observed mortality events, the staff of MNWR has proposed additional contaminant studies on the refuge to document the body burden of pesticides and Hg in reptile and amphibian species. The staff of the Columbia, MO Ecological Services Field Office (CMFO) supports this further inquiry into contaminant effects at MNWR.

6. MANAGEMENT RECOMMENDATIONS

1. Data collected from this contaminant investigation suggest that dredging is decreasing the amount of MeHg stored in the ditches at MNWR. Subsequent deposition of dredge spoils does not have elevated levels of MeHg. Therefore, the dredging program should continue as planned on the refuge.

2. Concentrations of Se do not appear to be a concern for the biota of MNWR. No further management recommendations are suggested for Se.

3. Hg is accumulating in the biota of MNWR. Predatory species investigated in this study had consistently elevated levels of Hg in their tissues. Bass and bowfin had concentrations of Hg above USEPA's consumption advisory level. The CMFO staff will work with the Missouri Department of Conservation to establish statewide consumption advisories for bowfin. MNWR should establish and maintain a signage effort warning the fishing public at the refuge of the hazards associated with the consumption of certain fish.

4. Of the organisms studied in this project, hooded mergansers appear to be most susceptible to the toxic effects from Hg. Additional follow up on hatching success or other population level affects on hooded mergansers is necessary to confirm impacts to this species.

5. If hooded merganser population impacts are confirmed, additional refuge management options could be considered. Given the differences in MeHg found between dredged and undredged ditches, and the prevalence of MeHg in large areas of organic-rich wetlands, MNWR managers may consider creating some additional portion of habitat that is less

conducive to MeHg formation. Deeper water, more oligotrophic habitats may provide prey items for mergansers and other piscivorous birds that have lower Hg content due to lower levels of Hg methylation. However, this management recommendation may have serious practical, regulatory, and ecological limitations. For example, newly created habitat with deeper water may be less productive ecologically and, therefore, may not be utilized sufficiently by mergansers or other piscivorous birds to the extent that their MeHg dose is reduced. Additionally, it may not be feasible to establish deep-water, oligotrophic habitat in the Mingo basin.

6. Additional investigations of contaminants associated with herpefauna mortality may be warranted.

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TABLES

Table 1. Sample Sites, Habitat Descriptions and Justifications

	NAME	DESCRIPTION	JUSTIFICATION
1)	Ozark Escarpment	a. Located on the western edge of the refuge b. Upland site c. Foothills of the Ozarks	a. Receives only direct precipitation and runoff from uphill b. Background
2)	Monopoly Marsh	a. Located in the middle of the refuge b. 2405 acre marsh	a. Periodic drawdown (5 year intervals between drawdown) b. Heavy waterfowl usage
3)	South of Shaw Ridge	a. Bottomland hardwoods	a. Usually a dry site although may become saturated with heavy rains b. Background
4)	Stanley Creek	a. Input of water into the refuge b. Natural stream that forms out of the ridge from rainfall and runoff c. Permanent stream, not ephemeral d. Mostly surrounded by upland forest with minor agricultural fields bordering e. Comes off private land onto the refuge f. Drains the wilderness area	a. Less agricultural runoff than other drainages
5)	May Pond	a. Man made pond with average depth 6 feet b. Runoff from one hill and direct precipitation feed the pond c. Approximately 19 acres	a. Background
6)	Ditch 1	a. Runoff and discharge from Duck Creek Conservation Area and agricultural fields to the north feed this ditch b. Receives water from Castor River periodically from a structure that is maintained by Duck Creek c. Receives water from Brush Creek d. Watershed feeding it approximately 18 square miles	a. Heavy agricultural influence.
7)	Ditch 2	a. Fed by McGee Creek b. Runoff from agricultural fields to the north c. Watershed feeding ditch approximately 15 square miles	a. Heavy agricultural influence.
8)	Ditch 3	a. Some runoff from agriculture fields to north, usually only during large scale rain events	a. No creek feeds ditch
9)	Ditch 4	a. Runs north from a couple of fields to the south eastern border of Monopoly Marsh b. Connected to Monopoly and Gum stump (Pool 3)	a. Has earthen plug that keeps it separated from Ditch 11
10)	Ditch 5	a. Runs up to middle of Monopoly and dead ends	a. Runs into Ditch 11 and is main drain for Monopoly Marsh
11)	Ditch 6	a. Runs out of Monopoly Marsh from Old Mingo River b. Very shallow, filled with silt c. Secondary outlet for Monopoly Marsh	

12)	Ditch 10	a. Receives water from west side of refuge off the Ozark foothills b. Connects with Stanley Creek, Ditch 4, Ditch 6 and Ditch 11 c. Watershed feeding it is approximately 20 square miles	
13)	Spillway at Ditch 11	a. The outlet site for all waters in the combined 90 square mile watershed	a. Samples will be representative of a composite of water from all other ditches in the refuge
14)	Moist Soil Unit 1	a. Floods in winter every year by pumping from Ditch 2 b. Drawdown occurs every year in spring or summer c. A lot of disking in unit to set back woody plants	
15)	Binford	a. Floods in winter every year by rainfall b. Drawdown occurs every year in spring or summer c. Was initially scraped when levees were build around it	a. Anecdotal evidence suggests that Se is an issue with this unit b. Plant growth is very poor in the unit
16)	Pool 8	a. Green tree reservoir 1191 acres b. Receives flooding from east and west via Ditches 1 and 2 c. Stays flooded in December and January almost every year for waterfowl hunting d. Some years in the past have been wet almost all year	
17)	Rockhouse Marsh	a. A 1500 acre marsh that floods from Ditch 3 b. Floods and dries every year for the past 10 years c. Prior to 1996 would be drawn down every other year	
18)	Sandblow	a. A sand boil possibly created from a major earthquake	a. Infiltration and CEC, etc., will be completely different for this area due to sand content b. Background
19)	MDNR Air monitoring station	a. Upland location in fescue field b. Monitors deposition of atmospheric Hg, Se, and other air quality parameters	a. Allows correlation with air deposition and soil concentrations b. Background

*Sediment or soil will be collected at all of these locations

Table 2. Sample locations and justification for methyl Hg (MeHg) samples.

Location	Justification
Ditch 1 above dredging	In flow from Castor River, Brush Cr., and agricultural fields, constantly saturated
Ditch 1 dredged portion	Measure dredging effects on MeHg in the ditch, unsaturated
Ditch 1 dredged sediment	Measure 2001 dredging effects on MeHg, constantly saturated
Ditch 2 above dredging	In flow from McGee Cr., springs, and agricultural fields, constantly saturated
Ditch 2 in dredged portion	Measure differences in dredged and undredged portions of ditch
Ditch 2 dredged material	Measure 2004-5 dredging effects on MeHg
Ditch 3, above dredging	In flow from agricultural fields, constantly saturated
Ditch 3 below dredging	Measure differences in dredged and undredged portions of ditch
Ditch 3 dredged material	Measure 1998 dredging effects on MeHg, unsaturated
Ditch 5 dredged portion	Drains Monopoly Marsh and other varied sources, constantly saturated
Ditch 5 dredged material	Measure 1999 dredging effects on MeHg, unsaturated
Ditch 6 dredged portion	In flow from Monopoly Marsh, constantly saturated
Ditch 6 dredged material	Measure 1997 dredging effects on MeHg, unsaturated
Ditch 10, undredged portion	Measure undredged ditch draining multiple areas, including Ozark upland
Ditch 11	Receives flow from all ditches, drains entire refuge
Ditch 11 dredged material	Measure 2000-1 dredging effects on MeHg, unsaturated
Stanley Creek	Drains wilderness area and Ozark upland, fluctuating water level
May Pond	Not connected to drainage basins, background
Monopoly Marsh	Fluctuating water level

Table 3. Water, fish and invertebrate sampling locations.

Location	Justification
Ditch 1	Water quality and organisms effected by multiple inflow sources, including heavy agricultural influence, corresponds with methyl Hg/dredging sampling effort.
Ditch 2	Water quality and organisms affected by flow from McGee Cr., springs, and agricultural fields, corresponds to MeHg sampling effort, fish have access to dredged and undredged portions of ditch.
Ditch 5	Drains Monopoly Marsh and other varied sources, isolated from Ditches 1 and 2, corresponds to MeHg sampling effort, fish have access to dredged and undredged portions of ditch.
Ditch 11	Receives flow from all ditches, drains entire refuge
Stanley Creek	Drains wilderness area and Ozark upland, fish and water quality not influenced by runoff from most of the rest of the refuge.
May Pond	Not connected to drainage basins, water quality mostly reflective of rainfall, background.

Table 4. Sample Media and Analytes

MEDIA	ANALYTICAL PARAMETERS	EPA (or other) ANALYTICAL METHOD
Soil/Sediment	Total Hg and Se	7473, USGS-CERC-SOP P.207
Soil/Sediment	Total Hg, Se, Pb, Zn, Co, Ni, Cr, Ag, As	7473, 6020A, USGS-CERC-SOP P.207
Soil/Sediment	MeHg	1630
Soil/Sediment	TOC, CEC	8081B
Dredge spoil	Total Hg, Se, Pb, Zn, Co, Ni, Cr, Ag, As	7473, 6020A, USGS-CERC-SOP P.207
Dredge spoil	MeHg	1630
Water	Inorganic Hg (total)	7470/7471
Water	Total Se, Pb, Zn, Co, Ni, Cr, Ag, As	6020A, USGS-CERC-SOP P.207
Water	Dissolved Se, Pb, Zn, Co, Ni, Cr, Ag, As	6020A, USGS-CERC-SOP P.207
Water	DOC, hardness and sulfate	USGS-CERC-SOP P.200
Duck Eggs	Total Hg and Se	7473, USGS-CERC-SOP P.207
Invertebrates	Total Hg and Se	7473, USGS-CERC-SOP P.207
Fish	Total Hg and Se	7473, USGS-CERC-SOP P.207

Table 5. Final Project Schedule

Activity	Schedule
Low- Flow Soil, Water, Sediment, Fish and Invertebrate Sampling	August-September 2007
Chemical Analysis Low-Flow Water and Sediment Sampling and Invertebrate and Fish Tissue and Report	September 2007-February 2009
High-Flow Soil, Water and Sediment Sampling	March-May 2008
Duck Egg Collection	March-May 2008
Chemical Analysis High Flow Sampling, Duck Eggs, and Archived Tissues and Report	April-February 2009
FY08 Interim Progress Report	June 2008
Low- Flow Soil, Water and Sediment Sampling	August- September 2008
Chemical Analysis Low-Flow Soil, Water and Sediment Sampling and Report	September 2008-February 2009
MeHg Analytical Chemistry Report	June 2009
Final Report	August 2010

Table 6. Concentrations of inorganic mercury in water from the Mingo National Wildlife Refuge during varying hydraulic regimes from 2007-2008.

Sample Event	*Sample ID*	*Wet Weight Hg (ug/kg)*	*Sample Event*	*Sample ID*	*Wet Weight Hg (ug/kg)*	*Sample Event*	*Sample ID*	*Wet Weight Hg (ug/kg)*
LF 2007	D-1-W-CL	0.00240	LF 2008	D-1-W-CL	0.00178	HF 2008	D-1-W-CL	0.00351
LF 2007	D-11-W-CL	0.00222	LF 2008	D-11-W-CL	0.00497	HF 2008	D-11-W-CL	0.00213
LF 2007	D-2-W-CL	0.00310	LF 2008	D-2-W-CL	0.00579	HF 2008	D-2-W-CL	0.00596
LF 2007	D-5-W-CL	0.00717	LF 2008	D-5-W-CL	0.00178	HF 2008	D-5-W-CL	0.00374
LF 2007	MP-1-W-CL	0.00091	LF 2008	MP-1-W-CL	0.00471	HF 2008	MP-1-W-CL	0.00646
LF 2007	SC-1-W-CL	0.00160	LF 2008	SC-1-W-CL	0.00663	HF 2008	SC-1-W-CL	0.00248
Mean of LF 2007 Samples =		**0.00290**	**Mean of LF 2008 Samples =**		**0.00428**	**Mean of HF 2008 Samples =**		0.00405

[ug/kg, micrograms/kilogram wet weight; LF, Low Flow Conditions; HF, High Flow Conditions]

Table 7. Concentrations of Cr, Co, Ni, Zn, As, Ag, and Pb in unfiltered and filtered water from sites in the Mingo National Wildlife Refuge during low flow 2007 conditions.

Site	Field/lab ID	Collection date	Water type	Cr	Co	Ni	Zn	As	Ag	Pb
							(ng/mL)			
Ditch 1	D-1-W total	09/05/07	unfiltered	< 2.0	***0.40***	***1.95***	< 4.3	4.01	< 0.23	0.60
Ditch 1	D-1-W Dup total	09/05/07	unfiltered	< 2.0	***0.43***	4.20	***5.1***	3.99	< 0.23	0.47
Ditch 2	D-2-W total	09/05/07	unfiltered	< 2.0	0.80	2.38	< 4.3	***2.56***	< 0.23	1.17
Ditch 5 Dredged	D-5-D-W total	09/05/07	unfiltered	9.0	2.84	7.14	21.2	5.57	***0.44***	10.9
Ditch 11 Spillway	D-11-D-W total	09/05/07	unfiltered	***2.5***	1.66	3.12	***10.0***	***2.85***	< 0.23	2.84
May Pond	MP-1-W total	09/05/07	unfiltered	< 2.0	***0.36***	3.10	***5.5***	***1.61***	< 0.23	***0.19***
Stanley Creek	SC-1-W total	09/05/07	unfiltered	< 2.0	***0.42***	***0.97***	< 4.3	***1.62***	< 0.23	***0.11***
Ditch 1	D-1-W dissolved	09/05/07	filtered	1.0	0.25	1.01	< 0.4	3.48	< 0.03	< 0.03
Ditch 1	D-1-W Dup dissolved	09/05/07	filtered	1.1	0.22	0.98	***0.4***	3.46	< 0.03	< 0.03
Ditch 2	D-2-W dissolved	09/05/07	filtered	1.2	0.48	0.81	***0.9***	2.55	< 0.03	< 0.03
Ditch 5 Dredged	D-5-D-W dissolved	09/05/07	filtered	0.8	1.34	1.46	***0.7***	1.64	< 0.03	0.21
Ditch 11 Spillway	D-11-D-W dissolved	09/05/07	filtered	0.7	0.77	0.81	5.2	1.74	< 0.03	***0.069***
May Pond	MP-1-W dissolved	09/05/07	filtered	0.6	0.17	***0.20***	< 0.4	1.05	< 0.03	< 0.03
Stanley Creek	SC-1-W dissolved	09/05/07	filtered	0.8	0.48	***0.45***	2.0	1.33	< 0.03	< 0.03

[---, no data; ng/mL, nanograms per milliliter; bold and italicized values are greater than method detection limit but less than method quantitation limit and have higher uncertainty.

Table 8. Concentrations of Se in unfiltered and filtered water from sites in the Mingo National Wildlife Refuge during low flow 2007 conditions.

Site	Field/lab ID	Collection date	Water type	Se (ng/mL)
Ditch 1	D-1-W	09/05/07	unfiltered	< 0.35
Ditch 1	D-1-W Dup	09/05/07	unfiltered	< 0.35
Ditch 2	D-2-W	09/05/07	unfiltered	< 0.35
Ditch 5 Dredged	D-5-D-W	09/05/07	unfiltered	0.42
Ditch 11 Spillway	D-11-D-W	09/05/07	unfiltered	< 0.35
May Pond	MP-1-W	09/05/07	unfiltered	< 0.35
Stanley Creek	SC-1-W	09/05/07	unfiltered	< 0.35
Ditch 1	D-1-W	09/05/07	filtered	< 0.35
Ditch 1	D-1-W Dup	09/05/07	filtered	< 0.35
Ditch 2	D-2-W	09/05/07	filtered	< 0.35
Ditch 5 Dredged	D-5-D-W	09/05/07	filtered	< 0.35
Ditch 11 Spillway	D-11-D-W	09/05/07	filtered	< 0.35
Stanley Creek	SC-1-W	09/05/07	filtered	< 0.35
May Pond	MP-1-W	09/05/07	filtered	< 0.35

[---, no data; ng/mL, nanograms per milliliter; <, less than

Table 9. Concentrations of Se in unfiltered and filtered water from sites in the Mingo National Wildlife Refuge during low flow 2007 conditions.

Site	Field/lab ID	Collection date	Percent moisture	Cr	Co	Ni	Zn	As (µg/g)	Se	Ag	Hg	Pb
Binford	BF-1 Metals	09/05/07	3.4	28.6	8.31	14.7	55.0	5.12	0.45	0.12	***0.044***	58.8
Ditch 1 Dredged	D-1-D Metals	09/05/07	49.3	17.2	6.34	11.1	34.2	2.97	0.18	0.033	***0.047***	9.32
Ditch 1 Dredged	D-1-D Dup Metals	09/05/07	50.5	16.4	6.12	10.6	33.5	2.51	0.20	0.035	***0.026***	9.27
Ditch 2 Dredged	D-2-D Metals	09/04/07	42.6	37.2	11.4	25.4	68.5	5.87	0.16	0.065	***0.032***	16.7
Ditch 4 Undredged	D-4-UD Metals	09/04/07	72.4	44.9	11.9	27.9	103.	5.50	0.70	0.12	0.084	23.3
Ditch 5 Dredged	D-5-D Metals	09/05/07	29.5	33.8	11.1	21.8	61.9	10.8	0.20	0.066	***0.030***	22.9
Ditch 6 Dredged	D-6-D Metals	09/06/07	44.0	42.6	12.4	19.5	65.4	5.37	0.55	0.099	***0.038***	51.2
Ditch 6 Dredged	D-6-D Dup Metals	09/06/07	43.8	43.4	12.1	19.2	66.4	5.26	0.54	0.092	***0.040***	47.1
Ditch 10	D-10-1 Metals	09/06/07	58.2	27.6	4.18	9.77	36.9	2.12	0.26	0.10	***0.032***	16.1
Ditch 11 Spillway	D-11-D Metals	09/05/07	32.4	36.9	22.0	22.1	69.5	16.9	0.74	0.051	***0.018***	30.5
May Pond	MP-1 Metals	09/05/07	69.5	27.3	9.26	19.8	101.	4.11	0.36	0.11	0.069	26.1
Stanley Creek	SC-1 Metals	09/05/07	54.5	28.9	10.6	14.4	51.0	4.94	0.40	0.068	***0.049***	21.0
Shaw's Ridge	SR-1 Metals	09/05/07	17.3	41.2	8.18	24.5	90.8	4.47	0.88	0.13	0.12	128.
Air Monitoring	AMS-1 Metals	09/04/07	2.1	23.0	5.14	13.0	36.0	3.30	0.23	0.093	***0.051***	12.8
Rock House Marsh	RH-1 Metals	09/04/07	77.9	38.7	8.91	31.0	117.	10.2	1.13	0.19	0.10	28.7
Sand Blow	SB-1 Metals	09/04/07	1.5	15.1	6.09	16.6	61.9	2.82	0.18	0.063	***0.024***	11.8
Moist Soil Unit	MSU-1 Metals	09/06/07	7.6	27.9	3.47	11.0	37.2	2.86	0.37	0.075	***0.030***	19.5
Pool 8	P8-1 Metals	09/06/07	25.7	30.1	3.92	11.9	44.1	2.64	0.70	0.11	0.075	32.2
Ozark Escarpment	OE-1 Metals	09/06/07	43.8	24.2	12.4	11.3	39.1	4.30	0.27	0.060	***0.037***	16.3
Monopoly Marsh	MM-1 Metals	09/06/07	84.8	44.2	11.5	29.6	113.	5.96	1.30	0.10	0.099	45.9

[µg/g, micrograms per gram dry weight; bold and italicized values are greater than method detection limit but less than method quantitation limit and have higher uncertainty.]

Table 10. Measured hardness in water from Mingo National Wildlife Refuge during 2007 low flow conditions.

Site	Field ID	Collection date	Sample volume (mL)	Titrant added (mL)	Hardness (mg/L $CaCO_3$)
Ditch 1	D-1-W	09/05/07	50	4.8	96.
Ditch 1	D-1-W Dup	09/05/07	50	4.6	92.
Ditch 2	D-2-W	09/05/07	50	5.9	118.
Ditch 5 Dredged	D-5-D-W	09/05/07	50	2.0	40.
Ditch 11Spillway	D-11-D-W	09/05/07	50	3.4	68.
May Pond	MP-1-W	09/05/07	50	2.9	58.
Stanley Creek	SC-1-W	09/05/07	50	3.0	60.

[mL, milliliter; mg/L, milligram per liter; ID, identification]

Table 11. Measurement of sulfate in water samples from Mingo National Wildlife Refuge during low flow 2007 conditions.

Site	Field ID	Collection date	Sulfate (mg/L)
Ditch 1	D-1-W	09/05/07	< 5.0
Ditch 1	D-1-W Dup	09/05/07	< 5.0
Ditch 2	D-2-W	09/05/07	< 5.0
Ditch 5 Dredged	D-5-D-W	09/05/07	< 5.0
Ditch 11 Spillway	D-11-D-W	09/05/07	< 5.0
May Pond	MP-1-W	09/05/07	< 5.0
Stanley Creek	SC-1-W	09/05/07	< 5.0

[mg/L, milligram per liter; ID, identification; <, less than]

Table 12. Dissolved organic carbon (DOC) in water samples from Mingo National Wildlife Refuge during low flow 2007 conditions.

Site	Field ID	Collection date	DOC (mg/L)
Ditch 1	D-1-W	09/05/07	5.9
Ditch 1	D-1-W Dup	09/05/07	5.8
Ditch 2	D-2-W	09/05/07	3.1
Ditch 5 Dredged	D-5-D-W	09/05/07	8.6
Ditch 11 Spillway	D-11-D-W	09/05/07	6.6
May Pond	MP-1-W	09/05/07	4.3
Stanley Creek	SC-1-W	09/05/07	4.7

[mg/L, milligram per liter]

Table 13. Percent total organic carbon and cation exchange capacity of sediments from Mingo National Wildlife Refuge during low flow 2007 conditions

Site	Field ID	Collection date	TOC (percent)	CEC (meq/100g)
Binford	BF-1	09/05/07	2.4	9.5
Ditch 1 Dredged	D-1-D	09/05/07	2.1	6.9
Ditch 1 Dredged	D-1-D Dup	09/05/07	4.1	9.0
Ditch 2 Dredged	D-2-D	09/04/07	3.0	14.7
Ditch 3 Dredged	D-3-D	09/06/07	5.2	15.2
Ditch 4 Undredged	D-4-UD	09/04/07	9.9	17.1
Ditch 5 Dredged	D-5-D	09/05/07	1.3	14.9
Ditch 6 Dredged	D-6-D	09/06/07	1.9	16.1
Ditch 6 Dredged	D-6-D Dup	09/06/07	2.2	15.9
Ditch 10	D-10-1	09/06/07	7.1	8.5
Ditch 11 Spillway	D-11-D	09/05/07	1.5	9.5
May Pond	MP-1	09/05/07	4.6	8.3
Stanley Creek	SC-1	09/05/07	4.1	7.5
Shaw's Ridge	SR-1	09/05/07	15.3	20.2
MDNR Air Monitoring	AMS-1	09/04/07	3.8	9.2
Rock House Marsh	RH-1	09/04/07	25.1	21.4
Sand Blow	SB-1	09/04/07	1.5	8.7
Moist Soil Unit	MSU-1	09/06/07	3.7	12.3
Pool 8	P8-1	09/06/07	7.7	16.1
Ozark Escarpment	OE-1	09/06/07	4.7	10.4
Monopoly Marsh	MM-1	09/06/07	19.4	16.1

[meq/100g, milliequivalents per 100 grams; TOC, total organic carbon; CEC, cation exchange capacity]

Table 14. Concentrations of elements in unfiltered and filtered water from sites in the Mingo National Wildlife Refuge during 2008 low-flow conditions.

Site	Field ID	Collection date	Water type	Cr	Co	Ni	Zn	As	Ag	Pb
							(ng/mL)			
May Pond	MP-1-W Total	09/16/08	unfiltered	< 0.35	0.32	0.83	< 3.9	1.20	< 0.037	0.64
Stanley Creek	SC-1-W Total	09/17/08	unfiltered	< 0.35	0.13	***0.75***	< 3.9	1.24	< 0.037	< 0.072
Stanley Creek	SC-1-W Total Field Dup	09/17/08	unfiltered	< 0.35	0.21	1.01	< 3.9	1.33	< 0.037	0.36
Ditch 11	D-11-D-W Total	09/16/08	unfiltered	1.29	1.17	2.89	< 3.9	2.73	< 0.037	1.50
Ditch 5	D-5-D-W Total	09/16/08	unfiltered	***1.00***	0.55	1.79	< 3.9	2.15	< 0.037	1.27
Ditch 1	D-1-D-W Total	09/16/08	unfiltered	***0.89***	0.62	2.22	< 3.9	2.56	< 0.037	0.92
Ditch 2	D-2-D-W Total	09/15/08	unfiltered	2.79	1.21	3.43	***4.8***	1.71	< 0.037	2.19
May Pond	MP-1-W Dissolved	09/16/08	filtered	< 0.29	0.46	< 0.17	< 1.3	0.98	***0.026***	***0.019***
Stanley Creek	SC-1-W Dissolved	09/17/08	filtered	< 0.29	0.23	***0.44***	< 1.3	1.11	< 0.011	***0.027***
Stanley Creek	SC-1-W Field Dup Dissolved	09/17/08	filtered	< 0.29	0.19	***0.27***	< 1.3	1.04	< 0.011	***0.023***
Ditch 11	D-11-D-W Dissolved	09/16/08	filtered	< 0.29	0.80	1.63	< 1.3	1.72	< 0.011	0.21
Ditch 5	D-5-D-W Dissolved	09/16/08	filtered	< 0.29	0.66	0.58	< 1.3	1.78	< 0.011	0.055
Ditch 1	D-1-D-W Dissolved	09/16/08	filtered	< 0.29	0.34	0.89	< 1.3	1.82	< 0.011	0.099
Ditch 2	D-2-D-W Dissolved	09/15/08	filtered	< 0.29	0.73	0.92	13.8	1.11	< 0.011	0.087

; ng/mL, nanograms per milliliter; ---, no data; bold and italicized values are greater than the method detection limit but less than the method quantitation limit and have higher uncertainty; concentrations of unfiltered water samples are "total recoverable"]

Table 15. Concentrations of selenium in unfiltered and filtered water from sites in the Mingo National Wildlife Refuge during 2008 low-flow conditions.

Site	Field ID	Collection date	Water type	Se ng/mL
May Pond	MP-1-W Total	09/16/08	unfiltered	< 0.15
Stanley Creek	SC-1-W Total	09/17/08	unfiltered	< 0.15
Stanley Creek	SC-1-W Total Field Dup	09/17/08	unfiltered	< 0.15
Ditch 11	D-11-D-W Total	09/16/08	unfiltered	0.21
Ditch 5	D-5-D-W Total	09/16/08	unfiltered	< 0.15
Ditch 1	D-1-D-W Total	09/16/08	unfiltered	< 0.15
Ditch 2	D-2-D-W Total	09/15/08	unfiltered	< 0.15
May Pond	MP-1-W Dissolved	09/16/08	filtered	< 0.15
Stanley Creek	SC-1-W Dissolved	09/17/08	filtered	< 0.15
Stanley Creek	SC-1-W Field Dup Dissolved	09/17/08	filtered	< 0.15
Ditch 11	D-11-D-W Dissolved	09/16/08	filtered	< 0.15
Ditch 5	D-5-D-W Dissolved	09/16/08	filtered	< 0.15
Ditch 1	D-1-D-W Dissolved	09/16/08	filtered	< 0.15
Ditch 2	D-2-D-W Dissolved	09/15/08	filtered	0.17

[Se, selenium; ---, no data; ng/mL, nanograms per milliliter; <, less than]

Table 16. Concentrations of elements in sediment from sites in the Mingo National Wildlife Refuge during 2008 low-flow conditions.

Site	Field ID	Collection Date	Percent Moisture	Cr	Co	Ni	Zn	As (µg/g)	Se	Ag	Hg	Pb
Rock House Marsh	RH-1	09/15/08	61.2	52.1	6.30	22.8	79.8	4.50	0.42	0.25	0.043	22.4
Ditch 2 Dredged	D-2-D	09/15/08	34.8	38.9	13.5	25.6	67.3	10.8	0.10	0.15	0.027	16.8
Sand Blow	SB-1	09/15/08	15.2	14.5	6.22	19.1	78.3	2.79	0.21	< 0.078	0.024	14.9
Moist Soil Unit	MSU-1	09/16/08	25.9	24.2	2.60	8.28	30.0	1.85	0.26	0.16	0.022	15.4
Pool 8	P8-1	09/16/08	30.0	34.2	6.16	17.0	57.0	2.59	0.60	0.19	0.098	37.1
Ditch 1 Dredged	D-1-D	09/16/08	21.3	8.3	4.29	7.92	15.1	2.45	0.19	< 0.078	< 0.015	3.99
Ditch 5 Dredged	D-5-D	09/16/08	38.9	52.1	8.98	25.0	80.3	6.41	0.71	0.23	0.044	40.4
Shaw's Ridge	SR-1	09/16/08	35.8	40.6	6.91	23.4	89.4	2.75	0.82	0.19	0.097	76.8
Ditch 11Dredged	D-11-D	09/16/08	33.3	29.4	17.8	20.8	58.6	10.7	0.24	0.12	0.015	23.0
Binford Unit	BF-1	09/16/08	17.1	29.5	9.63	14.9	47.3	5.62	0.54	0.19	0.033	41.8
Ditch 6 Dredged	D-6-D	09/16/08	54.8	34.7	9.90	21.1	75.7	4.24	0.50	0.14	0.051	61.3
May Pond	MP-1	09/16/08	68.5	28.2	8.42	26.4	147.	3.20	0.27	0.17	0.073	32.8
Air Monitoring Station	AMS-1	09/16/08	27.2	28.1	5.29	13.2	35.9	3.26	0.27	0.17	0.029	14.4
Ditch 3 Dredged	D-3-D	09/17/08	23.1	14.4	5.63	14.9	26.4	2.19	0.096	< 0.078	< 0.015	7.21
Ditch 3 Dredged	D-3-D Dup	09/17/08	23.4	13.9	5.57	12.5	25.7	1.99	0.10	< 0.078	< 0.015	7.38
Ditch 4 Undredged	D-4-UD	09/17/08	56.8	31.8	7.34	18.7	68.6	3.34	0.45	0.17	0.057	17.9
Ozark Escarpment	OE-1	09/17/08	15.8	19.9	6.25	10.3	41.2	2.49	0.29	0.085	0.055	18.3
Monopoly Marsh	MM-1	09/17/08	67.8	40.6	6.54	21.9	87.1	3.38	1.21	0.20	0.096	55.4
Ditch 10	D-10	09/17/08	73.8	30.2	3.75	13.1	48.0	2.14	0.42	0.13	0.051	16.9
Stanley Creek	SC-1	09/17/08	57.1	27.9	4.54	12.6	43.4	1.87	0.30	0.10	0.038	18.2

[µg/g, micrograms per gram dry weight; <, less than; concentrations of Cr, Co, Ni, Zn, As, Ag, and Pb are "total recoverable;" concentrations of Se and Hg are "total"]

Table 17. Concentrations of elements in sediment from sites in the Mingo National Wildlife Refuge during 2008 high-flow conditions.

Site	Field ID	Collection Date	Percent Moisture	Cr	Co	Ni	Zn	As (µg/g)	Se	Ag	Hg	Pb
May Pond	MP-1	05/05/08	73.7	33.9	7.04	24.2	150.	2.82	0.30	0.21	0.079	37.4
Stanley Creek	SC-1	05/05/08	72.1	24.9	14.6	16.6	55.3	6.41	0.53	0.11	0.055	21.4
Stanley Creek Dredged	SC-1-D	05/06/08	71.7	24.7	13.6	16.4	83.4	6.33	0.47	0.12	0.056	20.8
Ditch 11	D-11	05/06/08	36.7	43.8	13.2	22.7	77.7	7.96	0.80	0.20	0.056	34.2
Ditch 11Dredged	D-11-D	05/06/08	15.4	32.4	11.4	19.6	59.3	4.70	0.41	0.13	0.033	21.7
Ditch 5	D-5	05/06/08	31.4	40.5	16.8	29.8	82.7	8.07	0.21	0.16	0.041	27.3
Ditch 5 Dredged	D-5-D	05/06/08	28.6	40.2	13.1	25.2	72.1	12.1	0.25	0.17	0.044	25.2
Binford Unit	BF-1	05/06/08	21.0	29.1	9.50	15.9	48.1	5.57	0.49	0.19	0.030	49.8
Ditch 6	D-6	05/06/08	77.7	41.4	11.9	24.5	121.	6.21	0.83	0.20	0.079	28.9
Ditch 6 Dredged	D-6-D	05/06/08	26.2	31.6	8.33	18.1	73.5	3.77	0.54	0.17	0.048	39.7
Ditch 1	D-1	05/06/08	30.2	27.9	9.81	15.5	42.1	6.37	0.31	0.12	0.030	14.6
Ditch 1 Dredged	D-1-D	05/06/08	31.3	28.2	10.6	18.1	45.2	5.23	0.28	0.10	0.028	14.6
Air Monitoring Station	AMS-1	05/07/08	32.4	26.4	4.96	12.6	33.9	3.04	0.25	0.14	0.027	14.0
Rock House Marsh	RH-1	05/07/08	54.6	27.4	4.32	14.0	44.3	3.00	0.32	0.16	0.034	15.7
Ditch 2 Dredged	D-2-D	05/07/08	30.6	33.8	9.38	22.1	69.8	4.53	0.53	0.15	0.048	25.1
Moist Soil Unit 1	MSU-1	05/07/08	41.1	31.0	4.44	13.3	48.7	3.24	0.43	0.17	0.028	22.1
Pool 8	P-8-1	05/07/08	58.9	32.3	4.48	14.0	56.3	2.94	0.52	0.19	0.060	26.3
Ditch 3 Dredged	D-3-D	05/07/08	32.8	33.5	4.90	15.0	51.5	3.81	0.56	0.16	0.038	23.3
Ditch 4 Undredged	D-4-UD	05/07/08	56.0	30.5	3.42	12.3	45.8	1.50	0.53	0.16	0.076	24.0
Sand Blow	SB-1	05/08/08	20.6	14.3	5.85	16.1	60.4	2.68	0.16	< 0.10	0.021	14.0
Ozark Escarpment	OE-1	05/08/08	23.3	19.9	6.32	11.7	34.1	5.17	0.26	0.14	0.094	15.3
Monopoly Marsh	MM-1	05/08/08	45.0	27.4	3.56	11.3	44.4	2.25	0.66	0.15	0.050	26.4
Ditch 10 Undredged	D-10-UD	05/08/08	85.4	37.5	11.3	22.8	104.	8.05	0.85	0.17	0.075	31.4
Ditch 10 Undredged	D-10-UD-DUP	05/08/08	86.9	36.9	12.7	24.0	87.0	8.85	0.87	0.16	0.077	32.4
Shaw's Ridge	SR-1	05/08/08	66.2	49.6	6.72	26.4	67.1	2.66	1.12	0.29	0.094	107.0

[µg/g, micrograms per gram dry weight; <, less than; concentrations of Cr, Co, Ni, Zn, As, Ag, and Pb are "total recoverable"]

Table 18. Dry Weight Concentrations of mercury and selenium in whole-body fish and invertebrates from Mingo National Wildlife Refuge during 2007 and 2008.

Location	Common name	Percent Moisture	Hg (µg/g)	Se (µg/g)
May Pond	bass	71.9	2.18	0.76
May Pond	bass	71.7	1.50	0.79
May Pond	bass	71.7	1.25	0.80
May Pond	bass	76.3	0.99	0.81
Ditch 1	bowfin	72.0	1.08	1.80
Ditch 1	bowfin	71.8	1.35	1.36
Ditch 1	bowfin	73.7	1.70	1.46
Ditch 1	bowfin	77.1	0.76	1.63
Ditch 2	bowfin	72.2	1.53	1.59
Ditch 2	bowfin	73.1	1.48	1.43
Ditch 2	bowfin	72.4	1.57	1.24
Ditch 2	bowfin	70.2	1.57	1.65
Ditch 11	bowfin	73.2	0.83	0.85
Ditch 11	bowfin	72.7	0.71	0.72
Ditch 11	bowfin	72.1	2.01	1.27
Ditch 11	bowfin	71.2	1.67	0.95
Mingo River	bowfin	71.1	0.82	0.66
Mingo River	bowfin	69.4	0.57	0.71
Stanley Creek	bowfin	74.3	1.34	0.89
Stanley Creek	bowfin	72.4	1.43	0.87
Stanley Creek	bowfin	71.3	1.21	0.79
Stanley Creek	bowfin	72.0	1.85	0.98
Stanley Creek	bowfin	71.1	0.96	0.91
Ditch 2	bullhead	77.4	***.066***	0.49
Ditch 2	bullhead	76.5	0.11	0.58
Ditch 2	bullhead	79.5	0.13	0.64
Ditch 2	bullhead	78.9	1.82	1.51
Ditch 11	bullhead	78.6	0.74	0.90
Ditch 11	bullhead	78.0	0.67	0.90
Ditch 11	bullhead	76.7	0.57	1.03
Ditch 11	bullhead	78.7	0.27	0.73
May Pond	bullhead	76.6	0.20	1.02
May Pond	bullhead	78.5	0.38	0.70
May Pond	bullhead	78.3	0.34	0.57
May Pond	bullhead	78.9	0.17	0.71
Stanley Creek	channel catfish	78.3	0.20	1.01
May Pond	bluegill	76.0	0.37	0.49
May Pond	bluegill	75.8	0.66	0.68
May Pond	bluegill	72.9	0.44	0.53
May Pond	bluegill	74.1	0.21	0.45
May Pond	bluegill	75.7	0.46	0.69
Ditch 1	crappie	72.1	1.01	1.18
Ditch 1	crappie	72.6	0.97	1.17
Ditch 1	crappie	74.7	0.76	1.18
Ditch 1	crappie	75.7	1.04	1.25
Ditch 2	crappie	72.6	0.77	1.06
Ditch 2	crappie	72.4	0.81	1.12
Ditch 2	crappie	72.7	0.83	1.17

Ditch 2	crappie	72.3	0.72	1.11

Table 18 Continued

Location	Common Name	Percent Moisture	Hg (µg/g)	Se (µg/g)
Ditch 11	Crappie	73.1	0.83	1.16
Ditch 11	Crappie	73.6	1.10	1.12
Ditch 11	Crappie	72.2	0.76	0.92
Ditch 11	Crappie	71.5	1.14	0.88
Mingo River	Crappie	75.3	0.31	0.69
Mingo River	Crappie	73.7	0.16	0.64
Mingo River	Crappie	75.6	0.24	0.75
Mingo River	Crappie	75.4	0.47	0.68
Mingo River	Crappie	72.7	0.15	0.75
Mingo River	Crappie	75.2	0.38	0.73
Mingo River	Crappie	72.1	0.25	0.68
Mingo River	Crappie	75.9	0.30	0.72
Mingo River	Crappie	75.6	0.34	0.81
Mingo River	Crappie	74.1	0.26	0.50
Mingo River	Crappie	75.2	0.26	0.69
Mingo River	Crappie	74.6	0.25	0.60
Mingo River	Crappie	73.9	0.27	0.60
Mingo River	Crappie	73.9	0.16	0.70
Mingo River	Crappie	77.4	0.27	0.78
Mingo River	Crappie	72.9	0.17	0.78
Mingo River	Crappie	74.2	0.18	0.65
Mingo River	Crappie	74.6	0.25	0.65
Mingo River	Crappie	75.0	0.27	0.75
Mingo River	Crappie	73.7	0.27	0.70
Ditch 1	Invertebrates	78.9	0.12	1.03
Ditch 2	Invertebrates	75.5	0.10	1.66
May Pond	Invertebrates	77.1	0.18	0.89
Stanley Creek	Invertebrates	86.8	0.088	1.05
Stanley Creek	Invertebrates	58.1	0.20	0.89
Ditch 11	Invertebrates	61.4	***0.076***	0.73
Ditch 11 Spillway	Invertebrates	69.6	***0.067***	0.76

[µg/g, micrograms per gram dry weight; ; bold and italicized values are greater than method detection limit but less than method quantitation limit and have higher uncertainty]

Table 19. Dry Weight Concentrations of mercury and selenium in duck eggs from the Mingo National Wildlife Refuge

Location	Duck common name	Percent Moisture	Hg (µg/g)	Se (µg/g)
BOX# 401	hooded merganser	68.5	4.92	1.86
BOX# 418	hooded merganser	68.6	2.31	2.22
BOX# 408	hooded merganser	68.6	2.83	2.12
BOX# 278	hooded merganser	68.6	4.27	2.12
BOX# 249	hooded merganser	66.8	4.31	1.58
BOX# 251	hooded merganser	67.6	4.65	1.58
BOX# 421	hooded merganser	68.9	3.09	1.91
BOX# 260	hooded merganser	67.5	3.11	1.59
BOX# 219	hooded merganser	69.0	4.07	2.03
BOX# 239	hooded merganser	69.6	3.61	1.93
BOX# 284	hooded merganser	70.7	5.27	1.76
BOX# 246	hooded merganser	70.0	3.08	1.95
BOX# 335	hooded merganser	69.3	1.89	1.59
BOX# 362	hooded merganser	69.7	3.23	1.92
BOX# 241	hooded merganser	68.5	3.34	2.28
BOX# 263	hooded merganser	68.5	3.94	2.28
BOX# 295	hooded merganser	68.7	1.83	1.73
BOX# 338	hooded merganser	69.2	7.02	1.78
BOX# 337	hooded merganser	69.0	3.48	1.90
BOX# 201	hooded merganser	68.3	3.28	1.94
BOX# 269	hooded merganser	68.8	2.07	1.72
BOX# 234	hooded merganser	69.3	1.72	1.51
BOX# 247	hooded merganser	68.9	4.34	1.64
BOX# 244	hooded merganser	67.8	2.79	1.59
BOX# 209	hooded merganser	68.5	1.62	1.87
BOX# 404	hooded merganser	68.6	2.89	1.80
BOX# 302	hooded merganser	69.4	4.68	1.82
BOX# 423	hooded merganser	68.6	2.93	1.93
BOX# E32 DC	hooded merganser	68.5	2.14	1.50
BOX# E49 DC	hooded merganser	69.4	1.75	1.74
BOX# 303	hooded merganser	68.6	3.77	2.13
BOX# 364	hooded merganser	69.4	2.34	1.31
BOX# 361	hooded merganser	68.3	4.12	1.89
BOX# 240	hooded merganser	68.6	2.60	1.81
BOX# 230	hooded merganser	69.1	1.61	1.14
BOX# 207	hooded merganser	67.9	3.66	1.95
BOX# 207	hooded merganser	69.0	5.43	2.02
BOX# 413	hooded merganser	68.4	3.31	1.62
BOX# 350	hooded merganser	69.1	2.19	1.60
BOX# 424	hooded merganser	68.1	2.25	2.05
BOX# 415	hooded merganser	67.4	2.64	1.58
BOX# 205	hooded merganser	68.3	1.98	1.75
BOX# 418	wood duck	68.2	0.050	1.11
BOX# 208	wood duck	68.1	***0.046***	0.77

Table 19 Continued

Location	Duck common name	Percent Moisture	Hg (µg/g)	Se (µg/g)
BOX# 404	wood duck	69.9	0.087	1.00
BOX# 302	wood duck	70.6	0.060	1.11
BOX# 426	wood duck	69.7	0.26	1.37
BOX# N51 DC	wood duck	69.7	0.11	1.32
BOX# S08 DC	wood duck	69.6	0.22	1.48
BOX# 419	wood duck	68.8	< 0.055	0.98
BOX# 423	wood duck	68.6	< 0.055	0.94
BOX# E08 DC	wood duck	70.2	***0.089***	1.29
BOX# E49 DC	wood duck	69.5	***0.15***	1.19
BOX# E21 DC	wood duck	67.9	***0.092***	1.29
BOX# L24 DC	wood duck	69.4	0.18	1.73
BOX# 240	wood duck	69.6	0.19	1.22
BOX# 221	wood duck	68.5	***0.078***	0.77
BOX# 424	wood duck	69.6	***0.11***	1.07
BOX# N14 DC	wood duck	69.4	< 0.055	1.11
BOX# E33 DC	wood duck	69.2	***0.17***	1.33
BOX# E05 DC	wood duck	69.8	0.20	1.45
BOX# N76 DC	wood duck	68.6	***0.13***	1.23
BOX# 424	wood duck	68.9	0.18	0.95
BOX# 293	wood duck	69.7	***0.13***	0.99
BOX# 415	wood duck	68.5	***0.12***	1.27
BOX# 204	wood duck	70.7	< 0.055	1.01
BOX# 422	wood duck	69.9	0.18	1.34
BOX# 203	wood duck	69.1	***0.065***	1.19
BOX# 401	wood duck	70.1	***0.10***	0.82
BOX# 414	wood duck	68.7	***0.15***	1.31
BOX# 406	wood duck	70.5	0.30	1.86
BOX# 222	wood duck	68.7	***0.15***	1.33
BOX# 409	wood duck	69.3	***0.13***	1.32

[µg/g, micrograms per gram dry weight; bold and italicized values are greater than method detection limit but less than method quantitation limit and have higher uncertainty]

Table 20. Concentrations of methyl mercury in soils and sediments from the Mingo National Wildlife Refuge during all flow regimes from 2007-2008 categorized by excavation status.

Undredged Area Samples			Dredged Area Samples			Dredge Spoil Samples		
Sample Event	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*
2007 LF	D-1-UD-CL	0.00028	2007 LF	D-1-D-CL	0.00061	2007 LF	D-1-DM-CL	0.00022
2007 LF	D-10-UD-CL	0.00091	2007 LF	D-1-D-CL-Dup	0.00064	2007 LF	D-11-DM-CL	0.00054
2007 LF	D-2-UD-CL	0.00033	2007 LF	D-11-D-CL	0.00031	2007 LF	D-2-DM-CL	0.00047
2007 LF	D-3-UD-CL	0.00115	2007 LF	D-2-D-CL	0.00035	2007 LF	D-3-DM-CL	0.00023
2007 LF	MM-1-CL	0.00150	2007 LF	D-3-D-CL	0.00074	2007 LF	D-5-DM-CL	0.00028
2007 LF	MP-1-CL	0.00043	2007 LF	D-5-D-CL	0.00030	2007 LF	D-6-DM-CL	0.00027
2007 LF	SC-1-CL	0.00047	2007 LF	D-6-D-CL	0.00045	2008 HF	D-1-DM-CL	0.00018
2008 HF	D-1-UD-CL	0.00067	2007 LF	D-6-D-CL-Dup	0.00048	2008 HF	D-1-DM-CL-Du	0.00021
2008 HF	D-10-UD-CL	0.00168	2008 HF	D-1-D-CL	0.00042	2008 HF	D-11-DM-CL	0.00029
2008 HF	D-2-UD-CL	0.00060	2008 HF	D-1-D-CL-Dup	0.00048	2008 HF	D-2-DM-CL	0.00044
2008 HF	D-3-UD-CL	0.00380	2008 HF	D-11-D-CL	0.00027	2008 HF	D-3-DM-CL	0.00033
2008 HF	MM-1-CL	0.00109	2008 HF	D-3-D-CL	0.00057	2008 HF	D-5-DM-CL	0.00043
2008 HF	MP-1-CL	0.00072	2008 HF	D-5-D-CL	0.00037	2008 HF	D-6-DM-Cl	0.00042
2008 HF	SC-1-CL	0.00077	2008 HF	D-6-D-Cl	0.00051	2008 LF	D-1-DM-CL	0.00018
2008 HF	SC-1-CL-Dup	0.00091	2008 LF	D-1-D-CL	0.00016	2008 LF	D-11-DM-CL-Du	0.00015
2008 LF	D-1-UD-CL	0.00094	2008 LF	D-1-D-CL-Dup	0.00012	2008 LF	D-11-DM-CL	0.00032
2008 LF	D-10-UD-CL	0.00184	2008 LF	D-11-D-CL	0.00029	2008 LF	D-2-DM-CL	0.00028
2008 LF	D-2-UD-CL	0.00031	2008 LF	D-2-D-CL	0.00038	2008 LF	D-3-DM-CL	0.00025
2008 LF	D-3-UD-CL	0.00215	2008 LF	D-3-D-CL	0.00036	2008 LF	D-5-DM-CL	0.00052
2008 LF	MM-1-CL	0.00098	2008 LF	D-5-D-CL	0.00042	2008 LF	D-6-DM-Cl	0.00028
2008 LF	MP-1-CL	0.00070	2008 LF	D-6-D-Cl	0.00042			
2008 LF	SC-1-CL	0.00162						
2008 LF	SC-1-CL-Dup	0.00180						
Mean of Undredged Samples =		**0.00112**	**Mean of Dredged Area Samples =**		**0.00041**	**Mean of Dredge Spoil Samples=**		**0.000315**

[mg/kg, milligram/kilogram dry weight; LF, Low Flow Conditions; HF, High Flow Conditions; UD, Undredged; D, Dredged; DM, Dredge Spoils]

Table 21. Concentrations of methyl mercury in soils and sediments from the Mingo National Wildlife Refuge during low flow conditions.

LOW FLOW CONDITIONS								
Undredged Area Samples			**Dredged Area Samples**			**Dredge Spoil Samples**		
Sample Event	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*
2007 LF	D-1-UD-CL	0.00028	2007 LF	D-1-D-CL	0.00061	2007 LF	D-1-DM-CL	0.000220
2007 LF	D-10-UD-CL	0.00091	2007 LF	D-1-D-CL-Dup	0.00064	2007 LF	D-11-DM-CL	0.000540
2007 LF	D-2-UD-CL	0.00033	2007 LF	D-11-D-CL	0.00031	2007 LF	D-2-DM-CL	0.000470
2007 LF	D-3-UD-CL	0.00115	2007 LF	D-2-D-CL	0.00035	2007 LF	D-3-DM-CL	0.000230
2007 LF	MM-1-CL	0.00150	2007 LF	D-3-D-CL	0.00074	2007 LF	D-5-DM-CL	0.000280
2007 LF	MP-1-CL	0.00043	2007 LF	D-5-D-CL	0.00030	2007 LF	D-6-DM-CL	0.000270
2007 LF	SC-1-CL	0.00047	2007 LF	D-6-D-CL	0.00045	2008 LF	D-1-DM-CL-Du	0.000150
2008 LF	D-1-UD-CL	0.00094	2007 LF	D-6-D-CL-Dup	0.00048	2008 LF	D-11-DM-CL	0.000320
2008 LF	D-10-UD-CL	0.00184	2008 LF	D-1-D-CL	0.00016	2008 LF	D-2-DM-CL	0.000280
2008 LF	D-2-UD-CL	0.00031	2008 LF	D-1-D-CL-Dup	0.00012	2008 LF	D-3-DM-CL	0.000250
2008 LF	D-3-UD-CL	0.00215	2008 LF	D-11-D-CL	0.00029	2008 LF	D-5-DM-CL	0.000520
2008 LF	MM-1-CL	0.00098	2008 LF	D-2-D-CL	0.00038	2008 LF	D-6-DM-Cl	0.000280
2008 LF	MP-1-CL	0.00070	2008 LF	D-3-D-CL	0.00036			
2008 LF	SC-1-CL	0.00162	2008 LF	D-5-D-CL	0.00042			
2008 LF	SC-1-CL-Dup	0.00180	2008 LF	D-6-D-Cl	0.00042			
Mean of LF Undredged Samples =		**0.00103**	**Mean of LF Dredged Area Samples=**		**0.00040**	**Mean of LF Dredge Spoil Samples=**		**0.000318**

[mg/kg, milligram/kilogram dry weight; LF, Low Flow Conditions; HF, High Flow Conditions; UD, Undredged; D, Dredged; DM, Dredge Spoils

Table 22. Concentrations of methyl mercury in soils and sediments from the Mingo National Wildlife Refuge during high flow conditions.

HIGH FLOW CONDITIONS								
Undredged Area Samples			**Dredged Area Samples**			**Dredge Spoil Samples**		
Sample Event	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*	*Sample Event*	*Sample ID*	*Dry Weight MeHg (mg/kg)*
2008 HF	D-1-UD-CL	0.00067	2008 HF	D-1-D-CL	0.00042	2008 HF	D-1-DM-CL	0.000180
2008 HF	D-10-UD-CL	0.00168	2008 HF	D-1-D-CL-Dup	0.00048	2008 HF	D-1-DM-CL-Du	0.000210
2008 HF	D-2-UD-CL	0.00060	2008 HF	D-11-D-CL	0.00027	2008 HF	D-11-DM-CL	0.000290
2008 HF	D-3-UD-CL	0.00380	2008 HF	D-3-D-CL	0.00057	2008 HF	D-2-DM-CL	0.000440
2008 HF	MM-1-CL	0.00109	2008 HF	D-5-D-CL	0.00037	2008 HF	D-3-DM-CL	0.000330
2008 HF	MP-1-CL	0.00072	2008 HF	D-6-D-Cl	0.00051	2008 HF	D-5-DM-CL	0.000430
2008 HF	SC-1-CL	0.00077				2008 HF	D-6-DM-Cl	0.000420
2008 HF	SC-1-CL-Dup	0.00091						
Mean of HF Undredged Samples =		**0.00128**	**Mean of HF Dredged Area Samples=**		**0.00044**	**Mean of HF Dredge Spoil Samples=**		**0.000329**

[mg/kg, milligram/kilogram dry weight; LF, Low Flow Conditions; HF, High Flow Conditions; UD, Undredged; D, Dredged; DM, Dredge Spoils]