Watch What You Drink: Great Miami Water Observation Network

Project Prospectus

GMWON Working Group

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Overview

We propose creation of a Great Miami Water Observation Network (GMWON) to raise the awareness of residents of the Great Miami Basin to the necessity of conservation and sound management of the Great Miami Buried Valley Aquifer system (GMBVAS), an indispensible natural resource. The GMBVAS provides an abundant, reliable, and clean source of water for Southwestern Ohio, more than sufficient to support the region's 1.6 million residents as well as its significant industrial and agriculture production. To protect and maintain the GMBVAS it is necessary to prevent contamination of the water entering the GMBVAS from the Great Miami drainage basin

The GMBVAS was formed by outwash streams emanating from melting glaciers that deposited roughly 150-200 feet[1] of highly transmissive sand and gravel in deeply incised, flat-bottomed valleys averaging several kilometers in width beneath the modern course of Great Miami River and its tributaries. The United States Environmental Protection Agency (USEPA) has designated the GMBVAS as *a sole source aquifer* (SSA), "…*an aquifer that supplies at least 50 percent of the drinking water consumed in the area overlying the aquifer. These areas may have no alternative drinking water source(s) that could physically, legally and economically supply all those who depend on the aquifer for drinking water*."[2]

The GMBVAS is an alluvial aquifer with constant exchange of ground and surface water between the aquifer and adjoining river. Virtually all of the public water supplies in the 3,930 mi^2 Great Miami drainage basin are from wells drilled immediately adjacent to Great Miami River or its tributaries. In recognition that such wells are recharged from the rivers and are therefore particularly vulnerable to contamination by surface water, the USEPA has designated water in such wells g*round water under the direct influence of surface water* (GWUDI)[3]. Although the water quality of Great Miami River is now quite good, prior to enactment of the Clean Water Act (CWA) in 1972 and the resultant improvement in waste water treatment, there were serious pollution problems in Great Miami River. As a result, the quality of water from the GMBVAS was deteriorating. Despite their current good health, Great Miami River and the GMBVAS, the basin contains fifteen USEPA Superfund Sites on the National Priority List, including two Department of Energy (DOE) nuclear facilities, 380 Toxic Release Inventory sites, 35 waste water treatment facilities, and thousands of square miles of agricultural fields treated with fertilizers, pesticides, and herbicides[4]. In addition, extensive areas of the GMBVAS are being removed to supply demand for sand and gravel. All of these potential sources for concern result from the past and present robust industrial and agricultural economy of the region and the presence of its numerous population centers. Any plan to manage these potential concerns must balance the economic importance of these potential contamination sources with public safety and environmental quality issues.

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[1] Measurements are presented here in the units in which they are given in their data source. Unit conversions are in Appendix 1.

[2] http://cfpub.epa.gov/safewater/sourcewater/sourcewater.cfm?action=SSA

[3] any water beneath the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as *Giardia lamblia* or *Cryptosporidium*, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions..

[4] From January, 2010 EPA Geospatial Data Program.

The proposed Great Miami River Observatory consists of two major parts. First, a Great Miami Ground-Water Observatory (GMGWO) would be constructed in the GMBVAS immediately adjacent to Great Miami River near its confluence with Ohio River in Miami-Whitewater Forest, part of the Hamilton County Park District. GMGWO would continuously monitor the flow and quality of ground water in the GMBVAS, store and distribute these data from a server at the University of Cincinnati and provide a site for conducting basic ground-water research for undergraduate and graduate students at area colleges and universities as well as for water managers and water scientists, public water suppliers and municipal, regional, state, and federal water regulators. Second, an adaptable network of water quality observers from local K-12 schools scattered throughout the basin would learn to sample, test and evaluate their local water. After quality assurance review, their data would be stored, and distributed on a centralized server at the University of Cincinnati.

The goals of the proposed Great Miami River Observatory are nine fold:

- Build understanding that the surface and ground-water in the Great Miami basin are two parts of a single, interconnected system and that changes in the quality of one will inevitably lead to similar changes in the other
- Foster appreciation of the importance and vulnerability of the GMBVAS by those living and working above it and within the source area of its water
- Promote public awareness of the necessity of conservation and sound management of the GMBVAS
- Provide a source for real-time and near-real-time observations of the flow and quality of both surface and ground water within the Great Miami basin
- Establish a baseline dataset to assess the impact changes in water use, land use, climate, and new emerging contaminants have on the quality of surface and ground-water
- Provide a secure site for developing, testing, and deploying water quality sensors
- Establish a research site to investigate the complex and highly variable changes in river channel conductance which is of fundamental importance for quantifying the rate and nature of exchange between the GMBVAS and Great Miami River
- Promote water education, research and awareness at K-12 schools, colleges, and universities within the Great Miami Basin
- Promote Science, Technology, Engineering, Mathematics, and Medicine (STEMM) education by providing teacher training, field trips of local relevance and interest and by providing basic analytical equipment for measuring water quality within local school districts

The following project prospectus provides an overview of the Great Miami Buried Aquifer System, its fundamental importance to the well being of the Great Miami Basin, and concerns about its continued health. A broad outline is presented for a project combining basic scientific research and educational outreach program to provide a better understanding of surface-water – ground-water dynamics and foster environmental conservation education at the K-12 and the college-levels.

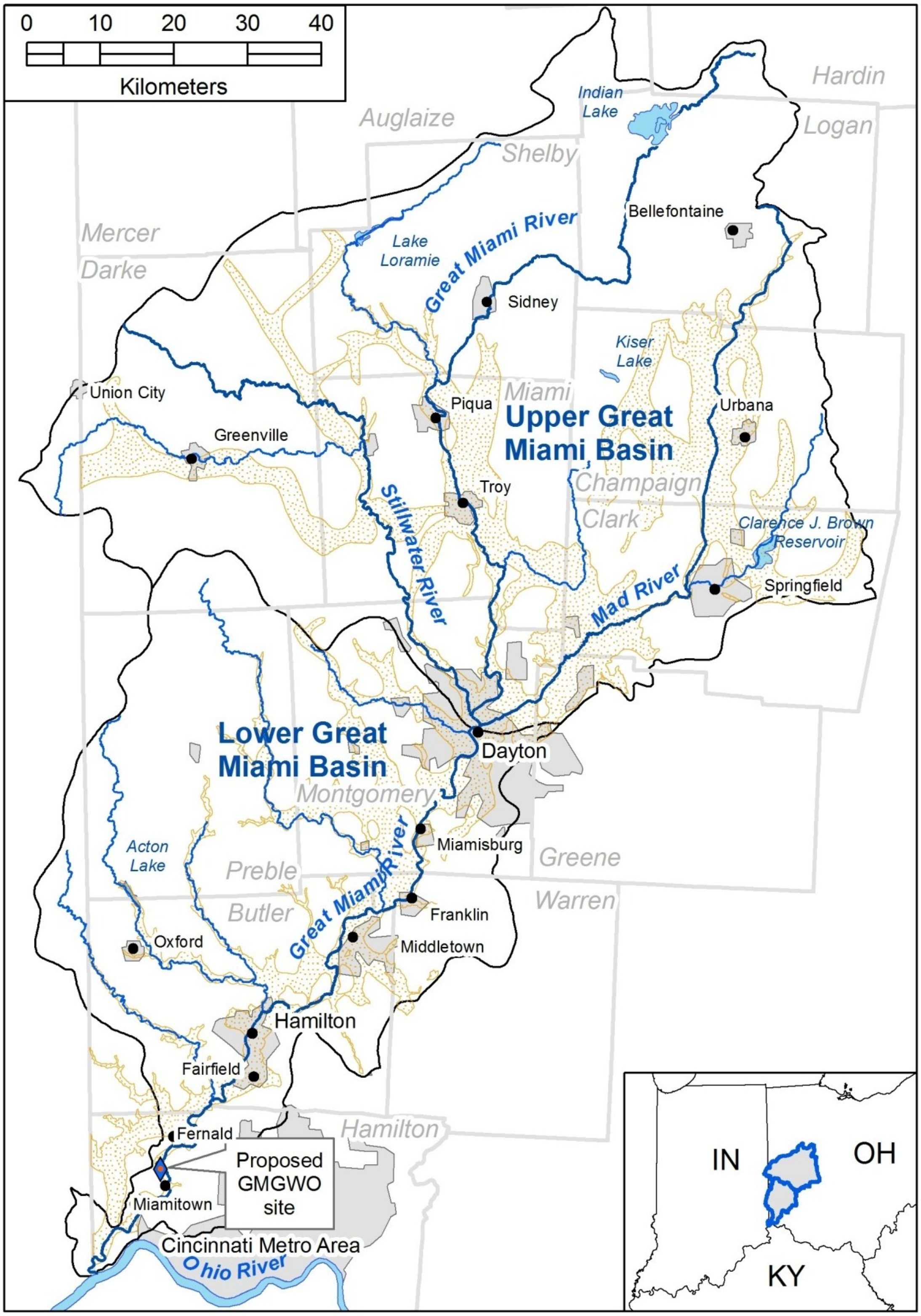

Figure 1. The Great Miami River drainage basin area is 10,178 km^2 of which 9,926 km^2 and 252 km^2 are in Ohio and Indiana respectively. The area within Ohio is proposed for study here. The basin covers all or parts of fifteen Ohio counties.

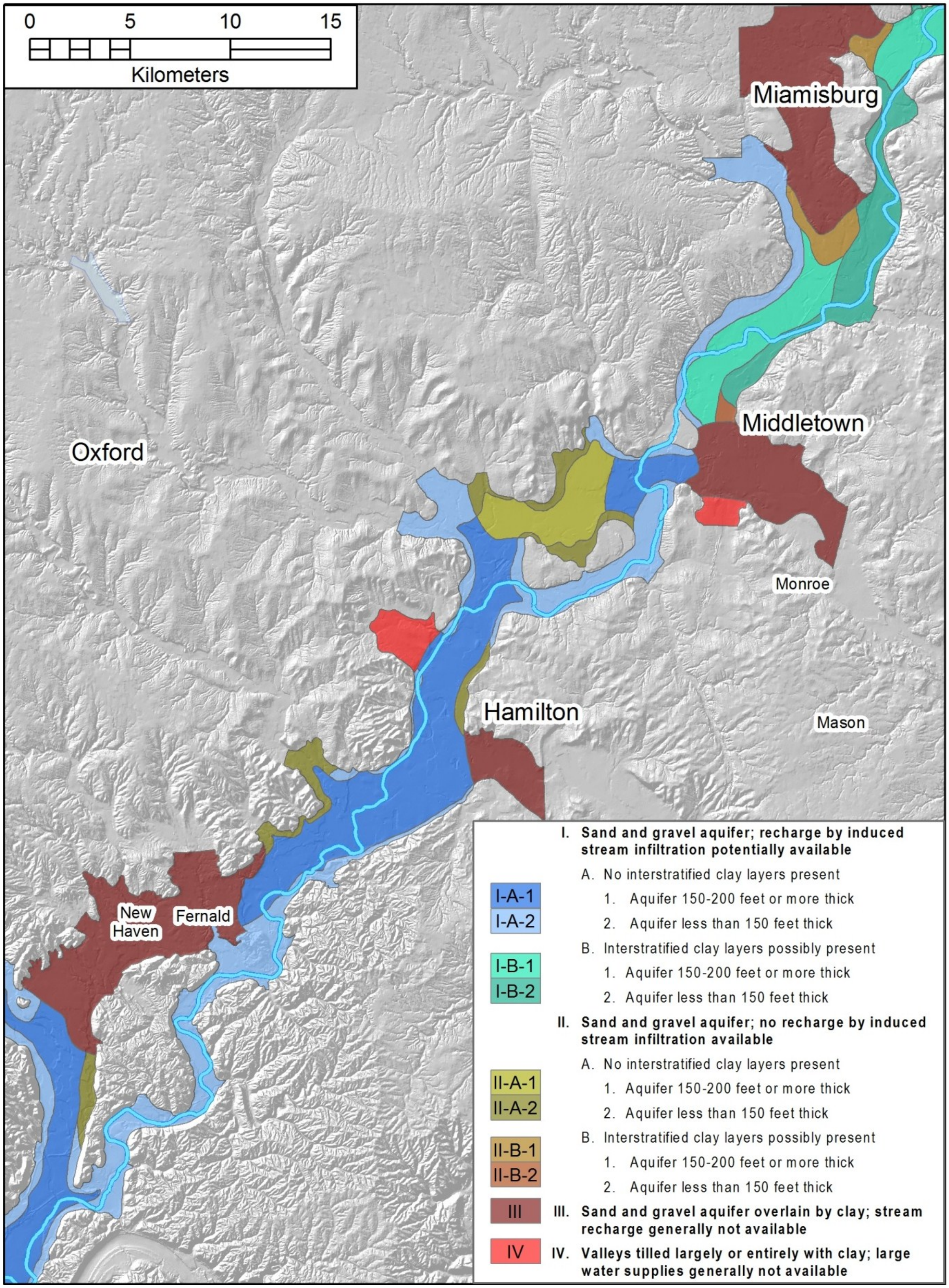

Figure 2. Spieker's (1968a) map of the Geohydrologic Environments of the GMBVAS between Dayton and Cincinnati.

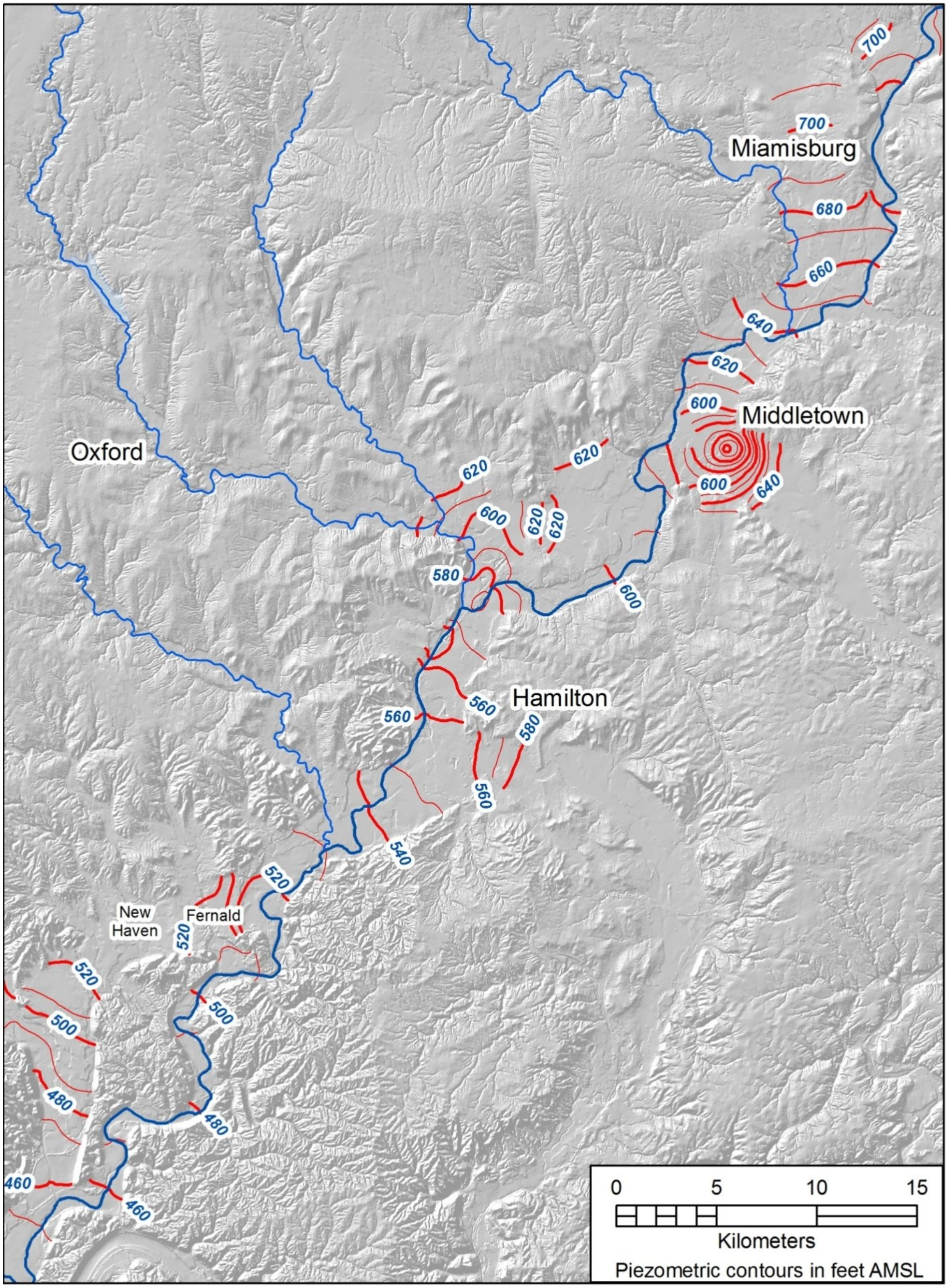

Figure 3. Spieker's (1968a) contour map of the steady-state piezometric surface of the GMBVAS.

The Great Miami Buried Valley Aquifer System

No Shortage of Water

A recent article in the *Dayton Daily News* entitled, "Region's water to be marketed to draw new businesses", reports that Dayton's Development Coalition will use the Great Miami Buried Aquifer System (GMBVAS) to draw new businesses to the region[5]. The GMBVAS (**Figure 1**) is one of the most productive sources of potable water in the Midwest (Sheets, 2007). A comprehensive study of the GMBVAS by the US Geologic Survey (Spieker, 1968a) addresses concerns about overdrafting the aquifer. At the time of the study, the Greater Cincinnati Water Works was planning to construct a major well field (subsequently to become the Charles M. Bolton Water Plant) near Fairfield (**Figure 1**). Butler County was concerned with the impact the additional pumpage would have on their existing well fields near Hamilton. Spieker classifies the GMBVAS within the Lower Great Miami basin into 10 *hydrogeologic environments* (**Figure 2**)"…on the basis of hydrologic and geologic factors affecting the ability of each part of the area to sustain the development of large ground-water supplies. The key factor, then, is the availability (or the lack) of water for recharge by induced stream infiltration." These hydrogeologic environments combine geologic units in some areas while subdividing them in others.

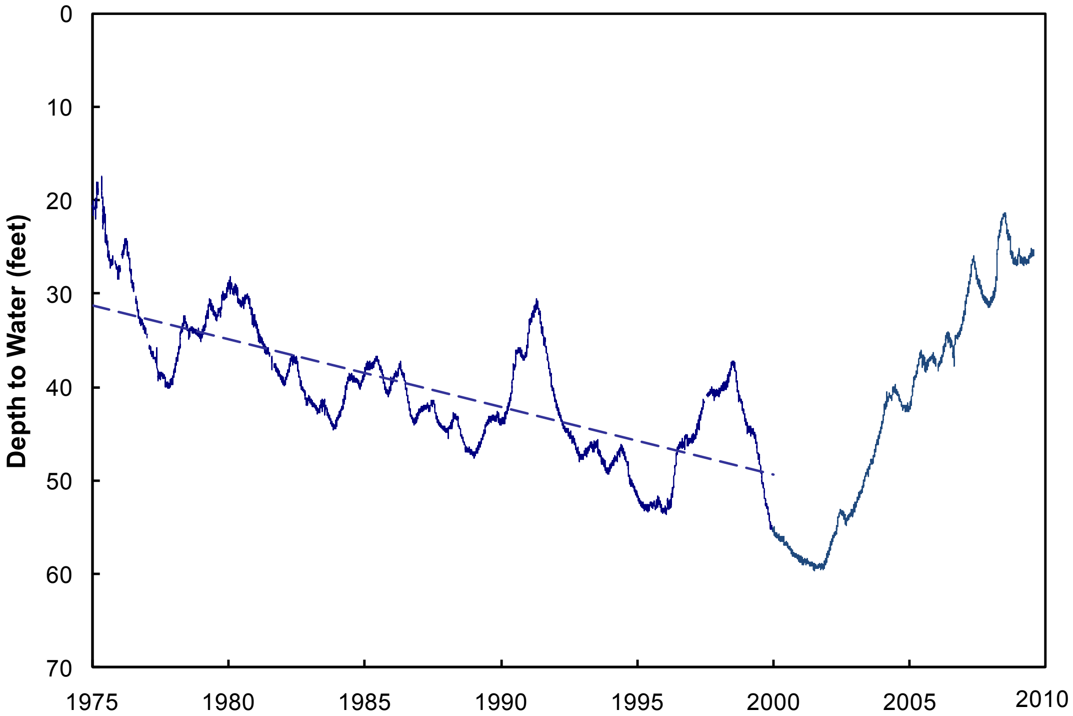

Figure 4. Water levels from Ohio Department of Natural Resources, Division of Water Observation Well W-5 near Mason, Ohio. Ground-water levels declines steadily by more than 0.7 ft/yr due to heavy pumpage by AK Steel, and the cities of Mason and Monroe. In 2001 the city of Mason reduced pumpage from the GMBVAS and was supplied by water from the Greater Cincinnati Water Works taken from Ohio River.

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[5] http://www.daytondailynews.com/business/region-s-water-to-be-marketed-to-draw-new-businesses-478341.html?cxtype=ynews_rss

Spieker (1968a) noted that the only hydrogeologic environment in which the GMBVAS was being seriously overdrafted was near Middletown by wells operated by what is now AK Steel (**Figure 3**). These wells are in hydrogeologic environment III where the aquifer is overlain by a thick clay unit and an adjacent surface water source is not available to provide induced recharge. The decline in piezometric levels south of Middletown has been subsequently exacerbated by the rapid growth of the nearby cities of Mason and Monroe and their increased withdrawals from the GMBVAS. The piezometric level measured in the area by Ohio Department of Natural Resources, Division of Water Observation Well W-5[6] dropped steadily by more than 0.7 ft/yr (**Figure 4**) for 30 years. In 2001, the city of Mason reduced withdrawal from their wellfield and switched to water provided by the Greater Cincinnati Water Works from Ohio River water and ground-water levels rose.

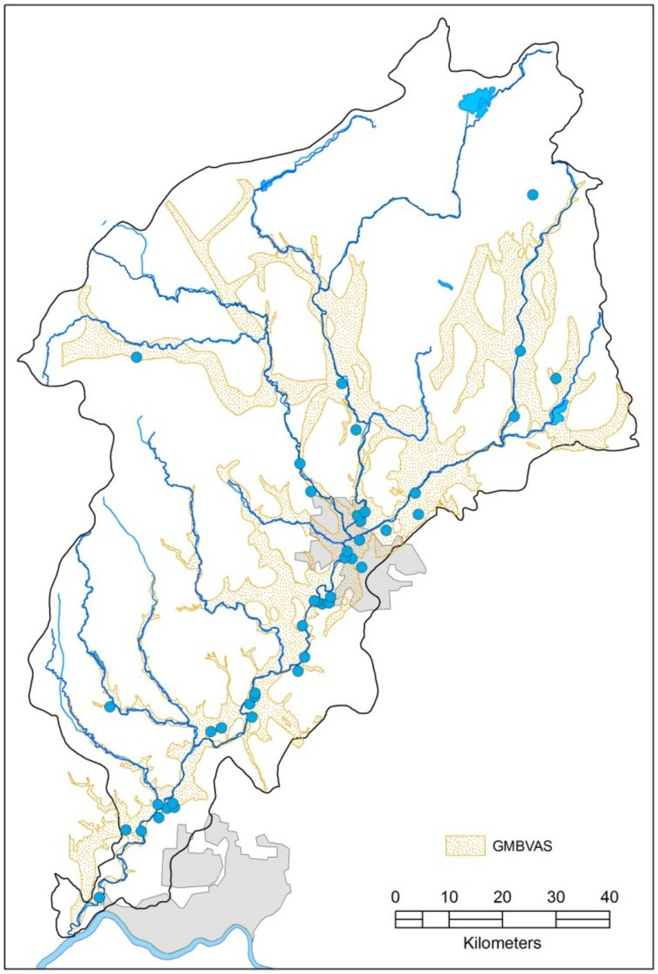

Figure 5. Location of major (>1 billion gallons a year) public water supply wells. The vast majority are using GWUDI and are supplied by induced infiltration from the adjacent river channel.

Spieker (1968a) concluded the GMBVAS would easily sustain a doubling of the 110 million gallons per day (mgd) withdrawn from the GMBVAS in 1964 and predicted this doubling would occur by the year 2000. Based on his analysis he found the GMBVAS could provide a *sustained yield* (which he defined as "… the withdrawal which can be achieved without exceeding the rate of recharge to the aquifers over an extended period of time. ") of as much as 300 mgd. He cautioned however that withdrawal above 300 mgd could only be achieved if water withdrawn from the GMBVAS were returned to Great Miami River as treated waste water and, unless sewage treatment improved substantially, this would increase the temperature of the water in the GMBVAS and decrease its quality. The Division of Water of the Ohio Department of Natural Resources reported that withdrawal rate from the GMBVAS had, in fact, reached 320 mgd by 2005 (162.5 and 157.7 mgd from the Lower[7] and the Upper[8] Great Miami Basins respectively) and that the quality of

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[6] http://www.dnr.state.oh.us/water/waterobs/wellinfo.asp?wellid=W-5

[7] http://www.dnr.state.oh.us/GWPPMetaDataButtonScript3227/wwfr/Lower_Great_Miami_Basin/tabid/19039/Default.aspx

both the surface and ground water in the Great Miami basin had improved dramatically since 1964 by significantly improved sewage treatment (Reutter, 2003).

In *Ground Water and Surface Water : a Single Resource*[9], Winter, et al. (1998) stress the close connection between surface- and ground-water systems and the fundamental error made when they are treated as two independent systems. The interconnectedness of the surface and ground-water is evident from the location of the major public water supply wells in the Great Miami Basin (**Figure 5**). Whereas most of the Great Miami is a gaining stream, the piezometric surface in the vicinity of the well fields is lowered sufficiently that the flow is reversed and, near the well fields, the river becomes a losing stream. Despite the enormous induced flow from the river to the GMBVAS, the flow duration curve for the river has not decreased over the last seven decades (**Figure 6**).

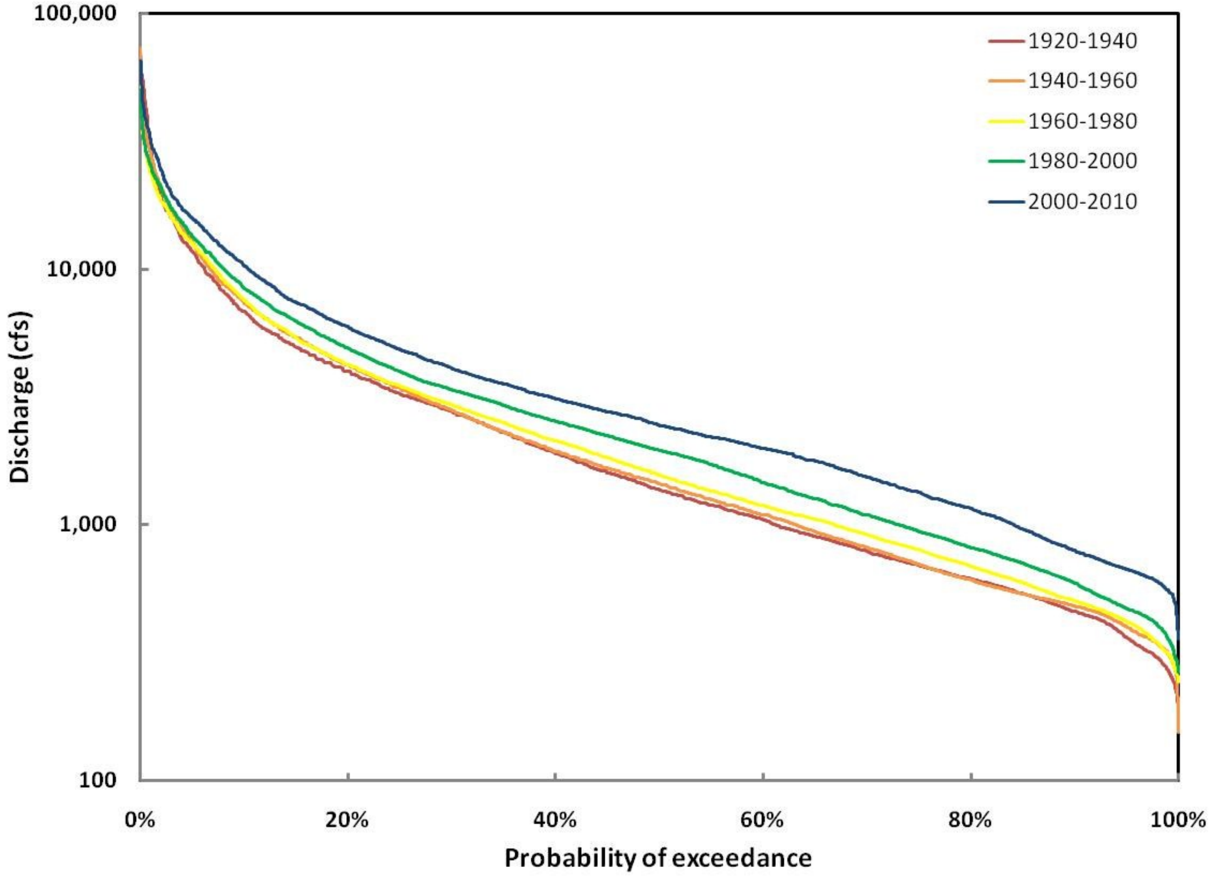

Figure 6. Despite the steady increase in the amount of ground water withdrawn from the GMBVAS, the flow to Great Miami River which is supplying the aquifer through induced infiltration, discharge at Hamilton has not decreased over the last ninety years.

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[8] http://www.dnr.state.oh.us/GWPPMetaDataButtonScript3227/wwfr/UpperGreatMiamiBasin/tabid/19057/Default.aspx

[9] http://pubs.usgs.gov/circ/circ1139/

The River Runs Through Us

Virtually all of the water in the GMBVAS comes from precipitation within the Great Miami Basin; the contribution of ground water from the Upper Ordovician limestones and calcareous shales underlying most of the basin (Appendix 2) are assumed to make a negligible contribution (Dumouchelle & Schiefer, 2002). The discharge of Great Miami River has not decreased despite the steady increase in both surface and ground water usage because the water withdrawn for irrigation runs off as surface water or infiltrates directly to the GMBVAS. Water withdrawn for industrial and domestic use returns to the basin's hydrologic system as treated waste water. Great Miami River is not unique in this way as has been documented for Scioto River by Childress, *et al*. (1991) and Arkansas River by Sophocleous, *et al*. (1988) particularly during dry, low-flow periods.

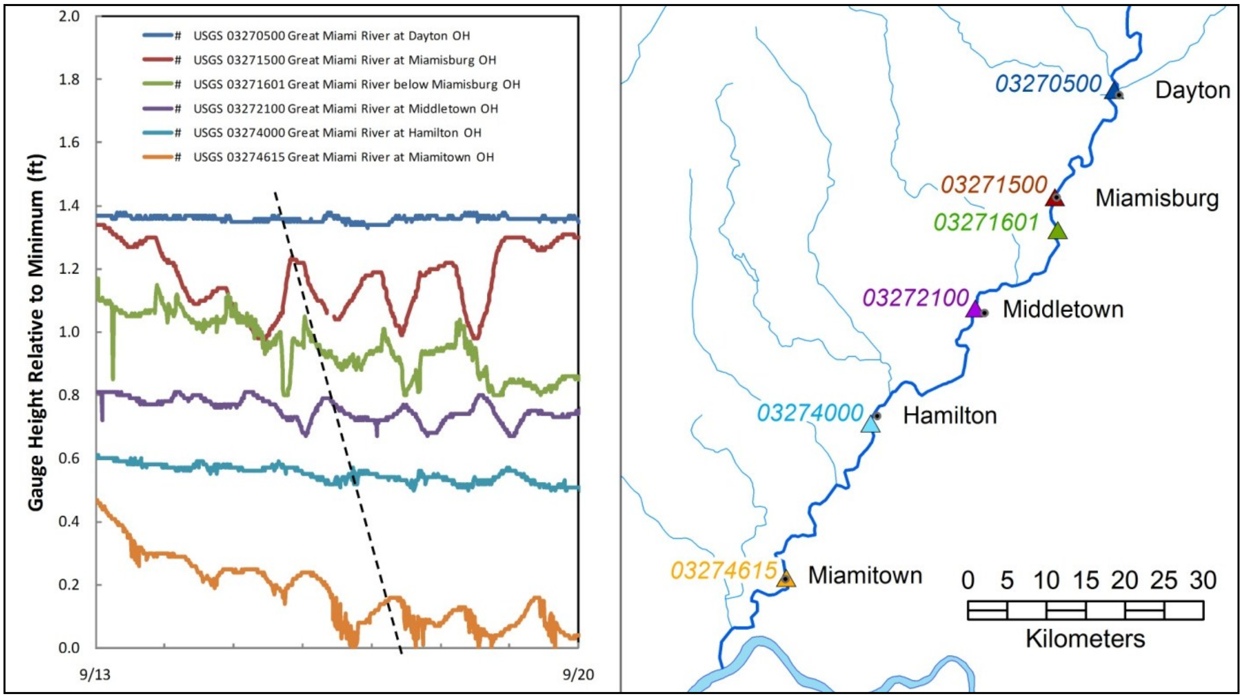

Figure 7. At low flow during the week September 13, 2009, the diurnal cycle of waste water released by Dayton WWTP is recognizable at gauges for the next 50km downstream. Gauge 03270500 is above Dayton WWTP. The amplitude of the cycle in gauge height varies by gauge because of differences in channel cross section.

The contribution of treated waste water is evident from the discharge records at gauges downstream from the Dayton Waste Water Treatment Plant (**Figure 7**). Provided the treated waste water is returned to the basin, Great Miami River discharge will be minimally affected. The only water removed completely from the Great Miami Basin is by Southwestern Ohio Water (between Hamilton and Fernald, **Figure 1**) which in 2009 pumped an average of 14.25 mgd (Mr. Frank Divole, Southwestern Ohio Water Co., pers. comm., January 29, 2010) of untreated water to industrial users in the adjacent Mill Creek Drainage basin to the east. Debrewer *et al*. (2000) estimate 23% of the median, long-term Mill Creek discharge in 1998 was water from the GMBVAS exported by the Southwestern Ohio Water Co. Water from Ohio River is imported into the Great Miami Basin by the Greater Cincinnati Water Works to municipalities in Butler County and Western Hamilton County. An average of 5 mgd was imported in 2008 (Mr. Jeff Swertfeger, Greater Cincinnati Water Works, pers. comm., January 20, 2010.

Natural recycling of drinking water through waste treatment either directly in what is often referred to as "toilet to tap"[10] systems being built in some urban areas with critical water shortages (*e.g.* Orange County[11] and San Diego[12] in California and Tucson, Arizona[13]) or indirectly as done in the Great Miami Basin raises concerns. In the 1960's, Spieker (1968a) reports significant pollution of Great Miami River which was spreading to the GMBVAS. With the enactment of the Federal Water

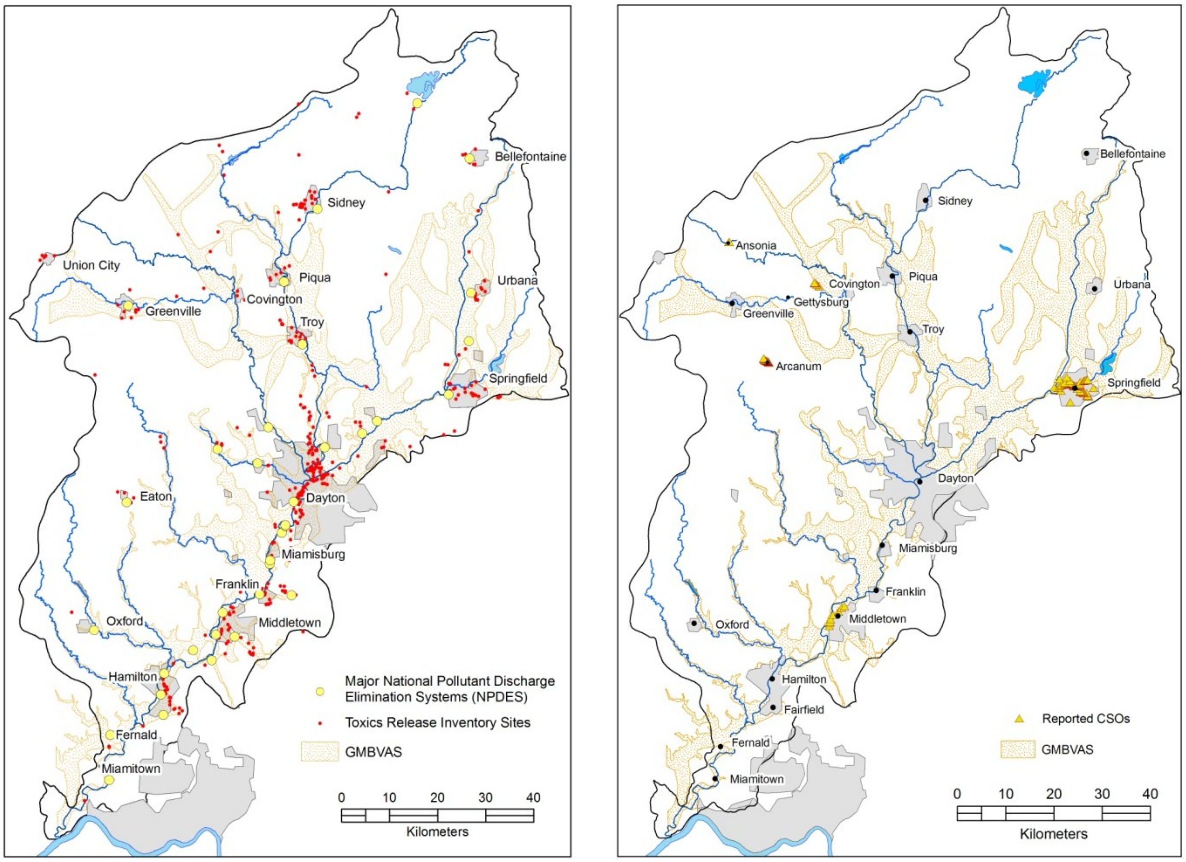

Figure 8. There are 35 EPA listed Major National Pollutant Discharge Elimination Systems (NPDES) and 380 reported Toxic Releases Inventory sites (TRI) in the Great Miami Basin (left). Incidents of combined sewer overflows reported to OEPA (right) are confined to towns and cities with combined sanitary and stormwater sewer systems.

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[10] http://www.slate.com/id/2182758

[11] http://www.npr.org/templates/story/story.php?storyId=17354825

[12] http://www.sdnn.com/sandiego/2009-05-27/special-sections/water/overcoming-the-stigma-of-toilet-to-tap-water

[13] http://www.tucsonweekly.com/tucson/from-the-toilet-to-your-tap/Content?oid=1082588

Pollution Control Act Amendments of 1972[14], subsequently referred to as the Clean Water Act (CWA), sewage treatment improved dramatically and pollution of Great Miami River and the GMBVAS improved. Debrewer *et al*. (2000) find about 1% of the wells they tested had nitrate levels above the USEPA Maximum Contaminant Level (MCL) of 10mg/L, an improvement over similar testing done in the late 1980s and 1990s.

USEPA lists 35 major National Pollutant Discharge Elimination Systems (NPDES) in the Great Miami Basin (**Figure 8**). A few towns and cities in the basin have sewage systems in which stormwater runoff and sanitary sewage is combined in a single sewer line (notably Springfield and Middletown). During storm events these system are prone to overflow (combined sewer overflows, CSOs), discharging raw sewage into adjacent streams. The Ohio Environmental Protection Agency (OEPA) compiles reported CSOs (**Figure 8**,) but not Sanitary Sewer Overflows (SSOs). SSOs are caused by inflow of surface water to sanitary sewer lines (through leaks and unauthorized taps to the line) and infiltration of ground water to the sanitary lines (Nash, 2000). SSOs occur during heavy rain events in older sewer systems. Both SSOs and CSOs are point sources of nitrates and phosphates to Great Miami River and the GMBVAS.

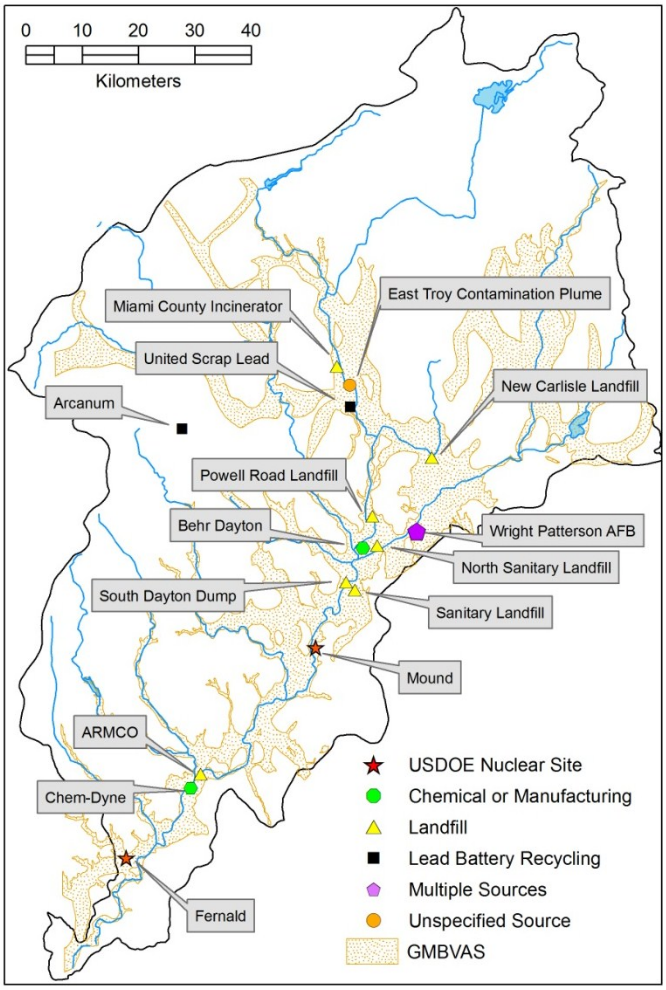

Figure 9. Fifteen USEPA Superfund sites on the National Priority List are located in the Great Miami Basin. Fourteen of them are on the GMBVAS.

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[14] http://www.epa.gov/history/topics/fwpca/

Toxic Legacy

Superfund Sites

The USEPA has fifteen Superfund sites in the Great Miami Basin on the National Priority List (NPL) (**Figure 9**). Seven of the sites are active or abandoned landfills, two are former lead storage battery recycling facilities, two are former USDOE atomic energy sites, two are former manufacturing or chemical processing sites, one is an active military base with multiple sources of contamination, and the source of contamination for one is not specified by the EPA. A brief synopsis of each of the sites follows. More detailed descriptions of each site are available on the USEPA Region 5 Superfund NPL Fact Sheets for Ohio[15]. The USDOE Feed Materials Production Center at Fernald is examined in more detail because of its proximity to the proposed Great Miami Ground-Water Observatory and the relevancy of the observatory to the study of the Fernald Site.

Arcanum Iron & Metal[16] Recycled lead storage batteries and reclaimed the lead cores from 1960s to 1982. Caused several fish kills in streams adjacent to site. Lead contaminated soil and battery casings buried on site.

Armco Incorporation-Hamilton Plant[17] 252 acre site used for coking and steel production. Unlined Landfills on site contaminated with tar and coal waste and sludge from air cleaners.

Behr Dayton Thermal System VOC Plume[18]. The site was used by Chrysler Corporation and subsequently Chrysler Daimler from 1937 to 2002 to manufacture vehicle air conditioning systems. The site is contaminated with volatile organic compounds (VOC's) trichloroethene (TCE) and perchloroethylene (PCE). The VOC plume in the GMBVAS has moved beneath residences adjoining the site.

New Carlisle Landfill[19] Solid waste industrial, commercial, and residential landfill active from mid-1950s through early 1970s. TCE and other VOCs have been found in ground-water plume beneath the site.

North Sanitary Landfill[20] 102 acre site on which industrial and municipal waste was stored in unlined pits, some of which were former quarries in direct contact with the GMBVAS. The site is contaminated with several different VOCs and heavy minerals including lead, mercury, cadmium, and cyanide. The site is close to Dayton's two municipal well fields serving 430,000 people. Remediation of the site including removal of 26,000 drums and vapor extraction begun in 1998 is ongoing.

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[15] http://www.epa.gov/region5superfund/npl/ohio/

[16] http://www.epa.gov/region5superfund/npl/ohio/OHD017506171.htm

[17] http://www.epa.gov/region5superfund/npl/ohio/OHD074705930.htm

[18] http://www.epa.gov/region5superfund/npl/ohio/OHN000510164.htm

[19] http://www.epa.gov/superfund/sites/npl/nar1787.htm

[20] http://www.epa.gov/region5superfund/npl/ohio/OHD980611875.htm

Powell Road Landfill[21] Similar to the North Sanitary Landfill. A 70 acre landfill in from 1959 to 1984 disposing commercial, industrial and domestic waste in a former gravel pit in the GMBVAS. Contaminated with numerous VOCs and heavy metals. Remediation by pump and treat and removal of contaminated soil began in 1987.

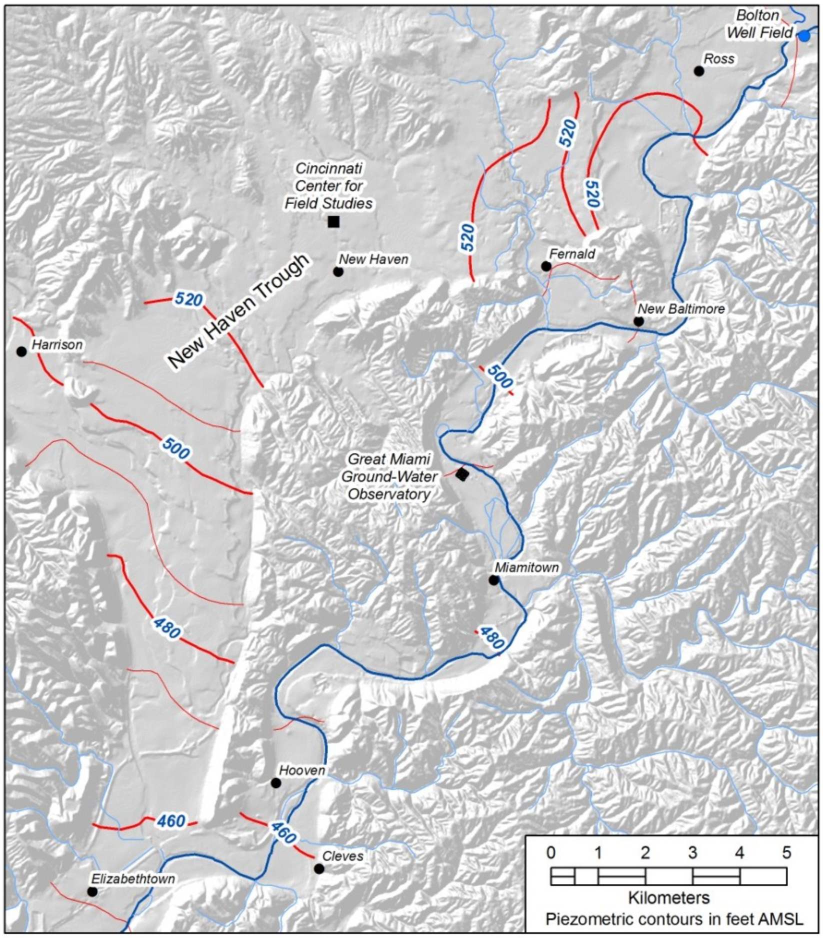

Figure 10. Feed Materials Production Center at Fernald, Ohio is located just east of the ground-water divide at New Haven. A plume of uranium contaminated water is moving to the southeast. Red lines are contours of the steady-state piezometric surface mapped in 1964.

Sanitary Landfill Co. (Industrial Waste Disposal Co., Inc.)[22] 36 acre landfill in a former sand and gravel quarry in the GMBVAS. In continuous operation by several owners from 1950s until its closure in 1981. Ground water is contaminated with a variety of VOCs and heavy metals including chromium, copper, cadmium, and lead. Remediation includes removal of landfill gases and installation of capping materials to reduce infiltration.

South Dayton Dump & Landfill[23] Another Dayton-area landfill in a former sand and gravel quarry in the GMBVAS. The 25 acre site accepted drums, metal turnings, fly ash, foundry sand, demolition material, wooden pallets, asphalt, paint, paint thinner, oils, brake fluids, asbestos, solvents, transformers and other industrial waste between 1941 and its closure in 1996. The site's soil and ground water are contaminated with VOCs and heavy metals.

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[21] http://www.epa.gov/region5superfund/npl/ohio/OHD000382663.htm

[22] http://www.epa.gov/region5superfund/npl/ohio/OHD093895787.htm

[23] http://www.epa.gov/region5superfund/npl/ohio/OHD980611388.htm

United Scrap Lead Co., Inc.[24] 25 acre site recycling lead storage batteries from 1948 to 1980. Neutralized battery acid was disposed onsite. 56,000 cubic yards of lead-contaminated battery casing residue, and approximately 20,000 cubic yards of lead-contaminated soils are estimated to remain onsite.

Wright-Patterson Air Force Base[25] Active USAF base including thirteen landfills, twelve earth fill disposal zones, nine fuel or chemical spill sites, six coal storage piles, five fire-training areas, four chemical burial sites, two underground storage tanks, and miscellaneous other sites immediately over the GMBVAS.

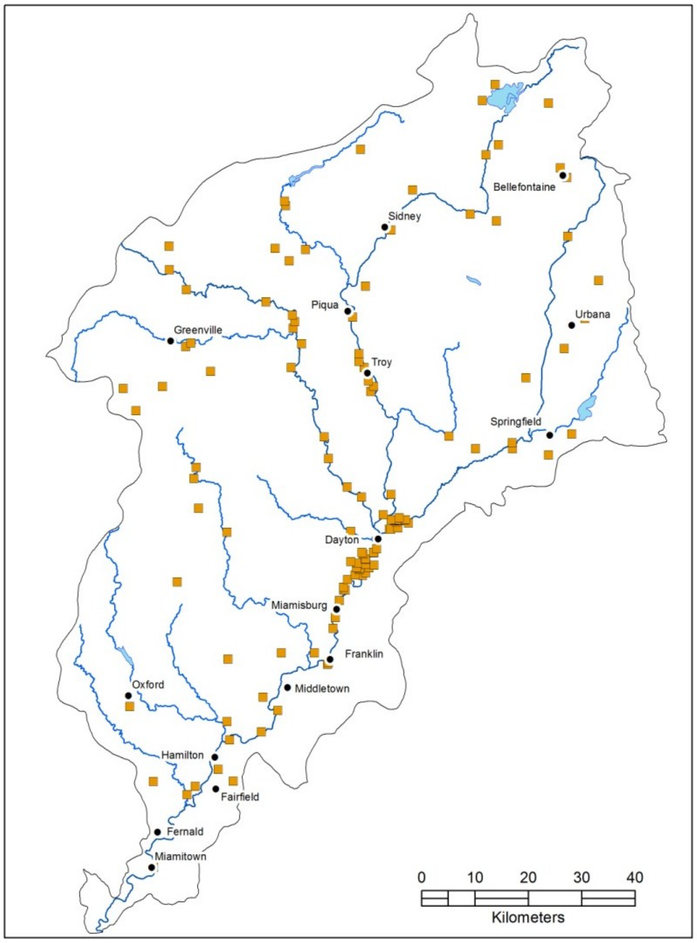

Figure 11. Ohio EPA has compiled a preliminary list of 123 abandoned landfills. Most are immediately adjacent to rivers. Many are former GMBVAS quarries.

Fernald Feed Materials Production Center (USDOE)[26]The 1,050 acre Feed Materials Production Center at Fernald, Ohio was designated a USEPA Superfund site and placed on the National Priorities List in 1989. Constructed in 1951 for the US Atomic Energy Commission (abolished in 1974 and responsibilities transferred to the Nuclear Regulatory Commission), it produced uranium metal which was shipped to other facilities for reactor fuel and nuclear weapons production. As a result of contamination issues, the USEPA issued a notice of noncompliance in 1985. As a result of this notification and a decrease in demand, the US Department of Energy stopped production and closed the site in 1989. The Fernald facility produced more than 500 million pounds of pure uranium metal and, in the process, 31 million net pounds of nuclear product, 2.5 billion pounds of waste and 2.5 million cubic yards of contaminated soil and debris that remained on site[27]. At the time of its closure, according to the Alliance for Nuclear Accountability, it was the third most contaminated nuclear facility in the country after the Hanford and Savannah River nuclear facilities[28].

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[24] http://www.epa.gov/region5superfund/npl/ohio/OHD018392928.htm

[25] http://www.epa.gov/region5superfund/npl/ohio/OH7571724312.htm

[26] http://www.epa.gov/region5superfund/npl/ohio/OHSFN0507962.htm

[27] http://www.lm.doe.gov/land/sites/oh/fernald_orig/Cleanup/PDFs/FactSheets/DDa.PDF

[28] http://www.ananuclear.org/Portals/0/documents/Water%20Report/waterreportfernald.pdf

Several plumes of uranium contaminated[29] groundwater have formed in the GMBVAS beneath the Fernald facility. One plume, approximately 50 acres in area and extending beyond the southern boundary of the facility had uranium concentrations in excess of 300µg/L[30]. An aquifer restoration project was started in 1993 to reduce the uranium concentration in the plumes to 30µg/L by pumping, treating, and returning the treated water to the aquifer or Great Miami River. As of 2006, 11.9 billion gallons of water had been treated and 7,500 pounds of uranium removed[31].

The Fernald site is located immediately to the east of the ground-water divide beneath New Haven, Ohio separating flow to the west through the New Haven Trough, the pre-glacial course of the ancestral Great Miami River towards Harrison, Ohio from flow to the east (**Figure 10**). The piezometric surface mapped in 1964 by Spieker (1968a) suggests the contamination plume would move towards the southwest; that map was made before the construction of the Bolton well field (pumping 17 mgd in 2000) and an increased pumpage by the Southwestern Ohio Water Company near Ross, Ohio from 15 mgd in 1964 to 18 mgd in 2000 but is unlikely that this added pumpage has reversed the hydraulic gradient and caused the plume to move towards the northeast. Uranium

Figure 12. Quarries and abandoned landfills at Hamilton, Ohio. Elevated nitrate and ammonia levels, sometimes exceeding MCL have been detected at SWRWDC observations wells. The contaminants are presumed to have originated from the now-abandoned Schlichter Landfill.

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[29] Uranium contamination is defined here as a concentration above 30µg/L, the USEPA's MCL for uranium (http://www.epa.gov/safewater/radionuclides/basicinformation.html) increased from the previous MCL of 20µg/L in 2000

[30] http://www.lm.doe.gov/land/sites/oh/fernald_orig/NewsUpdate/FPMP_PDFs/FPMP_11-03/10%20-%20Strategic%20Initiative%207%20-%20Aquifer%20-%2011-03%20pgs%2021-22.pdf

[31] http://www.lm.doe.gov/land/sites/oh/fernald_orig/Cleanup/Aquifer.htm

concentration could be continuously monitored at the proposed Great Miami Ground-Water Observatory to assess the effectiveness of the pump and treat remediation effort.

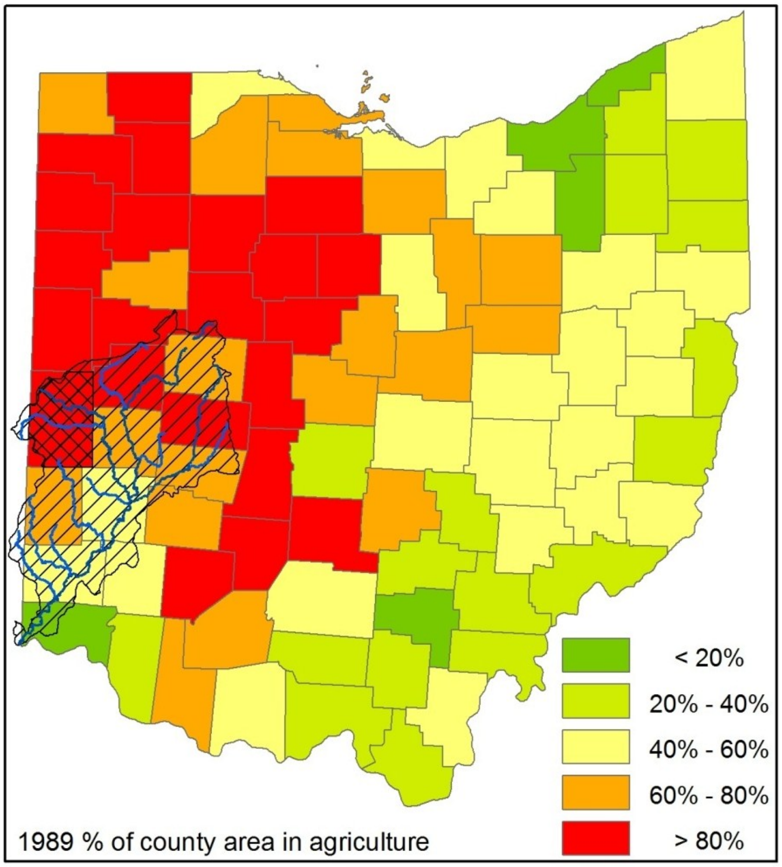

Figure 13. The Great Miami basin (hatched) is intensively cultivated (Battaglin and Goolsby, 1995). In 2007 Darke County (cross hatched) accounted for nearly a half billion dollars of agricultural sales (second highest of any Ohio county).

Active and Abandoned Landfills

At least four of the Superfund sites (North Sanitary Landfill, Powell Road Landfill, South Dayton Dump and Landfill, and Sanitary Landfill Co) in the Great Miami Basin are abandoned or active landfills in former GMBVAS gravel quarries. The very common practice of locating landfills in former quarries was ended in 2003 by Ohio Administrative Code 3745-27-07[32] prohibiting the issuance of landfill permits on sole source aquifers pursuant to the Safe Drinking Water Act[33]). Prior to this prohibition, quarries often became landfills after quarrying ended. OEPA is in the process of compiling and verifying a comprehensive list of abandoned landfill sites, but provided a preliminary list of locations (**Figure 11**).

An unknown but likely substantial number of these landfills are unlined and leaking leachate to the GMBVAS. It is probable that substantial remediation will be necessary before developing any of these sites and some may be sufficiently contaminated that they will be added to the NPL.

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[32] http://codes.ohio.gov/oac/3745-27-07

[33] http://www.epa.gov/safewater/sdwa/laws_statutes.html

Whitteberry (2009) documents an example of a problematic abandoned landfill, the former Schlicter Landfill at Hamilton. This landfill is immediately up the ground-water gradient from several large, active quarries (**Figure 12**). The Bolton well field is down gradient from these quarries (**Figure 12**). Whitteberry found elevated nitrate and ammonia levels in SWRWDC monitoring wells 1-5.

Emerging Concerns

Pharmaceuticals and Personal Care Products (PPCPs)

There is increasing concern about the effects discarded pharmaceuticals and personal care products (PPCPs) introduced to streams by waste water treatment facilities have on human health and the health of the aquatic ecosystem[34]. USEPA defines PPCPS as prescription and over-the counter therapeutic drugs, veterinary drugs, fragrances, cosmetics, sun-screen products, diagnostic agents, and nutraceuticals (*e.g.*, vitamins). Antibiotics, anti-inflammatory drugs, hormones and hormone mimics (*e.g.*, estrogen and estradiol), and antidepressants are all PPCPs that are not currently removed during waste-water treatment. Although it is unclear how much the concern over PPCPs results from an increase in their presence in the environment and how much is the result of better and more widely applied analytical techniques, the potential deleterious effects of PPCPs has raised public concern[35] and the USEPA has started a research program to investigate the issue[36].

Impact of Climate Change

Recently USEPA established the Water Resource Adaptation Program (WRAP) to "to provide water resource managers and decision makers with the tools they need to adapt water resources (*e.g.*, watersheds and infrastructure) to future climate change and demographic and economic development)[37]. Clark *et al.* (2009) evaluate the impact that various scenarios of future changes in climate would have on the quality of water produced by the Greater Cincinnati Water Works Richard Miller water treatment plant from Ohio River water. Although the impact on public water suppliers producing from the GMBVAS probably would be less (or more delayed) than those using surface water, if the climate becomes more variable (*e.g.*, large magnitude rain events become more frequent) it could substantially increase the number and severity of sanitary and combined sewer overflows within the Great Miami Basin, particularly in towns and cities with antiquated sewage infrastructures (*i.e.*, most cities and towns on the GMBVAS).

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[34] http://www.epa.gov/ppcp/

[35] http://www.pollutionissues.com/Co-Ea/Consumer-Pollution.html

[36] http://www.epa.gov/ppcp/opportunities.html

[37] http://www.epa.gov/nrmrl/wswrd/wqm/wrap/index.html

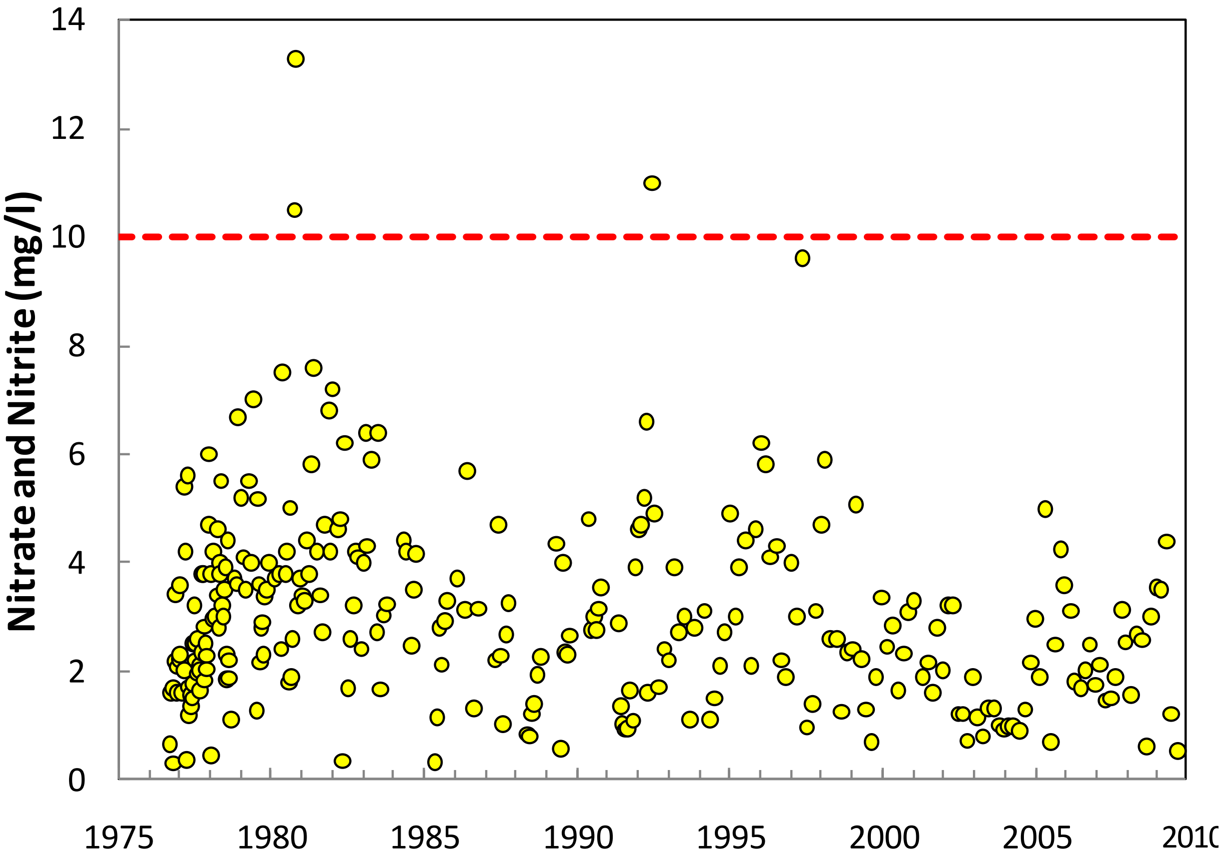

Figure 14. Nitrate and nitrate levels measured by ORSANCO at Elizabethtown near confluence of Great Miami – Whitewater River with Ohio River[42]. The USEPA MCL for nitrate is 10 mg/L.

Balancing Productive Economy with Healthy Water

Agriculture

Ohio is a major agricultural state with more than $7 billion in sales of farm products in 2007 (USDA, 2009)[38]. The Great Miami basin is intensively farmed (**Figure 13**). Darke County alone had $480 million in agricultural sales in 2007 (second highest farm production of Ohio counties). In addition to being a major source of revenue and employment, agriculture presents several environmental challenges.

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[38] http://www.ers.usda.gov/StateFacts/OH.HTM

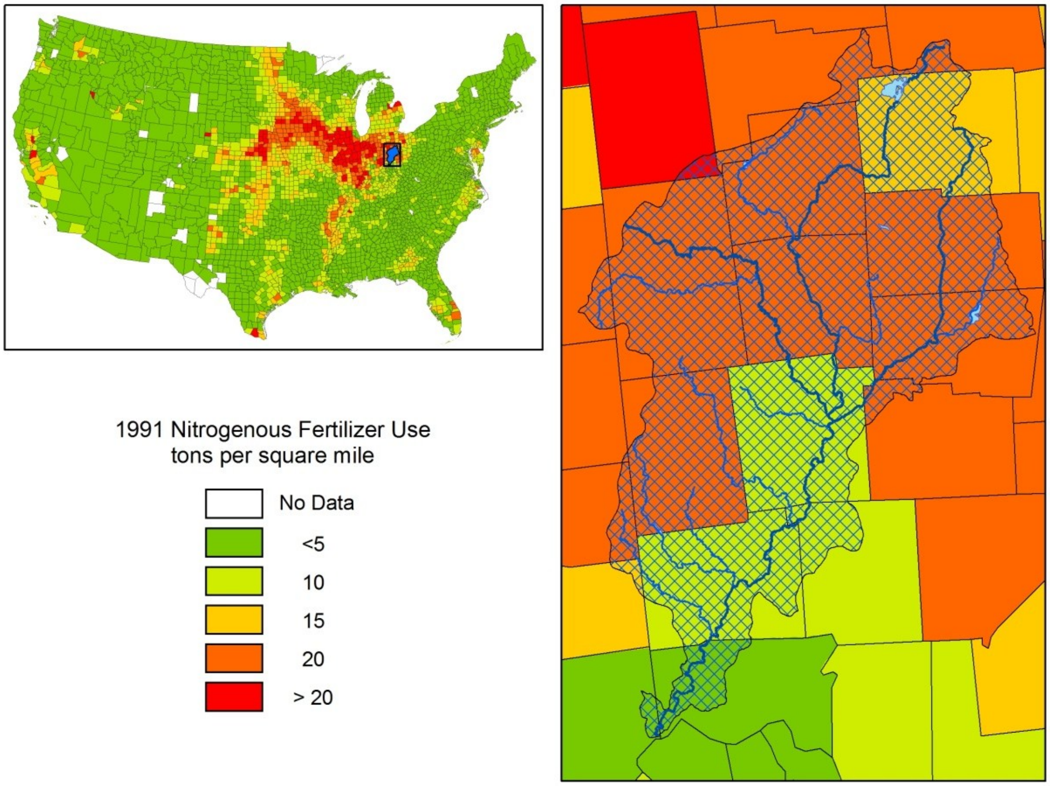

Figure 15. Application of nitrogenous fertilizers in the Great Miami Basin is among the heaviest in the US (Battaglin and Goolsby, 1995).

Nitrates

Nitrates raise both environmental and health concerns. The Council on Environmental Quality of The Office of Science and Technology Policy notes Harmful Algal Bloom (HABs) in fresh water lakes and rivers as well as the dramatic HABs in the Gulf of Mexico may be linked in part to the heavy use of nitrogenous fertilizer[39]. USEPA notes health risks associated with high levels of nitrates in drinking water including potentially serious breathing problems for infants[40] and establishes an nitrate MCL of 10 mg/L in drinking water. This MCL has been exceeded on several occasions in Great Miami-Whitewater River near its confluence with Ohio River at Elizabethtown, Ohio (**Figure 14**)[41]

There are several sources for nitrates in Great Miami River, including treated and untreated waste water and nitrogenous fertilizers (Debrewer *et al*., 2000). Nitrate concentrations in larger streams *averages* 3 to 4 mg/L and show strong seasonal variation related to application of agricultural fertilizer. The highest nitrate concentrations generally result from runoff produced by the first substantial rainfall after application. Application of nitrogenous fertilizer is among the heaviest in the US (**Figure 15**).

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[39] http://www.ostp.gov/galleries/NSTC%20Reports/National%20Asseess%20Efforts%20to%20Predict%20HABs%202007.pdf

[40] http://www.epa.gov/safewater/contaminants/basicinformation/nitrate.html

[41] http://www.orsanco.org/index.php/nitratenitrite

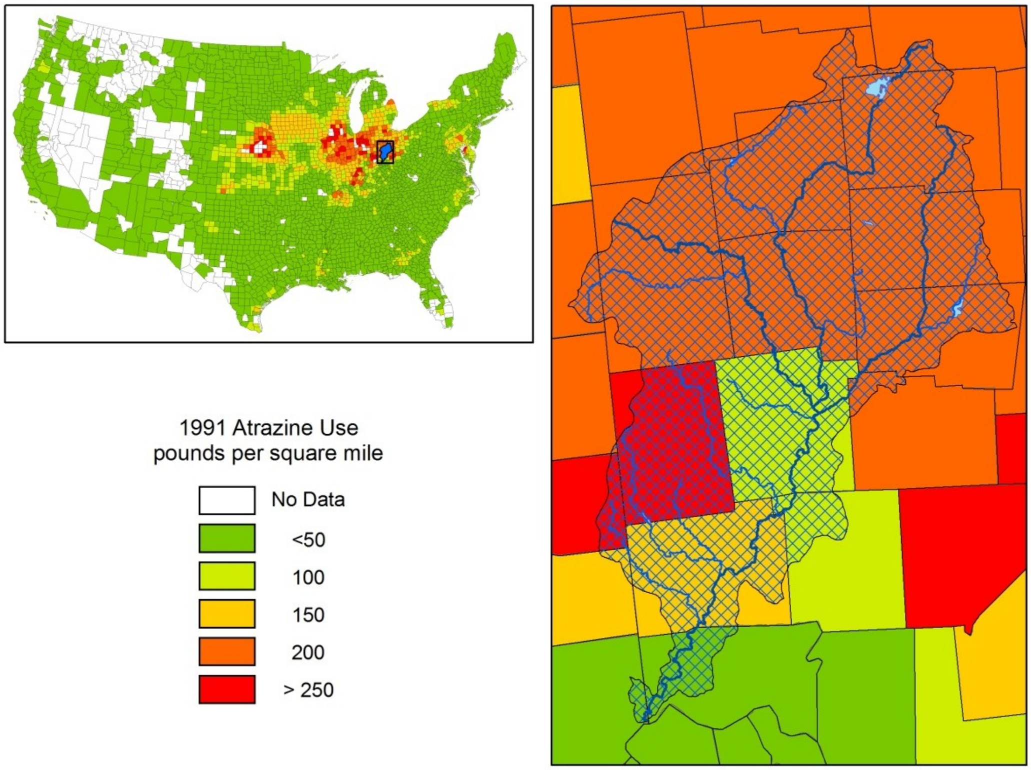

Figure 16. Concerns have been raised about the health effects of the commonly used herbicide, Atrazine. Its application the Great Miami Basin is among the heaviest in the US.

Atrazine

The application Atrazine, a commonly used broad-leaf weed control for corn, in the Great Miami Basin is among the heaviest in the US (**Figure 16**). The impact of short- and long-term exposure to Atrazine on human health is currently being investigated. A recent study of the occurrence of a specific birth defect in Washington State by Waller et al (2010) concludes "Maternal exposure to elevated atrazine levels in surface water is associated with fetal *gastroschisis*, particularly among women who conceive in the spring." This claim has been emphatically denied[42] by Syngenta, the manufacturer of Atrazine. The USEPA has set Atrazine concentration limits of 298 ppb, 37.5 ppb, and 3 ppb for short-term (daily), intermediate-term (90 days), and long-term (yearly) exposure[43]. The USEPA continues to monitor and investigate the effects of Atrazine on aquatic habitat, particularly on aquatic plants. In an article entitled "Debating how much weed killer is safe in your water glass", the *New York Times*[44] reports Piqua (**Figure 1**) residents' concern on learning Atrazine levels as high a 59.57 ppb had been found in their municipal water supply.

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[42] http://www.atrazine.com/news_releases/news.aspx?id=116433

[43] http://www.epa.gov/opp00001/reregistration/atrazine/atrazine_update.htm

[44] http://www.nytimes.com/2009/08/23/us/23water.html

Quarries

The sand and gravel of the GMBVAS are quarried extensively (**Figure 17**). Quarrying operations are found in most cities and towns situated on the GMBVAS. These operations are a major source of employment and revenue within the Great Miami Basin. Of the 390 sand and gravel quarries in Ohio, 100 (25.6%) are within the Great Miami Basin. 37.2 million tons of sand and gravel from Ohio were sold for $217.3 million in 2007 (a 20.8% decrease from 2006 sales). In 2007, quarries employed 1,493 people and paid $65.9 million in wages (Wolfe, 2009). Assuming 25.6% percent of the Ohio's total quarry activity was in the Great Miami Basin, sand and gravel quarrying in the basin produced 9.5 million tons of sand and gravel and $55.6 million in sales, and employed 380 people earning $16.9 million in wages.

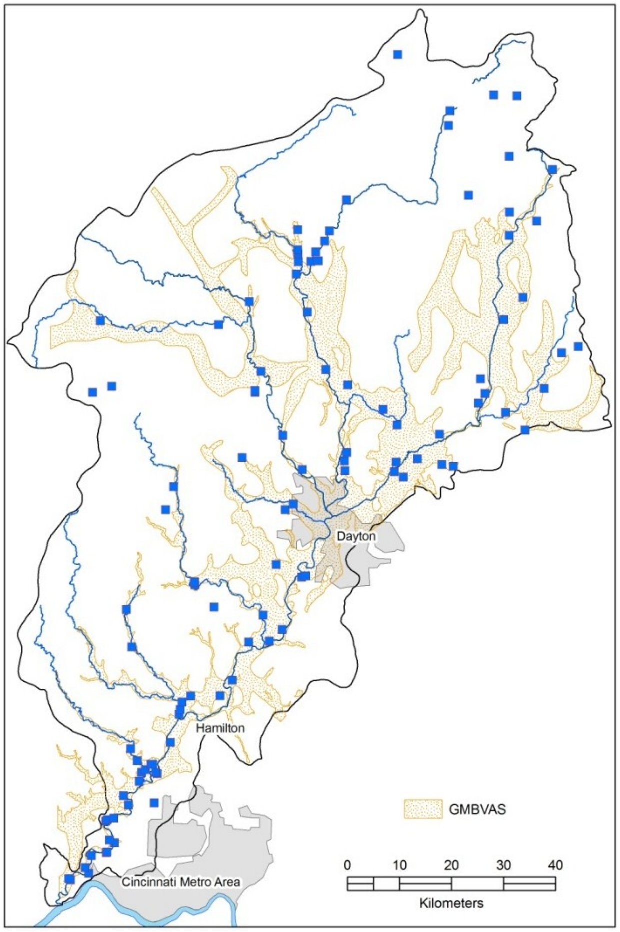

Figure 17. Active sand and gravel quarries in the Great Miami Basin. (GIS information from Wolfe, 2007).

Clearly sand and gravel quarrying in the Great Miami Basin is of significant financial benefit to the area. Despite this benefit, quarrying raises some concerns. The most obvious but probably the least significant is the removal of the quarried material itself. As noted earlier, the GMBVAS is a unique "sponge" capturing and storing water from large precipitation and discharge events. Assuming a unit weight of 103 lbs/ft^3 for dry sand and gravel, roughly 184.5 million ft^3 (5.22 million m^3) of the GMBVAS's storage capacity was removed in 2007.

As noted above, Whitteberry (2009) documents contamination which appears to be migrating southward from the abandoned Schlicter Landfill near Hamilton. This migration could adversely affect water quality in drinking water wells south of the quarries (*e.g.*, Charles M. Bolton well field). During quarrying operations, particularly dredging with rotary cutters and gravel pumps, substantial amounts of water are pumped from, and returned to the quarry. The quarrying operation may exacerbate and accelerate the amount and rate of southward movement of leachate-contaminated ground-water by steepening the ground-water gradient towards the quarry and, by agitating the water within the quarries, promote rapid mixing of contaminants with quarry water accelerating the movement of contaminants southward across the quarries.

Under current law, quarrying operations must maintain a 75 foot setback from the Great Miami River (Ohio Revised Code 1514.10). Often only a 75-foot wide sand and gravel berm separates the quarry from the river (**Figure 12**). Even in active quarries, undercutting by the river during flooding has breached the berm (*e.g.*, during a 2003 flood event, the berm separating the Martin Marietta / American Aggregate quarries from Great Miami River was breached (**Figure 12** and **Figure 18**). After the quarries are abandoned, there is no ordinance mandating maintenance of the berm so eventually the lake and river may be directly joined. This joining provides a means for river-borne contaminants to be directly introduced to the GMBVAS without the filtering provided by the river bed materials.

Figure 18. Site of the 2003 breach (yellow arrow) of berm separating quarry from Great Miami River (see **Figure 12**).

Coal

In 2007, the most recent year for which the Department of Energy provides statistics, Ohio produced 147.3 million MWh of electrical power from burning coal, second only to Texas. Although the largest coal-fired power plants are along Ohio River or Lake Erie, several intermediate-sized coal burning facilities producing electrical power, steel and coke are located in the Great Miami Basin. The 2004 amended Clean Air Act's (CAA) goal to "… collect, capture or treat…" pollutants in stack emissions for coal-fired boilers and furnaces has resulted in the installation of stack particulate collectors that have produced cleaner air and large quantities of Coal Combustion Waste (CWW) including scrubber sludge containing heavy metals, mercury, and arsenic which must be disposed in landfills . Ironically the benefits of improved air quality have come at the expense of a reduction in water quality. Leaching from these landfills resulted in the contamination of local ground-water supplies in Alabama, Kentucky, North Carolina and Ohio as reported in "Cleansing the Air at the Expense of Waterways", which appeared recently in the *New York Times*. Three large coal-burning facilities are located in the lower Great Miami Basin: Dayton Power and Light Co., AK Steel Corp., and Hamilton Municipal Electric Plant (**Figure 19**).

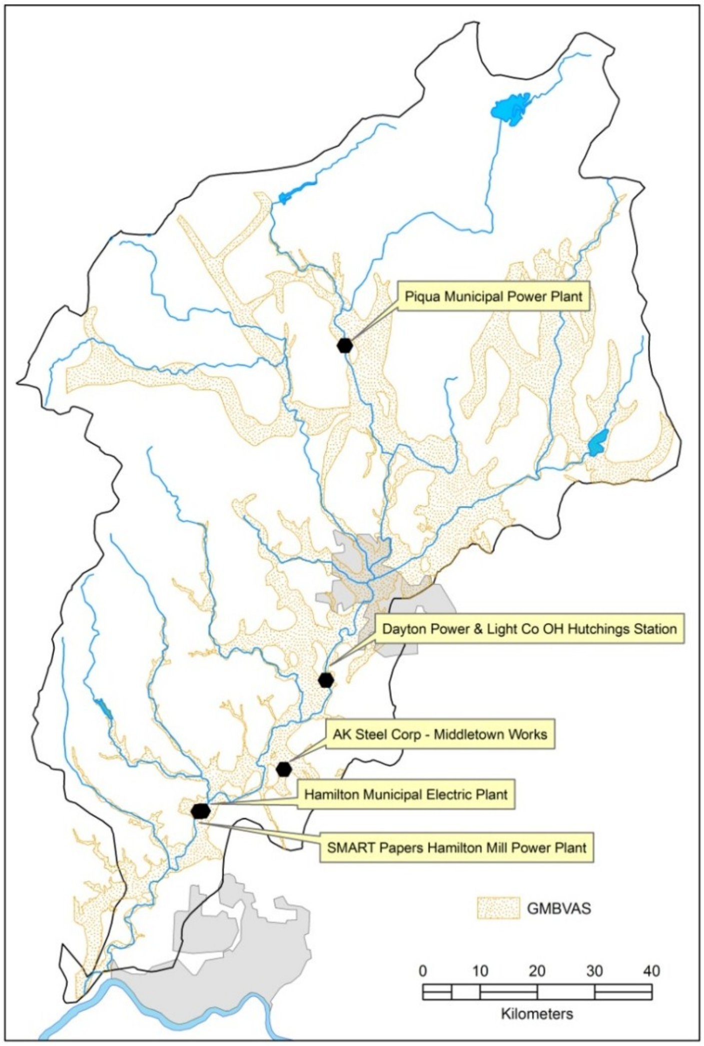

Figure 19. There are five coal combustion waste (CCW) producers in the Great Miami Basin.

Manufacturing and Industrial Production

The Great Miami Basin has an enormous and diverse industrial and manufacturing base that includes truck and automotive assembly, fuel refining, iron and steel production, and paper production. Because manufacturing processes must use numerous toxic materials, USEPA has compiled a Toxic Release Inventory (TRI) with the location of TRI sites and toxic material utilized[45]. The TRI requires businesses to report the type and location of the chemicals it stores and uses so

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[45] http://www.epa.gov/TRI/

nearby communities are aware of the potential hazard and are prepared to respond to spills and similar emergencies". As of January 2010, 385 TRI sites were listed in the Great Miami Basin (**Figure 8**).

Ground Water Flow Paths in the GMBVAS

The path ground water takes to arrive at public water supply wells is critically important because it determines

- The amount of natural filtration provided by the aquifer material
- The length of time the water may spend in an anoxic or reduced oxygen environment
- The time it has to react chemically with the constituent aquifer material
- The risk of contamination by river-borne pathogens (*e.g.*, *Giardia*, and *Cryptosporidium*)

Surface water enters the GMBVAS two ways: by *induced infiltration* and by *bank storage* (also referred to as *bank infiltration*). Induced infiltration results when pumping draws the piezometric surface down below the water level in the river causing river water to infiltrate to the aquifer (**Figure 20**). This is particularly likely when water wells are immediately adjacent to the river (the vast majority of public supply wells are literally within "a stone's throw" of the river, **Figure 21**).

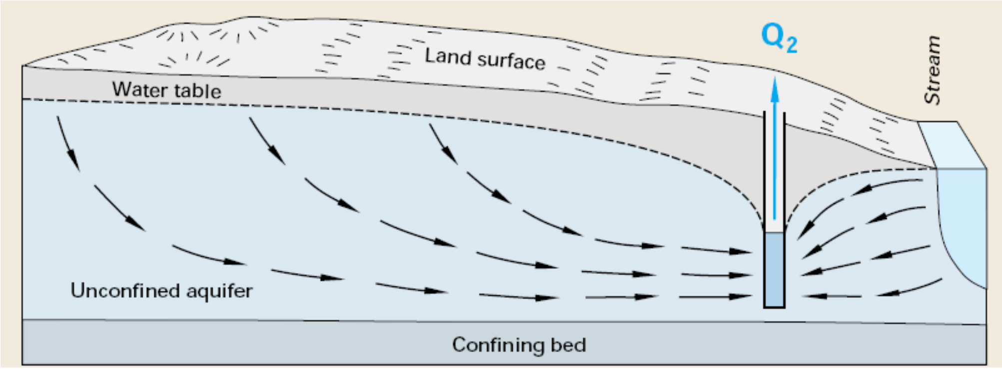

Figure 20. Pumpage induced infiltration (from Winter, *et al.*, 1998)

Figure 21. The majority of public water supply wells in the GMBVAS are literally within a stone's through of Great Miami River as is this one in Hamilton County.

Banks storage results when flood events cause river stage to rise above the piezometric surface in the aquifer forcing river water into the aquifer (**Figure 22**). The flow paths to the well resulting from either induced infiltration or bank storage are relatively short reducing the travel time of water between the river and well, thereby reducing or eliminating filtering by the aquifer materials or other benefits of longer travel through the GMBVAS.

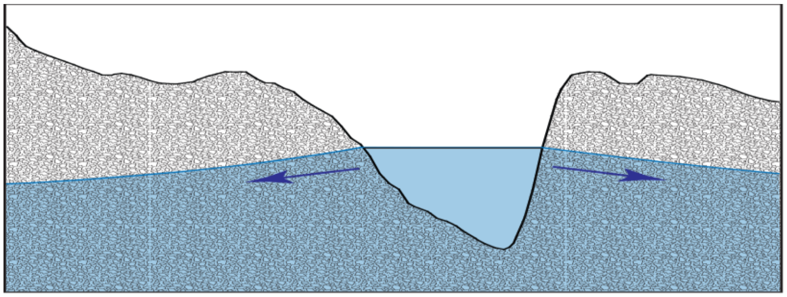

Figure 22. Bank storage resulting from storm-induced increase in river stage above piezometric surface.

Base flow versus underflow

Larkin and Sharp (1992) draw a distinction between two fundamentally different patterns of ground-water flow in alluvial aquifers*: baseflow* in which the elevation contours of the piezometric surface parallel the adjacent river causing ground water flow perpendicular to the course of the river and *underflow* in which elevation contours of the piezometric surface are perpendicular to the river resulting in ground-water flow parallel to the river.

Larkin and Sharp (1992) give Great Miami River's steady-state piezometric surface as a type example of underflow (**Figure 23**). They observe underflow-dominated alluvial aquifers have a longer flow path than baseflow-dominated aquifer. This longer path provides more opportunity for metals and organic compounds in the surface water to be attenuated by cation exchange and/or sorption onto clays. Organic carbon and natural microbial processes in the aquifer may also reduce levels of undesirable organics or nitrates. Of course an underflow dominated-system must become base-flow-dominated, at least locally, by induced infiltration around a pumping well. During high discharge events, bank storage will result in baseflow away from the river.

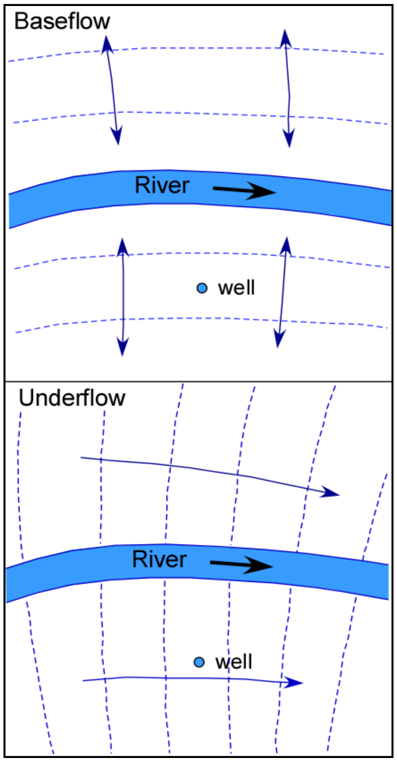

Figure 23. Dashed lines are contours of equal piezometric elevation.

The deviation from underflow caused by induced infiltration or bank storage has important implications for the amount of natural remediation of the water as it travels between the river and well. Although the transmissivity of the GMBVAS has been thoroughly measured, the conductivity of the channel material is much more difficult to determine. The amount of water entering the aquifer by bank storage or induced infiltration is strongly dependent on this conductivity.

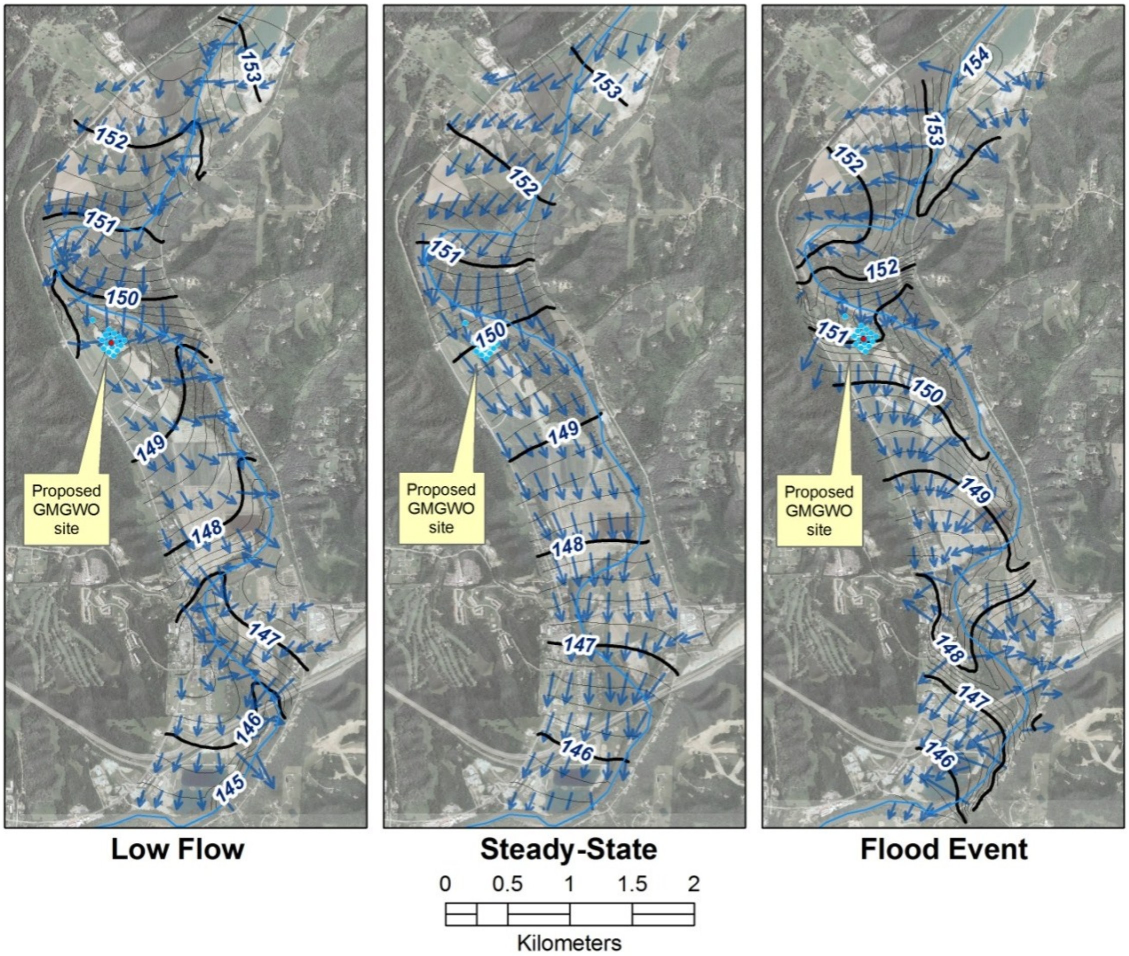

Figure 24. MODULAR modeled piezometric surface (meters) for GMBVAS between Fernald and Miamitown using Spieker (1968a) values for transmissivity, stream routing with discharge from the Hamilton Gauge 03274000, and a possible value for stream channel conductivity.

Conductivity of River Channel Sediments

Although transient flow paths in the GMBVAS are easily modeled (**Figure 24**), without accurate values for channel conductivity they are of suspect accuracy and of questionable value. Spieker (1968a) prefaces his estimates of induced infiltration with:

> “Induced infiltration, despite its major role in the hydrologic system, is, nonetheless, one of the least understood phenomena. That it is not more clearly understood can be partly attributed to the fact that meaningful results are obtainable only with fairly large expenditures of time and funds. Induced infiltration in the lower Great Miami River valley certainly should receive future study.” (p. A9)

Measurement of the transient piezometric elevation in the river and the hydraulic properties of the GMBVAS are straightforward. In order to model induced infiltration, however, the conductivity of the streambed must be known and its measurement is not straightforward. Current methods for assessing channel conductivity are detailed in the Appendix 8.

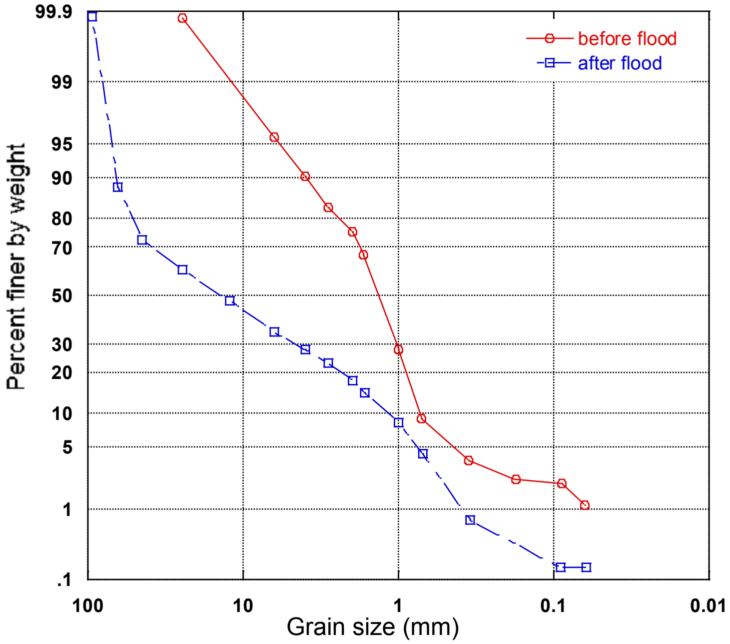

Figure 25. Changes in bed granulometry at Heritage Park near Ross before and after a Great Miami flood event in January, 2008 (from Levy, *et al.*, 2008).

Calver (2001) compiles a list of published riverbed conductance values which concentrate around 10^{-7} to 10^{-3} m/sec but range over seven orders of magnitude from less than 10^{-9} to more than 10^{-2} m/sec! In addition, studies of Great Miami and other rivers find dramatic changes in riverbed conductance both spatially and temporally. Clearly there is no "typical" or reasonable value that may be assumed.

Channel conductivity varies significantly even for a given section of one stream. From an analysis of discharge and sediment load, Nash (1994) found most sediment transport occurs during frequent (*i.e.*, more frequent than the annual flood) high discharge events. It is, therefore, not surprising that Levy (2008) finds an enormous change in granulometry of channel bed material before and after a flood event on Great Miami River near Hamilton (**Figure 25**). Mutiti *et al.* (2006) report Great Miami River bed conductivity temporally varying by two orders of magnitude at a single location. Belanger and Montgomery (1992) and Landon *et al.* (2001) find similar spatial variation in bed conductivity at a given channel cross section. Landon *et al.* (2001) oFbserve "… that the method used [for measuring riverbed conductance] may matter less than making enough measurements to characterize spatial variability adequately." They conclude that "[Seepage meter] errors are small compared to spatial and temporal components of sampling error typically encountered in the field." In addition to its high temporal and spatial variability, an accurate measure of bed conductance is most critical during floods when it is most difficult and dangerous to measure. Spring and early summer high discharge events are also the times when the concentration of agricultural pollutants (*e.g.*, Atrazine and nitrogenous fertilizer) are highest following the first heavy rain after their application flushes them into streams and rivers. Debrewer et al (2000) and Sophocleous (1988) show injection of Atrazine and nitrates into the aquifer by bank storage are highest during these events. Any method involving wading in Great Miami River or accessing it by point is not feasible during these critically important high discharge events.

Educational Outreach

Conservation education and enhancement of scientific interest and competency of K-12 students in the Great Miami Basin is a major goal of the Great Miami Water Observatory Network. This goal would be achieved by working with the many existing water education efforts conducted at all levels, from conservation organizations to federal agencies. There are already innovative and effective local educational efforts, particularly at the county level. The Great Miami Water Observatory Network would enhance and augment these efforts.

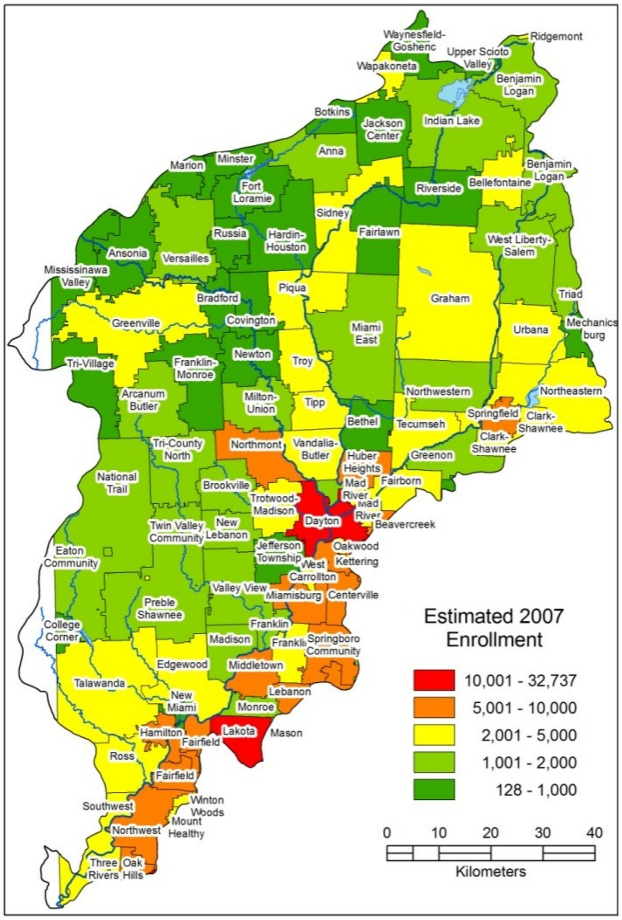

Figure 26. There are 95 public school districts partially or completely within the Great Miami Basin with a K-12 2007 enrollment of more than 350,000

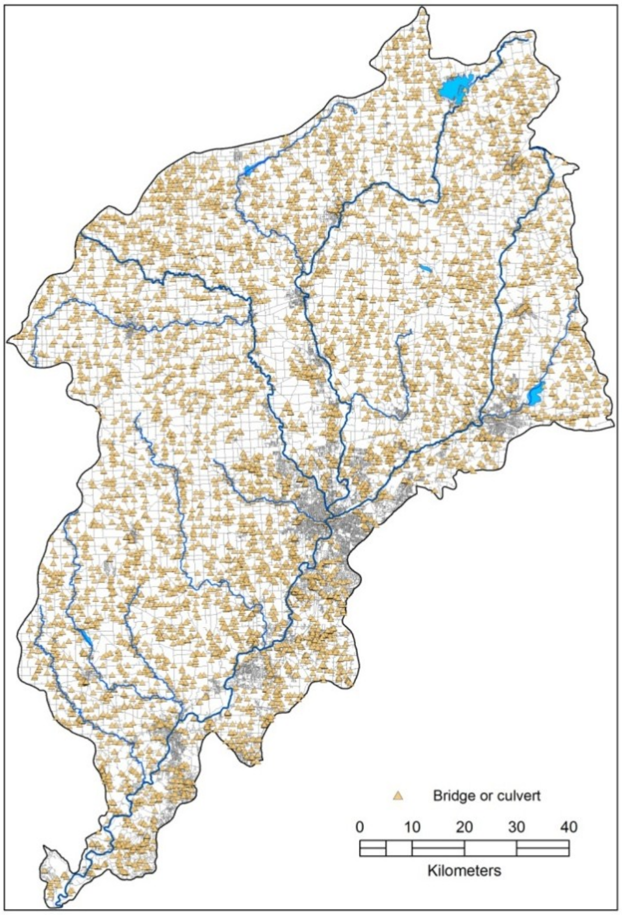

Figure 27. There are more than 6,000 bridges and culverts over Great Miami River or its tributaries providing access points for sampling and observing.

The University of Cincinnati would provide the web-based infrastructure to store local observations on a centralized server and to distribute those data with an informative, easy to use website. There are 95 school districts (**Figure 26**) and many potential sampling points: over 6,000 bridges and culverts (**Figure 27**) over Great Miami River and its tributaries in the basin. The university would provide opportunities for teacher training at the Cincinnati Center for Field Studies that would include sampling philosophy and chemical and biological techniques for sampling and observation.

Equipment for either field-based or laboratory-based measurement of water chemistry would be provided to districts sending teachers to these training opportunities.

Lesson plans stressing an integrative approach employing STEMM disciplines (Science, Technology, Engineering, Mathematics, and Medicine) would be stressed. These plans would focus on collection and placement of local data on the centralized server and use of the regional data in learning exercises. The importance of field study and sound field methodology would be stressed in teacher training and lesson plans. UC faculty would travel around the districts providing consultation on field opportunities unique to particular districts.

In addition to coordinating with water education and outreach programs by USDA county extensions agents, parks, health departments, Ohio River Sanitation Commission (ORSANCO), the Miami Conservancy District (MCD), etc., the Great Miami Water Observation Network would coordinate its program with ProjectWET[46] (Water Education for Teachers). ProjectWET is an international education program which in Ohio is coordinated by the Ohio Department of Natural Resources, Division of Soil and Water[47]. Nine of the twenty-five counties in the Great Miami Basin have ProjectWET leaders offering workshops in their counties, particularly in schools[48]. ProjectWET has a strong emphasis on surface water because it is an international project requiring its class exercises to be widely applicable. Because of its local importance, the Great Miami Water Observation Network will use data from the Great Miami Ground-Water Observatory (GMGWO) to focus on the GMBVAS and concerns particularly pertinent to residents of the basin (*e.g.*, nitrates, Atrazine, PPCP, etc.).

The Great Miami Water Observatory Network would be used for education and training at the undergraduate and graduate levels by the University of Cincinnati and other area colleges and universities. Water education would be used as a unifying concept for promoting a multidisciplinary, integrative approach in science courses taken by students in the college of education. GMGWO would be used at the undergraduate level to teach ground-water field methods, and to conduct pump tests. At the graduate level it would be used to provide facilities for a wide range of research projects including sensor development and testing, aquifer-river interaction, contaminant movement, interaction of contaminants with aquifer materials, aquifer anisotropy, and contaminant dispersal.

In addition to involving K-12 students in locally-relevant scientific research, the focus of this widely distributed network of observers could be shifted rapidly to assess specific concerns as they arise. Unlike fixed, automated sensor networks, this flexible and adaptable observer network is readily adaptable and can be modified by instruction and lesson plans available on the data distribution website. The infrastructure for teacher training permits the kinds of observations made and measurement techniques employed to evolve as needed.

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[46] http://www.projectwet.org/

[47] http://www.dnr.state.oh.us/tabid/3501/Default.aspx

[48] http://www.dnr.state.oh.us/water/educate/owep/cocntacs/contmain/tabid/3504/Default.aspx

Great Miami Ground-Water Observatory

The Great Miami Ground-Water Observatory (GMGWO) is the central component of the Great Miami Water Observatory Network. It will:

- Provide real-time data on ground-water flow direction, velocity, temperature, and specific conductance
- Provide the infrastructure for detailed and accurate determination of an areally representative and temporally appropriate (*i.e.*, as affected by season and flow condition) values for riverbed conductance
- Collect baseline data for assessing long-term impact of changes in resource management, land-use, waste-water treatment, climate, contaminant movement, etc.
- Provide a secure and controlled site for chemical sensor development and testing
- Provide a site for high school and undergraduate ground-water education and training
- Provide a protected and stable **site** for graduate research in ground-water
- Provide a site for federal, state and local agencies to monitor the health and protect the safety of water in the GMBVAS
- Provide a site at which companies developing ground-water monitoring, testing, or remediation equipment may field test their products

Figure 28. GMGWO would consist of a well field and the USGS surface water gauge at Miamitown Bridge

The site of the observatory, provided by the Hamilton County Park District (HCPD) is ideal for several reasons. It is just above the confluence of Great Miami and Whitewater rivers (**Figure 28**) so is downstream from all sources of contamination for the entire basin and thus situated to monitor them. The area is relatively undeveloped, and there is no major pumpage in the vicinity to interfere with the natural ground-water flow vector in the GMBVAS. The geology of the area was determined by Spieker (1968a) from local cores and is relatively homogenous sand and gravel without significant or laterally continuous clay units. The area is readily accessible to researchers at University of Cincinnati, Miami University and several other area universities and colleges including the College of Mount St. Joseph, Xavier University, and Cincinnati State. Because it is within the Miami-Whitewater Forest boundaries, Hamilton County Park District police can monitor and protect the site. Also, because it is within an HCPD park, land use in the immediate vicinity is controlled and not likely to change.

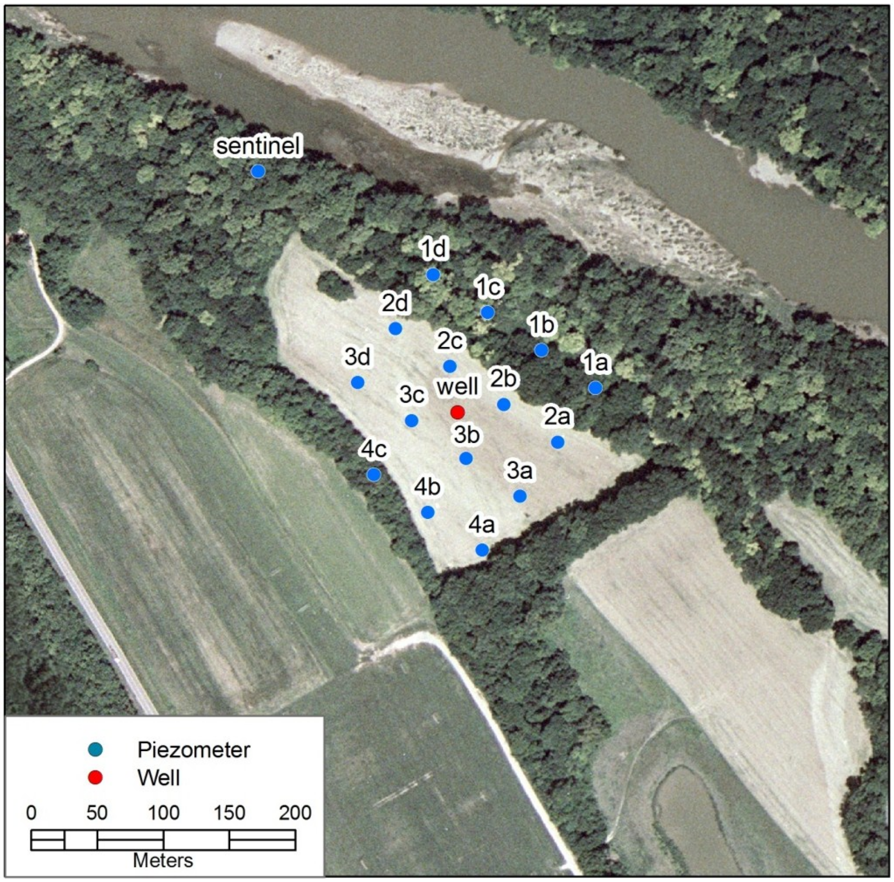

Figure 29. GMGWO would consist of 16 observation arrays and one pumping

Figure 30. Proposed site of GMGWO viewed from the southwest to the northeast July 1, 2008

Infrastructure

The Hamilton County Park District's (HCPD) Board of Directors has agreed to provide a site in Miami-Whitewater Forest immediately adjacent to Great Miami River (**Figure 28**). The site (**Figure 30**) is an abandoned agricultural field. It is within the active floodplain of Great Miami River but is sufficiently protected by a mature growth of timber and by the retarding effects of multiple channel scrolls that the surface is minimally eroded by flood events although fresh alluvium is frequently deposited.

The surface materials are alluvial silt and fine sand. Spieker (1968a) maps the GMBVAS between 30 to 40m at the site. HCPD had two water supply wells drilled a few hundred meters to the southwest of the proposed GMGWO site (ODNR well logs 703426[49] and 703427[50]) reached the aquifer at depths of 12 and 7 feet respectively and 703427 encountered bedrock at a depth of 61 feet respectively (the GMGWO site is closer to the center of the valley than that well so it is likely to encounter deeper depths to bedrock. As predicted by Spieker (1968a), the GMBVAS is free of clay units except immediately overlying bedrock.

GMGWO would consist of a grid of fifteen wells at 50 meter centers around a central pumping well (**Figure 29**). A sixteenth "sentinel" piezometer would be installed upstream of the array and as close to the river as prudent. The sentinel piezometer and piezometers 1a, 1d, and 4a would be 4-inch diameter to allow insertion of larger instrumentation sondes. The pumping well would be 8-inch diameter, large enough to insert a rented submersible pump capable of making 300gpm (necessary for making aquifer tests with the piezometer array. All other piezometers would have 2-inch diameters. All casings and screens for the piezometers and pumping well would be of stainless steel.

The 100-year flood level is less than 4m above grade. A 5m high tower would be erected above the pumping well to house monitoring and communication electronics and keep them above flood stage. Each well head would be water-tight and extend 50cm above grade. Each would be vented by a snorkel run below grade from the well-head enclosure to the central tower where it would be joined with the snorkels from the other well heads and vented above the 100-year flood level. The snorkel from each well head would be graded towards the well, when water level drops following flooding, it will drain out of the snorkel into the well head where it will run into the piezometer through well screen inserted into the top of the casing in the well enclosure**.** Cabling to the array would also be through the snorkel which would have a diameter large enough to accommodate cabling for future instrumentation.

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[49] http://www.dnr.state.oh.us/water/maptechs/wellogs/appNew/report.aspx?s=c&wln=703426

[50] http://www.dnr.state.oh.us/water/maptechs/wellogs/appNew/report.aspx?s=c&wln=703427

The USGS gauge at Miamitown (USGS Gauge 03274615)[51] (**Figure 31**) is located 2,300m downstream from the GMGWO well field. It is mounted on the Miamitown bridge and is the nearest site with a fixed pier that is above flood level. It was installed in early September 2009 to replace a manually read gauge operated for NOAA. At the time of installation, a Cat 6[52] internet cable was run from the gauge house to the gauge for future installation of additional instrumentation. Although the gauge is currently powered by a solar panel and transfers data in near-real time by a satellite uplink, sources of 120V power and a DSL service are close to the site and could be used for powering and communicating with future instrumentation packages.

Figure 31. USGS gauge 03274615 at Miamitown bridge.

Additional instrumentation would be installed at the Miamitown gauge to be used with instrumentation at the well field to monitor river water quality. Sensors would include temperature, specific conductance, and nitrate (when reliable optical-based instrumentation is available). Load cells would be installed for monitoring channel erosion. The harness on which instrumentation would be mounted and attached to the downstream side of the bridge pier would be designed to be readily adaptable to additional instrumentation as it is developed or needed.

Continuous monitoring of Ground-Water flow vector

Water levels would be measured continuously by pressure transducers in each of the piezometers and the central well. These levels would be used with the conductivity of the aquifer to map the transient piezometric surface and determine the direction and velocity of ground-water flow. The results of the analysis would be put onto the webserver and made available at regular, frequent intervals (fifteen minute to three hours depending on the rate at which the velocity changes). The website presentation would be similar to that in **Error! Reference source not found.**. These data will e archived for future reference and analysis

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[51] http://waterdata.usgs.gov/nwis/uv?03274615

[52] http://en.wikipedia.org/wiki/Category_6_cable

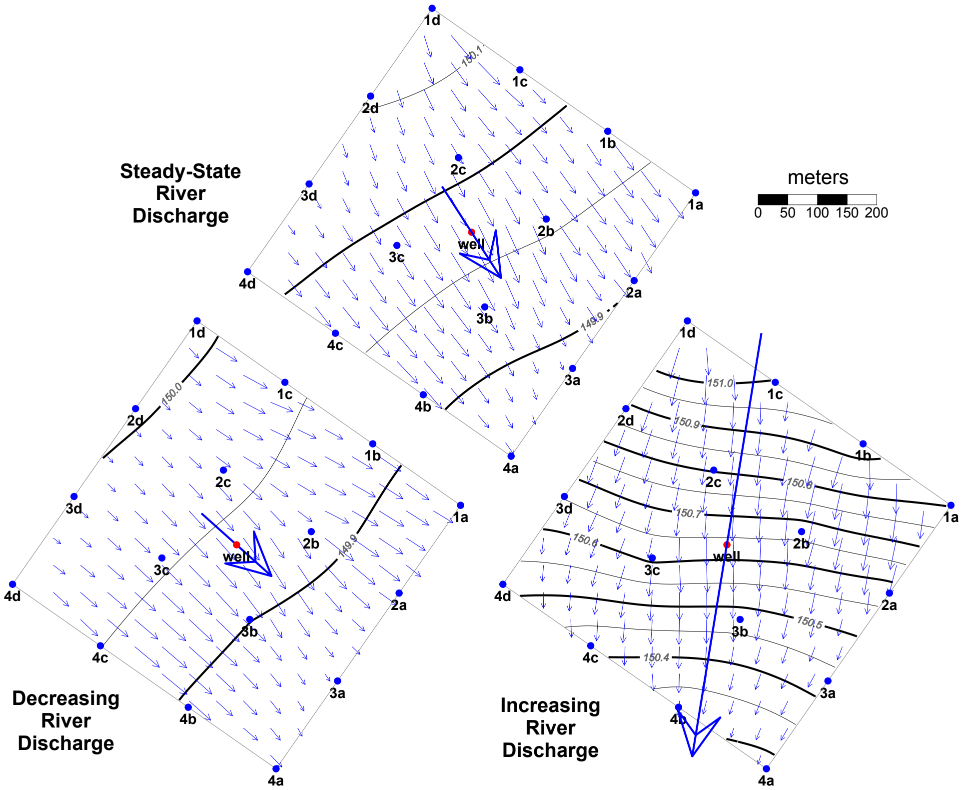

Figure 32. Maps showing the current piezometric surface at the observatory and the direction and rate of ground-water flow would be uploaded to the website and archived for future reference. The examples shown here are generated from model data (**Figure 24**). The lengths of the large arrows are proportional to discharge velocity and show average direction of flow. Contour lines and flow vectors generated for simulated heads measured in GMGWO piezometers (0.5m contour interval).

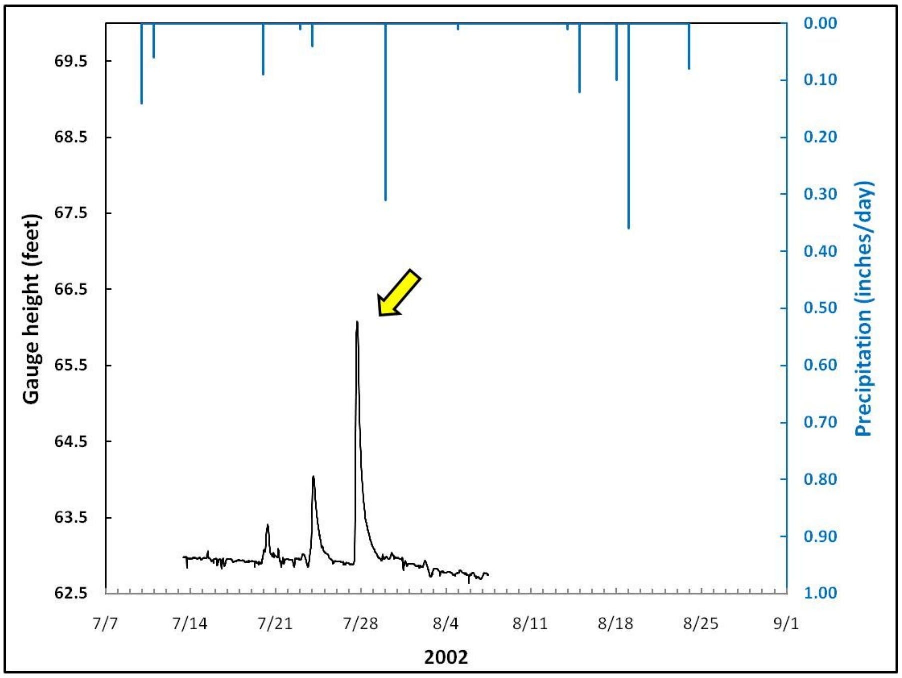

Figure 33. Rainless flood (yellow arrow) at Hamilton USGS gauge 03274000 on Great Miami River, July, 2002

Riverbed conductivity from flood pulses

GMGWO would be used to observe areally representative values for channel bed conductivity by observing the attenuation and phase delay in the GMBVAS produced by Great Miami River flood pulses from upstream storm events but during which there is no precipitation in the vicinity of GMGWO. The Great Miami Drainage area is 10,178km^2 of which 2,290 km^2, less than 23% is underlain by the GMBVAS. The bulk of the basin is relatively steep uplands underlain by shales with very low infiltration rates. As a result, discharge during heavy rains peaks quickly with high stages (**Figure 34**). The flashiness of discharge response to precipitation and the large size of the basin results in flood pulses produced by upstream rain events that do not fall in the local area (**Figure 33**).

Figure 34. Views of Great Miami River looking upstream from the Miamitown bridge: high-normal discharge, July 1, 2008 and flood discharge March 20, 2008 (bottom)

The rise and fall of the piezometric surface produced by such floods will have decreased amplitude and a phase delay from the river's flood pulse. Because the conductivity of the aquifer material can be accurately determined by aquifer tests and does not change with time (confined), the riverbed conductivity, the only parameter that changes, may be determined. This method of determining bed conductivity has advantages over the streambed measurement approaches discussed in **Appendix 8**. Its advantages are similar to those of aquifer pump tests over laboratory permeameter tests to determine aquifer conductivity. First, it is based on testing a representative, large area of the riverbed. Second, it does not disturb the system being measured by inserting instruments into the streambed. It also has the additional advantage of determining the appropriate value of bed conductivity at the critical times of bank storage during flood events. This approach is also appropriate for the extremely coarse, boulder channel of Great Miami that makes the insertion of instrumentation in most parts of its channel impossible.

Establishing Baseline Conditions and Assessing Changes in Ground-Water Quality

In order to assess the impact of any environmental change, a database from reliably collected, quality-controlled observation to establish baseline conditions is essential. The necessity of detailed baseline conditions for recognizing environmental changes led the USGS to establish the National Water-Quality Assessment (NAWQA) Program to

> "… describe water-quality conditions for a large, representative part of the Nation's surface and ground-water resources; define long-term trends in water quality; and identify the natural and human factors that affect observed water-quality conditions and trends…. The goal of the NAWQA Program is to provide water-quality information to policy makers and resource managers at the Federal, state, and local level so they can better prioritize and manage water resources in diverse hydrologic and land-use settings. Results of the NAWQA studies also can be used to consider the effects of key natural processes and human activities on water quality when management strategies and policies designed to restore and protect the Nation's waters are being developed." (Debrewer *et al.,* 2000)

GMGWO would have a similar objective with a high resolution spatial and temporal focus on the GMBVAS.

The location of GMGWO at the outlet of Great Miami Basin is ideal to assess the long-term effectiveness of Superfund remediation efforts within the basin. Its proximity to the Fernald Superfund site makes it particularly appropriate for assessing any possible migration of the ground-water contamination plume from that site. Long-term monitoring of background radiation at a site through which uranium escaping from the Fernald site must pass could be used to address public concern about the safety of the site, the effectiveness of its remediation and its impact on the GMBVAS. In addition to providing a baseline to recognize changes in GMBVAS water quality, an absence of base level changes could be used to allay public fears. An example of such fears may have been raised on a website[53] arguing against Ohio's program of sequestering carbon dioxide in deep injection wells. The website used fears of the impact the program was having on the GMBVAS to argue against the program.

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[53] http://citizensagainstco2sequestration.blogspot.com/2009_05_28_archive.html

Summary

The Great Miami Water Observation Network would address several critical needs of our area. It would involve K-12 and college students in locally relevant scientific research stressing an approach that integrates many different scientific and technologic disciplines. It would emphasize field-based, hands-on inquiry and promote the development of observation and measurement in the field. It would promote awareness of the necessity of sound stewardship and protection of the Great Miami Buried Valley Aquifer System (GMBVAS) and the interrelatedness of ground and surface water. By providing a web-based server for receiving, storing, and disseminating water data from its school-based network of observers and from the sensor array at the Great Miami Ground-Water Observatory (GMGWO), it would provide timely and relevant data on water quality to regulatory agencies, planners, researchers, and the general public.

The GMBVAS is one of the most vital natural resources in our area. While much of the rest of the world confronts serious problems with the availability and quality of water, our region benefits from its abundant and healthy water. This resource supports our highly productive industrial and agricultural base and is used to attract businesses to our region. It also supports a large urban, suburban, and rural population with more than a quarter of a million students in K-12. The proposed The Great Miami Water Observatory Network not only would protect a resource on which everyone depends but would also involve students in its monitoring and scientific study.

Appendices

Appendix 1

Definitions and Abbreviations

Advective Transport		Movement of a dissolved ground water component by ground-water movement (*i.e.*, without contribution from diffusive or dispersive mechanisms)
	AMSL	Elevation above mean seal level
Atrazine		A broad-leaf weed suppressant commonly used in agriculture, particularly corn production.
Bank Storage or Bank Filtration		Movement of water from a stream or river into the adjoining alluvial aquifer as a result of higher water levels in the river than in the aquifer. Frequently a result of flooding.
Baseflow		Used by Larkin and Sharp (1992) for movement of water between the aquifer and river roughly perpendicular to the course of the river (opposite of underflow)
	cfs	Cubic feet per second
Clean Water Act	CWS	US Federal act to reduce toxic substances released to natural water system
Clean Air Act	CAA	US Federal act to reduce emission of unhealthy materials to the atmosphere
Coal Combustion Waste	CCW	Residue produced in large quantities by burning of coal. Contains heavy metals and other unhealthy materials.
Combined Sewer Overflow	CSO	Storm induced overflows of older sewer systems in which the sanitary and storm-water sewer lines are combined in a single sewer line
Flow Duration Curve		Curve specific to a given gauge on a given stream or river showing the percent of time at which a discharge is equaled or exceeded
Gaining Stream		A stream in which the adjacent alluvial aquifer is discharging to the surface water system. Most streams in a humid region are gaining. Opposite of losing stream.
gastroschisis		Birth defect in which a portion of an infant’s intestine protrudes from the body. Treatable with surgery.
	GetWET	Surface and ground-water observatory on the campus of Colorado State University used for water education.
	GMBVAS	Great Miami Buried Valley Aquifer System
	GMGWO	Great Miami Ground-Water Observatory

	GMWON	Great Miami Water Observation Network
Granulometry		Statistical distribution of grain size of a sedimentary sample
Ground Water Under the Direct Influence of Surface Water	GWUDI	USEPA designation for "significant occurrence of insects or macroorganisms, algae, organic debris, or large-diameter pathogens such as Giardia lamblia." or "significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water condition."
	HCPD	Hamilton County Park District
Heavy Metals		Naturally occurring metals that can be concentrated to harmful levels by human activities including waste water treatment and burning of fossil fuels. May include cobalt, copper, manganese, molybdenum, zinc, mercury, plutonium, lead, vanadium, tungsten, and cadmium.
Hydrogeologic Environments		Spieker (1968a) divides the Great Miami Basin into 11 hydrogeologic environments on the basis of the nature and thickness of the aquifer materials, the availability of recharge by induced stream infiltration, and the presence or absence of semiconfining clay layers.
Hydraulic Conductivity		Ground-water velocity is proportional to the slope of the piezometric surface (or hydraulic gradient). Hydraulic conductivity is the coefficient of proportionality (units of LT^{-1})
Induced Infiltration		Infiltration from a surface water source to an adjoining aquifer resulting from lowering of the piezometric surface in the aquifer by pumping.
Lacustrine		Relating to lakes
Littoral		Relating to shoreline processes particularly wave action.
Losing Stream		A stream in which surface water is flowing into the adjacent alluvial aquifer as a result of surface water elevation above the elevation of the piezometric surface in the aquifer. Losing streams are often found in arid regions. Opposite of gaining stream.
Maximum Contaminant Level	MCL	USEPA established highest permissible level of contaminant in drinking water for it to be deemed suitable for human consumption
	mgd	Million gallons per day

National Water-Quality Assessment Program	NAWQA	USGS program analyzing water quality at the national scale using consistent well type, sampling depth, targeted land use, and laboratory analytical methods.
New Haven Trough		Wide alluvial valley between Ross and Harrison, Ohio formed and once occupied by the pre-recent Great Miami River. The deeply alluviated valley is not occupied by any substantial surface stream. Present location of the USDOE Fernald Feed Materials Facility.
	OEPA	Ohio Environmental Protection Agency
Overdrafting		Removal (pumpage) of ground water from an aquifer at a rate exceeding that at which it is supplied.
Perchloroethylene	PCE	Also referred to as PERC. Is widely used in dry cleaning and has numerous other industrial uses. Is a common VOC.
Permeameters		A laboratory or *in situ* field device for determining hydraulic conductivity.
Pharmaceuticals and Personal Care Products	PPCP	Chemicals that are increasingly detected in surface and ground water both as a result of better detection methods and, presumably, greater use. An emerging concern.
Piezometer		A simple field device for measuring the elevation of the piezometric surface consisting of an open ended pipe screened in the aquifer.
Piezometric Surface		The elevation to which water will rise in an open ended standpipe. Corresponds to the water surface in surface water. Is also the energy per unit weight of water. Water flows from higher piezometric elevation to lower.
Pollutant Discharge Elimination Systems	NPDES	USEPA maintains a database of industrial and public dischargers of water. All waste water treatment plants are on the list as are power and other industrial facilities using surface and ground water as a coolant.
	ProjectWET	National and international program providing educational resources to teachers for water education.
Sanitary Sewer Overflows	SSO	Sanitary sewers may overflow as a result of blockage but more commonly as a result of infiltration from elevated ground-water levels during storms and by inflow from roof and floor drains and illegal drain hookups.

Seepage Meter		Simple device for measuring water flow in to or out of the bed of a stream, lake, or ocean. Commonly is made from the top section of a 55 gallon drum which is pushed into substrate sediments. A flexible, impermeable bag containing a known amount of water is attached to an outlet from the drum. Seepage into or out of the substrate is determined by measuring the water in the bag after some time interval.
Sole Source Aquifer	SSA	USEPA designation for an aquifer or aquifer system supplying 50% or more of the drinking water for which there are no reasonably available alternative sources should the aquifer become contaminated.
	STEMM	Science, technology, engineering, mathematics, and medicine education. A national education initiative to improve science education and increase scientific proficiency of students at all educational levels, particularly K-12.
Superfund Sites On The National Priority List	NPL	USEPA designated toxic waste sites recognized under Comprehensive Environmental Response, Compensation, and Liability Act. USEPA oversees remediation of the site.
	NRC	"The U.S. Nuclear Regulatory Commission (NRC) was created as an independent agency by Congress in 1974 to enable the nation to safely use radioactive materials for beneficial civilian purposes while ensuring that people and the environment are protected." (from NRC website)
Thermistor		Simple and inexpensive temperature sensing device in which electrical resistance changes as an accurately-measurable function of temperature.
Toxic Release Inventory	TRI	USEPA requires businesses to report the locations and quantities of chemicals stored on-site to state and local governments in order to help communities prepare to respond to chemical spills and similar emergencies.
Transmissivity		Product of hydraulic conductivity times wetted aquifer thickness (units of L^2T^{-1})
Trichloroethene	TCE	Commonly used industrial solvent and degreaser. VOC component.
Underflow		Used by Larkin and Sharp (1992) for situations in which water in the aquifer moves parallel to the adjoining stream (opposite of baseflow)
	USDOE	US Department of Energy

	USEPA	US Environmental Protection Agency
	USGS	United States Geological Survey, Water Resources Division. The Water Resources Division is organized into separate districts in most states.
Volatile Organic Compounds	VOC	Some have been shown or are suspected to be carcinogens. Some are hydro fluorocarbons which may cause depletion of the ozone layer.
Water Resource Adaptation Program	WRAP	"The Water Resource Adaptation Program (WRAP) contributes to EPA's efforts to provide water resource managers and decision makers with the tools they need to adapt water resources (*e.g.*, watersheds and infrastructure) to future climate change and demographic and economic development." (from USEPA website)

Appendix 2

Unit Conversion Factors

Length:

1 meter = 3.2808 feet

1 foot = 0.3048 meters

Volume

1 cubic meter = 35.314 cubic feet

1 cubic foot = 0.028316 cubic meters

1 gallon = 0.1336 cubic feet

1 cubic foot = 7.4805 gallons

1 gallon = 0.0037854cubic meters

1 cubic meter = 264.17 gallons

Discharge

1 million gallons per day = 1.5473 cubic feet per second

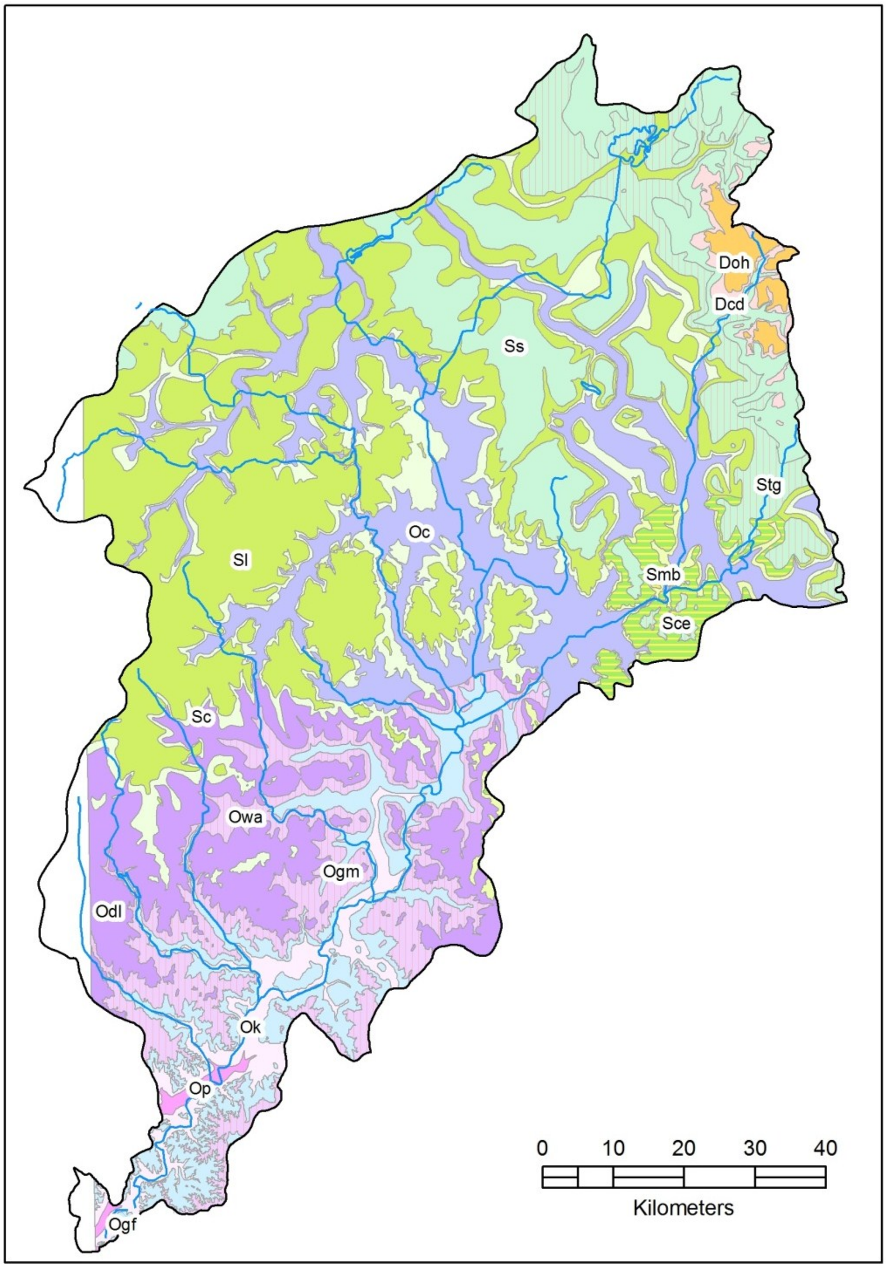
1 cubic foot per second = 0.64627 million gallons per day

1 million gallons per day = 0.005857cubic meters per second

1 cubic meters per second = 22.8235 million gallons per day

Transmissivity

1 gallon per foot per day = = 0.1336 square feet per day



Doh	Ohio Shale: shale, siltstone, and very fine-grained sandstone
Dcd	Columbus Limestone and Detroit River Group, Undifferentiated: Dolomite
Ss	Salina Group: Dolomite, anhydrite, gypsum, salt, and shale
Stg	Tymochtee and Greenfield Dolomites, Undivided: Dolomite and shale
Sc	Clinton and Cataract Groups, Undifferentiated: Dolomite, limestone, and shale
Sl	Lockport Dolomite: Dolomite
Sce	Cedarville, Springfield, and Euphemia Dolomites, Undivided: Dolomite
Smb	Massie Shale, Laurel Dolomite, Osgood Shale, Dayton Limestone, and Brassfield Formation, Undivided: Limestone, shale, and dolomite
Oc	Cincinnati Group: Shale, limestone, and dolomite, interbedded
Odl	Drakes, Whitewater, Saluda, and Liberty Formations, Undivided: Shale, limestone, and dolomite, interbedded
Owa	Waynesville Formation and Arnheim Shale and Limestone Undivided: Shale and limestone, interbedded
Ogf	Grant Lake and Fairview Formations Undivided: Limestone and shale, interbedded
Ogm	Grant Lake Formation, Miamitown Shale and Fairview Formation, Undivided: Limestone and shale, interbedded
Ok	Kope Formation: Shale (75 percent) and limestone, interbedded
Op	Point Pleasant Formation: Limestone (60 percent) and shale, interbedded

Appendix 3. Geologic bedrock map of the Great Miami Basin derived from Slucher *et al.*, 2006[54].

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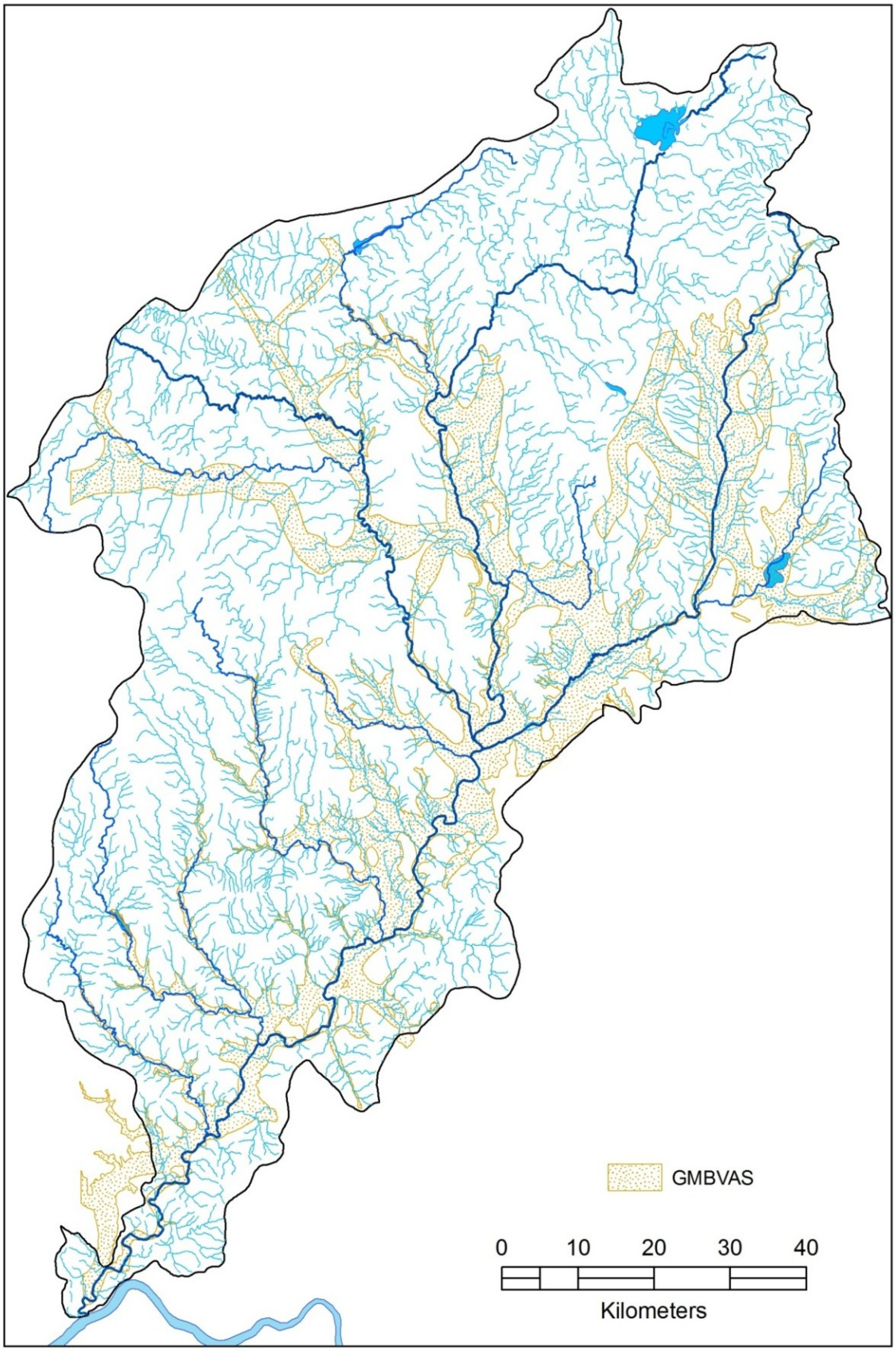
[54] http://www.ohiodnr.com/geosurvey/pub/maps/bgmap/tabid/7224/Default.aspx



Appendix 4. Great Miami River drainage network (from USGS National Hydrography Dataset[55] for Subregion 508).

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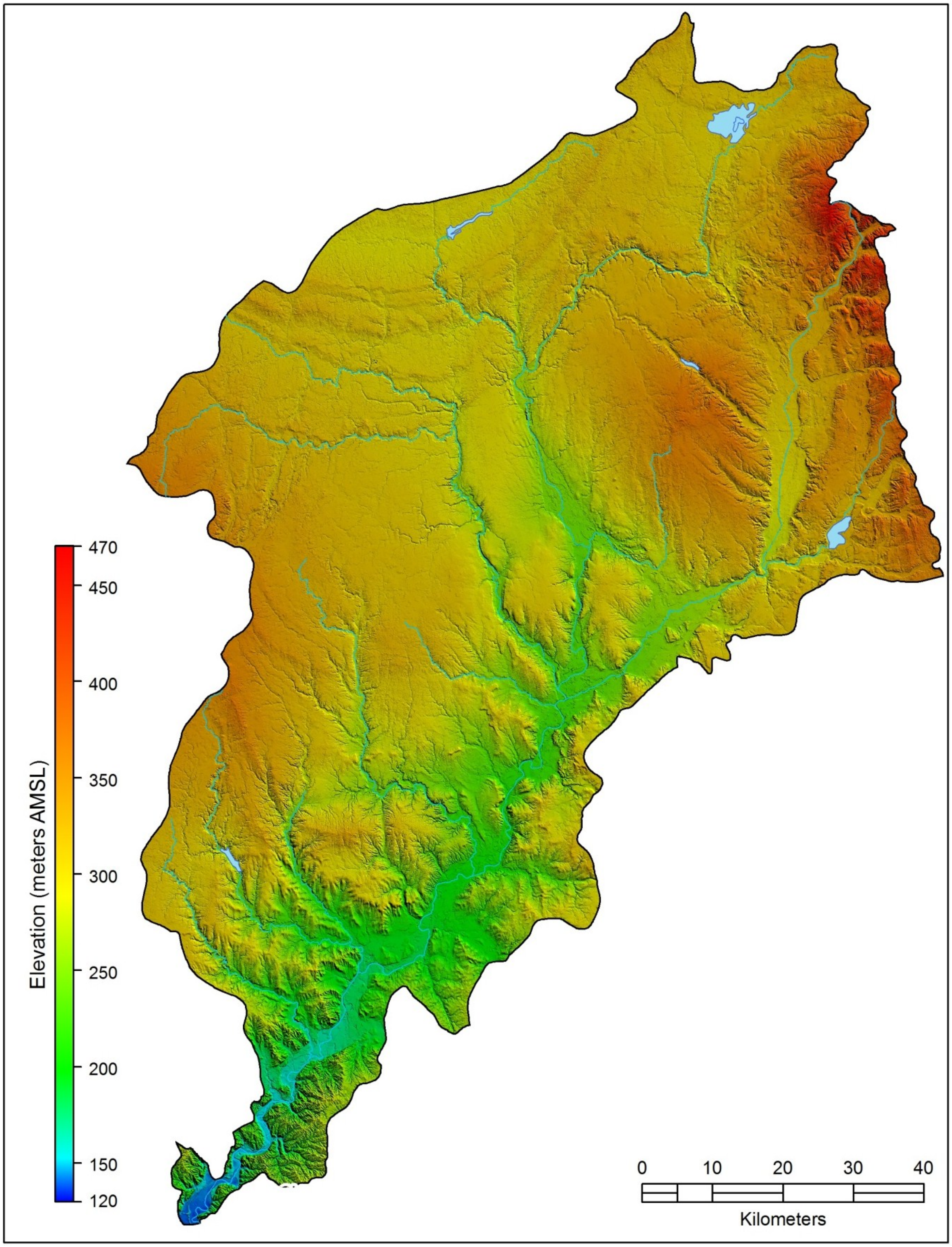
[55] http://nhd.usgs.gov/data.html



Appendix 5 Topography of the Great Miami Basin (from Seamless[56] $^1/_3$arc-second DEM).

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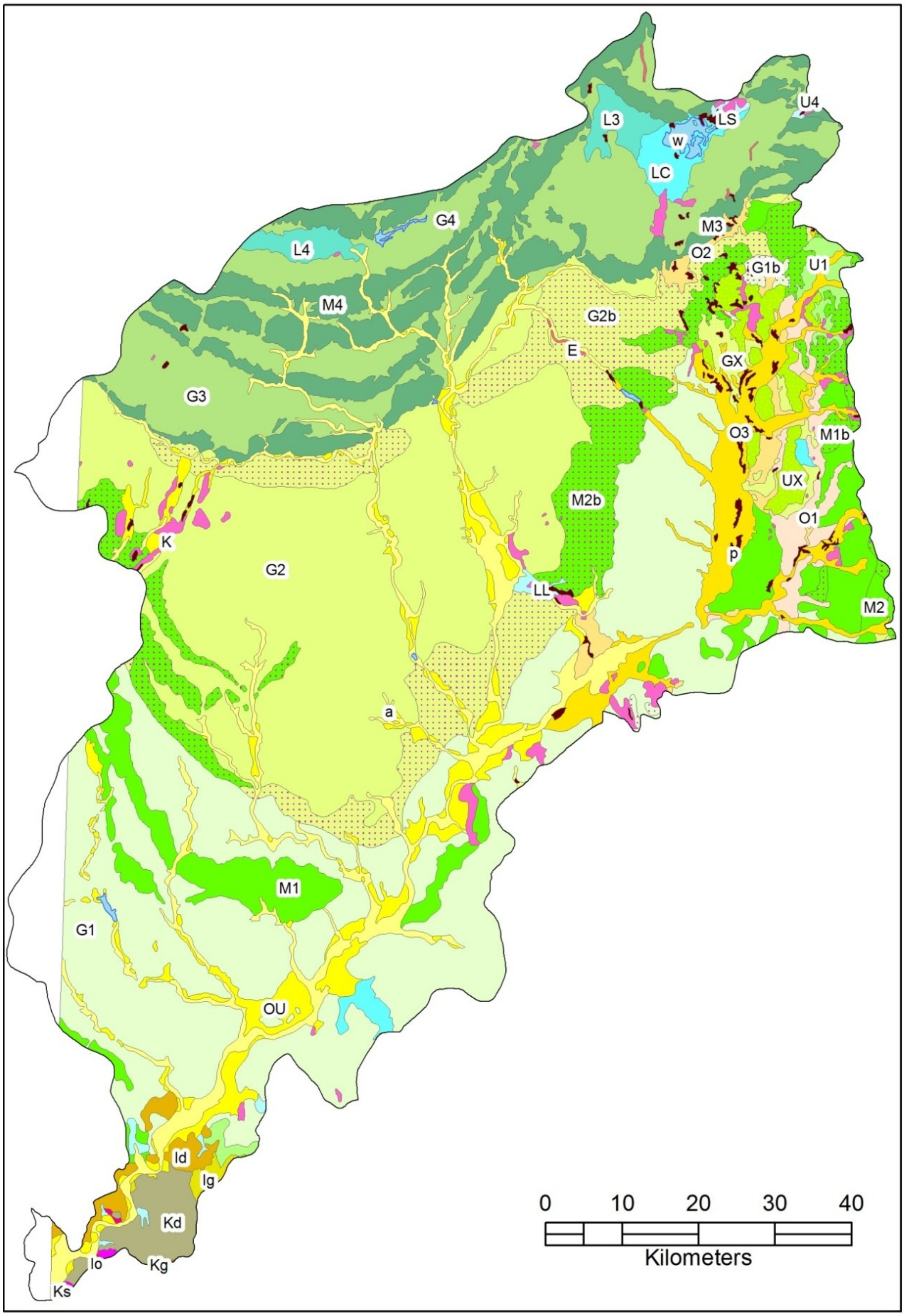
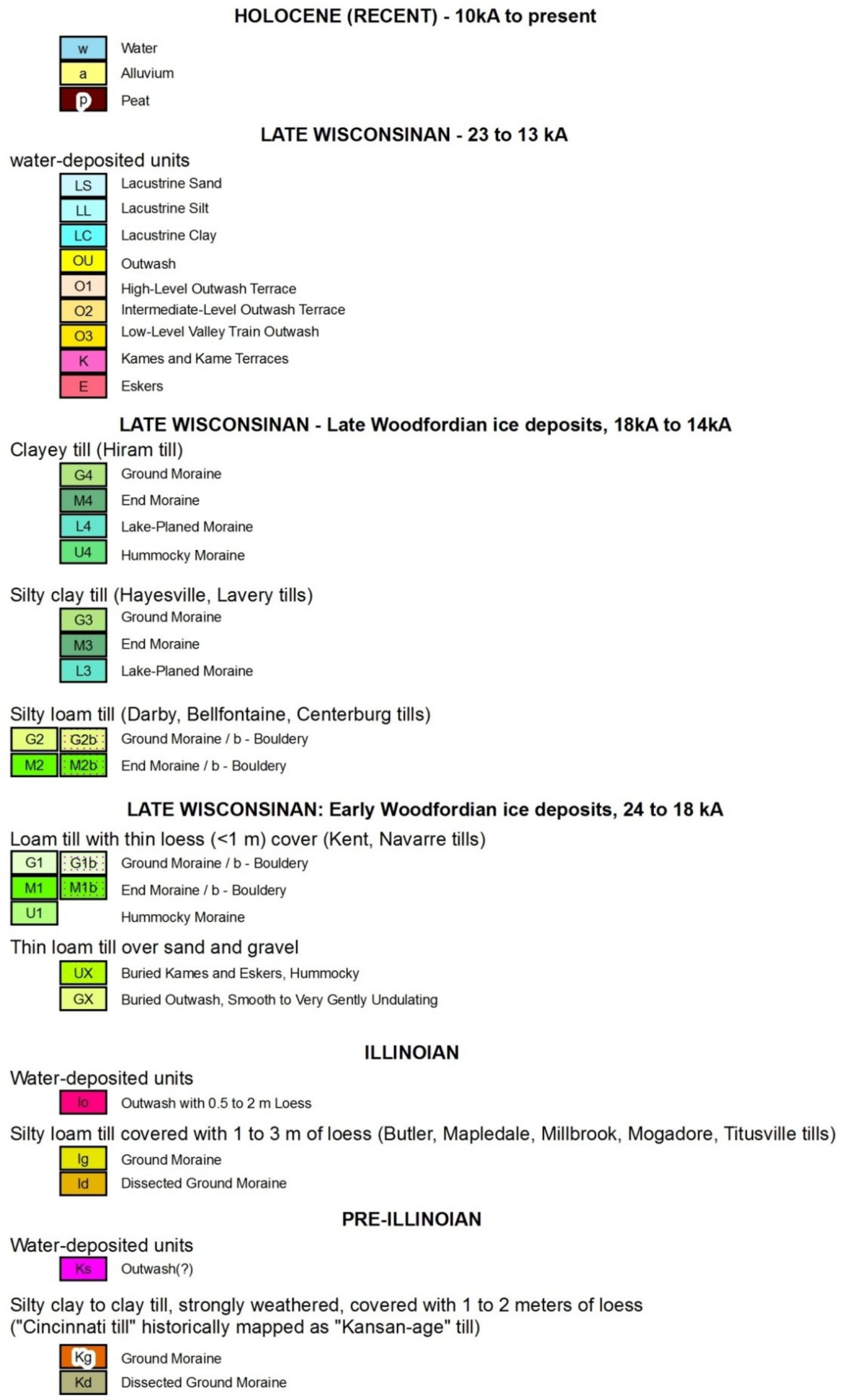
[56] http://seamless.usgs.gov/website/seamless/viewer.htm



Appendix 6a. Quaternary geology map of the Great Miami Basin from Pavey et al. (1999). Legend on following page (**Appendix 6b**).



HOLOCENE (RECENT) - 10kA to present

w	Water
a	Alluvium
p	Peat

LATE WISCONSINAN - 23 to 13 kA

water-deposited units

LS	Lacustrine Sand
LL	Lacustrine Silt
LC	Lacustrine Clay
OU	Outwash
O1	High-Level Outwash Terrace
O2	Intermediate-Level Outwash Terrace
O3	Low-Level Valley Train Outwash
K	Kames and Kame Terraces
E	Eskers

LATE WISCONSINAN - Late Woodfordian ice deposits, 18kA to 14kA

Clayey till (Hiram till)

G4	Ground Moraine
M4	End Moraine
L4	Lake-Planed Moraine
U4	Hummocky Moraine

Silty clay till (Hayesville, Lavery tills)

G3	Ground Moraine
M3	End Moraine
L3	Lake-Planed Moraine

Silty loam till (Darby, Bellfontaine, Centerburg tills)

G2	G2b	Ground Moraine / b - Bouldery
M2	M2b	End Moraine / b - Bouldery

LATE WISCONSINAN: Early Woodfordian ice deposits, 24 to 18 kA

Loam till with thin loess (<1 m) cover (Kent, Navarre tills)

G1	G1b	Ground Moraine / b - Bouldery
M1	M1b	End Moraine / b - Bouldery
U1		Hummocky Moraine

Thin loam till over sand and gravel

UX	Buried Kames and Eskers, Hummocky
GX	Buried Outwash, Smooth to Very Gently Undulating

ILLINOIAN

Water-deposited units

Io	Outwash with 0.5 to 2 m Loess

Silty loam till covered with 1 to 3 m of loess (Butler, Mapledale, Millbrook, Mogadore, Titusville tills)

Ig	Ground Moraine
Id	Dissected Ground Moraine

PRE-ILLINOIAN

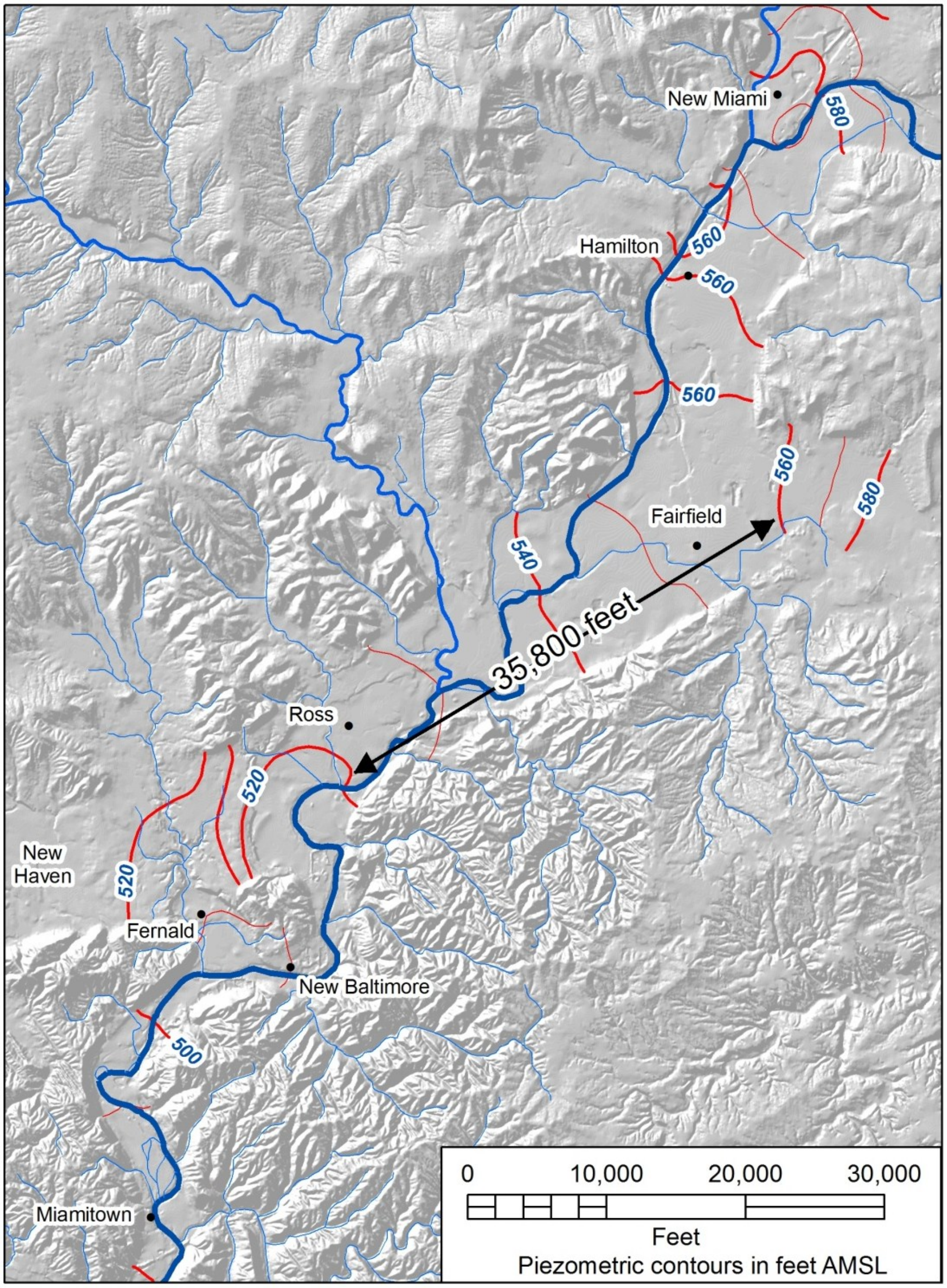
Water-deposited units

Ks	Outwash(?)

Silty clay to clay till, strongly weathered, covered with 1 to 2 meters of loess
("Cincinnati till" historically mapped as "Kansan-age" till)

Kg	Ground Moraine
Kd	Dissected Ground Moraine

Appendix 6b. Legend for **Appendix 6a**, Quaternary map of Ohio



Appendix 7. The horizontal distance between the 560-foot piezometric contour near Fairfield and the 520-foot piezometric contour near Ross is ~35,800 feet, therefore the hydraulic gradient is roughly 0.00112. Using Spieker's (1968a) range of transmissivities and thicknesses for Hydrologic Environment I-A-1: 300,000 – 500.000 gallons/day/foot (40,100 – 66,800 ft^2/day) and 150 – 200 feet respectively, the hydraulic conductivity is between 267 and 334 feet/day so the specific discharge is between 0.267 and 0.334 feet/day. Assuming a porosity range of 25% to 30%, the average pore velocity is between 1.49 to 0.996 feet/day. At this velocity, it would take between 65.6 and 98.4 years to travel the distance of the line. This assumes, however, a steady-state piezometric surface.

Appendix 8

Measurement Methods for Seepage and Conductance of Bed Materials

A considerable effort has been made to better understand the exchange between ground water and surface water (*i.e.,* stream, lake, or ocean). The most direct measurement technique uses a seepage meter developed by Lee (1977) and Lee and Cherry (1979) employing the upper section of a 55-gallon drum connected to a partially filled, flexible reservoir (usually, but not exclusively, a plastic bag (Figure A-8). The upper section of the drum is pushed into the sediment and the volume of water gained or lost into the reservoir is divided by the drums cross-sectional area to calculate the seepage velocity.

Lee developed the flow meter for studying the exchange of water in a lacustrine environment. Problems arise in its use in fluvial or littoral environments with significant currents where the bag is subject to movement in the current and divergence of the current around the apparatus causes pressure changes as a result of the Bernoulli effect (*e.g.,* Belanger and Montgomery, 1992; Shinn *et al.,* 2002; Cable *et al.,* 2006; etc.). Rosenberry (2008) offers modification of the basic seepage meter giving the apparatus a lower profile and protecting the reservoir bag from currents.

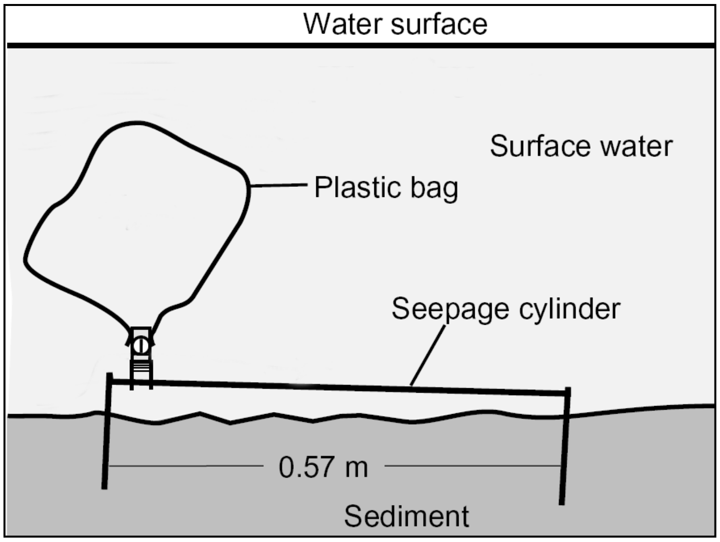


Figure A-8-1. Basic seepage meter (Lee, 1977) made from the top of a 55-gallon drum (from Rosenberry, 2008).

Belanger and Montgomery (1992), Taniguchi and Fukuo (1993), Isiorho and Meyer (1999), Schincariol and McNeil (2002), Murdoch and Kelly (2003) document the significant influence the type of reservoir bag has on the measured seepage. Taniguchi and Fukuo (1993) developed a seepage meter in which the reservoir is replaced with a very accurate flow meter making the bag unnecessary.

Other methods for measuring seepage or channel bottom conductivity use drive-point piezometers[57] or similar devices as *in situ* mini-permeameters (*e.g.,* Landon *et al.,* 2001; Murdoch and Kelly, 2003; Conant, 2004; Yamada *et al.,* 2005; Wojnar *et al.,* 2008, Chen *et al.,* 2009; etc.) or for slug tests (*e.g.,* Landon, *et al.,* 2001; Conant, 2004; Levy, *et al.,* 2005a; etc.). Landon *et al.,* (2001), Conant (2004), Levy *et al.* (2005b and 2006), Mutiti *et al.*(2006), Keery *et al.,* (2007), Essaid, *et al.,* (2008), Huntsman *et al.,* (2008) and others have used heat flow models and thermistor arrays to determine seepage indirectly.

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[57] E.g., http://www.solinst.com/Prod/601/601.html

All of the direct methods of streambed seepage and conductivity involve disturbing the system being measured by driving or drilling in seepage meters, piezometers, or thermistor arrays (*e.g.*, Yamada *et al.,* 2005; and Cable *et al.,* 2006) which will change the measured values particularly in courser grained materials such as the riverbed materials of Great Miami River. Sheets and Dumouchelle (2009) indirectly assess channel bed conductivity with boat-mounted geophysical instrumentation for continuous seismic, resistivity, and electromagnetic profiling. There is not, however, a clear functional relation between these geophysical parameters and streambed conductance.

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