ABSTRACT

TEMPORAL VARIABILITY OF RIVERBED HYDRAULIC CONDUCTIVITY ALONG THE GREAT MIAMI RIVER, SOUTHWEST OHIO: A CONTINUANCE OF DATA GATHERING AND INSTRUMENTATION

by Britton Windeler

A year-long practicum was undertaken to continue the investigation of riverbed scour and deposition at a site on the Great Miami River. Data were gathered by conducting falling and rising head slug tests, surveying, drilling wells, and measuring change in riverbed thickness as a result of sediment scour and deposition. Results indicated riverbed hydraulic conductivity values ranging from 1.1 to 28.9 ft/day to a measured depth of 4 ft, with aquifer hydraulic conductivity values ranging from 75 to 453 ft/day at depths from 22 to 41 ft. Maximum measured difference between deposition and scour in the riverbed was 1.70 ft. Scour measurements indicate an “armored layer” in the riverbed sediment which is scoured away only during extremely high-flow (flood) events.
TEMPORAL VARIABILITY OF RIVERBED HYDRAULIC CONDUCTIVITY ALONG THE GREAT MIAMI RIVER, SOUTHWEST OHIO: A CONTINUANCE OF DATA GATHERING AND INSTRUMENTATION

A Practicum Report

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TABLE OF CONTENTS

I. Introduction ..................................................................................................................... 1

II. Site Description ............................................................................................................. 7

III. Methods ......................................................................................................................... 9
    A. Load Cells .................................................................................................................. 9
    B. River Stage ............................................................................................................... 12
    C. Velocity Sensor ........................................................................................................ 12
    D. Monitoring Wells ..................................................................................................... 13
    E. Slug Tests ................................................................................................................. 15
       1. Rising Head Slug Tests ......................................................................................... 15
       2. Falling Head Slug Tests ........................................................................................ 16
    F. Channel Cross Section .............................................................................................. 17

IV. Results and Discussion ............................................................................................... 17
    A. Riverbed Scour ......................................................................................................... 17
       1. November-December 2005 ................................................................................... 20
       2. January-February 2006 ........................................................................................ 21
       3. March-April 2006 ................................................................................................. 23
       4. May-June 2006 ...................................................................................................... 24
       5. Lower Scour Limit ................................................................................................ 25
    B. Hydraulic Conductivity ............................................................................................ 26
    C. Channel Migration .................................................................................................... 29

V. Conclusions .................................................................................................................. 30
    A. Regulation ................................................................................................................ 30
    B. Future Study ............................................................................................................. 31

VI. References ................................................................................................................... 32

VII. Appendix A. Verification of load cell results............................................................... 36
LIST OF TABLES

1. Contaminant removal methods ........................................................................... 4
2. Physical contaminant removal costs ................................................................ 5
3. Common wastewater pharmaceutical contaminants ...................................... 6
4. Rising head slug test results ........................................................................... 27
5. Falling head slug test results .......................................................................... 28
# LIST OF FIGURES

1. Charles M Bolton wellfield ............................................................................. 8
2. Great Miami River watershed .......................................................................... 8
3. Emplacing load cells ....................................................................................... 9
4. Campbell Scientific datalogger ....................................................................... 10
5. Roctest vibrating wire total pressure cell ....................................................... 10
6. Verification of load cell data .......................................................................... 11
7. Geotivity VMT velocity probe and signal converter ...................................... 12
8. Using hollow stem drilling to emplace monitoring wells .............................. 14
9. Schematic of 6D well nest ............................................................................. 14
10. Rising head slug test apparatus ................................................................... 16
11. Load cell and level logger schematic ............................................................. 18
12. River stage and load-cell recorded scour Nov 2005 to Jun 2006 ................ 19
13. Load cell results Nov-Dec 2005 .................................................................. 20
14. Load cell results Jan-Feb 2006 ..................................................................... 21
15. River debris impact on load cell observations .............................................. 22
16. Load cell results Mar-Apr 2006 .................................................................. 23
17. Load cell results May-Jun 2006 .................................................................. 24
18. Riverbed armor layer .................................................................................... 26
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Finally, I owe a special thanks to my wife Angelea for her love, friendship, and patience in listening to my stories about riverbed scour and “that cold damn river.”
This practicum is a contribution to an ongoing project to investigate riverbed hydraulic conductivity in the Great Miami River near the Charles M Bolton water plant in Harrison, OH. Specifically, a continuation of a study to determine effects of flooding and resultant riverbed scour on riverbank filtration (RBF) was completed by measuring the amount of riverbed scour and riverbed hydraulic conductivity. Measurements were taken in the field, and the data were analyzed using a variety of methods. These measurements include:

- Driving wells in the riverbed and on shore
- Performing rising and falling head slug tests on these wells to determine aquifer hydraulic conductivity
- Performing surveying
- Using load cell sensors to determine amount of scour
- Emplacing and maintaining various instruments
- Collecting data from a variety of emplaced instruments
- Testing validity of instrument data

I. Introduction

Riverbank filtration is a method to remove impurities from surface water by pumping groundwater from a well located close to the surface water. This allows the surface water to recharge the groundwater aquifer. As the water passes through the porous material of the aquifer, biological and chemical contaminants are attenuated by physical, chemical and/or biological processes. The purpose of this practicum is to add information to a research project currently being conducted on RBF at the Great Miami River near the Charles M Bolton water plant in Harrison, OH.

Riverbank filtration is not a new idea. It is mentioned in Exodus 7:24: “And all the Egyptians made holes round about the Nile to get drinking-water, for they were not able to make use of the Nile water.” RBF has been common in Europe for more than 130 years (Schubert, 2002), and although it has not been prevalent in the US, it is gaining in
popularity. In the United States bank filtration systems have only existed for the past 50 years (Ray, 2002).

US state and federal regulations regarding public water supplies are being written and revised to take riverbank filtration into account in determining what treatment processes public water utilities are required to implement. There is significant concern regarding introduction of contaminants to public water supplies, with an emphasis on Cryptosporidium bacteria (USEPA, 2005). To date, the USEPA has not fully acknowledged RBF for use as the primary filtration process because of a lack of understanding of its ability to remove Cryptosporidium (Gollnitz, 2005). However, in most applications RBF has been proven to be very effective in filtering out surface water contaminants, including Cryptosporidium. A study in Finland found that RBF reduced up to 87% of high-molecular-weight organic materials (Ray, 2002). In 1995, a study in Louisville found that water reaching a well 30 ft. from the river’s edge experienced a 60% reduction in total organic carbon (Ray, 2002). Riverbank filtration has also been found to be highly effective in filtering out particles, bacteria, viruses, and parasites (Kuehn, 2002). A study by Gollnitz (2005) in Wyoming found that RBF as the primary treatment source resulted in up to 4.0 log (99.99%) reduction in algae and diatoms and at least 2.0 log (99%) reduction in both Giardia and Cryptosporidium surrogates (no Giardia or Cryptosporidium were found in the samples) (Gollnitz, 2005).

In addition to filtering out contaminants, RBF has the ability to compensate for “shock loads.” RBF reduces the effect of a concentration peak due to, for example, a chemical spill in the river. This is due to the varying transport times for each water molecule from the river to the well. “Blending” of RBF water with groundwater may also dilute contaminants (Kuehn, 2000).

The issue is that RBF systems are classified by the USEPA as ground water under the direct influence of surface water (GWUDI). Historically, despite the inherent benefits of RBF, GWUDI has been regulated the same (i.e., required the same treatment processes) as surface water. Current regulations promulgated in 2006 grant a 1.0 log credit for use of RBF, depending on certain criteria (USEPA, 2005). In other words, significant treatment of RBF-derived water is still required to remove, kill, or inactivate Cryptosporidium, despite aforementioned studies that found RBF accomplishes this. Another option has been
for public water utilities to demonstrate on a case-by-case basis the efficacy of their RBF systems in removing these pathogens. A conditional 2.0 log reduction credit was granted to the Central Wyoming Regional Water System as the result of a two-year study to demonstrate the effectiveness of RBF (Gollnitz, 2005). One difficulty for public water utilities wishing to utilize RBF as an alternative to other treatment methods is that these studies can be lengthy and costly.

In addition to effectiveness in reducing pathogens in public water supplies, RBF has several other advantages over other water supply methods. One benefit over groundwater not in proximity with surface water is recharge. It is not uncommon for typical groundwater pumping methods to deplete aquifers. The Ogalalla aquifer provides water for about 20% of the irrigated land in the United States (Epstein, 1999). Although this aquifer is not uniform in discharge and recharge rates, overall groundwater levels have been falling since the 1940’s due to groundwater pumping. Lowered groundwater levels can result in increased pumping and drilling costs, diminished groundwater quality, land subsidence, salt water encroachment, and eventual loss of an aquifer. Current groundwater mining practices are not sustainable in many cases.

Riverbank filtration has the benefit of rapid groundwater recharge from adjacent bodies of surface water. The residence time of bank filtrate may be anywhere from 5 to 100 days (Kuehn, 2000), depending on the distance between the well and the surface water. The closer the well is to the surface water, the more the well can take advantage of induced infiltration. This results in little or no drawdown in aquifer levels.

Overall water quality is also improved with the use of RBF as a result of reduced treatment methods. RBF reduces the amount of treatment required to make surface water safe for drinking. Chlorination is one of the main methods used by public water providers to disinfect water. Due to the increased quality of RBF water over surface water, RBF water requires less chlorination. This has the benefit of reducing the amount of harmful chemicals in public water formed as a byproduct of chlorination. Two common byproducts of chlorination include trihalomethanes (THMs) and haloacetic acids (HAAs) (Ray, 2002). The USEPA lists these chemicals as causing an increased risk of cancer, as well as liver, kidney or central nervous system problems (USEPA, 2003). In a 1995 study in Louisville, KY, researchers found that THMs and HAAs in treated RBF water were less than 50% of
that found in treated river water (Ray, 2002). Table 1 lists several contaminants common in river water, typical treatment solutions, and the processes by which RBF reduces or eliminates the need for these treatments.

<table>
<thead>
<tr>
<th>River Water Contaminant</th>
<th>Bank Filtration</th>
<th>Engineering Treatment Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>Nitrification</td>
<td>Oxidation (chlorine or stripping)</td>
</tr>
<tr>
<td>Nitrate</td>
<td>Denitrification</td>
<td>Flocculation</td>
</tr>
<tr>
<td>Misc. Inorganic Compounds</td>
<td>Adsorption, precipitation, ion exchange</td>
<td>Flocculation</td>
</tr>
<tr>
<td>Organic Compounds</td>
<td>Biological Degradation</td>
<td>Oxidation, flocculation</td>
</tr>
<tr>
<td>Particles</td>
<td>Filtration</td>
<td>Flocculation, filtration, membranes</td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Adsorption, filtration</td>
<td>Disinfection, membranes, filtration</td>
</tr>
<tr>
<td>Persistent compounds</td>
<td>None</td>
<td>Adsorption, oxidation</td>
</tr>
</tbody>
</table>

*From Kuehn, 2002*

Riverbank filtration also makes sense from a purely economic standpoint. A study performed in the Central Wyoming Regional Water System found that the use of RBF saved the local public water utility $15 to $20 million (Gollnitz, 2005). Without RBF, the utility would have had to construct a new water treatment plant as demand increased. The USEPA has found that RBF is the most economical method for physical removal of contaminants for almost all size public water utility operators except for the very smallest (USEPA, 2005) (Table 2, below). However, due to insufficient data the USEPA study assumes plants less than 0.6 million gallons per day (mgd) in design flow incur the same costs as a 0.6 mgd plant. Costs for plants with greater than 0.6 mgd were calculated assuming a linear cost versus design flow function. It is entirely possible that RBF is the most economical option even for the smallest public water utilities.
Table 2: Physical contaminant removal costs ($ per kgal)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Design Flow (mgd)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Bag Filters*</td>
<td>$0.17</td>
</tr>
<tr>
<td>Cartridge Filters*</td>
<td>$0.28</td>
</tr>
<tr>
<td>Microfiltration/Ultrafiltration</td>
<td>$3.96</td>
</tr>
<tr>
<td>Pre-sedimentation</td>
<td>$3.22</td>
</tr>
<tr>
<td>Second stage filtration</td>
<td>$3.74</td>
</tr>
<tr>
<td>Watershed control</td>
<td>$10.05</td>
</tr>
<tr>
<td><strong>Riverbank filtration</strong></td>
<td><strong>$0.28</strong></td>
</tr>
</tbody>
</table>

Note: * considered options only for small systems

From USEPA Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule, 2005

Riverbank filtration is not a panacea. Although it reduces the amount of water treatment necessary over that of surface water, some treatment must still occur. There are some compounds that RBF does not have the ability to remove from surface water. Additionally, the right geological conditions need to exist to implement a successful RBF system.

Pharmaceutically active compounds (PhAC’s) are a common surface water contaminant. Most sewage treatment plant processes are ineffective at significantly reducing PhAC concentrations in effluent that is discharged into rivers (Grischek, 2002). Table 3 shows some common PhAC’s present in wastewater from a study conducted in Berlin. This study evaluated the effectiveness of RBF in filtering out many of these PhAC’s, and found measurable concentrations in water at several plants. The researchers determined that, for several compounds listed in Table 3, RBF was ineffective at reducing contaminant levels much below that found in surface water. However, the RBF water was always lower in concentration than the surface water (Heberer, 2002). The authors were careful to point out that these levels of PhAC’s have not been demonstrated to be harmful to humans. However, detectible concentrations of these compounds are undesirable, and wastewater discharge locations need to be carefully planned (i.e, not upstream of public water supplies).
Table 3: Common Wastewater Pharmaceutical Contaminants

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Use/origin</th>
<th>Influent concentration in µg/l</th>
<th>Effluent concentration in µg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aminophenazone</td>
<td>Analgesic/antiinflammatory</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Not identified because of potential legal ramifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>Anticonvulsant</td>
<td>1.78</td>
<td>1.63</td>
</tr>
<tr>
<td>Clofibric acid</td>
<td>Active metabolite of lipid regulators</td>
<td>0.46</td>
<td>0.48</td>
</tr>
<tr>
<td>Diclofenac</td>
<td>Analgesic/antiinflammatory</td>
<td>3.02</td>
<td>2.51</td>
</tr>
<tr>
<td>Gemfibrozil</td>
<td>Blood lipid regulator</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>Analgesic/antiinflammatory</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Indomethacine</td>
<td>Analgesic/antiinflammatory</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Ketoprofen</td>
<td>Analgesic/antiinflammatory</td>
<td>0.3</td>
<td>0.23</td>
</tr>
<tr>
<td>Naproxen</td>
<td>Analgesic/antiinflammatory</td>
<td>0.44</td>
<td>0.08</td>
</tr>
<tr>
<td>Oxazepam</td>
<td>Neuroleptics</td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td>Phenazone</td>
<td>Analgesic</td>
<td>0.92</td>
<td>0.52</td>
</tr>
<tr>
<td>Phenobarbital</td>
<td>Barbiturate, anticonvulsant, major metabolite of primidone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenytoine</td>
<td>Anticonvulsant</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Primidone</td>
<td>Anticonvulsant</td>
<td>1.08</td>
<td>0.14</td>
</tr>
<tr>
<td>Propyphenazone</td>
<td>Analgesic/antiinflammatory</td>
<td>1.08</td>
<td>0.39</td>
</tr>
<tr>
<td>Sulphadiazine</td>
<td>Sulphonamide</td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>Sulphamethizole</td>
<td>Sulphonamide</td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Sulphamethoxazole</td>
<td>Sulphonamide</td>
<td></td>
<td>0.90</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Fecal sterol</td>
<td>200</td>
<td>6.75</td>
</tr>
<tr>
<td>Coprostanol</td>
<td>Fecal sterol metabolite of cholesterol</td>
<td>1430</td>
<td>3.2</td>
</tr>
<tr>
<td>Sitosterol</td>
<td>&quot;Phytoestrogen&quot;</td>
<td>15.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Salicylic acid</td>
<td>Primary metabolite of acetylsalicylic acid, keratolytic, dermatrice, preservative of foods</td>
<td>0.34</td>
<td>0.04</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Beverages, drugs</td>
<td>230</td>
<td>0.18</td>
</tr>
</tbody>
</table>

From Heberer, 2002.

There are several other chemical compounds that RBF is not effective in filtering out. Nitrosamines are among the most toxic and carcinogenic compounds known (cancer risk is increased at human ingestion levels of only 0.0008 µg/L) (USEPA, 2003). Conventional water treatment processes, including RBF, are poor at removing these compounds (Kuehn 2005).

Careful engineering design needs to ensure that water flowing from rivers to pumping wells has a long enough flowpath that it receives the benefits of riverbank filtration. USEPA regulations state that surface water must have at least a 25’ flowpath to the RBF well collection screen for a 0.5-log credit, and a 50’ flowpath for a 1.0-log credit (USEPA, 2005).

Some of the USEPA reluctance to grant increased credit for RBF may be due to concern regarding whether hydraulic conductivity (and filtering effectiveness) of rivers are significantly affected during flooding events. During low-flow events (most of the year), fine sediment is deposited in riverbeds. Because of its fine grain size, this sediment has a
low hydraulic conductivity, long residence times for transient water, and the ability to filter out many types of contaminants. This study is investigating if during flood events this fine sediment is scoured away, greatly increasing infiltration of river water into the aquifer below.

II. Site Description

The study area for this project lies in the wellfield for the Charles M Bolton water plant in Harrison, OH, on the bank of the Great Miami River (Figure 1). The wellfield lies in a glacial-outwash, buried-valley aquifer and comprises 10 municipal wells supplying 12% of the water for the City of Cincinnati (Levy, 2006). The aquifer is 1.5-2.0 miles wide and between 80 to 185 ft deep (Gollnitz, 2003). Between 15 to 30 million gallons per day (mgd) are withdrawn from the wellfield (Gollnitz, 2003). The watershed for the Great Miami River drains 5,702 square miles, of which 80% is used for agriculture (Figure 2) (MCD, 2005). The mean daily discharge for the Great Miami River as recorded at the Hamilton gauging station (approximately 6 miles upstream of the Bolton site) over the past 67 years is 3419 ft³/sec, with a standard deviation of 1216 ft³/sec. Values for hydraulic conductivity for the aquifer range from 200 to 400 ft/day (Gollnitz, 2003).
Figure 1. The study area was centered around the observation well labeled 6B. Modified from Birck, 2006.

Figure 2. The Great Miami River watershed. From MCD, 2006.
III. Methods

A. Load Cells

In order to directly measure the amount of scour that occurs as a result of high-stage (i.e., flood) events, two Roctest vibrating wire total pressure cells (henceforth called load cells) were emplaced in the river near observation well 6B. One of these load cells (s/n 5292) was emplaced prior to the start of this practicum, in November 2005. A second load cell (s/n 6047) was emplaced in August 2006 (Figure 3). These load cells are connected to a Campbell Scientific CR-10X datalogger placed on a pole approximately 10 ft above the land surface (Figure 4). These load cells measure total pressure applied to the pressure pad (Figure 5), and output this information to the datalogger. The load cells also have an integrated thermistor.

Figure 3. Partially excavated load cell trench during period of extreme low flow. Note bin used for load cell calibration in background.
The load cells were buried in trenches dug in the riverbed during periods of low river flow. These trenches were approximately 1.5 ft deep, and medium-grained sand was used to line the trenches in order to avoid measurement error from large pebbles or cobbles impacting the surface of the load cells. Medium-grained sand was also used to cover the load cells.

These oil-filled vibrating wire pressure sensors were designed to be used in high-pressure situations, such as buried in concrete underneath a dam. They can withstand
pressures up to 7000 kPa (1015 psi). There was some concern regarding the sensitivity of the load cells to minute changes in pressure as a result of riverbed scour. In order to verify the accuracy of the data, in June 2005 load cell s/n 5292 was excavated, placed in a 45-gallon plastic storage container, and covered in increasing amounts of water. A Solinst Levelogger and In Situ Mini-Troll were also placed in the container to compare depth measurements with load cell reported pressure. After the storage container was full of water, the load cell was covered in 6” of sediment from the riverbed in order to compute wet bulk density of the riverbed sediment (Appendix A).

Additional tests were run on load cells s/n 6046 and 6048 in June 2006 in order to verify accuracy of data from future experiments (Appendix A). Load cells s/n 6046 and 6048 were placed in a large plastic water tank at Miami University’s Ecology Research Center (ERC), along with a Solinst Levelogger and an In Situ Mini-Troll (Figure 6). A similar experiment was performed in July 2006 with load cell s/n 6047 in a large bathtub in order to verify accuracy of load cell data. Load cell s/n 6047 was subsequently buried in the riverbed 10 ft closer to the center of the channel than s/n 5292.

Figure 6. Load cells were tested under controlled conditions alongside a Solinst Levelogger and an In Situ Mini-Troll in order to verify accuracy of pressure data.
B. River Stage

The load cells measure total pressure above them. In order to determine changes in weight of sediment as a result of riverbed scour, the weight of overlying river water needed to be subtracted. This river stage was measured using a Solinst levelogger placed in a wire cage at the bottom of a fencepost in the riverbed. This stage data were then subtracted from the load cell observations.

C. Velocity Sensor

A GEOTIVITY Velocity Sensor VMT-2 probe and accompanying signal converter (Figure 7) was emplaced approximately 3 ft downstream of load cell s/n 6047 and 6 inches above the bottom of the riverbed in November 2006. This sensor measures water velocity by measuring the Doppler shift of an ultrasonic signal generated by the probe. The probe was mounted to a fencepost by Miami University’s Instrumentation Lab and placed perpendicular to river flow in order to measure current velocity with the ultimate goal of correlating river velocity, river stage, and riverbed scour. The signal converter was connected to the Campbell CR-10X datalogger.

![Figure 7. Geotivity VMT velocity probe and signal converter.](image)

One obstacle to emplacing the probe is that the velocity signal reported by the probe is sent to the signal converter in volts. The signal converter then converts this signal to a modulating frequency and sends it to the CR-10X datalogger. A fixed length of cable with a known resistance transmits the signal from the probe to the signal converter. This
cable cannot be lengthened without affecting the accuracy of the measurement. The included cable length was 50 ft, which was not long enough to place the probe in the desired spot in the river and have the signal converter above flood stage. It was decided to enclose the signal converter in a watertight box and bury it in the riverbank. A cable was then run from the signal converter to the CR-10X datalogger. Since this cable transmits data via modulating frequency and not voltage, maximum length was irrelevant.

The velocity sensor was emplaced at the end of this practicum; data it recorded are not presented in this report.

**D. Monitoring Wells**

A well nest of three monitoring wells was emplaced between 3 and 4 March, 2006. This well nest, labeled 6D in Figure 1, was constructed by hollow-stem auger drilling using a drill rig belonging to the Department of Geology (Figure 8). The three wells were drilled to depths of 22.4 ft, 27.6 ft, and 41.6 ft. The shallower well was screened from the bottom to 5 ft of the bottom, while the two deeper wells were screened from the bottom to 1 ft of the bottom (Figure 9). These wells were constructed to conduct a study of aquifer hydraulic conductivity via slug tests and temperature modeling, as well as a future virus-transport study.
Figure 8. Using hollow-stem drilling to emplace monitoring wells.

Figure 9. Schematic of 6D well nest.
One week after emplacement of the wells it became apparent that sediment was entering through the well screens of the two deeper wells and causing them to clog. Approximately 2.1 ft of sediment entered well 6D-3; 1.0 ft of sediment entered well 6D-2. In order to remedy this, on 31 April 2006 wells 6D-2 and 6D-3 were surged using a surge rod and then pumped using a gasoline-powered semi-trash pump. This process was repeated several times for each well until there was little or no sediment remaining in the wells.

**E. Slug Tests**

Slug tests were conducted in the 6D well nest, as well as in piezometers driven in to different depths and locations in the riverbed.

1. **Rising Head Slug Tests**

   Rising head slug tests were conducted on the 6D well nest using the pneumatic apparatus shown in Figure 10. This device allows for controlled depression of the water level in the well using compressed air. A Hermit transducer was used to measure the rate at which water refilled the well after release of the pressure. Data were then entered into the program AQTESOLV and the Bouwer-Rice method applied (Bouwer and Rice, 1976) to determine aquifer hydraulic conductivity.
2. Falling Head Slug Tests

In order to determine values for riverbed hydraulic conductivity, a 1 in. diameter piezometer with a 1.5 ft long well screen was manually pounded into the riverbed at three separate locations starting at the position of the load cell and extending 15 ft farther towards the opposite shore for each subsequent test. Three slug tests were conducted at a shallower depth for each location (2 ft deep), and three were taken at a depth of 4 ft. A gradient in the piezometer was created by filling it with river water. Again, a Hermit transducer was used to measure changes in water level and results were analyzed for hydraulic conductivity using the Bouwer-Rice method in AQTESOLV (Bouwer and Rice, 1976).
**F. Channel Cross Section**

In order to quantify channel migration a channel cross section was completed in May 2006 and added to data collected in December 2004, February 2005 and September 2005. A line marked in 20 ft increments was fixed between wells 6B and 6C. River depth was measured using a surveying scope on the bank to read a stadia rod extended to the river bottom by a project member in a rowboat.

**IV. Results and Discussion**

**A. Riverbed Scour**

Using the Roctest load cells, riverbed scour was quantified for the period 21 November 2005 through 6 June 2006. Due to low river levels the load cell was not underwater for the rest of summer 2006, so no data were collected for this period.

The scour was calculated using an assumed wet bulk density for sediment of 2.17 g/cm$^3$. This value for density was verified to be reasonable by measuring the pressure of a known thickness of sediment on top of a load cell in a controlled experiment. This test gave a range of values for sediment density of between 2.04 to 2.20 g/cm$^3$ (Appendix A) (the range of values was due to uncertainty in water depth as measured by the Mini-Troll and the Solinst Levelogger).

In order to calculate riverbed scour, an adjustment had to be made due to the fact that the Solinst Levelogger would record how much water was above it, but not necessarily how much was above the load cell. This was due to the fact that scour would change the amount of sediment above the load cell, but the Levelogger would stay in a constant position above the load cell. This resulted in erroneously low values calculated for height of sediment above the load cell (Figure 11). In order to correct this an iterative solution was employed in the data spreadsheet which allowed data values to converge on the real amount of scour that occurred.
Riverbed scour for several periods is displayed in figure 12. The maximum amount of sediment recorded on the load cell was 2.23 ft; minimum was approximately 1.0 ft. A discussion of riverbed scour broken down over several time periods follows.

**Figure 11.** Due to the fact that the saturated sediment has a higher density than water (approx. 2.17 times as much), a correction was made to load cell data when scour or deposition occurred. In the scenario above, without this correction the load cell on the right would underestimate scour due to the fixed position of the levelogger.
Figure 12. Complete record of river stage and load cell-recorded scour Nov 2005 to Jun 2006. An error in the datalogger program resulted in no data recorded June 5 through June 21, at which point the level of the river was below where the load cell was buried. Additionally, results obtained from 10 through 27 January were not indicative of typical scour due to a large piece of plywood which became lodged against a fencepost directly upstream of the load cell (Figure 15).
1. November-December 2005

The load cell was emplaced 21 November 2005 and immediately started collecting data (Figure 13). The first high-stage event recorded was from 28-30 November. Immediately prior to this, on 26 Nov., approximately 0.5 ft of sediment was deposited on the load cell. This sediment was subsequently scoured away during the flood event.

A data gap is shown from 18-24 December. During this time, the load cell recorded temperatures as low as -1.5 °C. Low flow conditions during this period resulted
in freezing of the riverbed down to the load cell. The low temperatures and possible ice formation in the sediment above the load cell resulted in erroneous readings.

2. January-February 2006

![Figure 14. Load cell sediment height and river stage above load cell, January 1 through February 28, 2006.]

There were several high stage events during the time period shown in Figure 14. Most notable is the difference between the series of events from 11-26 January and the other events. There was a large amount of both scour and deposition recorded from 11-26 January that was not recorded the rest of this time period.

One possible explanation for this scour and deposition is the presence of a 3 ft by 4 ft sheet of plywood that was discovered on 1 February wedged against a fencepost approximately 10 ft upstream of the load cell (Figure 15). This plywood was discovered
with its large surface perpendicular to flow. It is possible that an eddy formed behind the plywood, which resulted in significant scour during this time period. The plywood was removed and no significant scour was observed the duration of this time period.

Figure 15. This large sheet of plywood was found wedged perpendicular to flow approximately 5 ft upstream of the load cell on 1 February. It is possible that this debris caused the unusual scour measurements noted 10-28 January.
3. March-April 2006

![Graph showing river stage above load cell and sediment height.](image)

*Figure 16. Load cell sediment height and river stage above load cell, March 1 through April 30, 2006.*

The highest stage event recorded during this project was between 12-13 March, 2006, with river levels reaching 12 ft above the load cell (Figure 16). The rising limb of this event resulted in approximately 0.4 ft of scour. The flood did not crest until 2100 on 12 March. However, sediment above the load cell actually increased by 0.7 ft from 1200 on 12 March through 1100 on 13 March. It is possible that this apparent increase in sediment thickness during the rising limb of the flood was actually caused by large cobbles or other debris being transported on the riverbed over the load cell by the large amount of flow.
4. May-June 2006

The period shown in Figure 17 represents the last load cell data collected during this project. A programming error resulted in no data collected from 5 June through 21 June, at which point the river was at baseflow and no water was flowing over the load cell.

The fluctuations on the rising limbs in Figure 17 are daily, possibly due to temperature fluctuations. A regression analysis of change in temperature and change in sediment height was conducted, and a significant relationship between the two was noted. The $R^2$ value for a fitted line plot was 8.5%. This could have some effect on comparisons of sediment height over different seasons. However, changes in sediment height as a
result of high-stage events are still valid, as load cell-recorded temperature did not significantly change during these events.

5. Lower Scour Limit

Data for the period from May through June 2006 (Figure 17) exhibit deposition during periods of low flow, followed by scour due to small-scale flood events. It appears there is a lower limit for scour (approx. 1.1 ft above the load cell), above which sediment is transient. The second event in Figure 17 (starting 17 May), while larger than the event starting 11 May, does not result in any significant scour. This could be due to the fact that the May 11 event scoured the sediment down to some lower limit below which sediment is mobile only in times of extremely high flow. This lower limit for scour can also be seen starting 20 January. During the duration of this project only the large flood event in March resulted in scour below the 1.3 ft limit, with two exceptions. The series of events from 10-28 January were likely caused by the piece of plywood shown in Figure 15. Additionally, one reading on 8 March indicated that sediment height went from 1.16 ft at 1 AM, to 0.97 ft at 2 AM, and back to 1.15 ft at 3 AM. It is possible that an error in the load cell or Solinst Levelogger resulted in this measurement.

This layer resistant to scour is likely the “riverbed armor” described by Schubert (2002) (Figure 18). It is likely that fine sediment trapped in this armor layer causes “clogging”, resulting in a low hydraulic conductivity in the riverbed. It is also possible that this armor layer protects the finer sediment beneath, resulting in a low overall K value for the riverbed.
Figure 18. The riverbed armor layer is resistant to scour during all but the highest flow regimes. The intermediate conductivity layer represents the hydraulic conductivity measured in the riverbed; the high conductivity layer represents that measured in the wells driven into the aquifer. Modified from Schubert (2002).

**B. Hydraulic Conductivity**

Pneumatic rising head slug tests at well 6D on 4 May 2006 (described above) yielded results for hydraulic conductivity shown in Table 4. An anisotropy ratio of 0.5 was assumed for these analyses. Best estimates took into account fit of data to Bouwer-Rice curves. Error in measurements could have been due to turbulence in inflowing water, especially for the first four tests for well P6D-3. Excessive displacement in these tests could have resulted in turbulent flow of water back into the wells. This would have caused inflow to take longer than with laminar flow, resulting in abnormally low values for hydraulic conductivity.
### Table 4: Rising head slug test results

<table>
<thead>
<tr>
<th>Well</th>
<th>Well screen length (ft)</th>
<th>Well depth (ft)</th>
<th>Displacement (ft)</th>
<th>K (ft/day)</th>
<th>K (m/day)</th>
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<tr>
<td>P6D-1</td>
<td>5</td>
<td>22.4</td>
<td>1.8</td>
<td>368</td>
<td>112</td>
</tr>
<tr>
<td>P6D-1</td>
<td>5</td>
<td>22.4</td>
<td>2.3</td>
<td>433</td>
<td>132</td>
</tr>
<tr>
<td>P6D-1</td>
<td>5</td>
<td>22.4</td>
<td>2.3</td>
<td>453</td>
<td>138</td>
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<td></td>
<td><strong>Best estimate for P6D-1:</strong></td>
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<td></td>
<td><strong>420</strong></td>
<td><strong>127</strong></td>
</tr>
<tr>
<td>P6D-2</td>
<td>1</td>
<td>26.7</td>
<td>10.2</td>
<td>92</td>
<td>28</td>
</tr>
<tr>
<td>P6D-2</td>
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<td>26.7</td>
<td>10.4</td>
<td>75</td>
<td>23</td>
</tr>
<tr>
<td>P6D-2</td>
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<td>26.7</td>
<td>4.8</td>
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<td>33</td>
</tr>
<tr>
<td>P6D-2</td>
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<td>4.1</td>
<td>94</td>
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<td><strong>Best estimate for P6D-2:</strong></td>
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<td></td>
<td><strong>100</strong></td>
<td><strong>30</strong></td>
</tr>
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<td>15.9</td>
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<tr>
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<td>16.3</td>
<td>83</td>
<td>25</td>
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<tr>
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<td>41.6</td>
<td>16.1</td>
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<td></td>
<td><strong>150</strong></td>
<td><strong>46</strong></td>
</tr>
</tbody>
</table>

Falling head slug tests conducted in the riverbed on 29 June 2006 yielded results for hydraulic conductivity shown in Table 5. The two different depths indicate different depths to which the piezometer was driven. An anisotropy ratio of 0.5 was assumed for modeling purposes. This range of 100-420 ft/day is in accordance with published values of 200-400 ft/day for aquifer conductivity (Gollnitz, 2003). Despite the fact that the wells were cleaned of clogging sediment, some may have remained, resulting in values for hydraulic conductivity slightly lower than expected.
The difference in hydraulic conductivity between the riverbed and the aquifer approximately 200 ft from the river is apparent when comparing Table 4 with Table 5. The hydraulic conductivity of the riverbed is an order of magnitude less than that of the aquifer. This lends credence to the hypothesis that the riverbed has lower hydraulic conductivity than the aquifer and is important in filtering out contaminants. It is also important to note that the riverbed hydraulic conductivity remained low even at a depth of 4 ft. The difference between the maximum and minimum amount of sediment over the load cell was only 1.8 ft. It is unlikely that, at least at the site where the load cell was emplaced, that the riverbed is ever scoured to a depth of 4 ft.

![Table 5: Falling head slug test results](image-url)
**C. Channel Migration**

Figure 19, below, shows the amount of channel migration that has occurred from December 2004 through May 2006. This shows that net erosion is occurring on the northern bank. During the period measured, the northern bank has migrated more than 40 ft to the north. Additionally, a significant amount of deposition (up to 5 ft) has occurred in the channel directly south of the thalweg. Minimal net scour or deposition has occurred where the load cell is emplaced (at approximately the 100 ft point).

![Cross Sectional Profile Comparison At Site 6](image)

*Figure 19. The cross sectional profile of the river at the test site indicates erosion is occurring on the north (right) side of the river. The load cell is at approximately the 100’ point; little net scour or deposition occurred at this point between Sep 05 and May 06.*
V. Conclusions

A. Regulation

As stated before, an estimated 67 million people in the US could benefit from riverbank filtration. Due to unfavorable geologic conditions or lack of adequate surface water bodies some locations are not suitable for RBF. Several alternatives exist to RBF:

- Surface water treatment- This is common practice in most of the United States. There are several possible methods for treating surface water. As demonstrated in Table 2, all of these alternatives are more costly than RBF. Additionally, many of these alternative treatment methods introduce harmful byproducts into the water supply. Direct pumping of surface is the only option in some locations due to geologic conditions, although RBF could be implemented in many locations that use surface water in order to reduce cost and increase water quality.

- Implementation of water conservation methods. Use of low-flow devices in a three-person residence has been estimated to reduce annual water usage by around 54,000 gallons annually (USEPA, 2006). These devices can save homeowners and businesses money, and can be implemented in conjunction with other methods.

- Increase in groundwater mining. This is not a sustainable alternative.

Riverbank filtration definitely remains a viable option along the Great Miami River. Over the course of this study, minimal riverbed scour was observed. Scour was also observed below a “minimum threshold” only three times during the course of this project, with two of these possibly due to experimental error. Additionally, hydraulic conductivity values were found to be lower in the sediment up to four feet below the riverbed than in other parts of the aquifer. This low-K area in the riverbed extended to a greater depth than would be scoured away due to a high-stage event.

Regulations as promulgated by the USEPA are currently vague regarding RBF. The USEPA currently certifies RBF systems on a case-by-case basis. It can take public
water supply operators a matter of years to demonstrate that their RBF systems are
effective in removing pathogens from water supplies. These regulations need to be
clearer, and the certification process needs to be more streamlined. Additionally, the
USEPA needs to increase treatment credits given to public water utilities based on the
demonstrated efficacy of their RBF systems. In the case of the Charles M Bolton plant,
this study lends credence to the theory that riverbed scour as a result of flood activity
does not significantly affect the filtering effect of the riverbed. This is in accordance with
previous studies on the subject (Gollnitz, 2004).

Riverbank filtration has been in operation for more than a century. It is a proven,
sustainable method for ensuring uninterrupted, high-quality municipal water supplies.
Increased use of RBF in the United States to meet escalating demand is inevitable, and
needs to be encouraged and supported by the proper regulatory framework.

**B. Future Study**

Many facets of this project exist for future study. Deeper slug tests could be
conducted in the riverbed to determine at what depth the hydraulic conductivity becomes
similar to that of other areas of the aquifer. One difficulty with this is the type of
sediment in the riverbed. Many large cobbles exist, which makes emplacement of deep
wells difficult (especially if done by hand).

Another area of interest is seasonality of deposition and scour. It is possible that
there is more deposition during different times of the year than others due to increased
suspended sediment in the river. This might be linked to such things as ground cover,
temperature, or agriculture. A continuance of data collection may reveal such trends.
Additionally, emplacement of a probe that records turbidity would allow for a quantified
measurement of suspended sediment.

Additional load cells placed in the river would give additional credibility to
measurements of scour. Currently, the project has an extra datalogger and several
additional load cells. Placing these in a different location would allow comparison of
scour in different parts of the channel.

Another method to back up the load cell data would be to use sensors that rely on
different methods to measurement to quantify scour. Campbell Scientific sells an
Ultrasonic Distance Sensor (SR-50L) that is accurate to within 1 cm. Placement of one of
these sensors in the river over a load cell would negate any doubt as to the reliability of scour data.

VI. References


VII. Appendix A. Verification of load cell results.

Load cell s/n 5292 bin test

Water added to the bin during this period.

Load cell covered in 6" (0.5') of sand from the river during this period. This yields a density of sand of between 2.04 - 2.2 times that of water.
Load cells s/n 6046 and 6048 tub test

Elapsed time (minutes)

Depth (ft water)

6046 Load Cell
6048 Load Cell
Troll 9000
Solinst