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The Yellow River Water Quality Improvement Project

Prepared for:

Indiana Department of Environmental Management
ARN 00-39

Prepared by:

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and
The City of Plymouth, Indiana

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EXECUTIVE SUMMARY

The City of Plymouth, Indiana received a Section 319 water quality grant from the Indiana Department of Environmental Management to monitor pollutants associated with nonpoint source runoff in the Yellow River watershed and to explore ways to reduce pollutant inputs. This was a follow-up study to previous water quality monitoring done in the watershed.

Several novel monitoring techniques were used. These included sterile sandbags for locating *E.coli* sources, semipermeable membrane devices (SPMDs) for locating PAH sources, and oil detectors for locating oil and grease sources.

The bacteria analyses showed that *E.coli* levels in the river are often quite high, especially during wet weather. The most important sources were upstream from Plymouth. Unsewered areas in Wyatt, Indiana (upstream from Plymouth) combined sewer overflows in Bremen, and areas of livestock production were important sources of bacteria in the watershed.

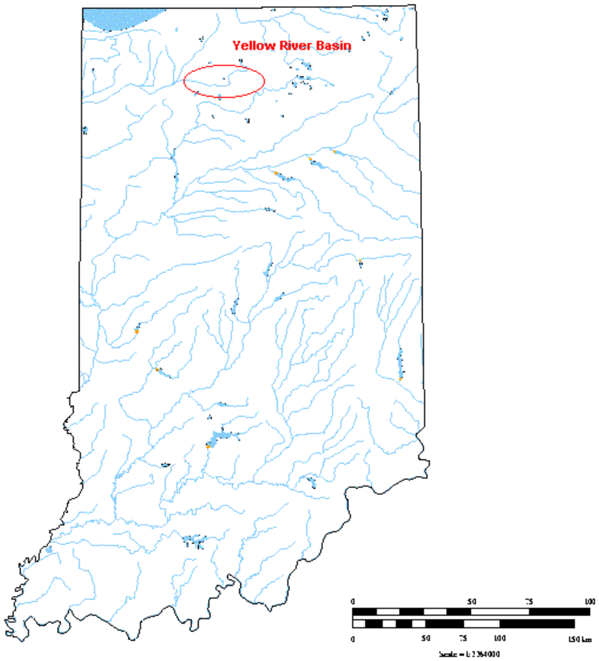
Polycyclic aromatic hydrocarbons (PAH) and oil and grease compounds were present at relatively high levels as well. Schuh Ditch, draining the northern part of Plymouth, was an important source of these chemicals. There are many acres of asphalt streets and parking lots in this industrial area of the city.

Geofabric storm filter inserts were used to trap sediment and oil in Plymouth's urban stormwater. Twelve sites were monitored regularly for a year. Trapped sediment at each site varied from 0.5 to 17 kg per storm event (more than 0.3 inches of rainfall in 24 hours). The average was about 5 kg per storm event. The filters were also successful in trapping oil and grease in stormwater (41 to 95% removal). Efficiency of the filters for removing most PAH compounds was lower (less than 14% for total PAHs). However, removal rates of 25 to 40% were achieved for some PAH components, including benzofluoranthene, which was common in Plymouth stormwater and is potentially toxic to aquatic life at low concentrations.

Regular use of these storm filters within the City of Plymouth could eliminate over 15,000 kg of sediment and associated nutrients and chemicals from entering Yellow River each year at a cost of about $15,000 per year.

Public education materials produced as part of this contract included a project website, two project brochures, and a public meeting.

Recommendations for future directions include (1) continuing the storm filter program, (2) concentrating stormwater control efforts on the Schuh Ditch watershed, (3) considering the use of other best management practices for stormwater cleanup, and (4) working with IDEM and local Soil and Water Conservation Districts to reduce *E.coli* loading from unsewered areas, combined sewer overflows, and livestock.



INTRODUCTION

The Yellow River is a major tributary of the Kankakee River in northern Indiana (Fig. 1). In 1997 the City of Plymouth sponsored a study to measure water quality of the river using three techniques: bacterial analysis, bioassessment, and bioconcentrating substances. The study (Bright, 1997) found that the river's water quality was degraded in some areas by *E. coli* bacteria, by excess sedimentation from urban stormwater sources, and by PAH contamination. A watershed sampling study by the Indiana Department of Environmental Management (McFall, 1990) found water quality problems associated with "semi-public" wastewater dischargers in the area.

Figure 1. The Study Area

The 1997 showed that *E. coli* concentrations were highest in Yellow River upstream from Bremen and in a tributary (Wolf Creek). PAH compounds were highest downstream from urban areas in Bremen and Plymouth. Biotic communities were indicative of excessive sedimentation, especially in Plymouth. Although several pollution "hotspots" within the Yellow River watershed were identified by the first study, the precise sources of contamination were not determined. A follow-up study was needed to zero-in on sources of contaminants and to explore ways to reduce them.

The previous study identified some of the most serious contaminants in the watershed and showed that urban stormwater is a major source of pollutants. In the summer of 2000 the City of Plymouth received a Section 319 water quality grant designed to supplement the first study in two ways:

C Precisely identify the most important sources of contaminants in the watershed (e.g. industrial areas, parking lots, construction sites, residential development, agriculture, etc.)

C Do field trials with storm filters as a way to reduce contaminant levels in urban stormwater

There were four distinct phases in the project. First, identify where pollutant loadings are greatest. Second, install stormwater filters in those areas identified by the first part of the study where the greatest amounts of urban stormwater pollution occur. Third, measure the efficiency of the filters in their ability to remove pollutants (sediment, PAH compounds, and oil and grease). Fourth, educate the community on the results of the study, including potential costs and benefits.

METHODS AND MATERIALS

The project used several novel monitoring techniques. The sterile sandbag technique [2] has been shown to locate important sources of bacteria without repeated sampling. Semipermeable membrane devices (SPMDs) have been used to locate sources of bioaccumulating chemicals [4]. Oil absorbance samplers have been used to locate and quantify sources of oil and grease in stormwater. In addition to these relatively novel monitoring techniques, grab samples of water were collected and analyzed weekly for *E. coli* bacteria. Shown below is a summary of samples taken as part of this project:

Parameter	When	Where	Why
E. coli in water	weekly 100 weeks	Yellow River 3 sites	Provide instream data above and below urban influence under various flow and weather regimes.
E. coli in sandbags	summer 1 time	Yellow River 10 sites	Determine most important sources of bacteria at many locations using a single sampling device and single monitoring period
PAH in SPMDs	summer 1 time	Yellow River 8 sites 3 storm filters	Determine where PAHs are originating in the watershed. Monitor storm filter efficiency for PAH removal.
Sediment in filters	summer 1 time	10 storm filters	Measure storm filter efficiency for sediment removal.
Oil and Grease in filters	summer 1 time	3 storm filters	Measure storm filter efficiency for oil and grease removal.

RESULTS

A. Quality Assurance

A quality assurance project plan (QAPP) was prepared and approved prior to project start-up. The plan included SOP's for each of the monitoring techniques, chain of custody forms, maps of study sites, and information on storm filters.

The QAPP also included details on sampling (procedures frequency, number of samples, location), analysis (methods, precision, accuracy, completeness), and reporting. A summary of quality assurance results for this project is shown below:

Methods: All samples were analyzed using the methods described in the QAPP.

Procedures: All procedures planned for the project were carried out as planned in the QAPP.

Precision:

E.coli duplicates		52 cfu/g	64 cfu/g
PAH duplicates			
	Acenaphthene	100 ug/l	104 ug/l
	Benzopyrene	100	101 ug/l

Both analyses met the project goal of less than 10% deviation for sample duplicates.

Accuracy:

E.coli:	True value:	34 mpn/100 ml
	Measured value:	32 mpn/100 ml
PAH:	True value:	18.0 ug/spmd
	Measured value:	16.2 ug/spmd

Both analyses met the project goal of 90% accuracy.

Analysis "blank": One SPMD was dialyzed and submitted for PAH analysis as a "blank" (no exposure to PAHs). Fourteen of eighteen PAH analytes were less than detection limits. Trace amounts of 4 PAH compounds were present.

Completeness: All samples planned for the project were successfully completed as described in the QAPP

In summary, the project met all quality assurance project goals. The data collected as part of this project can be used with a high degree of confidence.

B. Instream Bacteria Monitoring

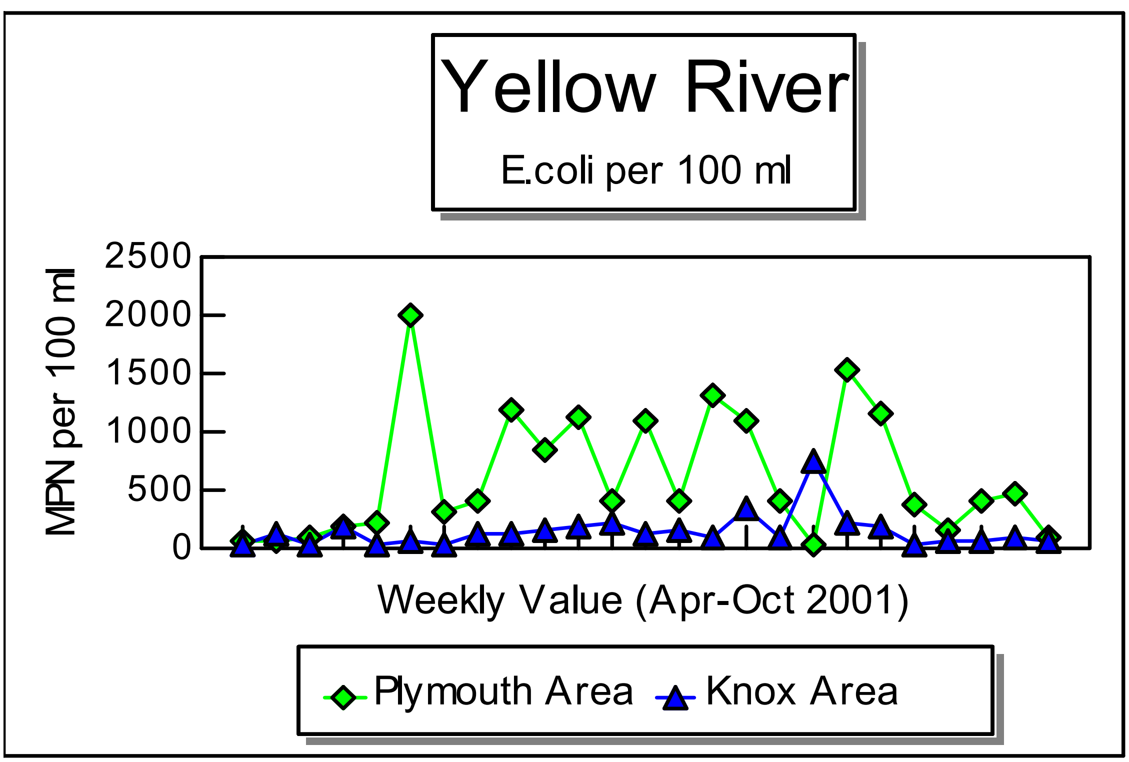
The City of Plymouth collected samples of *E.coli* at three sites each week during the course of the project. The City of Knox collected similar samples at two sites during the summer months. All data are attached to this report in Appendix A. A summary is shown below: The Indiana water quality standard for *E.coli* is exceeded almost half the time in the Plymouth area. In wet weather (greater than 0.3 inches of precipitation during the previous 24 hours) this percentage increases even more. The concentration of bacteria does not increase significantly downstream from Plymouth, indicating that the major loadings to the river occur in upstream areas.

Table 1. Summary of *E. coli* monitoring data from Yellow River water samples

	Upstream Plymouth	Downstream Plymouth
Median Concentration (cfu/100 ml)	255	260
% Samples > Indiana Standard	53	51
Dry Weather	42	43
Wet Weather (>0.3 ")	68	78

Because samples were taken at both Plymouth and Knox during the summer of 2001, a comparison can be made between *E.coli* numbers "upstream" at Plymouth and "downstream" at Knox. These data are summarized in Figure 2. The mean values at Plymouth were much higher than those at Knox. This means that most of the *E.coli* loading to Yellow River is occurring in the headwater areas upstream from Plymouth.

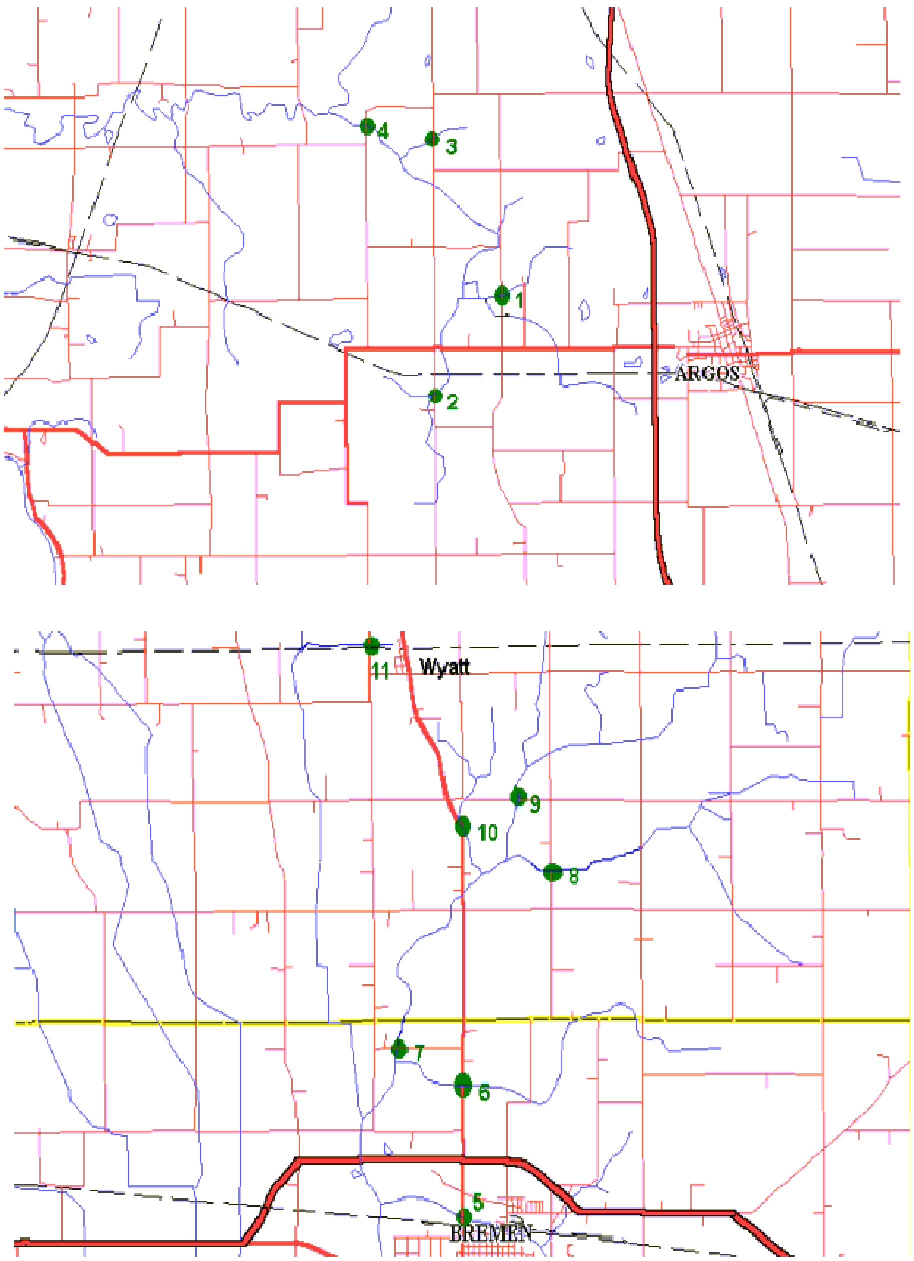
Figure 2.



B. Sterile Sandbag Study

Details of the sterile sandbag study are attached in Appendix B. There purpose of the study was to help locate important sources of *E.coli* loading in the upper Yellow River watershed. Sampling sites are shown in Figure 3. The sandbags with the largest concentrations of *E.coli* were located in Army Ditch in Bremen (site 5), an unnamed tributary west of Wyatt (site 11), Gross Ditch south of Wyatt (site 10), and Lefeert Ditch near Argos (site 1). Potential sources of *E.coli* in these tributaries are combined sewer overflows (Bremen), failing septic tanks (Wyatt), and livestock (Gross Ditch and Lefeert Ditch).

Figure 3. Sterile Sandbag Sampling Sites



C. Identification of Problem Areas for Urban Stormwater Runoff

The project used Streamguard Oil Detectors to help locate areas within Plymouth that could be impacted by oil in stormwater. Monitored sites are shown in Figure 5. Results from the first set of samplers is shown in Table 2.

Table 2. Results of FIRST Streamguard Oil Detect Monitoring Effort
Samplers set June 20 and retrieved July 10, 2001

		Weight Gained (grams)
Site 1	Pine Avenue	1.33
Site 2	Walter Glaub Dr.W	1.50
Site 3	Walter Glaub Dr. E	1.53
Site 4	Pidco	0.81
Site 5	Western Avenue	2.19
Site 6	Michigan Street	2.14
Site 7	Plymouth-Goshen Road	6.67
Site 8	Baker Street	0.83
Site 9	Berkley Street	2.63

Figure 4. Location of Sampling Sites - June/July 2001

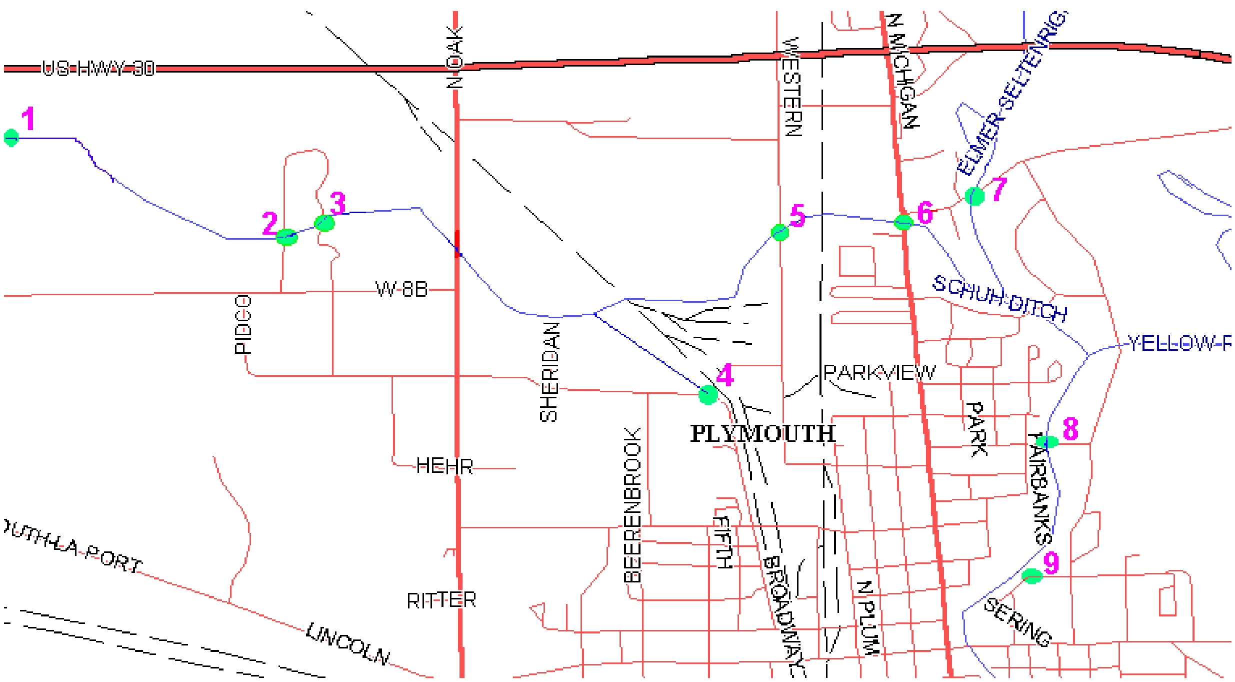


Figure 4 suggests that Elmer Seltenright Ditch was a major source of oil pollution. Other potential sources of oil pollution were storm sewers draining into Schuh Ditch near Western Avenue (site 5) and storm sewers draining into Yellow River near Berkley Street (site 9). Based on this information, additional oil detect samplers were set in Elmer Seltenwright Ditch (Fig. 5). Results are shown in Table 3.

Table 3. Results of SECOND Streamguard Oil Detect Monitoring Effort
Samplers set July 19 and retrieved August 9, 2001

		Weight Gained (grams)
Site 1	Maple Road	0.313
Site 2	Road 5A	0.3286
Site 3	Road 6	0.5511
Site 4	Road 7B	0.5063
Site 5	U.S. 30	0.4537
Site 6	Plymouth-Goshen Road	0.9135
Site 7	Tributary @ Michigan St.	1.1924
Site 8	Tributary @ Ramada	2.0818
Site 9	Parking lot @ Quick Auto Inc.	0.5821
Site 10	Parking lot @ Long John Silvers	0.7709

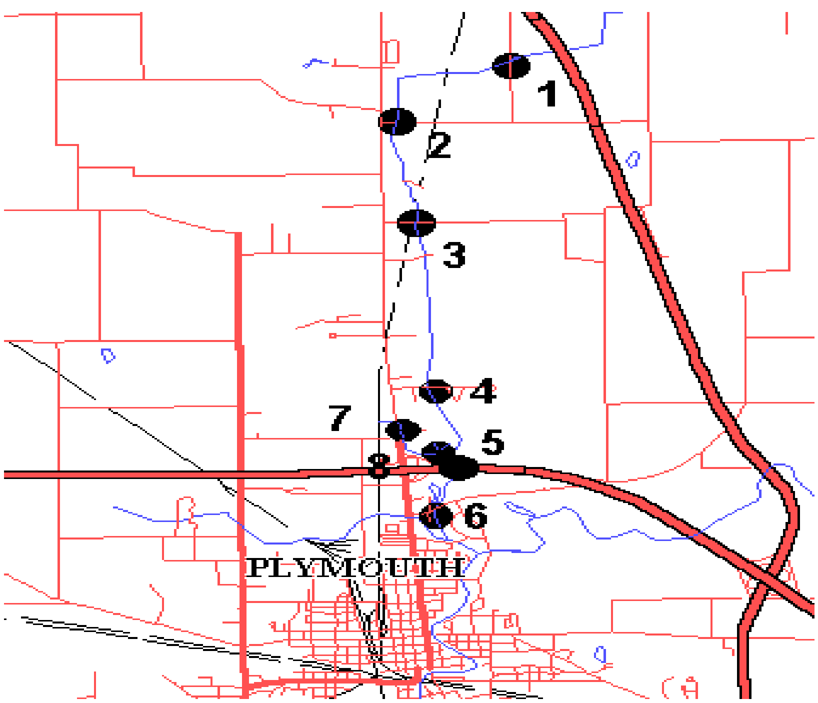


Figure 5. Location of Sampling Sites - July/Aug. 2001

The second set of samples suugests that the small tributary flowing past the Ramada Inn is the largest source of hydrocarbon pollutants. Efforts to control oil-related pollution should concentrate on this tributary.

Another tool to identify problem areas in the city was the installation of semipermeable membrane devices (SPMDs) to monitor PAH compounds in water. SPMDs were placed at eight sites in Yellow River and retrieved after a 3 week exposure period (March 29-April 17, 2001). The sites are shown in Figure 6. Results are shown in Table 4. These results show that Site 4 (Schuh Ditch in Plymouth) is the largest source of PAH loading. Schuh Ditch drains the northern part of Plymouth, where an industrial park and many acres of asphalt parking lots are located.

Table 4. PAH compounds in semipermable membrane devices
Reported as ng/spmd

	Site Number							
	1	2	3	4	5	6	7	8
fluorene			210	150	200	170	160	190
benzoanthracene				290		170	200	250
benzofluoranthene				600			140	140
chrysene		140	200	710	150	320	420	490
fluoranthene	340	930	1100	3000	1700	2500	2500	3100
phenanthrene	270	750	1100	1800	1700	1900	1700	2300
pyrene	290	750	550	2700	880	2100	2000	1400
acenapthene			170	130	130			130
TOTAL PAHs	900	2570	3330	9380	4760	7160	7120	8000

Fig. 6. Sites where SPMDs were placed

Additional SPMDs were set within the Schuh Ditch watershed, to help locate important sources of PAHs. One sampler was set in Schuh Ditch upstream from Elmer Seltenwright Ditch (Site 9). A second sampler was set in Elmer Seltenwright Ditch upstream from Schuh Ditch (Site 10). A third sampler was set in a storm sewer draining into the Plymouth airport storm grate (Site 11). These samplers were set on August 15 and retrieved on September 11, 2001. Results are shown in Table 5.

Table 5. Results of SPMD analysis within Schuh Ditch Drainage

	Site Number		
	9	10	11
fluorene	410	190	48
benzoanthracene	650	460	18
benzofluoranthene	1440	630	70
chrysene	1900	1400	220
fluoranthene	10000	5900	370
phenanthrene	5000	2100	340
pyrene	2000	3100	270
acenapthene	160	160	16
anthracene	330	130	26
napthalene	50		
acenapthylene	10		
benzopyrene	180		
dibenzoanthracene	20		
TOTAL PAHs	22160	14070	1378

These results show that Schuh Ditch upstream from Elmer Seltenwright Ditch is the most important source of PAH loadings in the watershed. Efforts to control urban stormwater pollution should concentrate on this area.

D. Storm Filter Efficiency

The first storm filters were installed in June 2001. Thirteen sites were monitored for sediment accumulation. Amounts of trapped sediment at each site varied from 0.5 to 17 kg per storm event, defined as more than 0.3 inches of rainfall in 24 hours or 50% of the average daily precipitation event for a given area [9]. The average for all storm filters was about 5 kg per storm event (Table 6).

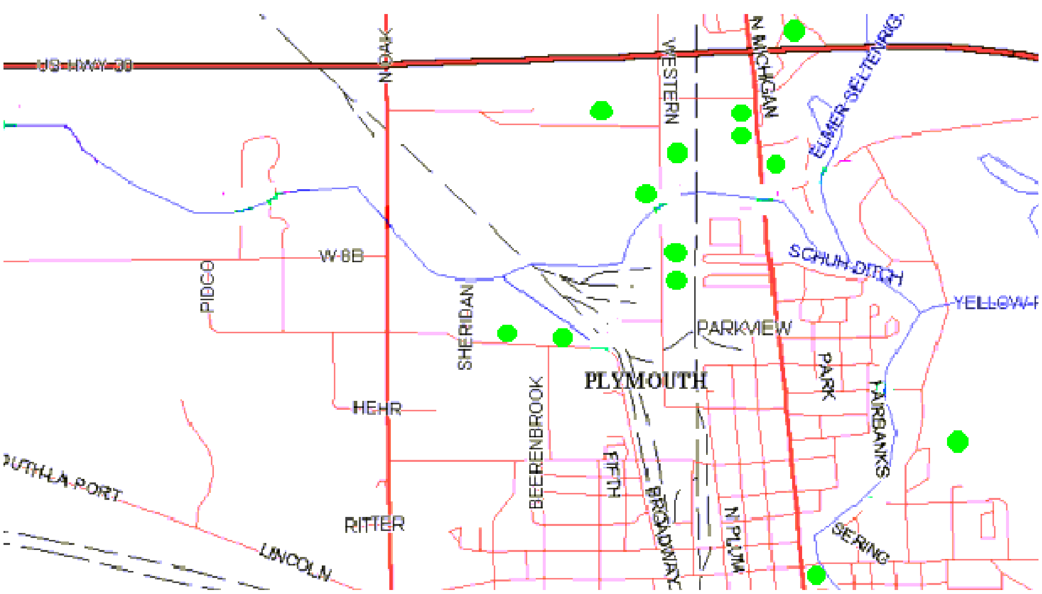
Table 6. Results of Storm Filter Efficiency for Sediment Removal

	Dates	Sediment Retained	Storm Events	Sediment/ Storm Event	Estimated Sediment Retained Per Year
Site 1 Airport	8/15-21	2.4 kg	1	2.4 kg	72
	8/21-29	1.6 kg	1	1.6 kg	48
	8/29-9/11	2.0 kg	1	2.0 kg	60
Site 2 Street Dept.	6/20-8/31	183 kg	11	17 kg	510
Site 3 Dean Foods N	6/20-9/17	46 kg	13	3.5 kg	100
	9/17-11/20	73 kg	10	7.3 kg	220
Site 4 Dean Foods S	6/20-8/31	123 kg	10	12 kg	360
	8/31 9/17	17 kg	2	8.5 kg	260
	9/17-11/20	90 kg	10	9 kg	270
Site 5 Kroger North	6/20-9/17	24 kg	13	2 kg	60
Site 6 Kroger South	6/20-9/17	11 kg	13	1 kg	30

Estimated

	Dates	Sediment Retained	Storm Events	Sediment/ Storm Event	Sediment Retained Per Year
Site 7 Western Ave.	6/20-9/17	7 kg	13	0.5 kg	15
	9/17-11/20	42 kg	10	4.2 kg	130
Site 8 Delmonte	6/20-8/13	Filter Missing on Retrieval			
Site 9 High School	6/20-7/30	11 kg	3	3.7 kg	111
Site 10 Laporte St.	8/15-9/11	2.0 kg	5	0.4 kg	12
Site 11 Long Johns	8/15-9/11	0.3 kg	5	0.1 kg	3
Site 12 Patterson	8/13-11/20	55 kg	16	3.4 kg	100
Site 13 Motel 6	6/20-8/13/02	3	1	3 kg	90

Fig. 7. Sites for Storm Filter Monitoring



In Indiana, there are an average of 30 storm events per year where precipitation exceeds 0.3 inches in a 24-hour period [9]. If each filter removes 5 kg of sediment from urban stormwater, as indicated by the data in Table 2, 150 kg of sediment could be kept from reaching Yellow River in the course of a year. The City of Plymouth has hundreds of storm grates along its streets. If filters are installed and maintained in 100 of them, it would be possible to eliminate the discharge of over 15,000 kg (20 pickup loads) of sediment and its associated nutrients and toxic chemicals to Yellow River each year.

In addition to locating problem spots for oil pollution (as in Section C, above), the Streamguard Oil Detectors were also useful in monitoring the effectiveness of Foss Storm Filters in removing oil and grease from stormwater. Oil detectors were placed inside and outside the storm filters, exposed to stormwater, and analyzed for removal efficiency of trapped oils and greases. Results are shown in Table 7.

Table 7. Results of Storm Filter Efficiency for Oil and Grease Removal

	Oil & Grease At Inlet	Oil & Grease at Outlet	Percent Oil & Grease Removed
Site 1 Dean Foods N 2/8 - 3/22/02	2.1652 g	0.5011 g	77
Site 2 KFC 2/8 - 3/22/02	2.1214 g	0.0999 g	95
Site 3 Patterson 4/4-23/02	1.3620 g	0.7983 g	41

Table 7 shows that the Foss storm filters were capable of removing 41 to 95% of all oil and grease present in urban stormwater.

Another goal of the project was to measure the capacity of the Storm filters to remove PAH compounds present in stormwater. Results of PAH concentrations going into a filter and coming out of the filter at three sites are shown in Table 8.

Table 8. Results of Storm Filter Efficiency for PAH Removal - ng/spmd

	Site 1		Site 2		Site 3	
	In	Out	In	Out	In	Out
methylnaphthalene					230	178
acenaphthylene					57	62
naphthalene					66	46
fluorene	140	160	900	530	180	210
benzoanthracene	19	22	2000	1300	46	74
benzofluoranthene	156	104	9800	5400	159	137
chrysene	290	410	10000	7900	140	260
fluoranthene	710	660	23000	23000	800	1200
phenanthrene	1100	940	8600	6900	1000	1200
pyrene	220	380	12000	14000	410	770
acenapthene	40	39	220	180	37	46
indenopyrene	51	18	2300	990	42	48
benzopyrene	14	13	1700	1000	40	61
benzoperylene	38	25	2500	1300	55	76
TOTAL PAHs	2778	2771	73020	62880	3262	4368

	PAH at Inlet (ng)	PAH at Outlet (ng)	PAH Removed	Percent Removed
Site 1 Airport 8/15-9/11/01	2778	2771	6	0.2%
Site 2 Long John Silver's 8/15-9/11/01	73020	62880	10140	14%
Site 3 Broadway 10/24-12/28/01	3262	4368	-1006	0%

For the most part, storm filters were not very effective in removing most PAH components. Maximum removal was only 14% for total PAHs. This is not surprising, since most PAHs are highly soluable in water and would not adhere to the absorbant material in the storm filters. However, certain types of PAH compounds were removed fairly effectively by the storm filters (Table 9). Removal rates of 25 to 40% could be achieved for some compounds.

By dividing the maximum concentration of a particular PAH compound found in Yellow River SPMDs by it's toxicity potential [7], a ranking priority for removal can be established (the highest numbers get the highest priority for potential water quality problems in Yellow River): The ability of Foss storm filters to remove the compound is also shown:

Table 9. Priority Ranking for PAH removal

Rank	PAH component	Maximum ug/spmd	14-day LC50 (ug/l)	Priority Ranking	Average % Removal Efficiency
13	napthalene	50	17,000	0.003	41
12	acenapthylene	10	3500	0.003	0
11	acenapthene	160	4800	0.03	10
10	fluorene	410	2700	0.15	25
9	anthracene	330	1400	0.24	25
8	dibenzoanthracene	20	10	2	28
7	benzopyrene	180	50	3.6	24
6	phenanthrene	5000	1100	4.5	17
5	pyrene	2000	330	6.1	0
4	benzoanthracene	650	60	11	20
3	chrysene	1900	70	27	0
2	benzofluoranthene	1440	50	29	39
1	fluoranthene	10,000	310	32	3

Table 9 shows that the Foss storm filters are capable of removing a significant portion of one of the most common and potentially toxic PAH component in Plymouth stormwater (benzofluoranthene). Two other high-ranking components (fluoranthene and chrysene) are not reduced very much.

D. Public Education

An internet website was produced as part of this project. The goal of the website was to provide easy access to data produced by the monitoring segment of the study. Several pages of the site are attached in Appendix D.

Two brochures were produced as part of this project. The first brochure explained the goals of the project. The second summarized the findings. Copies of the brochures are attached in Appendix D.

On April 23, 2002, a meeting was held in the Plymouth public library to present the findings and ask for input into how the City of Plymouth should use the information. Meeting summaries and a Powerpoint presentation describing the project are attached in Appendix D.

DISCUSSION

Many Indiana streams are impacted by excessive *E.coli* that impair their use for recreational activities [10]. The Yellow River is currently not on Indiana's list of impaired waterbodies but the upper watershed clearly has *E.coli* concentrations high enough to be of concern. The sterile sandbag technique was useful in locating some of these pathogen sources. Additional sampling in Gross Ditch and Lefeert Ditch would be useful in further pinpointing important sources in these Yellow River tributaries.

Excessive sediment inputs are another common cause of use impairment in waters of the United States [11]. A previous study of the Yellow River showed that excessive sediments caused mild impairment to the aquatic community in the Plymouth area [3]. Therefore, sediment control should remain an important goal for the community. This study demonstrated that using storm filters in urban stormwater inlets was an effective way to reduce sediment and oil loading to surface water. A program of installing and maintaining storm filters in Plymouth could reduce sediment inputs by 15,000 kg per year. The type of storm filter used in this study is relatively inexpensive (less than $100) and can be used for up to a year before replacement. The cost for filters in 100 stormwater inlets would be less than $10,000 annually. Maintenance is also relatively easy. The additional labor costs to check, empty, and replace these filters would vary according to rainfall and drive time, but in a city like Plymouth would probably be less than $5000 per year. A total program of storm filter maintenance would be approximately $15,000 annually. If 15,000 kg of sediment are removed annually, the cost per kilogram is $1.

PAH compounds are a common component in urban stormwater [8]. They are of environmental concern because they are potentially toxic to aquatic life at low concentrations [7] and because they have the potential to bioconcentrate to even higher levels in fish and other aquatic life [4]. Their toxicity is greatly enhanced when they are exposed to sunlight [12], a common occurrence in stormwater. The highest PAH concentrations in SPMDs occurred in Schuh Ditch (site 9), which drains the northern half of Plymouth. This area of the city is highly industrial, with numerous areas of impervious surface for parking, loading, and manufacturing. An urban stormwater runoff program for Plymouth should focus its attention on controls in the Schuh Ditch area.

Fluoranthene was the PAH compound that appeared in highest concentrations in Plymouth stormwater. This was also true in a previous study of urban stormwater constituents in Birmingham, Alabama [8]. Since fluoranthene concentrations are high and because this compound also has the highest potential for toxicity, finding an effective way to reduce loadings should be a high priority. Table 9 shows that the storm filters used in this study had almost no ability to remove fluoranthene. Therefore, other ways of reducing or treating fluoranthene are needed. However, benzofluoranthene, which was common in most samples and is potentially toxic to aquatic life in low concentrations, was reduced by almost 40% by Foss storm filters. Therefore, although not effective for all PAH contamination, use of Foss storm filters can help reduce some of the most toxic components.

Other best management practices (BMPs) for urban stormwater control should also be considered. Many of these are described in detail by others [13]. Some of these are already being used by the City of Plymouth. For example, the city already has an aggressive street sweeping program. Other BMPs may include use of porous pavement, construction of stormwater retention ponds, installation of swales and filter strips, flushing storm drains, implementing a vehicle spill control plan, and setting up a used oil recycling program.

RECOMMENDATIONS

1. Continue to use storm filter inserts on as many stormwater inlets as possible.

2. Concentrate urban stormwater control efforts on the Schuh Ditch watershed.

3. Consider the use of additional best management practices to improve water quality in urban stormwater.

4. Work with the Indiana Department of Environmental Management to encourage elimination of failing sewers near Wyatt and reduction of combined sewer overflows in Bremen. Work with the Marshall County Soil and Water Conservation District to locate important sources of *E.coli* loading from livestock.

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Appendix A. Instream *E.coli* Data

Randolph Street (Upstream from Plymouth Urban Area)

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
09/07/00	**320**	50	0
09/14/00	**>10,000**	234	0.41
09/20/00	**800**	87	0.08
10/05/00	**3890**	163	0.43
10/12/00	100	97	0.03
10/19/00	40	65	0.01
10/26/00	**324**	77	0
11/08/00	**370**	71	0.12
11/15/00	**260**	195	0
11/20/00	49	104	0
11/30/00	130	174	0.28
01/11/01	1	139	0
01/18/01	110	140	0
01/25/01	40	168	0.01
02/08/01	160	150	0.32
02/15/01	200	176	0.14
02/22/01	**330**	300	0
03/01/01	**250**	261	0
03/07/01	**400**	329	0.02
03/14/01	130	264	0
03/21/01	100	291	0
03/28/01	40	341	0
04/04/01	40	349	0
04/19/01	64	345	0.05
04/26/01	79	278	0
05/03/01	170	133	0
05/10/01	210	112	0.03
05/17/01	**>2,000**	314	0.11
05/24/01	**316**	111	0.06
05/31/01	**400**	148	0.22
06/07/01	**1,202**	412	0.07
06/14/01	**831**	361	0
06/21/01	**1,120**	161	0.92
06/28/01	**400**	113	0

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
07/05/01	**1,100**	140	0.53
07/12/01	**398**	115	0
07/19/01	**1,315**	93	0
07/26/01	**1,096**	1090	1.15
08/02/01	**398**	140	0.13
08/09/01	6	175	1.23
08/16/01	**1,548**	74	0.79
08/23/01	**1,148**	140	0.35
08/29/01	**355**	81	0
09/06/01	140	60	0.21
09/13/01	**398**	90	0.08
09/20/01	**458**	120	0.57
09/27/01	89	71	0
10/04/01	140	75	0.52
10/11/01	**320**	93	0.63
10/18/01	**390**	1750	1.86
10/25/01	**64,000**	1100	0.81
11/01/01	200	326	0
11/08/01	229	266	0.09
11/15/01	**250**	198	0.16
11/29/01	180	163	0.78
12/06/01	170	273	0.08
12/13/01	**460**	188	0.36
12/20/01	**260**	479	0.08
12/26/01	**540**	228	0
01/03/02	120	142	0
01/10/02	90	134	0
01/17/02	60	123	0
01/24/02	90	113	0.04
01/30/02	180	161	0.74
02/07/02	**1,778**	414	0
02/14/02	110	228	0
02/21/02	**661**	619	0.36
02/28/02	70	253	0
03/07/02	**520**	576	0
03/14/02	40	503	0
03/21/02	70	264	0
03/28/02	60	234	0.4

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
04/04/02	**370**	1470	0.08
04/11/02	**240**	1010	0
04/18/02	209	308	0.04
04/25/02	**270**	485	0.21
05/02/02	30	383	0.26
05/09/02	**64,000**	414	0.75
05/16/02	**794**	2070	0.71
05/23/02	**400**	359	0
05/30/02	150	242	0
06/06/02	**1,438**	308	0.82
06/13/02	**400**	205	0.01
06/27/02	**500**	190	0.05
07/12/02	**447**	100	0
07/18/02	180	78	0
07/22/02	**400**	83	0.17

Immediately downstream from WWTP

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
09/07/00	**598**	50	0
09/14/00	**>10,000**	234	0.41
09/20/00	**800**	87	0.08
10/05/00	**4677**	163	0.43
10/12/00	**295**	97	0.03
10/19/00	180	65	0.01
10/26/00	**417**	77	0
11/08/00	**509**	71	0.12
11/15/00	**360**	195	0
11/20/00	83	104	0
11/30/00	140	174	0.28
01/11/01	1	139	0
01/18/01	100	140	0
01/25/01	30	168	0.01
02/08/01	**270**	150	0.32
02/15/01	**400**	176	0.14
02/22/01	184	300	0
03/01/01	**250**	261	0
03/07/01	100	329	0.02
03/14/01	110	264	0
03/21/01	40	291	0
03/28/01	50	341	0
04/04/01	45	349	0
04/19/01	45	345	0.05
04/26/01	76	278	0
05/03/01	100	133	0
05/10/01	170	112	0.03
05/17/01	**<2,000**	314	0.11
05/24/01	**457**	111	0.06
05/31/01	**300**	148	0.22
06/07/01	**1,096**	412	0.07
06/14/01	**549**	361	0
06/21/01	**<2000**	161	0.92
06/28/01	**400**	113	0

Previous 24-hr

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Precipitation (Inches)
07/05/01	**500**	140	0.53
07/12/01	**794**	115	0
07/19/01	**776**	93	0
07/26/01	**1,318**	1090	1.15
08/02/01	**437**	140	0.13
08/09/01	**646**	175	1.23
08/16/01	**1,202**	74	0.79
08/23/01	**1,122**	140	0.35
08/29/01	199	81	0
09/06/01	129	60	0.21
09/13/01	**646**	90	0.08
09/20/01	**479**	120	0.57
09/27/01	209	71	0
10/04/01	129	75	0.52
10/11/01	**279**	93	0.63
10/18/01	**410**	1750	1.86
10/25/01	**64,000**	1100	0.81
11/01/01	**900**	326	0
11/08/01	199	266	0.09
11/15/01	190	198	0.16
11/29/01	**310**	163	0.78
12/06/01	229	273	0.08
12/13/01	**700**	188	0.36
12/20/01	**280**	479	0.08
12/26/01	**620**	228	0
01/03/02	**270**	142	0
01/10/02	90	134	0
01/17/02	60	123	0
01/24/02	100	113	0.04
01/30/02	**260**	161	0.74
02/07/02	**1,778**	414	0
02/14/02	140	228	0
02/21/02	**676**	619	0.36
02/28/02	50	253	0
03/07/02	**400**	576	0
03/14/02	40	503	0
03/21/02	150	264	0
03/28/02	110	234	0.4

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
04/04/02	**420**	1470	0.08
04/11/02	**246**	1010	0
04/18/02	170	308	0.04
04/25/02	**320**	485	0.21
05/02/02	30	383	0.26
05/09/02	**64,000**	414	0.75
05/16/02	**794**	2070	0.71
05/23/02	**400**	359	0
05/30/02	150	242	0
06/06/02	**1,438**	308	0.82
06/13/02	**400**	205	0.01
06/27/02	**500**	190	0.05
07/12/02	**447**	100	0
07/18/02	180	78	0
07/22/02	**400**	83	0.17

11th Road Bridge (Downstream from Plymouth Urban Area)

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)
09/07/00	**540**	50	0
09/14/00	**>10,000**	234	0.41
09/20/00	**400**	87	0.08
10/05/00	**2454**	163	0.43
10/12/00	200	97	0.03
10/19/00	60	65	0.01
10/26/00	**369**	77	0
11/08/00	**440**	71	0.12
11/15/00	**320**	195	0
11/20/00	40	104	0
11/30/00	104	174	0.28
01/11/01	1	139	0
01/18/01	50	140	0
01/25/01	30	168	0.01
02/08/01	170	150	0.32
02/15/01	200	176	0.14
02/22/01	229	300	0
03/01/01	**320**	261	0
03/07/01	100	329	0.02
03/14/01	140	264	0
03/21/01	120	291	0
03/28/01	20	341	0
04/04/01	35	349	0
04/19/01	60	345	0.05
04/26/01	71	278	0
05/03/01	120	133	0
05/10/01	140	112	0.03
05/17/01	**<2,000**	314	0.11
05/24/01	**371**	111	0.06
05/31/01	200	148	0.22
06/07/01	**1,445**	412	0.07
06/14/01	**630**	361	0
06/21/01	**<2,000**	161	0.92
06/28/01	**no data**	113	0

Sample Date	*E.coli*	Yellow River	Previous 24-hr Precipitation

	MPN/100 ml	Flow (cfs)	(Inches)
07/05/01	**no data**	140	0.53
07/12/01	**600**	115	0
07/19/01	**832**	93	0
07/26/01	**740**	1090	1.15
08/02/01	**379**	140	0.13
08/09/01	**776**	175	1.23
08/16/01	**1,514**	74	0.79
08/23/01	**977**	140	0.35
08/29/01	219	81	0
09/06/01	**299**	60	0.21
09/13/01	**724**	90	0.08
09/20/01	**628**	120	0.57
09/27/01	190	71	0
10/04/01	140	75	0.52
10/11/01	**269**	93	0.63
10/18/01	**320**	1750	1.86
10/25/01	**64,000**	1100	0.81
11/01/01	**500**	326	0
11/08/01	170	266	0.09
11/15/01	190	198	0.16
11/29/01	**320**	163	0.78
12/06/01	**240**	273	0.08
12/13/01	**620**	188	0.36
12/20/01	100	479	0.08
12/26/01	**570**	228	0
01/03/02	**320**	142	0
01/10/02	80	134	0
01/17/02	100	123	0
01/24/02	90	113	0.04
01/30/02	70	161	0.74
02/07/02	**1,175**	414	0
02/14/02	90	228	0
02/21/02	**759**	619	0.36
02/28/02	70	253	0
03/07/02	**450**	576	0
03/14/02	20	503	0
03/21/02	120	264	0
03/28/02	70	234	0.4

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Previous 24-hr Precipitation (Inches)

04/04/02	**480**	1470	0.08
04/11/02	**295**	1010	0
04/18/02	117	308	0.04
04/25/02	**290**	485	0.21
05/02/02	30	383	0.26
05/09/02	**64,000**	414	0.75
05/16/02	**794**	2070	0.71
05/23/02	**400**	359	0
05/30/02	150	242	0
06/06/02	**1,438**	308	0.82
06/13/02	**400**	205	0.01
06/27/02	**500**	190	0.05
07/12/02	**447**	100	0
07/18/02	180	78	0
07/22/02	**400**	83	0.17

Knox - upstream from WWTP

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Precipitation (Inches)
04/05/01	11	303	0
04/10/01	117	716	0.41
04/19/01	19	439	0
04/26/01	162	499	0
05/03/01	17	320	0
05/10/01	42	271	0
05/17/01	26	255	1.83
05/24/01	120	287	0.29
05/31/01	129	333	0.
06/06/01	155	371	0.96
06/14/01	182	764	0
06/21/01	204	324	0.54
06/28/01	100	232	0
07/05/01	155	195	2.02
07/12/01	91	303	0
07/26/01	**347**	1010	0.73
08/02/01	85	224	0.
08/09/01	**759**	160	0.02
08/16/01	210	108	1.10
08/23/01	174	146	1.31
08/30/01	26	133	0.
09/06/01	36	114	0.
09/13/01	65	177	0.
09/20/01	78	188	0.85
09/27/01	55	127	0.28
04/18/02	22	592	0.16
05/09/02	158	567	0.81
05/16/02	214	2950	0.02
06/06/02	**331**		

Knox - downstream from WWTP

Sample Date	*E.coli* MPN/100 ml	Yellow River Flow (cfs)	Precipitation (Inches)
04/05/01	25	303	0
04/10/01	102	716	0.41
04/19/01	37	439	0
04/26/01	138	499	0
05/03/01	30	320	0
05/10/01	28	271	0
05/17/01	52	255	1.83
05/24/01	110	287	0.29
05/31/01	69	333	0.
06/06/01	**257**	371	0.96
06/14/01	76	764	0
06/21/01	209	324	0.54
06/28/01	35	232	0
07/05/01	85	195	2.02
07/12/01	31	303	0
07/26/01	**240**	1010	0.73
08/02/01	89	224	0.
08/09/01	**457**	160	0.02
08/16/01	**2630**	108	1.10
08/23/01	105	146	1.31
08/30/01	26	133	0
09/06/01	36	114	0.
09/13/01	120	177	0.
09/20/01	93	188	0.85
09/27/01	49	127	0.28
04/18/02	20	592	0.16
05/09/02	135	567	0.81
05/16/02	224	2950	0.02
06/06/02	**398**		

Appendix B. Sterile Sandbag Monitoring Data

Appendix C. PAH Data

Appendix D. Public Education Materials