Remediation of the Irwin Discharge through Passive Treatment and Resource Recovery

An investigation funded by a Growing Greener Grant to Westmoreland County

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December 31, 2005

Brush Creek Below the inflow of the Irwin Discharge

Executive Summary The Irwin Discharge is one of the largest sources of acid mine drainage in the bituminous coal fields of Pennsylvania. The discharge flows from a drainage way installed in the early 1900's that drains much of the shallow groundwater entering the Irwin coal basin between Export and Irwin. The discharge is piped from the drainage way beneath a warehouse to Tinkers Run, just upstream of its inflow to Brush Creek (Westmoreland County), a major tributary of Turtle Creek (Westmoreland and Allegheny Counties). The discharge has been considered for treatment in the past, but the proposed conventional lime treatment was too expensive. During the last 25 years, the discharge pollution has moderated and new treatment procedures have been developed. This project reconsidered treatment options for the Irwin Discharge. Flow and chemical measurements were made between March 2003 and December 2004. Flow rates ranged between 3,226 and 9,254 gpm and averaged 6,364 gpm. The flow rates represent high flow conditions because precipitation during the monitoring period was 40% higher than normal. The average discharge has pH 6.0 and contains 111 mg/L alkalinity (as $CaCO_3$), 65 mg/L acidity (as $CaCO_3$), 71 mg/L Fe, 2 mg/L Mn, and <0.5 mg/L Al. The average acidity and Fe loadings during the monitoring period were 4,934 lb/day and 5,190 lb/day, respectively. The water is well-suited to passive treatment where the acidity is neutralized with limestone and the iron is precipitated in settling ponds and constructed wetlands. Passive treatment of the average loadings would require a 31,500 ton limestone bed, 19 acres of settling ponds, and 24 acres of constructed wetlands. The total footprint of the passive system is about 61 acres. A site in the Brush Creek flood plain 1.5 miles downstream of the Irwin Discharge was identified that contains ~100 acres of undeveloped land (BC site). The discharge can be piped to the BC site without pumps. Resource recovery opportunities were investigated. The discharge is suited for the production of pigment-quality iron oxide. The recovery and sale of iron oxide could produce $200,000/yr of gross revenue and off-set long-term O&M costs. The BC site is about 20 feet lower than the discharges and the pipeline could be sized to facilitate the generation of electricity with a low-head microhydropower system above the passive system. The electricity generation was estimated at 100,000 kWh/yr, which has a value of about $7,000/yr. The discharge contains thermal energy that could be extracted using existing heat pump technologies. The limestone bed could be used as a heat exchange point and could theoretically generate enough heat to provide base HVAC for about 400,000 ft^2 of commercial building space, at a potential value of about $200,000/yr. This application requires further investigation because GeoExchange has not been attempted at this scale previously in PA.

The costs to install a conventional lime plant and passive system designed for iron oxide recovery were estimated. A 1977 estimate for construction of the lime treatment was adjusted using the USACE's Civil Projects Cost Index, and then adjusted for recent flow rates. The construction estimate in 2005 dollars is $7.0 million. Annual operation costs, estimated from known costs for large lime plants in SW PA, were estimated at $1.0 million/year. The 20 year present value calculation for the capital and annual costs was $21.2 million. Construction costs for the passive system were estimated at $4.8 million. If the recovery of saleable iron oxide from the system can offset long-term sludge management, the 20-year present value of the passive treatment option is $5.6 million. The entire treatment system, with its hydroelectric and GeoExchange products could be the central piece of a "Green" industrial development that would provide major environmental and economic benefits to the region.

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I. Introduction

The Irwin Discharge is one of the largest sources of water pollution in Pennsylvania's bituminous coal fields. It pollutes Tinkers Run, Brush Creek, and Turtle Creek. Treatment of the discharge was evaluated in 1977 by Pullman Swindell in an Operation Scarlift report (SL 103-5). The recommended solution, a lime treatment plant, was considered too expensive and was not implemented. Since 1977, there have been advances in mine water treatment technologies, the chemistry of the Irwin discharge has moderated somewhat, and interest in the recovery of resources from mine water has developed. The goal of this project was to reevaluate the treatment opportunities for the Irwin discharge and determine if a cost-effective solution might be available. The primary objectives of the evaluation were to:

1. Identify the most cost-effective method for moving the discharge from its current location to a suitable treatment location.
2. Identify the most cost-effective method for treating the discharge.
3. Evaluate the cost-effectiveness of implementing the iron recovery technology developed recently by Iron Oxide Recovery, Inc.
4. Evaluate the feasibility of extracting energy from the discharge through hydroelectric and ground-based geothermal technologies
5. Evaluate water treatment technologies that could process the treatment system effluent to a higher quality and yield a saleable water product.

The investigation methods and findings are discussed in following sections.

II. Discharge Investigation

A. Source

The Irwin Discharge flows from a mine pool that developed in the Irwin coal basin as a result of a century of underground mining. The basin is a synclinal "bathtub" formation that is oval in shape and extends 24 miles from Murrysville to Smithton. The basin dips to the south, resulting in variable hydrologic conditions. A large portion of the northern basin is above the local drainage, resulting in thousands of acres of abandoned mines that are generally unflooded and drain by gravity. There are numerous discharges in the northern basin and most are acidic and contaminated with Al. This geochemistry is explained by the open, aerobic conditions in the abandoned mines – which promote pyrite oxidation and the generation of acidic water – and the minimal contact of this acidic water with alkaline strata that are present above the coal seam in this region. The southern portion of the Irwin basin is almost entirely below drainage and the mine workings are largely flooded. Discharges tend to occur from drainage structures or adits, and many are artesian in nature. Mine discharges in the southern basin are generally alkaline and contaminated with iron. This geochemistry results when the acidic water flowing from the flanks and upper portion of the syncline contacts carbonate minerals that occur above the Pittsburgh Coal seam. In the flooded conditions, carbonate dissolution neutralizes the acidity and precipitates aluminum. Iron, however, is not precipitated and flows out of the mines. The

Irwin discharge drains the middle portion of the basin and the discharge chemistry is at a mid-point between the acidic northern flows and alkaline southern flows.

The underground coal mines that contribute AMD to the Irwin Discharge were mined between the 1852 and 1955. Figure 1 shows the locations of deep mines in the Irwin Coal Basin. The South Side Mine operated from the 1870's until the early 1950's. At some point during the mining, the South Side Drainage Way was installed to promote drainage from the mine to the current discharge point above Tinkers Run. Figure 2 shows the location of the Drainage Way. When active mining was occurring in the local coal basin, pumping prevented the basin from filling and the South Side Drainage Way would have only discharged flow produced by the South Side Mine. When pumping ceased in 1955, the abandoned mine workings flooded and the water level in the central basin rose until it reached the lowest unobstructed discharge point – the South Side Drainage Way. The discharge of the Drainage Way has produced a large volume of polluted mine water since 1957 and has become known as the Irwin Discharge.

The current Irwin Discharge flows from two pipes that discharge directly into Tinkers Run. The original discharge point appears to have been through the coal crop in the hillside above Tinkers Run. The discharge probably flowed through an open ditch to Tinkers Run when the drainage way was installed. Sometime in the early 1900's, the discharge was collected and piped directly to Tinkers Run, and the land between the hillside and Tinkers Run was developed as a warehouse site. The discharge was piped in a 30 inch terracotta pipe from the buried coal crop to Tinkers Run. At some point in the late 1900's, an additional pipe was installed at a location about halfway between the coal crop and Tinkers Run. The modification is accessible through a manhole in the floor of the warehouse. A sump was installed that receives water from the 30 inch pipe and discharges through both the original 30 in pipe and a new 15 in pipe that discharges to Tinkers Run 50 feet downstream of the 30 in pipe. Figure 3 shows the configuration of the discharge pipes.

The warehouse is currently owned by Peter Alfieri, president of Alfieri Scrap Metal Company, Inc. During this project, Mr. Alfieri and his staff were very cooperative, providing access to the discharges and opening the manhole, when requested. Mr. Alfieri has shown continuing interest in remediation of the discharge and is amenable to providing access to the discharge structures.

B. Chemistry

The Irwin discharge was sampled for field and laboratory parameters 15 times between August 2004 and December 2005. Both the small pipe and large pipe were sampled each time, but the chemistry from the pipes was nearly identical because they share a common source. Table 1 summarizes the data. The complete data set is included in the Appendices.

Table 1: Irwin Discharge Chemistry Summary, August 2004 – December 2005 (n=15)

	pH	**Alk (mg/L)**	**Cond (uS)**	**Temp (^oC)**	**Acid (mg/L)**	**Fe (mg/L)**	**Al (mg/L)**	**Mn (mg/L)**	**SO_4 (mg/L)**
Average	6.0	111	1,733	12.7	65	71	<0.5	2.0	778
St. dev.	0.3	11	107	1.1	17	7	na	0.2	72
Min	5.2	84	1,585	10.0	23	57	<0.5	1.7	598
Max	6.5	128	1,896	14.6	91	89	<0.5	2.3	861

Alkalinity and acidity are as $CaCO_3$

The discharge is net acidic and contaminated with iron. Manganese concentrations are low and are not a concern. Aluminum concentrations were less than the laboratory's detection limit (0.5 mg/L) on every sampling occasion.

The Irwin discharge was sampled between 1973 and 1975 by Pullman Swindell as part of Operation Scarlift and between 1978 and 1980 by PADEP, apparently in conjunction with the Turtle Creek Watershed Association. Table 2 shows the average values for the sampling efforts. The contamination has moderated with the passage of time. Over the last 30 years concentrations of iron have decreased at an average rate of 18 mg/L per decade. If this linear trend continues, the discharge will improve to an uncontaminated condition (<3 mg/L) in about 40 years. If the trend is exponential, not linear, the amelioration will slow as the concentration decreases and the time period to reach < 3 mg/L will be much longer. A restoration plan based on waiting for natural amelioration to solve the problem does not seem practical, to current generations.

Table 2. Improving chemistry of the Irwin Discharge, 1973 - 2005

Period (# samples)	**pH**	**Acid (mg/L)**	**Fe (mg/L)**	**SO_4 (mg/L)**
1973-1975 (27)	4.0	290	126	1,164
1978-1980 (51)	5.0	176	116	875
2004-2005 (15)	6.0	65	71	778

Acidity as $CaCO_3$

C. Flow Rate

The flow rate of discharges from the two pipes was calculated by measuring the cross sectional area of each pipe and the discharge velocity. The velocity measurements were made with a Swoffer Model 3000 flow velocity meter. The cross sectional area was measured from the depth of the water in the pipe and an assumption that the pipe was round and unobstructed. The pipe was cleaned of debris and iron sludge, and both assumptions were reasonable. The cross sectional area (ft^2) was multiplied by the velocity (ft/min) to yield ft^3/min, which was translated into gallons per minute (gpm).

Velocity measurements were made seven times. The flow rates on these days were related to the depth of the water in each pipe. In practice, it is easier to accurately measure the depth from the top of each pipe *to* the water, than the depth of the water because of turbulence when the measuring stick is put into the flowing water. Figures 4a and 4b show the relationships between measured flow rate and depth to the water for each pipe. The regressions calculated from the relationships can be used to estimate flow from measurements of water depth in the pipes. This method was used to estimate flows on nineteen days when only water depths were known.

Flow rates are shown in Table 3 and represented graphically in Figure 5. The discharge from the small pipe was fairly consistent throughout the course of this project. Because both the small pipe and the large pipe originate from the same manhole, it is hypothesized that a restriction in the manhole or in the small pipe limits the total amount of flow from this pipe to about 2,400 gpm. The flow rate from the large pipe varied significantly throughout the course of the project, from a low of 1,300 gpm to a high of 6,600 gpm. Apparently the large pipe carries whatever flow cannot be carried by the small pipe.

Precipitation data were obtained for two Westmoreland County stations – Derry and Mt. Pleasant – and averaged. Table 4 shows monthly totals for 2004 and 2005. Precipitation during the monitoring period was unusually high. Precipitation totals for 2004 and 2005 were 22.5 inches and 10.9 inches above average, respectively. During the flow measurement period, March 2004 – December 2005, the regional precipitation was 30 inches or 41% above normal.

The discharge varied seasonally. High flows were observed in March-June 2004 and again in March-June 2005. Figure 6 plots the discharge flow rate with monthly rainfall totals. The response of the discharge flow to rainfall appeared to be delayed by at least two months. The discharge flow rate did not respond, in the short-term, to the September 2004 hurricane events. Table 5 shows the flows measured in August – October in relation to these events. The Irwin Discharge flows did not increase in September or even in October.

The flow rate was not correlated with iron or acidity concentrations of the discharge. Figure 7 shows the relationship between flow and iron concentrations. This result verifies that the Irwin Mine pool is not subjected to large inflows of precipitation-related freshwater that dilute the chemistry or cause rapid changes in flow. Instead, the pool is characterized by a steady-state chemical condition that drains at a rate affected by long-term precipitation trends.

Because of the high precipitation during our study period, the flows that were measured represent higher-than-average conditions. The higher flow rates measured in this study fairly represent the highest flow rates that can be expected from the Irwin Discharge, under the current hydrogeological conditions.

Table 3. Irwin Discharge Flow Rate Measurements

Date	Large Pipe (gpm)	Small Pipe (gpm)	Total (gpm)
3/5/04	***6,100***	***2,380***	***8,480***
3/26/04	***6,543***	***2,681***	***9,224***
4/16/04	***6,638***	***2,261***	***8,899***
5/6/04	5,742	2,102	7,844
6/1/04	5,742	2,299	8,041
7/15/04	4,536	2,102	6,638
8/12/04	4,134	2,299	6,433
8/17/04	***3,287***	***2,172***	***5,459***
9/10/04	3,330	2,102	5,432
9/21/04	3,531	2,004	5,535
10/19/04	3,330	2,102	5,432
11/16/04	3,330	1,905	5,235
12/14/04	2,526	2,102	4,628
1/13/05	***4,134***	***2,016***	***6,150***
2/9/05	5,742	2,102	7,844
3/10/05	6,144	2,102	8,246
3/16/05	***6,077***	***2,393***	***8,470***
4/22/05	6,144	2,102	8,246
5/5/05	6,144	2,102	8,246
6/14/05	4,938	2,102	7,040
7/13/05	4,536	2,102	6,638
8/16/05	3,330	2,102	5,432
9/13/05	2,526	1,905	4,432
10/5/05	2,124	1,905	4,030
11/14/05	1,320	2,102	3,422
12/6/05	***1,607***	***1,892***	***3,499***
Average ^{M}	**4,253**	**2,111**	**6,364**
Standard dev ^{M}	**1,653**	**138**	**1,745**
Min ^{A}	**1,320**	**1,905**	**3,226**
Max ^{A}	**6,554**	**2,700**	**9,254**

*Data in **bold italic** was measured for velocity and depth.*
All others calculated using regression curves.
^{M} *indicates the statistic is for the monthly averages*
^{A} *indicates the statistic is for all the data*

Table 4. Monthly Precipitation Totals for 2004 and 2005 in Westmoreland County (average of Mt.Pleasant and Derry measurements)

Month	Ave	Actual 2004	Actual 2005
Jan	2.7	6.6	8.7
Feb	2.4	2.7	2.6
Mar	3.2	3.6	7.2
Apr	3.0	6.5	2.7
May	3.8	4.2	3.6
Jun	4.1	5.9	4.7
Jul	4.0	7.2	4.1
Aug	3.4	5.3	4.2
Sep	3.2	7.2	1.2
Oct	2.3	3.5	4.5
Nov	3.0	3.9	3.8
Dec	2.9	3.8	1.5
Totals	**37.9**	**60.4**	**48.8**

Table 5. Irwin Discharge Flow in relation to heavy precipitation events, September 2004.

Date	Event	Flow (gpm)
August 12, 2004	Routine flow measurement	5,459
September 9, 2004	Hurricane Francis, 2.4 inches rain	
September 10, 2004	Routine flow measurement	5,432
September 18, 2004	Hurricane Ivan, 4.9 inches rain	
September 21, 2004	Special site inspection	5,535
October 19, 2004	Routine flow measurement	5,432

D. Contaminant Loading

Contaminant loadings for the Irwin discharge were calculated from the product of contaminant concentrations and flow rates. Table 6 shows statistical summaries for the Fe and acidity loadings on all days that both flow and chemical data were collected (14 days). Iron loadings averaged 5,200 lb/day and ranged as high as 7,300 lb/day. The table shows percentile values, calculated by Excel, which indicate the percentage of measurements below a particular value. For example, 75% of the time the iron loadings are less than 6,480 lb/day. Conversely, 25% of the loadings are higher than 6,480 lb/day.

Table 6. Summary statistics for contaminant loadings for the Irwin Discharge, 2004-05.

Statistic	Acidity, lb/day	Fe, lb/day
Average	4,934	5,190
Minimum	2,083	3,280
25th percentile	4,078	3,784
75th percentile	6,246	6,480
Maximum	7,337	7,294

Based on 14 measurements of flow and chemistry.

E. Impact on Tinkers Run and Brush Creek

The PADEP has published Total Maximum Daily Loads for Brush Creek that are based on the Department's sampling of the stream between July 2002 and August 2003. The report is available at the Department's web site under the TMDL section. The final Brush Creek TMDL report can be accessed at the following address:
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/BrushCreek_FINAL_TMDL.pdf

The designated use of both Tinkers Run and Brush Creek is a warm water fishery. The in-stream limits for this designation are shown in Table 7. Table 8 shows the TMDL report's summarized results for ten stream sampling stations. Brush Creek above Tinkers Run (BRSH13) is not contaminated with mine drainage. The mouth of Tinkers Run and all Brush Creek stations downstream of the inflow of Tinkers Run exceed the instream standard for Fe. No other large flows of AMD were documented by the TMDL study. As water flows downstream, iron concentrations are lessened by dilution and by iron precipitation in the stream channel. During high flow events, the iron precipitated on the channel is mobilized and flushed downstream to Turtle Creek. The highest Fe concentrations at the Brush Creek mouth, 20 mg/L, occurred during the highest flow event sampled (April 11, 2003). During this event the Fe loading at the downstream stations was 10,000 – 12,000 lb/day. As noted in Table 6, the Irwin Discharge averages 5,200 lb/day of Fe and the highest Fe load measured in 2004/05 was 7,300 lb/day. Mobilization of iron off of the stream bed was occurring during the April 2003 sampling event.

Table 7. Applicable Water Quality Criteria for Brush Creek.

Parameter	Criterion Value	Comment
pH	6.0 – 9.0	Standard units
Fe	1.50 mg/L	Total recoverable, 30 day average
Mn	1.00 mg/L	Total recoverable
Al	0.75 mg/L	Total recoverable

Table 8. Average results from Brush Creek TMDL study.
All stations are in Brush Creek. Stations are arranged and numbered moving upstream from the mouth. Based on six rounds of sampling between July 2002 and August 2003.

Station	Flow	pH	Alk	Fe	Mn	Al
BRSH01 (mouth)	32,305	7.5	94	5.7	0.4	<1
BRSH02	26,370	7.4	97	8.0	0.5	<1
BRSH05	19,412	7.1	98	6.1	0.6	<1
BRSH07	22,011	6.9	101	8.7	0.6	<1
BRSH09	18,441	6.8	104	13.8	0.6	<1
BRSH10	17,240	6.8	105	13.2	0.6	<1
BRSH11	16,505	6.5	124	35.2	1.1	<1
Tinker mouth	10,066	6.9	142	36.9	1.1	<1
BRSH13 (above)	Na	8.3	133	<0.3	0.1	<1

Flow is gpm, alkalinity, Fe, Mn and Al are mg/L.

The instream standards for pH were never exceeded. The lowest pH value for a Brush Creek sample measured during the TMDL study was 6.3. The alkalinity loading provided by Brush Creek and Tinkers Run is able to buffer the acidity introduced by the Irwin Discharge. This result indicates that remediation that only focuses on Fe would be sufficient to restore Brush Creek. In practice, it is difficult to efficiently remove the iron (by passive, mechanical, or chemical means) without also neutralizing the acidity.

The instream standard for Mn was exceeded in Brush Creek four times, all at BRSH11, the first station below the inflow of Tinkers Run. The four exceedances were less than 2 mg/L. At all stations further downstream, Mn concentrations were less than 1 mg/L. Low concentrations of Mn in an alkaline environment are not considered toxic to warm water fish and invertebrates. As noted previously, Mn concentrations in the Irwin Discharge average 2.0 mg/L (Table 1). Manganese removal is not considered in the treatment discussions that will be presented.

Instream concentrations of aluminum were below detection (0.5 mg/L) for 39 of 44 samples collected. Five samples exceeded 0.75 mg/L. The Irwin Discharge has < 0.5 mg/L Al and cannot be responsible for these exceedences. The most likely cause is sediment-containing runoff from local agricultural operations.

F. Possible Increased Flow from the Northern Irwin Coal Basin

Flow of water through the Irwin basin is in a north-to-south direction and is controlled by barriers and discharge points. Flow in the northern portion of the syncline is partially controlled by a coal barrier that crosses the basin south of Export, beneath the abandoned Penn Central Railroad line. The barrier was crossed during mining by three mains (tunnels). Two mains were sealed when the Delmont Mine closed. The third main, located in the Export Mine, was not sealed but is apparently blocked because AMD discharges on the northern side of the barrier only a thousand feet from the main's location.

The Export and Delmont discharges flow from the basin north of the Penn Central coal barrier. Table 9 shows the average flow rates measured by the Operation Scarlift study and chemistry measured in 1999 by students from the University of Pittsburgh Program in Geology and Planetary Sciences. The discharges have similar flows, but different chemistry. The Export discharge has low pH and is contaminated with Al. The Delmont discharge has moderate pH and is contaminated with Fe. The Turtle Creek Watershed Association (TWCA) estimates that the two discharges account for about 75% of the contaminant loading to upper Turtle Creek.

In the original Operation Scarlift report, Pullman Swindell noted the absence of treatment options and recommended that the discharges be passed over the coal barrier and allowed to flow to the Irwin discharge. The recommendation was not implemented. The concept was recently revived by the TCWA, who received a 2005 PADEP Growing Greener grant to reassess treatment and mitigation options for the discharges and, if none arise, develop the barrier bypass alternative. At this point, it appears that the bypass option is the only feasible solution.

Table 9. Characteristics of the Export and Delmont Discharges.
Flow rates from Pullman Swindell (1977). Chemistry measured in 1999 by University of Pittsburgh (personal communication, Rosemary Capo).

	Flow, gpm	**pH**	**Acidity, mg/L**	**Fe, mg/L**	**Mn, mg/L**	**Al, mg/L**	**Acid, lb/day**	**Fe, lb/day**	**Al, lb/day**
Export	792	3.3	172	1.3	1.9	13.4	1,632	13	128
Delmont	785	4.7	72	34.7	1.8	1.4	678	326	13
Total	1,577						2,310	339	141

Table 10 shows the predicted hydrologic and contaminant consequences of diverting the Export and Delmont discharges to the south where they will presumably discharge at the Irwin Discharge. The calculations are made with the average characteristics reported in Tables 1 and 9 and assume simple mixing. In reality, chemical reactions would modify the final effluent somewhat. When Al flows into a bicarbonate-buffered environment, it is hydrolyzed to $Al(OH)_3$, consuming 5.6 kg alkalinity for each kg of Al. This reaction between the Al supplied by the Export discharge and the alkalinity present in the central basin pool likely would decrease the alkalinity of the Irwin Discharge by an additional 9 mg/L. Table 10 shows the predicted discharge chemistry assuming that this reaction occurs (I&E&D*). The Irwin Discharge should retain its alkaline, net acidic condition. A pH between 5.5 and 6.0 is expected.

Table 10. Calculated Irwin Discharge Changes with Diversion of Export and/or Delmont.

Source	Flow	Alk	Acid	Fe	Mn	Al	Alk	Acid	Fe	Mn	Al
	gpm	Concentration, mg/L					Loading, lb/day				
Irwin	6,364	111	65	71	2	<1	8,618	4,934	5,190	160	<7
Export	792	0	172	1	2	13	0	1,632	13	18	128
Delmont	785	6	72	35	2	1	57	678	326	18	13
I&E	7,156	98	80	64	2	2	8,618	6,566	5,203	208	~130
I&D	7,149	99	68	67	2	<1	8,675	5,612	5,516	208	~20
I&E&D	7,941	90	79	61	2	<1	8,675	7,244	5,529	226	~148
I&E&D*	7,941	80	79	61	2	<1	7,627	7,244	5,529	226	<9

** predicted mixture chemistry that assumes Al hydrolysis with the mine pool.*
Alkalinity and acidity are $CaCO_3$

Because diversion of the Export and Delmont discharges to the central basin is being seriously considered, the treatment scenarios that are presented in the report will consider this action and the chemistry/loadings shown by "I&E&D*" in Table 10. If the Export and Delmont discharges are diverted before the recommendations provided in this report are implemented, the actual impact on the Irwin Discharge should be evaluated through continued monitoring of its flow and chemistry.

III. Recommended Treatment System

Treatment of the Irwin Discharge requires neutralization of acidity and the precipitation/collection of iron solids. The treatment can be accomplished by conventional or passive technologies. This proposal was justified, in part, because of the recent development of passive treatment techniques that are known to yield good treatment results with minimal O&M. The analysis will focus on the passive alternative. As a comparison, the Pullman Swindell lime treatment plan is updated to reflect current costs.

Regardless of the treatment technology, there is insufficient available land area in the discharge's immediate vicinity to site a treatment plant at/near the outfall. (Condemnation or purchase and razing of the established commercial and industrial properties is not considered a realistic option.) The discharge must be relocated to an area suitable for treatment. Thus the remediation involves two actions: 1) discharge relocation, and 2) treatment.

A. Location and Conveyance

<u>Relocation of the Discharge through Pumping</u>

One goal of the project was to assess the feasibility of relocating the discharge through pumping. At least a dozen mine pools in western PA are managed through pumping operations. The pumps are usually located above a deep portion of the minepool, near a synclinal axis. A pumping scheme for the Irwin Discharge would involve the selection of a site above the mine pool where the surface is well suited for construction of a treatment system. Several wells would be drilled into the mine void and equipped with large pumps, each capable of pumping 3,000 – 4,000 gpm. At least two pumps would be operated to draw down the pool and eliminate flow from the Irwin Discharge. The pool would be maintained at an elevation lower than the Irwin Discharge, thus creating storage space that would be used when the pumps were shut down or when inflows to the minepool exceeded the pumping capacities.

A hydrological analysis of the middle Irwin basin by the University of Pittsburgh did not identify any flaws in the pumping approach. The report is attached in the Appendix. A cost analysis was performed for installing and maintaining a pumping station. The costs were based on discussions with local mining companies that operate pump and treat operations. Table 11 shows the assumptions and cost estimates. The calculations assume that the treatment system is located in an upland location (out of the flood plain) that requires the water to be raised 200 feet. Two 24 in dewatering wells must be installed at a cost of $100,000 per well. Two turbine pumps are installed, each capable of raising 3,000-4,000 gpm of flow. These pumps cost approximately $600,000 each. The annual operation costs (electricity) are estimated by assuming that the annual cost is $0.15 per gpm of flow per foot of lift. This relationship was developed at a site where 6,000 gpm is raised 700 feet (continuously) and electrical usage is metered. Pump O&M is assumed to be 10% of the annual power cost

Table 11. Estimated pumping costs for the middle Irwin basin.

	Units	**Unit cost**	**Total cost**
Establish two dewatering wells	200 ft deep	$100,000	$200,000
Turbine pumps	2	$600,000	$1,200,000
Operate pumps	6000 gpm, lift 200 ft	$0.15/gpm/ft	$180,000
Maintain pumps		20% of operation	$18,000
Total pumping O&M			$198,000
Present Value of O&M	20 years, 4% net		$2,700,000
	50 years, 4% net		$4,300,000
	75 years, 4% net		$4,700,000
Present Value of O&M plus Capital	20 years, 4% net		$4,100,000
	50 years, 4% net		$5,700,000
	75 years, 4% net		$6,100,000

It is possible that the capital costs involved with a pumping station could be obtained through the PADEP, if assurances were provided that the annual O&M costs were paid. The annual O&M cost is estimated at $198,000 per year. Typically, the long-term costs for treatment systems are analyzed using present value calculations that estimate the size of a trust fund necessary to assure O&M for a set period of time. For permitted mine sites, a 75 year time period is used. Table 11 shows the present value of the long-term O&M costs calculated for 20, 50, and 75 yr scenarios. The values range from $2.7 to $4.7 million. The total cost of the pumping alternative is evaluated from the PV of the O&M plus the capital costs. These values range from $4.1 to $6.1 million and are the values against which alternative relocation procedures should be compared. These costs are for the Irwin-only alternative. Diversion of Export and Delmont flows to the middle pool would increase flows and annual pumping costs by about 25%.

Relocation of the Irwin Discharge through Gravity Piping

An alternative to pumping the minewater to a preferred treatment location is to search for a site that is assessable via a gravity pipeline. In this case, a less-than-ideal property might be feasible if resolution of difficulties involved in developing the property were less expensive than the pumping scenario. The land area downstream of the Irwin discharge was examined for a large, flat, undeveloped piece of property that might be suitable for construction of a treatment system. A suitable property was located in the Brush Creek flood plain approximately 1.5 miles downstream of the discharge location. Figure 8 shows the property, which totals about 100 acres on both sides of the stream. The location will be referred to as the BC site (Brush Creek).

An elevation survey was completed in April 2005 to determine if the discharge could be piped to the BC site using gravity flow. The elevations were determined by survey-quality GPS methods that are accurate to one inch and were tied into two local benchmarks. The survey included points critical to potential pipeline paths and the treatment location. Figure 9 shows the locations of the points and Table 12 shows selected critical elevations. All of the survey point elevations are presented in the Appendix.

The closest access to the original South Side Drainage Way discharge box was at the manhole in the Alfieri warehouse. The water elevation in the manhole was 880 ft. The discharge can likely be collected at the original Drainage Way discharge point at an elevation 2-3 feet higher than the manhole. The highest point in the BC site that would be considered for treatment is east of the railroad (Point 6) and is about 860 feet or 20 feet lower than the manhole. The Irwin Discharge can be piped by gravity to the location.

Two possible routes for a pipeline between the discharge and BC site were identified. Both routes take advantage of an active railroad that is located adjacent to Brush Creek between Irwin and Trafford. Half of the right-of-way is undeveloped and contains buried water, sewer, and communications lines. The discharge pipeline could share this right-of-way.

Both options involve the collection of the discharge from the Alfieri Scrap Metal Company property and piping it along Pacific Ave, adjacent to Tinkers Run, to Route 993 and Brush Creek. The first option has the pipe turn north at Brush Creek and follow Route 993 for approximately 1.3 miles and then 0.5 mile down the railroad right-of-way to the BC site. This route crosses Brush Creek four times using existing PennDOT bridges and would be a total of 1.8 miles long. As shown in Table 12, Route 993 is at or below elevation 880 in this region. The second possible route has the pipe continue from Pacific Ave beneath Route 993 and across Brush Creek where it can access an abandoned rail siding that eventually connects with the active railroad. The pipe follows the right-of-way to the BC site. The property around the abandoned right-of-way has been developed, but the actual right-of-way is only used for parking and storage. This route crosses Brush Creek twice using existing railroad bridges and would be a total of 1.4 miles long. The surface elevation at the intersection of the abandoned siding and railroad and siding is as high as 895 ft. The pipeline would need to be buried at least 20 feet in this area. This is not unreasonable.

Table 12. Critical Survey Elevations.
Elevations are feet above mean sea level (MSL) made April 5, 2005.

Point	Elevation	Point Description
		Discharge Location
4D	880.2	Water surface in manhole in warehouse
4C	876.0	Bottom of sump accessible in manhole in warehouse
1	877.8	Water surface out of large discharge pipe
3A	875.0	Tinkers Run at large discharge pipe, stream bottom
4A	884.7	Base of hill where discharge box is buried
		Route 993 between Discharge and BC site
14	874.5	Route 993 at Pacific Street
9	872.2	Route 993 at Westmoreland Street
19	880.4	Route 993 at Bridge 1
21	873.7	Route 993 (east edge) at Bridge 2
		Abandoned Railroad Siding (no longer tracks)
17	879.5	Rail siding across from Tinker Run
18	879.6	Rail siding at Westmoreland Street
25	891.9	Juncture of rail siding and active railroad
		BC Treatment Site
6	865.3	Railroad above BC site
5A	837.6	Brush Creek above BC site, stream bottom
5B	845.4	Brush Creek above BC site, top of stream bank
7A	820.9	Brush Creek below BC site, stream bottom
7B	827.1	Brush Creek below BC site, top of stream bank
8	857.7	Railroad below BC site

The second pipeline option is preferred because it uses, primarily, existing right-of-ways, and it is shorter. Figure 8 shows the pipeline route. The route has an overall grade of approximately 0.3%.

The size of the pipe necessary to carry the design flow was calculated with the Hazen-Williams equation. The calculations assumed 9,000 ft of pipe with a roughness coefficient of 130. Flow rates were varied and head losses were calculated. The minimum size pipe was one that would pass the highest expected flow with 20 ft of head loss, or less.

If only the Irwin Discharge is treated, the pipe should pass 10,000 gpm. A 30 inch diameter pipe will pass this flow with a head loss of 19 feet. The combined Irwin & Export & Delmont flow is estimated to have a maximum flow of about 12,500 gpm. A 36 inch diameter pipe will pass this flow with a head loss of 12 feet. These calculations do not account for head losses due to pipeline turns and bends, which cannot be calculated until the final pipeline path is determined. For the purpose of estimating pipeline construction costs and hydroelectricity potentials, the

Irwin-only alternative was assumed to include a 30 in pipe, while the Irwin&Ex&Del alternative was assumed to include a 36 in pipe.

Table 13 shows cost estimates for the two pipelines. The pipe product specified was JMM PVC Perma-Loc Gravity Sewer pipe. The estimate assumed that the buried pipe is bedded with 6-12 in of aggregate and is wrapped in geotextile fabric. The installation costs were assumed as $45/ft for 30 in pipe and $50/ft for 36 in pipe. The O&M on the pipeline is minimal because the anoxic water will not precipitate solids within the pipe. $10,000 per year is assumed for general inspection and right-of-way access. The total present value costs range from $1.1 to $1.4 million. The pipeline alternative is 75% less expensive than the pumping alternative (20 year present value analysis).

Table 13. Cost estimate for pipeline to transport Irwin Discharge to BC site

Parameter	**Unit**	**Irwin only**	**Irwin&Ex&Del**
Flow	gpm	10,000	12,500
Distance	ft	9,000	9,000
Grade, average	%	0.3%	0.3%
Pipe size	Diameter, inches	30	36
Roughness coefficient		130	130
Installation			
Collect discharge	Estimate	$50,000	$50,000
Cross Brush Creek	Estimate	$50,000	$50,000
Pipe, 9000 ft	$26.26 / $30.55	$236,313	$274,923
Aggregate and fabric	Estimate	$61,200	$61,200
Installation	$45/ft 50/ft	$40,500	$450,000
Construction Total		$802,513	$886,123
Engineering	10%	$92.289	$101,904
Contingency	15%	$120,377	$132,918
Total Capital Cost		$1,015,179	$1,120,946
Annual ROW cost	Estimate, $/yr	$10,000	$10,000
Present Value of Capital and O&M			
	20 years, 4% net	$1.1 million	$1.3 million
	50 years, 4% net	$1.2 million	$1.3 million
	75 years, 4% net	$1.3 million	$1.4 million

B. Passive Treatment Design

The chemistry of the discharge – slightly acidic, high iron, no aluminum – is amenable for reliable passive treatment technologies. The basic treatment system components are an anoxic limestone drain (ALD) followed by settling ponds and constructed wetlands. This type of passive treatment is highly reliable when correctly applied and designed. An explanation for the design follows.

Basis for Passive System Design

The effectiveness of the passive system for Fe removal is primarily dependent on the presence of enough alkalinity to neutralize the acidity produced by iron hydrolysis. The reactions below show the generation of acidity, and its subsequent neutralization by bicarbonate.

$$Fe^{2+} + \frac{1}{4} O_2 + 5/2\ H_2O \rightarrow Fe(OH)_3 + 2\ H^+$$
$$H^+ + HCO_3^- \rightarrow H_2O + CO_2$$

Stochiometric relationships developed from the reactions above indicate that an adequately buffered minewater contains at least 2 mg/L alkalinity for each 1 mg/L Fe. The Irwin discharge is deficient in alkalinity because it contains 110 mg/L alkalinity and 70 mg/L Fe. If the discharge is treated directly with settling ponds and constructed wetlands, about 55 mg/L Fe will readily precipitate in the ponds where the pH will be above 6. However, when the alkalinity is consumed, further iron hydrolysis will lower the pH to less than 5 and Fe removal will slow substantially. The final discharge from an adequately sized passive system that treats the Irwin Discharge *without* alkalinity adjustment will likely have pH ~4 and Fe concentrations of 5-15 mg/L. Because Brush Creek is so well buffered, the acidic discharge would be immediately neutralized. The iron would precipitate within the streambed.

Low pH is not a desirable condition for a treatment system effluent (or a legal one for a permitted effluent), so alkalinity adjustment is normally attempted to assure that the final discharge has pH 6-9. The Irwin Discharge is well suited to alkalinity adjustment using an anoxic limestone drain (ALD). An ALD is a buried bed of limestone where the acidic mine water reacts with calcite to yield more alkalinity as shown below.

$$H^+ + CaCO_3 \rightarrow Ca^{2+} + HCO_3^-$$

The limestone bed is designed to maintain anoxic conditions because the presence of oxygen will result in iron oxidation and fouling of the limestone aggregate with iron solids. Anoxic conditions must be maintained during collection, transfer and flow through the limestone bed. This is achieved by collecting the mine water from the pool before it can contact the atmosphere, transferring the water in a closed pipe, and burying the bed of limestone. The construction of collection, transfer, and treatment of minewater under anoxic conditions is achieved through careful design and has been accomplished dozens of times at coal mine sites.

A properly functioning ALD is the most cost-effective method for making long-term additions of alkalinity to acidic minewaters (Ziemkiewicz et al. 2003). When properly designed and installed, an ALD functions for at least a decade with minimal operation and maintenance needs. An ALD in at the Howe Bridge passive treatment system (Jefferson County) has successfully treated an acidic discharge for 15 years without any maintenance. Two ALDs in the Slippery Rock Creek watershed (Butler County) have operated successfully for ten years without any maintenance.

The amount of alkalinity that is generated by an ALD is limited by the minewater's equilibrium with calcite. This limit varies between minewaters. In some cases where the mine water is highly acidic, a properly installed and functioning ALD cannot generate enough alkalinity to provide a net alkaline final discharge. There is not currently a method for analyzing minewater chemistry and confidently predicting the alkalinity that would be generated from treatment with an ALD. The best prediction is obtained by incubating the minewater with limestone in a closed, anoxic environment.

A limestone incubation test was performed for the Irwin Discharge. The results indicate that several hours of retention time within limestone aggregate will yield about 200 mg/L alkalinity. Retention of the water in an ALD for at least 10 hours will yield about 275 mg/L alkalinity.

The highest Fe concentration measured during this study was 89 mg/L. An ALD should be designed that provides a discharge with at least 180 mg/L alkalinity. The limestone incubation tests indicate that this level of alkalinity can be achieved with an ALD that provides at least 3 hours of retention.

Iron removal occurs in the passive system in settling ponds and constructed wetlands. The settling ponds are intended to promote oxygen transfer to the water, oxidation and formation of iron oxyhydroxide particulates, settling of the solids, and storage of the sludge. Settling ponds have proven effective for iron removal when the iron concentrations are greater than 10-15 mg/L. At lower iron concentrations, the settling of iron particles slows substantially. For these lower concentrations, the most effective passive treatment is provided by a wetland where interaction with plant and microbial biomass and exudates remove particulate iron. Empirical evidence from a variety of passive systems indicates that settling ponds precipitate iron at rates of 20-30 grams of Fe per square meter of pond per day ($g\ m^{-2}\ d^{-1}$). Empirical evidence from constructed wetlands that effectively remove iron to <2 mg/L indicates an iron removal rate of about 5 $g\ m^{-2}\ d^{-1}$.

The removal rate for iron in settling ponds is directly affected by the transfer of oxygen into the water and the pH. Both of these parameters are affected by aeration which transfers O_2 into the water and degasses CO_2 out of the water, increasing pH. In a passive system, gas transfer occurs at the pond surface and in structures that create turbulent flow. The removal of iron in a passive system can be increased through mechanical aeration. While many claims have been made about the ability of aeration to decrease the need for settling ponds by large factors, no empirical evidence supporting these claims yet exist. In the single system where iron removal with and without a properly sized aerator (Maelstrom Oxidizer) was measured, the aeration appeared to double the iron oxidation rate over the passive process (personal communication, George Watzlaf, US Department of Energy; based on studies done at the Scrubgrass system, Allegheny County, PA). This analysis will assume that the addition of an aerator system doubles the rate of iron removal in the settling ponds.

Treatment assumptions used in developing the conceptual treatment designs are shown in Table 14. The calculated surface areas necessary for the ALD, ponds and wetlands were adjusted to account for essential, but non-functional items like ditches, berms, access roads, flow control structures, and surface water diversions. At a similar project that contains 6 acres of settling ponds and 7 acres of constructed wetlands (Lowber Passive Treatment Project), the realized area adjustments were +49% for the settling ponds and +23% for the constructed wetlands. The model assumed 50% for settling ponds, 25% for constructed wetlands, and 25% for the ALD.

Table 14. Passive Treatment Design Assumptions

Anoxic Limestone Drain	
Alkalinity generation, 10-12 hour retention	275 mg/L
Alkalinity generation, 3-4 hour retention	200 mg/L
Target Alkalinity concentration	190/160 mg/L[A]
Retention time necessary to reach target alkalinity concentration	3 hours
Period of performance for design flow	10 years
Porosity of limestone aggregate	40%
Depth of limestone in ALD	10 ft
Area adjustor[B]	+25%
Settling Ponds	
Fe influent concentration	71/61 mg/L[C]
Fe removal rate, 100% passive	25 g $m^{-2}day^{-1}$
Re removal rate, aerator	50 g $m^{-2}day^{-1}$
Limit of Fe removal	15 mg/L
Area adjustor[B]	+50%
Constructed Wetlands	
Fe removal rate	5 g $m^{-2}day^{-1}$
Average effluent Fe	1 mg/L
Area adjustor[B]	+25%

[A] *the ALD target is 190 mg/L for the Irwin-alone design and 160 mg/L for the combined design*
[B] *the adjustment to the calculated acreage necessary to account for berms, surface water diversions, access roads, etc.*
[C] *Irwin-only, 71 mg/L; Irwin & Export & Delmont, 61 mg/L*

Treatment evaluations were performed for two mine water chemistries at three flow conditions. The different chemical conditions reflect treatment of the Irwin discharge alone and treatment of the combined Irwin, Export and Delmont discharges. The three flow conditions assumed for each chemistry were average flow, 75th percentile flow, and maximum flow.

Table 15 shows the size of the major treatment system elements under the six chemistry and flow conditions. The ALDs range from 31,500 to 49,500 tons. The total acreage estimates for the systems range from 61 to 98 acres.

Table 15. Calculated sizes of treatment units.
Systems were designed to obtain a final discharge with pH 6-9 and Fe < 2 mg/L.

	Irwin alone Ave flow	**Irwin alone 75th % flow**	**Irwin alone Max flow**	**Ir&Ex&Del Ave flow**	**Ir&Ex&Del 75th % flow**	**Ir&Ex&Del Max flow**
Design Flow, gpm	6,364	7,991	9,256	7,941	9,905	11,276
Fe influent, mg/L	71	71	71	61	61	61
Fe loading, kg/day	2,469	3,100	3,591	2,624	3,273	3,726
ALD limestone tonnage	31,500	36,500	40,000	39,000	45,000	49,500
ALD, acreage	2	2	2	2	3	3
Settling Ponds, treatment acreage	19	24	28	20	24	28
Settling Ponds, total acreage	29	36	42	30	36	42
Wetland treatment acreage	24	30	35	30	37	42
Wetland, total acreage	30	38	44	37	46	53
System total acreage	61	76	88	69	85	98

"75th %" indicates the 75th percentile flow condition

The size of the conceptual systems is very large relative to existing passive systems. The largest ALDs constructed in the eastern US have been 3,000 – 6,000 tons of limestone. No scaling issues have been reported for large ALDs. As long as the water is maintained in an anoxic condition and preferential flow paths through the limestone aggregate are avoided, performance by the ALD is certain. A single large ALD will be equipped with influent and effluent manifolds to assure that the water is distributed throughout the limestone bed. If concerns are raised about the scale, it is feasible to construct several smaller limestone beds that function in parallel or series. This design involves more berms and increases the footprint of the ALD.

Unexpected scaling problems could exist with the iron removal aspect of the system because as settling ponds and wetlands increase in size, it has proven increasingly difficult to prevent performance-decreasing preferential flow regimes. Wetland #3 at St Vincent College (Monastery Run Improvement Project) has demonstrated that sustainable treatment of flows of 300-500 gpm is possible. The system treats alkaline water containing 70-100 mg/L Fe with a series of settling ponds and wetlands that have a total surface area of 3.5 acres. Over a seven year period the final discharge has averaged 2 mg/L Fe and removed iron at an average system-wide rate of 12.6 gFe $m^{-2}d^{-1}$. The system-wide iron removal rate for the Irwin passive system is 12.8 gFe $m^{-2}d^{-1}$. To avoid scaling problems associated with increasing from 300-500 gpm to 5,000-8,000 gpm, the Irwin system will be designed as a 10-15 parallel “sub-systems” that each treat ~500 gpm of flow. The ALD will discharge to a flow splitting structure that directs each flow to a three pond series. The discharge of each pond will be collected in an open channel and directed to the common constructed wetlands for polishing.

A large passive treatment system is currently under construction at the Lowber site in Sewickley Township, Westmoreland County. The system will treat a 1,500 flow with a sequential series of six settling ponds followed by two constructed wetlands. Concerns about short-circuiting of water through the ponds are being handled through the installation of 50-foot-long troughs that discharge and collect water from the ends of each rectangular pond. If this approach proves successful in producing higher rates of iron removal, the concept will be applied to the Irwin system.

Undeveloped Land in the lower Watershed

Figure 11 shows parcels of undeveloped property that exist in the Brush Creek drainage downstream of Tinkers Run and the Irwin Discharge. Table 16 shows the acreage of the parcels assuming different elevation constraints. There is a discrepancy between the survey conducted for this project and the USGS topographic map. The USGS shows the surface elevation of SR 993 at the Tinker Run crossing as above 880. The project survey indicated an elevation of 872. The railroad elevation on southeast corner of the BC site is shown on the USGS as 880 ft. The survey indicated an elevation of 866 ft. It is likely that the acreage measured on the USGS maps below the 880 ft USGS contour line is actually 10 ft lower than indicated and thus accessible by a gravity pipeline.

Table 16 also shows the amount of stream frontage at each parcel. The acreage totals are adjusted to account for a 50 ft setback from the stream. These values are the acreage of land that is suitable for construction of a gravity flow system, after accounting for the 50 ft stream setbacks.

The BC site includes parcels D, E, F, G, and H. Assuming that treatment occurs in the same progression, then the pertinent acreages are those at less than 860 ft for parcels D, E, F, and G, and less than 840 ft for parcel H. The total acreage of the parcels with these constraints is 85 acres. When the 50 ft stream setback is assumed, the total acreage is 69 acres.

Table 16. Acreage of undeveloped land parcels downstream of the Irwin Discharge. The table shows acreage between USGS elevation lines and stream, road, or railroad constraints. "Strmft" is stream front distance. The set back values refer to acreage assuming a 50 ft setback.

Parcel	< 900 acres	< 880 acres	< 860 acres	< 840 acres	Strmft ft	<900 setback	< 880 setback	< 860 setback	<840 setback
A	12	7	none	none	0				
B	6	6	4	none	1,700	4	4	2	none
C	11	8	4	none	2,300	8	5	1	
D	24	23	22	none	1,800	22	21	20	
E	26	19	13	none	3,300	22	15	9	
F	14	12	10	none	3,000	11	8	6	
G	21	18	16	none	1,800	19	16	14	
H	35	34	31	24	3,000	31	30	27	20
I	46	36	28	19	2,400	43	33	25	16

C. Land Constraints and Passive Treatment

The amount of undeveloped property in the BC area, 69 acres, is sufficient to contain a system that passive treats the average flow produced by the Irwin discharge in 2004/05 and the average flow of the combined Irwin, Export and Delmont discharges. The performance predictions provided above are likely conservative because the base years for the Irwin discharge, 2004/05 were very wet and the measured flows were surely higher than the long-term average. In a normal precipitation year, the average flow from the Irwin Discharge is likely 25% less than that measured in 2004/05. In such a year, the proposed treatment system would be sized large enough to treat the 90^{th} percentile flow conditions.

When iron loadings exceed those expected, the system will discharge water containing more than 1 mg/L. One option for dealing with an undersized passive system is to install aerators in the settling ponds. When turned on, the aerators will increase the rate of iron oxidation in the settling ponds and the performance of the system. Aeration would only be necessary when the final discharge from the passive system was not meeting effluent targets.

The aeration option can increase the performance of the system and assure a good discharge under all flow and loading conditions. The disadvantages of the aeration backup are: higher capital costs, 2) operational costs (primarily electricity), and 3) possible impacts on resource recovery opportunities. Samples of iron sludge collected from systems with aeration and mechanical mixing were less pure than ones from passive systems and were note suitable for sale as pigment (Hedin 2006). Because resource recovery is an important component of the long-term operation of the system, the implementation of aeration options must be done cautiously.

D. Permitting Challenges

The BC site is largely located in the Brush Creek floodplain. Wetlands occur on the site and would be eliminated by the proposed system. At this time, stream benefits resulting from mine drainage treatment and ecological benefits provided by the constructed wetlands are not recognized as mitigation for impacts caused by the construction of treatment systems. At a project meeting (November 2004), both the US Army Corps of Engineers and PA Department of Environmental Protection Bureau of Water Quality indicated that the permitting of the full-scale treatment system would almost certainly require mitigation for wetland, stream encroachment (if any) and flood plain impacts.

It is unlikely that permitting issues would prevent the construction of a large passive treatment system at the BC site. However, it is likely that the permitting agencies will require appropriate mitigation efforts. Plans to proceed with a treatment plan for the Irwin Discharge should account for mitigation requirements in work plans and budgets. At this time, it is considered possible that mitigation costs could increase the project budget by 25%.

E. Treatment System Cost Estimate

<u>Estimated Cost to Construct a Passive Treatment System</u>

Cost estimates were developed for designs that treat the average inflow of an Irwin-only system and the average inflow of an Irwin & Export & Delmont system. The assumptions used in the development of the estimate are shown in Table 17. The cost is for a system that includes:

- Collection of the Irwin Discharge from the Alfieri Property,
- Piping of flow down Pacific Avenue, across Brush Creek, onto the abandoned RR right-of-way, and on the active RR right-of-way to the BC site,
- Treatment of the flow with an anoxic limestone drain,
- Treatment of the flow with settling ponds designed to facilitate sludge recovery,
- Treatment of the settling pond discharge with constructed wetlands,
- Discharge to Brush Creek

The estimate includes a 15% construction contingency. Professional fees, which include system design, construction plans, permitting and construction management, are assumed as 10% of construction costs.

Table 17. Assumptions used to develop the cost estimate.

Activity	Quantity assumptions	Unit cost
Construct Pipeline		
Pipe	9000 ft; 30 in or 36 in	\$26/ft or \$31/ft[A]
Aggregate	0.6 ton/ft	\$8/ton delivered
Fabric	20 ft^2/ft	\$0.10/ft^2
Installation		\$45/ft or \$50/ft[A]
Collect discharge	Estimate	\$50,000
Cross Brush Creek (buried)	Estimate	\$50,000
construct ALD		
Limestone Aggregate	From design	\$12/ton delivered
Earthwork	Limestone volume X 2	\$5/CY
Construct Settling Ponds		
Size of ponds	50,000 ft^2	
Clear and grub	Total acreage	\$3,000
Earthwork	Surface area X depth	\$5/CY
Aggregate pond bottoms	6 in aggregate on geotextile	\$12/ton installed
Troughs	Two 50 ft troughs per pond	\$130/ft installed
Construct Wetlands		
Size of wetlands	250,000 ft^2	
Clear and grub	Total acreage	\$2,500/acre
Earthwork	Surface area X depth	\$3/CY
Planting	Bare root plants, 2 ft spacing	\$0.15/plant
General Cost Assumptions		
Purchase property	Total acreage	\$2,500/acre
Access roads through system	Acreage basis	\$250/acre
Design, Permitting, Construction Oversight		10% of total construction
Contingency		15%

[A] *first value is Irwin-only system; second value is Irwin&Export&Delmont system*

The estimate does not include costs associated with diverting the Delmont and Export discharges to the middle basin. These costs are currently being developed by Turtle Creek Watershed Association and GAI Consultants. The estimate does not include off-site projects that would mitigate for impacts to existing wetlands at the BC site. The need to provide such mitigation varies between projects and is difficult to predict until the site's resources have been delineated and the final impacts to these resources are known. (The cost to perform delineation and resource impact assessments is included in the profession fees as a standard part of permitting.) The estimate also assumes that the project excavation and filling can be balanced on site. The assumption cannot be assessed until a survey and system layout is developed.

Table 18 shows the cost estimate breakdown. The total cost estimate for the Irwin-only alternative is \$4.1 million. This works out to \$644 per gpm of design flow and \$2.16 per lb/yr of Fe. The Sewickley Creek Watershed Association is currently constructing a passive system that will treat 1,800 gpm of flow containing 60 mg/L Fe. The cost to design and construct the system is $1.1 million or $611 per gpm and $2.43 per lb/yr of Fe. The Sewickley Creek system does not include a large pipeline or ALD, but it does include the off-site disposal of a substantial amount of excess cut. The general correspondence of unit costs for the two projects indicates that the Irwin cost estimate is reliable.

Table 18. Cost estimate for the Irwin-only and Irwin&Ex&Del scenarios

Component	Description	Construction	D&P&CM*	Total
Irwin Only				
Pipeline	30 in pipe, 9000 ft	$922,890	$92,289	$1,015,179
ALD	27,000 tons	$621,201	$62,120	$683,321
Settling Ponds	16 @ 50,000 ft^2 each	$1,615,995	$161,599	$1,777,594
Constructed Wetlands	4 @ 250,000 ft^2 each	$598,759	$59,876	$658,635
Complete System		$3,758,845	$375,884	$4,132,729
Irwin & Export & Delmont				
Pipeline	36 in pipe, 9000 ft	$1,1019,041	$101,904	$1,120,945
ALD	39,000 tons	$914,522	$91,452	$1,005,974
Settling Ponds	17@ 50,000 ft^2 each	$1,656,360	$165,636	$1,821,996
Constructed Wetlands	5 @ 250,000 ft^2 each	$747,131	$74,713	$821,845
Complete System		$4,337,054	$433,705	$4,770,751

* Design, permitting and construction management

F. Estimated Cost to Construct and Operate a Conventional Lime Treatment Plant

Table 19 shows the estimated costs to construct and operate a conventional lime treatment plant. The baseline costs were obtained from the original Pullman Swindell report. These 1977 capital costs were adjusted to 2005 using the Civil Works Construction Cost Index System. The adjustment suggests that construction of lime plant capable of treating an average flow of 8,400 gpm and a high flow of 12,600 gpm will cost $11.8 million. A useful general estimator for lime treatment plants is $1,000 per gpm of design flow. The Irwin ratio is $933 per gpm of design flow.

To fairly compare the conventional lime alternative with the passive treatment, similar flow assumptions must be made. The passive treatment alternatives were designed and costed at 6,364 gpm (Irwin only) and 7,941 gpm (Irwin & Export & Delmont). Assuming that the cost of the conventional lime plant scales directly with flow rate, the construction costs are adjusted to:

- Irwin-only, 6,364 gpm design: $5,589,967
- Irwin&Exp&Del, 7,941 gpm design $6,975,161

Pullman Swindell estimated annual plant operation costs at $0.25 per 1000 gallons of water. If this value is adjusted for inflation, it increases to $0.70 per 1000 gallons. Advances in the automation of lime plants have decreased the unit operational costs for lime plants. The Commonwealth operates two lime treatment plants in SW PA. One treats 1,000 gpm of flow at a unit annual cost of $0.57/1000 gallons. The second treats 6,000 gpm at a unit annual cost of $0.27/1000 gallons. Assuming that the Irwin plant would be highly automated, the unit operational costs were assumed to be $0.25/1000 gallons. The actual average flow rate for the Irwin&Ex&Del system, 7,941 gpm, was used to estimate annual costs. The estimated annual O&M cost was $1.043 million per year. Table 19 shows the elements of the cost estimate.

Table 19. Estimated cost to treat the Irwin Discharge using conventional lime plant.

	Units	**1977 estimate**	**2005 estimate**
flow design	gpm	12,639	12,639
flow average	gpm	8,403	7,941
Fe load	lb/day	11,896	5,813
price index*		216	606
Site Preparation	$	$ 1,913,200	$ 5,373,424
operations building	$	$ 37,800	$ 106,165
mechanical	$	$ 1,149,300	$ 3,227,930
Electrical	$	$ 332,700	$ 934,423
Exploratory excavation	$	$ 95,000	$ 266,818
sub-total	$	$ 3,528,000	$ 9,908,760
contingencies	10%	$ 352,800	$ 990,876
engineering	8%	$ 310,464	$ 871,971
Total Capital Cost	$	$ 4,191,264	$ 11,101,758
Capital adjustment to decrease flow design to 7,941 gpm			
Irwin&Exp&Del Capital Cost	62% adjustment		$6,975,161
Annual O&M cost basis		$0.25/1000 gal	$0.25/1000 gal
Annual O&M	$/yr	$ 1,104,125	$1,043,447

**Composite weighted average from "Civil Works Construction Cost Index System", US Army Corps of Engineers, EM 1110-2-1304, September 30, 2005*

Table 20 shows a present value analysis of the estimated costs to construct and operate a lime treatment plant. The present value of 20 years of annual O&M is $14.2 million. When the capital costs are added, the total present value (20 years) of the lime treatment plant is $25.3 million.

Table 20. Total cost of conventional lime treatment over 20 year period; Irwin&Exp&Del option.

Capital	$6,975,161
Annual O&M	$1,043,447
Discount rate	4%
PV of O&M, 20 years	$14,180,791
Capital plus PV of O&M, 20 years	$21,155,952

IV. Potential Treatment System Benefits and Products

The mine water treatment system can produce a variety of benefits. The primary benefit is decreased water pollution to Brush Creek. The Irwin Discharge is the primary source of water pollution to the stream, and the treatment of the discharge should bring the stream into compliance with its instream standards. The proposed passive treatment system will produce a discharge with < 2 mg/L Fe under design conditions. The presented design is based on average flows measured during a very wet period. During a normal precipitation year, flow rates and contaminant loadings will likely be 25% lower. Under these hydrologic conditions, the proposed system design will produce an effluent with < 2 mg/L Fe 90% of the time.

If flow conditions like those observed in 2004/05 occur again, the system will be overloaded about half of the time. During periods when flows are similar to the highest flows observed in 2004/05, the system would receive 40-50% more Fe loading than designed and would discharge an effluent containing 5-10 mg/L Fe. If the flow in Brush Creek under these conditions was also high (60,000 – 80,000 gpm), then dilution of the treatment system inflow will yield conditions at or near compliance with the in-stream standard. If the performance of the passive system during these periods was not satisfactory, an aeration system could be installed so that iron removal would be improved. Investment in the aerator system is not recommended until the performance of the installed system under a variety of flow conditions is observed.

The treatment system can produce other benefits. Those benefits include saleable iron oxide, hydroelectric power, and geothermal energy. These potential products are discussed below.

A. Iron Oxide

The passive system will produce a clean iron sludge that could be recovered for sale as iron oxide. The recovery of saleable iron oxide from passive treatment systems has been demonstrated during the last five years. The most successful example is the Lowber site in Westmoreland County where 1,200 tons of iron sludge was recovered, processed, and sold as crude (unfinished) pigmentary product (Hedin and Weaver, 2002). Iron was recovered at the site from a channel that had passively collected clean iron sludge. A treatment system is currently under construction at the site that will passively treat the mine water (1,800 gpm, 60 mg/L Fe) through the production of recoverable iron oxide in settling ponds, followed by a constructed wetland that polishes the discharge. The settling ponds are designed to produce a clean iron oxide and to facilitate recovery of the iron product, without substantially disrupting the treatment performance of the system. The ponds will passive collect iron sludge, which will be removed every 5-7 years. On average the system will produce about 600,000 lb/yr of iron oxide (dry weight). The sludge will processed (screened, dewatered, dried) and sold to a pigment producer.

Not all iron sludge is suitable for pigment use (Hedin 2006). Saleable pigment-quality sludge has been recovered where the iron is precipitated passively at pH 6-7. The maintenance of pH 6-7 requires the presence of alkalinity, which can be natural or generated by pre-treatment with limestone. Iron sludge produced at pH less than 6 has weaker pigment characteristics. Aeration of alkaline mine drainage can increase the pH above 7, which accelerates iron oxidation. Sludge collected from environments with pH > 7 has proven, thus far, to have poor pigment characteristics.

The Irwin discharge, after it is pretreated in the anoxic limestone drain, is well suited for production of pigment-quality iron sludge. The ALD will buffer the acidic aspects of the dissolved iron, assuring that the pH will not fall below 6. Passive aeration of the water will result in pH values of 6-7 in the settling ponds. These geochemical characteristics should yield iron oxide that has good color and pigment strength.

During the 2004/05 study, the Irwin Discharge produced 3,300 – 7,300 lb/day of Fe. In the proposed passive system, 75-85% of the iron loading will be collected in the settling ponds. Because the solid iron oxide (FeOOH) weighs more than then dissolved iron (Fe^{2+}), the actual amount of iron oxide collected in the ponds will range from approximately 4,500 – 8,500 lb/day FeOOH. In 2004/05, the Irwin Discharge would have yielded about 1,200 ton/yr of recoverable iron oxide sludge (using the proposed design). Assuming that flows and loadings were about 25% higher than normal, then the system can be expected to produce about 900 ton/yr FeOOH in an average precipitation period.

The Export and Delmont discharges may be relocated to Irwin. The two discharges average about 339 lb/day of Fe. If the settling ponds retain 80% of this iron, the annual production will be approximately 80 ton/yr FeOOH. The total iron recovery from a combined Irwin & Export & Delmont system is estimated at 1,000 tons/yr FeOOH.

This is a large quantity of iron oxide. The Sewickley Creek Watershed Association's Lowber passive treatment system (under construction) will collect about 300 ton/yr FeOOH. The Lowber system is the largest iron-recovery passive system constructed to date. Between 2001 and 2005, Iron Oxide Recovery, Inc. produced and sold a total of 1,700 tons FeOOH. Sales were limited over this period by supply, not demand. A strong market exists for high quality iron oxide pigment produced from mine drainage. As long as the Irwin product has strong pigment characteristics, it will be saleable.

The iron product sold recently by IOR is considered unfinished iron oxide pigment because the buyer must further process and blend the material to produce a finished pigment. The value of the unfinished iron oxide varies depending on pigmentary characteristics and marketability. Iron oxide produced passively from the Irwin Discharge will likely have a value of $200-300/ton. The Irwin treatment system will produce iron oxide with a gross value of $200,000 - $300,000. The net value of the iron oxide depends on the cost to recover the solids from the settling ponds and process them to a saleable condition. Recovery and processing procedures have been developed by Iron Oxide Recovery, Inc. (Hedin and Weaver 2002). Total recovery costs of about $250-300/ton were realized for small recovery projects (50-200 tons). Economies of scale for larger projects should decrease processing costs by at least 25%.

The Irwin system has been designed with features that assure the production of clean iron oxide and also facilitate iron recovery. The bottoms of the settling ponds will have a geotextile liner to prevent contamination of the iron sludge with underlying soils. Portions of the settling pond bottoms will contain an aggregate base to support the placement and operation of sludge pumping units during recovery operations. The passive design, where all flow is by gravity, cannot be turned off during sludge maintenance operations. The current design includes a parallel arrangement of ponds so that when iron recovery is occurring in one set of ponds, no more than 10% of the treatment capacity will be off-line, and the system will still provide effective treatment.

The incorporation of features that decrease sludge recovery and processing costs should allow profitable recovery of iron oxide from the settling ponds. In 2005, Iron Oxide Recovery, Inc. contracted with Scott Township (Allegheny County) to provide basic operation and maintenance for a minewater treatment system in return for ownership of all iron sludge recovered. A similar contract will be negotiated with the Sewickley Creek Watershed Association when the Lowber system is completed. If the Irwin system is constructed and operated in a manner that assures the production of pigment-quality iron oxide, all of the long-term sludge management costs and a portion of the general system O&M costs can likely be offset by iron oxide revenues.

Currently, all unfinished pigment-quality iron oxide derived from mine drainage is shipped out-of-state for processing. Finished iron oxide pigments sell for $800-2000/ton. If the Irwin system is constructed, it is likely that opportunities to produce a finished pigment from the system's production will be explored. The processing requirements include dewatering, drying, milling, blending, and packaging operations. As the Irwin system would produce a substantial portion of such a facility's initial production, placement of the facility in close proximity to the treatment system would certainly be considered. Assuming that the facility processed all of the Irwin production, and an equal amount of iron oxide from other sites, the annual production would be about 2,000 ton/yr and the value would be at least $1 million/yr. The operation of such a facility would create 10-15 jobs.

B. Hydropower

The treatment plan includes a pipeline that carries water from the current discharge point to the BC treatment area. The elevation difference for the pipeline is approximately 20 ft. Electricity can be generated with a low-head hydroelectric generator set at the end of the pipe (and above the ALD). The amount of power that can be generated is dependent on the usable head at the end of the pipeline. As water flows through the pipeline, head is lost. Power is generated from the net head: the difference between the elevations at the beginning and end of the pipe and the head losses (expressed in feet) that occur in the pipeline. Head losses vary with the size and length of the pipe and the flow rate. Table 21 shows calculations of head losses and power production of the two piping alternatives at various flow rates.

Table 21 shows the electricity generation at various flow rates. The value of the electricity was estimated by surveying the cost of "green" power in PA. The average cost in PA for fully renewable electricity is ~$0.07/kWh. The 30-inch diameter pipe provides 91,000 kWh/yr of electricity at the average Irwin flow rate, which has a value of $6,270/yr. The 36-inch diameter pipe provides 143,000 kWh/yr of electricity at the average Ir&Ex&Del flow rate, which has a value of $10,010.

The costs of a micro-hydroelectric system on the Irwin discharge were estimated through discussions with Melvin Koleber of Paul C. Rizzo Associates (Monroeville, PA), an expert in hydroelectricity generation. The capital costs associated with the purchase and installation of an 18 kW turbine generator on the 36 inch pipe are estimated at $40,000. Amortized over 20 years at 5%, the annual capitalization cost would be $3,200/yr. O&M costs for this equipment are not well known. Assuming that the generator requires $3000/yr for servicing, then the net value of the hydroelectric is $3,900/yr. This cost estimate does not include equipment required to put the electricity into the local electrical grid. According to Mr. Koleber, this equipment would substantially increase the capital costs and make the electricity generation unprofitable. The electricity should be used locally, off-grid. Possible uses are public lighting and heating locally or at the treatment system complex.

Table 21. Possible hydroelectricity production at various flows and pipe diameters.

	30 in pipe (Irwin-only system)				**36 in pipe (Irwin & Export & Delmont)**			
Flow rate, gpm	Head loss	Net head	kW	kWh/yr	Head loss	Net head	kW	kWh/yr
3,000	2	18	8	65,000	1	19	9	69,000
4,000	3	17	10	80,000	1	19	11	90,000
5,000	5	15	11	89,000	2	18	14	108,000
6,364[A]	8	12	11	91,000	3	17	16	128,000
7,741	12	8	9	74,000	5	15	18	143,000
10,000	19	1	2	14,000	8	12	19	148,000
12,500	26	-6	0	0	11	9	17	132,000

[A] *average flow for the Irwin-only system*
[B] *average flow for the Irwin & Export & Delmont system*

One local use would be to power aerator units that are used under high flow conditions to assure good final effluent quality. One such aerator that has been installed at several sites in western PA is the Maelstrom Oxidizer, manufactured by Environmental Solutions, LLC. A system sized to aerate 6,000 gpm requires 36 kW of power. If a system was installed to aerate 3,000 gpm (approximately the excess flow under high flow conditions), its power needs would match the power production by the system under high flow (36 inch pipe alternative).

The use of aeration to decrease the size of the treatment system must be done cautiously because aeration appears to decrease the value of the iron oxide product. Samples of iron sludge collected at sites with aggressive aeration have, thus far, proven to have weak pigmentary characteristics and have not been marketable (Hedin 2006). If, through aeration, the iron sludge is rendered valueless, the cost to manage sludge (collect and dispose) is likely to far outweigh the cost savings realized by building a smaller system. The recommended action, at this time, is to construct as large a passive system as is reasonable, and consider the installation of aeration capabilities that are powered by the site's hydroelectricity generator. The aeration would only be used when the effluent of the system did not meet discharge targets.

C. Geothermal Heat Pump Opportunities

The constant temperature of the mine pool is a geothermal resource that can be harvested using conventional heat pump technology. The Irwin discharge has a constant temperature of approximately 13^{o}C (55^{o}C) and could be used as a heat source/sink. Tens of thousands of GSHP systems are in operation in the US. Locally, the Westmoreland Conservation District Barn is heated and cooled with a GSHP system. Mine pools are being used for GSHP applications, although the use is limited. In Nova Scotia, a 78,500 ft^2 manufacturing facility is completely heated and cooled with GSHP that is tied into a flooded underground coal mine. In Park Hills, Missouri, an 8,100 ft^2 municipal building is heated and cooled with a GSHP system tied to a flooded underground lead mine. Both applications involved drilling into the mine pools and extraction, by pumping, of mine water. The Irwin Discharge would use gravity to deliver the water to the heat exchange units, lessening operational costs. A possible location for heat exchange to occur is in the anoxic limestone drain. Primary heat exchange coils or plates would be placed in the ALD, where heat exchange would occur. The primary heat exchanger would heat/cool the secondary closed-loop system which would circulate between heat pumps in the residential or commercial structures. The mine water would not be used directly in the heat pumps because of the corrosive character of the water.

The double heat exchange system degrades the system's efficiency. Open loop systems where the water source feeds directly through the heat pump system can heat/cool 1000 ft^2 of building space for each gpm of flow. The Park Hills system pumps an alkaline mine water that contains elevated Fe (like Irwin Discharge). To avoid fouling of the heat pumps, the system utilizes the double heat exchange system, at a loss of efficiency. The Park Hills system uses one gpm of flow to heat/cool each 100 ft^2 of building space. While a backup system is installed in Park Hills, it is rarely needed and the system has been able to meet heating targets even when outside temperatures are below 0^{o}F. The annual cost of operating the Park Hill GSHP system was 30% less than the alternative natural gas and electricity system.

Assuming that a double heat exchange is utilized that is as efficient as the Park Hills system (100 ft^2 of heating space per gpm) , then the Irwin Discharge could support provide the heat source for 400,000 – 800,000 ft^2 of office or commercial space. The energy produced from the system, if fully utilized, would be 4-7 million kWhr per year of heating, with a value of $200,000 – 400,000 per year. This scale of GSHP system is far beyond the scope of anything implemented in Pennsylvania to date and it is difficult to imagine how this much commercial space could be developed near the ALD. Partial extraction of energy from the ALD is probably most likely. The calculations show, however, that the extraction of energy from the discharge is worth investigating further.

The heat exchange process usually decreases the water temperature by 4-5^{o}C. This change in temperature is unlikely to substantial affect the performance of the passive system, where the water temperature is eventually brought to equilibrium with the ambient temperature, regardless of the inflow temperature.

The recovery of energy from a flowing mine discharge has never been attempted. It is recommended that a pilot system be implemented so that the problems (and advantages) of this innovative concept can be explored. The pilot system should allow an evaluation of both energy exchange aspects and the impact that the change in water temperature has on passive treatment processes.

D. Potable Water

The passive treatment system will discharge 6-12 million gallons per day of water directly to Brush Creek. A portion of this water could be collected, further treated, and sold. The degree of water treatment depends on the end user. Two potential users are envisioned. The first user would require a large quantity of water, but would not have high quality standards. This user does not need the quality of water supplied by the Westmoreland Water Authority, at a cost of $3/1000 gallon. Specifically, the user would need to be tolerant of water with 300-400 mg/L hardness ($CaCO_3$) and 600-800 mg/L sulfate. Such water could be produced from the treatment system effluent with sand filtration and disinfection. The unit cost of production would rely on the production volume, but a cost of $0.50 per 1000 gallons is likely achievable.

The second user is an industrial customer who requires large quantities of pure water. Possible users are pharmaceutical, chemical, and computer chip manufacturers. These industries can consume 500-2000 gpm of water that is more pure (lower total dissolved solids) than can be delivered by a municipal water supplier. These industries routinely operate in-house water purification units that produce ultrapure water from tap water. Recently, companies with high water demands have had problems obtaining reliable long-term supplies of large (>500 gpm) quantities of water. Water from the Irwin Treatment system might be further treated to meet these companies' minimum needs, and sold in high volume, long-term contracts.

Veolia North America, a major water treatment and water management firm in the US, was contacted about the treatment of the discharge of the Irwin treatment system to a condition saleable to an industrial user. Water samples and analyses were provided and a treatment plan using nanno-filtration to decrease the total dissolved solids to a saleable level was developed. Costs were developed for a plant that produced 2,800 gpm of product water containing <10 mg/L hardness, <20 mg/L sulfate, and <300 mg/L total dissolved solids. The cost range for the product was estimated at $2.60 - $3.10 per 1000 gallons. This cost is higher than would be the case if municipal water was used as the influent. The attractive element of the concept would be the availability of a large volume of water over a long-term period.

V. Putting it All Together

The Irwin Discharge provides an opportunity to combine several state-of-the-art technologies in a manner that treats mine drainage at a low cost and provides unique economic development potentials. Figure 12 shows the aggregate conceptual plan. The discharge is collected and piped 9,000 feet to the treatment site, which is 20 feet lower in elevation. A low-head hydropower generator placed at the end of the pipe generates 90,000 – 140,000 kWh/yr of electricity that can be used to lower operational costs of the treatment system. The water flows into an anoxic limestone drain that adds alkalinity to the water. Heat exchange units are placed within the ALD, that are connected via a closed loop system to heat pumps placed in local buildings. The heat exchange system has the potential to generate 4,000,000 kWh/yr of heat energy, if the demand can be developed. The water flows from the ALD and is split into a dozen flows that each flow to a series of three settling ponds designed to promote iron oxide production and recovery. The ponds produce about 1,000 ton/yr of iron oxide that is processed and sold as pigment. The settling ponds discharge to large constructed wetlands that remove the residual iron and produce a final effluent to Brush Creek that contains <2 mg/L Fe. The constructed wetlands – 30 acres of diverse, dense wetland vegetation – are an ecological sanctuary that provide waterfowl habitat. A portion of the system's discharge is available for removal, further treatment, and sale to local industrial customers. The remaining water discharges to Brush Creek, and contributes substantially to the restoration of Brush Creek and improved water quality in Turtle Creek.

Table 22 compares the total costs estimated for three alternatives: 1) conventional lime treatment, 2) passive treatment of the Irwin&Ex&Del alternative without resource recovery, and 3) passive treatment of the Irwin&Ex&Del alternative with resource recovery. The conventional lime costs were presented in Section 3F. The passive treatment with resource recovery costs were presented in Section 3E. This scenario assumes that the iron oxide that is produced in the settling ponds is recoverable and saleable as pigment and there are no sludge management costs. The system costs were developed with features that facilitate the production and recovery of saleable iron oxide.

The alternative where passive treatment occurs but without attention to resource recovery requires lower capital costs, but includes sludge management costs. The settling ponds can be built without features that assure the purity of the iron or make sludge recovery easier. Removal of these features lessens the cost of the settling ponds by about $400,000. The ALD and the wetland are not affected by iron oxide recovery concerns. Sludge management costs were estimated by assuming that the annual production of iron sludge is removed and disposed of in an abandoned mine. The disposal site would need to be developed by drilling a large diameter hole and installing pumping equipment. A capital cost of $250,000 is estimated. Sludge would be pumped from the settling ponds into tankers and trucked to the disposal site. The passive system will produce about 2,500,000 lb/yr of iron oxide which has a wet volume of about 1,250,000 gallons (25% solids). Assuming that the sludge is pumped from the ponds for $0.10 per gallon, and trucked to the disposal site for $5/ton, then the annual costs would be $150,000/yr.

Both of the passive scenarios are assumed to have a $50,000 general O&M cost. It is envisioned that a private company will be hired to regularly inspect the system, collect water samples, assure that it is functioning as expected, and provide regular reports to the PADEP and County.

The conventional treatment approach has a 20 year total present value cost of $20 million. It is unlikely that the water quality benefits of the treatment would justify such a high public investment.

The passive treatment approach, *without* resource recovery is about 60% lower than the conventional lime alternative. The passive approach with resource recovery is 70% less expensive than the conventional lime alternative and 25% less expensive than the passive *without* resource recovery alternative. These comparisons are made of using the 20 year present value analysis. When the analysis is extended to 50 or 75 years – the time frame commonly used for these analyses, the differences are greater. The inclusion of $400,000 of extra costs for features that enhance resource recovery is economically justified by the $150,000 per year savings in sludge management costs. These resource recovery costs are uneconomical if sludge can be managed (disposed of) for less than $30,000 per year (20 year present value analysis). This is not a realistic expectation given the volume of the sludge and current management technologies.

Table 22. Comparative Cost of Treatment Alternatives: Passive alone, Passive with Resource Recovery, and conventional lime treatment.

	Conventional lime	**Passive, no RR**	**Passive with RR**
Initial Capital Costs			
AMD collection and pipeline	$600,000[A]	$1,100,000	$1,100,000
Construct Treatment Facility	$7,000,000	$3,300,000[B]	$3,700,000
Total Capital Costs	$7,600,000	$4,400,000	$4,800,000
Annual Costs			
Maintain pipeline	Included	$10,000	$10,000
Operate treatment facility	$1,000,000	$50,000	$50,000
Sludge Management	Included	$150,000	$0
Total Annual	$1,000,000	$210,000	$60,000
Present Value of O&M			
20 yr, 4% net	$13,600,000	$2,800,000	$800,000
50 yr, 4% net	$21,500,000	$4,500,000	$1,300,000
75 yr, 4% net	$23,700,000	$5,000,000	$1,400,000
Present Value of O&M and Capital			
20 yr, 4% net	$20,200,000	$7,300,000	$5,600,000
50 yr, 4% net	$28,100,000	$8,900,000	$6,100,000
75 yr, 4% net	$31,300,000	$9,400,000	$6,200,000

[A] *The lime plant is assumed to be placed at a location along Brush Creek closer than the passive treatment site*
[B] *The settling ponds in this option do not contain liners or aggregate.*

The financial analyses in Table 22 do not consider the added capital or economic return of GeoExchange, hydroelectricity, water treatment and sales, and advanced iron oxide processing. Each of these has the potential to provide an economic benefit to the local community, but net cost of each is difficult to estimate because each is either novel or proposed at an unprecedented scale. If these energetic, water, and materials benefits prove practical, it is possible that the Irwin treatment system could be the stimulus for local economic revitalization and development that promotes "Green" principles and design standards. If realized, the Irwin Discharge would be transformed from a monstrous environmental liability into an asset that benefits not just Brush Creek but local communities and Westmoreland County in ways never envisioned before.

VI. Next Steps

In 2005, taxpayers in Pennsylvania approved the Growing Greener II referendum which authorized the borrowing of $600 million for environmental projects. Much of the funding will be spent in the next six years. A major component of the program is the restoration of streams polluted by AMD, with a stated emphasis on projects that also create economic benefits and/or generate energy products. The Irwin Discharge appears to fit the Growing Greener II goals.

In January 2005, the Bureau of Abandoned Mine Reclamation (PADEP) requested proposals for the projects that address AML concerns and create economic benefits. A proposal to advance the Irwin Discharge treatment project ways prepared and submitted by Turtle Creek Watershed Association. The proposal outlined a plan to develop public support for the project, obtain property easements for the project, develop construction plans suitable for bidding, and obtain all necessary permits. The proposal described the development of a Green Enterprise Zone around the treatment system where energy, water, and material (iron oxide) products harvested from the system would be used to attract commercial and industrial development. Funds to develop the Green Enterprise Zone elements were not requested. The Pennsylvania Environmental Council indicated that, if the AMD treatment component of the project was funded, it would work to develop the Green development aspects. The proposal is attached in Appendix 4.

The proposal was not funded. DEP indicated in a debriefing that the proposal was ranked second, but funding was only available to fund one project. The Department recommended resubmittal of the proposal through the Growing Greener Program.

The County and Turtle Creek Watershed Association must decide if remediation of the Irwin Discharge is enough of a priority to proceed with the project. It is possible that the proposed passive treatment system with resource recovery opportunities could be implemented with little expenditure of County Funds. At this time, there is no financial match requirement for design and permitting projects (submitted through Growing Greener I) and the proposed match on construction projects is only 5% (submitted through Growing Greener II).

The Green aspects of the project (hydroelectricity, GeoExchange, water sales) can likely be advanced through other PADEP funding mechanisms. The Commonwealth's Energy Harvest Program supports projects that create renewable energy and provide environmental benefits. It is possible that the Program would finance the capital costs of the hydroelectric generator. The GeoExchange opportunities should be explored in a pilot scale system where AMD in a treatment system is used to power a GBHP system. Because this use of AMD had wide application in PA, the Energy Harvest Program would likely support such a proposal.

In conclusion, this report's analyses have shown that changes in water chemistry and advances in mine drainage treatment technologies have substantially reduced the cost for remediation of the Irwin Discharge. The estimated 20-year present value total cost for a passive system that produces an iron oxide product is $5.6 million. While the project costs could likely be justified simply on environmental benefits, the economic benefits produced by energy, water, and iron oxide products make the economic assessment particularly beneficial. The goals of the project are consistent with the Greener Greener II Program and funding can likely be obtained.

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Appendices

Appendix 1: Complete Chemistry Results

Appendix 2: Complete Elevation Survey Results

Point	Elevation	Point Description
1	879.3	Large pipe outlet, top of curve
2	876.5	Small pipe outlet, top of curve
3A	875.0	Tinker Run at discharge (stream bottom)
3B	882.6	Tinker Run at discharge (top of bank)
4A	884.7	Base of hill where the discharge may be located (near building)
4B	882.1	Top of Manhole
4C	876.0	Bottom of Manhole
4D	880.2	Water surface in manhole (4/5/05)
5A	837.6	Brush Creek above Barners (stream bottom)
5B	845.4	Brush Creek above Barners (top of bank)
6	865.3	Railroad above Barners
7A	820.9	Brush Creek below Barners (stream bottom)
7B	827.1	Brush Creek below Barners (top of bank)
8	857.7	Railroad below Barners
9	872.2	Route 993 at Westmoreland Street
10	903.4	Intersection Westmoreland & Glass Streets
11	926.7	South end Westmoreland Street
13	883.2	Intersection Pacific & Glass Streets
14	874.5	Route 993 at Pacific Street
15	865.8	Tinker Run (stream bottom) at Brush Creek
15N	865.1	Brush Creek (stream bottom) at Tinker Run
16	864.3	Brush Creek (stream bottom) at Westmoreland Street
17	879.5	Rail siding at Tinker Run
18	879.6	Rail siding at Westmoreland Street
19	880.4	Route 993 at Bridge 1
20A	860.3	Brush Creek (stream bottom) at Route 993 at Bridge 1
20B	868.5	Brush Creek (top of bank) at Route 993 at Bridge 1
21	873.7	Route 993 (east edge) at Bridge 2
22A	854.0	Brush Creek (stream bottom) at Route 993 at Bridge 2
22B	861.4	Brush Creek (top of bank) at Route 993 at Bridge 2
23	875.3	Route 993 (east edge) near rail road
24	851.4	Brush Creek (stream bottom) between Route 993 and railroad
25	891.9	Juncture of railroad and old rail siding
26A	882.1	Rail siding near points 21 and 22
26B	885.3	Rail siding at Russel Standard driveway

Appendix 3: Hydrologic Report by Bill Winters, University of Pittsburgh

Appendix 4: Proposal submitted to PADEP Bureau of Abandoned Mine Reclamation in May 2005.

Figure 1. Deep mines and discharges in the Irwin Basin. The Irwin Discharge is #4.

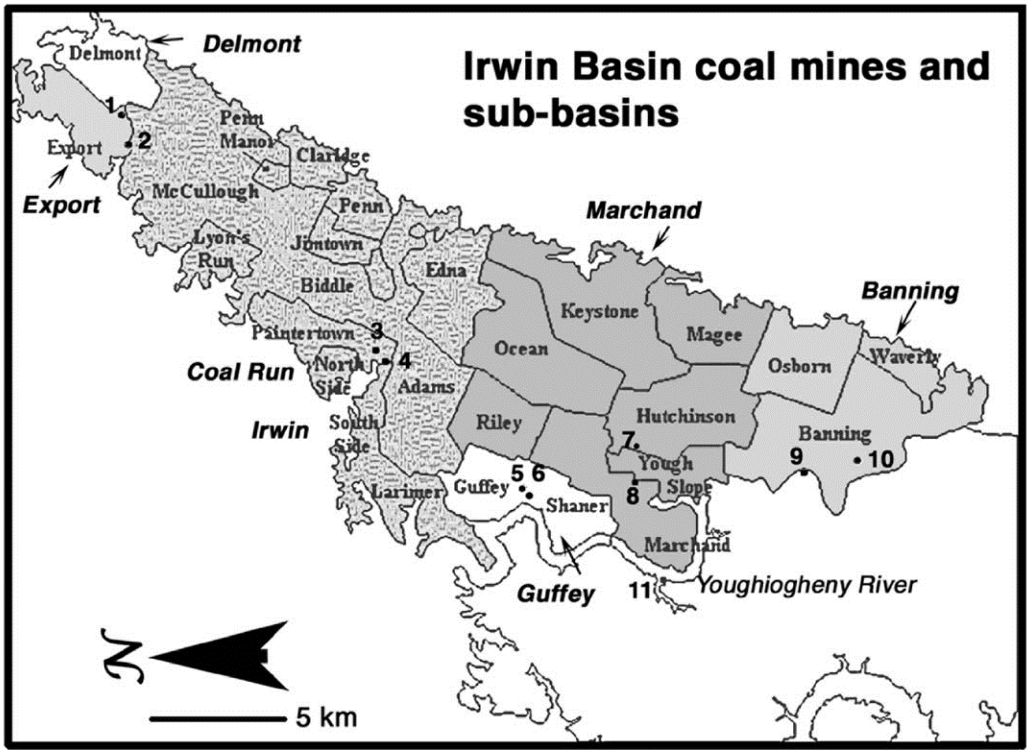


Figure 2. South Side Mine drainage way.

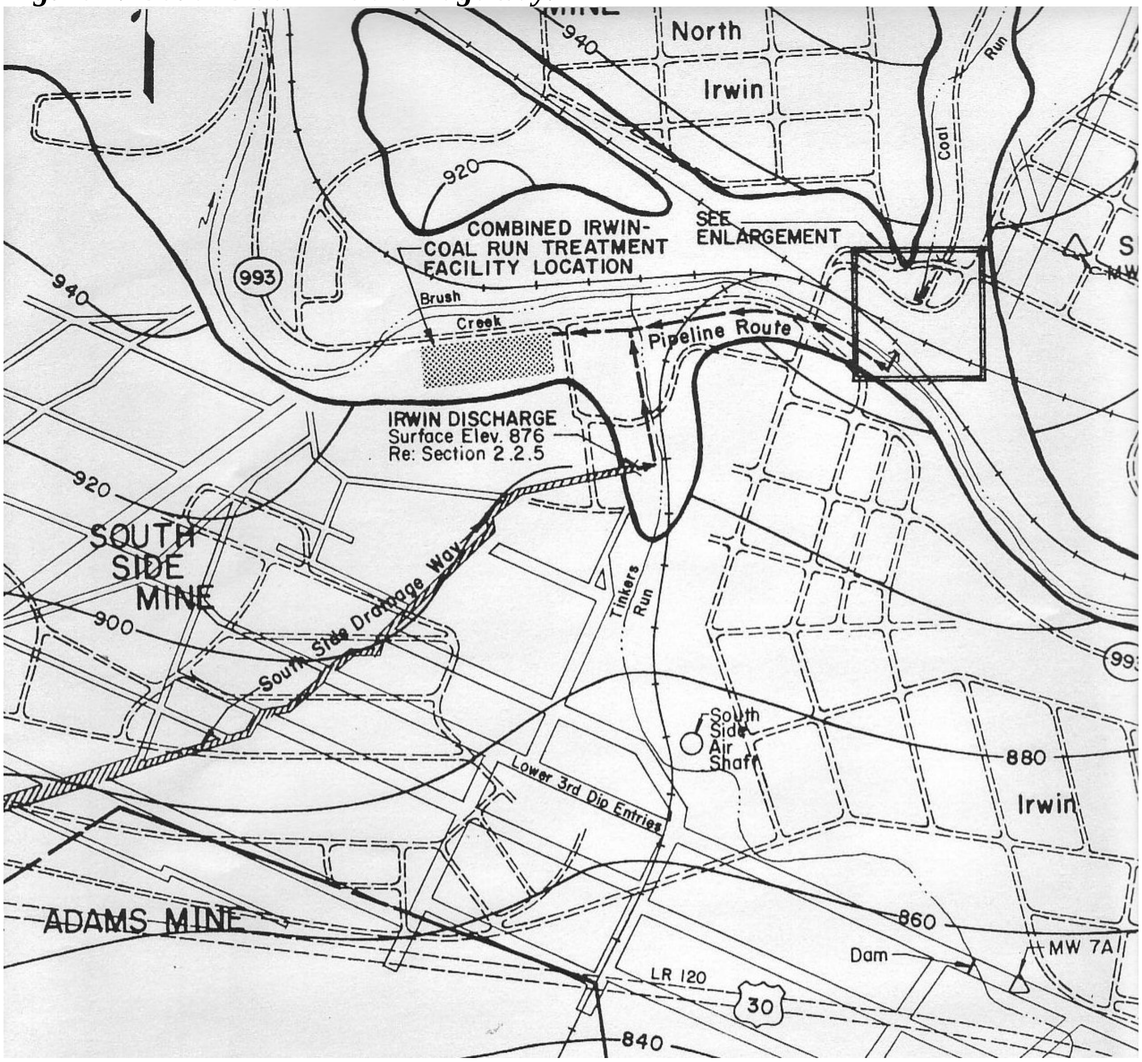


Figure 3. Current Irwin Discharge configuration.

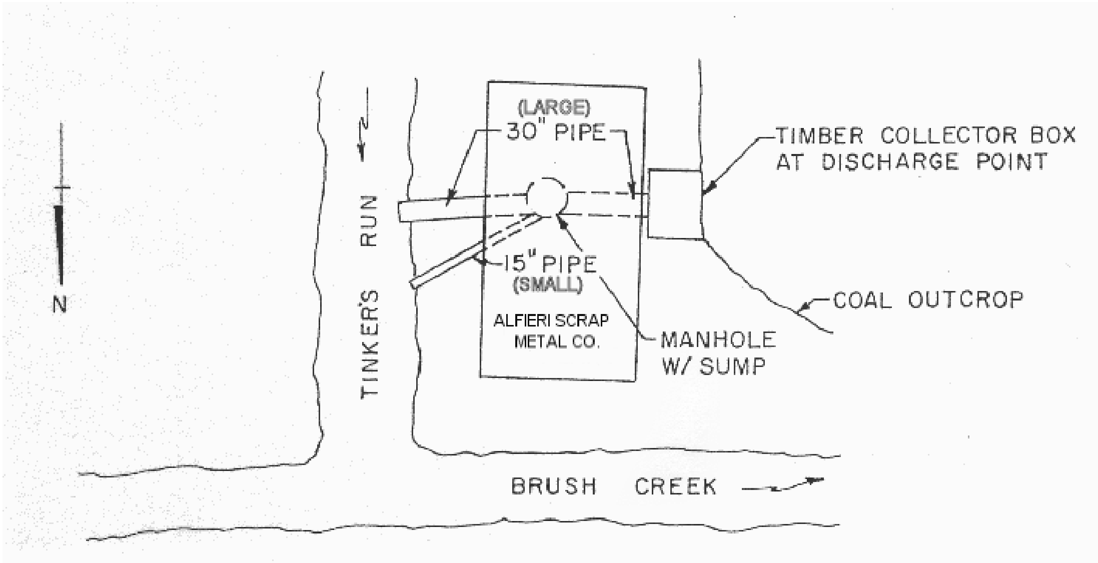


Figure 4a : Relationship between measured flow and depth to water for the Irwin large pipe.

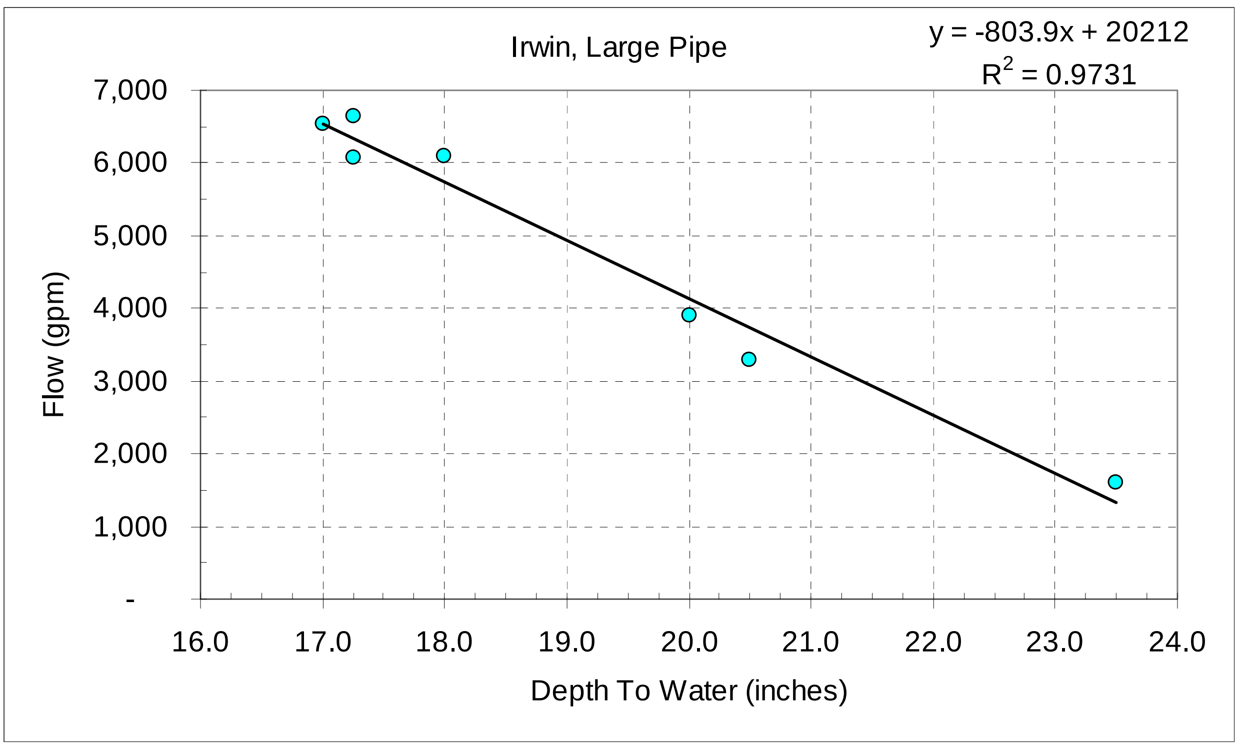


Figure 4b : Relationship between measured flow and depth to water for the Irwin small pipe.

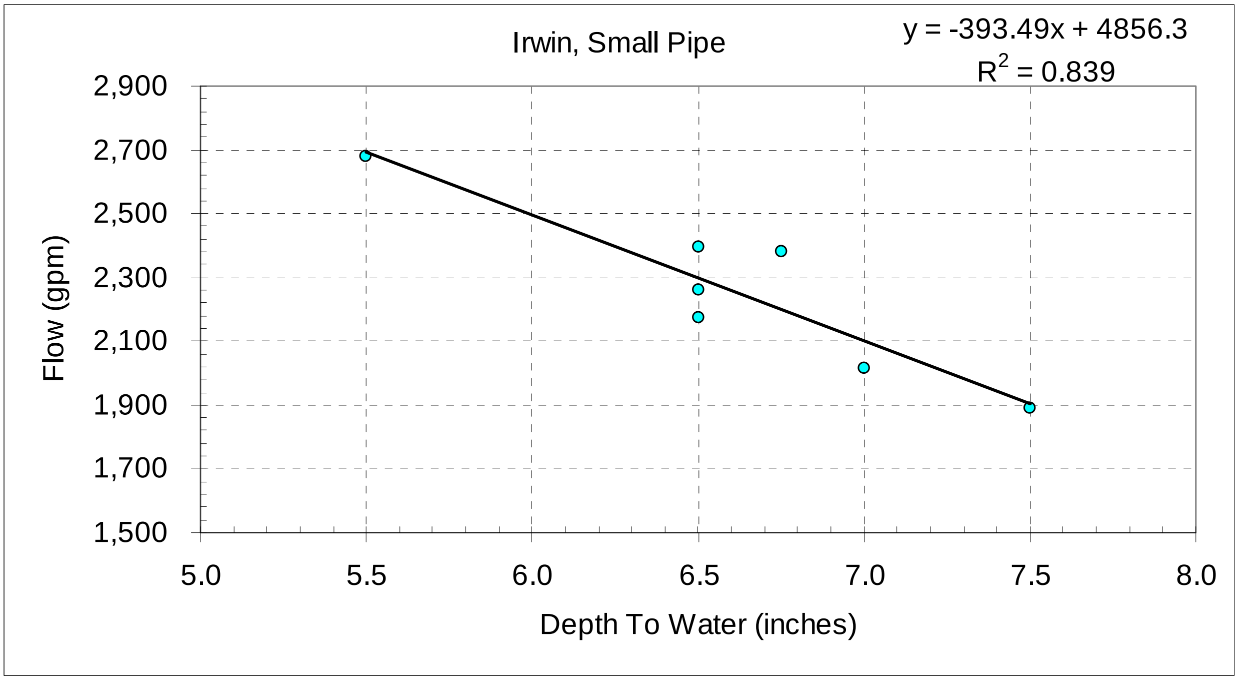


Figure 5: Irwin Discharge Flow Rates.

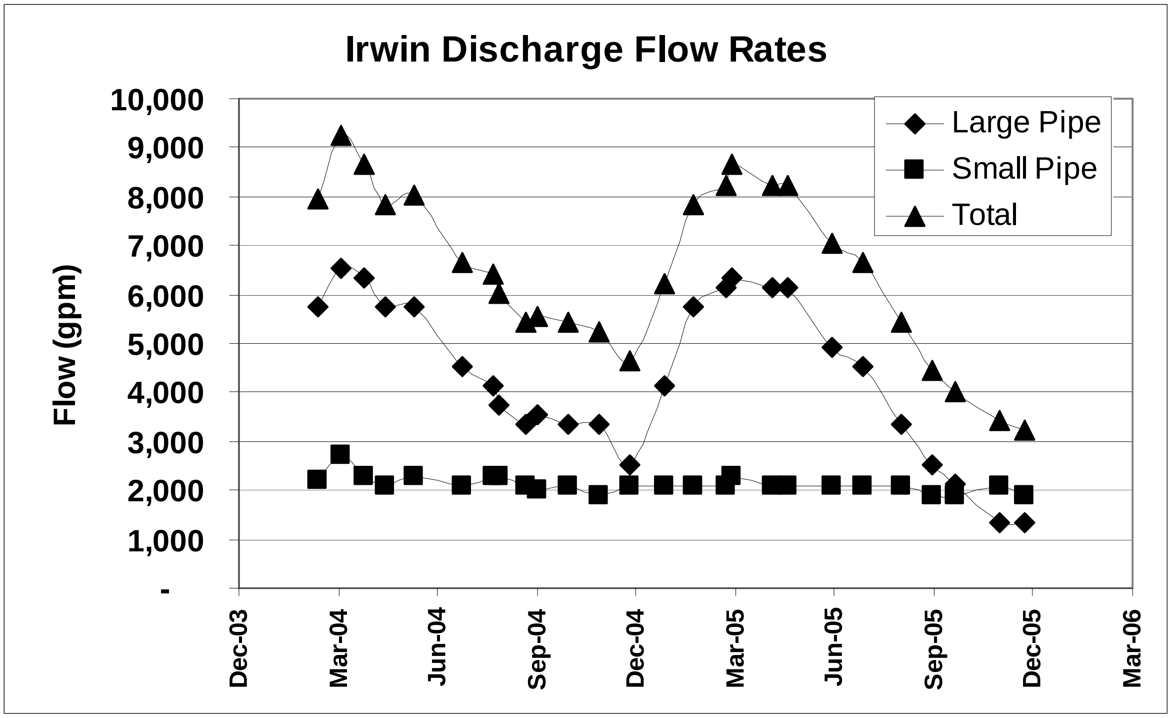


Figure 6. Irwin Discharge and precipitation.

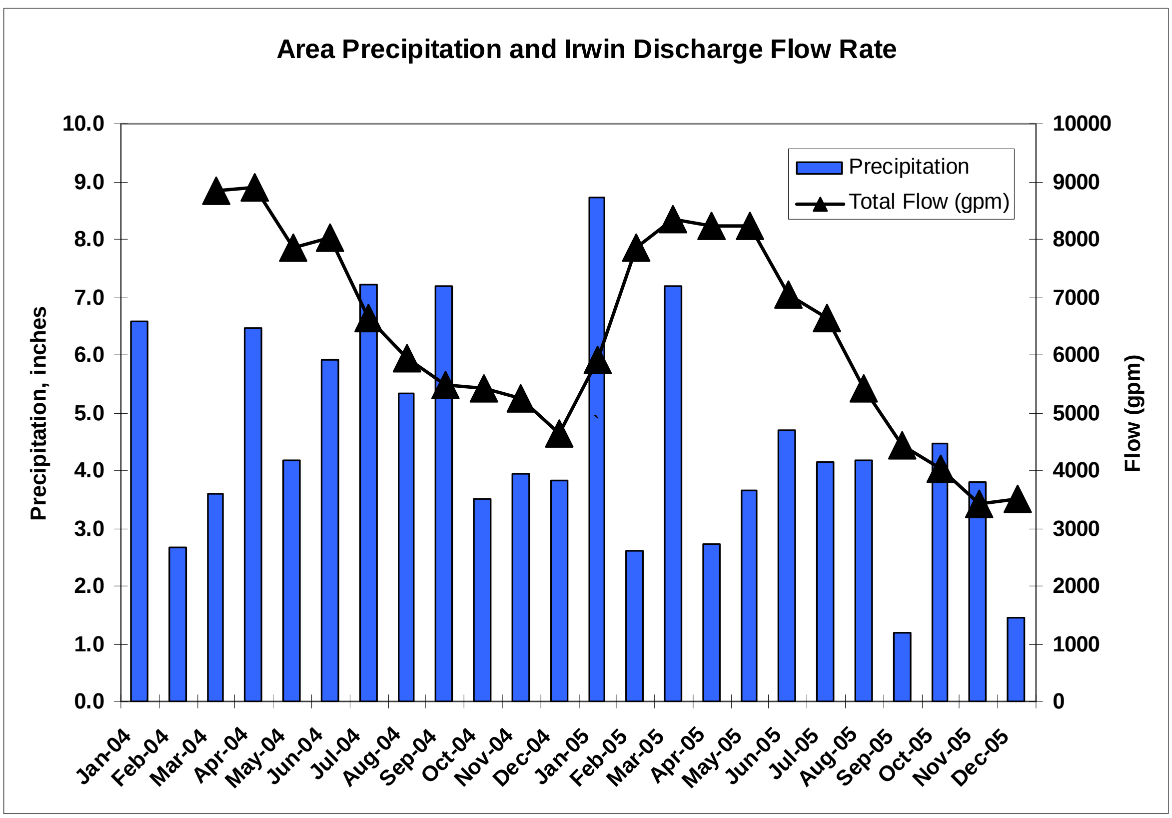


Figure 7. Relationship between flow rate and iron concentration for the Irwin Discharge, 2004/05.

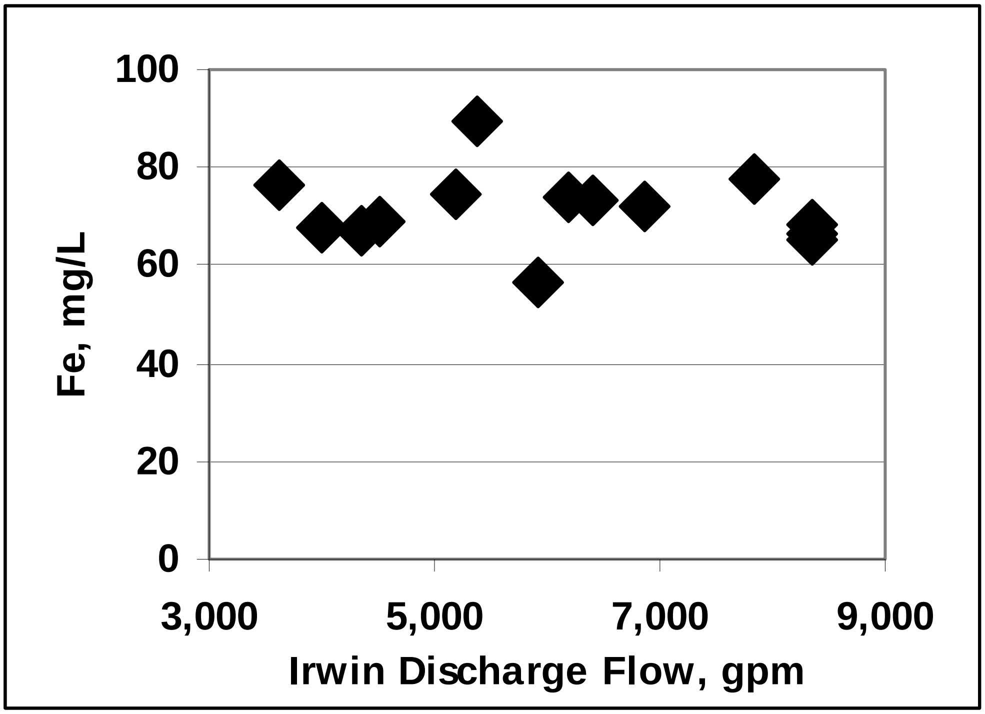
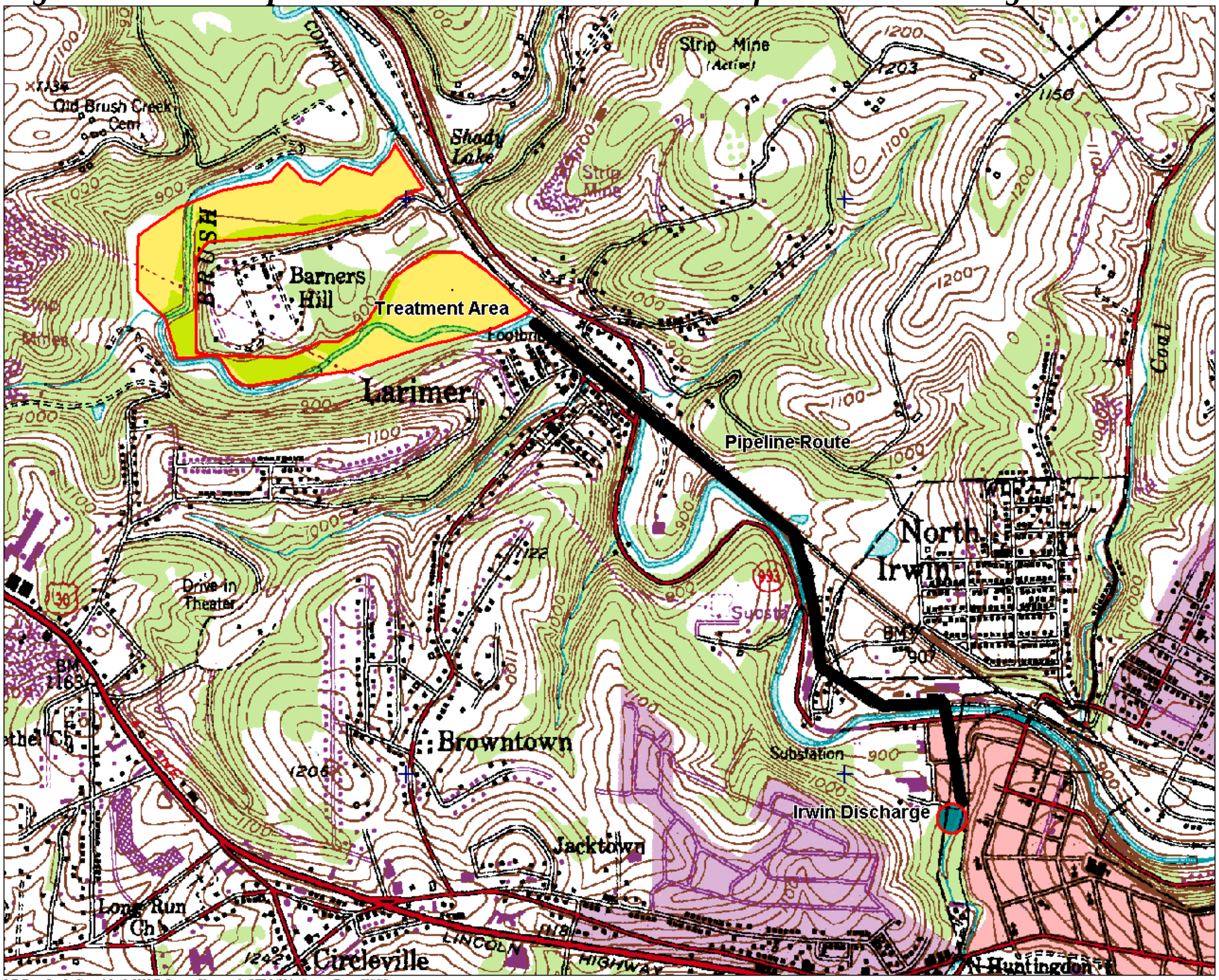


Figure 8. Potential passive treatment area downstream of the Irwin Discharge



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 450 ft Scale: 1 : 16,000 Detail: 13-0 Datum: WGS84

Figure 9: Elevation Survey Points.

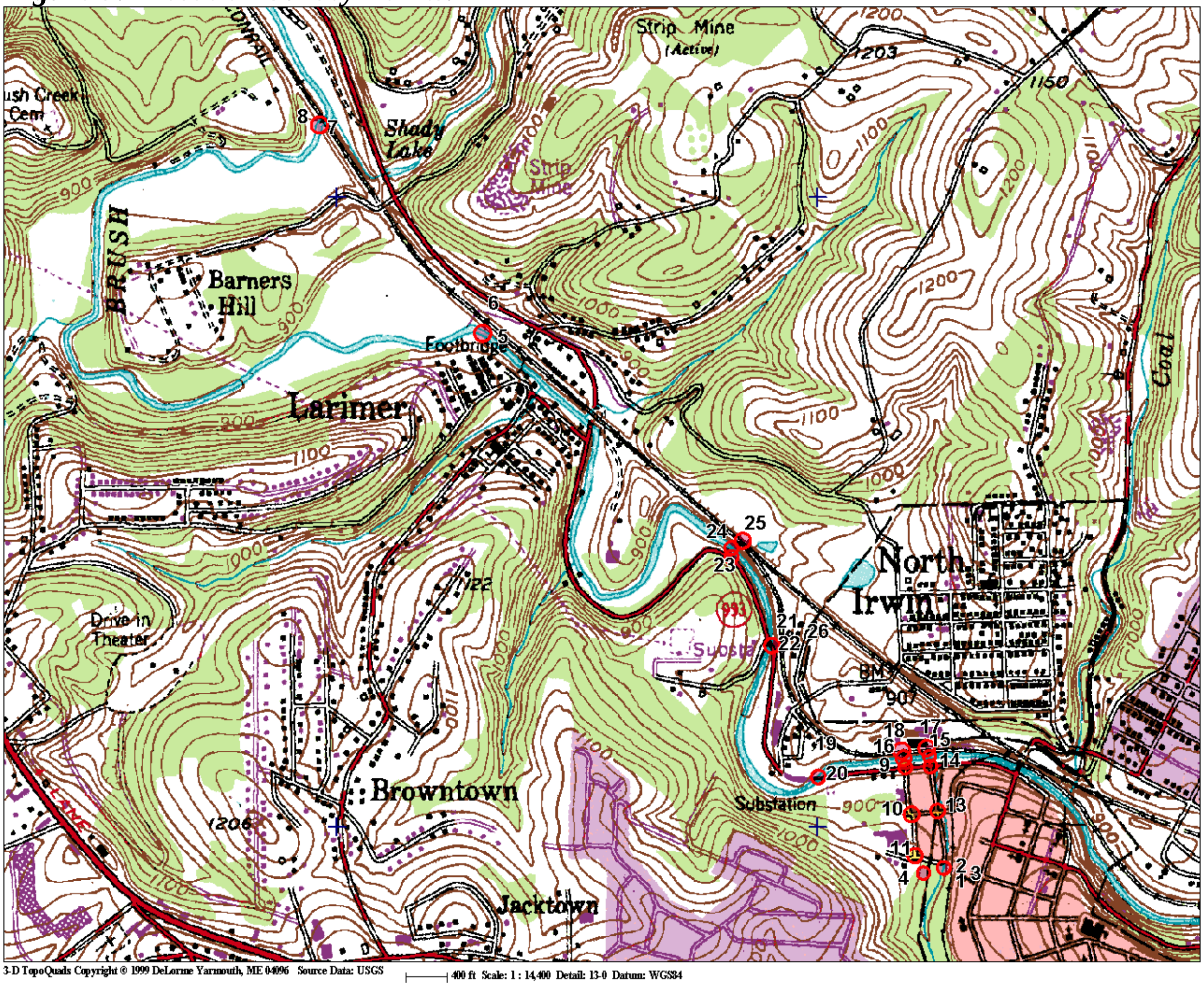


Figure 10. Property parcels (defined by elevation and Brush Creek) downstream of the Irwin Discharge. The letter refer to parcels identified in Table 16.

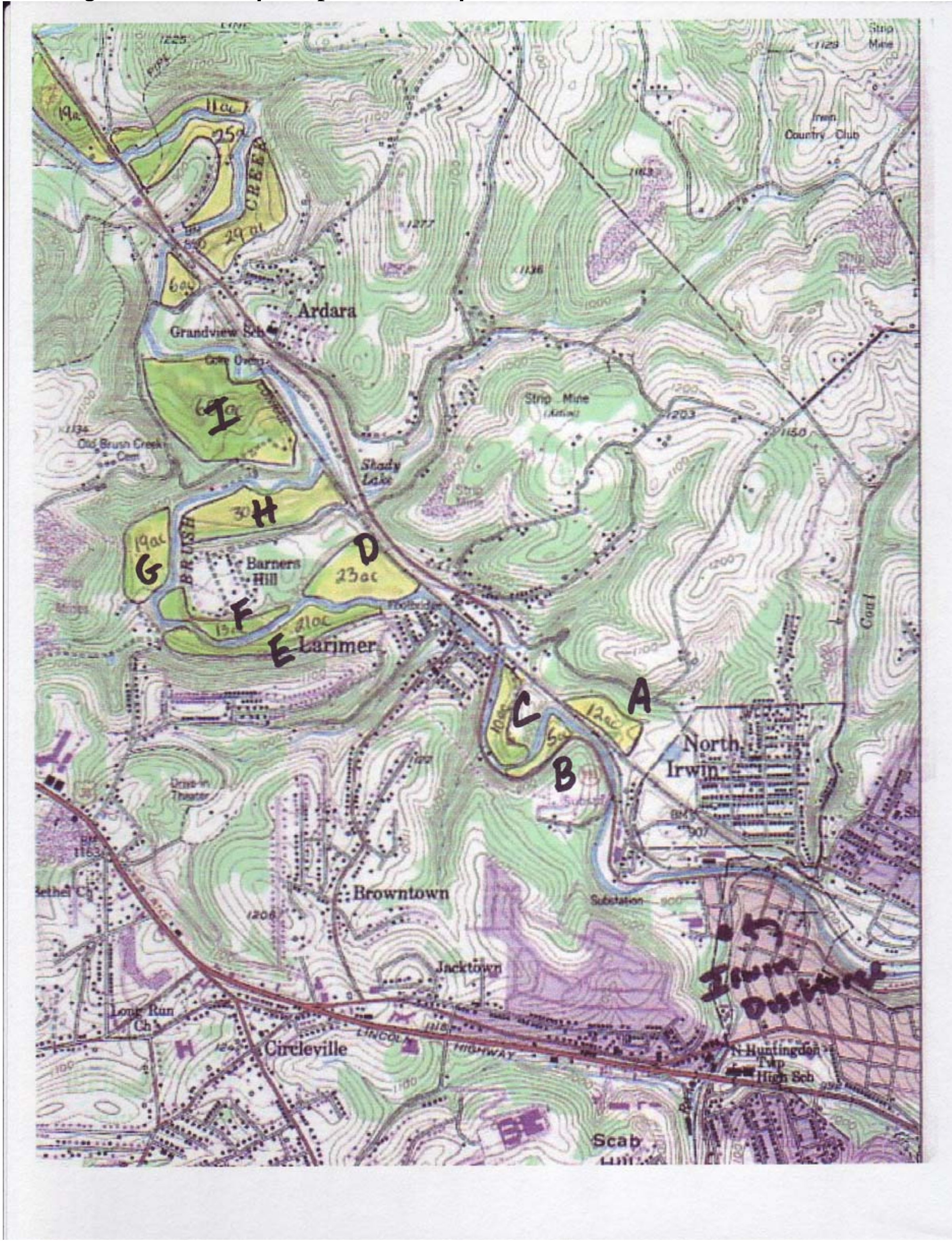


Figure 11. Benefit Stream from Irwin Discharge Passive Treatment System.