TMDLs & Treatment of Abandoned Mine Drainage

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TMDLs & Treatment of Abandoned Mine Drainage by Charles A. Cravotta III, USGS, New Cumberland, PA

The "some-treatment-is-better-than-none" approach is a common watershed restoration strategy for abandoned mine drainage (AMD) in Pennsylvania. This approach has been effective for the implementation of watershed restoration plans but has not supported the development and implementation of the best available treatment technology and has led to uncertainty in the results of AMD treatment. The consideration of various regulatory criteria for stream-water quality, such as those considered for "total maximum daily loads" (TMDLs) for mining-affected watersheds could lead to improved methods for the selection, design, and performance of passive treatment and an improved basis for the implementation and funding of watershed restoration strategies that target AMD. Balance is needed between current strategies for the passive treatment and regulation of AMD.

The Commonwealth of Pennsylvania stipulates that effluent from a coal mine permitted after passage of the Surface Mining Control and Reclamation Act of 1977 must have alkalinity > acidity and an instantaneous maximum concentrations of iron (< 7 mg/L), manganese (< 5 mg/L), and aluminum (< 0.75 mg/L). The average daily concentration of sulfate must not exceed 250 mg/L for discharges that could affect public water supplies. Mining companies must ensure these criteria are met, or face legal penalties. Consequently, treatment methods for active mine discharges typically utilize costly chemical reagents and energy inputs based on their reliability to consistently meet effluent criteria.

In contrast, effluent criteria generally are not applied for discharges from coal mines in Pennsylvania that were abandoned before 1977. Treatment of AMD typically is conducted by government or citizen groups with a goal of improving the local environment and rarely considers meeting effluent criteria. Generally, the prevailing approach for these pre-1977 AMD discharges is that any treatment is better than none, and low-cost treatment options are desirable. Consequently, passive-treatment methods for AMD commonly use limestone and other low-cost materials and tend to be less reliable or predictable for meeting effluent criteria than active-treatment methods. (continued next page)

Although they are rarely considered, existing aquatic criteria could provide a regulatory framework for the design and treatment of AMD, and various modeling tools could be used to evaluate passive-treatment performance and downstream effects. In-stream criteria for chemical constituents have been incorporated in recent TMDLs for mining-affected watersheds. A TMDL is a mathematical model for a specific pollutant's) that considers input loadings from all known sources, including AMD, above the stream reach and establishes loading limits on these sources based on the water-quality characteristics and assimilatory capacity of the stream. The criteria for TMDLs generally are consistent with those established to meet the warm-water fishery (WWF) or cold-water fishery (CWF) designation of a stream or other freshwater body:

- temperature during July and August not to exceed 66°F (18.9°C) or 87°F (30.6°C) for CWF and WWF, respectively;
- dissolved oxygen concentration greater than 5.0 mg/L for CWF and 4.0 mg/L for WWF;
- alkalinity not less than 20 mg/L as $CaCO_3$, except where natural conditions are less;
- pH not less than 6.0 or greater than 9.0;
- total iron concentration not to exceed 1.5 mg/L as a 30-day average;
- dissolved iron concentration not to exceed 0.3 mg/L;
- total manganese concentration not to exceed 1.0 mg/L; and
- total aluminum concentration not to exceed 0.75 mg/L.

Additional U.S. EPA water-quality criteria for the protection of freshwater aquatic life also have been adopted by the Commonwealth of Pennsylvania. These criteria recommend continuous and maximum exposure limits for cadmium, nickel, zinc, and other trace metals. Criteria for protection of benthic aquatic organisms from metals in streambed or lakebed sediments are available but not adopted by regulatory authorities in the U.S.

Performance of treatment systems generally is indicated by the removal of metals and acidity at the site of treatment. However, the pollutant load removed within the treatment system does not necessarily translate to a corresponding load reduction downstream. Iron, aluminum, and other pollutants from AMD sources can be precipitated within the stream; the attenuated fraction contributes to streambed degradation but reduces the in-stream load at downstream points, particularly during base flow. Consequently, considering a TMDL load reduction goal for a downstream reach, a greater quantity of pollutants may need to be removed at upstream AMD sources to achieve the TMDL. Nevertheless, passive treatment designs rarely assure effluent quality that would meet TMDL goals or other criteria. Most systems are constructed recognizing that some treatment will improve downstream conditions, but with uncertain results.

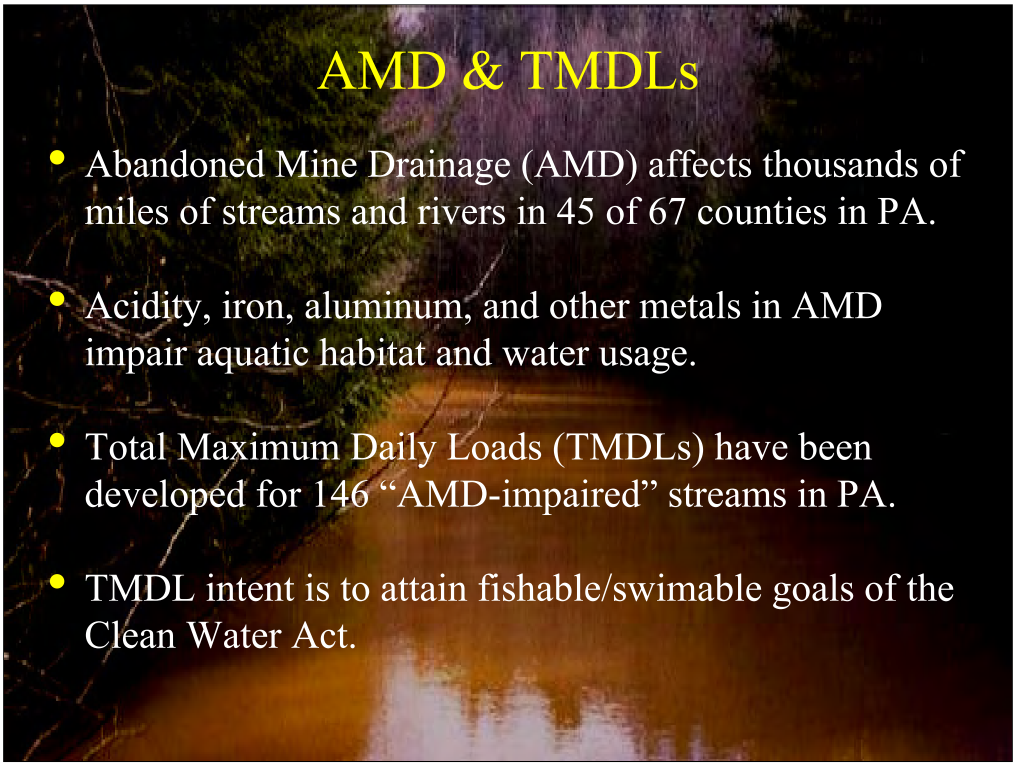
In conclusion, those who design and fund treatment are commonly willing or forced to accept uncertain results. TMDLs and corresponding AMD restoration strategies that consider (1) chemical and other sources of aquatic degradation; (2) potential for “natural attenuation” of pollutants within the stream; (3) effects of treatment on chemical load, temperature, and dissolved oxygen of downstream reaches; and (4) treatment designs that result in predictable reductions in pollutants to meet TMDLs while maintaining favorable attributes of some AMD sources such as sustained base flows of constant-temperature water favored by trout and other fish are likely to succeed in improving stream quality. The implementation of TMDLs and adoption of aquatic criteria could lead to improved methods for the selection, design, and performance of passive treatment and an improved basis for the selection and funding of watershed restoration alternatives, but also could limit the support provided for watershed restoration. Both support for restoration efforts and improvement on treatment technologies can be achieved with planning and funding.

Conclusions

- AMD cleanup strategies can succeed considering:
  - ✓ chemical sources and transport processes;
  - ✓ "natural attenuation" of pollutants within watershed;
  - ✓ treatment designs that result in *predictable and measurable* reductions in pollutants to meet TMDLs;
  - ✓ effects of treatment on temperature and dissolved oxygen of AMD and downstream reaches.

CONCLUSIONS:

In conclusion, those who design and fund treatment are commonly willing or forced to accept uncertain results. TMDLs and corresponding AMD restoration strategies that consider (1) chemical and other sources of aquatic degradation; (2) potential for "natural attenuation" of pollutants within the stream; (3) effects of treatment on chemical load, temperature, and dissolved oxygen of downstream reaches; and (4) treatment designs that result in predictable reductions in pollutants to meet TMDLs while maintaining favorable attributes of some AMD sources such as sustained base flows of constant-temperature water favored by trout and other fish are likely to succeed in improving stream quality. The implementation of TMDLs and adoption of aquatic criteria could lead to improved methods for the selection, design, and performance of passive treatment and an improved basis for the selection and funding of watershed restoration alternatives, but also could limit the support provided for watershed restoration. Both support for restoration efforts and improvement on treatment technologies can be achieved with planning and funding.



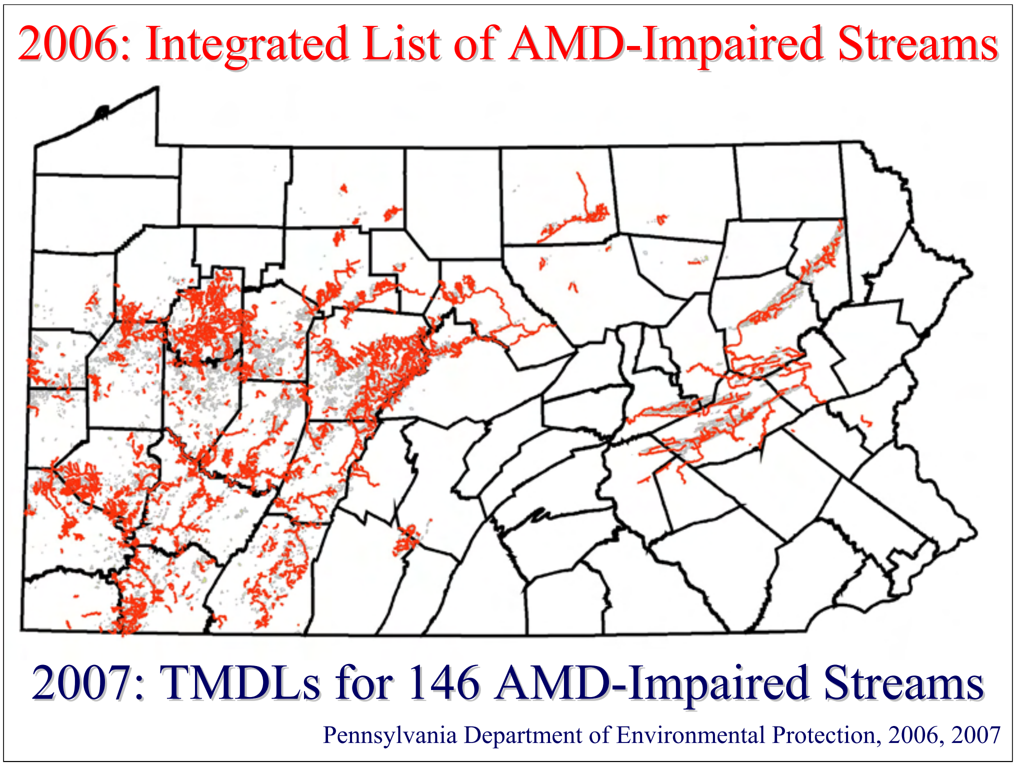
AMD & TMDLs

•Abandoned Mine Drainage (AMD) affects thousands of miles of streams and rivers in 45 of 67 counties in PA.

•Acidity, iron, aluminum, and other metals in AMD impair aquatic habitat and water usage.

•Total Maximum Daily Loads (TMDLs) have been developed for 146 “AMD-impaired” streams in PA.

•TMDL intent of attaining fishable/swim able goals of the Clean Water Act.



2006: Integrated List of AMD-Impaired Streams – thousands of miles of streams in 45 of 67 counties PA.

2007: TMDLs for 146 AMD-Impaired Streams – Since 1999 to date, TMDLs have been developed for 146 streams and are planned for others based on year that stream was listed.

What is a TMDL?

- **TMDL = “Total Maximum Daily Load”**
- Maximum amount of pollutant that a stream can assimilate without exceeding water-quality standards.
- TMDL process is a planning tool to indicate pollution-reduction goals to meet water-quality standards.
- TMDL accounts for point sources, nonpoint sources, and margin of safety.

PaDEP, 2002; Dillon, 2006

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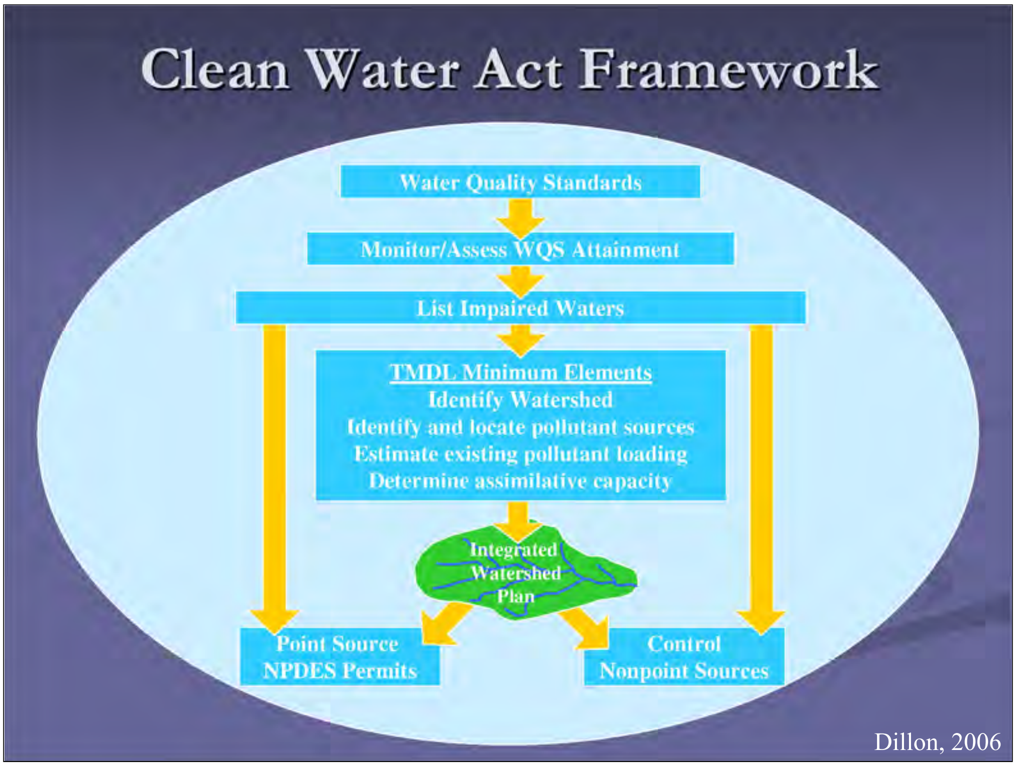
Relevant Water-Quality Standards

- ✓ Alkalinity > 20 mg/L (*for AMD: net acidity < 0*);
- ✓ $9 \geq \text{pH} \geq 6$ (*for AMD: net acidity < 0*);
- ✓ Iron, dissolved $\leq$ 0.3 mg/L & total $\leq$ 1.5 mg/L (30-day avg);
- ✓ Manganese, total $\leq$ 1.0 mg/L;
- ✓ Aluminum, total $\leq$ 0.75 mg/L;
- ✓ Temperature, $\leq$ 66°F for CWF or $\leq$ 87°F for WWF; and
- ✓ DO $\geq$ 5.0 mg/L for CWF or $\geq$ 4.0 mg/L for WWF;

Commonwealth of Pennsylvania, 2002; PaDEP, 2002

The criteria for TMDLs generally are consistent with those established to meet the warm-water fishery (WWF) or cold-water fishery (CWF) designation of a stream or other freshwater body:

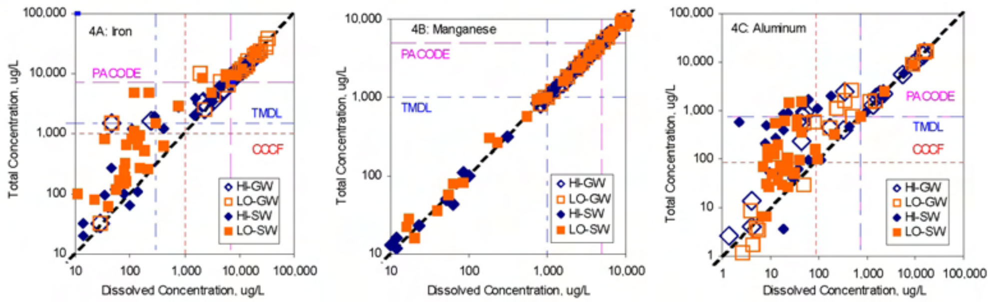
- alkalinity not less than 20 mg/L as CaCO3, except where natural conditions are less;
- pH not less than 6.0 or greater than 9.0;
- dissolved iron concentration not to exceed 0.3 mg/L;
- total iron concentration not to exceed 1.5 mg/L as a 30-day average;
- total manganese concentration not to exceed 1.0 mg/L;
- total aluminum concentration not to exceed 0.75 mg/L;
- temperature during July and August not to exceed 66°F (18.9°C) for CWF or 87°F (30.6°C) for WWF; and
- dissolved oxygen concentration greater than 5.0 mg/L for CWF and 4.0 mg/L for WWF;



Clean Water Act Framework

Mahanoy Creek Watershed Assessment Report

Data on the flow rate and chemistry for 35 AMD sources and 31stream sites throughout the Mahanoy Creek Basin were collected by USGS during high base-flow conditions in March 2001 and low base-flow conditions in August 2001.



Concentrations of metals in AMD (GW) and streamwater (SW) frequently exceeded water-quality "criteria continuous concentration" (CCCF) values for protection of freshwater organisms, water-quality standards for TMDLs, or active mine effluent limits (PACODE).

Cravotta, 2005

Mahanoy Creek Watershed Assessment Report – USGS Scientific Investigations Report 2004-5291.

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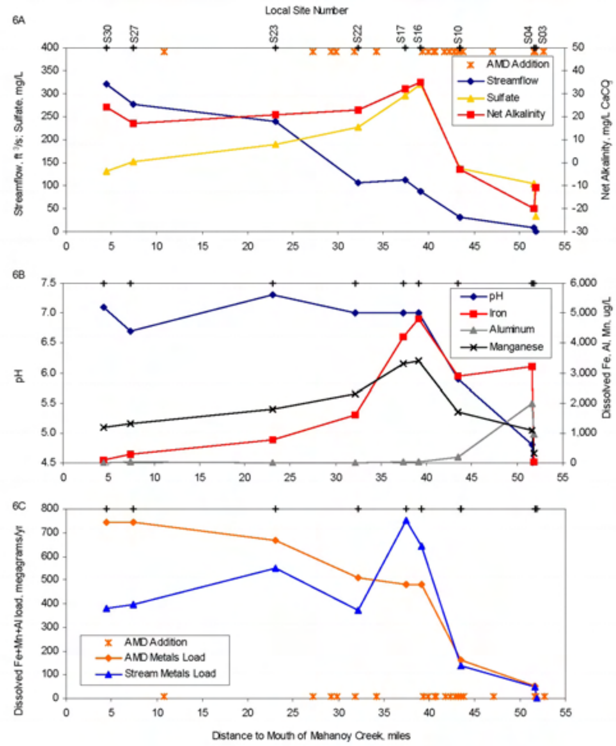
Mahanoy Creek Assessment Report



Streamflow increased progressively downstream.

AMD loading indicated by SO_4 concentration; dilution decreased concentrations.

Al, Fe, & Mn from AMD sources were not transported conservatively.

Some Al, Fe, & Mn in stream from unidentified sources.

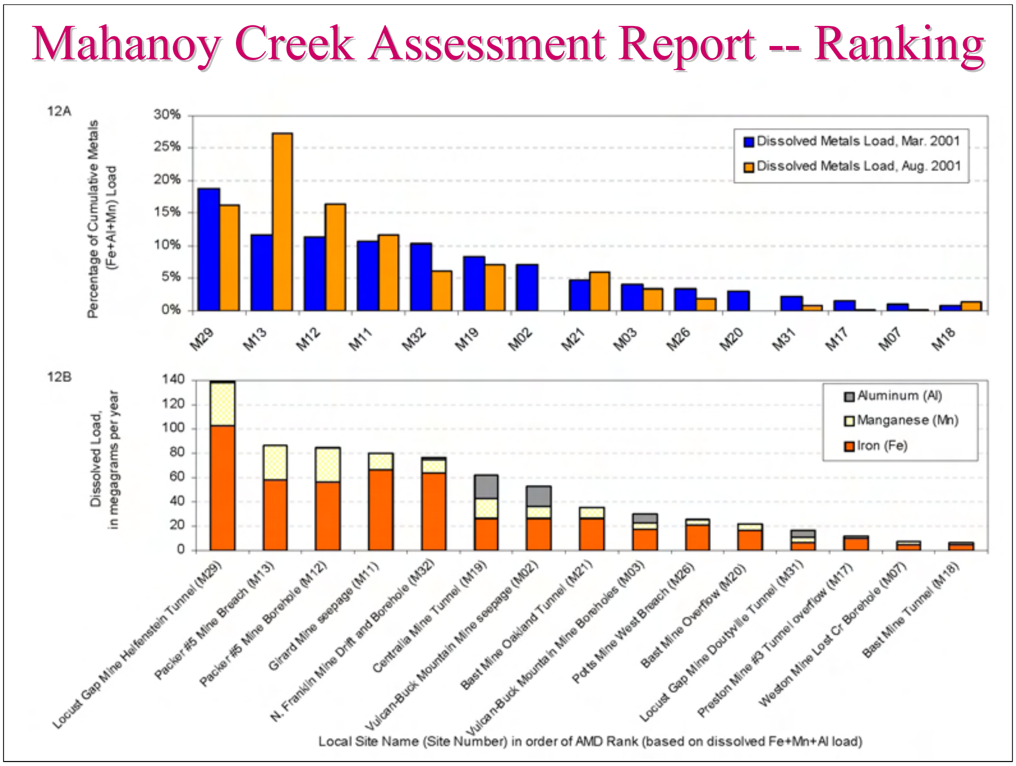
Mahanoy Creek Assessment Report

•Streamflow increased progressively downstream.

•AMD loading indicated by SO4 concentration; dilution by "clean tributaries" decreased SO4 concentrations and contributed additional alkalinity.

•Al, Fe, & Mn from AMD sources were not transported conservatively. The metals from AMD sources were precipitated or adsorbed by Fe(OH)3 in the stream bed. Residual Mn at downstream sites results from slow rate of MnII oxidation compared to FeII.

•Some Al, Fe, & Mn in stream in vicinity of Ashland are from unidentified sources. Unknown discharges could enter the stream through the fractures under the stream bed.



Mahanoy Creek Assessment Report

Ranking of AMD sources based on measured flow and metals concentrations to compute loadings. The rankings indicate the relative loads of metals at the AMD sources and do not consider the potential removal of metals during transport to the stream. Some intermittent AMD sources, such as Gilberton Pump, were not flowing when samples were collected and, therefore, were not considering in the loading ranking.

Mahanoy Creek Assessment Report

Priority ranking based on measured flow and metals concentrations.

Passive or active treatment strategies identified based on flow, chemistry, and site conditions.

Intermittent AMD sources ranked low; insufficient data.

Results used for TMDLs.

Site name and local identification number[1]	Percentage dissolved Fe, Al, and Mn load	Metals rank[2]	Net alkalinity rank	Sulfate rank	Principal characteristics[3]	Remedial Alternatives[4]: Remove culm bank	VFCW	ALD	OLD	OLC	Aerobic pond(s)	Active treatment	Comments	Wetland area, acres[5]
Locust Gap Mine Helfenstein Tunnel (M29)	18.7	1	25	1	Very large flow; high Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	X	Area inadequate for passive treatment.	5.8
Packer #5 Mine Breach (M13)	11.6	2	20	3	Very large flow; very high Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	X	Area adequate for wetland (?). Combine w/borehole.	3.9
Packer #5 Mine Borehole (M12)	11.4	3	24	2	Very large flow; high Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	X	Area adequate for wetland (?). Combine w/breach.	3.4
Girard Mine seepage (M11)	10.8	4	21	9	Very large flow; high Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	X	Area inadequate for passive treatment.	3.0
N. Franklin Mine Drift and Borehole (M32)	10.3	5	15	4	Very large flow; moderate Fe, Mn; moderate Al; net alkaline?; oxic	-	-	-	X	-	+	X	Area available for passive treatment.	2.6
Centralia Mine Tunnel (M19)	8.4	6	1	5	Very large flow; moderate Fe, Mn; very high Al; net acidic; oxic	X	X	-	-	-	+	X	Area available for passive treatment.	0.9
Vulcan-Buck Mtn. Mine seepage (M02)	7.1	7	2	8	Intermittent flow; moderate Fe, Mn; high Al; net acidic; anoxic	-	-	-	-	X	-	-	Fill channel with limestone or consider diversion well.	0.9
Bast Mine Oakland Tunnel (M21)	4.8	8	22	6	Very large flow; high Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	X	Area inadequate for passive treatment.	1.7
Vulcan-Buck Mtn. Mine Boreholes (M03)	4.1	9	3	12	Very large flow; moderate Fe, Mn; moderate Al; net acidic; anoxic	-	-	X	-	X	+	X	Area inadequate for passive treatment.	1.0
Potts Mine West Breach (M26)	3.4	10	23	7	Large flow; high Fe, Mn; moderate Al; net alkaline; suboxic	-	-	-	-	-	X	-	Area adequate for wetland (?).	1.3
Bast Mine Overflow (M20)	3.0	11	19	10	Intermittent flow; high Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	-	Area adequate for wetland (?).	.6
Locust Gap Mine Doutyville Tunnel (M31)	2.2	12	4	11	Large flow; moderate Fe, Mn; moderate Al; net acidic?; oxic	-	-	-	X	X	+	-	Area inadequate for passive treatment (?).	.4
Preston Mine #3 Tunnel overflow (M17)	1.6	13	18	15	Large flow; moderate Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	-	Area inadequate for passive treatment (?).	.3
Weston Mine Lost Cr Borehole (M07)	.9	14	14	14	Moderate flow; very high Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	-	Discharge drains to existing wetland.	.4
Bast Mine Tunnel (M18)	.9	15	9	13	Moderate flow; high Fe, Mn; moderate Al; net acidic; oxic	-	-	-	X	-	+	-	Area available for passive treatment.	.4
Potts Mine East Breach (M27)	.3	16	16	17	Moderate flow; high Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	-	Area adequate for wetland (?).	.1
Hammond Mine Seepage (M08)	.3	17	17	16	Intermittent flow; moderate Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	-	Discharge drains to existing wetland.	<.1
Lavelle Mine Lavelle slope (M28)	.1	18	5	19	Moderate flow; moderate Fe, Mn; moderate Al; net acidic; anoxic	-	-	X	-	-	+	-	Area available for passive treatment.	.1
Tunnel Mine seepage to ditch (M22)	.1	19	7	18	Small flow; moderate Fe, Mn; very high Al; net acidic; oxic	X	X	-	-	-	+	-	Source removal best; area available for treatment.	<.1
N. Franklin Mine bank seepage (M34)	.1	20	6	22	Small flow; high Fe, Mn; very high Al; net acidic; anoxic	X	-	-	-	-	-	-	Source removal best; area available for treatment.	<.1
N. Franklin Mine seepage (M33)	.1	21	8	21	Intermittent flow; moderate Fe, Mn; very high Al; net acidic; oxic	X	X	-	-	-	+	-	Source removal best; area available for treatment.	<.1
Tunnel Mine drain pool area (M24)	<.1	22	13	20	Moderate flow; moderate Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	-	Possibly enhance existing ponds for treatment.	.1
Tunnel Mine discharge from spoil bank (M23)	<.1	23	12	23	Small flow; moderate Fe, Mn; low Al; net alkaline; anoxic	-	-	-	-	-	X	-	Area available for passive treatment.	<.1
Tunnel Mine Orchard Drift overflow (M25)	<.1	24	11	24	Small flow; low Fe, Mn; low Al; net alkaline; suboxic	-	-	-	-	-	X	-	Area available for passive treatment.	<.1
Locust Gap Mine Helfenstein seepage (M30)	<.1	25	10	25	Small flow; low Fe, Mn; low Al; net alkaline; oxic	-	-	-	-	-	X	-	Discharge drains to existing wetland.	<.1
Weston Mine surface areas seepage (M05)	<.1	26	28	26	Intermittent flow; moderate Fe, Mn; moderate Al; net alkaline?; oxic	?	-	-	-	-	-	-	Insufficient data.	-
Vulcan-Buck Mtn. Mine Morris Tunnel (M01)	<.1	27	26	27	Intermittent flow; not sampled.	?	-	-	-	-	-	-	Insufficient data.	-
Gilberton Mine Pump (M04)	<.1	28	27	28	Intermittent very large flow; not sampled.	-	-	-	-	-	-	?	Insufficient data.	-

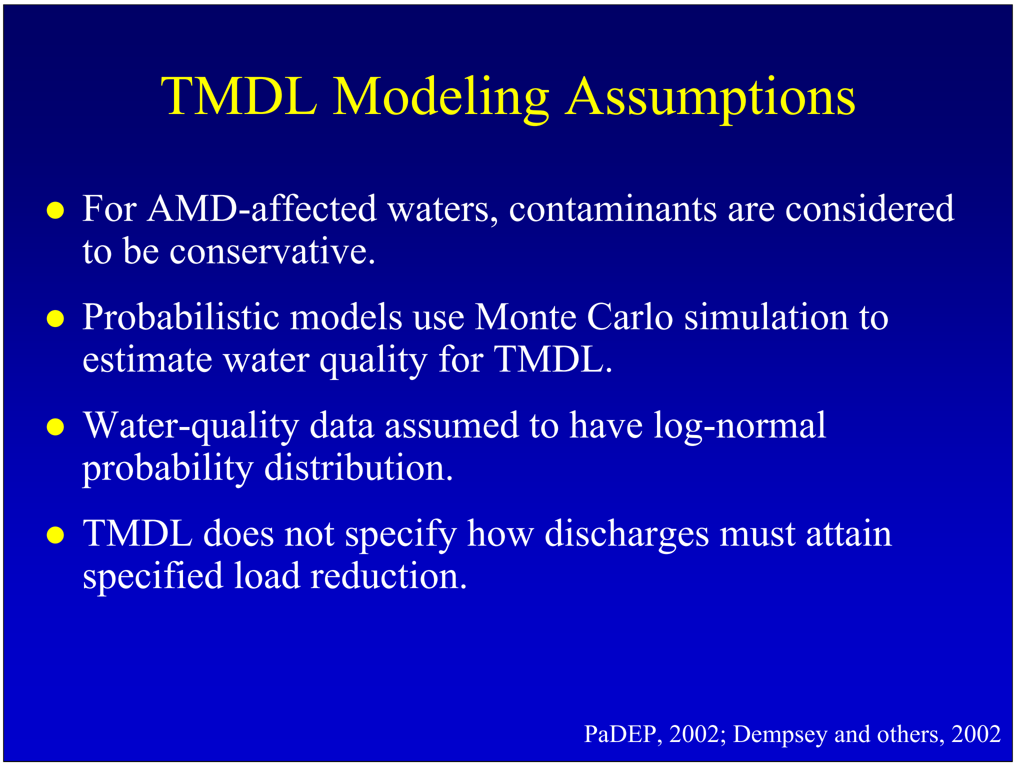
Mahanoy Creek Assessment Report

•Priority ranking based on measured flow and metals concentrations.

•Passive or active treatment strategies identified based on flow, chemistry, and site conditions.

•Intermittent AMD sources ranked low; insufficient data.

•Results of AMD prioritization referenced in TMDL report regarding AMD cleanup strategy. Data for stream monitoring also used for TMDLs.



TMDL Modeling Assumptions

•For AMD-affected waters, contaminants are considered to be conservative.

•Probabilistic models use Monte Carlo simulation to estimate water quality for TMDL.

•Water-quality data assumed to have log-normal probability distribution.

•TMDL does not specify how discharges must attain specified load reduction.

TMDL = LC = WLA + LA + MOS

- LC "loading capacity" is amount of pollutant that water can receive without violating water-quality standards.
- WLA "waste load allocation" is load that is allocated to existing or future *point sources* of pollution.
- LA "load allocation" is loading capacity that is attributed to existing or future *non-point sources* of pollution (AMD) or to natural background sources.
- MOS "margin of safety" accounts for uncertainty in data, modeling, and analysis.

PaDEP, 2002; Dempsey and others, 2002

TMDL = LC = WLA + LA + MOS

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•MOS "margin of safety" accounts for uncertainty in data, modeling, and analysis.

Mahanoy Creek TMDL Report

Identifies AMD as general source of impairment based on prior water-quality assessment.

Requires pollution loading allocations for point sources (permitted discharges) and nonpoint sources (AMD) within the watershed.

TMDL[1]
Mahanoy Creek Watershed
Columbia, Northumberland and Schuylkill Counties, Pennsylvania

INTRODUCTION

This Total Maximum Daily Load (TMDL) calculation has been prepared for segments in the Mahanoy Creek Watershed (Attachment A). It was done to address the impairments noted on the 1996, 1998, and draft 2002 Pennsylvania Section 303(d) lists and the 2000 305(b) report required under the Clean Water Act. The TMDL covers five segments on these lists (Table 1). High levels of metals, and in some areas depressed pH, caused these impairments. All impairments resulted from acid drainage from coal mining. The TMDL addresses the three primary metals (iron, manganese, and aluminum) associated with acid mine drainage (AMD) and pH.

Table 1. Mahanoy Creek Segments Addressed

State Water Plan (SWP) Subbasin: 06-B Susquehanna River								
Year	Miles	Segment ID	DEP Stream Code	Stream Name	Designated Use	Data Source	Source	EPA 305(b) Cause Code
1996	52.2	Not placed on GIS	17556	Mahanoy Creek	WWF	305(b) Report	RE	Metals
1998	26.07	2227	17556	Mahanoy Creek	WWF	SWMP	AMD	Metals
1998	27.59	2228	17556	Mahanoy Creek	WWF	SWMP	AMD	Metals
2000	26.1	2227	17556	Mahanoy Creek	WWF	SWMP	AMD	Metals
2000	27.6	2228	17556	Mahanoy Creek	WWF	SWMP	AMD	Metals
2002	11.1	20000808-1500-MAF	17556	Mahanoy Creek	WWF	SWAP	AMD	Metals
2002	21.6	20000810-1530-MAF	17556	Mahanoy Creek	WWF	SWAP	AMD	Metals
2002	6.6	20010629-1230-MAF	17556	Mahanoy Creek	WWF	SWAP	AMD	Metals
2002	12.8	20010820-1200-MAF	17556	Mahanoy Creek	WWF	SWAP	AMD	Metals, pH

PaDEP, 2007

Mahanoy Creek TMDL Report

- Identifies AMD as general source of impairment based on prior water-quality assessment.
- Requires pollution loading allocations for point sources (permitted discharges) and nonpoint sources (AMD) within the watershed.

Mahanoy Creek TMDL Report

Determines existing *"in-stream"* loadings at TMDL site using available data.

Indicates loading reductions at TMDL site *(not above)* to meet water-quality standards at site.

HOW? Identifies AMD priorities and passive-treatment strategies from USGS Assessment Report.

PaDEP, 2007

Table 5. Mahanoy Creek Watershed Summary Table

Parameter	Existing Load (lbs/day)	TMDL Allowable Load (lbs/day)	WLA (lbs/day)	LA (lbs/day)	NPS Load Reduction (lbs/day)	% Reduction
MC1 – Mahanoy Creek upstream of Girardville						
Aluminum (lbs/day)	105.28	27.37	1.67	25.7	77.91	74%
Iron (lbs/day)	2274.14	159.19	1.67	157.52	2114.95	93%
Manganese(lbs/day)	674.94	94.49	0.83	93.66	580.45	86%
Acidity (lbs/day)	2482.99	893.88	-	893.88	1589.11	64%
SC1 – Shenandoah Creek near mouth						
Aluminum (lbs/day)	20.41	16.14	6.52	9.62	4.27	21%
Iron (lbs/day)	152.80	19.93	5.52	14.41	132.87	87%
Manganese(lbs/day)	224.94	18.03	3.32	14.71	206.91	92%
Acidity (lbs/day)	134.30	NA	-	NA	NA	NA
MC2 – Mahanoy Creek near Gordon						
Aluminum (lbs/day)	726.24	101.67	57.59	44.08	542.39	85%*
Iron (lbs/day)	6038.72	422.71	242.14	180.57	3368.19	89%*
Manganese(lbs/day)	2677.90	348.13	161.42	186.71	1542.41	82%*
Acidity (lbs/day)	834.88	83.49	-	83.49	193.61	70%*
Unt.MC – ""Big Run" near mouth						
Aluminum (lbs/day)	7.41	3.00	-	3.00	4.41	60%
Iron (lbs/day)	43.24	6.41	-	6.41	36.83	86%
Manganese(lbs/day)	27.62	8.81	-	8.81	18.81	69%
Acidity (lbs/day)	77.66	NA	-	NA	NA	NA
MC3 – Mahanoy Creek near Gowen City						
Aluminum (lbs/day)	836.31	117.08	0.63	116.45	90.25	44%*
Iron (lbs/day)	5850.55	292.53	0.32	292.21	119.73	30%*
Manganese(lbs/day)	2674.46	294.19	0.16	294.03	55.77	16%*
Acidity (lbs/day)	1827.80	329.01	-	329.01	669.74	68%*
MC4 – Mahanoy Creek near Kneas						
Aluminum (lbs/day)	742.13	304.27	24.44	279.83	0	0%*
Iron (lbs/day)	3658.92	914.73	36.93	877.80	0	0%*
Manganese(lbs/day)	3260.67	521.71	24.62	497.09	358.69	41%*
Acidity (lbs/day)	6842.46	1436.92	-	1436.92	3906.75	74%*

Mahanoy Creek TMDL Report

•Determines existing "in-stream" loadings at TMDL site using available data. By using data for in-stream conditions, effects of assimilation or natural attenuation are incorporated, implicitly. Specifically, Fe and Al need removal at upstream monitoring points (MC1, MC2, MC3), but meet TMDL at downstream point (MC4). If metals are removed from points above MC4 to meet TMDLs for upper sites, conditions would improve at MC4 but the mass removed at upper points will not translate to the same mass removed from downstream site because of non-conservative transport.

•Indicates loading reductions at TMDL site (not above) to meet water-quality standards at site. The load reduction indicated is at the site of monitoring. The TMDL does not indicate how to achieve the target. A larger load than indicated may need to be removed from upstream sources to achieve downstream target because some AMD metals already are removed in the stream.

•HOW does the TMDL get implemented to achieve targets? The Mahanoy Creek TMDL identifies AMD priorities and passive-treatment strategies from USGS Assessment Report. The USGS report does not indicate how loads may change if AMD sources are treated. Some AMD sources are indicated as too large or too close to the stream for passive treatment.

ACTIVE TREATMENT: Generally, treatment of AMD requires pH adjustment, aeration, and settling of metal-rich particles. Alkaline chemical reagents such as sodium hydroxide (NaOH), sodium carbonate ($NaCO_3$), and hydrated lime [$Ca(OH)_2$] are used in conventional, “active” AMD treatment systems to achieve high pH and rapid particle formation. Subsequently, iron and other metallic particles accumulate as sludge in settling basins. Space and costly infrastructure are needed for such treatment.

PASSIVE TREATMENT

low cost(?); uncertain

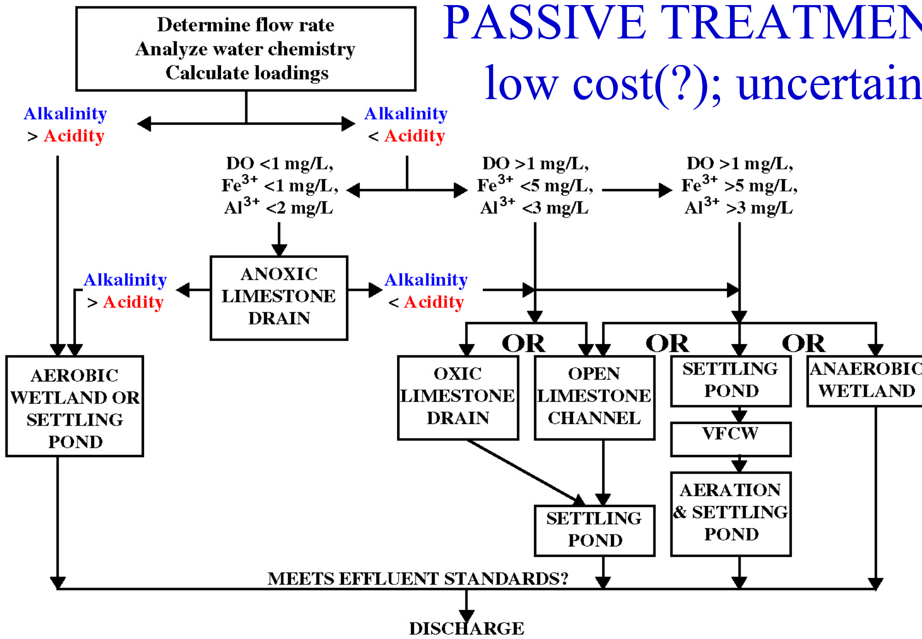

Figure 3. Flow chart for selection of passive treatment alternatives modified from Hedin and others (1994), Skousen and others (1998), and Pennsylvania Department of Environmental Protection (1999). Vertical flow compost wetland (VFCW), also known as SAPS or RAPS.

PASSIVE TREATMENT: Acidity and metals can be removed from AMD through various passive treatment systems that increase pH and alkalinity and may enable aeration and oxidation. Flow rate and water chemistry data are needed to evaluate treatment alternatives. Generally, criteria for selection of treatment and determining outcome are vague.

If acidity exceeds alkalinity, alkalinity producing components are needed as precursor steps in series with aerobic wetlands or settling ponds. If alkalinity exceeds acidity, aerobic wetlands or settling ponds may be the sole step needed to facilitate iron oxidation and metals removal. Wetlands have chemical and physical functions, providing for oxidation of dissolved metals and filtration of solids.

Less costly infrastructure but greater space may be required for passive treatment systems than active treatment system.

Passive Treatment —
Effective? Reliable? Appropriate?

- General sizing and design criteria lead to uncertain results.
- Accept “some AMD treatment is better than none.”
- Modeling and testing (before and after implementation) can improve on passive-treatment designs to assure desired results.
- Periodic measurement of flow and chemistry of AMD (untreated and treated) and stream segments can be useful to update TMDLs and AMD cleanup strategies.

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Conclusions

- AMD cleanup strategies can succeed considering:
  - ✓ chemical sources and transport processes;
  - ✓ "natural attenuation" of pollutants within watershed;
  - ✓ treatment designs that result in *predictable and measurable* reductions in pollutants to meet TMDLs;
  - ✓ effects of treatment on temperature and dissolved oxygen of AMD and downstream reaches.

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CONCLUSIONS:

In conclusion, those who design and fund treatment are commonly willing or forced to accept uncertain results. TMDLs and corresponding AMD restoration strategies that consider (1) chemical and other sources of aquatic degradation; (2) potential for "natural attenuation" of pollutants within the stream; (3) treatment designs that result in predictable reductions in pollutants to meet TMDLs; and (4) effects of treatment on chemical load, temperature, and dissolved oxygen of downstream reaches. It should be emphasized that in attempting to improve quality by removing metals, other favorable attributes of AMD sources such as sustained base flows of constant-temperature water favored by trout and other fish should be maintained within acceptable limits. The implementation of TMDLs and adoption of aquatic criteria could lead to improved methods for the selection, design, and performance of passive treatment and an improved basis for the selection and funding of watershed restoration alternatives, but also could limit the support provided for watershed restoration. Both support for restoration efforts and improvement on treatment technologies can be achieved with planning and funding.

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