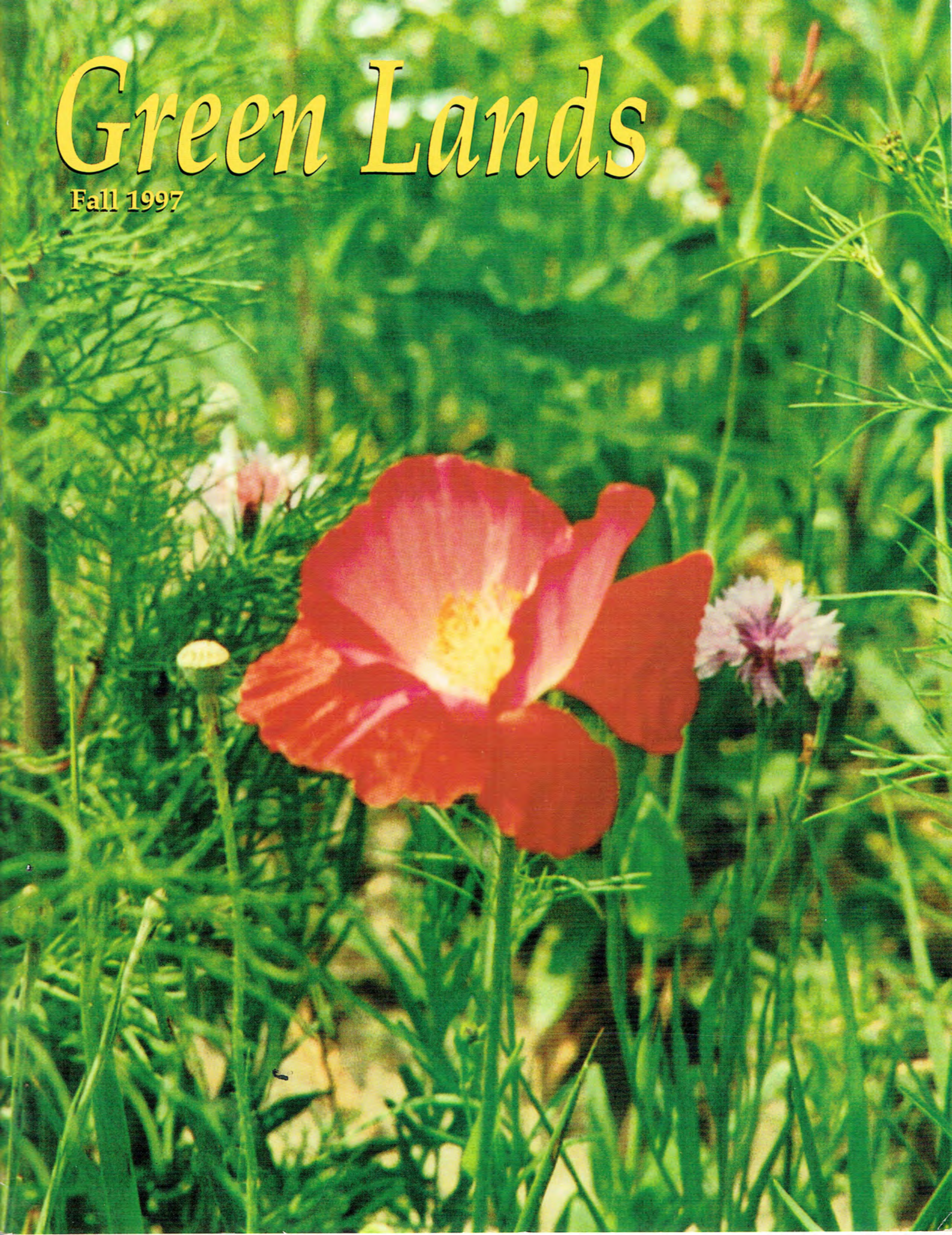
Green Lands

Fall 1997



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Green Lands

Volume 27 Number 4

Green Lands
is a quarterly publication of the
West Virginia Mining & Reclamation Association,
with offices at 1624 Kanawha Boulevard East
Charleston, West Virginia 25311
(304) 346-5318, FAX 346-5310.

Our Cover
Arch Coal, Inc. has suddenly blossomed into West Virginia's largest coal company, with an all star lineup of award winning mining operations. Our cover story begins on page 20. (photo by Frank Robinette)

Index to Advertisers

COAL CALENDAR

October

24-25 **West Virginia Mining & Reclamation Association, Fall Board Meeting,** The Lakeview Resort & Conference Center, Morgantown, WV, contact Patty Bruce, WVMRA, 1624 Kanawha Blvd. E., Charleston, WV 25311, (304) 346-5318, FAX 346-5310.

28-29 **Cavalcade of Trade '97,** Charleston Civic Center, Charleston, WV, contact Charleston Regional Chamber of Commerce, 106 Capital St., Suite 100, Charleston, WV 25301, (304) 345-0770.

November

13-14 **Eighth Pennsylvania Blasting Conference,** Penn State University, University Park, PA, contact Chriss Schultz, 225 Penn State Conference Center Hotel, University Park, PA 16802, (814) 863-5130, FAX 863-5190.

January

14-16 **25th West Virginia Mining Symposium** Holiday Inn - Charleston House, Charleston, WV, contact Patty Bruce, WVMRA, 1624 Kanawha Blvd. E., Charleston, WV 25311, (304) 346-5318, FAX 346-5310.

18-24 **Annual Mountain State Coal Classic,** Raleigh County Armory, Beckley, WV, contact Bluestone Coal Corp., P.O. Box 1085, Beckley, WV 25802, (304) 252-8528, FAX 255-6106.

27-1 **West Virginia Mining & Reclamation Association, Semi-Annual Meeting,** El Conquistador Resort & Country Club, Fajardo, Puerto Rico, contact Patty Bruce, WVMRA, 1624 Kanawha Blvd. E., Charleston, WV 25311, (304) 346-5318, FAX 346-5310.

James C. Justice, II, son of the Association's 8th Chairman, began his own term as WVMRA's 31st Chairman on Satuday, August 9.

Former Chairmen

1966-67	Leo A. Vecellio, Sr.
1967-68	F. B. Nutter, Sr.
1968-69	Arch F. Sandy, Jr.
1969-70	John C. Anderson
1970-72	G. B. Frederick
1972-73	James L. Wilkinson
1973-74	Lawson W. Hamilton, Jr.
1974-75	James C. Justice, Sr.
1975-76	H. L. Kennedy
1976-77	Frank D. Jennings
1977-78	James H. Harless
1978-79	John J. Faltis
1979-80	Charles T. Jones
1980-81	Lawrence A. Streets
1981-82	William C. M. Butler, III
1982-83	Donald R. Donell
1983-84	Tracy W. Hylton
1984-85	Carl DelSignore
1985-86	Dwight M. Keating
1986-87	Theodore J. Brisky
1987-88	James W. Anderson
1988-89	Roy G. Lockard
1989-90	Paul F. Hutchins
1990-91	Kenneth J. Woodring
1991-92	R. Donald Cussins
1992-93	Gerald W. Ramsburg
1993-94	John R. Bryan
1994-95	Sidney R. Young, III
1995-96	K. Donald Nicewonder
1996-97	Markus J. Ladd

WVMRA elects Jim Justice Chairman for 1997-98

James C. Justice, II of Beckley is the new Chairman of the Association's Board of Directors. Jim was elected in August at The Greenbirer during the 31st Annual Meeting. He succeeds Markus Ladd of Mingo Logan Coal Co., who served in 1996-97.

Jim has served on WVMRA's Board since 1993, including previous terms as Secretary, Second Vice Chairman and First Vice Chairman. His election marks the first time in the history of the Association that a father and son have both served as Chairman. The late James C. Justice, Sr. led WVMRA during 1974-75.

A Beckley native, Jim is a graduate of Marshall University, where he also received his MBA. He joined the family business, Bluestone Industries Inc. in 1974 and, three years later, founded Bluestone Farms, which now harvests over 45,000 acres of corn, wheat and soybeans in West Virginia, Virginia, North Carolina and South Carolina.

Following the death of his father in 1993, Jim became President and CEO of Bluestone Industries, Inc. and Bluestone Coal Corp. The coal firm now produces over a million tons annually of low volatile coal.

Jim is also a civic leader of youth sports programs in Raleigh County. He has been President of the local Little League for the past five years and has coached youth basketball teams for ten years, including an 11 and under girls team which won the national championship this summer.

He is also the owner of the Beckley franchise in the semi-professional Mountain State Basketball League, and is the Director of the coal industry sponsored Mountain State Coal Classic basketball tournament, which raises thousands of dollars annually for college scholarships and grants to secondary schools.

Outgoing Chairman Markus Ladd (l) turned the reins of the Association over to newly elected Jim Justice at the Saturday morning's New Chairman's Breakfast.

WV-DEP Director JackCaffery
New directions for his agency

AEP President Dana Waldo - *Utility deregulation and new expectations.*

Robinson & McElwee Attorney Kip Power - *Air quality compliance and the the general permit.*

Other new officers

The Board also elected Wayne Stanley of Stanley Industries, Bridgeport, to the post of 1st Vice Chairman. Bill Broshears of Eastern Associated Coal Corp., Henderson, KY, was chosen as 2nd Vice Chairman for the coming year. Dick Bolen of Anker Energy Corp., Morgantown, was elected Secretary and John Skidmore of New Allegheny, Inc., Charleston, is the new Treasurer. Chris Supcoe of Crown Hill Equipment Co., Hansford, was elected Chairman of the Associate Division.

Board members

Four members were newly elected to the Board, including James O. Bunn of Eaglehawk Carbon, Inc., Grundy, VA; Steve Capelli of Pen Coal Corp, Kenova; Charles R. Sutton of United Coals, Jane Lew; and Steve Walker of Cecil I. Walker Machinery Co., Charleston,

Seven others were reelected to the Board, including Jim Justice, Wayne Stanley, John Bryan of Pittston Coal Group, Lebanon, VA; Dave Hibbs of Cummins Cumberland, Inc, South Charleston; Pete Moran of Princess Beverly Coal Co., Charleston; John Smith of Rudd Equipment Co., Charleston; and Ken Woodring of Arch Coal, Inc., Huntington.

New members

The Board also approved six companies as new Associate members, including **Campbell Tractor and Equipment Co., Inc.,** Summersville, George Harris, representative; **Associates Commercial Corp.**, Charleston, L. Blair DeVan, representative; **Cellular One**, Charleston, Sonie Petry, representative; **Central Contracting, Inc.**, St. Albans, J. Steven Cvechko, representative; **Smith-Manus Agency, Inc.,** Louisville, KY, Brook T. Smith, representative; and **Stagg Engineering Services, Inc.**, Cross Lanes, Alan K. Stagg, representative.

(l-r) Louie Southworth of Jackson & Kelly, Andrew Jordon of Prichard Mining Co., Dick Lewis of Benefit Services, Inc., Michelle and Brian Johnson of Land Use Corp.

John and Beth Krebs of Republic Industries.

(l-r) Mike Burke of White Flame Energy, Inc., Steve Walker and Wayne Coleman of Cecil I. Walker Equipment Co., Don Nicewonder of Premium Energy, Inc.

Associate Members'
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Appalachian Tire Products, Inc.
Aqua-Fix Systems
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Austin Powder Company
Beckwith Machinery Company
Benefit Services, Inc.
Black Diamond Construction, Inc.
Bowles Rice McDavid Graff & Love
Brocoal, Inc.
Carter Machinery Company, Inc.
Cascades Coal Sales, Inc.
Cecil I. Walker Machinery Company
Criste Engineering & Reclamation Services
Crown Hill Equipment, Inc.
Cummins Cumberland, Inc.
Daniels Law Firm
Driltech Inc.
Dyno Nobel Inc.
El Dorado Chemical Company
Employers Service Corporation
Engineering Services, Inc.
Ensign-Bickford Company
Fielding Hydroseeding Inc.
Foster Supply
GH-Hensley Industries Inc.
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Killam Associates
Kimberly Industries, Inc.
Komatsu Mining Systems, Inc.
L & S Chevrolet-Olds, Inc.
Logan Corporation/Kanawha Steel
Logan & Kanawha Coal Company, Inc.
Long-Airdox Company
Morton Specialty Insurance Partners, Ltd.
Mt. State Bit Service, Inc.
Nelson Brothers, Inc.
O&K Orenstein & Koppel, Inc.
Ohio Seed Company
Petroleum Products, Inc.
Pocahontas Land Corporation
Potesta & Associates, Inc.
R & K Enterprises
RMI, Ltd.
Rag Pickers, Inc.
Republic Industries
Rish Equipment Company
Robinson & McElwee
Rogers Petroleum Services, Inc.
Rudd Equipment Company
Skelly and Loy, Inc.
Smith-Manus Agency, Inc.
Spilman, Thomas & Battle
Summit Engineering, Inc.
Triad Engineering, Inc.
Triangle Surety Agency, Inc.
Turner & Company, P. A.
United National Bank
Varel Manufacturing Company
Vibra-Tech Engineers, Inc.
Western Pocahontas Properties Ltd. Partnership
WOPEC
Worldwide Equipment, Inc.

(l-r) Susan Hochbein of Chafin Branch Coal Co., Martha and Fred Harless of Gilbert Distributing Co., Linda Heatherman of Laurel Creek Co., Norm Duncan of GH Hensley Industries, Inc.

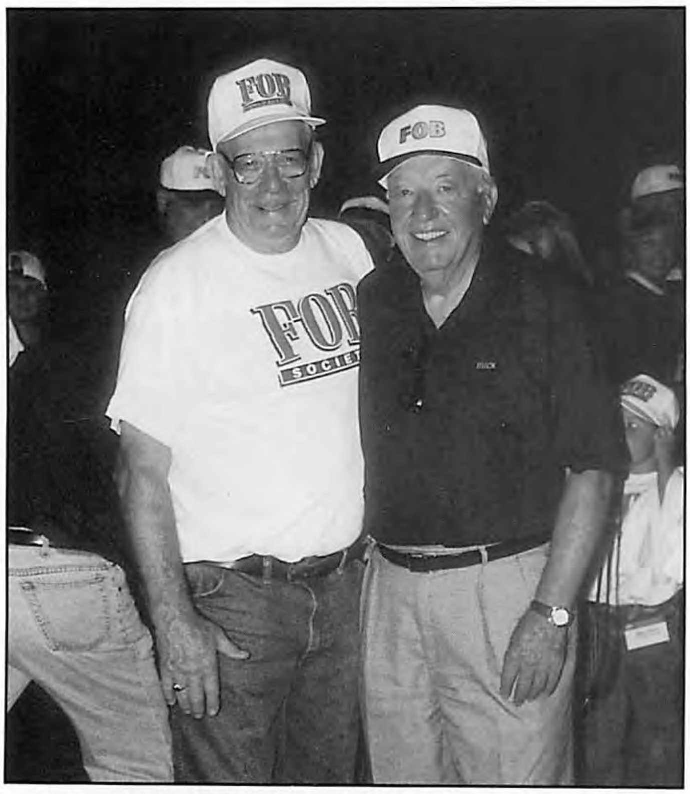
Joe and Bonnie Scholl of Triangle Surety Agency, Inc.

(l-r) John Williamson of Cecil I. Walker Equipment Co., John Wellford of Kimberly Industries, Inc., Pat Graney of Petroleum Products, Inc.

The "Friends of Buck", known in previous years as "Buck's Bunch", turned out in force on Kate's Mountain to capture the annual "Company Pride" award in the General Division.

Meanwhile, Lawson Hamilton's crew from Ford Coal Co., Buck's best competition in recent years, incarnated themselves this year as "Friends of Buck - Greenbrier County Chapter," and grabbed second place in the General Division.

'Friends of Buck' have 'Company Pride' to spare



The title character of "Friends of Buck," namely Buck Harless (r), celebrates with the head of his Greenbrier County chapter, Lawson Hamilton.

Mt. State Bit Service took home the "Bronze Bucket," as the top 1997 participant in the Associate Division "Company Pride" competition.

Pat Graney (l) and John Ford (r) accept the plaque commemorating Petroleum Products, Inc. as the 1996 winner of the Associate Division "Company Pride" award.

Company Pride — Winners All

WVMRA President Ben Greene presents a pecan Mountaineer statue to Andy Willis of Mining Consulting Services, Inc. in recognition of his status as the most authencially dressed guest at the Coal Miners' Party .

Mingo Logan Coal Co. lacked the sheer numbers to compete with the "Friends of Buck" and their various county chapters, but this bunch was awarded a pecan Mountaineer statue just because they looked so doggone good.

Outgoing Board Chairman and fishing enthusiast Markus Ladd received a bronze sculpture depicting his favorite quarry as a going away gift from the Association. Markus has since moved to Charlottesville, VA.

Association President Ben Greene was presented with a chrystal sculpture of eagles in recognition of his 20 years of service to WVMRA.

Greenbrier Scrapbook

Dean Hunt of Buchanan Ingersoll lets his hair down, so to speak, at the Coal Miners' Party on Kate's Mountain.

The Production Company provided music for all ages on Kate's Mountain.

Monte Carlo night always draws a crowd, and a wide selection of prizes added to the fun.

A special golf tournament was held on Saturday to raise funds for the "Larry Joe Harless Community Center Foundation." It was an expensive event for Buck Harless of Gilbert, who is matching his hometown's fundraising effforts on a 4-1 basis. Left to right are Buck, the winning team from Bluestone Coal Corp. - Byrd White, Jim Justice, Mike Mays and Gary Foster - and Tournament Director Fred Harless.

Annual Meeting
Event Prize Donors

The Association extends its appreciation for the generosity of the many members who donated prizes for the various events which added so much to our 31st Annual Meeting.

MONTE CARLO NIGHT
Beckwith Machinery Company (Dave Trueman) - $100
Cecil I. Walker Machinery Co. (John Williamson) - $100
Crown Hill Equipment, Inc. (Chris Supcoe) - $200
Cummins Cumberland, Inc. (Dave Hibbs) - $100
El Dorado Chemical Co. (Joe Ferguson) - $100
Employers Service Corp. (Paul Ayers) - $100
Fielding Hydroseeding, Inc. (Ed Brown) - $100
Gibson-IRECO, Inc. (Grant Schrader) - VCR
Ingersoll-Rand Company
(Tim Larson) - I-R Electric Drills & Air Impact Wrench
K & P Mining (Mike Perilli) - $100
Nelson Brothers, Inc. (Wade Bowman) - $100
Republic Industries (John Krebs) - Gold Coin
Rish Equipment Co. (Myron Jones) - $50
Worldwide Equipment, Inc.(Chuck Bradley) - Jackets

FUN RUN
Appalachian Mining Services (Charlie Miller) - $100
Cummins Cumberland, Inc. (Dave Hibbs) - $50
Killam Associates (Phil Longenecker) - $50

BOWLING
Cummins Cumberland, Inc. (Dave Hibbs) - $50
Jackson & Kelly (Dan Stickler) - $50
Nelson Brothers, Inc. (Wade Bowman) - $50
Rudd Equipment Company (John Smith) -$50

CHILDRENS' BOWLING
Cascades Coal Sales, Inc. (Flick Goldsmith) - $50
Cummins Cumberland, Inc. (Dave Hibbs) - $25
El Dorado Chemical Co. (Robert Giovando) - $50
Triangle Surety Agency, Inc.
(John Jacobs) - $50 Bonds (2)

CHILDREN'S PUTTING
Cascades Coal Sales, Inc. (Flick Goldsmith) - $50
Cummins Cumberland, Inc. (Dave Hibbs) - $25
El Dorado Chemical Co. (Robert Giovando) - $50
Triangle Surety Agency, Inc.
(John Jacobs) - $50 Bonds (2)

GOLF
Anderson of West Virginia
(Dave Gettman) - $10,000 for hole-in-one on 18
Appalachian Mining Services (Charlie Miller) - $100
Appalachian Tire Products (Walt Dial) - $100
Beckwith Machinery Company (Dave Trueman) - $100
Cascades Coal Sales, Inc. (Flick Goldsmith) - $100
Cecil I. Walker Machinery Co. (John Williamson) - $100
Crown Hill Equipment, Inc. (Chris Supcoe) - $100
Cummins Cumberland, Inc. (Dave Hibbs) - $100
Fielding Hydroseeding, Inc. (Ed Brown) - $100
Hitachi Construction Machinery Corp.
(Fred Caddell) - Golf Bag & Putter
Kimberly Industries, Inc.(Kitt Wellford) - Putter
Morton Specialty Insurance Partners
(Charlie Morton) - $200
Mt. State Bit Service, Inc.
(Paul Laskody, Jr.) - Golf Towels
Nelson Brothers, Inc. (Tab Hudson) - $100
O&K Orenstein & Koppel, Inc. (Mike Richardson) - $100
Penn Line Service, Inc. (Larry Roberts) - $50
Petroleum Products, Inc. (Tom Taylor) - $100
Rish Equipment Co. (Myron Jones) - $100
Rudd Equipment Company
(John Smith) - Beverage Carts & Cigars
Smith-Manus Agency, Inc. - $100
Worldwide Equipment Company (Chuck Bradley) - Putter

TENNIS
Cummins Cumberland, Inc. (Dave Hibbs) - $50
Ingersoll-Rand Company (Tim Larson) - $50 + Trophy
Kimberly Industries, Inc.(John Wellford) - $50
Penn Line Service, Inc. (Larry Roberts) - $50
Rish Equipment Co. (Dan Pichick) - $100
Skelly and Loy, Inc. (John Gunnett) - $100

TRAP
Cecil I. Walker Machinery Co. (Stevve Walker) - $50
Nelson Brothers, Inc. Wade Bowman) - $50
Robinson & McElwee, LLD (Kip Power) - $200

Thank You

FISHING
Appalachian Mining Services (Charlie Miller) - $50
Ingersoll-Rand Company (Tim Larson) - $50
Nelson Brothers, Inc. (Tab Hudson) - $50
Potesta & Associates
(Dana Burns) - Tackle Boxes & Coleman Lantern

MOUNTAIN BIKE RIDE
O&K Orenstein & Koppel, Inc. (Peter Causer) - $100

KATE'S MOUNTAIN
West Virginia Coal Association
(Bill Raney) - 2 Pecan Mountaineers

NEW CHAIRMAN'S BREAKFAST
Black Diamond Construction, Inc. (Bill Casto) - $100
Cascades Coal Sales, Inc. (Flick Goldsmith) - $100
Crown Hill Equipment, Inc. (Chris Supcoe) - $100
Cummins Cumberland, Inc. (Ed Surgeon) - $100
El Dorado Chemical Co. (Joe Ferguson) - $50
Fielding Hydroseeding Inc. (Ed Brown) - $100
Hitachi Construction Machinery Corp. -
(Fred Caddell) - Hitachi Camcorder
Ingersoll-Rand Company (Tim Larson) - $100
Nelson Brothers, Inc. (Wade Bowman) - $50
O&K Orenstein & Koppel, Inc. (Rolf Weber) - $100
Rudd Equipment Company (John Smith) -$200

NAME TAG DRAWING
Black Diamond Construction, Inc. (Bill Casto) - $100
Bright Enterprises (Bill Bright) - Golf for 2 at Glade Springs
Crown Hill Equipment, Inc. (Chris Supcoe) - $100
Cummins Cumberland, Inc. (Dave Hibbs) - $100
El Dorado Chemical Co. (Joe Ferguson) - $50
Employers Service Corp. (Paul Ayers) - $100
Fielding Hydroseeding Inc. (Ed Brown) - $100
The Greenbrier (Lee Doggett) - Weekend at the Greenbrier
Ingersoll-Rand Company (Tim Larson) - $100
K & P Mining (Mike Perilli) - $100
Long-Airdox (Mike Hastings) - 13" Color TV
Nelson Brothers, Inc. (Tab Hudson) - $100

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Catenary Coal's Samples mine represents a huge investment on the part of Arch and a major economic boon to eastern Kanawha County.

Arch eMERGES in West Virginia

With the merger of Arch Mineral Corp. and Ashland Coal Co. came the rise of a new giant in the American coal industry and the creation of an all star lineup of mining operations in West Virginia.

Arch Coal, Inc., now the nation's sixth largest producer of bituminous coal, is headquartered in St. Louis, MO, but the majority of its mining operations are in West Virginia, where it has immediately assumed the position of leading producer.

The new Arch Coal, Inc. has reserves of 2.1 billion tons, with total assets of $1.7 billion and 1996 revenues of $1.4 billion. Components of the merged corporation produced 47.3 million tons of coal last year, 30.9 million in West Virginia, where the company employs 2,088.

Total Arch employment is 3,658 at 32 mines in West Virginia, Kentucky, Virginia, Illinois and Wyoming. Arch is the largest producer of low sulfur coal is the eastern US. It ships coal to 62 power plants in 22 states, and exports to ten foreign countries.

Impressive as the company's mining resume is, it nearly pales in comparison with the reclamation record compiled by its various West Virginia subsidiaries.

Leading the way is Hobet 21, in Boone County, which has won just about every reclamation award offered. Founded by WVMRA pioneer Fil Nutter, Hobet won an early Reclamation Award in 1974. Under its Ashland Coal ownership, Hobet repeated in 1982 and again in 1986, 1989 and 1992. Then, in 1993, the National Wild Turkey Federation honored Hobet with its "Wildlife West Virginia Award," for the creation and enhancement of wildlife habitat.

In 1994, the mine was recognized with the "David C. Callaghan Award" as the best overall operation in West Virginia. Also in 1994, Hobet became the first West Virginia operation to win the "Director's Award," given by the federal Office of Surface Mining to the most outstanding reclamation performance nationwide. Last year Hobet completed its statewide collection with the "Wetlands West Virginia Award," given by Ducks Unlimited for the creation and preservation of wetlands habitat.

Still early in its mine life, Catenary has already won the "David C. Callaghan Award," symbolic of West Virginia's most outstanding mining operation.

The reborn Samples Mine, the primary facility at Arch subsidiary Catenary Coal Co. in eastern Kanawha County, won its first Reclamation Award in 1995, then took home the "Callaghan Award" in 1996 and recently won the "Kenes R. Bowling Reclamation Award," presented by the Interstate Mining Compact Commission.

Arch subsidiary Mingo Logan Coal Co. won two "Callaghans" within a three year period in 1990 and 1992. Dal-Tex Coal Co. won a regular Reclamation Award in 1986, and then the "Wildlife West Virginia Award" in 1995. Another subsidiary, Cumberland River Coal Co. won a Reclamation Award in 1994 for its Mingo County operation, and recently won an OSM award for "zero impact mining" in Breathitt, KY.

Arch of West Virginia has currently won four consecutive Reclamation Awards, including the 1994 "Wetlands West Virginia Award."

That's a total of 21 various major reclamation awards statewide for Arch Coal, Inc. operations, including four "Callaghans," two "Wetlands," two "Wildlifes," and three from national organizations. Fifteen of these awards have come in the last five years.

The "Mountaineer Guardian Awards" are presented annually to those operations which achieve designated production totals, based on numbers of employees, without fatality.

In this decade, Arch subsidiaries have earned 38 Mountaineer Guardians. Two Arch of WV operations in Logan County, the Wylo and Ruffner surface mines, have each won the award every year since 1990, and in 1992, Wylo claimed the "Barton B. Lay" Award as the overall safest mining operation in the state.

All of these same companies have simultaneously been among the most public spirited "citizens" of West Virginia, assuming leadership roles in scholarships, school partnerships, cleanup projects, and general community involvement.

Arch Coal Inc. may be a new entity, technically, but it certainly has hit the ground running in West Virginia, laying the basis for a long and mutaully rewarding relationship.

West Virginia will take all it can get of companies like that.

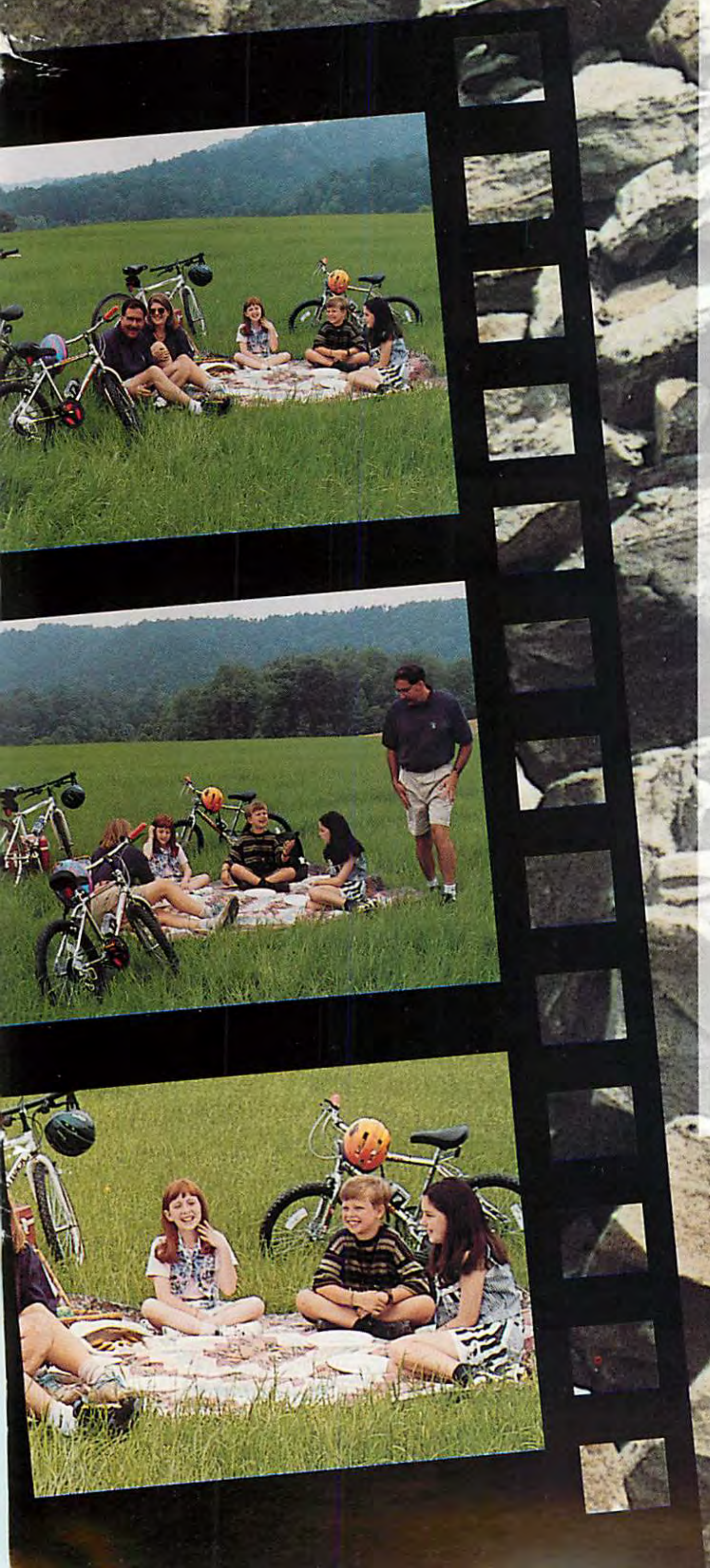
Hobet 21, in Boone County, is one of West Virginia's most decorated mining operations, having won virtually every national and state award which is offered.

In 1993, Hobet won the "Wildlife West Virginia Award," given by the National Wild Turkey Federation for the establishment and enhancement of wildlife habitat.

In 1994, Hobet was honored with the "Director's Award" as the best reclamation operation in the entire country, as well as West Virginia's top award, the "Callaghan."

In 1996, Hobet won the "Wetlands West Virginia Award," given by Ducks Unlimited for the creation and preservation of wetlands habitat.


CATERPILLAR



Dal-Tex Coal Co.'s massive operation in Logan County reclaimed over 800 acres and eliminated a 630 foot highwall in one year.

Dal-Tex was the 1995 winner of the "Wildlife West Virginia Award."

Mingo Logan Coal Co. in Mingo County won the "Callaghan Award" two times in three years, in 1990 and again in 1992.

In 1994, the Cumberland River operation won a Reclamation Award for the voluntary cleanup of the "Twenty-Six Fines Area," which negated a principal source of blackwater runoff to streams in Mingo County.

In 1994, the Wylo operation won the "Wetlands West Virginia Award," given by Ducks Unlimited for the creation and preservation of wetlands habitat.

Arch of West Virginia also won a 1996 Reclamation Award for its use of passive water treatment to restore the stream quality of Slab Fork, adjacent to its Ruffner Mine in Logan County.

Arch won a Reclamation Award in 1993 for the "Abe Burgess Refuse Area," for its innovative seeding techniques in rehabilitating a 40 year old refuse pile.

Arch won a Reclamation Award in 1994 for the "Hicks Hollow Refuse Area" where the company restored an abandoned refuse pile into a wildlife habitat.

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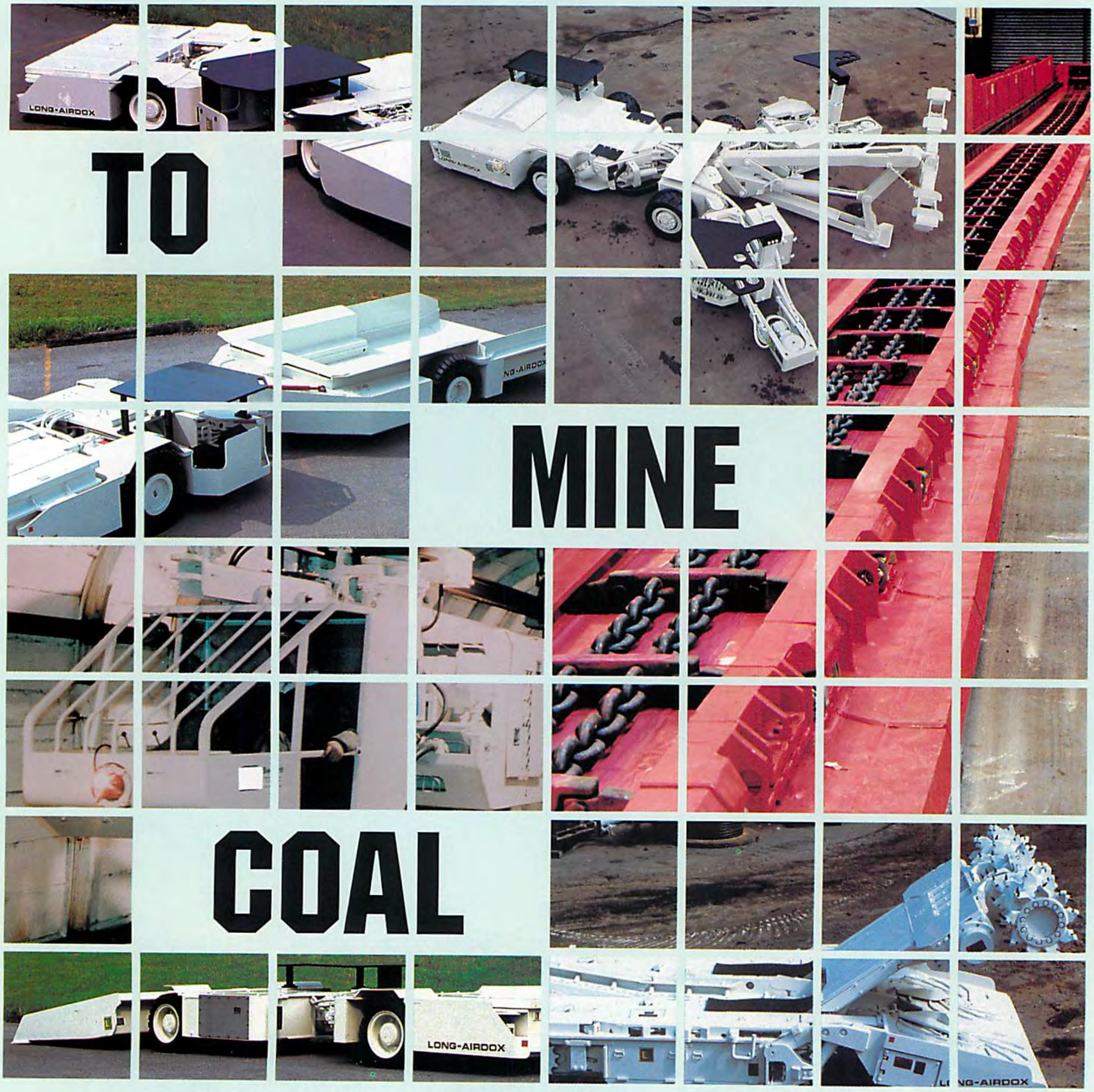
Standard	51,000 lbs. (23,133 kgs.)	66,000 lbs. (29,937 kgs.)	84,000 lbs. (38,102 kgs.)
High Lift	48,000 lbs. (21,773 kgs.)	60,000 lbs. (27,216 kgs.)	78,000 lbs. (35,381 kgs.)
SAE-Rated Bucket Capacity			
Standard	17 yd^3 (13.00 m^3)	22 yd^3 (16.82 m^3)	28 yd^3 (21.4 m^3)
High Lift	16 yd^3 (12.00 m^3)	20 yd^3 (15.29 m^3)	26 yd^3 (19.9 m^3)
Dump Heights			
Standard	18'-5" (5.61 m)	18'-10" (5.74 m)	21'-6" (6.55 m)
High Lift	19'-10" (6.04 m)	20'-0" (6.10 m)	23'-6" (7.16 m)

EVERYTHING YOU NEED TO MINE COAL



LONG-AIRDOX COMPANY

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Overview of Passive Systems For Treating Acid Mine Drainage

by Jeff Skousen, West Virginia University

Introduction

Active chemical treatment of AMD to remove metals and acidity is often an expensive, long-term proposition (Skousen et al. 1996). In recent years, a variety of passive treatment systems have been developed that do not require continuous chemical inputs and that take advantage of naturally occurring chemical and biological processes to cleanse contaminated mine waters. The primary passive technologies include constructed wetlands, anoxic limestone drains (ALD), successive alkalinity producing systems (SAPS), limestone ponds, and open limestone channels (OLC).

Natural wetlands are characterized by water-saturated soils or sediments with supporting vegetation adapted to reducing conditions in their rhizosphere. Constructed wetlands are man-made ecosystems that mimic their natural counterparts. Often they consist of shallow excavations filled with flooded gravel, soil, and organic matter to support wetland plants, such as *Typha*, *Juncus*, and *Scirpus* sp. Treatment depends on dynamic biogeochemical interactions as contaminated water travels through the constructed wetland. ALDs are abiotic systems consisting of buried limestone cells that passively generate bicarbonate alkalinity as anoxic water flows through. SAPS combine treatment concepts from both wetlands and ALDs. Oxygenated water is pre-treated by organic matter removing O_2 and Fe^{+3}, and then the anoxic water flows through an ALD at the base of the system. Limestone ponds are ponds built over the upwelling of a seep and the seep is covered with limestone for treatment. OLCs are surface channels or ditches filled with limestone. Armoring of the limestone with Fe hydroxides decreases limestone dissolution by 20 to 50%, so longer channels and more limestone is required for water treatment.

At their present stage of development, none of the passive systems can be reliably implemented as a single permanent solution for most AMD problems to meet effluent limits. Relative to chemical treatment, passive systems require longer retention times and greater space, provide less certain treatment efficiency, and are subject to failure in the long term. However, a great many passive systems have realized successful short-term implementation in the field and have substantially reduced water treatment costs at many mine sites (Faulkner and Skousen 1994). Current research seeks to understand the dynamically complex chemical and biological mechanisms that occur within passive systems and are responsible for AMD treatment. Selection of an appropriate passive system is based on water chemistry and flow (Figure 1, adapted from Hedin et al. 1994) and refinements in design are ongoing. As scientists and practitioners improve treatment predictability and longevity of passive systems, they will play a more important role in pollution abatement and environmental protection.

Natural Wetlands

Huntsman et al. (1978) and Wieder and Lang (1982) first noted amelioration of AMD following passage through naturally occurring *Sphagnum* bogs in Ohio and West Virginia. Studies by Brooks et al. (1985), Samuel et al. (1988), and Sencindiver and Bhumbla (1988) documented similar phenomena in *Typha* wetlands. Although evidence suggests that some wetland plants show long term adaptation to low pH and high metal concentrations, AMD eventually degrades the quality of natural wetlands, which is contrary to federal laws designed for wetland protection and enhancement. Such regulations do not govern use of artificially constructed wetlands for water treatment, leading to the suggestion that these engineered systems might provide low cost, low maintenance treatment of AMD (Kleinmann 1991). Over a thousand wetlands have since been constructed to receive AMD from both active mines and abandoned mine lands.

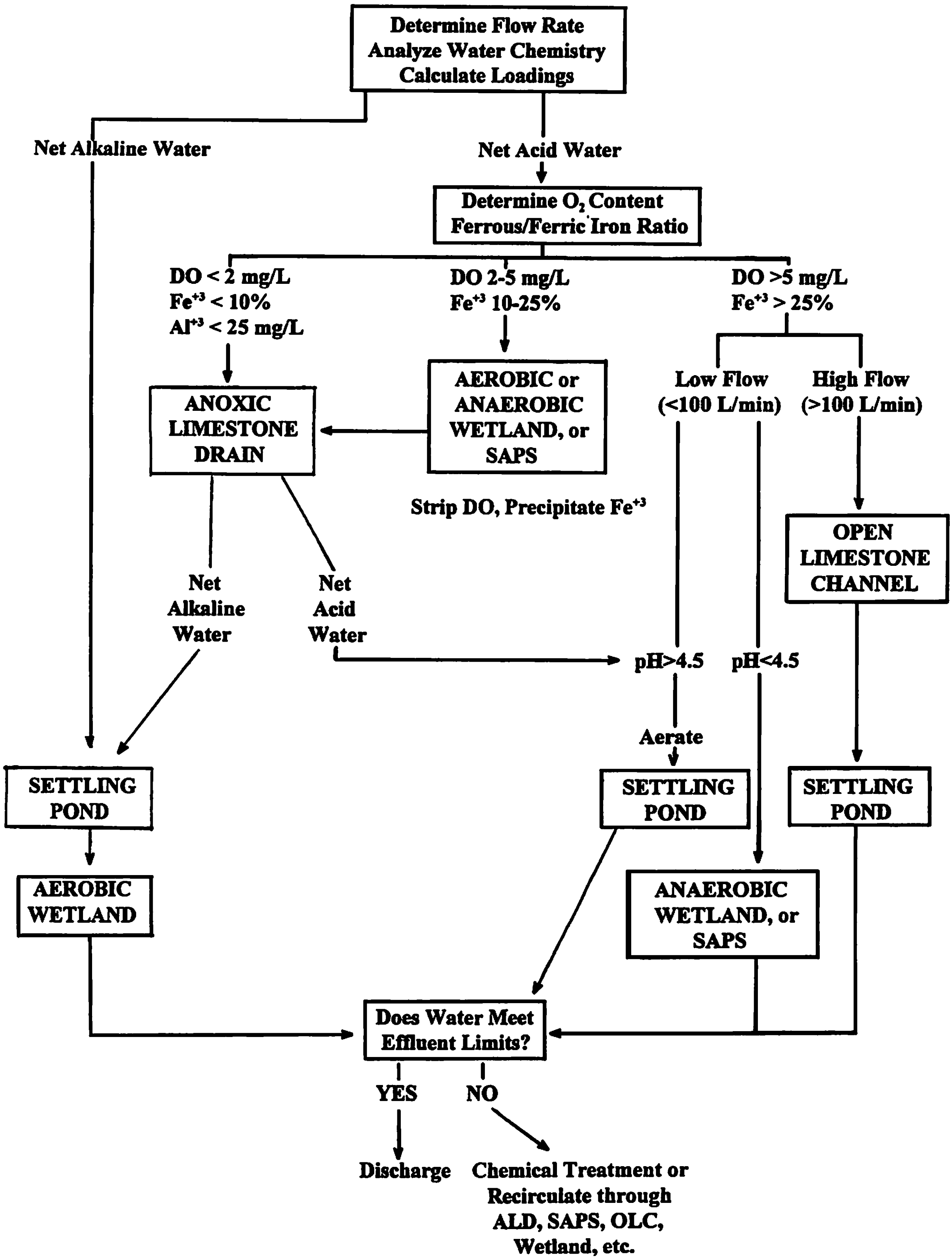

Figure 1. Flowchart for selecting a passive AMD treatment system based on water chemistry and flow. (adapted from Hedin et al. 1994.)

Constructed Wetlands

Mechanisms of metal retention within wetlands listed in their order of importance include: 1) formation and precipitation of metal oxides and hydroxides, 2) formation of metal sulfides, 3) organic complexation reactions, 4) exchange with other cations on negatively-charged sites, and 5) direct uptake by living plants. Other mechanisms may include physical retention of suspended metal colloids and adsorption/exchange of metals onto algal mats. Other beneficial reactions in wetlands include generation of alkalinity due to microbial mineralization of dead organic matter, microbial dissimilatory reduction of Fe hydroxides and SO_4, and dissolution of carbonates.

The way in which a wetland is constructed ultimately affects how water treatment occurs. Two construction styles currently predominate: 1) "aerobic" wetlands consisting of *Typha* and other wetland vegetation planted in shallow (<30 cm), relatively impermeable sediments comprised of soil, clay or mine spoil, and 2) "anaerobic" wetlands consisting of *Typha* and other wetland vegetation planted into deep (>30 cm), permeable sediments comprised of soil, peat moss, spent mushroom compost, sawdust, straw/manure, hay bales, or a variety of other organic mixtures, which are often underlain or admixed with limestone.

Aerobic wetlands are generally used to collect water and provide residence time so metals in the water can precipitate. The water in this case usually has net alkalinity and metals precipitate as the water is retained in ponds. Wetland species are planted in these systems for aesthetics and to add some organic matter, but the organic matter is not necessary to the function of the system. The wetland species also encourage more uniform flow and thus more effective wetland area.

Aerobic wetlands promote metal oxidation and hydrolysis, thereby causing precipitation and physical retention of Fe, Al, and Mn hydroxides. Successful metal removal depends on dissolved metal concentrations, dissolved oxygen content, pH and net acidity of the mine water, the presence of active microbial biomass, and detention time of the water in the wetland. The pH and net acidity/alkalinity of the water are particularly important because pH influences both the solubility of metal hydroxide precipitates and the kinetics of metal oxidation and hydrolysis. Metal hydrolysis lowers pH, so alkalinity in the water buffers the pH and allows metal precipitation to continue. Oxidation reaction rates decrease a hundred-fold with each unit drop in pH, and this oxidation rate decrease is partially compensated for by microbial Fe oxidation at pH ranges from 1 to 4. Following Fe oxidation, abiotic hydrolysis reactions precipitate Fe hydroxides. Therefore, aerobic wetlands are best used in conjunction with water that contains net alkalinity to neutralize metal acidity. Abiotic Mn oxidation occurs at pH >8 while microorganisms are thought to catalyze this reaction at pH >6 (Wildeman et al. 1991). Manganese precipitation occurs much more slowly than Fe and is sensitive to the presence of Fe^{+2}, which causes chemical reduction of oxidized Mn. Consequently in aerobic net alkaline water, Fe and Mn precipitate sequentially, not simultaneously, with the practical result that several staged aerobic wetlands must be constructed in series if removal of both metals is to be attempted.

Brodie and co-workers at the Tennessee Valley Authority (TVA) have reported extensively on their use of aerobic wetlands to treat AMD (Brodie 1993). A typical staged design might include an ALD (see next section) to passively add alkalinity to the source AMD, a settling basin to hold precipitated Fe flocs, followed by two or three aerobic wetland cells to sequentially remove additional Fe and Mn. TVA currently operates nine wetlands receiving moderate quality AMD (pH range of 3.1 to 6.3; total Fe < 70 mg/L; total Mn < 17 mg/L; total Al < 30 mg/L; alkalinity 35 to 300 mg/L as $CaCO_3$), which require no further post-system treatment of water exiting the wetlands. Four TVA wetlands are associated with high Fe (>170 mg/L) and low influent alkalinity, which produces water with low pH and high metal acidity. Two of these systems require NaOH treatment to comply with NPDES effluent limits, while two others use ALDs for further treatment of the effluent. A final TVA wetland system receives low Fe (<0.7 mg/L) and Mn (5.3 mg/L) and is ineffective in Mn removal. Based on their experience with these systems since 1985, Brodie suggests that staged aerobic wetland systems can accomodate Fe loads of up to 21 GDM (grams/day/m^2) even in the absence of excess alkalinity. Manganese loads up to 2 GDM can be accomodated if alkalinity is present.

Long term successful treatment by a staged aerobic wetland has also been reported for net alkaline water (total Fe 89 mg/L; alkalinity 88 mg/L as $CaCO_3$) at the Simco constructed wetland near Coshocton, OH (Stark et al. 1994). The wetland, built in 1985, has improved in treatment efficiency over time, not requiring any chemical treatment since 1990. The density of cattail shoots has increased to a current density of 17 shoots/m^2. Success at the Simco wetland is attributed to the presence of moderate mine water quality (near neutral pH and Fe <100 mg/L), sound wetland design, periodic site maintenance, and high vegetative cover.

Analysis of 73 sites in Pennsylvania suggested that constructed wetlands are the best available technology for many postmining ground water seeps, particularly those of moderate pH (Hellier et al. 1994). However, those site with net acidic discharges have a much lower successful treatment efficiency. For example, the Rougeux #1 site has a flow of 5.2 gpm and influent chemistry of 2.9 pH, 445 mg/L acidity as $CaCO_3$, Fe 45 mg/L, Mn 70 mg/L, and Al 24 mg/L. After flowing through a two-celled aerobic wetland, pH increased to 3.2, acidity was decreased by 43%, Fe by 50%, Mn by 17%, and Al by 83%. The wetland cost about $15/m² to build in 1992 and was severely undersized. Although there is improvement in the water, the wetland effluent did not conform to effluent limits. Two other wetlands constructed on the site show similar results.

Anaerobic wetlands contain a layer of limestone in the bottom of the constructed wetland. The limestone is overlain by organic material and wetland species are transplanted into the organic substrate. These systems are used when the water has net acidity. Alkalinity must be introduced into the water before dissolved metals will precipitate. The alkalinity can be generated in an anaerobic wetland system in two ways (Hedin and Nairn 1990). Certain bacteria, Desulfovibrio and Desulfotomaculum, can utilize the organic substrate (CH_2O, a generic symbol for organic matter) as a carbon source and sulfate as an electron acceptor for growth. In the bacterial conversion of sulfate to hydrogen sulfide, bicarbonate alkalinity is produced:

$$SO_4^{-2} + 2\,CH_2O = H_2S + 2\,HCO_3^- \qquad (1)$$

Alkalinity can also be generated as the limestone under the organic material dissolves and reacts with acidity in the wetland:

$$CaCO_3 + H^+ = Ca^{+2} + HCO_3^- \qquad (2)$$

The limestone continues to dissolve when kept in an anaerobic environment because ferrous iron is relatively soluble at pH 7-8 in anoxic water and does not precipitate or coat the limestone. If iron is allowed to oxidize and convert from ferrous to ferric iron, the ferric iron does tend to coat limestone when pH is above 3.0. Both of these processes, bacterial sulfate reduction and limestone dissolution, produce water with higher pH and add bicarbonate alkalinity for metal removal.

Anaerobic wetlands promote metal oxidation and hydrolysis in aerobic surface layers, but also rely on subsurface chemical and microbial reduction reactions to precipitate metals and neutralize acidity. The water infiltrates through a thick permeable organic subsurface sediment and becomes anaerobic due to high biological oxygen demand. Several additional treatment mechanisms function in anaerobic wetlands compared to aerobic wetlands, including metal exchange and complexation reactions, formation and precipitation of metal sulfides, microbially generated alkalinity due to reduction reactions, and continuous formation of carbonate alkalinity due to limestone dissolution under anoxic conditions.

Since anaerobic wetlands produce alkalinity, their use can be extended to poor quality, net acidic, low pH, high Fe, and high dissolved oxygen (>2 mg/L) AMD. However, Wieder (1992) documents that the mechanism and efficiency of AMD treatment varies seasonally and with wetland age. Microbial mechanisms of alkalinity production are likely to be of critical importance to long term AMD treatment. When wetlands receive high acid loads (>300 mg/L as $CaCO_3$), the pH sensitive microbial activities are eventually overwhelmed. Therefore, like their aerobic counterparts, anaerobic wetlands are most successful when used to treat small AMD flows of moderate water quality. At present, the sizing value for Fe removal in these wetlands is 10 GDM (Hedin and Nairn 1992).

Sorption onto organic materials (such as peat and sawdust) can initially remove 50 to 80% of the metals in AMD (Brodie et al. 1988), but eventually all sorption sites on substrate materials were exhausted by continual introduction of metals in acid water. Kleinmann (1991) suggested adsorption of metals by organic substrates may compensate for limited initial biological activity during the first few months of operation in a new wetland system. A field study, which examined five wetland substrate types over a 25-month period, also demonstrated that organic substrates were saturated after only 1 to 7 months of AMD input at 9 to 17 mg Fe per gram substrate (Wieder 1988). Although some natural inputs of organic matter occur annually at plant senescence, the adsorption capacity of a wetland will ultimately be finite as all exchange sites become metal saturated. Substantial artificial inputs of organic matter have been used as a successful strategy to temporarily renew this adsorption capacity, following an observed decline in wetland performance (Eger and Melchert 1992, Haffner 1992, Stark et al. 1995).

Insoluble precipitates such as hydroxides, carbonates, and sulfides represent a major sink for metal retention in wetlands. About 50 to 70% of the total Fe removed from AMD by wetlands is found as Fe^{+3} hydroxides (Henrot and Wieder 1990, Calabrese et al. 1991, Wieder 1992). Hydroxide formation depends both on the availability of dissolved oxygen and on the inital oxidation state of Fe in the AMD. Wieder (1993) reported significant retention of Fe^{+3} hydroxides in surface sediments of anaerobic wetlands due to the preponderance of dissolved Fe^{+3} in their source AMD. Once Fe^{+3} is present, then oxygen is unnecessary for hydrolysis to the hydroxide. Ferric hydroxides can be reduced with time to Fe^{+2} by anaerobic Fe-reducing bacteria in the wetland as these hydroxides accumulate and become buried in wetlands. Similarly, the use of Fe^{+3} as a pyrite oxidant under anaerobic conditions would result in Fe^{+2} in wetland effluents.

Up to 30% of the Fe retained in wetlands may be found as reduced Fe and may be combined with sulfides (Calabrese et al. 1991, McIntyre and Edenborn 1990, Wieder 1992). Iron mono and disulfides form as a result of H_2S formation by microbial sulfate reduction in the presence of an oxidizable carbon source. In addition to its metal removal potential, sulfate reduction consumes acidity and raises water pH (Hedin and Nairn 1992, Rabenhorst et al. 1992).

Long term retention of Fe sulfides and Fe hydroxides in a wetland is not well understood. Under continued anoxic conditions and in the absence of soluble Fe^{+3}, pyrite should remain stable. Calabrese et al. (1994) changed the influent of their anaerobic wetland from AMD to freshwater with no concomitant export of Fe^{+2}. Since their effluent pH was greater than pH 6 due to continued limestone dissolution, dissimilatory Fe reduction in surface sediments may have been inhibited (Wieder 1994).

Some workers have indicated that wetland systems can be seeded with specially designed and selected microorganisms (Davison 1993, Phillips et al. 1994) to introduce or re-establish microbial activity (see bioremediation section). However, experiments utilizing appropriate controls have not established the efficacy of this approach (Calabrese et al. 1994). Experience with bioremediation of other wastes suggests that selection and enrichment of naturally occurring microbial populations is a superior, more cost-effective approach (Alexander 1993).

In constructed wetlands, higher plants serve several purposes including: substrate consolidation, metal accumulation, adsorption of metal precipitates, stimulation of microbial processes, wildlife habitat, and aesthetics. Wetland plant species vary in their ability to accumulate metals (Fernandes and Henriques 1990). Some reports document elevated tissue concentrations (Spratt and Wieder 1988), while others show little metal accumulation (Folsom et al. 1981). On an annual basis, uptake by *Typha* accounted for less than 1% of the Fe removed by volunteer wetlands treating AMD (Sencindiver and Bhumbla 1988).

Several studies report on the effects of different plant species in wetlands. Early in the development of AMD treatment with constructed wetlands, *Sphagnum* was the predominant wetland species because *Sphagnum* has a well documented capacity to accumulate Fe (Gerber et al. 1985, Wenerick et al. 1989). However, Spratt and Wieder (1988) found that saturation of *Sphagnum* moss with Fe could occur within one growing season. Some have indicated that metal retention over the long term is limited in some wetlands because organic matter inputs by wetland plants is limited (Kleinmann 1990). Many of the original constructed wetlands were vegetated with *Sphagnum* but few remained effective. Cattails (*Typha*) have been found to have a greater environmental tolerance than *Sphagnum* moss (Samuel et al. 1988). One of the reasons is cattails do not accumulate metals into their tissues through uptake. Algae and a few other wetland species have also received attention due to the observation that enhanced metal removal was associated with algal blooms (Hedin 1989, Kepler 1988, Pesavento and Stark 1986, Phillips et al. 1994). In Colorado, algal mixtures were found to aerobically remove Mn from mine drainage (Duggan et al. 1992), presumably due to elevated pH resulting from algal growth. Probably the most important role that wetland plants serve in AMD treatment systems may be their ability to stimulate microbial processes. Kleinmann (1991) explains that plants provide sites for microbial attachment, release oxygen from their roots, and supply organic matter for heterotrophs.

Five anaerobic wetland systems in WV receiving 4 to 98 L/min of net acid water reduced acidity by 3 to 76% and Fe concentrations by 62 to 80% (Faulkner and Skousen 1994). These wetlands were generally much smaller in area than that recommended by earlier formulas based on iron loads. For example, one of these wetlands, Keister, reduced the acidity of a 17-L/min flow from 252 to 59 mg/L as $CaCO_3$ (76% reduction) and increased pH from 3.1 to 5.4. Iron was reduced from 23 to 9 mg/L (62%), Mn from 23 to 20 mg/L (11%), and Al from 27 to 13 mg/L (52%). The Pierce wetland used an organic substrate over limestone and treated a 98-L/min flow. Influent pH was 3.3, acidity was 118 mg/L as $CaCO_3$, Fe of 10 mg/L, Mn of 8 mg/l, and Al of 9 mg/L. Outflow pH was 4.4, acidity was reduced to 57 mg/L as $CaCO_3$ (52%), Fe decreased to 2 mg/L (80%), Mn was reduced by 11%, and Al by 25%.

A wetland system consisting of six wetland cells (total area of 2500 m^2) and a sedimentation basin each received a small flow (5 L/min) of AMD with pH of 3.0, acidity of 217 mg/L as $CaCO_3$, Fe of 27 mg/L, Al of 12 mg/L, and Mn of 2 mg/L. At this site in PA, the effluent after passing through the wetland was raised to pH 5.1, and the water contained a net acidity of 16 mg/L as $CaCO_3$, with about 46% iron removal and 56% Al removal (Hellier 1996).

A 1022 m^2 surface flow wetland was constructed in KY to treat 37 L/min of AMD with a pH of 3.3, acidity of 2280 mg/L as $CaCO_3$, Fe of 962 mg/L, Mn of 11 mg/L, and Al of 14 mg/L. After construction in 1989, metal concentrations in the effluent were reduced during the first six months of treatment, however, the system failed thereafter due to insufficient wetland area and metal overloading. In 1995, a two-phase renovation project began incorporating the use of an ALD, and a series of anaerobic drains that promote vertical flow through limestone beds overlain by organic compost (much like a SAPS). Results to date indicate a pH of 6.4, slightly net alkaline water (15 mg/L as $CaCO_3$), Fe reduction of 96%, Mn removal of 50%, and Al by 100% (Karathanasis and Thompson 1995).

Anoxic Limestone Drains

Anoxic limestone drains (ALD) are buried cells or trenches of limestone into which anoxic water is introduced. The limestone dissolves in the acid water, raises pH, and adds alkalinity. Under anoxic conditions, the limestone does not coat or armor with Fe hydroxides because Fe^{+2} does not precipitate as $Fe(OH)_2$ at pH < 6.0. ALDs were first described by theTennessee Division of Water Pollution Control (TDWPC) (Turner and McCoy 1990). TVA subsequently observed that AMD seeping through a coal refuse dam was being treated passively by limestone contained in an old haul road buried under the dam. Once the water containing excess alkalinity reached aerobic conditions at the ground surface, the metals oxidized and precipitated while the water remained near pH 6 (Brodie et al. 1990). TVA and TDWPC began building ALDs in 1989. Originally, ALDs were used for pre-treatment of water flowing into constructed wetlands. Brodie (1993) reported that ALDs improved the capability of wetlands to meet effluent limitations without chemical treatment. Since 1990, ALDs have also been constructed as stand-alone systems, particularly where AMD discharges from deep mine portals.

Longevity of treatment is a major concern for ALDs, especially in terms of water flow through the limestone. Eventual clogging of the limestone pore spaces with precipitated Al and Fe hydroxides, and gypsum ($CaSO_4$) is predicted (Nairn et al. 1991). For optimum performance, no Fe^{+3}, dissolved oxygen (DO), or Al should be present in the AMD. Selection of the appropriate water and environmental conditions is critical for long term alkalinity generation in an ALD.

Faulkner and Skousen (1994) reported both successes and failures among 11 ALDs treating mine water in WV. In all cases, water pH was raised after ALD treatment but three of the sites had pH values <5.0, indicating that the ALDs were not fully functioning or that the acidity concentrations and flow conditions were too high for effective treatment. When working correctly and adequately sized, the pH values of water in ALDs should achieve 6.0. Water acidity in these drains decreased 50 to 80%, but Fe and Al concentrations in the outflow, unfortunately, were also decreased. Ferric iron and Al precipitated as hydroxides at this pH in the drains. With Fe and Al decreases in outflow water, it is probable that some coating or clogging of limestone is occurring inside the ALD.

At the Brandy Camp site in PA, an ALD was employed to treat AMD with a pH of 4.3, acidity of 162 mg/L as $CaCO_3$, Fe of 60 mg/L, Mn of 10 mg/L, and Al of 5 mg/L. After passage through the ALD, the effluent had a pH of 6.0, net alkalinity of 10 mg/L as $CaCO_3$, Fe of 50 mg/L, Mn of 10 mg/L, and Al of <1 mg/L. Most of the Fe and Mn remained conservative in this system, while Al was precipitated inside the drain (Hellier et al. 1994).

Since many sources of AMD have mixed amounts of Fe^{+3} and Fe^{+2} and some DO, utilization of an ALD under these conditions compromises the effectiveness and longevity of the system. Current research involves pre-treatment of AMD with an anaerobic wetland (SAPS, see next section) to strip oxygen from the water and to convert Fe^{+3} to Fe^{+2} (Kepler and McCleary 1994, 1997; Skousen, 1995). The anoxic water after passing through an anaerobic organic substrate wetland can then be directed downward into underlying limestone or introduced into an ALD. There are still many questions relative to the longevity of ALDs and the factors involved in limestone dissolution and metal precipitation in ALD environments. Like wetlands, ALDs may be a solution for treating specific types of AMD or for a finite period after which the system must be replenished or replaced.

Limestone has also been placed in 60-cm corrugated pipe and installed underground, and water is introduced into the pipe. Septic tanks have also been filled with limestone and AMD introduced into the tank. These applications have been used on steep slopes in lieu of buried cells or trenches, and on sites that have poor access and small water quality problems.

Successive Alkalinity Producing Systems

Successive alkalinity producing systems (SAPS) combine the use of an ALD and an organic substrate into one system (Kepler and McCleary 1994). Oxygen concentrations in AMD are often a design limitation for ALDs. In situations where the dissolved oxygen concentrations are above 1 or 2 mg/L, the water can be introduced into a pond with the following design. Acid water, from 1 to 3 m, is ponded over 0.2 to 0.3 m of an organic compost, which is underlain by 0.5 to 1 m of limestone. Below the limestone is a series of drainage pipes that convey the water into an aerobic pond where metals are precipitated. The hydraulic head drives ponded water through the anaerobic organic compost, where oxygen stripping as well as Fe and sulfate reduction can occur prior to water entry into the limestone. Water with high metal loads can be successively cycled through additional SAPS. Iron and Al clogging of limestone and pipes can be removed by flushing the system (Kepler and McCleary 1997). Changes in the design are possible like the system installed at the Douglas Abandoned Mine Land Project (Skousen 1995).

Kepler and McCleary (1997) reported the use of SAPS in OH, PA, and WV. In all cases, Al in AMD precipitated in their systems. Their drainage design incorporates a flushing system called the 'Aluminator.' This allows for the precipitated Al to be flushed from the pipes thereby maintaining hydraulic conductivity through the limestone and pipes. One SAPS, Buckeye, received 3 L/min of very acid water (pH of 4.0, acidity of 1989 mg/L as $CaCO_3$), Fe of 1005 mg/L, and Al of 41 mg/L. Over a two-year period, the effluent had a pH of 5.9, net acidity concentration of about 1000 mg/L, Fe of 866 mg/L, and <1 mg/L Al. A second site, Greendale, treated a 25-L/min flow, and increased the pH from 2.8 to 6.5, changed the water from a net acid water (925 mg/L as $CaCO_3$) to a net alkaline water (150 mg/L as $CaCO_3$), Fe from 40 to 35 mg/L, and Al from 140 to <1 mg/L.

A large SAPS located at Douglas, WV treated a 1000/L min flow effectively for one year (Cliff et al. 1996). The influent pH was 3.0, with acidity of about 500 mg/L as $CaCO_3$, Fe of 30 mg/L, and Al of 40 mg/L. An average net alkalinity of 127 mg/L as $CaCO_3$ was realized in the effluent water, but dissolved oxygen, Eh and Fe data suggest that poor hydraulic conductivity caused this system to act as an Fe-oxidizing metal sink, rather than an Fe-reducing system. The system's long term effectiveness for treating AMD was compromised. Four years after installation, the original acidity of 500 mg/L as $CaCO_3$ is being reduced to between 250 to 300 mg/L as $CaCO_3$. It has remained at this level of treatment for the past two years.

At the Brandy Camp site in PA, a SAPS was employed to treat AMD with a pH of 4.3, acidity of 162 mg/L as $CaCO_3$, Fe of 60 mg/L, Mn of 10 mg/L, and Al of 5 mg/L. After passage through the SAPS, the effluent had a pH of 7.1, net alkalinity of 115 mg/L as $CaCO_3$, Fe of 3 mg/L, Mn of 10 mg/L, and Al of <1 mg/L. The system effectively increased alkalinity, but retained most of the Fe and Al inside the system (Hellier et al. 1994).

Limestone Ponds

Limestone ponds are a new passive treatment idea in which a pond is constructed on the upwelling of an AMD seep or underground water discharge point. Limestone is placed in the bottom of the pond and the water flows upward through the limestone (Faulkner and Skousen 1995). Based on the topography of the area and how the water emanates from the ground, the pond can be built to pond water from 1 to 3 m deep, containing 0.3 to 1 m of limestone immediately overlying the seep. The pond is sized and designed to retain the water for 1 or 2 days for limestone dissolution, and to keep the seep and limestone under water. If limestone coating occurs by Al or Fe hydroxides, the limestone in the pond could be periodically disturbed with a backhoe to either uncover the limestone from precipitates or to knock or scrape off the precipitates. If the limestone is exhausted by dissolution and acid neutralization, then more limestone can be added to the pond over the seep.

Open Limestone Channels

Open limestone channels (OLCs) introduce alkalinity to acid water by the use of open channels or ditches lined with limestone (Ziemkiewicz et al. 1994). AMD is introduced to the channel and the AMD is treated by limestone dissolution. Past assumptions have held that armored limestone (limestone covered or coated with Fe or Al hydroxides) ceases to dissolve, but experiments and demonstrations show that limestone continues to dissolve after coating at rates of 20 to 50% of unarmored limestone (Pearson and McDonnell 1975, Ziemkiewicz et al. 1994, 1997). Therefore, OLCs neutralize acidity in AMD as long as open channels are constructed of sufficient length to maintain contact time between the limestone and acid water. Open limestone channels show promise for neutralizing AMD in watershed restoration projects and AML reclamation projects where one-time installation costs are incurred, little to no maintenance is required, and systems do not have to meet specific water quality standards. Long channels of limestone can be used to convey acid water to a stream or other discharge point. Based on flows and acidity concentrations, cross sections of stream channels (widths and heights) can be designed with calculated amounts of limestone (which will become armored) to treat the water. Open limestone channels work best where the channel is constructed on steep slopes (>20%) and where flow velocities keep metal hydroxides in suspension, thereby limiting their precipitation and plugging of limestone pores in the channel. Utilizing OLCs with other passive systems can maximize treatment and metal removal. If constructed correctly, OLCs should be maintenance free and provide AMD treatment for decades.

Ziemkiewicz et al. (1997) found armored limestone to be 50 to 90% effective in neutralizing acid compared to unarmored limestone, and seven OLCs in the field reduced acidity in AMD by 4 to 62% compared to a 2% acid removal in a sandstone channel.

Three OLCs were installed in the Casselman River Restoration project (Ziemkiewicz and Brant 1997). One OLC received 60 L/min of pH 2.7 water, 1663 mg/L as $CaCO_3$ acidity, 830 mg/L Fe, 67 mg/L Mn, and 153 mg/L Al. The effluent pH was 2.9, acidity of 455 mg/L as $CaCO_3$ (73% removal), Fe of 135 mg/L (84% decrease), Mn of 21 mg/L (69% decrease), and 38 mg/L Al (75% decrease).

At the Brandy Camp site in PA, an OLC was employed to treat AMD with a pH of 4.3, acidity of 162 mg/L as $CaCO_3$, Fe of 60 mg/L, Mn of 10 mg/L, and Al of 5 mg/L. After passage through the OLC, the effluent had a pH of 4.8, net acidity of 50 mg/L as $CaCO_3$, Fe of 17 mg/L, Mn of 8 mg/L, and Al of 3 mg/L. The OLC removed 72% of the Fe and about 20% of the Mn and Al from the water (Hellier et al. 1994).

Bioremediation

Bioremediation of soil and water involves the use of microorganisms to convert contaminants to less harmful species in order to remediate contaminated sites (Alexander 1993). Microorganisms can aid or accelerate metal oxidation reactions and cause metal hydroxide precipitation. Other organisms can promote metal reduction and aid in the formation and precipitation of metal sulfides. Reduction processes can raise pH, generate alkalinity, and remove metals from AMD solutions. In most cases, bioremediation of AMD has occurred in designed systems like anaerobic wetlands where oxidation and reduction reactions are augmented by special organic substrates and limestone. In a few cases, substrates have been incorporated into spoils to aid in in-situ treatment of water by the use of indigenous microorganisms.

A mixture of organic materials (sawdust and sewage sludge) was emplaced into a mine spoil backfill to stimulate microbial growth and generate an anoxic environment through sulfate reduction. The results of the organic matter injection process caused no change in water pH, about a 20% decrease in acidity (1500 to 1160 mg/L as $CaCO_3$, and a similar decrease in Fe, Mn, and Al. The results indicate that the process works, but improvements in organic material injection and the establishment of a reliable saturated zone in the backfill are needed for maximum development (Rose et al. 1996).

The Lambda Bio-Carb process is a bioremediation system utilizing site-indigenous, mixed microorganism cultures selected for maximum effectiveness (Davison 1993). On a field site in PA using this bioremediation process, Fe in AMD was decreased from 18 mg/L to < 1 mg/L, Mn declined from 7 mg/L to 2 mg/L, and pH increased from around 6.0 to 8.0.

The Pyrolusite process uses selected groups of microorganisms growing on limestone to oxidize Fe and Mn into their insoluble metal oxides (Vail and Riley 1997). On a field site in PA using a limestone bed inoculated with microorganisms, Fe was decreased from 25 mg/L to < 1 mg/L, Mn went from about 25 mg/L to < 1 mg/L, while pH and alkalinity in the effluent were increased.

Diversion Wells

The diversion well is a simple device initially developed for treatment of stream acidity caused by acid rain in Norway and Sweden (Arnold 1991). It has been adopted for AMD treatment in the eastern USA. A typical diversion well consists of a cylinder or vertical tank of metal or concrete, 1.5-1.8 m in diameter and 2-2.5 m in depth, filled with sand-sized limestone. This well may be erected in or beside a stream or may be sunk into the ground by a stream. A large pipe, 20-30 cm in diameter, enters vertically down the center of the well and ends shortly above the bottom. Water is fed to the pipe from an upstream dam or deep mine portal with sufficient hydraulic head of at least 2.5 m (height of well). The water flows down the pipe, then exits the pipe near the bottom of the well, then flows up through the limestone in the well, thereby fluidizing the bed of limestone in the well. The flow rate must be rapid enough to agitate the bed of limestone particles. The acid water dissolves the limestone for alkalinity generation, and metal flocs produced by hydrolysis and neutralization reactions are flushed through the system by water flow out the top of the well. The churning action of the fluidized limestone also aids in limestone dissolution and helps remove Fe oxide coatings so that fresh limestone surfaces are always exposed. Metal flocs suspended in the water are precipitated in a downstream pond.

Arnold (1991) used diversion wells for AMD treatment in PA and reports that three wells increased pH from 4.5 to 6.5, with corresponding decreases in acidity. For example, one diversion well located at Lick Creek treats about 1000 L/min of slightly acid water. After passing through the diversion well, the pH changes from 4.5 to 5.9 and the net acid water (8 mg/L as $CaCO_3$) changes to net alkaline water (6 mg/L as $CaCO_3$). Similar results are found for several other sites in PA.

Diversion wells have also been constructed in the Casselman River Restoration Project. This large diversion well has a retention time of about 15 min for a 360-L/min flow of moderately acid water. The diversion well reduces the acidity from 314 to 264 mg/L as $CaCO_3$, Fe from 83 to 80 mg/L, and Al from 24 to 20 mg/L (Ziemkiewicz and Brant 1996).

At the Galt site in WV, a diversion well changes a 20-L/min flow from a pH of 3.1 to 5.5, acidity from 278 to 86 mg/L as $CaCO_3$, Fe from 15 to 2 mg/L, and Al from 25 to 11 mg/L (Faulkner and Skousen 1994).

Limestone Sand Treatment

Sand-sized limestone may also be directly dumped into AMD streams at various locations in watersheds. The sand is picked up by the streamflow and redistributed downstream, furnishing neutralization of acid as the stream moves the limestone through the streambed. The limestone in the streambed reacts with acid in the stream, causing neutralization. Coating of limestone particles with Fe oxides can occur, but the agitation and scouring of limestone in the streambed keep fresh surfaces available for reaction.

The WV Division of Environmental Protection treats 41 sites in the Middle Fork River, including the headwaters of 27 tributaries. The first year's full treatment was based on four times the annual acid load for non-AMD streams and two times the load for AMD tributaries. During subsequent years, limestone sand was applied at an amount equal to the annual acid load, or about 2,000 tons/year. About 8,000 tons of limestone were deposited among the 41 sites in 1995. Water pH has been maintained above 6.0 for several miles downstream of the treatment sites. The anticipated precipitate coating on limestone was not observed. It is predicted that treating the river with limestone sand will be necessary three times a year to maintain water quality for fish populations (Zurbuch 1996).

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Geological Survey has served West Virginia well for 100 years

WVGES celebrates centennial

"Experience has shown but one way in which to open up the resources of a country, and this is a geological Survey. . . ."

With these words in 1869, distinguished West Virginia University geologist John James Stevenson advocated the State's need for a geological survey.

But it was not until 1897 that the West Virginia Geological and Economic Survey was established by an act of the Legislature. Its purposes were to investigate the state's geological and physical resources, to make the results of these investigations promptly available to the public, and to provide topographic, geologic, and other maps of the State.

Dr. Israel Charles White, one of the most prominent geologists of that time, was chosen to head the new agency. Under his leadership, the Survey soon became internationally known. White supervised the preparation of topographic maps covering the entire state and edited 34 geologic reports. By 1927, the Survey had made detailed geologic studies of every county except Greenbrier, and it was held in some quarters that the geologic record of West Virginia exceeded that found for any like area in the world.

In 1934, Dr. Paul H. Price assumed the position of Director and State Geologist and the Survey entered a new period, characterized by an intensive program to examine more fully the physical and chemical properties of the state's resources. Extensive coal, oil, and natural gas studies were undertaken. In 1941, Price initiated a cooperative U.S. Geological Survey program to study the groundwater resources of the state. In 1942, the Survey moved into West Virginia University's new Mineral Industries Building, later renamed White Hall in honor of Dr. I.C. White.

Map publishing reached a new high in the postwar years of Price's directorship and included a new state geologic map, shaded relief map, base map, mineral resources and mineral industries map, three editions of an oil and gas map, a limestone map, and produced nearly 300 topographic maps under a cooperative agreement with the U.S. Geological Survey.

By the late 1960s, the application of geologic information, long restricted to development of mineral resources, increasingly became part of land-use planning, water-resource management, building construction, planning of transportation and utility facilities, and the safe disposal of wastes. Consequently, when Dr. Robert B. Erwin became Director and State Geologist in 1969, the Survey enlarged the scope of its activities to include detailed statewide coal studies, land-use mapping, remote sensing, sophisticated analytical capabilities, and computerized data processing.

Under Erwin, the Survey established its unique Coal Program and began a comprehensive reevaluation of the geology, composition, and extent of all 117 West Virginia coal seams. Increased study of nonfuel mineral resources and important acid mine drainage research was conducted. Computerization of the Survey's enormous quantity of geologic data was undertaken. Significant publications were completed such as the 50th anniversary edition of *Springs of West Virginia*, and the *West Virginia Gazetteer of Physical and Cultural Place Names*. The Survey relocated to Mont Chateau Research Center, allowing most of the staff to be housed in one building.

Since 1988, Larry D. Woodfork has served as the Survey's Director and State Geologist. Woodfork is intent on expanding the Survey's prominent role in geologic research and committed to upholding the agency's long tradition of public service, technical excellence, and professional integrity in the tight economic climate of the 1990s. This has resulted in significant economies in the Survey's operating costs while still allowing an expansion of its public service and outreach operations, participation in an increased variety of externally funded research projects, and computerization of nearly all geoscience and support functions, all of which positions the Survey for its second century of service to the Mountain State.

Coal Based Programs and Services of WVGES

• **Geographic Information System (GIS)** - The survey serves as the fiscal agent in the collaborative effort with the other Mineral Lands Mapping Project participants; supports the characterization of the mineral parcels by the WV Dept. of Tax and Revenue, the development of digital line graphs by the WVU Department of Geology and Geography, the mission of the State GIS coordinator, and WVU's Statewide GIS Technical Center; maps the economic coal beds of the State in GIS format.

• **Coal Bed Mapping Project** - A GIS-based inventory of coal in West Virginia is being created: new and existing data will be consolidated into a computer database for each 7.5' quad; GIS technology will be utilized to generate structure contour, outcrop, surface and underground mined area, and modeled thickness maps for each coalbed and quadrangle; GIS coal bed data layers will be serve as a compliance tool for the mineral lands tax program of the State Department of Tax and Revenue.

• **Other related projects** in this program include those of the WV State GIS Coordinator, the Mineral Lands Mapping Project of the WV Dept. of Tax & Revenue, the Digital Line Graph Development Project of the WVU Dept. of Geology and Geography, and the WVU GIS Technical Center.

• **Applied Coal Resources Investigations** - The Survey calculates remaining Appalachian coal resources available for extraction; documents the location of underground and surface mining activity; collects, prepares, and analyzes coal-bed samples and develops information about the chemical characteristics and properties of coal in West Virginia.

• **National Coal Resources Data System**, a cooperative project with the USGS Branch of Coal Resources, develops point-source information characterizing WV coals.

• **Coal resources studies** by 7.5' quadrangles include the development of GIS-based structure contour, outcrop, and overburden layers of data and a thickness model for each target coal bed; restrictions to mining reconsidered and original, mined, remaining, restricted, and available resource tonnages for each target coal bed are determined.

• **Surface and underground mine locations,** and other related information, are compiled.

• **A computerized coal quality database** has been developed, providing information on the chemical and physical properties of various coals at various locations around the State.

West Virginia Senate Resolution 8

By Senators Oliverio, Hunter, Prezioso and Minear
[Adopted by the Senate February 26th, 1997.]

Recognizing, commending and honoring the West Virginia Geological and Economic Survey's 100 years of service to West Virginia.

Whereas, Governor Boreman in 1864 through House Bill No. 22 attempted to recognize the role of geology in West Virginia's future prosperity and the necessity for the state to appoint a state geologist who would conduct a geological survey determining the resources of our state; and

Whereas, The Legislature continued to discuss the question of the necessity of establishing a state geological survey and its potential for contributions to the well-being and economic opportunity for West Virginia in 1870, 1876, 1882 and 1897; and

Whereas, The West Virginia Legislature on February 26, 1897, passed an act to establish a state geological and economic survey to provide for the prepartion and publication of reports and maps to illustrate the natural resources together with the necessary investigations preparatory thereto; and

Whereas, The West Virginia Geological and Economic Survey, from the time of its first state geologist, the venerable Dr. Israel Charles White, succeeded by eight other state geologists in either acting or appointed capacity, including Dr. Paul H. Price, Dr. Robert B. Erwin and Larry D. Woodfork; the current director and state geologist, has expertly focused on understanding the natural resources of the state, sharing that knowledge with citizens of the entire state and various corners of the nation and world; and

Whereas, Today's devoted state employees on the staff of the Geological and Economic Survey continue the tradition of 100 years of unsurpassed service, insightful geological research and effective outreach with recognized distinction; and

Whereas, The West Virginia Geological and Economic Survey is on the forefront of technological development to provide geological maps, information and publications in the most expeditious way that promotes geological science for the public good into the twenty-first century; therefore, be it

Resolved by the Senate: That congratulations are given to the West Virginia Geological and Economic Survey, its director and state geologist, Larry D. Woodfork, and the entire staff of dedicated state employees, at the end of their first 100 years of service to the citizens of the state of West Virginia; and, be it

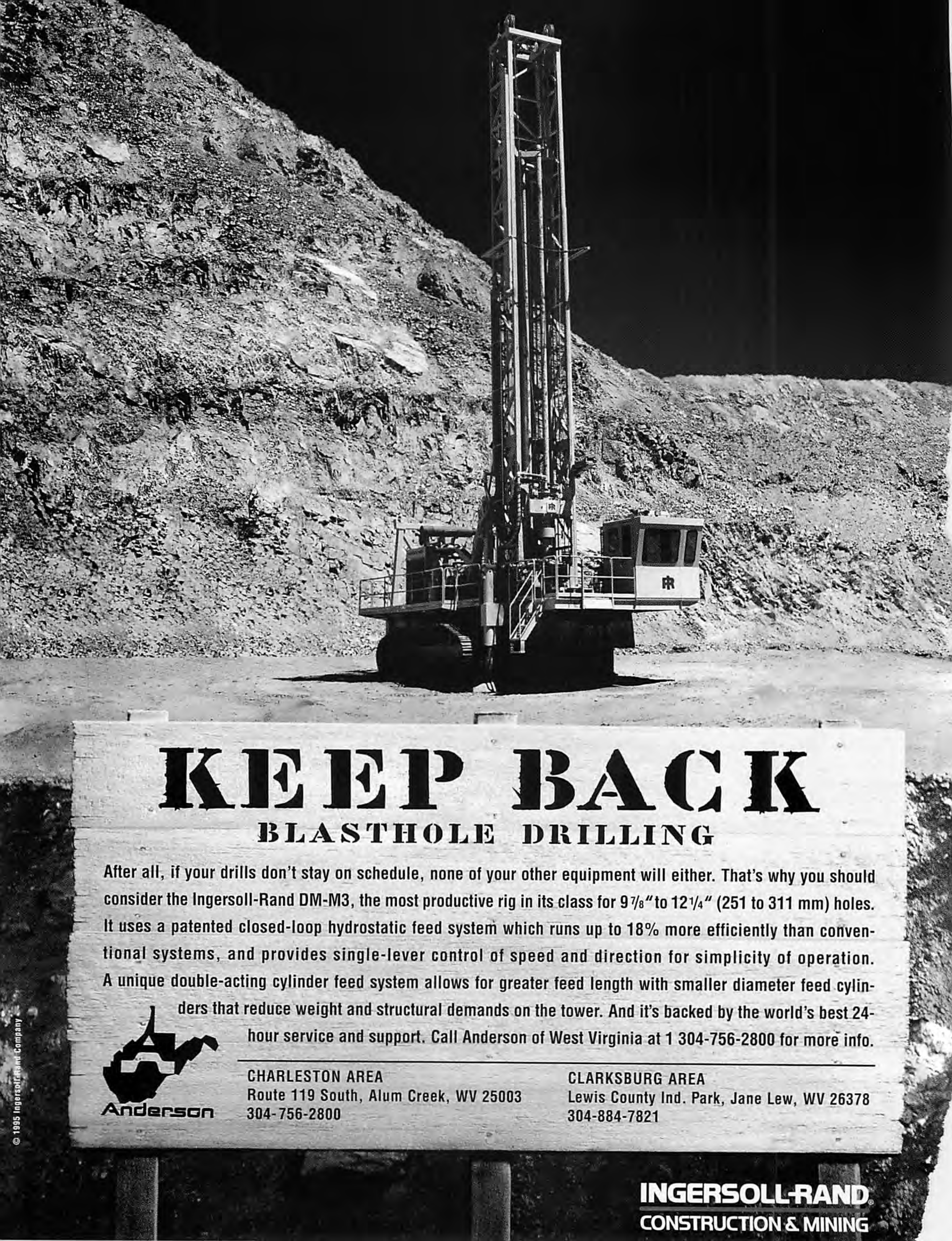
Further Resolved, That the West Virginia Geological and Economic Survey is hereby recognized, encouraged and supported for its next century in its mission to provide unbiased, quality and effective geological research and information for the well-being of the state of WestVirginia in the same fashion it has so aptly done throughout the past 100 years; and, be it

Further Resolved, That the Senate hereby designates the 26th of February of each year to be "West Virginia Geological and Economic Survey Day" and hereby encourages all citizens to recognize the Survey and its employees who have served the citizens so admirably through their dedication to the well-being of our state; and, be it

Further Resolved, That the Clerk is hereby directed to forward a copy of this resolution to Larry D. Woodfork and the employees of the West Virginia Geological and Economic Survey with the warmest congratulations and best wishes of the Senate.

Given under our hands and the SEAL of the SENATE of WEST VIRGINIA this 26th day of February, 1997.

Senate President Earl Ray Tomblin
Senate Clerk Darrell E. Holmes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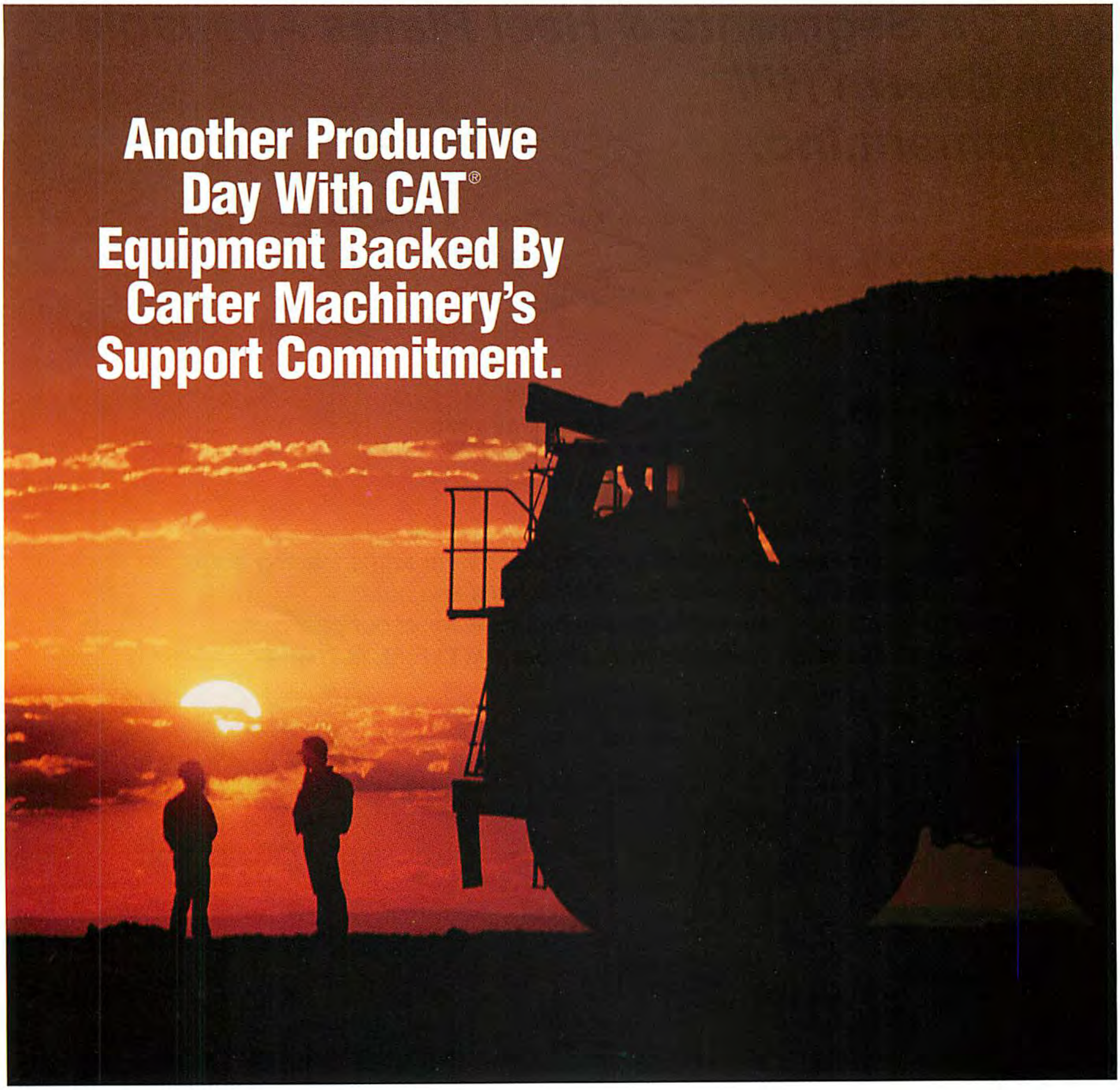
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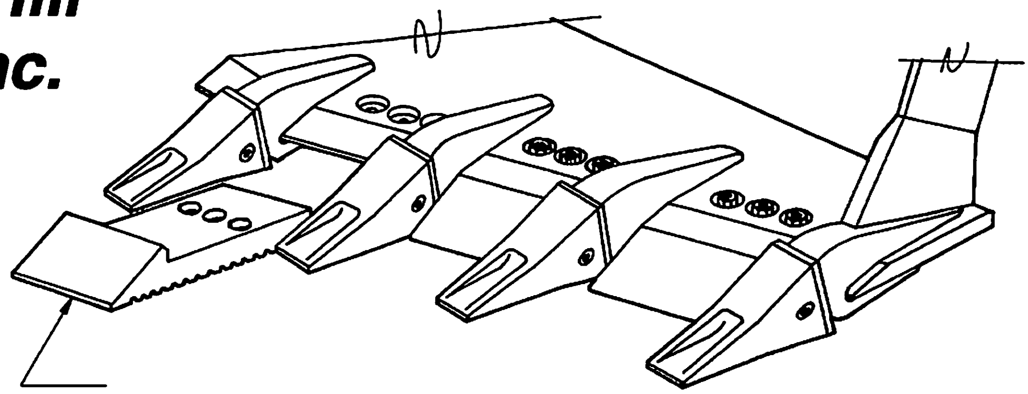

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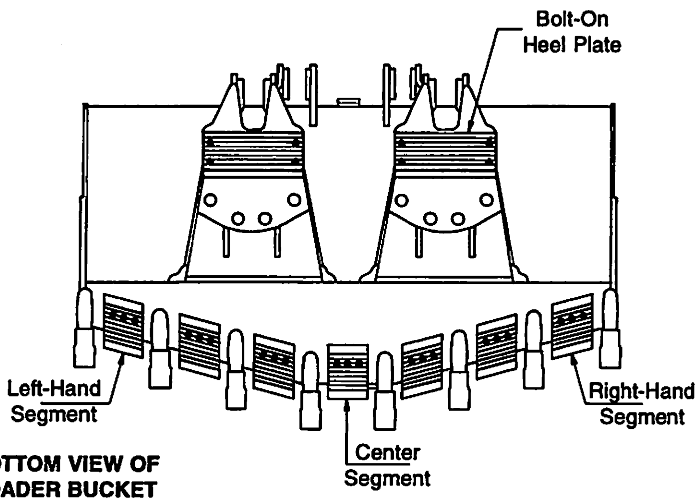

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