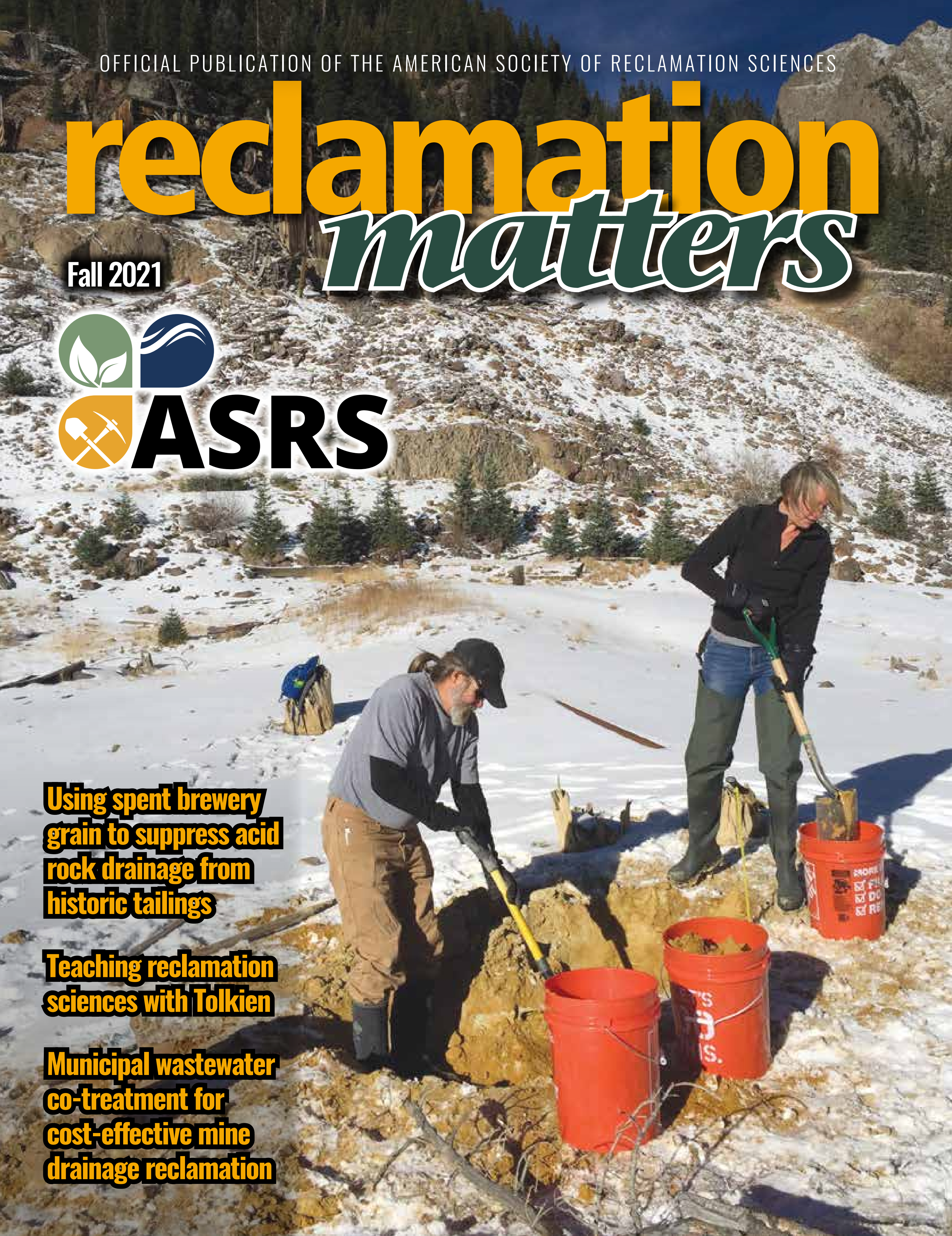
OFFICIAL PUBLICATION OF THE AMERICAN SOCIETY OF RECLAMATION SCIENCES

reclamation matters

Fall 2021

ASRS



Using spent brewery grain to suppress acid rock drainage from historic tailings

Teaching reclamation sciences with Tolkien

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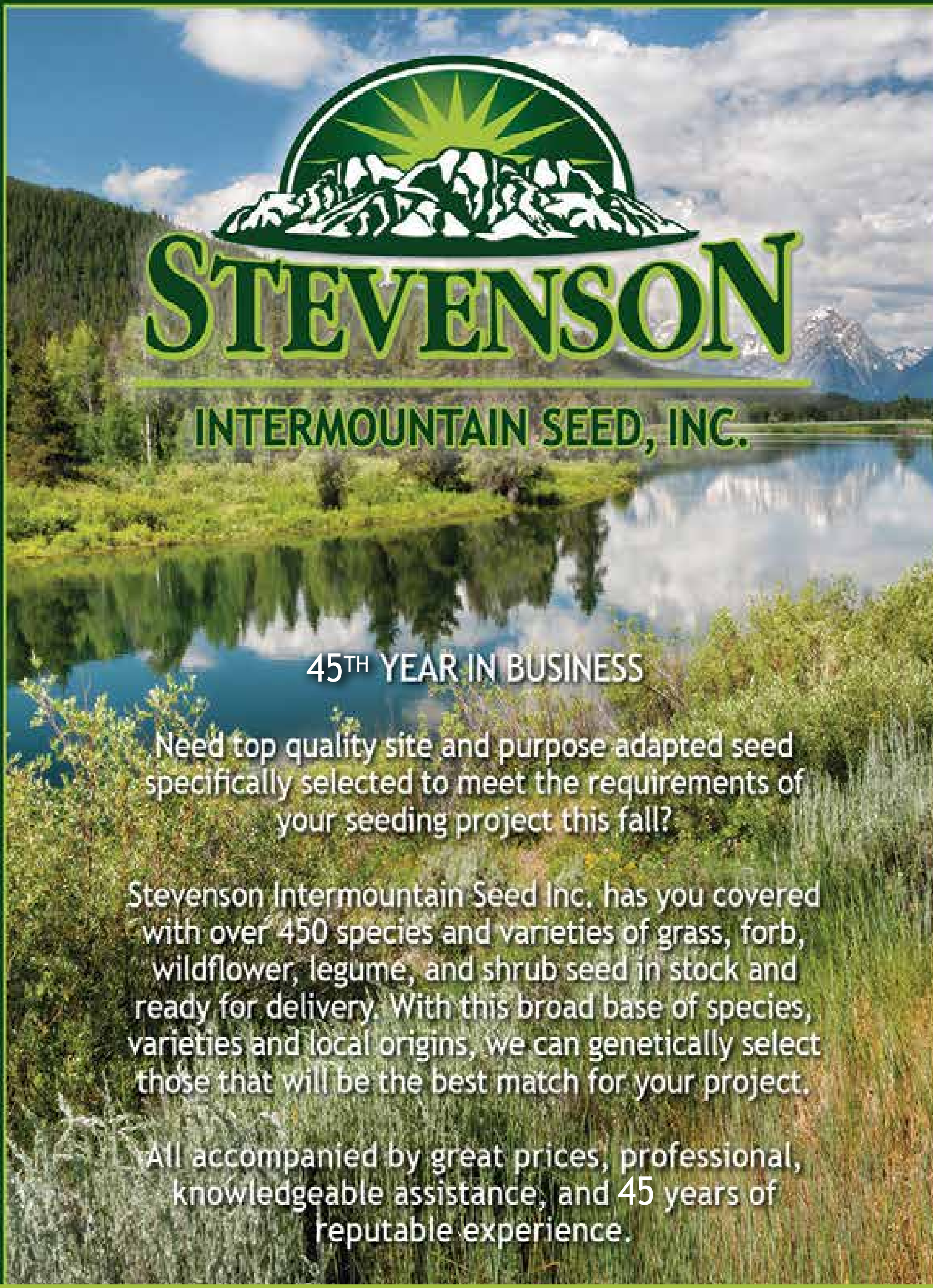

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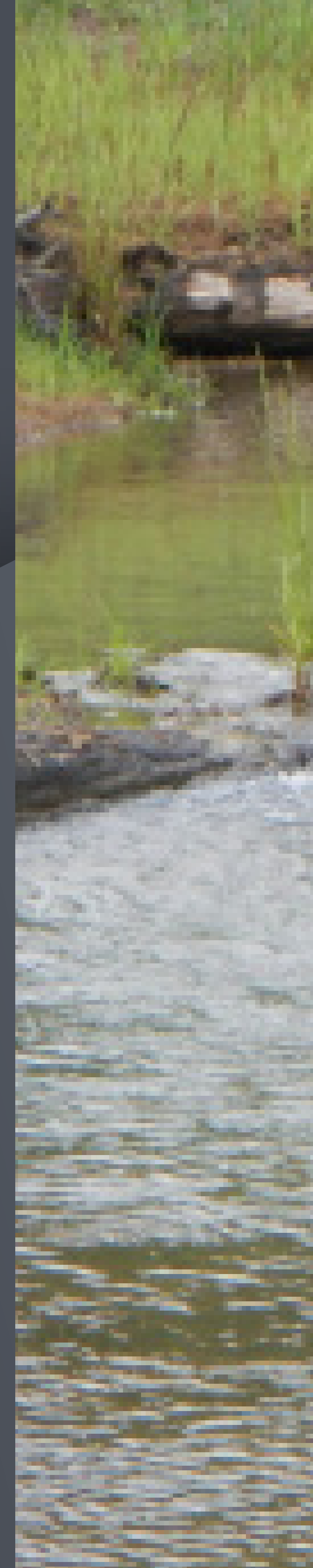

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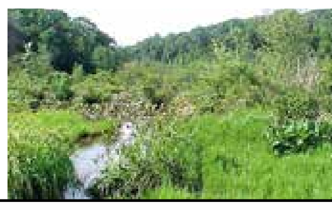
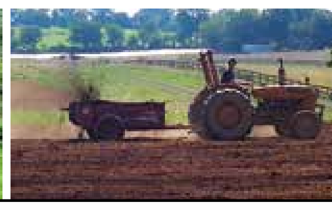


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reclamation matters

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Why am I president of ASRS?

Well, I'm as surprised as you!

Apparently enough members were willing to elect me as the presiding officer of this great organization. I have been on the National Executive Council for several years and I will continue to do my best to help further the mission of the American Society of Reclamation Sciences (ASRS).

As a little bit of background, my interest in reclamation began when I first learned about passive treatment technology and observed the amazing results that building some ditches and ponds could accomplish on water quality. Streams that had been void of life for over a century could become viable fisheries again. How cool is that!? As I learned when I attended my first meeting of what was then the American Society for Surface Mining and Reclamation (ASSMR) in 1998, there is a lot of research that goes into understanding *why* and how those ponds and ditches work.

Why … is a question we need to ask more often. We often focus on who, what, when, where, and how. But *why* could be asked more often. Strangely, I was once told that asking *why* is dangerous and should be avoided.

So *why* would I want to be President of the ASRS? Let alone a member? It is because I have a passion for reclamation and want to learn how to best fulfill my vocation. ASRS provides a forum where I can learn from others so I can do my job better. I also have learned to share information gleaned through my experiences, so others can find more success in their own endeavors. A symbiosis of science, if you will.

Our organization is in the process of undergoing some major changes. We have recently changed our name. *Why*? So that we can be more inviting to those working to restore environments impacted by all disturbances, not just mining. We are updating our website. *Why*? Because that is the portal through which others can learn about what we have to offer. We are reinventing our Journal. *Why*? To take better advantage technology, expand our legacy of knowledge, and improve the realm of reclamation sciences.

By the time we meet in Duluth for the first time in three years, we will have a new name, a new website, and a new journal. This is an exciting time in our Society's history, and I invite you to ask yourself *why* you chose to be part of ASRS. Moreover, how will you share what you have with others in our organization?

International knowledge and experience

BY JEFF SKOUSEN, WEST VIRGINIA UNIVERSITY

Jeff Skousen and Dave Trumm in New Zealand.

Two years ago, I was asked by a good friend and colleague, Dave Trumm, to provide a presentation on the history of the development of passive systems for treating mine water at the 2020 International Mine Water Association's (IMWA) annual meeting in New Zealand. I knew Dave because he came to the United States more than 10 years ago to learn about passive systems. During that visit, we spent several days traveling to a variety of sites in West Virginia, where passive systems had been employed to treat mine drainage. I showed him old systems that were designed and installed in the late 1980s and took him to newer hybrid systems, and I presented data that had been gathered on treatment effectiveness over the years. A year later Dave invited me to New Zealand where he and his company were preparing to design and construct passive systems on dozens of abandoned and active mine sites with mine drainage problems. We spent a couple of weeks appraising all the potential sites, evaluating data on flow and chemistry, and discussing the site conditions that would influence the type of system selected. We wrote a long report on our findings, which offered recommendations for the type of system that could be developed along with designs and sizing specifications for each site. It was a glorious trip, and I'm proud to say that many of these systems were installed.

After accepting Dave's speaking invitation, I began preparing the presentation, but then the meeting was canceled due to COVID. The presentations accepted for the 2020 IMWA New Zealand meeting were pushed forward to the succeeding 2021 IMWA meeting in Wales. In January of this year, as I was preparing the presentation for 2021 IMWA, Bob Kleinmann sent an email to several people who had collaborated on a passive system review paper published in 2017. Amazingly, he wanted to develop a historical paper detailing the discoveries and advancement of passive systems for the journal he edits called Mine Water and the Environment (MWEN). I responded that I was doing the exact same thing and was preparing a presentation on the same subject. Since we both had been thinking about it, we quickly developed a rough draft and then added several other authors who contributed to the paper, including Bob Hedin, Bob Nairn, Tom Wildeman, and Jim Gusek. The paper will be published in one of the fall issues of MWEN.

This past summer, I gave the presentation virtually at the 2021 IMWA meeting. The presentation followed the information in the paper and was augmented with my own pictures and others from the authors. Within an hour after I spoke, I received email messages from scientists in Spain and Germany stating that they had developed passive systems in their countries and some of their discoveries and installations preceded those mentioned in my presentation. It was then that Bob Kleinmann and I, primarily familiar with the early work in the United States, realized that we had neglected the contributions of international scientists and practitioners in this story. Therefore, we added this acknowledgment to our paper:

"We apologize in advance for any North American bias in our coverage, but from our perspective at least, the most important early work took place there, although during the late 1990s, the use of passive treatment began to become truly international."

The point of telling this story here is not to debate when or by whom passive systems were discovered or to dispute system design differences, but to remind us that we work in a truly international field. We discovered, to our surprise, that the passive system developments in the United States originated independently from observations by researchers and groups in Pennsylvania, West Virginia, Ohio, Colorado, and Minnesota without knowing about each other's work. We should not have been surprised that similar discoveries were being made in other places around the world (like Canada, the United Kingdom, Spain, and Germany) who had similar mine drainage problems. We hope that the paper published in MWEN will entice those in other locations to tell their story of the first passive systems in their

> … we all benefit from an ever-widening network of colleagues and collaborators – particularly when they bring experiences and perspectives that differ from our own.

countries, and Bob will invite them to submit their perspectives to be published in subsequent issues of MWEN.

Discoveries don't often happen to only one person, and this story of passive system initiation is a good example of a technology whose time had come. The concepts of passive systems were being imagined, designed, and deployed by many observant people across the globe. This is also an example of how we all benefit from an ever-widening network of colleagues and collaborators—particularly when they bring experiences and perspectives that differ from our own. This historical review began as an individual effort for a single presentation, grew to include multiple peers for a journal article, then expanded to involve an international network of scientists in an ongoing dialog. While I have traveled to or hosted visiting scientists from multiple countries, I have come to realize how important those international connections have been to my understanding of passive systems and many other reclamation ideas and practices. We can learn from the experiences of others, particularly international colleagues, and we must embrace the contributions of others not within our immediate circle of partners or collaborators.

Special thanks are given to Andrea Hackbarth for insights to this article and to Dr. James Thompson for helpful comments and editing.

Early Career Professional update

Happy fall to the students, ECPs, and seasoned reclamation professionals of ASRS!

First, we want to highlight that this past June, several awesome students and ECPs received awards at our virtual annual meeting. Hannah Curtis, Brianna Slothower, and Dr. Brandon Holzbauer-Sweitzer were awarded Memorial Scholarships, and Dr. Kenton Sena received the Early Career Award.

In the coming months, the ASRS National Executive Committee is working to plan a virtual trivia night where students, ECPs, and ASRS members will team up to answer questions, network, and win prizes!

The ASRS National Executive Committee is also hard at work devising and implementing ways in which the society can most effectively support student and ECP members. If you have any suggestions, questions, or comments regarding student and/or ECP members of ASRS, please reach out to the NEC ECP Representative, Hannah Patton (hpatton@vt.edu).

CASE STUDY

Mission Reach Project for the San Antonio River Authority

The San Antonio River Authority needed to vegetate a section of the Mission Reach Project on the San Antonio River. The project site had previously needed to have invasive species removed and was in an area that was prone to erosion due to concentrated flow: quick and dense desirable vegetation establishment was imperative to combatting both issues. Joel Denofrio with Innovative Soil Solutions recommended the use of Biotic Earth to reach the desired goals of the project. Biotic Earth was applied at 3,500 lbs. per acre by Diamond M Field Services. The native seed mix was applied along with the Biotic Earth and then covered with a Flexible Growth Medium. Soil improvement and erosion control were accomplished in just a few hours time on the entire site with one crew and one hydromulch machine.

1.

2.

3.

"Our test plot of Biotic Earth accompanied with a native seed mix applied via hydroseed method showed a significant increase in initial germination of our warm season cover crop species, less weed competition, and higher density of vegetation with greater germination of native species with minimal irrigation vs. the adjacent area that was not treated with Biotic Earth. Even though the soil had a high level of existing organic matter, the added benefit of the Biotic Earth's water holding capacity definitely created a positive response in the germination and growth of the areas that were treated with Biotic Earth vs. areas that were not treated. We look forward to subsequent growing seasons to see the impact that Biotic Earth has on the vegetation.

Justin R. Krobot, PMP, CPRP
Landscape Superintendent,
Watershed and Park Operations
San Antonio River Authority

1. The test plot, immediately after insall
2. Three weeks after install, the test plot is flourishing
3.Three months after installation the site was fully and densely vegetated.

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2021 ASRS Professional Award Winners

Dr. Louis M. McDonald– William T. Plass Award

Nominated by Jeff Skousen

This award is the highest honor the society has and recognizes those in research, teaching, outreach, and administration. The award is given to a person who has distinguished themselves in the field of disturbed ecosystem reclamation at the local, regional, national, and international levels.

Dr. Louis McDonald has been involved in a distinguished career in research, teaching, and practicing of mine land reclamation for over 30 years. Contributions to the field of mine land reclamation is highlighted by over 24 years of research and teaching at West Virginia University. While at WVU, he was very involved in acid mine drainage (AMD) research as well as soil science and environmental chemistry work. Dr McDonald earned his BS at California Polytechnic State University in Economics and his MS from Louisiana State University in Agronomy, while his Ph.D. in Soil Science was earned at the University of Kentucky at Lexington.

While at the University of Kentucky, Louis worked with Dr. Bill Evangelou, who was one of the country's top soil scientist. Together they published three revered journal articles and multiple abstracts and book chapters. Since then while at WVU, Dr. McDonald published 58 peer-reviewed journal articles and authored or coauthored seven book chapters, including a chapter in *Appalachia's Coal-Mined Landscapes*, recently released, and has published more than 65 abstracts at international and national meetings. He has advised numerous graduate and undergraduate students while completing 28 projects with $1.5 million in funding. Dr. McDonald continues to host international scientists at WVU while excelling in teaching. He continues to add new courses and majors to the curriculum and is involved in multiple advisory committees at WVU. Louis is very active in ASRS as well as ARRI and the WV Mine Drainage Task Force. In 2017, he co-organized the ASRS/Task Force/ARRI conference in Morgantown WV. His list of honors and awards is long and includes the ASRS Richard I. and Lela M. Barnhisel Reclamation Researcher of the Year award in 2016.

Congratulations Dr. McDonald on this well-deserved honor.

Dr. William H. Strosnider – Richard I. & Lela M. Barnhisel Reclamation Researcher of the Year Award

Nominated by Natalie Kruse-Daniels

The Richard I. and Lela M. Barnhisel Reclamation Researcher of the Year Award recognizes substantial contributions to the advancement of reclamation science and technology through scientific research.

Dr. Strosnider has shown outstanding leadership in reclamation research while focusing on acid mine drainage chemistry as well as reclamation ecosystems in the mining industries in Pennsylvania and South America. Bill's education background resulted in a career in research and development which can be highlighted by the development of the accredited environmental engineering program at St. Francis University and the founding of the Center for Watershed Research and Service (CWRS). As a faculty member, while directing this program at St. Francis, he continued his research while mentoring many students in the reclamation sciences.

Bill received his BS from University of Dayton, his MS from The College of Charleston, and his Ph.D. from the University of Oklahoma. Currently, Bill is the Director/Associate Research Professor at the University of South Carolina's Baruch Marine Field Laboratory. His research in AMD in Bolivia for his doctoral dissertation resulted in twelve refereed journal articles and over twenty conference proceedings/presentations alone. He has since published 23 more journal articles and added 88 conference proceedings/presentations. His outstanding research has led to a large array of honors and awards. Bill was selected as the ASRS ECR award winner in 2017, and his accomplishments since then have shown that he continues to contribute to the reclamation sciences field through research and development in an absolutely positive manner.

Congratulations Dr. Strosnider on another outstanding honor for your dedication to reclamation research.

Joshua Sorenson – Reclamationist of the Year Award

Nominated by Pete Stahl

The Reclamationist of the Year award recognizes individuals demonstrating outstanding accomplishments in the practical application or evaluation of reclamation technology. It also rewards individuals responsible for implementing innovative practices or designs for new reclamation strategies.

Josh Sorenson received his BS degree from the University of Wyoming and MS degree from Texas A&M University. Josh currently works for Jonah Energy LLC as a reclamation specialist and has spent time working for the USFS as a rangeland and natural resource specialist.

Josh has been a significant asset during his time at Jonah Energy by developing and advancing the reclamation process of the ecosystem disturbance of over 1,900 oil & gas wellsites and associated transportation right of ways. He has implemented a management program to control invasive plant species while reducing pesticide applications and increasing native pollinator plants. This process has significantly improved the ecosystem and reduced costs to the company. The practice has helped allow for the rollover of hundreds of acres of successful reclamation back to the BLM for public use. Josh works closely with the regulatory and state wildlife officials in helping improve a habitat that is declining for numerous endangered wildlife and plant species. His management practices have resulted in improved reclamation that protects the environment and can be enjoyed by the landowners. Along with his busy schedule at work, Josh is involved in his local community and is often sought to share his knowledge and experience.

Congratulations Josh on this outstanding achievement and your persistence to improve a difficult ecosystem!

2021 ASRS Professional Award Winners

Dr. Kenton L. Sena – Early Career Award

Nominated by Chris Barton

This award is intended to recognize an early career member of ASRS who is involved in reclamation research, teaching, and/or on-the-ground reclamation practices within academics, regulatory oversite, or in an industry position. The nominee must have been employed in their field for a minimum of three years but not more than 10 years.

Dr. Kenton Sena has started the early stages of his career with a passion to help others with their advanced learning endeavors. He obtained his Bachelor of Arts from Asbury University, and his Master of Science and Ph.D. from The University of Kentucky. He is now a lecturer in the Lewis Honors College at the University of Kentucky.

Based on his letters of recommendations, he was strongly recommended for his teaching and research because of his work ethic and performance at UK. His research performance has been exceptional, with over 16 journal articles, along with multiple proceeding papers and book chapters. He has been honored with a vast range of research and talent awards throughout various programs involved in Forestry Research including close to $300,000 in grants and fellowships. He is very involved with ARRI and the Green Forests Work program, with Forestry Reclamation advisories, and mentoring programs. Kenton has also been a very active member of ASRS while co-chairing the Forestry and Wildlife TD and serving as an associate editor of the Journal of ASRS. Dr. Sena's has made outstanding contributions to reclamation sciences in his early career profession while his future looks bright and promising.

Congratulations, and keep up the good work!

Teck American Inc. and Halliburton – Distinction in Reclamation Award

Nominated by Mariah O' Brien

This award recognizes a specific project in which a company has demonstrated excellence in reclamation design, implementation, and overall success resulting in the conservation of natural resources and the ecosystem.

The Magmont Mine is in Southeast Missouri in the Viburnum Trend Lead District located in the Ozark-St. Francois Mountain range. The facilities extracted lead, zinc, and copper from the mined ore. This underground mine was in operation from 1968 to 1994, leaving a 24,500,000-ton tailings deposit impoundment to be mitigated starting in 1992. The Teck American Inc and joint venture partner Halliburton took on the challenge of this large-scale tailing's impoundment reclamation mitigation with notable success. The native wildlife species didn't take long to return to this reclaimed ecosystem, including amphibian and migratory waterfowl, as well as raptors and larger ungulates. Sixty-six native vegetative species are now found on site, and there is minimal routine maintenance required of the self-sustaining ecosystem. In December of 2017, the site was released from regulatory oversite, allowing the landowner to manage the property without regulatory control. The challenges were overcome, and the results show a true reflection of the practical side of "excellence in reclamation."

Congratulations to Teck American Inc. and Halliburton on this outstanding accomplishment.

2021 ASRS Memorial Scholarship Recipients

ASRS Memorial Scholarship: Bachelor of Science
Hannah Curtis

Hannah is a senior at the University of Oklahoma from Norman, Oklahoma. She will graduate in December 2021 with a double major in environmental engineering and cello performance and a minor in environmental sustainability. Hannah currently works as an undergraduate research assistant at both the OU Center for Risk and Crisis Management and the Oklahoma Water Survey and as a writing assistant for the OU Honors College. She conducts research with the Center for Restoration of Ecosystems and Watersheds, performs with the OU Symphony Orchestra, and is involved in OU's Integrity Council. Hannah is passionate about solving water quality issues with sustainable solutions and plans to pursue a master's degree in environmental science starting in Fall 2022.

ASRS Memorial Scholarship: Master of Science
Brianna Slothower

Brianna Slothower is a graduate research assistant working at Caesar Kleberg Wildlife Research Institute while attending Texas A&M University – Kingsville. In 2019, Brianna received her bachelor's degree in Fire Ecology and Management at University of Idaho. Her current project is evaluating the establishment of native grasses with an annual cover crop on a recently installed pipeline in south Texas. Upon completion of her master's degree in Range and Wildlife Management, Brianna would like to pursue a career in research and restoration. When she's not at work, Brianna enjoys exploring with her husband, collecting plants, and tending to her pet cat and lizard.

ASRS Memorial Scholarship: Doctoral Student
Brandon Holzbauer-Sweitzer

Brandon received his undergraduate degree in Environmental Geoscience from Winona State University in 2014. He then moved to Oklahoma and completed two Environmental Science graduate degrees. His Master's work focused on utilizing low-impact development best management practices as alternatives to traditional urban stormwater management. During his doctoral program, which he completed in May 2021, his work centered on using drones and spectral data to evaluate and predict surface water quality in passive treatment systems. He hopes to continue this work in a more applied setting when he starts a position with Linkan Engineering in June 2021. In his free time, Brandon enjoys cooking, being outdoors, relaxing with his wife, two dogs, and cat. Brandon is thrilled to be awarded the ASRS Scholarship at the Ph.D. level and hopes to continue participating and presenting at in-person meetings for years to come.

American Society of Reclamation Sciences

FEATURING

- **Keynote Address on the Great Lakes Area of Concern Estuary Restoration**
- **Parallel Technical Sessions**
- **Awards Luncheon**
- **Reclamation Film Festival**
- **Early Career Professionals Event**
- **Exhibition Hall & Poster Session**
- **Professional Field Tours:**
  - Peat Mining & Reclamation
  - Recreational Reuse of Mined Landscapes at the Redhead Mountain Bike Park
  - Iron Ore Mining & Reclamation
  - Estuary Boat Tour
- **Social Dinner on Lake Superior at Duluth's Historic Glensheen Mansion**

CALL FOR PAPERS AND RECLAMATION FILMS

This conference will provide a forum for the dissemination of information through presentation of research findings, field tours, workshops, and open discussion of public policy relating to mining and other mineral extraction, reclamation, restoration, reforestation, and land management issues.

June 12 - 16 Duluth Entertainment and Convention Center

Paper Categories: the following types of papers will be considered.

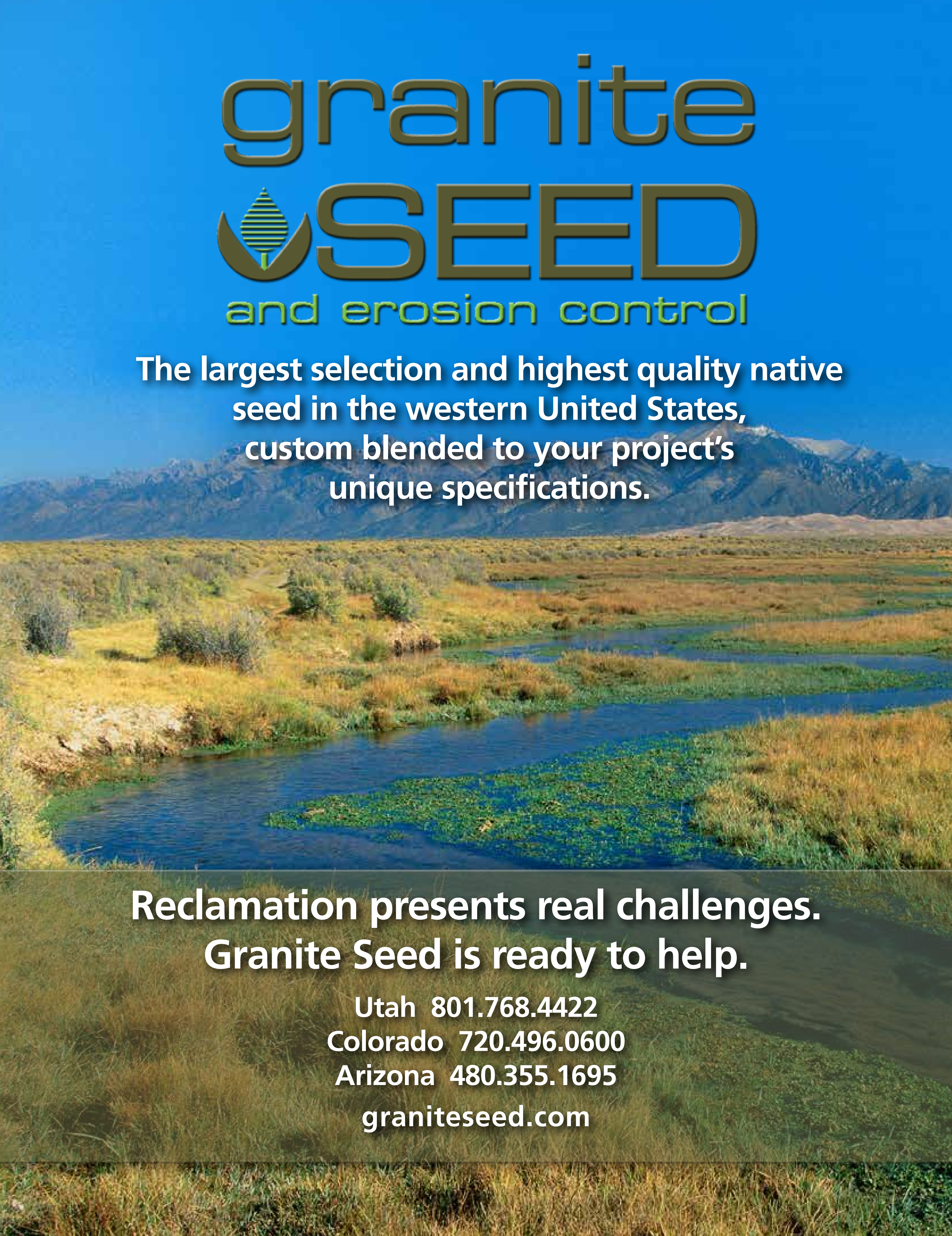
- **Research Papers**
- **Case Studies**
- **Demonstration Projects**
- **Other, such as Policy Papers**

Abstracts can be for oral Power Point presentations (25 minutes max), posters, or video presentations. **Draft copies of abstracts are due by January 14, 2022.** Abstracts will be placed on the ASRS website prior to the meeting and Power Point presentations and videos will be uploaded to the web after the meeting, pending the author's permission.

Submission of abstracts and other items should be sent to **Robert Darmody, ASRS Executive Director:** rdarmody@illinois.edu.

If you are interested in moderating and/or organizing a session, or developing a workshop, please contact **Mehgan Blair, Local Planning Committee Chair:** MBlair@barr.com

Featured Partner: Society for Ecological Restoration Midwest Great Lakes Chapter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Technical divisions in the American Society of Reclamation Sciences

Technical divisions (TDs) are smaller groups within the Society whose members have a specific professional interest. The TDs also represent the key technical disciplines that comprise the study and application of reclamation science. The Society recognizes their value and serves as an umbrella organization to provide national recognition. They may develop special sessions for the Society's annual meetings and publish professional manuals. Each agrees to support the policies and objectives of the Society. The Chair of each division facilitates at least one meeting of their division each year (at the Society's annual meeting) and helps to recruit new members and communicate the goals of the Society with their professional networks. With the help of the TD representative to the NEC, TD Chairs also solicit presenters for the annual meeting, solicit papers for the Society's journal, pursue sponsorships for the annual meeting, and suggest TD-specific webinars throughout the year.

As part of the strategic plan developed in 2018, the Society's TDs were reviewed and revised, with new TDs being proposed to and approved by the NEC in summer 2021. The new TDs were developed to continue the Society's focal transition to reclamation as whole, rather than solely mining. There are now six TDs in the Society: Soils, Water, Vegetation, Wildlife, Technology, and Engineering and Construction.

Soils

The Soils Technical Division of ASRS includes professionals who are involved in the characterization, use and management of soil, geological materials, and waste associated with environmental disturbances and their reclamation.

Water

The Water Technical Division of ASRS includes professionals who are involved in the treatment, management, and/or restoration of water resources impacted by environmental disturbances.

Vegetation

The Vegetation Technical Division of ASRS includes professionals involved in all aspects of vegetation establishment, survival, and study environmental disturbances and their reclamation, and who promote activities that lead to the establishment of self-sustaining, native vegetation.

Wildlife

The Wildlife Technical Division of ASRS includes professionals involved in the study and recovery of wildlife habitats and populations and who promote activities that lead to the establishment of self-sustaining wildlife habitats.

Technology

The Technology Technical Division of ASRS includes professionals involved in the development and/or utilization of innovative technologies to aid in the understanding of environmental disturbances and in the pursuit of environmental reclamation.

Engineering and Construction

The Engineering and Construction Technical Division includes professionals involved all aspects of reclamation who are interested in engineering and/or construction issues associated with environmental disturbances and their reclamation.

The NEC seeks chairs for all six of the new TDs. If you are interested or would like more information, please email the Technical Divisions Representative to the NEC, Julie LaBar, at Julie.LaBar@CentenaryUniversity.edu.

Using spent brewery grain to suppress acid rock drainage from historic tailings

BY JAMES GUSEK, LINKAN ENGINEERING, GOLDEN, CO; TAHNE PENNINGTON CORCUTT, BEER2CLEAR LLC, RIDGWAY, CO; AND LEE JOSSELYN, LINKAN ENGINEERING, GOLDEN, CO

Abstract

The pyritic Atlas mill tailings in Ouray County Colorado have been impacting nearby Sneffels Creek for about a century. Previous research suggests that the humic acids produced by decaying spent brewery grain (SBG) might suppress the acidophilic microbial community that produces acid rock drainage (ARD). This paper reports the results of a kinetic cell test (KCT) program whose goals are to determine the best relative ratio of SBG to the Atlas tailings, assess the potential benefits of adding other ARD-inhibiting amendments to the mix, and gauge field success of application methods. Twenty KCTs were constructed in January 2020 at an off-site location in Ridgway, Colorado, to facilitate sampling during the winter months. Preliminary monitoring results are encouraging: the KCTs that received SBG generated leachates with pH values near or above 8.0 while the two control KCTs produced leachate pH ranging from 4.5 (raw) to 6.1 (vegetated). The SBG-amended KCTs also out-performed other cells that received alternative proven ARD-inhibiting materials and lime. If implemented, this concept could transform local waste products from brewing beer into viable remediation media for abandoned mine sites.

Introduction

Amending potentially acid generating (PAG) mine wastes containing pyrite with probiotic materials can effectively suppress the production of ARD. These materials include pyruvic acid, composted paper mill sludge, and composted sewage sludge/ biosolids[1] and common organic acids (propionic, butyric, valeric, hexanoic, and oxalacetic)2. Other research[3] in the 1960s showed that when organic materials were added to pyritic materials with acidophilic bacteria (Thiobacillus) that the bacteria switched from being chemolithotrophs to heterotrophs. Based on research from a decade ago[4], it appeared that SBG could also perform an ARD-suppressing function.

Lindsay et al.[5] documented the success of SBG amendment in improving neutral pH leachates, i.e., neutral mine drainage (NMD) from one of six columns filled with sulfide mine waste and carbonate-rich mine tailings. The columns were monitored for six years. The researchers focused on in-situ sulfate reduction and reported increases in sulfate reducing bacteria (SRB) populations and decreases in sulfate concentrations. While their hypothesis was that the addition of SRB-hungry nutrients would support in situ sulfate reduction, i.e., in situ ARD treatment, a second mechanism may have been responsible, at least in part, for the decreases in sulfate in the column leachates: the decimation of the acidophilic bacterial population by organic acids generated by the degradation of the SBG in the column containing it and the potential accompanying chemolithotroph switch to heterotrophs. In essence, this ARD source control mechanism would have slowed pyrite oxidation and the generation of sulfate even in carbonate-rich mine waste that generates NMD. This secondary hypothesis, supported by successful organic-based bactericide application research conducted on PAG waste from the Barite Hill Superfund Site[5] and pioneering work by others[6], inspired the testing of SBG and other organic amendments on PAG tailings at the Atlas Mill site in Ouray County, Colorado in 2020.

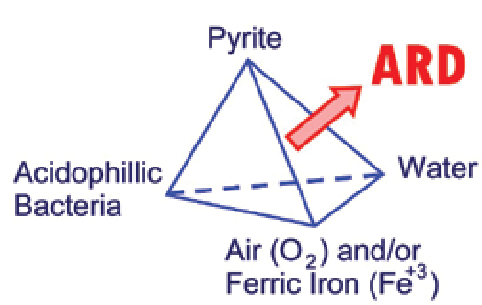
A Pathway to Walk Away?

An ideal process to prevent the adverse environmental effects from ARD, particularly from abandoned mine lands, is one that offers minimal disturbance of the watershed using natural, organic materials that once incorporated into tailings and waste rock require little or no maintenance, additives, or extensive engineering to achieve a healthy and fully functioning hydrologic environment. To this end, the role of probiotic amendments like SBG is critical to arresting the formation of ARD.

Like the "combustion triangle" taught in elementary school (fuel + heat source + air > fire), the tetrahedral relationship provided in Figure 1 shows that four components are necessary for ARD to form:

1. Pyrite (FeS_2) or other iron sulfides e.g., pyrrhotite
2. Water
3. Oxidizer (Air, ferric iron or Fe^{+3}, etc.)
4. Acidithiobacillus ferrooxidans [ATBFO] bacteria which consider pyrite a key nutrient for survival.

Figure 1. The ARD Tetrahedron



Eliminating any one of these components will prevent ARD formation. The simplest of these to eliminate is the "bad" ATFBO bacteria, which can be achieved through the introduction and nurturing of competing, probiotic "good bacteria" as well as other known surfactant-based bactericides that just focus on acidophilic bacteria mortality[7].

Besides the pioneering work by Pichtel & Dick[1] previously discussed, other innovative researchers considered the ATFBO suppressing effects from application of waste dairy products on PAG waste. In 2007, the Western Research Institute used a combination of waste milk and biosolids to target ARD at the Sequatchie Coal Mine in Tennessee where two doses of this inoculant/nutrient were applied via injection boreholes at the site. Testing of seepage from the site was reportedly net alkaline three years after application[6,8]. Undoubtedly, the robust vegetation at the site as evidenced by Google Earth images[9] is now providing a sustainable supply of acidophile-inhibiting organic acids naturally as a result of a new healthy root system that increases CO_2 in the soil and competes for both oxygen and moisture with acid-producing bacteria[10]. Similarly, sewage sludge was used as a probiotic amendment in combination with agricultural lime to successfully restore the upper reach of the Arkansas River near Leadville, Colorado, whose sediments predominantly consist of pyritic tailings that were producing ARD for decades[11,12]. The Upper Arkansas was reclassified as a gold medal trout fishery in 2014 even though the pyritic tailings remain in place[13].

This is a holistic strategy offering a sustainable solution that avoids traditional perpetual treatment approaches that are more costly, require constant maintenance, and do little to restore the watershed to its natural state. Treatment of ARD after it has formed is nothing more than a band-aide approach to the ATFBO "geo-infection"[14]. SBG and its natural degradation products like organic acids appear to be a potent "vaccine"[2] that alone or in combination with other ARD-inhibiting materials can suppress ARD formation.

Why SBG?

Beer is one of the most consumed beverages in the world, the industry annually produces more than 2.7 million tonnes of SBG in the United States alone – much of which is sent directly to landfills, thus contributing to the greenhouse gas emissions associated with its disposal[15]. In other words, the availability of this amendment is tremendous. SBG also possesses more charismatic qualities than other probiotic materials often used, such as sewage sludge. This presents an important advantage when seeking project funding or community support for important mine reclamation projects. The EPA estimates that it will cost over $50 billion USD to address all the abandoned mines that dot the American west and federal environmental programs simply do not have the resources to pay for all this remediation work. Therefore, private capital and environmental groups are increasingly key to plugging these funding gaps[16]. Recent progress through EPA's Office of Land and Emergency Management for Good Samaritan clean-up efforts on tailings and waste rock piles are advancing opportunities for projects using the Beer2Clear® method to be adopted where practical.

Had it been considered, SBG could have been substituted for the sewage sludge as the organic amendment in the Upper Arkansas tailings. This is supported by data from a field-scale experiment using a mixture of SBG and biosolids[17]. Researchers found that SBG successfully lowered concentrations of sulfate ion, which is a by-product of ARD generation, while simultaneously increasing populations of beneficial iron- and sulfate-reducing bacteria that likely out-completed ATFBO for resources.

It is worthy to note that the utilization of organic matter such as SBG in ARD suppression also provides a small measure of carbon sequestration. This is because the microbes that would utilize the SBG would convert it to bicarbonate alkalinity, not methane or carbon dioxide as would be the case if the SBG were used as animal feed or placed in a landfill.

The Beer2Clear® Pilot Project

Beer2Clear® Initiative is comprised of a team of partners including Linkan Engineering, Beer2Clear LLC, Ouray Silver Mines, Colorado Division of Mining Reclamation and Safety, and the Colorado Boy Brewing Company. The pilot project was launched in October 2019 with a proof-of-concept kinetic cell bench test of the application of SBG to an acid-generating mine waste site located in the Uncompaghre Watershed in southwest Colorado. Ouray Silver Mines agreed to allow the team to collect tailings waste from the Atlas Mill site located on Sneffels Creek of Forest Service Road 853.1B in Ouray County, Colorado (37°58'38.11"N and 107°45'32.31"W). Colorado Boy Brewing Company furnished 91 kg of SBG needed to construct the bench test cells.

Atlas Mill Site Tailings Characteristics

The site footprint is approximately two hectares, featuring remnants of the historic mill structure, coarse-grained waste rock pile, and fine-grained tailings sediment in the floodplain adjacent to Sneffels Creek.

The tailings have an estimated volume of 18,400 cubic meters, consisting of both "grey" and "red" tailings. As shown in Table 1, both kinds of tailings exhibit elevated concentrations of cadmium, lead, and zinc[18] but lead is the primary contaminant of concern in Sneffels Creek[19]. The fine texture of the tailings also makes them susceptible to fluvial transport. Though the site is mostly devoid of vegetation, under natural conditions riparian plant species would flourish in the floodplain[18].

Figure 2. Site Photo

Figure 3. Spent Brewery Grain

Table 1. X-Ray Fluorescence Data18

XRF Parameter	Atlas Mill Site (Grey)	Atlas Mill Site (Red)
S (mg/kg)	6587	5959
Mn (mg/kg)	2181	192
Fe (mg/kg)	9480	9404
Cu (mg/kg)	172	60
Zn (mg/kg)	4307	177
As (mg/kg)	29	149
Ag (mg/kg)	86	96
Cd (mg/kg)	18	ND
Pb (mg/kg)	2512	3675

Table 2. Brewery Waste Physical characteristics relative to raw sample weight[20]

Parameter	Value
Moisture	6.4%
Solids	94%
Organic	87.4%

Table 3. Brewery Waste Physical characteristics relative to dry sample weight[20]

Parameter	Value
Nitrogen	3.6%
Protein	22.3%
Carbon	46.8%
Organic	93.3%
Ethanol-soluable fraction (ESF)	19.4%
ESF as sugar	11.5%
Water-soluable fraction	26.8%

Table 4. Brewery Waste Carbohydrate Fraction Analysis[20]

Parameter	Value
Organic Acids	4.7%
Mono + Oligosaccharides	11.5%
Starch	16.4%
Hemicelluloses/Cellulose	38.3%
Lignin	15.5%
Organic	93.3%

A distilled water rinse of a saturated paste of the red tailings released about 64 times more soluble lead than an identical rinse of the grey tailings[18]. Acid base-accounting data for the two tailings revealed that the grey tailings contained some neutralizing potential while the red tailings contained none. The red tailings exhibited sulfide sulfur of about 3.1 t/kt and exhibited a paste pH of 3.4. Due to the higher propensity of lead to be leached from the red tailings and their lack of buffering alkalinity, the project team selected the red tailings for the testing with SBG.

Spent Brewery Grain Characteristics

SBG has a texture and consistency similar to a soggy granola bar; it is very hydroscopic and can retain a mass of water about five times its dry mass. It is very difficult to completely dry.

While the SBG used in the Atlas Tailings KCTs was not characterized due to budgetary constraints, Seyler et al.[20] analyzed a "brewery waste" sample and reported the following characteristics with respect to its use as a substrate component in biochemical reactors.

This data not only infers the likely presence of organic acids which are known bactericides[2] but also high carbon, protein, and lignin contents which would provide a steady, long-term supply of anti-bacterial organic acids as the SBG degrades under the steady attack of cellulolytic microbes and fungi.

Atlas Tailings Bulk Sample Collection and Sample Preparation

Beer2Clear saw the opportunity for local community engagement in the project by working with Ouray High School's science department. In December 2019, OHS students from the chemistry, biology, and geology programs worked with the team in the field to excavate and transport a bulk sample of 238 kg of red tailings from the Atlas Mill to the Beer2Clear laboratory site in Ridgway, Colorado. The tailings samples from the upper 25 cm were mixed via a modified cone-and-quartering method to produce multiple 20-liter buckets of representative tailings samples. See Figures 4 and 5 on the following page.

Figure 4. Red Tailings Bulk Sampling

Figure 5. Bulk Tailings Sample Preparation

KCT Set Up and Sampling Protocols

The bench test was constructed at the Beer2Clear laboratory and consisted of 20 20-liter plastic buckets fitted with drainage gravel in the bottom, drainage spigots (typically left open to allow air exchange), and arranged on two flat, elevated benches to allow for easy leachate sample collection in the field. Each cell contained equal measures of tailings from the Atlas Mill site, along with varying concentrations of SBG and other ARD-inhibiting amendments (Table 5 and Figure 6) including diluted milk, and sodium lauryl sulfate (SLS). All but three of the cells received a vegetative cover containing a carefully curated native seed mix representative of the native vegetation in the area. With the exception of KCT#20, the vegetative cover was comprised of a commercial biotic soil media with recommended amendments as determined by agronomic testing of the red tailings.

There were two control cells: one contained only tailings (KCT#1), the other contained only native soil with a vegetative cover (KCT#20). KCT#3 through KCT#15 received bagged, composted cow manure from a commercial garden center as a general organic material bacterial inoculant.

Table 5. Kinetic Cell Test Matrix

Test #	Red Atlas Tailings (kg)	Brewery Waste (BW)	Milk	Ag Lime	Manure Inoculant	Veg. Cover	Buffered SLS Rinse	Logic
1	20							**Control**
2	20					X		**Control w/veg**
3	20	Low % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column, low concentration, no lime
4	20	Med % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column, medium concentration,no lime
5	20	High % BW			X	X	Yes, but only if pH <5.5	BW in entire soil column high concentration , no lime
6	20	Low % BW		X	X	X		BW in entire soil column, low concentration, w/lime
7	20	Med % BW		X	X	X		BW in entire soil column, medium concentration, w/lime
8	20	High % BW		X	X	X		BW in entire soil column high concentration w/lime
9	20	Low % BW	X	X	X	X		BW in entire soil column, low concentration w/milk & lime
10	20	Med % BW	X	X	X	X		BW in entire soil column, med. concentration w/milk & lime
11	20	High % BW	X	X	X	X		BW in entire soil column high concentration w/milk & lime
12	20		X	X	X	X		No BW, just milk & lime **(Non-BW semi-control)**
13	20	Low % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, low concentration, w/lime
14	20	Med % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, medium concentration, w/lime
15	20	High % BW		X	X	X	Yes, but only if pH <5.5	BW in just upper soil column, high concentration w/lime
16	20						X	Once, week 0 to test SLS longevity
17	20						X	Week 0 and whenever pH drops to <5.5 (multiple applications)
18	20					X	X	Once, week 0 to test SLS longevity with vegetation
19	20					X	X	Week 0 and whenever pH drops to <5.5 (multiple applications)
20	**0**					**X**		**Background – no tailings with vegetation**

The amounts/masses of ARD-suppressing amendments used in the test are not provided in the paper because these values are unique to the Atlas Tailings and are based the results of preliminary screening tests. The screening test protocol was founded on research work conducted by Kleinmann and Erickson[21] at the former US Bureau of Mines in the early 1980s, modified to include organic amendments like SBG and milk. Based on experience, the amendment amounts might be different for PAG waste with different pyritic sulfur and carbonate contents.

Sampling was conducted in the field by collecting leachate generated by natural precipitation received by the KCTs from January through November of 2020 when the buckets froze with the onset of winter weather. Artificial rainfall consisting of bottled water (unchlorinated and unfluoridated) was added to the KCTs if natural precipitation was lacking prior to the planned sampling event. The field parameters measured included:

- Liquid volumes (milliliters)
- Leachate temperature (C°)
- pH
- Oxidation reduction potential (ORP) (millivolts)
- Conductivity (μS/cm)
- Alkalinity (mg/L @ pH>6)

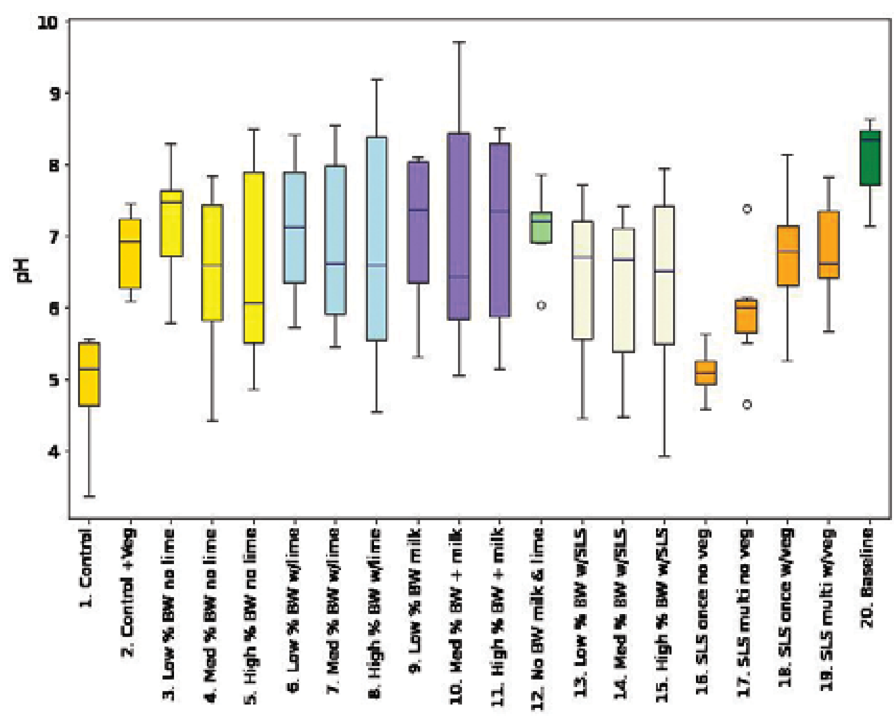
On three occasions during field sampling (March, July, and October), leachate splits were collected using a syringe and 45-micron filter to fill 20 15-mL vials and preserving them with nitric acid. The vials were then sent to the Colorado School of Mines laboratory for inductively coupled plasma atomic emission spectroscopy (ICP-AES) to analyze the metals content of the leachate samples. Sulfate concentration in the leachates was estimated by multiplying the reported ICP-AES sulfur concentrations times three.

Results – pH

Several months elapsed before the KCT leachates exhibited increasing pH values even with the presence of agricultural lime amendments. Leachate pH values from SBG-amended KCTs typically increased at least two standard units. See Figure 7 which is color-coded similar to the Test Matrix in Table 5. Interestingly, the greater the SBG content added, the lower the average leachate pH within the groups KCT#3 to #5, and #6 to #8. This might be attributed to the activity of pH-lowering fermenting bacteria. KCTs #13 to #15 only received SBG in the upper half of the cell contents; the pH trend differences as a function of SBG content are not as pronounced even with the inclusion of a sodium lauryl sulfate rinse. Other trends can be observed in the data, but the key finding is that increasing relative amounts of SBG amendment is counterproductive: "less is more" with respect to pH improvement compared to the Control.

Figure 6. Kinetic Cell Test Setup

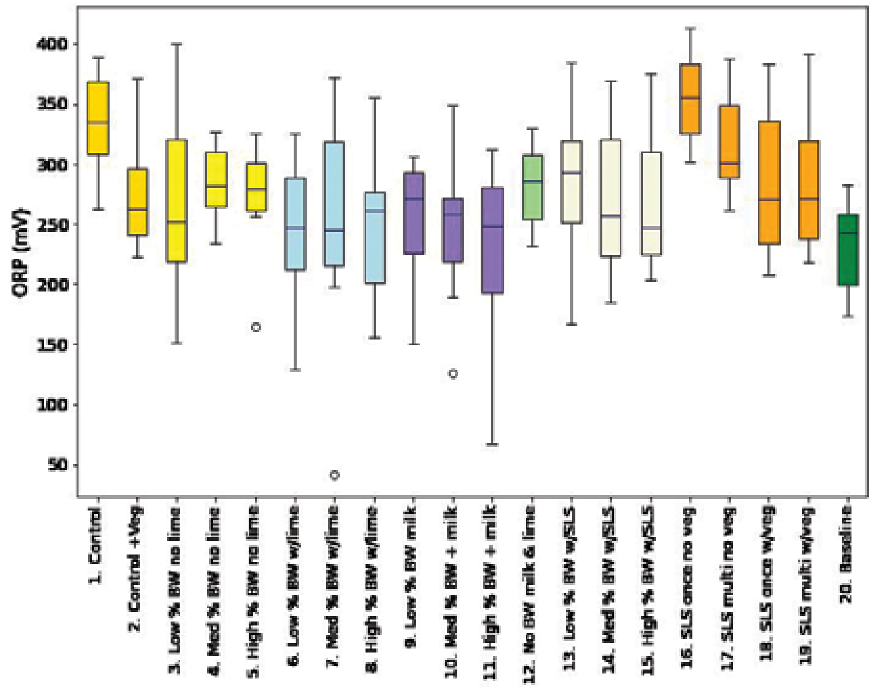
Figure 7. pH Data



Oxidation Reduction Potential

Attaining a leachate with neutral pH is only part of the remediation picture. Decreasing leachate ORP values compared to the control suggest less-oxidizing conditions within the KCT contents and less pyrite oxidation. However, lower ORP values can result in the mobilization of other constituents such as iron and manganese and the metals that might be adsorbed to the oxides and hydroxide phases that might be present. The low ORP values associated with KCTs that received milk (#9 through #12) are particularly noteworthy. Again, the more SBG with a constant amount of milk added, the lower the average leachate ORP was observed. Among this group of cells, the mobilization of lead, sulfate, and iron was the greatest in the KCT#11, which contained the highest SBG content. The Controls and the SLS-only KCTs (#16 to #19) leachates exhibited the highest ORP values and the most lead mobilization at startup and throughout the test. See Table 6.

Figure 8. Oxidation Reduction Potential Data



Lead, Sulfate, and Iron

Upon startup, control cells #1 and #2 released high amounts of lead, along with the cells with SBG only amended into the upper half of the soil column (KCT #13 to #15) and the SLS only KCTs exhibiting elevated ORP values as previously discussed. See Table 4; to facilitate comparisons among a data set for a given sample date, the data cells are color-coded from high values in red to lower values in green. Many of the cells containing SBG amendment released small amounts of lead upon startup and the concentrations continued to decrease exponentially over time.

The top-performing test cells containing SBG produced lead concentration reductions ranging from 600 percent

Table 6. Dissolved Lead, Sulfate, and Iron Trend Data

		Lead			Sulfate			Iron		
		March, 2020	July, 2020	Nov., 2020	March, 2020	July, 2020	Nov., 2020	March, 2020	July, 2020	Nov., 2020
1	Control	2.73	No data	4.05	64	No data	183	0.059	No data	0.047
2	Control w veg	2.27	0.06	0.5	55	3	12	0.15	0.009	0.15
3	*Low BW no ag lime*	*0.49*	*0.01*	*0.05*	*112*	*1*	*17*	*0.075*	*0.004*	*0.02*
4	Med BW no ag lime	0.44	0.01	0.04	126	14	113	0.078	0.003	0.04
5	High BW no ag lime	0.97	0.12	0.83	230	90	993	0.47	0.11	0.74
6	*Low BW OC ag lime*	*0.57*	*0.01*	*0.05*	*203*	*3*	*7*	*0.065*	*0.001*	*0.01*
7	Med BW ag lime	0.43	0.01	0.16	278	63	777	0.086	0.005	0.33
8	High BW ag lime	0.97	0.03	0.34	229	38	327	1.265	0.017	0.33
9	*Low BW ag lime, milk*	*0.28*	*0.01*	*0.04*	*286*	*2*	*9*	*0.15*	*0.002*	*0.07*
10	Med BW ag lime, milk	0.21	0.03	0.22	384	57	652	0.20	0.014	0.36
11	High BW ag lime, milk	0.43	0.30	0.47	449	168	529	0.29	0.71	0.39
12	Milk & Ag lime only, No BW	0.67	0.02	0.11	402	7	128	0.069	0.002	0.01
13	Low BW in Upper Zone, rinse if pH<5.5	1.89	0.11	0.53	63	5	35	0.14	0.029	0.17
14	Med BW in Upper Zone, rinse if pH<5.5	3.33	0.24	1.62	45	34	259	0.17	0.085	0.066
15	High BW in Upper Zone, rinse if pH<5.5	2.29	0.04	0.7	49	21	448	0.24	0.041	1.02
16	No BW, Milk etc. NO VEG Buffered Rinse Wk 0 ONLY	2.98	0.21	4.28	39	8	74	0.006	BDL	0.02
17	No BW, Milk etc NO VEG Buffered Rinse Wk 0 or if pH<5.5	1.30	0.22	8.6	44	14	78	0.068	0.004	0.02
18	No BW, Milk etc. YES VEG Buffered Rinse Wk 0	3.32	0.11	1.88	60	2	2	0.076	0.008	0.26
19	No BW, Milk etc YES VEG Buffered Rinse Wk 0 or if pH<5.5	3.36	0.07	1.1	54	3	14	0.089	0.004	0.18

to 1,100 percent when compared to leachates from the test cells lacking probiotic amendments. However, the relationship between pyrite oxidation, measured by sulfate and iron reductions, proved to be inversely proportional as many of the test cells containing higher amounts of SBG released greater concentrations of sulfate upon startup and continued to produce leachate samples with higher sulfate content than those test cells lacking probiotic amendment. Not only does this observation underscore the importance of SBG concentration and distribution throughout the soil column, but also the critical role that vegetative cover plays in those test cells that did not receive probiotic amendment (KCT#2, #18, and #19) but still produce favorable reductions in oxidation levels compared to their respective counterparts (KCT#1, #16 and #17).

As with the pH and ORP observations, the KCTs receiving relatively lower amounts of SBG, KCT #3, #6, and #9 (rows with italicized text in Table 6) exhibited less lead, sulfate, and iron mobilization than their higher SGB intergroup counterparts.

Based on the data collected, it appears that SBG possesses significant probiotic properties and impressive organic carbon content. Assuming SBG exhibits organic acid concentrations and other organic fractions similar to those cited by Seyler et al.[20], it should be capable of out-competing acidophilic bacteria that contribute to ARD or NMD formation long enough until the organic acids developed in the root zone of a successful vegetated cover are sustainably delivered.

The SBG amendment is appropriate for mine waste materials that are potentially acid generating or that produce NMD. There is no "standard" amount of SBG amendment that will work in every situation. The data from this test suggest that applying too much SBG can be counterproductive or even harmful to the environment. Amendment screening and KCT programs are strongly recommended before full scale field implementation.

Beer2Clear®'s SBG amendment strategy for mitigating pollution from mine sites will create robust public private partnerships with the ability to access private capital to pay for these projects. This strategy promotes sustainability through the beneficial use application of brewery waste in a way that sequesters carbon and reduces GHG emissions. The Beer2Clear® amendment is essentially a probiotic vaccination to a geo-infection with the ability to restore damaged watersheds to their natural state.

Postscript

The Beer2Clear® Atlas Tailings KCT experiment was officially concluded with the final sampling event and the hypothesis that spent brewery grain can effectively suppress acid rock drainage (as well as reduce heavy metals like lead, zinc and iron) has been demonstrated.

Decommissioning the experiment meant the appropriate and compliant handling and disposal of 682 kg (1,500 pounds) of mine tailings would be necessary. No matter how small or large the project, it is important to ensure that test waste is disposed of according to EPA regulations. This requires getting a TCLP (Toxicity Characteristic Leaching Procedure) test which will inform whether one can dispose of the waste at a landfill or if it will require hazardous waste disposal. The mine tailings that Beer2Clear® used were declared hazardous under the TCLP for high concentrations of lead. Based on the performance of KCT Controls, this outcome was not a surprise.

Hazardous waste disposal can be intimidating and expensive, which is why it is important to find a trustworthy service provider to offer guidance through the process, coordinate pick-up and transport logistics, and deliver at a fair price. Beer2Clear® was happy to have Clean Management Environmental Group assist with the disposal of the hazardous waste from this test. The paperwork received documents the "by-the-book" efforts to protect environmental and public health while maintaining compliance with all federal regulations.

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Teaching Reclamation Sciences

Ecology and Environment in Middle-earth: *The Lord of the Rings* as an entry point for teaching, learning, and serving in reclamation

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Introduction

J.R.R. Tolkien's *The Lord of the Rings* is one of the most well-known and beloved works of fantasy literature of all time. Among many things, Tolkien's work invites us to explore the natural world in an imagined context (Middle-earth), and, inspired by our reflection, think about the environment in the "real world" differently (a concept Tolkien and Tolkien scholars refer to as "recovery" or "re-enchantment," e.g., Curry, 2008). This recovered or re-enchanted perspective of the natural world can take multiple forms, including changed opinions, attitudes, and actions. Readers and students of Tolkien's work might emerge from their experience with newfound interest in and appreciation for the natural world. They may even be motivated to engage in actions to address environmental problems, reduce their environmental impact, or increase their exposure to the natural world. Importantly, as a work of fantasy fiction, Tolkien's work presents a unique opportunity to interface with diverse groups of people who may not already be engaged in environmental work. In this paper, I will share my experiences teaching a class on environmental themes in *The Lord of the Rings*, with an embedded service-learning component in which students helped to plant trees as part of a surface mine reforestation project.

Background

This course is an upper-level Honors course entitled "The Ecology of Middle-earth: Environmental Themes in Tolkien's *The Lord of the Rings*," which I teach in the Lewis Honors College at the University of Kentucky. This course fulfills an Honors curriculum requirement. In the spring semester of 2021, I received funding from the University of Kentucky Office of Service-Learning and Civic Engagement to develop a substantial service-learning component in the course. In partnership with Green Forests Work, a nonprofit engaged in surface mine reforestation throughout the Appalachian region, I planned a day trip to help plant shortleaf pine on a reclaimed mine site in the Daniel Boone National Forest in eastern Kentucky as part of an ongoing reforestation effort at the site. Students were invited to reflect creatively and critically on the service-learning experience, and their reflective work is archived here: https://realhon301.wixsite.com/portfolio. Importantly, the students who enrolled in this class represented a rich diversity of academic backgrounds and interests, with majors including chemistry, English, political science, natural resources and environmental sciences. They also represented a range of existing familiarity and engagement with environmental issues, as well as a range of prior experience with Tolkien's work.

Overall, the course learning objectives emphasized using *The Lord of the Rings* as an opportunity to explore environmental and ecological ideas, as well as their social and other human dimensions, in an imagined context, with the goal of drawing out implications for a "re-enchanted" perspective of the real world. The service-learning component was then an opportunity to apply these ideas to a real-world problem.

Imaginative Literature and Reclamation

The field of reclamation is particularly relevant to interrogating and experiencing through the lens of *The Lord of the Rings* because the characters of *The Lord of the Rings* encounter a number of highly degraded landscapes in need of reclamation throughout their journeys and they participate to varying extents in that reclamation (Figure 1). (And note that, particularly with respect to Tolkien's environmental spaces, Peter Jackson's film adaptations diverge somewhat from the text. If your only experience of Tolkien's work is the films, you may miss out on some of his treatment of these issues.) Key examples of these degraded spaces are Mordor and Minas Morgul, Isengard, and the Shire. Mordor and Minas Morgul are severely degraded spaces, fundamentally corrupted by the evil presence of their powerful inhabitants (Sauron and the Nazgul), as well as the ravages of war and military-associated industry. When Frodo and Sam first encounter the approach to Mordor, the space is described thus:

"Here nothing lived, not even the leprous growths that fed on rottenness. The gasping pools were choked with ash and crawling muds, sickly white and grey, as if the mountains had vomited the filth of their entrails upon the lands about. High mounds of crushed and powdered rock, great cones of earth fire-blasted and poison-stained, stood like an obscene graveyard in endless rows, slowly revealed in the reluctant light" (Tolkien, 631).

Especially of interest in the landscape of Mordor is the explicit connections of landscape degradation to unchecked and

Figure 1. Isengard with its pits of industrial activity.

unregulated mining, made later in the text when Sam and Frodo are descending into the plains of Gorgoroth: "Here in the northward regions were the mines and forges, and the musterings of long-planned war..." (Tolkien, 923). These extreme descriptions may remind the reader of real-world landscapes fundamentally (and seemingly permanently) altered by industrial activity, and those of us who have worked in damaged ecosystems can readily visualize or imagine such surroundings. The narrator suggests that Mordor could be cleansed only if the "Great Sea should enter in and wash it with oblivion" (Tolkien, 632) and Aragorn notes that it would be "many long years" (Tolkien, 969) before Minas Morgul could be inhabited again—essentially suggesting that these effects were irreversible.

But Tolkien's view of the legacies of industrial activity was not one-dimensional. The destruction and restoration of Isengard and the Shire highlight his hope for reclamation of these sorts of degraded spaces. Isengard was the home of the wizard Saruman, once a fruitful space of gardens and orchards, but degraded under Saruman's rule by industrial activity intended to build and arm his army. Gandalf describes this transformation in his report to the Council of Elrond: "whereas it had once been green and fair, it was now filled with pits and forges" (Tolkien, 260). Saruman sacrificed the natural beauty, order, and fruitfulness of the landscape he controlled in pursuit of military power, destroying both the fruitful treed spaces of Isengard and the surrounding forested landscape. After Saruman's defeat at the hands of the Ents, these mysterious and powerful tree-shepherds set out to undo what he had done, with great success: "the land within was made into a garden filled with orchards and trees, and a stream ran through it; but in the midst of all there was a lake of clear water..." (Tolkien, 978). The work of the Ents was described as a mystically accelerated natural recovery ("the work of great tree-roots in a hundred years, all packed into a few moments" [Tolkien, 567]), and nods toward the reality that many degraded landscapes can recover naturally over time if the degradation is not too severe.

Finally, the restoration of the Shire presents a compelling case study of individual and social responsibility to reclaim natural spaces affected by outsider interests and industrial activity. When the hobbits return from their journeys, they find that Saruman has beaten them home and implemented some serious changes to their beloved community. Trees had been cut down across the Shire, many for no reason, and many of their traditional homes had been demolished to make way for new brick buildings and a quarry. Of particular note, "the new mill in all its frowning and ugly dirtiness... fouled [the local stream] with a steaming and stinking outflow" (Tolkien, 1016). These impacts were devastating to the hobbits, especially Sam, who said "This is worse than Mordor! Much worse in a way. It comes home to you, as they say, because it is home, and you remember it before it was all ruined" (Tolkien, 1018). Sam takes the restoration of the Shire upon himself and uses the Lady Galadriel's gift (soil from her garden, and a seed of the Mallorn trees of Lothlorien) liberally: "Sam planted saplings in all the places where specially beautiful or beloved trees had been destroyed..." (Tolkien, 1023). His efforts were guided by his membership in the community and his knowledge of the community's values and priorities. And his work bore fruit: "Spring surpassed his wildest hopes... Not only was there wonderful sunshine and delicious rain, in due times and perfect measure, but there seemed something more: An air of richness and growth, and a gleam of a beauty beyond that of mortal summers that flicker and pass upon this Middle-earth" (Tolkien, 1023).

Real-World Application

With these imagined landscapes in mind, we engaged in reforestation work on a degraded site in eastern Kentucky, surface mined for coal and reclaimed under SMCRA, resulting in a site unable to recover ecologically on its own due to compacted soil and competitive non-native vegetation. Our partners with Green Forests Work had previously deep-ripped the site to

Figure 2. Students who planted trees on legacy mined lands as part of the service-learning project.

Figure 3. Student selecting site for tree planting.

Figure 4. Student contemplating soils and vegetation during the service-learning project.

alleviate soil compaction; we just helped with the tree planting. For many of my students, this experience was a first—first tree planted, first surface mined site visited, first time engaging in community service related to the environment (Figure 2). Their reflective work engaged their experiences from diverse critical and creative perspectives, and, in general, their feedback on the project was positive—it was an opportunity to work out in practice some of the ideas we talked about abstractly in the classroom (Figure 3).

Overall, the class (and our service-learning project) were incredibly successful. Students from diverse backgrounds were introduced to complex questions about the environment through the lens of *The Lord of the Rings*, and then were able to experience a practical outworking of those questions in real life, real space, and real time (Figure 4). Literature, especially science-fiction and fantasy literature, invites us to re-imagine our relationships with the world around us, sometimes in ways that can re-enchant our lived experiences. Thus, imaginative literature may create opportunities for reclamationists to engage diverse stakeholders in caring for the degraded landscapes in our real world.

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Municipal wastewater co-treatment for cost-effective mine drainage reclamation

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Project Background

Industrialization has left many areas with legacy pollution issues including acid mine drainage (AMD). AMD degrades tens of thousands of miles of waterways across the U.S. Each discharge requires a uniquely engineered approach to treatment as no two discharges are entirely alike. AMD can be treated by both passive (e.g., limestone rock dissolution, man-made treatment wetlands) and active (i.e., chemical addition and mechanical aeration) approaches. Mixing AMD with other waste streams for combined treatment has gained interest as a potential solution. One of the more unique opportunities for AMD water reclamation is "co-treatment" of AMD with secondary municipal wastewater (MWW) within the existing infrastructure of a conventional activated sludge MWW treatment plant. AMD and MWW each pose risks to the environment if poorly treated, and co-treatment allows for controlled combination of the waste streams while leveraging existing excess MWW treatment capacity that may be available in a post-industrial area. Co-treating MWW with AMD utilizes a waste source as a treatment resource and may also lead to improved MWW treatment while simultaneously decreasing degradation of surface water quality by AMD.

It is believed co-treatment will result in removal of AMD metals while also decreasing key MWW pollutants such as phosphorus and biochemical oxygen demand (BOD). However, co-treatment is not without operational risks. Secondary co-treatment may still have unintended impacts on the MWW biological treatment process, resulting from AMD compounds (e.g., metals) entering the activated sludge system through return activated sludge. Furthermore, any AMD constituents ending in settled waste sludge may have impacts on the sludge's conditioning (e.g., dewatering) and disposal (e.g., landfilling, incineration, etc.) processes. These research gaps must be addressed before utilities consider implementing co-treatment at full scale. Recent research (see references at end of article) supported by the Foundation for Pennsylvania Watersheds aimed to determine the feasibility of AMD and secondary MWW co-treatment through laboratory bench-scale experiments and a literature review. The feasibility study focused on the Johnstown, PA Dornick Point wastewater treatment plant (Johnstown Redevelopment Authority), which is located relatively close to an AMD discharge (Figure 1), making it an ideal location for implementation of co-treatment.

Figure 1: (A) Location of sampling site (Johnstown, PA) and (B) proximity of MWW and AMD discharges in Johnstown. Originally published as Figure S3 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314.

Methodology

A series of laboratory experiments were conducted intended to simulate co-treatment with AMD addition occurring after MWW biological treatment and before final clarification. Experiments utilized field-collected AMD from an abandoned coal mine discharge (Figure 2A), near the Johnstown Inclined Plane, and MWW aeration tank mixed-liquor was sampled from the Johnstown wastewater treatment plants aeration tank effluent (Figure 2B). Historical sampling data showed the AMD had average water chemistry of pH 6.1, 200 mg/L iron, and 0.3 mg/L aluminum. AMD (or deionized water) was mixed with MWW in two-liter batches (Figure 3) at ratios of 1:25, 1:15, and 1:5. After rapid mixing and then settling for 30 minutes, one-liter of supernatant (i.e. experimental secondary "effluent") was collected and analyzed for common wastewater effluent water quality parameters including turbidity, five-day BOD, chemical oxygen demand (COD), ions (NO_3, SO_4, and PO_4), total suspended solids (TSS), and residual metals concentration. A sub-set of experiments were also conducted to measure the immediate impacts of co-treatment mixing on the microbial community by measuring changes in cellular respirometric oxygen demand (i.e., respirometry) (Figure 4). In addition to the laboratory experiments, an extensive literature review was also conducted aimed at determining impacts of AMD co-treatment on the handling and processing of secondary sludge.

Figure 2: Field sampling locations for the raw AMD (A) and MWW mixed liquor (B) used in the laboratory study.

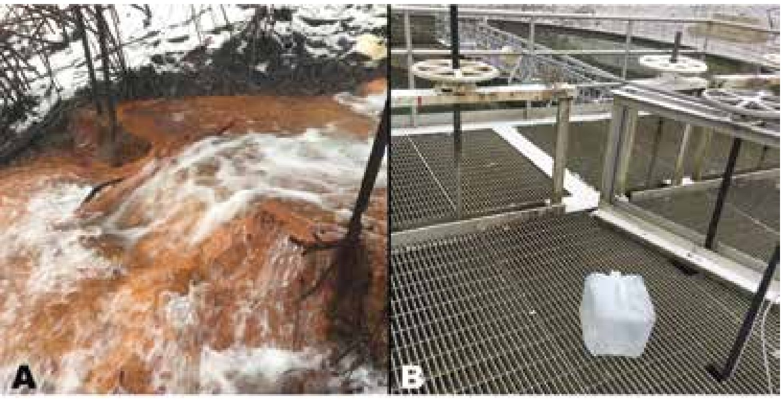


Figure 3: Experimental set-up for co-treatment batch tests.

Figure 4: Cellular respirometric oxygen demand experiments.

Results

The laboratory experiments addressed several primary research gaps related to MWW treatment processes impacted by co-treatment. Experiments showed co-treatment resulted in a stable particulate suspension in settling tanks, with differential settling as the primary mechanism for particle removal and co-treatment at higher AMD ratios leading to better sludge settling (Figure 5). The experimental effluent contained iron primarily in the form of nanoparticles (<0.2μm diameter) and resulted in only 30–50 percent of iron being removed by settling alone (Figure 6). Phosphorus was removed at >97 percent with effluent concentrations ranging from 0.2 to 1.4 mg/L. The high phosphorus removal was best described by Langmuir-type adsorption onto the formed iron oxide particles (Figure 7).

Figure 5: (A) Recorded sludge "height" (in mL) after 30 minutes of settling; (B) Total solids concentration remaining in supernatant; and (C) Dissolved solids in effluent. Originally published as Figure 2 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314.

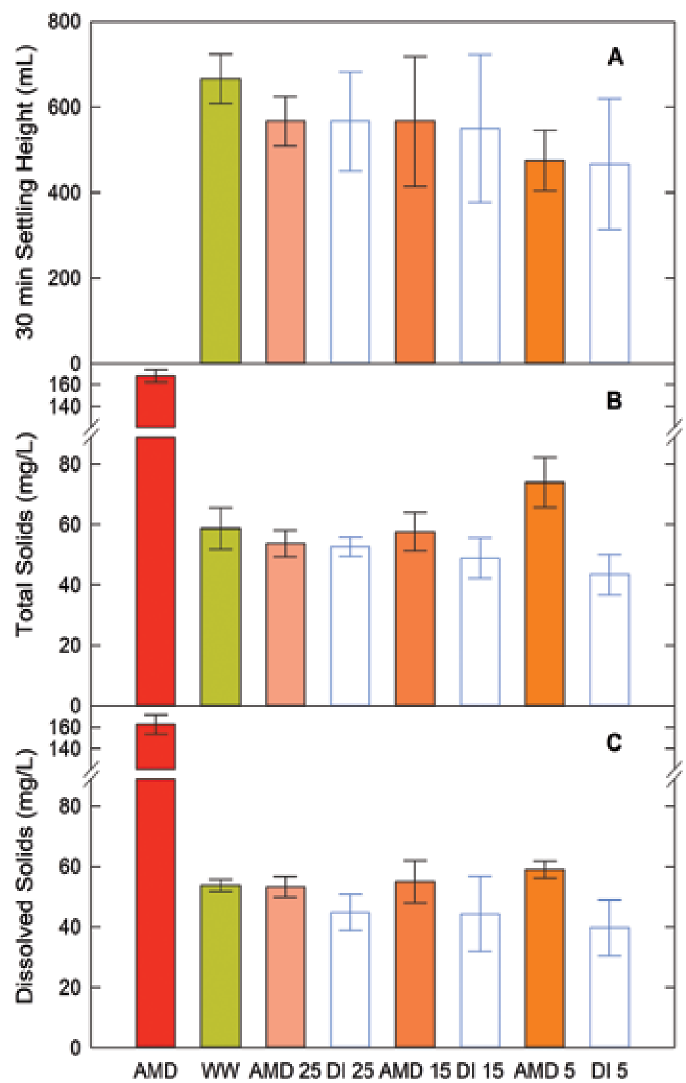


Figure 6: Fractionated iron content showing operationally) defined (size-based particulate, colloidal and dissolved portions of effiuent. Originally published as Figure 5 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314.

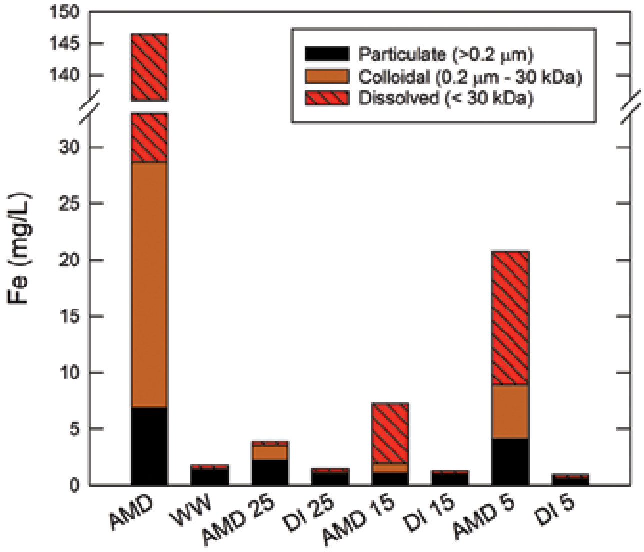
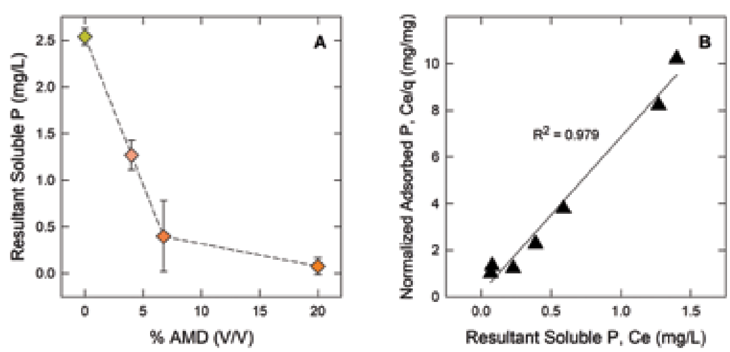
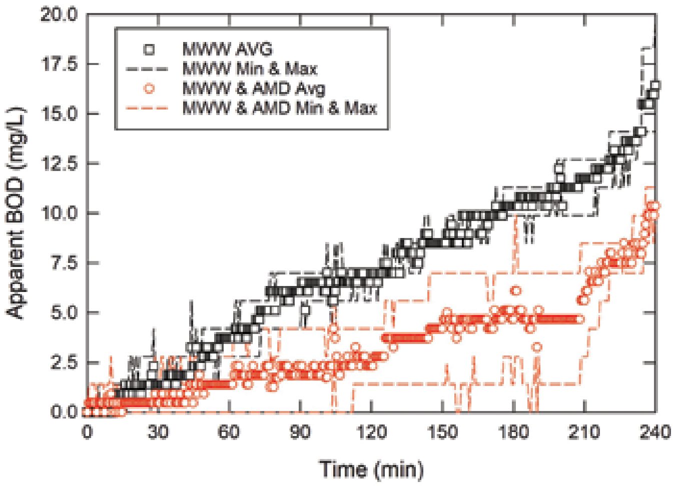


Figure 7: A) Total phosphorus remaining in each sample supernatants and B) Langmuir isotherm behavior of data, demonstrating likely adsorption mechanism. Originally published as Figure 4 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314.



Co-treatment had generally insignificant impacts on other measured parameters (e.g., TSS, BOD, COD) with <10 percent variation compared to controls. The introduction of AMD into MWW microbial communities did result in an initial decrease in oxygen demand by the microorganisms, followed by a recovered oxygen consumption rate after several hours of exposure (Figure 8). This shows that activated sludge microorganism communities might be able to adapt to addition of AMD to biological processes, but experiments over a longer time scale are required to truly understand impacts to microbial communities. Most results and conclusions of these experiments are inherently limited to the type of AMD chemistry found at the Johnstown inclined plane AMD site. However, additional modeling work (e.g., with alkalinity/pH) suggest results from this study may still be applicable to other AMD chemistries but needs to be confirmed by additional studies.

Figure 8: Cellular respirometry results, markers represent the mean value for each sample type, and dashed line represent the corresponding highest and lowest measured value at each point. Originally published as Figure 6 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314.



As related to MWW solids handling processes, co-treating with AMD could provide numerous operational benefits for a wastewater utility. The literature review discovered that several metals typically found in AMD (i.e., iron and aluminum) are also already common in most MWW sludges, and it is believed additional loads from co-treating with AMD would not result in concentrations above those already found in some sludges. Existing sludge regulations indicate that sludges with elevated iron or aluminum content could likely be landfilled or applied to land without additional permitting/analysis. The review also concluded that even if concentrations of aluminum and/or iron are elevated in sludges, this may provide further benefits that support the co-treating of AMD within a wastewater treatment plant. It is believed that iron and aluminum content in sludge could improve its dewatering, resulting in lower operating costs. Furthermore, the presence of aluminum may decrease sludge odors which often plague wastewater facilities. Additional disposal opportunities may also exist for co-treatment sludge, such as using the conditioned biosolids or incinerated sludges (i.e., ash) for land reclamation or agricultural enhancements (e.g., immobilizing trace metals in soils). Although the review conducted in this project suggests there are potential benefits to solids handling from co-treatment, questions remain that must be explored though laboratory studies before full-scale consideration.

Another primary research gap is the unknown cost of implementing co-treatment in a MWW facility. This project also included a preliminary comparative cost-analysis examining co-treatment with the alternatives to achieve the same water quality goals (Table 1). The results from the batch laboratory experiments demonstrated co-treatment could obtain effluent P values < 1 mg/L, which is typically achieved in MWW facilities through enhanced or tertiary treatment processes. The cost analysis suggests co-treatment, which leverages mostly existing infrastructure, may represent an order of magnitude (i.e.,

~$30,000,000 lifetime savings) more cost-effective treatment strategy when compared to totally separate AMD abatement and enhanced MWW nutrient treatment. The average capital cost and subsequent annual operating and maintenance costs (O&M) for a new active AMD treatment facility encompassed the values reported for eight currently operating AMD treatment systems in the Appalachia region using data from the Pennsylvania and West Virginia Departments of Environmental Protection (PADEP, WVDEP respectively). The capital and O&M costs for implementation of enhanced/tertiary phosphorus treatment processes is the average from 20 MWW facilities in the Northeast US that upgraded to new nutrient removal systems with treatment goals of < 1 mg/L phosphorus. The cost of a raw AMD collection system utilized a recent cost estimate for installing new sewer lines in the same state as these sites used in this study (Capital Region Water, Harrisburg, PA) and the average cost for O&M for these systems reported by the US EPA. The co-treatment system also includes an additional required preventative maintenance cost estimated at 75 percent of O&M.

Summary

AMD discharges located near an MWW facility may be an underexplored, unique, low-cost engineering solution for mutually beneficial co-treatment of two waste streams. Laboratory experiments showed addition of AMD can improve some secondary water quality characteristics (e.g., decreased effluent PO4) while having relatively minor impacts on pH, BOD, TSS, and activated sludge microbial activity. The literature review suggests co-treatment could improve resultant sludge dewaterability, odor, and land applications. Although research questions remain, these studies improve the understanding of physicochemical processes and other water quality implications from co-treating MWW and AMD. The results support the feasibility of full-scale AMD co-treatment as a low-cost alternative for AMD abatement and improved MWW effluent quality, which may be especially advantageous to communities with decreasing MWW production and legacy mine water concerns.

Original Publications:

- Spellman Jr, C., Tasker, T., Strosnider, W., Goodwill, J., 2020a, "Abatement of Circumneutral Mine Drainage by Co-treatment with Secondary Municipal Wastewater", Journal of Environmental Management, 110982, doi.org/10.1016/j.jenvman.2020.110982.
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- "Acid Mine Drainage Benefits from Co-Treatment"; Research Note; Water Environment & Technology, October 2020

Table 1: Preliminary cost assessment of AMD co-treatment at an existing MWW treatment plant compared to separate AMD treatment (by an active treatment facility) and upgrades for enhanced MWW PO4 removal to obtain the same effluent water quality (e.g., phosphorus < 1.0 mg/L) as co-treatment. All projections are presented in U.S. Dollars ($). Major assumptions included MWW flow = 12 MGD, AMD flow = 1.0 MGD, Required AMD conveyance = 3.5 miles, estimated system life = 25 years. Final values rounded up to nearest $5,000 for simplicity. Originally published as Table S2 in Spellman et al., 2020a and reproduced with permission under Elsevier License 5117151202314

Separate Active AMD Abatement + Enhanced MWW PO_4 Removal				
Item	**Unit Cost**	**Unit**	**25 Yr Cost**	**Source**
Active AMD treatment Capital	$4,179,621	$/MGD	$4,180,000	*PADEP; WVDEP*
Active AMD treatment O&M	$151,779	$/MGD/Yr	$3,795,000	*PADEP; WVDEP*
WWTP Enhanced PO_4 Capital	$1,006,007	$/MGD	$12,073,000	*Tetra Tech Inc.*
WWTP Enhanced PO_4 O&M	$55,782	$/MGD/Yr	$16,735,000	*Tetra Tech Inc.*
	TOTAL Lifetime:		**$36,785,000**	
Co-treatment (Combined AMD Abatement + Enhanced PO_4 Removal)				
Item	**Unit Cost**	**Unit**	**25 Yr Cost**	**Source**
Raw AMD Sewer Pipe Capital	$330	$/ln ft	$6,099,000	*Capital Region Water*
AMD Pipe O&M	$4,580	$/mi/yr	$401,000	USEPA
AMD Pipe Preventative Maintenance.	$3,435	$/mi/yr	$301,000	USEPA
	TOTAL Lifetime:		**$6,800,000**	

Estimated Co-treatment Lifetime Savings:	
vs Active AMD Treatment only	$1,175,000
vs AMD + New PO_4 Treatment	$29,985,000

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