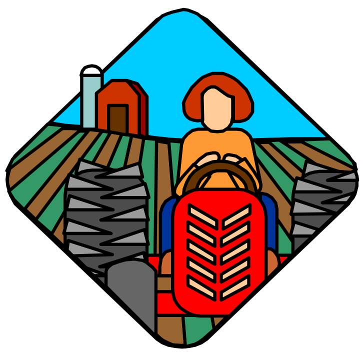
Proceedings of

PRIME, FARMLAND INTERACTIVE FORUM

University of Southern Indiana
at Evansville
March 3 & 4, 1998



Edited by:
Charles L. Hooks
Kimery C. Vories
Dianne Throgmorton

Session Editors:
Larry Emmons
Richard I. Barnhisel
Charles L. Hooks
Robert G. Darmody

SOUTHERN ILLINOIS UNIVERSITY
Carbondale

U.S. DEPARTMENT OF THE INTERIOR
OFFICE OF SURFACE MINING

Sponsored by:
U.S. Department of Interior, Office of Surface Mining, Alton, Illinois
Coal Research Center, Southern Illinois University, Carbondale
University of Illinois at Urbana/Champaign, and
Texas Utilities

Click anywhere for Table of Contents

PRIME FARMLAND
RECLAMATION WORKSHOP
AUGUST 11 & 12, 1998

REGISTRATION

planning committee organizations

♦ Black beauty coal co.
♦ Citizen's organizing project
♦ Coal extraction and utilization center at southern Illinois university, Carbondale
♦ Illinois department of agriculture
♦ Illinois farm bureau
♦ Illinois office of mines and minerals
♦ Indiana division of reclamation
♦ Peabody coal co.
♦ Texas a&m university at college station
♦ Texas utilities
♦ University of Illinois at Urbana / Champaign
♦ University of Kentucky at Lexington
♦ USDA natural resources conservation service
♦ USDI office of surface mining

SOUTHERN ILLINOIS UNIVERSITY AT CARBONDALE

Prime Farmland Interactive Forum

TABLE OF CONTENTS

Foreword

August of 1997 marked the twentieth year of reclaiming prime farmland under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The new rules defining prime farmland reclamation and their promise of post mine agricultural productivity have been a topic of intense interest both before and after the passage of SMCRA. The importance of prime farmland soils to the agricultural community, as well as the mandates placed on the coal industry, has made it one of the most heavily researched topics associated with surface coal mining. Volumes of information on reclamation methods, compaction management, productivity, and minesoil-crop interactions have been produced.

Progress has certainly been made since the passage of SMCRA. Coal mine operators are successfully attaining their revegetation goals and obtaining bond release. In some parts of the country, operators are actually improving premine clay pan soils or even, through selective material handling, constructing prime soils where none existed before. The yearly acreage being disturbed has rapidly diminished because of the reduction of surface coal mining in the Midwest. Thousands of acres will still remain in the reclamation and bond release process for the next ten years. The increasing use of underground mining methods in the Midwest, with the potential impacts to prime farmland, has been largely unanticipated by SMCRA.

While proven successful reclamation methodologies have been developed and adopted by the industry, concerns still remain with the public, industry, and regulators. State regulatory programs may be different due to regional needs and environments but the general concerns are the same:

1) The bond release process needs to be expedited.
2) Is reclamation success sustainable?

Current research efforts are beginning to address these concerns. Evaluation of productivity from soil properties and monitoring yields from twenty year old research sites are new initiatives receiving attention. The Natural Resources Conservation Service is actively working on an initiative to formally publish a detailed guide on the reconstruction of prime farmland soils. Initiatives to classify and map reconstructed soils will provide needed information on productivity and land use capabilities just as we have for natural soils. Prime farmland reclamation is no longer in its infancy. It is in the final states of refinement and mainstreaming with other proven technologies of this century.

I would like to sincerely thank the speakers, authors, and the administrative staff at the Coal Research Center for their time and efforts devoted to make this program a success, and especially the Steering Committee members for their assistance in planning and presenting this forum.

STEERING COMMITTEE MEMBERS

Kimery C. Vories (Chairperson)
USDI Office of Surface Mining

Mark Yingling
Black Beauty Coal Company

Anna Johnson
Citizens' Organizing Project

John Mead and Charles Hooks
Coal Research Center
Southern Illinois University

John Lohse
Illinois Department ofAgriculture

Nancy Erickson
Illinois Farm Bureau

Dean Spindler and Jack Simpson
Illinois Department of Natural Resources
Office of Mines and Minerals

Steve Wade and David Kiehl
Indiana Division of Reclamation

Brent Gray
Peabody Coal Company

Lloyd Hossner
Texas A&M University at College Station

Eddie Bearden
Texas Utilities

Robert Dunker
Crop Science

Robert Darmody
Natural Resources Environmental Sciences
University of Illinois at Urbana/ Champaign

Richard Barnhisel
University of Kentucky at Lexington

Robert McLeese, Bill Hosteter, Travis Neely, and Mack Hodges
USDA Natural Resources Conversation Service

Larry Emmons, Russ Miller, and Elaine Ramsey
USDI Office of Surface Mining

PRIME FARMLAND FORUM STEERING COMMITTEE RECOMMENDATIONS

The following research needs, based on the results of the forum, were identified by various members of the steering committee, although no consensus was reached on any particular need nor was any set of priorities established for the needs listed:

- Develop and publish region specific guidance on post reclamation management.
- Development of new soils series for classification of man-made reclaimed soils that would adequately and accurately provide important functional characteristics including new productivity indices.
- Development of a soils based productivity model with appropriate compaction standards that could be utilized to substitute for actual crop production. (This need was objected to by the Citizens' Organizing Project.)
- Development of a more mobile soil penetrometer system.
- Expansion of penetrometer studies for validation on a wider range of soils to include additional coal producing regions and states.
- Location of reclaimed prime farmland units by GPS for reference in future research studies.
- Evaluation of prime farmland performance over a longer term than that required by SMCRA to determine if productivity is being adequately maintained.

PURPOSE OF THE PRIME FARMLAND INTERACTIVE FORUM

INTRODUCTION: The steering committee has worked hard to provide each participant with the opportunity for a free, frank, and open discussion on issues related to the restoration of prime farmland disturbed by coal mining in an atmosphere that is both professional and productive.

During the two days of the forum, we have the opportunity to talk about technical, regional, and local issues, while examining new and existing methods for finding solutions, identifying problems, and resolving issues.

The forum gives us the opportunity to:

- share our experiences and expertise concerning prime farmland restoration,
- outline our reasons for taking specific actions, and
- give a rationale for why we should or should not be handling prime farmland soils at our mines in a specific manner.

A basic assumption of the interactive forum is that no person present has all the answers or understands all of the issues. It is also assumed that issues, solutions, and concerns may be very site, region, or state specific or may have a very broad application.

The purpose of the forum is to:

- present you with the best possible ideas and knowledge during each of the sessions;
- promote the opportunity for questions and discussion by the participants; and
- let each person decide what is most applicable to his/her situation.

The purpose of the forum is not to come up with new policy or regulation, but to empower the participants with better knowledge, new contacts, and new opportunities for problem solving and issue resolution.

BACKGROUND: August of 1997 marks 20 years of reclaiming prime farmland under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Prime farmland restoration and its promise of post mining agricultural productivity has been a topic of intense interest both before and after passage of SMCRA. The importance of prime farmland soils to the nation's agricultural community has made it one of the most heavily researched topics associated with surface coal mining, producing volumes of new information on the relationship of crop production to soil compaction, fertility, texture, and management.

The potential impacts of coal mining on prime farmland are very different from when SMCRA was first introduced. Coal mine operators are successfully attaining their revegetation goals and obtaining bond release. In some parts of the country, operators may be creating prime farmland soils where none existed before. The yearly acreage of prime farmland being disturbed by surface coal mining is rapidly diminishing because of the reduction of surface coal mining in the Midwest. The increasing use of underground mining methods in the Midwest, with its potential impacts to prime farmland through subsidence, has been largely unanticipated by SMCRA.

Controversy, however, remains. The scientific community is still unable to lift the shroud of complexity associated with projecting actual crop yields based on the measurement of existing soil qualities. Considerable difference of opinion still exists on the long term impacts of surface mining reclamation on the potential agricultural productivity of these soils. The Natural Resources Conservation Service (NRCS) is actively working on an initiative to formally publish detailed guidance on the reconstruction of prime farmland soils. Initiatives are needed to remap and reevaluate the "man-made prime farmland soils" now being returned to agricultural production so that essential information related to land values, crop production capabilities, and tax assessments can be accurately established.

LUNCHEON REMARKS

March 3, 1998

Kathy Karpan, Director
Office of Surface Mining
U.S. Department of the Interior

First, I would like to thank everyone who is involved in this event either as a sponsor or as a participant. I really have an investment is this subject because of my history as a daughter or granddaughter of people who were coal miners and farmers. I have always appreciated what both industries have to give; however, the coal only gives once, the prime farmland, if we manage it right, continues to give and is truly a renewable resource.

It was very interesting to be listening in the audience and to see the mix of people who are here today. I have heard people from many states including Kentucky, Kansas, Missouri, Illinois, and Indiana. We have people from the academic community, industry, and the farming community. I think it is an excellent idea to have these interactive forums.

I arrived at my own version of this type of event earlier this year. In the Office of Surface Mining, we are doing a lot of things that potentially have an impact on people in the coal industry and the states, but we never talk to other agencies to find out what their projections are, what they are doing, how they are looking at the future, and where they see the trends going. As a result, on January 21, 1998, we held a coal symposium where we brought in the Department of Energy to do some projections on how our nations energy needs will be met and predictions on coal prices. We brought in the Mining Safety and Health Administration to explain the differences in their inspections.We brought in the Army Corp of Engineers and the Environmental Protection Agency to talk about their related programs. We had 250 participants and the reception was so great that we will now be having a coal symposium in each OSM region. What you will see happening in the mid-continent region will be similar to this interactive forum except that it will not focus on a single issue like prime farmland but will be on a number of issues important to the mid-continent region.

I would like to rise to the defense of Paul Ehret of the Indiana program when he asked the question about whether or not the Surface Mining Control and Reclamation Act of 1977 (SMCRA) has been adequate or not in protecting prime farmland disturbed by coal mining. Finally, after he forced the issue, the panelists across the board stated that SMCRA was adequate, if it was implemented correctly.That is what we needed to hear and that is the point that Paul wanted to make.

At this point, I would like to start with something that we don't do very often and try to lift the dialog above the specific issues and say some basic things we need to hear. One is that SMCRA was a very good idea. This is based on my personal background, this is not something that is a result of some intensive indoctrination I received after I was sworn in as Director of OSM. I grew up in the underground coal mining community of Rock Springs, Wyoming where the subsidence problems were so bad that SMCRA made legislative findings to that effect. It was a wonderful immigrant community from all over western and eastern Europe.They had a great sense of aspirations and hope, and they were all struggling to become Americans. I appreciated what the coal industry meant in terms of income and our national security, but I also saw members of that community with black lung problems, broken backs, and amputations. The idea of reclamation in those days was to nail two boards across the entrance to the mine and walk away.

About 25 years later I got out of college and had the opportunity to work for a Wyoming congresswomen, Tina Roncolio, who was one of the prime SMCRA sponsors. I well remember the early discussions about whether there ought to be legislation to control surface coal mining. Some people felt we should just ban strip mining entirely. Others said that regulating the industry would drive it out of business. Time has shown that they were both wrong. SMCRA proves that we can do it right. The answer is that there is nothing wrong with SMCRA. We can make it work and that is what forums like this are all about. As befits all works of men and women and not of God, however, we and SMCRA are a work in progress. What it may eventually mean we may never know. All we can say is, that in contrast to the gloomy predictions and indignation of critics on all sides, 20 years after the initiation of SMCRA, we have twice the coal production at almost half the price. We are mining in a careful way. We are doing our best to reclaim the land and, with fees paid by the industry, we are going back to clean up the generations of neglect from abandoned coal mines. Not a bad piece of work.

Today our focus is on one of the works still in progress, namely prime farmland restoration. This is the most important land that Congress wanted to protect because it sustains us as a country and much of the world. One of rituals that needs to be brought out by this meeting is to note that worldwide there is only about 3.3 billion acres of economically farmable land to feed the 5.8 billion people on the planet. It will stun you to point out that this averages out to about one half acre of agricultural land per person. Contrast this to 20 years ago when SMCRA was passed when the world population was not 5.8 billion but only 4.5 billion people and the ratio was three fourths of an acre of agricultural land per person. That contrast, all by itself shows you the challenge we as a nation have in feeding the world.

Picking up on an earlier comment, 20 years ago we realized that urban sprawl and interstate highway developments were great threats to prime farmland. Congress also had the insight to see that the development of coal could be a threat to prime farmland. Some 43.4 million acres were identified as prime farmland underlain by economically recoverable coal reserves. This is about 17 percent of the total acreage of prime farmland soils. This is not an insignificant figure. Because of the recognition that the development of coal, in addition to urbanization and roads, could threaten our ability to produce food and fiber for ourselves and the world, Congress made special provisions for the care and restoration of these lands. For those of you who have a sense of history (I did not realize this until I was working on my remarks), SMCRA represents the first time in our history that a law mandated that a specific human activity can be conducted only when there is no net loss of prime farmland acreage or productive capacity. The coal mining statute is the only one that specifically protects these prime farmlands. I also want to support an earlier comment that not only can we protect, but sometimes we can enhance the productive capability of the land by the new ways we learn to conduct our reclamation. There is a lot of promise that the dreams of SMCRA will be fulfilled in the future in ways that we are only imagining now.

The intent of SMCRA was not to discourage coal development, but rather to assure that care would be taken so that coal mining would be enviromnentally sound and the land disturbed by mining would be restored to its pre-mining capabilities. In making the determination that nothing is more local than the land, Congress also made the judgement that the states were in the best position to administer the Act and therefore determined that local mining and environmental conditions were to be incorporated into each coal mining and reclamation operation. An integral part of this process has been the active input of land owners and citizens in making the decisions that are involved in approving permits. Very few statutes have safe guarded the citizen role as specifically as SMCRA We are seeing that by the people who have joined us today. In many of the prime farmland states, there has been a strong public interest in reclamation. In fact, we have seen that groups such as the Citizens' Organizing Project not only got involved but have stayed involved, working over 20 years to protect these valuable resources.

In the 20 years since the passage of SMCRA, we have seen dramatic changes in the coal industry. Some of them have been mentioned this morning. One significant fact is, that in the corn belt, coal production by surface mining is down. If you look at the states of Illinois, Indiana, Ohio, Iowa, and Missouri, coal production by surface mining methods has fallen from 84 million tons per year in 1980 to 47 million tons per year in 1996, or a 44 percent reduction in surface coal mining. In Illinois alone, coal production by surface mining methods has fallen by 70 percent in the same time period with the majority of its production now being produced by longwall underground mining methods. So the circumstances in which we are working are changing. Thus, the number of acres of prime farmland that were expected to be mined and reclaimed in the process of surface coal mining is not what it was expected to be. In addition, the amount of underground mining is significantly more and these trends are expected to continue. As we gear up to see these changes in more production of western coal and in longwall mining that can be done more efficiently, the issues we are wrestling with today will not go away and will take on a different focus.

Both before and after SMCRA, the restoration of prime farmland soils has been a topic of such interest that we think it might be the most researched part of our whole SMCRA set of issues. Volumes of new information have been produced showing the relationships of crop production to all aspects of surface coal mining and reclamation and the special methods and equipment developed to ensure successful reclamation, restoration, and management. I think it was fascinating to hear a research presentation and comments from the audience on how the study might take on different aspects and encouragement from the author for more ideas to come forward. So, as with SMCRA, the research is a work in progress. I think that alone is worth the price of admission to see this type of idea sharing. We do want to pay tribute to those who have given us the intellectual grist for the mills and, although I don't want to name anyone as I will surely leave someone out, I understand that researchers from the University of Illinois, University of Kentucky, Texas A & M University, and University of Iowa, some of whom are here with us today, have led in that research effort. Their work and the work of others is providing an invaluable body of information that we can use in the future.

As for the Office of Surface Mining, I want to talk about what we want to do here and then what the future holds for us. In my administration, I have said that we want to accomplish things that all provide a better value to you for the dollars we receive.

- We want to have better reclamation because we have a better appropriation to go to work on the thousands of abandoned mine land sites that are out there. Enhance AML where we can leverage dollars out of the private sector toward that goal.
- We want to have under better regulation some real movement toward remining in states like Virginia and Tennessee where we think, with careful controls, remining can be done right.
- We want to have electronic permitting.
- We want to go to work on contemporaneous reclamation issues in the West.
- A big part of what we want to do in the future is to do a better job of technology transfer.
- One of the priorities I see is to try to get more research done. With the departure from the scene of the Bureau of Mines, we have seen a gap in applied research that we can put out in our network. That is something I want to think about. I hope I can do something about this and would welcome your ideas.
- We use mechanisms like SOAP, TIPS, and the states to disseminate the results of research and best practices.
- Another one of our goals, in the regulatory area, is to make better science based decisions and use technology as fullyaswecan.
- The last goal I have is to make OSM a better agency by lifting the skills of our people by providing better training and educational opportunities and gearing up for 21st century OSM. In the next century, I think our role will be to be consultants in trying to grapple with problems. We should not be in the position of saying "That is a problem! Write the ticket!" Nor should we be saying "That is the problem! The state should write the ticket!" What we should be saying is "We have a problem. Let's see what we can do to solve it."

Beyond what I think we are doing in our own country, something else should be said at gatherings like this.We are the envy of the world for what is happening in this room today. We have people all over the developed world and in particular the developing world who are living amidst the ruin and the devastation of prior energy production and in many cases doing little or nothing about it. We have in our office a delegation that went to India and currently we have three OSM employees who are in Indonesia at the World Bank's behest. We have had visitors from Mongolia, Hungary, and South Africa interested in what we do. Literally there is a world out there that is fascinated that we have been able to do something that the critics said we couldn't do 20 years ago. That is to meet the energy needs of this country in a way that will protect us in terms of our national security and will fuel an economy that is enjoying the longest sustained period of growth in 30 years and not do it at the expense of our environment.

When you come together in a meeting like this you don't say, "Let's rest on the laurels of the last 20 years." Instead, in a very serious, conscientious, future minded, and respectful way you ask each other what can we do better to this wonderful prime farmland resource? What can we learn and pass on today? How can we get one more acre into good production knowing that there is only one half acre of good agricultural land for each person in the world? This is actually a wonderful example of what SMCRA was intended to accomplish.We are meeting our needs and doing it in the right way, sharing our research and looking in every way to get better and betterI say in all seriousness to all of the people who have worked so hard on this event. Congratulations!

It is not every day of the week that you can go home and say that I did a very good job today.But I think that these kinds of conferences ought to lead you to say, "I did a good job today for my country and for the world." This is what I think that the 21st century will be all about. It won't be about bringing our living standard down to some pre-industrial age level because we can't live with the impacts. It will be meeting our material needs in a way that is extremely sensitive to this planet and in a way that this is environmentally sound. We will be constantly challenged to do a better and better job so that we don't just restore the land but that we enhance and enrich in every way we can.

What you are doing here will make a difference. If out of this event you establish a consensus that some things ought to be different and need to be taken to the top level of OSM, tell our OSM people here and tell Brent Wahlquist our Regional Director and we will listen. We will consider it and we will take it up. That is our part of what is going on here today, to be open, to listen and learn, and always be willing to work with you, and that I promise we will do.

LUNCHEON REMARKS

March 4, 1998

Ray Sinclair
Natural Resources Conservation Service
U.S. Department of Agriculture

The first thing I would like for you to notice is that 90 percent of the people who understand prime farmland restoration are in this room today. It is an honor to be speaking to the group of people who really understand what prime farmland restoration is all about.

I would like to thank Kathy Karpan for her remarks yesterday about our constant loss of agricultural acreage not only to surface mining but to many other uses. Anything that we can do to reduce the loss of agricultural lands is very important. History should note this effort in the field of surface coal mining as a very special attempt to protect the lands that feed the world. It has been very alarming for me to watch the area between Denver and Fort Collins, Colorado that has been converted from agricultural lands to houses over the last few decades. Much of that land in terms of soil properties was prime farmland. We are losing land very quickly to developments like this.

I would like to read something written in 1985 by Dr. Ivan Jansen from the University of Illinois that describes very well what we are trying to do this week. "My concern as a pedologist is primarily related to the characteristics of the finished soil rather than about how the reclamation is done. It is apparent that some material handling methods are producing better soils than others. Perhaps less expensive means could be devised that would produce soils that are as good as or better than the best soils we are seeing now." I am sure that if Dr. Jansen could be here today he would say that we have made great strides since the late 1970s. I have been involved in prime farmland restoration since the beginning, and there is no comparison of what I saw in the beginning to what we are seeing here today. The people in this room are the ones who made it all possible. This has been one of the greatest partnerships of people and institutions that I have been involved with.

SMCRA required the Secretary of Agriculture to develop specifications for removal, storage, replacement, and reconstruction of prime farmland soils. The only responsibility of the Department of Agriculture on mined lands relates to prime farmland. I am disappointed because we started a rule in the *Federal Register* several years ago in order to accomplish what we were required to do by SMCRA in 1977. I can tell you that we are getting closer. I told you that four years ago, but we are getting closer. We had hoped to have it published in the *Federal Register* by now but we have been asked to rewrite a few paragraphs and make a statement of what its effects will be. We do plan to have it published in the *Federal Register* some time this year. I hope you all have a chance to look at the rule and regulation when it is published, and we sincerely want your comments. I think it will help us all have an overall appreciation for what we would like to have done as far as reclaiming prime farmland soils. Based on what I have heard at the forum so far, there is nothing that will come out in this rule that will not complement what has been said here. During the development of this rule, I made sure that I utilized the data developed by the experts at this forum to ensure that I would have the latest scientific findings in the document. This rule will integrate both the experience of the Department of Agriculture and the work that the experts at this forum have developed over the years. I can't give you too many details because we have not yet released the document for public comment. I can give you some general ideas of what will be in it.

The four things that soil scientists are concerned about are the physical and chemical properties of the soils, landscape features (in both the semi-arid and humid parts of the country), and climate. The proposed rule will cover all four of these concerns.

I would like to talk about soil properties, landscape, and climate. I developed a guide to array the soils of the United States for producing food, fiber, and seed. I have since learned that the Canadians have done something very similar. I bring this up to relate to concerns I have heard here about developing a soil based productivity index to utilize some time in the future in the process of bond release. In this case we may not have to grow crops in order to determine that the soil meets the bond release criteria. This may be possible. But it is only possible because of the fact that we have had all of this good research that has taken place over the last 20 years. The procedure that we are using now to measure soil productivity with crop yield is much more flexible than if we had to write criteria based on soil properties, landscape features, and climate. This can be done, but we will have to write these criteria in such a manner that we will have no doubt that the soil will be returned to the original yields it was capable of producing before mining. In addition, when we are not going to grow a crop to prove productivity, we will have to figure in a sufficient safety factor to ensure full restoration of soil capability.

The present guidance that will be coming out as a proposed rule in the *Federal Register* will take today's knowledge and provide uniform guidance to the restoration of prime farmland soils. Hopefully this will help people develop a plan for reclamation. It is only a guideline and will not dictate any particular methodology. It will suggest areas that should be considered when developing the reclamation plan. It fits in well with all of the current State and Federal rules and regulations. It should not create any difficulties with what is now being done in the states. At this time proof of productivity by actual crop yields is the best method available. We are very willing to work with other methods as the data is developed. We need to know what numbers to fill in the gap between 180 psi and 280 psi suggested in the talks earlier today.

We do plan to work on better soil classification systems so we can go back into the reclaimed areas and re-map and classify them. This would be a real opportunity for us. We could obtain the reclamation plans for each area and know exactly how each area has been reclaimed. Normally we never have this type of documentation. The mapping should go fairly quickly if we can obtain the documentation that is available in the reclamation plan. The reclamation plan should contain all of the information we would need to re-map the area. Every state has its own re-mapping program. Some states re-map on a cost share basis and others establish a priority system. Certainly if the county tax assessors make it known that they need this information, that should increase the possibility of a timely effort in mapping these mined areas.

THE SURFACE CONTROL AND RECLAMATION ACT OF 1977

Charles E. Sandberg'
USDI Office of Surface Mining
Alton, Illinois

Although we did not establish a theme for this forum, as I thought about what I might say it occurred to me that we do indeed have a theme. When I finish my remarks I would hope that you would agree with me.

For those of us who were here in the beginning and for those who weren't at least some review of the history is appropriate to the start of this forum.

The prime farmland provisions were different from most other requirements of SMCRA, which became effective on August 3, 1977. They created a high level of frustration for everyone with an interest in prime farmland mining and reclamation. The delay was due to problems related to the start up of a new Federal regulatory agency with a complex program that required a substantial amount of training for the technical staff. Other difficulties experienced during the start up of SMCRA were:

(1) Most of the existing expertise on mining reclamation regulation was at the state level.
(2) The first OSM inspectors did not reach the field until the summer of 1978.
(3) A major enforcement problem for field staff was that the interim program included performance standards but not permitting standards. This meant that both State and Federal inspectors had to enforce performance standards for prime farmland on permits that did not contain prime farmland restoration plans.
(4) The lack of long-term experience with returning reclaimed mine lands to row crop agriculture.
(5) It would take a long time to familiarize the operators, states, and OSM field staff with the new requirements.
(6) Operators would have to acquire new equipment in order to salvage topsoil, minimize compaction, and conduct the grading necessary to restore cropland. Some operators would be required to obtain specialized equipment to break up compaction following reclamation.
(7) Operators would be required to demonstrate that they had the capability to restore prime farmland to its original capability before they could begin mining.
(8) The lengthy amount of time necessary to develop the implementing regulations for SMCRA. Interpretation of many aspects of SMCRA was very difficult prior to the development of the regulations.
(9) Delays were experienced because of the time it took for states to pass legislation necessary to implement SMCRA. It took from 1977 until 1982 for most states to obtain approved regulatory programs.
(10) The number of legal challenges to SMCRA and its regulations with the resulting regulatory revisions ordered by the courts resulting in confusion over changing requirements.
(11) Although existing operations had the option of "grandfathering" some or all of their prime farmland soils, states needed time to develop standards for the "grandfathered" prime farmland soils. Although the application of the "grandfathering" regulation varied, it did allow the states and the operators some additional time to acquire the necessary equipment and gain experience with prime farmland reclamation. Citizens wanting immediate action on prime farmland restoration, however, were greatly concerned by the delays resulting from the "grandfathering" process.

The Present

The basic requirements of SMCRA are now a part of all state approved programs including:

(1) A soil survey of all prime farmland soils.
(2) A plan for soil reconstruction that separately removes the topsoil and adequate subsoil unless a plan for soil mixing and substitution is approved.
(3) Scientific data supporting the ability of the reclamation methods to achieve successful restoration of prime farmland capability.
(4) NRCS consultation concerning the reclamation plan and methods.
(5) The acreage of prime fam7dand soils will not be decreased.

(6) Crop production is to be monitored and measured for a period of three years in order to prove that the soil capability has been fully restored.

What have been the surprises?

(1) The "grandfathering" issue in many states turned out to be much larger than originally visualized. The process has also had a much longer life span than anticipated.

(2) The bond release process has taken much longer than anticipated with some acreage from the initial program and large acreage of "grandfathered" prime farmland soils still under bond. In fact, no one knows yet when many of these acreages will be ultimately released and what normal time for mining through bond release should be expected. We can not provide landowners any certainty as to when they can expect to be able to utilize their land for normal agricultural production.

(3) Many soils experts both from the NRCS and universities have been the greatest advocates of soil mixing and soil substitutes rather than replacement of the original soil horizons. This has resulted in soil mixing and substitution plans being the rule rather than the exception.

(4) The process of developing defensible standards and methods for measuring revegetation success has been much more complex than anticipated. The result has been an increase in the amount of time necessary to achieve bond release.

The Future

Trends that OSM expects to see continue into the future include:

(1) Applications for bond release for large amounts of prime farmland and other reclaimed areas are expected to be received all at once. This is beginning now and is expected to increase in the near future. It will place a heavy burden on state regulatory staffs already operating with continually reduced resources and personnel.

(2) There is increasing pressure being brought by land owners on the NRCS and other state agencies to provide new soil descriptions with associated soils data on productivity and capability for reclaimed soils. This information is necessary for accurate tax assessment and property values.

(3) Operators are desirous of new bond release methods that would shorten the time to prove restoration of the soil capability.

(4) In some states, the continuing trend to high extraction underground mining methods with associated subsidence and impacts to prime farmland and other cropland areas is expected to become increasingly more important.

(5) Increasing competition from cheaper coal sources outside the region leave the industry with fewer resources to conduct reclamation and increase the probability of bond forfeiture.

Where is OSM going in the future and what are the implications on prime farmland mining and reclamation?

The first area of change is in the manner in which OSM conducts oversight. In January of 1996, OSM released a new version of its Directive entitled REG-8. This document was the product of a team composed of OSM and state regulatory members and took several years to arrive at the initial version. Based on the first year's experience, adjustments were made, and on September 30,1997, the current version was signed by Director Kathy Karpan whom you will be hearing from today at lunch.

The changes brought about by the new oversight directive are significant in several ways. First it changes the focus of our efforts to the two areas which have the greatest impact on people and resources in and adjacent to mining operations.

The first is in the requirement that during our inspections we document all off-site impacts and that we make an assessment of the degree of impact on people, lands, water, and structures. This represents a change in how we assess the sucess of the state's program, the direction we take in identifying issues, and the resolution of those issues. First we are now starting out with an identified problem an off-site impact. From that we then work backwards to identify the cause. In the past we have been accused of nitpicking and spending time on issues that had no real impact. I firmly believe that this approach will have major benefits for those people and resources that potentially can be impacted by mining. There are those that don't agree with the new approach, and I would be happy to discuss the pros and cons of this approach with you during the breaks (See Overhead No. 1).

The second area where we have our oversight focus has a much stronger relationship to our forum on prime farmland. We are now concentrating our efforts more towards reclamation success and end results. Once again our intent is to address the issues that have the greatest "bang for the buck." Certainly the issues associated with end results and reclamation success meet that criteria. In our oversight directive, we have further refined our definition of reclamation success and end results as to include the following: land form/approximate original contour, land capability, hydrology reclamation, and contemporaneous reclamation. One cannot fault that these four areas define the product of our efforts as miners, regulators, scientists, and landowners, and the intent of SMCRA. Probably there is no area of reclamation where each of these factors is more critical than prime farmland. By definition the slopes of prime farmland are critical before and after mining; capability is the test that it must pass; the hydrology, both surface and subsurface, are basic to successful reclamation of prime farmland; and last, contemporaneous reclamation defines our ability to return the reclaimed land to the landowners without the incumbrance of SMCRA. Each of these have been around since the passage of the Act, but it is this issue of contemporaneous reclamation I want to discuss in more detail, which will lead into the last issue I want to address. First let me say that not everyone agrees on how to measure reclamation success and whether contemporaneous reclamation is really a part of end results. The acreage of prime farmland is at the heart of this issue because of the complexity of the reclamation, the time involved in pre-crop vegetation many believe to be critical to successful reclamation, and the number of years of testing required for prime farmland. The issue that arose in our initial process through which reclamation success was to be measured was that contemporaneous reclamation equated to successful reclamation and that bond release was the measure of our success. Many states made the argument that contemporaneous reclamation was measured by the adherence to time and distance requirements for grading, topsoil replacement, and establishment of vegetation. In recognition of the differences of opinion on this issue, the states and OSM have the option to report both the results of completion of the various time and distance standards and vegetation establishment and the bond release status. As we have seen, the complexities of prime farmland reclamation have had an impact on bond release time frames(See Overheads #2-#5).

This brings me to the last item on the horizon of OSM and SMCRA. The Government Performance and Results Act of 1993. The purposes of the Act in part are stated as:

1) improve the confidence of the American people in the capability of the Federal Government by systematically holding Federal agencies accountable for achieving program results; and
2) initiate program performance reform with a series of pilot projects in setting program goals, measuring program performance against those goals, and reporting publicly on their progress.

The Act also stated in part "No later than Sept. 30, 1997 the head of each Federal agency shall submit to the Director of the Office of management and Budget (OMB) and to Congress a strategic plan for program activities. Such plan shall contain general goals and objectives, including outcomes, for the major functions and operations of the agency."

By now you are asking what does this have to do with prime farmland and our forum. To clarify we need to look at OSM's initial performance goals in just one area. I had mentioned earlier our business line approach to budgeting. We have also adopted the business line approach to our GPRA requirements. The business line which impacts prime farmland is entitled Environmental Protection. The performance goals are listed in Overhead #6.

As you can see OSM will be measured by actions we (all of us in this room) control: the off-site impacts and the number of acres we can successfully move through the reclamation process. Our ability to successfully return prime farmland back to private production is a major component by which the public and Congress will assess our success in many Midwestern coal states. In addition, our budgets both for OSM and for state grants are already tied to our business line. It is only a small step to make the next connection between performance goals and budgets. As we go through this week and hear how we have progressed, let us be mindful that we are in this together and our responsibilities to complete reclamation of the highest producing soils in the world in a timely manner must continue as our highest priority.

In closing I would like you to see a graph (Overhead #7) of where we may be in meeting our goal of successful reclamation based upon permitted acres versus bond release acres. Note that if the same graph was created for prime farmland only, the gap would probably be wider.

During the remainder of the forum, we will have the opportunity to listen to the experts and discuss our success and problems with those most involved with prime farmland restoration. I would encourage you to take advantage of this opportunity to learn and share so that we will all leave with a better understanding of mining and reclamation processes that potentially impact the most productive soils in the world.

'Charles Sandberg, Manager, Program Support Division, Mid-Continent Regional Coordinating Center, Office of Surface Mining Reclamation and Enforcement; B. S. Civil Engineering, University of Illinois; Registered Professional Engineer in Illinois; 12 years as a county engineer, 4 years as a project engineer with the Illinois Department of Transportation, and 19 years with OSM in a variety of positions and locations.

TABLE 4

OFF-SITE IMPACTS

RESOURCES AFFECTED			People			Land			Water			Structures		
DEGREE OF IMPACT			minor	moderate	major	minor	moderate	major	minor	moderate	major	minor	moderate	major
TYPE OF IMPACT AND TOTAL NUMBER OF EACH TYPE	Blasting													
	Land Stability													
	Hydrology													
	Encroachment													
	Other													
	Total													

OFF-SITE IMPACTS ON BOND FORFEITURE SITES

RESOURCES AFFECTED			People			Land			Water			Structures		
DEGREE OF IMPACT			minor	moderate	major	minor	moderate	major	minor	moderate	major	minor	moderate	major
TYPE OF IMPACT AND TOTAL NUMBER OF EACH TYPE	Blasting													
	Land Stability													
	Hydrology													
	Encroachment													
	Other													
	Total													

The objective of this Table is to report all off-site impacts identified in a State regardless of the source of the information. Report the degree of impact under each resource that was affected by each type of impact. Refer to guidelines in Directive REG-8 for determining degree of impact. More than one resource may be affected by each type of impact. Therefore, the total number of impacts will likely be less than the total number of resources affected; i.e. the numbers under the resources columns will not necessarily add horizontally to equal the total number for each type of impact. As provided by the Table, report impacts identified on bond forfeiture sites separately from impacts identified on other sites. If bond forfeitures sites were not evaluated during the period, clearly note the table to indicate that fact. Impacts related to mine subsidence or other areas where impacts are not prohibited are not included in this table, Refer to report narrative for complete explanation and evaluation of the information provided by this table.

OVERHEAD #1

the **State** considers to be remined; i.e. areas that were previously mined and not properly reclaimed and will be re-affected by current mining and reclamation.

. NUMBER OF ACRES WHERE BOND WAS FORFEITED DURING THIS EVALUATION YEAR (also report this acreage on Table 7) - Enter the number of acres on which the State forfeited bond during the evaluation year.

Table 6: Optional Data Tables

- If agreed to in the PA, the collection and presentation of additional data for annual State mining and reclamation results is permissible and encouraged in an effort to report the reclamation performance of the State. Listed below are some suggestions, not intended to be all inconclusive, for collection of data. FOs and States will need to develop appropriate tables for the data. If optional tables are not included, Tables 7, 8, and 9 must be renumbered.

Table 6a:

This table or a similar table may be used where a State provides data to OSM on the status of reclamation in a State even though the State has made no final determination concerning site conditions as they relate to meeting all performance standards necessary for bond release. Data reported in this table must not be included in Table 5. Note: Since there has been no final determination on the acceptability of acres reported in this table for bond release purposes, there should be no implication that any of the acreage reported in this table meets any of the phase bond release performance standards.

ANNUAL STATE MINING AND RECLAMATION RESULTS

Reclamation Activity	**Applicable Performance Standard**	**Acreage During This Evaluation Period**
Backfilled/Graded	* Approximate original contour restoration * Drainage reestablishment	
Topsoil Replaced	* Topsoil or approved alternative replacement • Surface Stability	
Revegetation	• Establishment of vegetation	

The following tables or others developed by a FO or the State may be added to document specific aspects of reclamation success that are important to the State. These tables can document various aspects of reclamation in a State where bond release standards have been met and where the State has made no final determination concerning site conditions as they relate to

OVERHEAD

meeting all performance standards necessary for bond release. However, if there has been no final determination on the acceptability of reclamation reported in these tables for bond release purposes, there should be no implication that any of the reported reclamation meets the bond release performance standards.

Table 6b:

LAND USE ACREAGE

Land Use	**Acreage**
Cropland	
Pasture/Hayland	
Grazingland	
Forest	
Residential	
Fish and Wildlife Habitat	
Developed Water Resources	
Public Utilities	
Industrial/Commercial	
Recreation	
Remined	

Table 6c:

AVERAGE PRODUCTIVITY ACHIEVED

Crop	**Yield**	**Percent of Original Yield**
Corn (bu/ac)		
Beans (bu/ac)		
Wheat (bu/ac)		
Hay (bu/ac)		
Other		

OVERHEAD #3

Table 6d:

COVER RESTORED

Cover Type	Percent Cover or Stems/Acreage
Forest	
Fish and Wildlife Habitat	
Grazingland	
Residential	
Industrial/Commercial	
Recreation	
Remined	
Other	

Table 6e:

WATER QUALITY

	Average Upstream Data	Average Downstream Data
PH		
Fe		
TSS		
Mn		
Set. Solids		

Table 6f:

DISCHARGE POINTS

Percent of Complying Discharge Observations
NPDES Results

PH
Fe
TSS
Mn
Set. Solids

Table 7: State Bond Forfeiture Activity

- Include only those sites for which the indicated action is complete. For example, the "Bonds forfeited" categories do not include sites for which bond forfeiture proceedings

TABLE 5

ANNUAL STATE MINING AND RECLAMATION RESULTS		
Bond release phase	**Applicable performance standard**	**Acreage released during this evaluation period**
Phase I	• Approximate original contour restored • Topsoil or approved alternative replaced	-
Phase II	• Surface stability • Establishment of vegetation	-
Phase III	• Post-mining land use/productivity restored • Successful permanent vegetation • Groundwater recharge, quality and quantity restored • Surface water quality and quantity restored	-
	Bonded Acreage Status [A]	**Acres**
	Total number of bonded acres at end of last review period [B]	-
	Total number of acres bonded during this evaluation year	-
	Number of acres bonded during this evaluation year that are considered remining, if available	-
	Number of acres where bond was forfeited during this evaluation year (also report this acreage on Table 7)	-

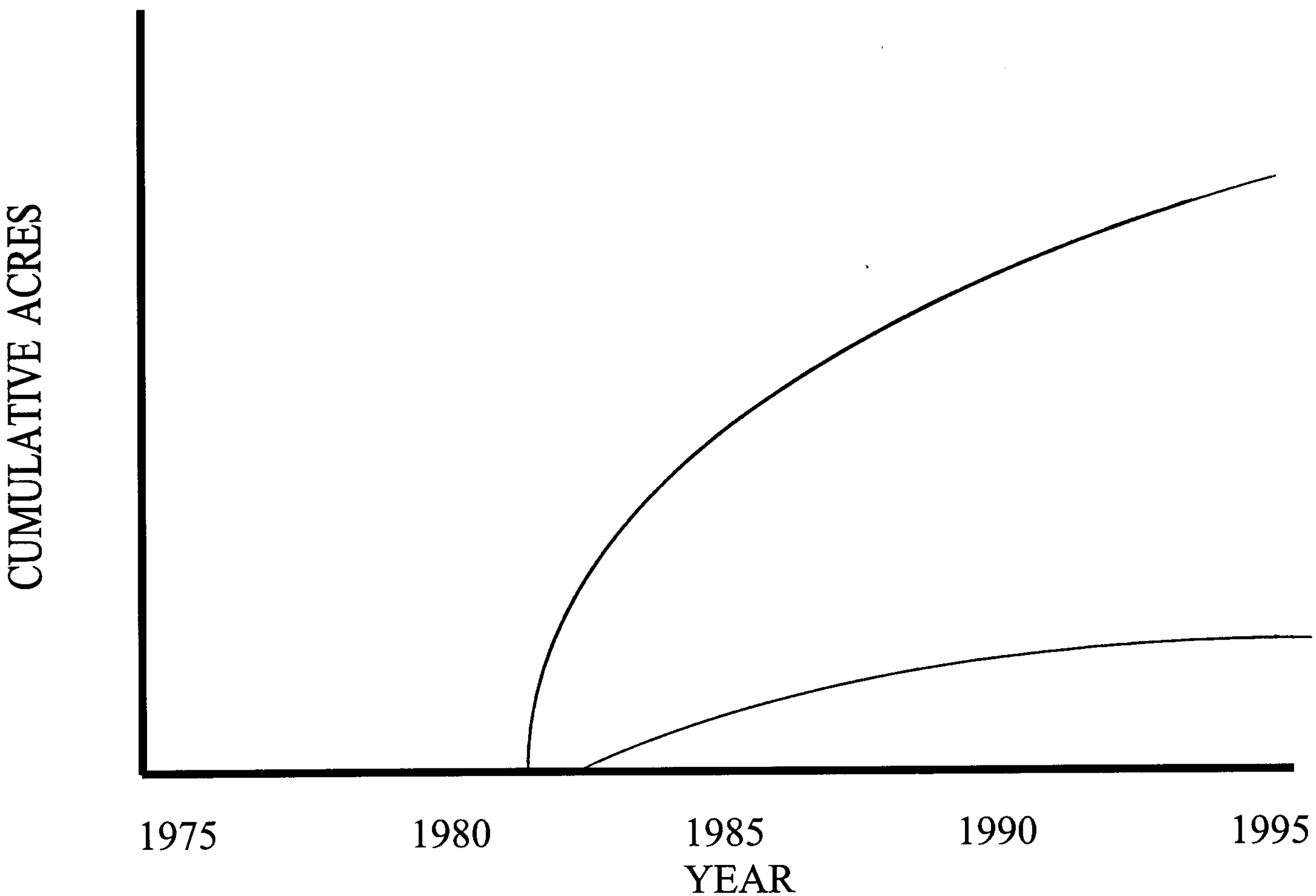
[A] Bonded acreage is considered to approximate and represent the number of acres disturbed by surface coal mining and reclamation operations.

[B] Bonded acres in this category are those that have not received a Phase III or other final bond release (State maintains jurisdiction).

Potential Strategic Measures and FY 1999 Measures	**1997**	**1998**	**1999**	**Annual Perf Goals**
By 2002, the SMP will minimize the number and severity of off-site impacts while protecting the environment and public from current mining. • In FY 1999, OSM will minimize the number and severity of off-site impacts while protecting the environment and public from current mining. Example: In 1999, the SMP will strive for **50%**? of the sites to be free of off-site impacts.	88%	90%	92%	2.2
By 2002, the SMP will report the number of acres released from Performance Bonding Phases I & II in order to show the progression of permitted acreage being reclaimed. • The SMP will report the number of acres released from Performance Bonding Phases I & II.	60,000 Phase I; 58,000 Phase II			2.3
*By 2002, the SMP will maintain the number of reclaimed acres **(250,000 acres?)** which are released from Phase III Performance Bonds, while encouraging more timely Phase III bond release by operators.* • The SMP will maintain the number of reclaimed acres (50,000) which meet the Phase III Performance Bond release criteria, while encouraging more timely Phase III bond release by operators.	82,000	90,000	100,000	2.4

* SMP — Surface Mining Program

ACRES PERMITTED V.S. RELEASED



OVERHEAD #7

ILLINOIS PROGRAM REQUIREMENTS, EXPERIENCE AND RESULTS

Dean R. Spindler'
Land Reclamation Division
Office of Mines and Minerals

Springfield, Illinois

Abstract

The prime farmland and high capability cropland reclamation program in Illinois is presented in terms of historic issues. statistics related to existing liability, current mining acreage, and theoretical impact. Monitoring procedures are discussed concerning the removal,, storage, and replacement of soils during mining and reclamation. The productivity standards of the Agricultural Land Productivity, Formula and regulatory initiatives are also discussed.

Introduction

The last 20 plus years have been very interesting in the area of cropland reclamation. I use the term cropland because not all cropland reclamation in Illinois is prime farmland. Prior to SMCRA, Illinois had its first soil replacement regulations in 1971. It established soil texture, thickness, and coarse fragment limits in the root medium. A major upgrade to this, known as Rule 1 104, was done in 1976 which added a topsoil requirement. This rule included all Class 1, 11, 111, and some of the flatter Class IV soils. This is obviously more broad than the prime farmland definition. These soils are now known as "high capability lands" and include prime farmland that has been exempted by grandfathering or historical use.

SMCRA came with many challenges of which prime farmland was a major issue, particularly in the early days. Illinois has a lot at stake with respect to prime farmland with 21 million of its 35 million acres being prime. Approximately 500,000 acres of prime and another 125, 000 acres of high capability land overlay theoretical surface mineable coal. It is almost impossible to open a surface mine without affecting prime or high capability land. One must keep in mind that this acreage reflects several hundred years of future mining, based on current mining activity. Presently there arc only six active surface mines in the state.

Historical Issues

One of the advantages of being second on today's program is to address some of the issues raised by Sandy in the previous talk. The first issue is grandfathering which was originally very contentious both with OSM and the industry. About 18,000 of the estimated 26,000 acres of eligible prime farmland have been grandfathered to date. Very few acres have been grandfathered in the last few years due to the closure of the larger surface mines. Only one of these operations which existed when SMCRA was passed is still in operation. Due to the fact of the preexistence of Rule 1 104 (High Capability) soil reconstruction standards, all grandfathered prime farmland defaulted to that category, with its 90% productivity, two-year standard. Current permits have approximately 10,000 acres of prime farmland liability. Of this 6,300 acres are proposed to incur overburden removal.

Another historically contentious issue, between OSM, the RA, and a few citizens groups has been the issuance of permits and the approval of subsoil mixing in the highly productive soils of western Illinois. Although one case is still pending on a mine, which has since closed, all other of the decisions of the department that have been contested have been upheld in favor of the department.

A third major issue has been the establishment of productivity standards to measure restoration. The primary portion of the regulations used today were adopted in 1986 after a multiyear rulemaking effort with many parties involved, including citizens groups, the industry, IDOA, USDA Crop Reporting Service, NRCS, University of Illinois, and our agency. I will defer my discussion on this topic to my session later on in the forum.

Field monitoring for compliance with prime reconstruction plans has been relatively easy for most soil parameters. This was primarily due to the fact that we already had inspection and sampling procedures in place when SMCRA was passed for monitoring soil removal and replacement to ensure soil quality and thickness. The most elusive parameter to measure and evaluate has been compaction. Some of you in the audience will remember the original proposals for using bulk density and the discussions on this at the 1979 prime farmland conference in St. Louis. Although no specific numerical standard or procedure has yet to be adopted there are specific tests which can be done to establish that some degree of compaction is present. One or more speakers in tomorrow's sessions will discuss this in detail. It is encouraging to note that many companies have acknowledged that compaction is a reality, at many sites and have now incorporated alleviation (deep tillage) into their reclamation operations prior to initiating productivity testing.

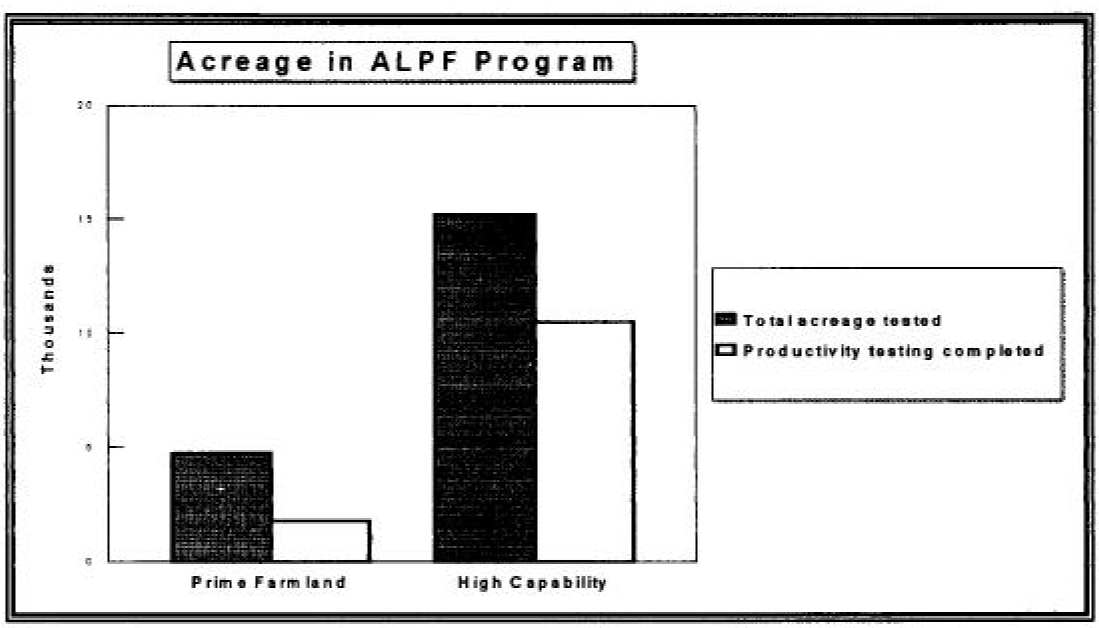
Statistics

The issue of the small numbers of acres of prime farmland final bond release has been raised. The issue of bond release as the measure for prime farmland restoration success, will undoubtedly, be argued from several points of view at this conference. Some will argue the three-year standard is too short, some too long, productivity targets too low and targets too high, and others will argue that until the bond release administrative procedure is completed the results arc not measurable. I plan to discuss our state results on the acreage that has met current productivity standards, regardless if the bond release has been applied for or not.

The Department has recently reviewed productivity testing on approximately 15,200 acres of high capability land and 4,700 acres of prime farmland. Most of these acres have permanent program liability. Testing is done using the Agricultural Land Productivity Formula (ALPF) which uses field sampling of corn, soybeans, wheat, and hay. Corn must be successful at least one year for all prime and high capability cropland. The 1997 crop success results have not been completed, but through the 1996 season, approximately 10,500 acres of high capability land and 1,800 acres of prime farmland have already completed the required two and three year standards. The remainder is still in testing and new fields are added each year (Figure 1). An additional estimate of several thousand acres of interim program high capability lands have also met the productivity requirements; however, the data is not conveniently retrievable for easy analysis.

While issues may be raised at this conference about the adequacy of the current regulations both pro and con', above numbers do make a case that cropland is meeting the established standards. When one also keeps in mind that all of the prime farmland and over 90 plus percent of the high capability acreage affected by surface mining since 1977 has had topsoil and a suitable root medium replaced, a good argument can be made that the combination of SMCRA and the high capability provisions of the Illinois Statute SCMLCRA have offered significant protection to the agricultural base of Illinois.

Figure 1.



[1]Dean Spindler, Supervisor of Operations/Soil Scientist, Illinois Office of Mines and Minerals, Land Reclamation Division; M.S. Plant and Soil Science, Southern Illinois University; Registered Professional Geologist, Certified Professional Soil Scientist; 22 years with the Land Reclamation Division.

INDIANA'S PROGRAM REQUIREMENTS, EXPERIENCES AND RESULTS

Steven L. Wade[1]
David W. Kiehl[2]
Indiana Department of Natural Resources
Division of Reclamation
Jasonville, Indiana

Abstract

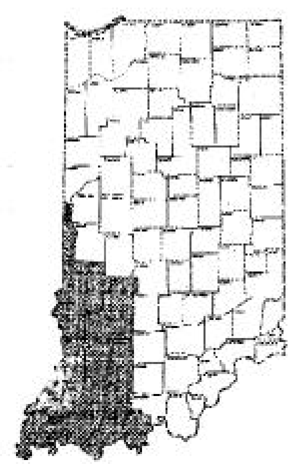
The prime farmland program in Indiana is presented in terms of statistics related to current mining acreage and future impact of these lands. This presentation will discuss how Indiana identifies prime farmland soils through the reconnaissance investigation, the Natural Resources Conservation Service involvement, and exemptions from prime farmland standards. Prime farmland restoration plans will be discussed including the removal, storage, and redistribution of soil materials. Discussion of proof of productivity and revegetation requirements will include success standards, liability period, cropping practices, and crop adjustments for each phase of the bond release process. Actual experiences of the program will be presented. The presentation concludes with a discussion of the Overall Reclamation Success Team (ORST) and potential impacts to the coal mining industry, landowners, and the Division of Reclamation.

Introduction

The coal producing region of Indiana is confined to a seventeen (17) county area located in the southwestern part of the state (Figure 1). The Indiana Coal Field occupies about 7,000 square miles (4,481,029 acres). Around 53.4% of those lands (2,392,078 acres) are classified by the Natural Resources Conservation Service (NRCS) as prime farmland. Since Indiana received primacy on July 29, 1982, 273,271 acres have been permitted for the purpose of coal mining. Underlying this area of Indiana there still remains about 34 billion tons of unmined coal, of which about 18 billion tons is recoverable by current technology. Of the recoverable coal, about 16 billion tons is recoverable by underground mining and 2 billion tons is recoverable by surface mining.

Requirements and Experiences Reconnaissance Investigation

In March 1985, the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), developed a listing of all prime farmland by soil map units in Indiana. These prime farmlands are those lands that the NRCS has determined to have the best combination of physical and chemical characteristics for producing food, feed, and forage. Most of the prime farmland in Indiana has premining slopes of 6% or less. No severely eroded map units are designated as prime farmland in Indiana. Prime farmland soils in Indiana have an estimated corn yield which ranges from 95 to 155 bushels per acre. In December 1986, Indiana became the first major agricultural state and the first midwestern state to have a modern soil survey completed for every county. Therefore, all soil surveys used in coal mine permitting were developed under the standards of the National Cooperative Soil Survey.



MAP OF INDIANA SHOWING COUNTIES PRODUCING COAL

Figure 1

After the NRCS determines that lands within the permit area are designated as prime farmland, the applicant may obtain an exemption from the prime farmland standards in one of two ways under existing law. First, the applicant may request a "negative determination." This requires a demonstration that the land has not been historically used for cropland. The exemption can be obtained if the lands have been used for cropland less than five (5) years out of the ten (10) years prior to acquisition for surface coal mining and reclamation operations. The most common requests for a "negative determination" in Indiana are for forested areas. The current use of the land may clearly indicate that no cultivated crops have been produced during the applicable five in ten year period. The age of the trees within a forested area provides the necessary demonstration. When the current use of the land does not clearly indicate that cultivated crops have not been produced during the applicable five in ten year period, sworn affidavits are required from the landowner and a disinterested third party. Negative determination is also possible under law if the slope of the land is 10% or greater, the surface is very rocky, or the land is flooded during a growing season more than once in two (2) years. However, the NRCS does not consider any soil in Indiana with a premining slope of 10% or greater to be prime farmland so this has not been a factor. The very rocky surface option also has not been used successfully in Indiana. Flooding during the growing season has been used to successfully obtain an exemption on a very limited basis.

The second means of obtaining an exemption from prime farmland reclamation standards is a demonstration that the prime farmland areas are eligible for "grandfathering." The exemption applies to those operations that were operating on August 3, 1977 and have held continuous permits since that date. In Indiana all "grandfathering" demonstrations were completed in 1985. It is estimated that since 1982, a total of 115,380 acres have been grandfathered and permitted by the permanent program, which is 42% of the 273,271 acres permitted throughout the life of the program. Approximately 58,524 of those acres were actual prime farmland soils. At this time, there are approximately 25,000 acres which have been grandfathered, but not yet permitted by a permanent program permit. Grandfathered prime farmland has been reclaimed in a variety of ways throughout the life of the program. Many acres have been converted to wildlife habitat and forest with replacement of 6 to 12 inches of topsoil on unsegregated mine spoil composed of a heterogeneous mixture of rock, shale, and soil rubble. The current requirement for land that was capable of supporting cropland prior to mining is replacement of topsoil and subsoil to a total thickness of 18 inches. However, this requirement is being challenged by two Indiana coal companies who believe the 18-inch standard is overly stringent.

Prime Farmland Restoration Plans

Removal

The operator is required to describe the thickness of the topsoil and subsoil to be removed for each prime farmland soil map unit within the permit. Most of the topsoil in the coal mining region of Indiana will vary from 8 to 15 inches. The subsoil usually varies in thickness from 4 to 10 feet. Most operators use the soil depth information from the published county soil survey. The operator is required to remove and replace a minimum of 48 inches of soil (topsoil and subsoil) for all prime farmland soils (including those soils with a fragipan) within the permit. However, in the early to mid 1980s a few permits allowed removal and replacement to the depth of the fragipan (30 to 36 inches). In 1986, the NRCS determined that in order for fragipans to qualify for exclusion from reconstruction, they must contribute little or nothing to the productive capacity of the soil. This contribution must be less than 0.06 inches per inch of available water capacity to qualify for such exclusion. The fragipans in Indiana contribute more than 0.06 inches of available water per inch and, therefore, are no longer eligible for exclusion from the reconstruction standards.

Operators are allowed to mix non-prime farmland and prime farmland topsoils and subsoils if the parent materials are the same. Any soil that has inferior qualities (i.e., severely eroded) are not allowed to be mixed. In a few instances, a mixing of the A horizon with the BE horizon has been approved. Approval to mix the A/BE has been allowed because this mixing has already occurred due to tillage practices. There are few (if any) plans approved that allow the mixing of the A horizon with deeper soil horizons.

Several operators have received approval to mix the B horizon with the C horizon in recent years. These plans, which allow the mixing of the horizons to a depth of generally 6 to 10 feet, have become more popular as the industry in Indiana has converted from scrapers to truck/shovel operations. The operator is still required to demonstrate that the soil materials that are created by mixing are equal to or more favorable for plant growth than the original B horizon. At a minimum, this demonstration is based upon the analysis of the thickness of the soil horizons, pH, buffer pH, texture, percent rock fragment (>2mm), percent organic matter, phosphorous, and potassium.

Prime farmland soils must be removed from the areas to be disturbed before drilling, blasting, or mining. Several operators have obtained approval to leave the B or C horizons in place in areas that will be affected but not mined (i.e., haulroads, mine management areas). In these areas all topsoil is removed and the unremoved subsoil is protected by a geotextile fabric or a layer of subsoil from a depth deeper than 48 inches. Where the B or C horizon is not removed, but may have been compacted or otherwise damaged during the mining operation, the operator is required to engage in deep tilling or use other appropriate means to restore premining capabilities.

Storage

Topsoil and subsoil materials are stockpiled (stored) only when it is impractical to replace the material immediately on a regraded area. Stockpiles must be located on stable areas located away from drainageways and depressions, located away from potential contamination sources, and out of the way of pit advancement. Stockpiles must be protected from wind and water erosion through prompt establishment and maintenance of an effective, quick growing non-noxious vegetative cover. Seeding and/or mulching is to be implemented within a time short enough to prevent erosion but in no case longer than 30 days after becoming inactive.

Redistribution

The operator is required to remove and replace a minimum of 48 inches of soil (topsoil and subsoil) for all prime farmland soils (including those soils with a fragipan) within the permit. As discussed in the removal section, in the early to mid 1980s a few permits allowed removal and replacement to the depth of the fragipan (30 to 36 inches).

Relocation of Prime Farmland

Indiana does not allow the aggregate total prime farmland acreage to be less than that which existed prior to mining. Water bodies, if any, to be constructed during mining and reclamation operations must be located within the post-reclamation non-prime farmland portions of the permit area. Operators will often try to aggregate (relocate) the areas of prime farmland to form larger blocks. As with water impoundments, the prime farmland must be relocated to areas of post-reclamation non-prime areas of the permit. Indiana does not allow any surface owner to lose prime farmland acreage except for the following example. There have been times when a surface owner wished to have a permanent impoundment and his/her property is all prime farmland. In these cases, the DOR has allowed the affected portion of the prime farmland to be relocated to a neighboring property. The consent of both parties is required prior to the approval of this type of relocation.

Proof of Productivity and Revegetation (Bond Release) Performance Bond and Liability Period

Prior to mining, the operator is required to put up a performance bond for the area within the permit area upon which the operator will conduct mining and reclamation operations. The bond rate will range from a minimum of $3,000 to a maximum of $10,000 per acre and is calculated upon the difficulty of reclamation should the operator fail to fully or properly restore the land and the state must complete reclamation. This bond shall be for the duration of the surface mining and reclamation operation plus a period of liability. The period of liability starts after the last year of augmented seeding, fertilizing, irrigation, or other work, and continues for not less than five (5) years. The DOR may release bond in whole or in part (phases), when the operator demonstrates the reclamation covered by the bond has been accomplished as required and public notice requirements have been met.

Phase I Release (Grading)

An area is eligible for Phase I release, upon completion of the backfilling, regrading, replacement of all soil materials (topsoil and subsoil), and drainage control of a bonded area according to the reclamation plan. The soil is probed by the DOR staff at an average of one (1) hole per three (3) acres to ensure the replacement of proper soil depths. The replaced soil must be seeded and/or protected with mulch. When this stage of reclamation is achieved, 60% of the bond may be released.

Phase II Release (Revegetation)

For an area to be eligible for Phase II release, one (1) proof of productivity is required. The yield must meet or exceed 100% of the success standard. Measurement of soil productivity must be initiated within ten (10) years after completion of the soil replacement. Upon completion of this stage of reclamation, 25% of the bond may be released

Phase III Release (Final)

For Phase III release, two (2) additional proofs of productivity are required. These yields must meet or exceed 100% of the success standard. The release of the remaining 15% of the bond occurs, when an operator has successfully completed all remaining surface mining and reclamation requirements. This portion of the bond must be held for the entire five (5) year period of liability.

Success Standards

Restoration of soil productivity is achieved when the crop yield during the measurement period equals or exceeds 100% of the success standard. The success standard must be met with a 90% statistical confidence level (a one (1) sided test with a 0.10 alpha error). The success standards are 1) an approved reference area, 2) a weighted average of the current (at the time of permit issuance) NRCS predicted yields for the unmined soil map units, or 3) other success standards approved by the director. Only one Indiana company has tried the reference area concept, but has since changed back to the NRCS weighted average of soil map units. A reference area is a land unit maintained under appropriate management for the purpose of measuring ground cover, productivity, and plant species diversity that are produced naturally or by crop production methods. A reference area must be representative of the geology, soil, slope, and vegetation in the permit area. Each reference area is to be located within 20 miles of the area represented.

Soil productivity of the mined and reclaimed prime farmland area must be measured by using one of the following methods: 1) growing crops on all of the area which we call a whole field harvest, or 2) growing crops on a representative area called test plots. The DOR evaluates the soils, topography, age, management, locality, and any other factor that effects production to determine whether a test plot is “representative.” Test plots collectively comprise at least 10% of the area under evaluation for bond release. No test plots smaller than one acre in size are allowed.

Random sampling procedures are often used to estimate yields for corn, soybeans, wheat, and hay. For corn, procedures used by the NRCS in Indiana and developed by Purdue University are recognized. We have also used the sampling techniques in Appendix A of 62 Illinois Administrative Code Section 1816 to obtain estimates for these crops.

Acres of Prime Farmland Released for Phase III

Since the end of 1994, DOR has released 1,259.6 acres of prime farmland for Phase III (Final Phase - totally released).

Cropping Practices/ Crops Used

All prime farmland must have a post-mining land use of cropland. One of the three proofs of productivity must be a corn or soybean crop. Other crops may be wheat or hay. The DOR has accepted any crop for which the NRCS can and will provide a target yield. In the past, these crops have included canola, grain sorghum, and corn silage.

Crop Adjustments

Adjustments to predicted target crop yields may be made according to accepted agronomic practices. Adjustments are requested through consultation with the Natural Resources Conservation Service or other sources approved by the director (includes Purdue University) for factors, including disease, weather, tillage management, pests, and seed or plant selection. The DOR has made adjustments for double cropped soybeans, freezing damage to winter wheat, and most recently a soybean disease, charcoal rot. A few operators are currently using Purdue University Cooperative Extension Service bulletin ID-152 which is entitled “Influence of Production Practices on Yield Estimates for Corn, Soybeans and Wheat” for adjusting yields. The DOR has on a limited basis also made adjustments to account for weather variations with the use of the county averages as determined by the Indiana Agricultural Statistics Service.

Results

In 1994, the Overall Reclamation Success Team (ORST) was formed between the Office of Surface Mining (OSM) and the Indiana Division of Reclamation. Three members from each agency met over a two-year time span to devise innovative, on-the-ground techniques to measure program success.

As a result of those meetings, seven projects were defined and studies were conducted for each. Three of those studies, Proof of Productivity, Post Mine Land Use, and Citizen Satisfaction Survey, have a direct relationship to the results of prime farmland reclamation in Indiana and will be further discussed in this presentation.

At this year's annual Division of Reclamation meeting held in mid-February, a group of four landowners considered to be good caretakers of their mined properties provided us a panel assessment of their reclaimed ground several years after mining had taken place. These gentlemen also expressed their opinions of the adequacy of the reclamation laws and their enforcement. Relevant portions of that panel discussion will be discussed at the forum.

Proof of Productivity

The ORST completed a study of the time required for operators to prove productivity on areas of prime farmland and non-prime cropland/pasture land. The study was conducted to determine (1) whether productivity standards are being met overall, (2) how long it is taking to accomplish this in the field. The ORST devised the study using the best available data.

Nearly 70% of the 504 acres of prime farmland included in the study achieved Phase II bond release within four years of initial seeding. An unexpected result of the study showed that only 40% of the 1,086 acres of non-prime cropland and pastureland acres had received a Phase II release and that it took at least seven years for nearly 50% of those released acres to achieve Phase II release.

Figure 2: Years to obtain Phase II release from prime farmland

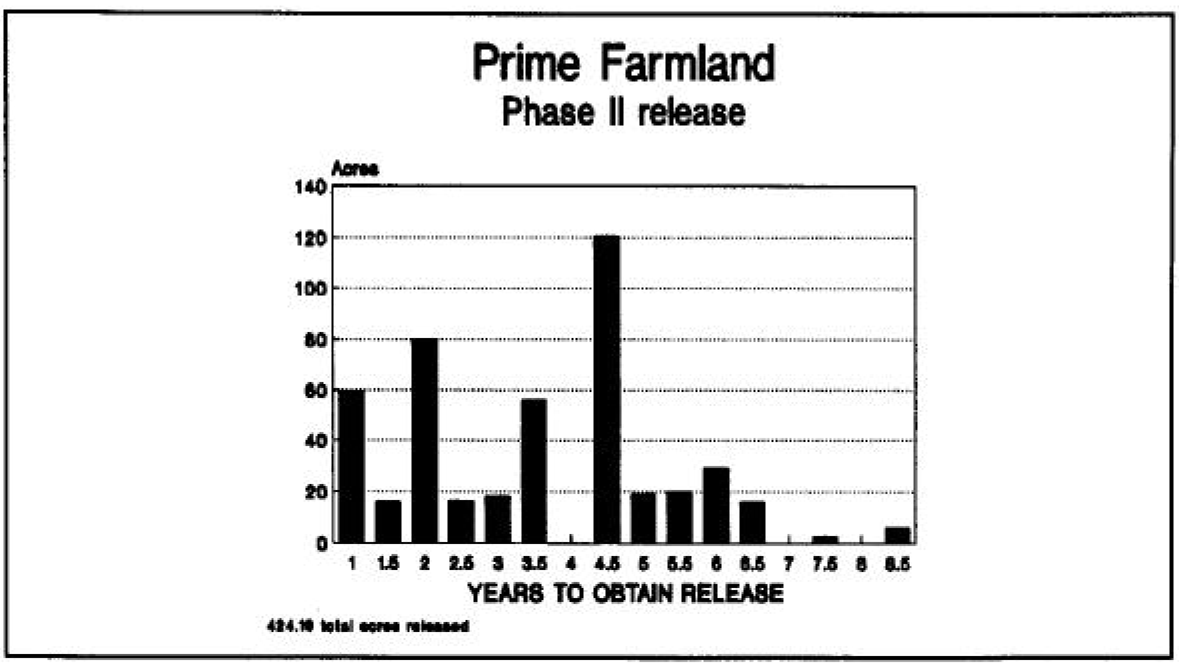


Figure 3: Years to obtain Phase III release for prime farmland

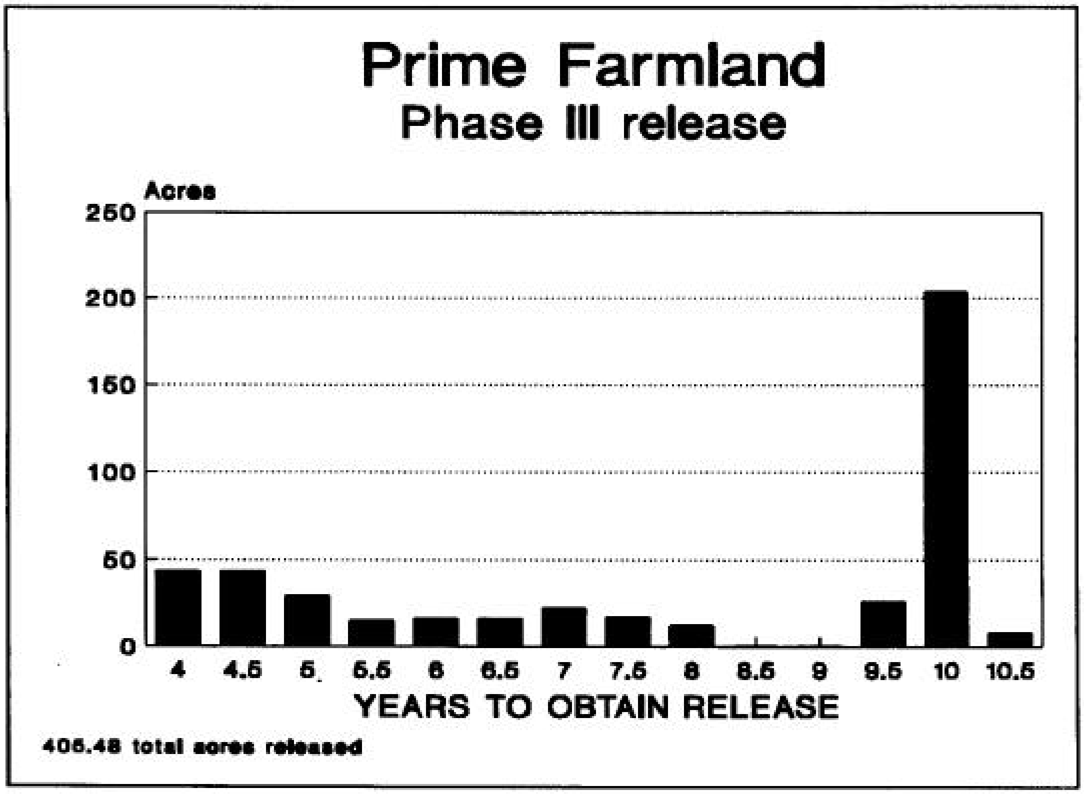
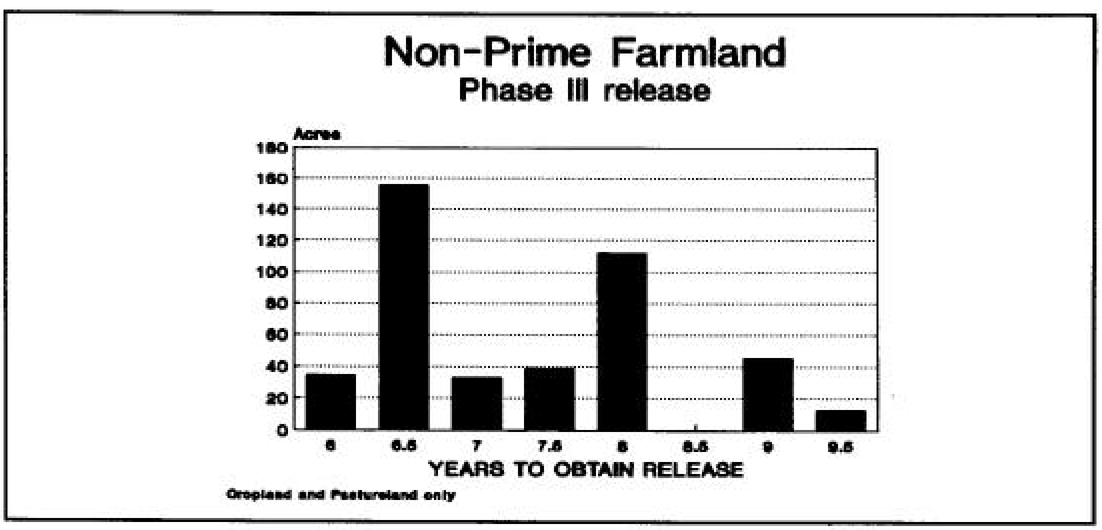


Figure 4. Years to obtain Phase III release for non-prime farmland



Of the 1,086 acres of nonprime cropland/pastureland included in the study, none had achieved a release of Phase III bond prior to six years after initial seeding; five years is the minimum regulatory requirement. This, was unexpected since nearly 100 acres of PFL had already received a Phase III release in the same time frame.

The largest block of NPFL to be Phase III released occurred 6.5 years from initial seeding compared to 10.0 years for PFL.

Post Mining Land Use

The ORST conducted a study of pre- and post- mining land use bond release as an indicator of land capability following the mining and reclamation process. Approved pre- and post-mining land use acreage information was gathered from permit documents. Post-release information was gathered by field visits which examined the actual use of the land on the ground following the completion of the phased bond release process. The most useful data was derived from 15 permit areas where the total affected areas had been 100% released form reclamation bond.

No distinction was made for the cropland land use of the actual number of acres classified as prime farmland vs. number of acres of non-prime farmland; four our study it was considered to be just cropland. Of the 3,391 acres of premining cropland land use, 3,005 were still being managed as cropland, post-bond release (87%). Of the 3,005 acres, 2,636 acres were in a row crop rotation of either corn, wheat, or beans; the remaining 369 acres were being managed as hayland. This shows a substantial continuing use of cropland and that the restored capability of reclaimed land has been sustained.

Citizen Satisfaction

The ORST was charged with designing and implementing methods to measure the overall success of the implementation of the Indiana Regulatory program. One method used by the team was a survey of 265 individuals who owned property that had been mined and reclaimed. The purpose of the survey was to gain, in general terms, a feel for the level of citizen satisfaction with completed mining and reclamation. The questions contained in the survey were not intended to gather technical or specific environmental information.

For the questionnaires sent out, the team received completed responses from 59 individuals. While the responses showed a general level of satisfaction with the completed mining and reclamation activities, several general comments were received which indicate that additional actions may be merited. For areas specific to this prime farmland presentation, six respondents indicated that they could not achieve pre-mining production on the reclaimed sites. Landowner estimates were generally in the range of 75% - 90% of pre-mining productivity. Two additional respondents indicated that the post mining land was fragile and that it was difficult to make a profit from it.

References

Doster, D.H., S.D. Parsons, D.R. Griffith, G.C. Steinhardt, D.B. Mengel, R.L., Nielsen and E.P. Ellsworth. 1992. Influence of Production Practices on Yield Estimates for Corn, Soybeans and Wheat. Bulletin ID-152. Purdue University Extension Service. West LaFayette, IN 47907.

Indiana Administrative Code, Title 310 Department of Natural Resources, Article 12 Coal Mining and Reclamation Operations.

Indiana Coal Facts. 1995-96 Indiana Coal Council, Inc. Indianapolis, In 46204.

Illinois Department of Mines and Minerals. 1986. 62 Illinois Administrative Code 1816.116 Appendix A.

Code of Federal Regulations. 1997. Title 30 Office of Surface Mining Reclamation and Enforcement, Department of Interior.

Indiana's Citizen Guide for Coal Mining Soil Resources. 1998. Indiana Department of Natural Resources, Division of Reclamation.

---

[1]Steven L. Wade, Staff Agronomist, Indiana Department of Natural Resources, Division of Reclamation; B.S. Purdue University, Agronomy; Certified Professional Agronomist, Certified Professional Soil Scientist; 22 years with the Division of Reclamation.

[2]David Kiehl, Bond Coordinator, Indiana Department of Natural Resources, Division of Reclamation; B.S. Forestry, Fisher, and Wildlife, University of Missouri; 20 years with the Land Reclamation Division.

SURFACE MINING AND RESTORATION OF PRIME FARMLAND SOILS IN KENTUCKY'S COAL INDUSTRY

Gary E. Welborn'
Kentucky Department of Surface Mining
Madisonville, Kentucky

Abstract

The Kentucky presentation takes the permittee from initiation of the permitting process through final bond release. Permit reclamation plans, determination of pre-mining and post-mining land uses, and exemptions are discussed. Information will be presented on methods utilized during the mining process for the removal, storage, and replacement of soil horizons. The final segment exhibits program requirements for meeting crop production goals and achieving final bond release.

The "Federal Surface Mining Control and Reclamation Act of 1977" (Public Law 95-87), " 1992 Kentucky Surface Mining Law" (KRS 350), and 405 KAR Chapter 7 through 24 regulate the surface mining and restoration of prime farmland soils in Kentucky. Surface mining of prime farmland sods in Kentucky's coal industry are divided into three processes. These processes are permitting, mining and reconstruction, and demonstration of productivity restoration.

Permitting

A valid permit must be obtained prior to surface coal mining in Kentucky as per 405KAR7:040(l). The permit applicant must, per 405KAR8:030(21), investigate to determine if lands within the permit area may be prime farmland. Prime farmland soils are defined as lands designated by the Secretary of Agriculture in 7 CFR 657 (also see 405KAR8:030(21)) and have been historically used as cropland. "Historically used for cropland" is defined by 405KAR7.001(64) as land used for cropland for any five (5) years or more of the last ten (10) years preceding an application for or acquisition of lands for the purpose of surface coal mining. Generally, soils are not considered prime farmland if (1) they have not historically been cropped; (2) the slope is 10% or greater; (3) they exhibit a very rocky surface; (4) they are subject to frequent flooding; or (5) they have not been designated by U.S. Soil Conservation Service (SCS) as prime farmland. Additional lands exempted are lands encompassed by coal mining permits issued prior to August 3, 1977, or areas that are part of a single continuous coal mining operation begun on permits issued prior to August 3, 1977.

The permit applicant is required to conduct an investigation to determine if prime farmland regulations apply. When an applicant's investigation concludes prime farmland soils are not present or exempt, the permit application must include a detailed request for negative determination. The Kentucky Natural Resources and Environmental Protection Cabinet (NREPC) shall approve or deny the negative determination based upon information provided by the applicant as well as any other pertinent information available. Other pertinent information may include cropping histories and records available from the Agriculture Stabilization and Conservation Service.

If the investigation indicates prime farmland is present, a plan in accordance with 405KAR8:050 Section 3 and 405KAR20:040must be included in the application. The plan must include a soil survey of the permit area by the SCS or to the standards of the National Cooperative Soil Survey (NCSC). The Survey shall provide a soils map, soil mapping unit descriptions, and soil profile descriptions with horizon depths, textures, pH values, and bulk densities. The plan shall also include details for the removal, storage, and replacement of soil horizons. "Soil Conservation Service, Kentucky Standard and Specifications for Land Restoration, Currently Mined Prime Farmland" establishes the guidelines for the removal, storage, and replacement of prime farmland soils. Adequate soil material must be removed to reconstruct 48 inches of soil. A lesser soil depth may be approved if the lesser depth is equal to the natural soil depth. A greater depth may be required if necessary to restore original soil productivity. Substitute soil materials or a combination of soil materials, B horizon, and/or C horizon may be utilized if proven to meet requirements. The proof must include an analysis by a qualified soil scientist of the physical and chemical parameters of the original soils, substitutes, and/or mixtures. The topsoil, B, and/or C horizons are to be removed separately. Regardless of the material approved, it is imperative to devise a plan for the implementation of all actions feasible during soil removal to minimize negative impacts during the reconstruction and proof of production phases.

Maps and plans designating the final grade and post-mining location of restored soil units are to be included. This plan must contain a demonstration of soil productivity restoration to equivalent or higher levels than non-mined prime farmland of the same type with equal levels of management. Revegetation plans, crop production plans, and yield measurement methodologies must be provided to demonstrate restoration of productivity.

Mining and Reconstruction

Upon issuance of the permit, the removal, storage, and replacement of soils may begin. During the times when prime farmland soils are being disturbed or restored, NREPC personnel will conduct at least weekly inspections. The plan's soil surveys will be used to locate and identify the soils to be removed prior to any drilling, blasting, or mining, and to flag the boundaries for easy field identification, Actual field conditions of topography, drainage patterns, flooding, soil descriptions, soil profile horizon thickness, and soil depth should be checked against permit plans. More detailed observations of soil color, texture, bulk densities, and fragment size may prove necessary. If discrepancies are found between permit plans and actual field conditions, further documentation by a professional sod scientist or soil classifier to meet standards of the NCSS and a permit revision may be necessary prior to disturbance. Consider soil moisture conditions and fluctuations to plan removal during dry conditions to avoid compaction. Physical soil loss will occur during removal, storage, and replacement; therefore, plan to remove sufficient quantities to replace horizons as per permit plans. Use equipment to allow for effective segregation of soil layers and minimize compaction. Back-dump trucks, low ground pressure dozers, and front-end loaders are currently the preferred equipment used. Taking up and replacing soil with a minimum number of lifts and traffic passes minimizes material handling and compaction.

If the natural topsoil (A or E horizon) is less than six (6) inches thick, remove and segregate the top six inches as topsoil. Separately remove the B and/or C horizon material or approved substitute material to a depth adequate for soil replacement.

If not replaced immediately, stockpile the soils removed in separate designated areas appropriately marked by horizon type. Locate the stockpile m areas of adequate drainage that are not subject to flooding or slippage and are protected from contamination, Remove all woody vegetation and other material that may interfere with placement or removal. Construct the pile to avoid ponding, erosion, or contamination from other sources. ff stockpiles are in place for more than thirty (30) days, erosion control measures are to be implemented to meet all requirements of 405KAR16:050.

The segregated B and/or C horizons and the topsoil are to be separately replaced upon removal or restored from stockpiles as the situation warrants. The replaced soils are to be restored to a uniform depth, typically to a total depth of 48 inches including a minimum of six (6) inches of topsoil. The reconstruction shall occur when moisture conditions minimize compaction. The equipment and methodology used in reconstruction shall avoid excessive compaction and preserve porosity. The reconstructed soil shall be replaced on the original land in the location specified in the permit plan. The final grade of the area will provide uniform slopes and adequate surface drainage. The average slope shall be within the slope range of the original soils mapping unit and not exceed 6%.

Appropriate erosion control measures shall be implemented immediately upon soil replacement. Mulching, or other soil stabilizing practices, shall be used until the first period for favorable planting conditions. Then the area will be seeded and planted with species approved in the permit to provide a stable ground cover of 90% until crop rotations are begun.

Productivity Demonstration

Crops must be grown on the replaced soils and the yields measured to prove soil productivity has been restored as per specifications in "Kentucky Prime Farmland Revegetation and Crop Production Restoration After Mining" incorporated by reference in 405KAR20:040(6). Production studies may begin anytime after replacement; however, the studies must begin within ten years. Target yields must be met for a minimum of three crop years. The crops grown must be selected from those most commonly grown in the surrounding area. Generally in Kentucky this means corn, soybeans, wheat, or grass-legume hay, The row crop requiring the greatest rooting depth shall be chosen as one of the reference crops; therefore, in Kentucky, corn shall be chosen as one of the reference crops. Corn may be grown for all three of the measurement years or grown in rotation with other approved crops. The same levels of management must be applied to the test crops as those on non-mined prime farmland. Fertilization, planting, tillage, and weed control records shall be kept on file by the pemiittee and made available to NREPC upon request.

Target yields are contained in "Estimated Crop Yields on Prime Farmland Soils in Western Kentucky Coalfields", SCS, 1980, and in "Estimated Crop Yields on Prime Farmland Soils in Eastern Kentucky Coalfields", SCS, 1985. Yields may be adjusted down by a maximum of 15% with the approval of SCS for damage by disease, pests, or weather. Where authorization has been granted for the mixing of two or more soil mapping units, a weighted average based upon acreage of the different soil mapping units prior to mining shall be calculated to determine the target yields.

Yield measurement techniques are taken from: (1) Technical Reclamation Memorandum # 19 "Field Sampling Techniques for Determining Ground Cover, Productivity, and Stocking Success of Reclaimed Surface Mined Lands." Kentucky DSMRE, 1991; (2) cropping the entire restored prime farmland area; or (3) any other sampling and techniques for productivity determinations approved m advance by NREPC in consultation with SCS as per 405KAR16:200(9). All crop yields shall be corrected to the standard moisture content for that crop. The standards are 15.5% for corn, 12.5% for wheat, and 15% for hay. All moisture levels are to be calculated on wet weight basis.

Notification of intention to measure productivity shall be provided to the NREPC regional office as per 405KAR 16:200(9). The notification shall be in writing at least thirty (30) days prior to and again by phone within two (2) days prior to the measurement dates. The NREPC may take measurement or other appropriate actions to verify measurements made by the permittee.

Conclusion

Thousands of acres of prime farmland soils have been successfully surface named and restored to production in Kentucky's coal fields. Prime farmland permits are eligible for Phase I release when the soil horizons have been physically restored and erosion control procedures have been implemented. A Phase 11 release is obtainable when target yields have been met for three (3) years. The fmal or Phase III bond release requirements have been met when the total five (5) year liability has expired. Careful planning during the permitting process, attention to detail in the mining and restoration process, and valid demonstration of productivity restoration have made successful restoration and bond release possible.

---

[1]Gary Welborn, Environmental Inspector/Bond Release Specialist, Kentucky Department for Sufface Nfining Reclamation and Enforcement; B.S. Forestry, University of Kentucky; 20 years with Kentucky Department for Surface Mining Reclamation and Enforcement.

NORTH DAKOTA PRIME FARMLAND RECLAMATION PROGRAM

Dean Moos[1] and Jim Deutsch
Reclamation Division, ND Public Service Commission
Bismarck, North Dakota

Abstract

North Dakota adopted prime farmland regulations with the passage of SMCRA in 1977. Many of the permitted areas are grand-fathered or exempt from the prime farmland standards. The mine operator must submit an operations and reclamation plan for the prime farmland areas that are subject to the prime farmland regulations. Full restoration of production must be achieved before final bond release can be granted.

Setting and Conditions

Currently, there are four surface mines operating in North Dakota. These mines are located in central and western North Dakota and produce approximately 30 million tons of lignite per year. The soils from this area developed from glacial till and soft sedimentary bedrock. The pre-mining land use of the area consists primarily of cropland and native grassland. Small grains, primarily spring wheat, are the dominant crops grown in the area. Average annual precipation in this area is approximately 16 inches per year.

In central and western North Dakota, approximately 13 soils have been identified as prime farmland soils by the Natural Resource Conservation Service (NRCS). These prime soils occur in small areas on foot slopes, swales, or mild depressions. They are usually 5 to 30 acres in extent. Generally, the prime farmland soils receive run-on water from higher surrounding upland areas that generally do not meet prime farmland criteria.

In many cases, the soils of the adjacent prime and nonprime areas are morphologically similar, oftentimes only differing by thickness of the A and B horizons, presence of argillic horizons, depth to carbonates, etc. The prime soils generally have thicker, darker topsoil layer, higher organic matter content, and thicker solum (A and B horizons) than the adjacent nonprime soils.

The prime soils generally have a higher productive capacity than the adjacent nonprime soils. Numerous studies (Richardson and Wollenhaupt 1983, Schroeder and Doll 1984, and Wollenhaupt and Richardson 1983) have shown that the higher productivity of the prime soils is related to the more favorable moisture regime as a result of the additional soil water contributed by the run-on water from the adjacent upland areas. The authors did not feel that the higher productivity of the prime soils was the result of any inherent soil properties.

Omodt et.al. (I 975) reported that the following soil properties are of special importance to reclamation of mined land in North Dakota: organic matter, soluble salts, exchangeable sodium free lime, soil texture, bulk density, soil structure, soil depth, and pH. It should be noted that bulk density and soil structure of pre-mining soils are drastically altered by the mining and reclamation activities. The remaining pre-mine soil properties tend to be little altered by mining and reclamation activities.

Prime Farmland Determination

Mining companies are required to identify prime farmland areas as part of the peanut application. This determination is based on the NRCS county soil surveys that have been completed for each county in the state. The NRCS has identified which map units in each county are considered prime farmland. The NRCS county soil surveys are prepared at a scale of 1:20,000 and the minimum size delineation is approximately five acres.

The mining company also has a detailed soil survey prepared for each permit area. A professional soil classifier prepares this detailed soil survey, and it is generally more detailed than the NRCS Soil Suney. The mining permit survey is prepared at a scale of 1:4,800, and the minimum size delineation is approximately two acres. This detailed soil survey is used to determine the soil salvage depths, the adequacy of the soil resources for reclamation, and development of the reclamation success standards.

When the NRCS soil survey map (from which the prime farmland determination is made) is enlarged to the same scale and overlaid on the detailed permit soil survey map, the locations of prime farmland as mapped by, the NRCS may not correspond with the detailed soil survey map. Stomberg (1985) found that within the areas mapped as prime farmland by the NRCS, about 35% of the acreage was actually comprised of nonprime soils-. for any particular landowner, nonprime soils comprised from 22 to 91% of mapped prime soils. The prime farmland section of Permit NAFK-9503 for the Falkirk Mine indicates nonprime components (based on the detailed soil survey) comprise from 7 to 93% of the prime farmland delineations within this permit area. Oftentimes, the discrepancies may be minor such as similar, nonprime soils being included in the prime delineation; however, significantly contrasting soils may be within the prime delineation. If significant differences exist between the two surveys, the NRCS and the professional soil classifier who prepared the permit soil survey may be requested to field review the questionable areas and, if necessary, make the appropriate adjustments.

Several exemptions to the prime farmland success standards exist. Lands that the permittee had the legal right to mine before August 3, 1977 and are part of a continuous mining plan that was under permit before August 3, 1977 are exempt from the prime farmland standards. This is commonly referred to as the "grandfather clause." Areas that are not "historically used as cropland" are not subject to the prime farmland standards. These include native grassland areas, tame pastureland, trees, and native and industrial areas.

Of the 55,425 acres currently under permit at the four active mines, approximately 28,760 (52%) acres are subject to the prime farmland handling requirements. The remaining acreage is exempt based on the "grandfather clause." There are approximately 4,285 acres of prime farmland within the 28,760 acres that are subject to the prime farmland standards.

Prime Farmland Operations and Reclamation Plans

Since 1975, North Dakota has required segregation of topsoil and subsoil from <u>all</u> mined lands. Topsoil normally consists of the A horizon and the upper part of the B horizon, typically the dark colored organic-rich, noncalcareous, non-sodic. and non-saline upper horizons of the soil profile. Subsoil typically consists of the calcareous, non-sodic and non-saline material to a depth of 5 feet. The stark color change between topsoil and subsoil makes it a fairly simple task for trained equipment operators to successfully segregate topsoil and subsoil materials.

The actual handling of prime and nonprime soils is similar with the exception that the prime farmland soils are removed, stockpiled and respread separately from nonprime soils. A total of 48 inches of topsoil and subsoil (if available) must be removed and respread from the prime farmland areas. Mine operators prefer to directly respread soils when possible, but when suitable respread areas are not available, the soil materials must be stockpiled.

Reclaimed prime farmland areas must have topography similar to the pre-mine prime farmland areas, i.e., concave or swale positions with gentle slopes (O-6%slopes) to ensure run-on water. Schroeder (199I) found that lower slope positions (foot slope and toe slope positions) had a positive effect on available soil water at planting and wheat yields. Post-mining topography including prime farmland areas must be approved by the Commission prior to soil respread. Soil is respread to a total depth of 48 inches on prime farmland areas. Typical cropland (prime and nonprime) reclamation consists of planting a pre-crop mixture of grasses and legumes following soil respread. The purpose of the pre-crop mixture is to stabilize the soil following reclamation and promote soil structure development. After several years the pre-crop mixture is plowed down and cropping with small grains begins. Recently, the mining companies have gone directly into small grain production following soil respread rather than planting the reclaimed areas to a pre-crop mixture of grasses and legumes.

The North Dakota prime farmland rules are similar to the Federal law and rules with one exception. North Dakota allows for the mixing of prime topsoil and subsoil with nonprime topsoil and subsoil, respectively, provided that the resulting mix is of equal or better quality, The permittee must demonstrate that the resulting mixture is of equal or better quality. If this demonstration can not be made, the prime and nonprime materials must be handled separately.

Mixing of prime and nonprime subsoil has been routinely allowed in those instances where the resulting mixture is of equal or better quality. The permittee must make a comparison in the permit application demonstrating that the resulting mixture will be of equal or better quality, i.e., that the prime and nonprime subsoil materials are of similar quality. In certain instances when the adjacent nonprime subsoil is of marginal quality, segregation of the prime subsoil is required.

Historically, prime topsoil has been segregated from nonprime topsoil. Halvorson and Nathan (1993, 1995) and Halvorson (1996) indicated that certain prime and nonprime soils could be mixed without affecting crop yields or reclamation success. This research found that landscape position was the most important factor in determining reclamation success of reclaimed prime farmland.

A comparison of the soil properties of a typical prime and nonprime soil is provided on tables I and 2. Table I compares the soil series criteria, characteristics, and interpretations of the most common prime and nonprime soils in the coal mining region. Soil laboratory data for typical prime and nonprime soils is compared on Table 2. A weighted average is provided for the topsoil and subsoil materials of the prime and nonprime soils. You will note that prime and nonprime soils are similar in chemical and physical characteristics.

Recently, The Falkirk Mining Company submitted a proposal to mix prime and nonprime topsoil materials. Table 3 compares the soil laboratory data of the most common prime and nonprime soils occurring within this permit area. These three soils make up approximately 80% of the entire permit area. This proposal is currently under review; however, the Commission feels this proposal has merit for the following reasons:

* The dominant prime and nonprime soils are very similar in chemical and physical characteristics.
* A significant amount of mixing of prime and nonprime topsoil is already taking place as discussed above.
* The required productivity standard for the reclaimed prime areas is generally not significantly higher than the nonprime areas, usually less than a bushel per acre for spring wheat.
* The topsoil respread thickness for prime and nonprime respread areas is not significantly different. Usually the prime topsoil thickness is only slightly thicker (oftentimes less than a 2-inch difference) than the adjacent nonprime areas.

Even though segregation of the prime and nonprime topsoil is currently being practiced, a significant amount of mixing of prime and nonprime topsoil is talking place due to the amount of nonprime "inclusions" within the prime areas. These nonprime inclusions result in a lower productivity standard for the prime areas and thinner topsoil respread thickness. It should be noted that the permittee will still be required to meet the required standard for the prime areas for three years prior to bond release.

The types and amount of nonprime topsoil that can be mixed must be restricted to similar prime and nonprime soils. In this instance, we do not feel that the benefits gained by segregating prime and nonprime topsoil are worth the additional cost. We feel the slightly elevated organic matter levels of the pre-mine prime farmland soils justify the segregation of the prime and nonprime topsoil materials especially when one considers that mixing of prime and nonprime topsoil is taking place with the current practice of segregating prime and nonprime topsoil.

Respread depths of nonprime areas are typically determined by the graded spoil quality. Total soil respread depths range from 2 to 4 feet depending on graded spoil quality. If the graded spoil is non-sodic (SAR<12) and medium textured (loam) or finer, then the total soil respread depth would be 24 inches, If the graded spoil is moderately sodic (SAR = 12-20) or coarse textured (sandy loam or coarser), then the total soil respread depth would be 36 inches. If the graded spoil is highly sodic (SAR >20), then the total soil respread depth would be 48 inches. As mentioned above, prime farmland areas are respread to a total depth of 48 inches regardless of the graded spoil quality. The Falkirk Mining Company has also submitted a proposal to utilize the graded spoil as part of the subsoil respread requirement provided that the graded spoil quality is of equal or better quality than the prime subsoil. Additional sampling of the graded spoil will be required. This proposal is currently under consideration by the Commission.

Determining Reclamation Success

North Dakota has a 10-year responsibility period, i.e., the reclaimed area must remain under bond a minimum of 10 years from the last augmented seeding. Productivity (crop yield) is the only vegetation parameter that must be assessed for final bond release. Reclamation success is achieved when the annual average crop production from the area is equal to or greater than that of the approved reference area or standard with 90% statistical confidence for a minimum of three years for prime farmland areas and two years for the nonprime areas,

For assessment of revegetation success on surface mined land reclaimed to prime farmland, the permittee may use either a reference area standard or a technical standard based on NRCS data. Each of these standards provides a procedure for climatic correction of yields. If a tract is owned by more than one landowner, production on each landowner's property must be assessed separately. A separate yield must be obtained and a separate standard developed for each landowner's property. A separate standard must be derived for prime farmland tracts. Spring wheat must be used to determine reclamation success for at least two of the three years that productivity measurements are taken. Barley and oats may be used for the remaining year.

The cropland reference area standard combines a reference area with SCS productivity indices for soil mapping units. This method is well suited to reclaimed prime farmland tracts and reclaimed nonprime cropland tracts that subtend only a few soil map units. A cropland reference area is established for soil mapping units that were predominant in the reclaimed tract prior to mining. The reference area must include one or two reference soils which singly or together occupy more than 50% of the reclaimed tract. The reference area must be topographically similar to the reclaimed tract and must be established in the vicinity of the mine area.

The yield from each soil map unit in the reference area must be separately harvested or sampled. The crop yield of one of the reference soils must be used along with the NRCS soil productivity indices to calculate the expected yields for the other premining mapping units not represented in the reference area. The current year's actual yield from the reclaimed tract is then compared to the derived standard. The yield standard must be derived for each year that the reclaimed tract is evaluated for bond release. Appropriate statistical tests must be applied as necessary to determine if the yields are significantly different.

Under the technical standard based on the NRCS productivity indices method, productivity index values for all premining soil map units which existed in the reclaimed cropland tract are obtained. Index values are converted to yields using the assigned county yield for the Productivity Index of 100%. A yield value is determined for each soil mapping m the tract and multiplied by the acreage each mapping unit occupied m the tract. These weighted yields are summed and divided by the total acreage of the tract to obtain a weighted average yield per acre. This value is the unadjusted yield standard for the reclaimed cropland tract. NRCS yield ratings for productivity indices are based on long-term average data and do not account for annual climatic variations. Therefore, the unadjusted yield standard must be adjusted using the four approved methods.

To date, no final bond release applications have been received for prime farmland.

Summary

Significant portions of permitted areas in North Dakota are exempt or grand-fathered from the prime farmland standards. Prime farmland soils in the coal mining region of North Dakota are morphologically similar to many adjacent nonprime soils. By regulation, prime soils are to be salvaged, stockpiled, and respread separately from nonprime soils. However, regulations allow for the mixing of prime and nonprime topsoil and subsoil, respectively, provided that the resulting mixture is of equal or better quality. In North Dakota mixing of prime and nonprime subsoil has been routinely approved provided that the resulting mixture is of equal or better quality. Recent research has indicated that certain prime and nonprime topsoil can be mixed without affecting reclamation success. Successful reclamation consists of restoring 100% of the premine productive capacity for a minimum of three years.

References

Friedlander, J.D., 1989, "Mining and Reclamation of Prime Farmlands in Western North Dakota," Reclamation, A Global Perspective, American Society for Surface Mining and Reclamation, pp. 447457.

Halvorson, G.A, 1996, "Comparative Evaluation of Productivity of Prime and Nonprime Land," North Dakota State University, Land Reclamation Research Center, Mandan, ND.

Halvorson, G.A., and Nathan, M.V., 1995, "Reclamation of Prime and Nonprime Soils," Mineland Reclamation Review, March 29, 1995, North Dakota State University, Land Reclamation Research Center, Mandan, ND.

Halvorson, GA, and Nathan, M.V., 1993, 'Research on the Reclamation of Prime Farmland in North Dakota,' North Dakota State University, Land Reclamation Research Center, Mandan. ND.

North Dakota Public Service Commission, 1997, "Rules Governing Surface Mining and Reclamation Operations, June 1, 1997," Bismarck, ND.

North Dakota Public Service Commission, 1995. "Standards for Evaluation of Revegetation Success and Recommended Procedures for Pre- and Postmining Assessments, Revised May 1995,"Bismarck, ND.

Omodt, H.W., Schorer, F.W., and Patterson, D.D., 1975, "The Properties of Important Agricultural Soils as Criteria for Mined Land Reclamation," Bulletin 492., North Dakota State University, Fargo, ND.

Richardson, J.L., and Wollenhaupt, N.C., 1983, "Natural Soil and Landscape Development," Can Mined Land Be Made Better Than Before Mining? Conference Proceedings, November 7, 1982, Stronghold Press, pp. 9596.

Schroeder, S.A., 1991, "Topographic Position Effects on Soil Water and Wheat Yields on Reclaimed Minelands.," North Dakota Farm Research, Vol. 48, No. 5, pp. 3-5.

Schroeder, S.A., and Doll, E.C., 1984, Productivity of Prime, Nonprime, and Reclaimed Soils in Western North Dakota, " North Dakota Farm Research, Vol. 4 1, No. 5, pp. 3-6., 31.

Soil Conservation Service, 1984, "North Dakota Important Farmlands," Bismarck ND.

Stomberg, A, 1985, "Prime Soils Handling in North Dakota," Proceedings of the 1985 Annual Meeting of American Institute of Mining Engineers, Albuquerque, NM, pp. 1-3.

The Falkirk Mining Company, 1995, "Surface Coal Mining Permit No. NAFK-9503," The Falkirk Mining Commpany, Underwood, ND.

Wollenhaupt, N.C. and Richardson, J.L., 1982, "The Role of Topography in Revegetation of Disturbed Lands," Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains Proceedings, March 8-9, 1982, pp. C.2. I-C.2. I 1.

Table 1. Comparison of Williams, Bowbells, and Falkirk Soils (based on soil series criteria, characteristics, interpretations, etc.)

Soil Property	**Williams Soil (nonprime)**	**Bowbells Soil (prime)**	**Falkirk Soil (prime)**
Classification	Fine loamy, mixed Typic Argiborolls	Fine-loamy, mixed Pachic Argiborolls	Fine-loamy, mixed Pachic Haploborolls
Drainage Class *[1]	Well	Well and moderately well	Well
Permeability *[1]	Moderately slow or slow	Moderate to slow	Moderate and moderately slow
Parent material *[1]	Calcareous glacial till	Glacial till and alluvium from glacial till	Glacio-fluvial sediments underlain by glacial till
Thickness of A horizon *[1]	5-15"	5-15"	5-15"
A horizon texture *1	L, CL, SL, FSL, SiL	L, SiL, CL	L, SiL
Thickness of mollic epipedon *[1]	< 16"	> 16"	16 – 30"
Thickness of non-calcareous B horizon *[1]	5-20"	6-24"	5-22"
B horizon texture *[1]	CL, L (24-35% clay)	CL, L	L (18-27% clay & >15% fine & coarser sand)
Bulk density (g/cm^3)*[1]	1.2-1.6 (0-24") 1.3-1.6 (24-60")	1.1-1.4 (0-6") 1.2 – 1.5 (6-23") 60")	1.1 - 1.4 (0-28") 1.3 - 1.7 (28-60")
Available Water Capacity (in/in) *[1]	0.17-0.24 (0-6") 0.16-0.2 (6-24") 0.15-0.18 (24-60")	0.17-0.24 (0-6") 0.16 - 0.22 (6-23") 0.14 -0.18 (23-60")	0.2 - 0.22 (0-7") 0.17 – 0.19 (7-28") 0.13 – 0.17 (28-34") 0.14 – 0.16 (34-60")
K factor *[1]	.28	.28	.28
T factor *[1]	4	5	5
Wind Erodibilty Group *[1]	6	6	6
Organic Matter (%) *[1]	2-7% (0-6")	2-6% (0-6")	2-6% (0-7")
Productivity Index	85 (0-3% slopes) 80 (3-6% slopes) 60 (6-9% slopes)	100 (0-3% slopes) 90 (3-6% slopes)	95 (0-3% slopes) 85 (3-6% slopes) 75 (3-6% slopes)

*[1] Source – The official series description and Form 5 for Williams, Bowbells, and Falkirk soils.

Table 2. Comparison of Williams & Bowbells Topsoil & Subsoil Properties Based on NRCS Lab Data

	Williams soil (nonprime)		Bowbells soil (prime)	
Soil Property	Topsoil	Subsoil	Topsoil	Subsoil
n (# of pedons)	4	4	3	3
Average Topsoil Thickness	10.2	40	22.3"	37.7
Electrical Conductivity (mmhos/cm)*1	0.57	0.71	0.71	0.43
Sodium Adsorption Ratio *1	0.12	1.9	Not available	1.33
Calcium Carbonate Equivalent *1	< 0.1	14.1	Not available	7.6
Organic Matter % *1	3.38%	0.5%	2.8%	0.96%
% Sand *1	27%	23.1	26.6%	29.3%
% Clay *1	28.4	29.2	29.3%	31.5%

*1 Weighted average

Table 3. Comparison of Williams, Bowbells, and Falkirk Topsoil Properties Based on Soil Lab Data Submitted with Permit NAFK-9503

Soil Property	Williams soil (nonprime)	Bowbells soil (prime)	Falkirk soil (prime) *2
N (# of pedons)	20	3	26
Average Topsoil Thickness	12.2"	17.1"	19.5
Electrical Conductivity (mmhos/cm) *1	0.33	0.46	0.41
Sodium Adsorption Ratio *1	0.41	0.35	0.39
Calcium Carbonate Equivalent *1	1.66	1.67	1.57
pH *1	6.7	7.1	
Organic Matter % *1	2.77%	3.06%	3.13%
% Sand *1	31.5	28.5%	51.6%
% Clay *1	25.3%	23.8%	15.8%

*1 Weighted average

[1]Dean Moos, Environmental Scientist, North Dakota Public Service Commission, Reclamation Division; B.S. Soil Science, North Dakota State University; Registered Professional Soil Classifier; 10 years with the Reclamation Division.

KANSAS PRIME FARMLAND PROGRAM REQUIREMENTS MEASUREMENT METHODS AND RESULTS

M. N. Spence'
Kansas Department of Health and Environment
Surface Mining Section
Frontenac, Kansas

Abstract

Prime farmland restoration accounts for more than 40 percent of the current surface coal mining reclamation activities in Kansas. Since 1991, Kansas has had formal revegetation guidelines in place to guide the coal mining industry through acceptable revegetation sampling methods for final bond release of this critical land use. This paper presents an overview of the Kansas program including permitting issues, reclamation plan requirements,. revegetation standards, and sampling methods involved. Program achievements, along with a discussion of problems and anticipated future modifications, complete this brief overview of the bond release program for Kansas prime farmland.

Introduction

The Kansas Department of Health and Environment, Surface Mining Section (SMS), is charged with the responsibility of administering all Title 5 Coal Mining and Title 4 Abandoned Mine Land Reclamation and Emergency Program activities in Kansas, a minimum program state. Fifteen people manage all three programs out of the Frontenac, Kansas office.

Coal mining in Kansas has been regulated since May 3, 1969. The Kansas Law, as it was known, required the surface mine operators to strike the tops of the spoil ridges so the area could be traversed by farm equipment and to then seed the area twice. Soils were not salvaged and minimum emphasis was placed on hydrology or revegetation success. With the passage of SMCRA, Kansas fell under the auspices of the interim law until primacy was achieved on January 26, 1981.

Kansas has a continental climate with warm to hot summers, generally mild winters, light to moderate winds, and low annual snowfall. The average annual precipitation is 40 inches for the coal bearing regions. The precipitation distribution, three-quarters being received from April through October, coincides with favorable crop and grass growth periods.

Located in the western region of the Interior Coal Province, Kansas coal resources have been mined for over a century by both surface and underground methods. The actively mined coal is classified as highly volatile A bituminous with 2 to 5% sulfur. The coal seams average I to 3 feet thick and are located generally in the eastern third of the state. The active coal fields are isolated in five southeast Kansas counties.

On a national scale, Kansas is estimated to have about 0.2% of the United States coal reserves. In financial terms, agriculture plays a much more important role in the economy of Kansas than does coal mining. Since program primacy, only thirty-one coal mining permits have been issued in Kansas. However, of these permits, nineteen contained prime farmland resources. Within the current permit sites, excluding tipples and haulroads, fully 45% of the permitted acreage is prime farmland cropland.

Permitting

Permitting requirements for Kansas prime farmland cropland parallel the Federal Regulations at 30 CFR 785.17. At this time, Kansas has not adopted any more stringent regulations. Permitting focuses on the existing soils volume, cropping history, proposed replacement depths, and productivity standards. Because the Kansas program has adopted the Federal regulations, permits are broken into appropriate sections utilizing the federal numbering system.

The primary task in permitting is to identify, and inventory prime farmland soils with a history, of cropping. The process begins by utilizing the county Soil Survey to map the soils on site. The applicant conducts a field reconnaissance to inventory the depth and distribution of the soils and ascertain current cropping status. The depth is measured by probing on 200 foot centers reported on an individual map in the permit and discussed in the applicable permit sections, specifically Soils (779.2 1) and Reclamation Plan (780.18). This information. correlated to a soils mass balance, is used to determine the reclamation soil and subsoil replacement depth. Kansas prime soils arc probably considered thin by comparison to other mid-western coal region states. Many prime soils are documented at less than 12 inches thick in the premine condition. Replacement depths are stated as a range,. with the overall minimum requirements being 6 inches topsoil and a total 48 inches horizon replacement for topsoil and subsoil combined.

The field review conducted by the applicant often identifies areas where minor modifications in soil boundaries need to be made. All changes to pre-mine soil boundaries must be reviewed and verified in writing by the responsible Natural Resource Conservation Service (NRCS) personnel. An administrative record of the process is included in the permit. Often the pre-mine soil boundaries include areas of previously mined land that must be more clearly and precisely identified in order to obtain an accurate accounting of the soil resources on site.

Aerial photography is used to gain insight into cropping history, along with personal interviews and signed affidavits bv landowners. The results arc presented in the permit under Prime Farmland (785.17). The staff of the SMS works with the NRCS to maintain a valid listing of those soils that are currently classified as prime. This, combined with a knowledge of the history of the area, provides the SMS with the appropriate requirements for the area. Historically, several of the large coal companies qualified for exemption from prime farmland standards through the grandfathering process.

Occasional allowances are made on a case-by-case basis for inclusion of some non-prime soil areas. These are typically where the soil was classified as non-prime due to its slope or position. Inclusions are allowed only in conjunction with NRCS approval and only on a small scale where the area of inclusion is typically less than one acre in size. The soils are reviewed to ascertain that they are of the same parent material as the prime soil. The overall standard for revegetation for the site is not lowered due to this inclusion.

During permitting, the productivity standards for bond release are addressed and incorporated into the permit. The operator has the option of setting a productivity standard based on the soil types for the area using NRCS soil productivity database standards or by selecting a reference area to use for comparison. The reference area method is seldom used and is discouraged due to the difficulty in selecting and managing the reference area site.

When the productivity standard is developed based on soil types, it is based on the acreage of the prime farmland soil mapping units being cropped premine. The acreages are used as weighting factors to develop the overall productivity standards for bond release. The premine acreage of each soil unit is verified to the nearest 1/10th acre. Accuracy is important as the productivity standard can vary substantially within different prime soil series.

Reclamation Plan

While several sections of each permit discuss prime farmland cropland reconstruction, the Reclamation Plan (780.18) outlines the minimum and average depth of soil replacement, as well as the methods to be used for handling prime farmland soils. During the active stages of mining, this information provides the basis for compliance determination during inspections.

Acceptable soil handling is outlined in NRCS Technical Guide *Kansas Standard and Specifications for Land Reconstruction, Currently Mined Land-544.* This document, first developed for use in Kansas in the mid 1980s', applies to the identification, removal, storage, replacement, and reconstruction of soils subject to coal mining.

As with any large construction job, the better the site conditions are studied and the more known about the site, the better the end result. Because mining deals with unknowns, the typical permit will have variations. There will be areas that are not mined due to poor coal quality, or the coal may dip and thus be uneconomical to recover. In almost every permit in Kansas, a final cut impoundment is part of the approved reclamation plan because landowners recognize the value of a large water body. Due to any of the variations that can occur, special attention must be taken to have a tight control on acres so there, will be no net loss of prime farmland. Accurate land use mapping is important and all acres must be accounted for to the nearest 1/10th acre.

The reclamation plan also includes the list of equipment to be used. From this the SMS determines if the soils can be suitably handled to insure adequate replacement with minimum compaction or destruction of the soil resources. There must be some demonstration that the operator has the technical expertise and sufficient experienced field personnel to handle prime farmland soils.

Revegetation Standards

While the productivity standard for revegetation success is set in the permit prior to the initiation of mining. the use of this standard does not apply until mining is complete. According to 30 CFR 816.116(a)(1), *"Standards for success and statistically valid sampling techniques for measuring success shall be selected by the regulatory authority and included in an approved regulatory program."* Kansas developed extensive guidelines to meet this requirement.

The process of developing the Kansas revegetation guidelines involved numerous hours by the SMS Soil Scientist in research, expert consultation, and consultation with the regulated industry. In 1991, the guidelines under the title *Revegetation Standards for Success and Statistically Valid Sampling Techniques for Measuring Revegetation Success*, became part of the approved program. It is important to note that the revegetation guidelines as written represent a "cookbook" approach that deals with revegetation requirements for bond release of all land uses. The document provides a clear step-by-step approach to the process that can be used by anyone.

The prime farmland cropland standards for revegetation success are based on the row crop productivity standards from the USDA-NRCS Technical Guide Notice KS-145 for each county by soil mapping unit. At the time of the development of the guidelines, this was the best available information for setting productivity standards for reclaimed prime farmland. There remains an allowance for adjustment to crop yields based on 30 CFR 823.15(b)(8).

The most common crops grown in the mined area of Kansas are soybeans, grain sorghum (milo), and wheat. During the initial research for the approved revegetation guidelines, it was determined that the most common row crop requiring the greatest rooting depth could not be practically determined on a statewide basis. Also, the subsurface clays can prohibit the penetration of roots and thus affect the productive capabilities of the soils. Overall it was determined that the most common row crops, with the greatest rooting depths regardless of soil physical barriers are soybeans and grain sorghum.

In Kansas,, the row crops of soybeans or milo must be used to achieve final bond release on prime farmland cropland. Row crops must be grown one out of the three required crop years. This required year of row crops must meet the calculated success standard to obtain a Phase 11 release. Two additional successful growing season data sets must be obtained for the Phase III release. The crops of wheat, milo, or soybeans may be used for the additional two years or forage can be used. The Kansas program allows a Phase 11 bond release to occur with only one year of row crop data.

Sampling Methods

The Revegetation Standards for Success and Statistically Valid Sampling Techniques for Measuring Revegetation Success document outlines approved sampling methods in a step-by step manner. The operator maintains the flexibility to choose between productivity standards based on a reference area or a productivity standard based on the technical standard for the soil types involved. The operator also determines whether the area will be put into a forage crop with row crop test plots or if the entire field will be put into row crop production.

Test plots have always been considered advantageous for soil conservation purposes. In many instances, once a forage crop is established on a mined area, it may be kept in grasses for years to come and actually put into a pasture type land use following bond release. More recently however, operators, either based on landowner request or in an attempt to offset costs, are returning entire areas to row crop production. In either case, the reclaimed soils production capability must still be proven based on crops prior to release. All methods require random samples to be taken from the cropped area. Presently, there is no approved method for whole field harvest sampling. Either representative samples are collected from a field that is being cropped in its entirety or representative samples are taken from test plots that represent the reclaimed area. When test plots are used the forage production and cover in the area around the test plot must also be sampled and meet prime farmland forage productivity requirements for the same sampling year.

According to the *Revegetation Standards for Success and Statistically Valid Sampling Techniques for Measuring Revegetation Success,* test plots are to be selected based on the replaced soil depth and the slope as the primary determinants, with a secondary grouping of bulk density. topsoil texture, and color. Test plots must be a minimum of two acres in size and in totality must be large enough to represent 5% of the representative area in size. For a 120 acre field, three two-acre test plots or one six-acre test plot could be used. The maximum representative area is 200 acres. For sampling data to be acceptable, each individual test plot in the representative field area must meet the production success standard for that season. Failure of any test plot to meet the success standard invalidates the data on the other test plots in that sample area.

Whether a row crop area is in test plots or is a field from which representative random samples are being taken, a minimum of 15 samples is required. Samples are checked on both a wet and a dry basis for statistical sample adequacy. Up to 30 samples can be collected from an area if needed to meet sample adequacy. If greater than 30 samples are required, then sampling has to be abandoned due to variability,

As required by regulation, the goal of reclamation is to meet or exceed the premine production capability of the area. The production databases used present yields in bushels per acre for wheat, milo, and soybeans, as well as forage production in animal unit month, or AUMs. Actual sampling can be tedious and labor intensive. The basic steps are summarized below:

For milo, the average row width is determined by measuring across five rows and dividing by four to calculate the average row width for the particular planter that was used. The grain heads in a ten feet section of a randomly located point are clipped about ½ inch below the grain and weighed to the nearest five grams. This wet weight is used to check sample adequacy for field purposes. The grain heads are stored in an individual container, then dried, thrasher and checked for moisture content. For milo, the moisture is adjusted to 13%, and the production is calculated on a 56 lb/bushel basis.

For wheat, the process is the same, except that a five foot section from each of five adjacent rows is clipped, and the production is calculated based on a 60 lb/bushel basis. Soybeans require the same five row/five foot section scenario, and the pods from the plants in the sample are to be removed. However, practicality dictates that removal of the entire plant is much easier for field adequacy determination.

In all sampling scenarios, the permittee is to mark the starting location of the random grid and the individual sampling spots. Since the Kansas program is small, the opportunity for the SMS to accompany operators or consultants while sampling or to review the area shortly thereafter is good. In order to minimize problems with verification of sample results, Kansas has adopted additional regulations that require all productivity and ground cover data to be submitted within 30 days of sampling. Raw field data is accepted for this requirement recognizing that drying and thrashing times can vary.

Prime farmland areas in forage require the same 15 minimum samples. The basal vegetation in a given sample circle, .96 ft^2 minimum to 2.4 ft^2 maximum,, is clipped between 1½ to 3 inches from the surface. All unacceptable species, as defined by the land use, and litter are removed and the sample weighed to the nearest five grams. Sample adequacy is calculated in the field based on the wet forage weight. Final sample adequacy is based on dry weights. Sample adequacy greater than 30 disqualifies the sampling. Once dry, the samples are reweighed and corrected to 12% moisture. Should an operator utilize a row crop test plot for productivity, then they must also assess the productivity and ground cover of the remaining prime farmland forage areas outside the row crop test plots according to the forage sampling techniques.

Forage sampling is based on the recognized Harvest Technique. All forage areas are stratified according to factors that would account for production variability. Most often field area locations have been defined previously. and the stratification factors used are vegetation types and planting dates. Sampling must be conducted during approved time frames, which involves sampling during periods of optimum performance. As with any land use in Kansas. a bond release can be denied based on active site erosion.

The standards for forage crops on prime farmland cropland have been set using the USDA-NRCS crop -yield database from the published county soil surveys and from technical guides of the NRCS. Both cool season and warm season grasses are addressed. When composition of a field is a combination, then the standard is based on a combination of the grasses. The production standards are derived from the AUM value from the databases. These are converted to a lbs/acre of dry forage per growing season by a factor of 900 pounds of dry forage per AUM. As with row groups, the soil productivity is given a weighted value based on the percentage of the permit it occupies.

Because eastern Kansas soils have high production capabilities under a high level of management, the technical success standard for ground cover was set by the SMS at 100%. A lower value can be approved based on premine sampling and demonstration by the operator why the site can not achieve the 100% standard. This justification must include site specific physical or chemical characteristics that can not be modified under a high level of management.

Ground cover sampling is limited to the time period of April 1 to November 1. The forage sampled must be representative of the species that comprised the seeding mix with allowances for up to 10% of other acceptable plant species as defined by the land use and up to 5% fitter to count as ground cover. Diversity is based on initial seed mixes.

Program Achievements: Phase III Bond Release Results

Since Kansas achieved primacy in 1981, there have been a total of 19 permits issued that contained prime farmland cropland disturbances. These permits represent over 11,000 acres containing about 41.500 acres of prime farmland cropland. Of this, about 2,200 acres of prime farmland on ten permits have achieved final bond release. The remaining 2,300 acres are contained on the two active coal mine permits presently operating in Kansas and on seven other special case permit sites. The special case permits have, in most instances, met liability time frames, but have not achieved final bond release due to bankruptcies of the three companies involved.

The majority of the successfully restored prime farmland cropland areas have had productivity demonstrated through forage sampling and row crop test plots. Recent permits are tending to return entire fields to row crop production with random sampling of the fields. Prior to the approval of the revegetation guidelines, wheat was accepted for both phase II and III bond release.

In Kansas, when a mining company declares bankruptcy and the reclamation responsibility shifts to the surety company, the surety is required to meet the terms and conditions of the regulations including the revegetation requirements and sampling methods as outlined in the *Revegetation Standards for Success and Statistically Valid Sampling Techniques for Measuring Revegetation Success.* Bond forfeiture areas are reclaimed using available funds according to the regulations and the approved reclamation plan; however, productivity sampling is not being conducted at this point in time.

Problems and Future Modifications for the Revegetation Guidelines

Several aspects of the Kansas revegetation guideline document met with resistance from the regulated industry. The nature of the concerns depended somewhat on the size of the company involved. The initial concern was that the flexibility to use the document as a guideline, and not as a regulation, was not clearly defined. In actuality, should an operator wish to sample using a method not included in the document, a program amendment must be processed to include the proposed methodology.

Numerous technical aspects of the document have also been challenged. The bulk density measurement for test plot location has met with resistance due to the increased cost and time involved. Industry representatives felt the results were so broad based that they did not have substantial meaning.

The requirement for all tests plots in a sample field to meet the productivity standards and sample adequacy during a given sampling has been challenged, as well as the requirement for a minimum number of 15 samples for any size field. The test plots, being located to represent the fields variety, will yield at different rates. Thus the request has been made to allow for the production of the test plots to be averaged. The minimum sample size of 15 was selected to protect against the loss of an entire year's worth of sampling due to variations between wet field adequacy weights and dry weights. However, the industry indicates that they should have the option to sample at a lower limit, such as 10 samples, as long as sample adequacy is achieved.

Stratification, while designed to define minimum sampling areas, came under appeal as the scale of reclamation for some companies was considerably larger than others. The current forage sampling requirements place limitations on the field size that-do not allow for reduced sampling on large contiguous tracts.

Other considerations needing attention are diversity and the AUM conversion factor. Diversity, according to regulation, requires that a diverse cover that is permanent and effective be established. The current Kansas diversity measurement requires percentage composition studies based on initial seed mixes. However, prime fanrdand does not need to meet this requirement when areas are cropped or where a forage monoculture for hay production is being established. The 900 lbs. conversion factor for the AUM value is, according to industry, artificially high and not based on valid technical and scientific data. The SMS is researching various sources, both county and state, to use the most suitable conversion factor for prime farmland soils in the coal mining region.

Since the initial introduction of a guideline for determining revegetation success, several extensive modifications to the approved document have been attempted. but none successfully completed. While some minor issues have been addressed through the program amendment process, the major issues dealing with prime farmland cropland are still being worked on. Future modifications may include allowances for different sampling methodology, especially a whole field harvest. Due to the perceived problems with test plots, there is a possibility they will be eliminated entirely; if not, a provision may be made to allow averaging of test plots within some minimum standard requirements. Kansas maN, also add an allowance to use corn to prove productivity, but not make it the required crop for Phase III.

Conclusion

Since primacy, the state of Kansas has released over 2,200 acres of prime farmland cropland. Approximately 1,950 acres of this has been maintained in forage production. The tendency on currently mined lands is to return the area to row crop production and prove productivity while enjoying the economic benefits of a crop. As of January, 1998, there was only one company actively mining in Kansas on two individual permit areas. Three coal company bankruptcies have resulted in the remaining permitted sites being reclaimed either by sureties or through a bond forfeiture proceeding.

The Kansas Surface Mining Section worked diligently to provide Kansas coal mine operators with a methodology that would allow for timely release of performance bonds from all permit areas. The revegetation guideline document provides a step-by-step procedure that, when followed will be acceptable for use in bond release. Both coal and prime farmland are valuable resources. While coal exists in very, limited quantities in Kansas, with proper planning and management, prime farmland soils can be an unlimited resource for generations to come.

References

Continental Coal, Inc.. 1997. Surface Coal Mining and Reclamation Permit LN-SM- 1201. Continental Coal, Inc., Leawood, Kansas.

Kansas Department of Health and Environment, Division of Environment, Surface Mining Section, 1991. Guidance Document-Revegetation, Revegetation Standards for Success and Statistically Valid Sampling Techniques for Measuring Revegetation Success. KDHE, Pittsburg, Kansas.

Kansas Department of Health and Environment, Division of Environment, Surface Mining Section, 1997-1998. Records and files. KDHE, Frontenac, Kansas.

The Clemens Coal Company, 1993. Surface Coal Mining and Reclamation Permit CR-SM-306. The Clemens Coal Company, Pittsburg, Kansas.

USDI-OSM, 1997. Annual Evaluation Summary Report for the Regulatory Program Administered by the State of Kansas, Office of Surface Mining, Alton, Illinois.

---

[1]Marlene N. Spence, Environmental Technician, Kansas Department of Health and Environment, Surface Mining Section; M.S. Pittsburgh State University, Technology; 4 years Research and Development, 10 years with the Surface Mining Section.

PRIME FARMLAND VARIABILITY IN MEETING POST-MINING YIELD TARGETS

Richard A. Stout[1,3]
Knox College
Galesburg, Illinois

Abstract

The data collected by the Department of Agriculture (DOA) and Department of Natural Resources (DNR) in Illinois on mining operations, soil replacement practices, and crop yields on post-mined soils is a rich source of information for assessing the reclamation of mined soils. The data set includes over 700 fields; however, the most complete data is for 448 fields in the Illinois Permanent Program. The yield testing data for fields in the Permanent Program span the years 1985 to 1996 (latest available data). Although the fields in the data set fall into three categories, this report focuses on fields designated as prime farmland (PF), which must pass the highest and most difficult-to-reach target yields. The working hypotheses were that variation in the success of restoring crop yields on mined farmland depends on the methods of sub-soil and top-soil replacement, soil compaction, the depth of deep tillage, crop growing conditions, the presence of problem sub-soils, the number of attempts per field to pass the yield tests, and whether the field is located in northern Illinois (young soil) or southern Illinois (old soil). At least for the data collected for fields in the Permanent Program, the reclamation of prime farmland apparently does not depend significantly on the index of growing conditions, the index of problem sub-soils, or the age of the soil (location of the field). However, the reclamation of prime farmland does depend statistically significantly on soil compaction (and, thus, on the soil replacement equipment), the depth of deep tillage, and the effort per field to pass the yield tests.

Introduction: Citizen Concerns

As consumers and producers, we benefit from cheap electricity-55% of our electricity comes from coal fired generation (Darmstader, 1997). As citizens, we benefit from a safe, healthy, and aesthetically pleasing environment. The environmental safeguards and benefits, of course, increase the cost of mining and burning coal and, thereby, the cost of coal generated electricity. The members of the Citizens' Organizing Project (COP), Knox County, Illinois and many other citizens from distant communities are genuinely concerned about how our society measures and balances such benefits and costs.

Thus, not completely impaired by romantic delusions, we raise specific, practical questions. They include: Are some property owners near the mines not receiving timely and adequate compensation for blasting damage? Are the regulations for post-mining water tables and surface water drainage enforced fully? Have post-mined fields that have passed the target yields really been restored to pre-mining productivity (as required by federal and Illinois law), or are the target yields too low? If the post-mined fields pass target yields that are too low, the fields will not be as productive as undisturbed fields, and the property tax base will not be restored to the pre-mining level. Even if target yields are unbiased, is passing three yield tests in a ten year liability period enough? Should the standard require five passes or six or some higher number? What constitutes a successful program of reclaiming and restoring prime farmland? Should mining firms with limited success in restoring fields to pre-mining yields be permitted to mine new areas? Are the standards for issuing mining permits too lenient? After satisfying the target yields, why do some mining firms wait so long to apply for bond release?

Data to Assess the Satisfaction of Yield Targets by Post-Mined Prime Farmland

My empirical results can help to answer some-but not all-of the questions raised. Satisfactory answers to some citizen concerns may require something beyond mine site inspection reports and peer-reviewed, scientifically controlled studies concluding that physical and chemical soil characteristics may be restored sufficiently that post-

[1]The author gratefully acknowledges the following individuals and institutions: Mr. Dean Spindler, Illinois DNR, for sending the DNR data. Dr. John Lohse. DOA, for providing yield data by field and year. Ms. Anna Sophia Johnson for suggesting that OSM invite me to make this report. And Mr. Emmons, OSM, and others for accepting her suggestion.

mined fields may satisfy the targeted crop yields, e.g., that post-mining deep tillage reduces soil compaction. Many of the public concerns require a broader assessment of the observed results of the farmland reclamation program in place in Illinois.

This report, focusing on prime farmland (PF) reclamation in Illinois, illustrates an approach to assessment that interested academics, citizens, mine operators, and regulators may wish to apply to assessing reclamation success of fields in the post-mining farmland reclamation program in Illinois (maybe to programs in other states, too). This approach to assessment is observational rather than experimental with several treatments and a control group. This method looks at the observed results of the farmland reclamation program in Illinois for many fields over many years and across numerous mine operators. It is data intensive. Fortunately, the Illinois Department of Natural Resources (DNR) and the Illinois Department of Agriculture (DOA) in the course of performing regulatory duties have collected most of the data needed to conduct such a study, and both departments supplied data. The data set consists of data on over 700 fields in the post-mining crop yield reclamation program in Illinois. Illinois started its Permanent Program of farmland reclamation in 1983, so the most complete data is for the 448 fields in the Permanent Program. For most fields the data include entries for the acreage, the year of final grading, the year of deep tillage, the years when yield testing occurred, the crop grown and tested the target yield and the average yield for each season the field was tested for crop productivity. Fields are not tested each growing season and are usually tested only enough seasons to reach the required number of passes in the approved crops (Appendix 1 summarizes the standards). The yield testing data aggregated over all the fields ever in the Permanent Program span the years 1985 to 1996 (latest available data).

I have chosen two measures of reclamation success: (1) the number of growing seasons before a PF field passes the requisite yield tests and (2) whether the field has passed the requisite yield tests by a PF field. The first, the number of growing seasons, measures the growing seasons elapsed from the year after final grading of the field to the year that the field satisfies the requisite crop yield targets or to the year 1996 if the field has not passed the requisite yield tests.

I approached the data set with several hypotheses in mind. Briefly, my hypotheses were that variation in both success measures depends on variation in and among the following factors: the compaction of the post-mined soils which, in turn, depends on the methods of sub-soil and top-soil replacement, the depth of deep tillage (if the field was deep tilled), the crop tested (beans, corn, hay, and wheat), growing conditions the year of yield testing, and whether the field is located in northern Illinois (young soil) or southern Illinois (old soil). I have not yet investigated whether fields tested for corn yield, for example, pass less frequently than fields yield-tested for more shallow rooted crops. The data do indicate that mining and reclamation practices account for more than 75% of the variation in reclamation success. The practical choices include the equipment for replacing the sub- and top-soils, the depth of deep tillage, and the number of seasons the mine operator grew a crop and tested it.

Natural History and Age of Soil

The surface geology and soil age of Illinois soils is the result of several episodes of glaciation during the Ice Age (Pleistocene). After the last glaciation, the Wisconsinan, winds deposited silt (loess), sometimes on territory beyond the reach of the glaciers. Loess, rich in calcium and possessing a high capacity to absorb water, is naturally fertile. Contemporary soils that developed from loess are extraordinarily productive and account for much of the farmland designated as prime farmland (PF) by NRCS. One effect of the Wisconsinan glaciation is that older, less fertile soils were replaced by soils that are younger (about 11,000 years old) and more fertile. Since the Wisconsinan glaciation did not reach as far south as the previous glaciation, the soils in southern Illinois are generally older (over 100,000 years old) and less fertile, (For this report I count Brown, Coles, Edgar, Fulton, Knox, Macoupin, McDonough, Peoria, and Schuyler as northern Illinois counties, and Gallatin, Jackson, Perry, Randolph, St. Clair, White, and Williamson as southern Illinois counties.‘) Mine operators have worked Pennsylvanian-age coal deposits in both northern and southern Illinois. This natural history and the locations of mines raise the related questions: Is there a North-South difference in reclamation success of post-mined soils? Is reclamation success for prime farmland lower or higher than for the less fertile soils?

[2] This geographical division of counties was suggested by Dr. John Lohse, DOA in a FAX dated Feb. 6, 1998.

Table 1 shows the North-South distribution of fields in the Illinois Permanent Program by productive capability. The classifications for capability or yield test liability for post-mining crop productivity are as follows: low capability (LC), high capability (HC), and prime farmland (PF). The first row of data in each cell gives the percentage of fields that have passed the requisite target yields for the required number of growing seasons and crops. The second row shows the average number of growing seasons for fields that have and have not passed the requisite yield tests. The third row counts the number of fields in each cell of the cross tabulation.

Table 1: Farmland Reclamation (% Passing and Seasons Elapsed)
Northern and Southern Illinois Fields by Yield Test Liability

	Yield Test Liability				
	LC	HC	PF	Total	
North	87.5	49.1	56.2	56.1	<-% Passing
	5.1	5.8	5.3	5.5	<-Avg. Seasons
	24	110	80	214	<-Count
South	20.0	45.3	16.3	37.6	
	6.7	6.0	6.7	6.2	
	15	170	49	234	
Total	61.5	46.8	41.1	46.4	
	5.7	5.9	5.8	5.9	
	39	280	129	448	

The following example illustrates how to count the seasons elapsed while a field is in the testing program. Suppose a mine operator contoured and graded Field 1 in 1988. then the field would have been eligible for crop testing in the 1989 growing season, If Field 1 passed the final required yield test in 1994, then it ‘required’ six seasons to pass the requisite tests and the reported average would reflect six seasons. Continuing the example, suppose that an otherwise similar field, Field 2, had not passed the requisite yield tests by 1996 (last year of data), then that field would have been in the Permanent Program without passing for a total of eight seasons, which the reported average would reflect.

```
 Final                                              Field 1 Passes
 Grading                                            3rd Yield Test
   ↓                                                     ↓
1988  1989  1990                                    1994       1996                 Year
  |-----|-----|-----|-----|-----|-----|-----|-----|-----|-->                      Time Line
  0     1     2     3     4     5     6     7     8     9                           Season
        ↑                                               ↑
     First Season                                  Last Available
     Fields 1 & 2 are Eligible                     Data
     for Yield Testing
```

Table 1 supports the notion that there is a North-South difference. In northern Illinois 56% of the fields had passed the requisite yield tests by 1996, better than the 37.6% pass rate for southern fields. Further, 56% of prime farmland fields in northern Illinois have passed, while only 16% in southern Illinois have passed. While these results are interesting in themselves, they also require some additional investigation and explanation. For example, do the differences in the percentages depend upon the method of soil replacement, soil compaction, deep tillage, and so forth? Do the data, adjusted and controlled for these additional factors, reveal which mining and reclamation practices speed (or retard) reclamation? After adjusting for these factors, is there a North-South difference? These are among the interesting investigations to which this report turns.

Post-Mining Soil Compaction

Soil compaction in part depends upon the weight of the equipment used to replace and grade freshly replaced soil. In the process of re-depositing soil, for example, scrapers with their weight carried by tires inevitably compact much of the freshly deposited soil as the tires pass over it. Bulldozers, riding on tracks, spread their weight over a greater surface area and generally compact the soil less in the process of distributing and grading the redeposited soil. Table 2 indicates the method or equipment used to replace soil and the degree of compaction associated with the combinations of equipment used in Illinois.

Table 2: Soil Replacement Equipment and Soil Compaction

Soil Replacement Equipment			
Sub-soil	**Top-soil**	**Combination (Sub-/Top-Soil)**	**Soil Compaction**
AP Belt (Belt)	**ABC** Mix	Belt/ABC	Low
AP Belt (Belt)	Scraper (Scr)	Belt/Scr	High
Bucket Wheel Excavator (BW)	BW & Bulldozer (BWDzr)	BW/BWDzr	Low
Bucket Wheel Excavator (BW)	Scraper (Scr)	BW/Scr	Medium
Dragline (DrgL)	Scraper (Scr)	DrgL/Scr	High
Shovel (Shv)	Scraper (Scr)	Shv/Scr	High
Shovel (Shv)	Truck (Trk)	Shv/Trk	Low
Truck (Trk)	Scraper (Scr)	Trk/Scr	Medium-High
Truck (Trk)	Truck (Trk)	Trk/Trk	Medium

The highly compacted soils slow the percolation of water through the soil and impede root growth. Consequently, one expects that the percentage of fields passing the yield tests to be lower on fields with highly compacted soils and that highly compacted fields spend more growing seasons in the yield testing program. The evidence is mixed. Table 3 (previous page) shows in each cell the percentage of passing fields, the growing seasons elapsed in the yield testing program, and the number of prime farmland fields.

A comparison across soil compaction categories shows that prime farmland fields have passed the requisite yield tests less frequently than the non-prime fields (41.4% to 47.4% in the bottom rows labeled "Total"). Also, according to the middle (PF) column of Table 3 and confirming one hypothesis, only 15.8% of the high-compaction prime farmland fields passed target yields the required three years in 10 with at least one passing corn crop. The comparable pass rate for low-compaction PF fields is 84%. The difference in pass rates between the medium-compaction and medium-high-compaction cells in the PF column, while not as dramatic, fits the expected pattern.

Deep Tillage

Deep tillage is used to reduce soil compaction following soil replacement by heavy equipment. While mine operators have deep tilled about 42% of all fields in the data set, they have deep tilled only about 30% of the fields in the Permanent Program. According to Table 4, among the fields in the Permanent Program, operators have deep tilled a smaller percentage of prime farmland (PF) fields (27%) than high capability (HC) fields (35%). Mine operators with fields in the Permanent Program have not deep tilled low- and medium-high compaction fields, and they have not deep tilled low capability (LC) fields, regardless of the degree of compaction. It seems reasonable that mine operators rarely deep till low-compaction fields. Table 4 does, however, contain a surprise. A single mine operator accounts for most of the fields in the medium-high compaction group. This operator deep tilled only a handful of high capability (HC) fields and no prime farmland (PF) fields after using a truck to replace the sub-soil and a scraper to replace the topsoil. Since scrapers usually compact the soil to a high degree, what is surprising is that this operator has a high percentage of fields passing the requisite yield tests. (This surprise raises questions for further research: Is the data set lacking important information about this mine operator and the fields it mined? Is the medium-high compaction category flawed?)

Table 3 : Prime Farmland Reclamation (% Passing and Seasons Elapsed) by Soil Compaction and Yield Test Liability

Compaction	not PF	PF	Total	
Low	66.7	84.8	80.0	<-% Passing
	5.6	5.3	5.4	<-Avg. Seasons
	12	33	45	<-Count
Med	44.4	50.0	44.8	
	6.7	9.5	6.9	
	27	2	29	
Med-High	61.6	41.7	55.0	
	4.1	5.3	4.5	
	73	36	109	
High	41.1	15.8	35.3	
	6.4	6.3	6.4	
	192	57	249	
Total	47.4	41.4	45.6	
	5.8	5.8	5.8	
	304	128	432	

As Table 5 shows, among the low-compaction fields that were not deep tilled one operator has passed 29 PF fields out of 34 (85%) and another has passed 15 never deep-tilled, medium-high compaction PF fields out of 36 (41.7%). One clear lesson is that high pass rates have been achieved on PF soils after the use of low-compaction soil replacement methods. As a result the pass rate is 42% for PF fields that were never deep tilled. By comparison, the pass rate for PF fields that were deep tilled was only 24%. The last result may be due to high soil compaction. Among the high-compaction PF fields, as expected, only those that were deep tilled passed (23%) the requisite yield tests, High-compaction fields account for 76 PF fields, slightly more than half of all PF fields. Of those 76 high-compaction PF fields, only 13% have passed.

Citizens in Knox County, Illinois have expressed a special interest in the restoration of crop yields on mined Ipava, Sable, and Tama soils, which are prime farmland soils. Investigating that specific issue is important and feasible; I may have the time to address it this summer. However, I can now report on restoration of yields in counties where mining has frequently disturbed Ipava, Sable, and Tama soils. These counties include Fulton, Knox, Peoria, and Schuyler. all north of the Illinois River. Table 6 (next page) indicates that four mine operators have mined 85 PF fields located in those counties. Of the high-compaction PF fields, two out of 15 (13%) had passed by 1996. Mine operator 11 used high-compaction soil replacement equipment and deep tilling, and had not passed a single PF field by 1996. On the other hand, operator 8 used low-compaction soil replacement equipment, never deep tilled, and has passed 85% of its PF fields. These observations raise an important policy question. Since the data can reveal the practices and mine operators that have passed a high percentage of PF fields and the practices and operators associated with failure to restore yields, should such results be used to deny new surface mining permits to operators with poor track records?

Table 4: Percentage of Fields Deep Tilled by Soil Compaction and Yield Test Liability

Compaction1	LC	HC	PF	Total	
		Liability			
Low		0	0	0	<-% Deep Tilled
	0	12	33	45	<-Count
Med	.	40.74	50	41.38	
	0	27	2	29	
Med-High	0	0	0	0	
	18	55	36	109	
High	0	47.67	59.65	46.59	
	20	172	57	249	
Total	0	34.96	27.34	29.63	
	38	266	128	432	

Table 5 :Percentage of Passing Prime Farmland Fields by Soil Compaction and Deep Tillage

Compaction	No Till	Deep Till	Total	
Low	85.3		85.3	<-% Passing
	5.4		5.4	<-Avg. Seasons
	0.0		0.0	<-Median Till Depth[1]
	34		34	<-Count
Med	0.0	50.0	33.3	
	11.0	7.5	8.7	
	0.0	30.0	30.0	
	1	2	3	
Med-High	41.7		41.7	
	5.3		5.3	
	0.0		0.0	
	36		36	
High	0.0	23.3	13.2	
	6.8	6.5	6.6	
	0.0	48.0	30.0	
	33	43	76	
Total	42.3	24.4	36.9	
	5.8	6.6	6.0	
	0.0	48.0	0.0	
	104	45	149	

Table 6: Percentage of Passing Prime Farmland Fields in Fulton, Knox, McDonough, Peoria, and Schuyler Counties, Illinois by Firm and Soil Compaction

Firm ID	Compaction: Low	Med-High	High	Total	
3	.	.	66.67	66.67	<-% Passing
	0	0	3	3	<-Count
5	.	41.67	.	41.67	
	0	36	0	36	
8	85.29		.	85.29	
	34	0	0	34	
11	.	.	0	0	
	0	0	12	12	
Total	85.29	41.67	13.33	54.12	
	34	36	15	85	

Variation in the Speed and Success of Mined PF Soils Satisfying Target Yields

The evidence presented in the cross tabulations indicate that soil compaction and deep tillage have an impact on yield restoration. Such cross tabulations are fine for showing that two variables may affect a third, but when three or more independent variables affect a dependent variable other methods may be less cumbersome and more powerful (if not as easy to digest). Therefore, I turn to multivariate analysis and the results from two multivariate regressions and two multivariate logits.

I used regression analysis to estimate how the first dependent variable, seasons elapsed until the field passes the yield tests or until 1996 (whichever came sooner), responds to several independent variables. Among them are variation in (1) soil compaction, (2) location (North-South), (3) deep tillage, (4) number of attempts to pass the field (which may measure in part the effort to pass the field), and (5) year or season the 10 year testing window opened for a field. The complete list of independent variables appears in Appendix 2 in column 1. The observations on each field were weighted for the acres actually cropped in that field; therefore, the regression results must be interpreted as seasons elapsed for an acre of prime farmland. Columns 2 and 3 contain the regression coefficients (t statistics in parentheses) and summary statistics, A blank cell indicates that the variable in that row was omitted from the regression analysis reported in that column.

In general a regression equation, with estimated coefficients A, B_1, B_2, B_3, etc., is useful for estimating or predicting the dependent variable (Y) given selected values for the independent variables (the Xs). An example of a regression equation in symbolic form follows:

$$\text{est.}Y = A + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + \ldots\ldots + B_mX_m$$

Each regression slope coefficient (each B) is the estimated magnitude and direction of response of the dependent variable to variations in the associated independent variable. Using the symbolic regression equation above, for example, the second slope coefficient B_2 reveals the expected magnitude and direction of change in the estimated dependent variable Y from a one unit change in the second independent variable X_2. Designating the symbol A to mean change, $B_2 = \Delta Y/\Delta X_2$.

As indicated by the F statistics and the R^2s near .79, the regressions reported in Appendix 2 in columns 2 and 3 fit the data for the 132 prime farmland fields about equally well. The error terms turned out roughly normal, and the coefficients have reasonable signs. For those interested in statistical significance, the coefficient t statistics appear enclosed in parentheses below the coefficients in columns 2 and 3. Using the estimated coefficients from column 3, I constructed the following regression equation:

Est.Seasons = 4.15 - .74*LowCompaction + .67*Med.Compaction
+ l.O8*HighCompaction - .59*North - .026*Depth + .37*Attempts
+ 1.O9*DuetoDeepTill - .516*NewWindow

The intercept coefficient suggests that the average acre of prime farmland would spend about four years in the testing program were it not for the effects of soil compaction and the other variables. The results for the policy relevant variables are highlighted next.

Low Compaction: Other things the same, an acre oflightly compacted prime soil has spent about nine months (3/4 year) less in the testing program than more compacted acres. This result does not necessarily mean that low-compaction acres passed nine months earlier than more compacted acres. The results in Table 3 are consistent with the results of the regression analysis.

High Compaction: Other things the same, an acre of highly compacted prime soil has spent about one year longer in the testing program.

Northern Illinois Location: Table 1 implies that an average northern Illinois PF field has spent 5.3 seasons in the testing program and that its southern analogue has spent 6.7 seasons, a difference of 17 months. This result is driven in part by the success achieved by operator 8 on low-compaction soils. The regression analysis, adjusting for the effects of compaction, depth of tillage, and other independent variables, implies that an acre of prime farmland spends about seven months less than its southern analogue in the testing program (one tail P value = 0.07).

Depth of Deep Tillage: This coefficient may seem small (-.026). but it has important policy implications. The coefficient indicates that PF acres deep tilled to a depth of 48 inches (a DM1 for example) have spent about l-1/3 fewer seasons in the testing program (-0.02655*48 = -1.27 years off the years spent in the testing program). The other regression reported in column 2 indicates that deep tillage in general reduces the seasons elapsed by about 1.3 years. Since the DNR does not allow yield testing the season following deep tillage, deep tillage adds one full season to the dependent variable. So the net gain from deep tillage for an average acre of prime farmland works out to about l/3 year or about four months.

Attempts: This variable (I hoped) would measure operator effort to pass a field. It is highly positively correlated with the dependent variable, which rises by one each season a field is in the Permanent Program whether or not it is tested. A better measure of effort is needed. I have experimented with an 'effort' variable constructed by dividing Attempts by the number of Seasons a field has been in the Permanent Program. Although not reported here, the estimated coefficient for the constructed variable is negative as expected.

Seasons Elapsed Due to Deep Tillage For a deep tilled field this variable accounts for and controls for the seasons after final grading spent marking time in the testing program. The time line illustrates the final grading, deep tillage, and yield testing story for one hypothetical field. In the illustration, the field spends five growing seasons in the Permanent Program without passing all the yield tests and is deep tilled at the end of the fifth season; so the seasons elapsed before deep tillage is equal to live. The deep tillage triggers the start of a new 10 year testing window, and the DNR does not allow testing the first season after deep tillage (season 6). Suppose the hypothetical field passes the three required yield tests during seasons 7 through 10. Deep tillage at the end of season 5 actually means that six of the 10 seasons this field needed to pass were just marking time and pushing upward the dependent variable, The estimated coefficient for this variable, therefore, should equal or be very close to one, which at 1.09 it is.

```
Final     1st 10 Year            Deep       New 10 Year
Grading   Win&w  Opens           Tillage    Win&w  Opens
   ↓         ↓                      ↓          ↓
   |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--→ Time Line
   0     1     2     3     4     5     6     7     8     9     10     Season
         ↑                             ↑     ↑                 ↑
      First  Season                    No   Field again        Field Passes
      Field is Eligible           Testing   Eligible for       3rd Yield Test
      for Yield Testing                     Yield Testing
```

New Window: This variable is the year the DNR opened the first 10 year testing window or opened a new window if a field had been deep tilled. Prime farmland must pass three yield tests in a 10 year window. The closer in time this opening was to 1996, the fewer the seasons available for a field to pass the three required yield tests. The further back in time the 10 year testing window opened for a field, the greater the number of opportunities that field had to pass three yield tests. The negative estimated coefficient seems reasonable.

I used logit analysis to estimate the Pass/Fail response of PF fields to variation in (1) soil compaction, (2) the location (North-South), (3) deep tillage, (4) the number of attempts to pass the field (which may measure in part the effort to pass the field), and (5) the year or season the 10 year testing window opened for a field. The observations on each field were weighted for the acres actually cropped in that field; so the logit results must be interpreted in terms of the probability of an acre passing the yield tests. Columns 5 and 6 in Appendix 2 contain the logit coefficients (t statistics in parentheses) and summary statistics.

In general a logit equation, with estimated coefficients A, B_1, B_2, B_3, etc., is useful for estimating the probability of an event, such as passing the three yield tests in a 10 year window, given selected values for the independent variables (the Xs). An example of a logit equation in symbolic form is:

$$\text{estimated probability of passing all tests} = P = 1/(1 + e^{-Z}) = 1/(1 + \exp(-Z)),\ e \cong 2.7183 \text{ and}$$

$$\text{estimated logit } Z = A + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + \ldots + B_mX_m$$

Each logit coefficient (each B) is the estimated magnitude and direction of response of the logit variable Z to variations in the associated independent variable. Using the symbolic logit equation above, for example, the third coefficient B_3 reveals the expected magnitude and direction of change in the estimated Z from a one unit change in the third independent variable X_3. That is, $B_3 = \Delta Z/\Delta X_3$. However, the estimated probabilities (P) are non-linearly related to the coefficients (Bs) and the independent variables (Xs).

As indicated by the high χ^2 statistics and the low rates of false negatives and false positives, the logit analyses reported in Appendix 2 in columns 5 and 6 fit the data for the 132 prime farmland fields quite well. The coefficient t statistics appear enclosed in parentheses below the coefficients in columns 5 and 6. Using the estimated coefficients from column 6, I constructed the logit Z equation below and the equation for predicting changes in the probability of an acre passing:

$$\text{est.logit } Z = -2.54 + 1.27*\text{LowCompaction} - 2.93*\text{Med.Compaction} - 5.7*\text{HighCompaction}$$
$$- 1.87*\text{North} + .13*\text{Depth} + 5{,}4*\text{Effort} - .63*\text{NewWindow}$$

$$AP = (P - P^2)*B*\Delta X = (p - P^2)*\Delta Z, \text{ where P is the average pass rate for PF acres} = .3623$$

The logit and regression results are generally consistent in the sense that the variables associated with reductions in the number of seasons taken by an acre to pass the yield tests are also associated with higher probabilities of passing the yield tests. Before concluding I highlight the logit results for several policy relevant variables.

Low Compaction: Other things equal, low soil compaction raises the probability that an otherwise typical acre of prime farmland passes the yield tests from .3623 to .6557. $AP = (.3623 - .3623^2)*1.27*(1) \cong .29$.

Northern Illinois Location: Table 1 reports that the percentage of northern Illinois PF fields having passed the yield tests is 56%, much higher than the 16% pass rate for southern PF fields. This implies that northern fields have a higher probability of passing. On the other hand the logit analysis, adjusting for the effects of the other independent variables, implies that a northern PF acre has a lower probabilitv of passing the tests. $\Delta P = (.3623 - .3623^2)*(-1.87)*(1) \cong -.432$. The one tail P value is 0.11. This result reflects the impact of the other independent variables as well as the poor showing by firm 11 (Table 6).

Depth of Deep Tillage: The estimated coefficient is statistically significant and implies that increasing the depth one inch increases the probability of passing by 0.03 = $(.3623 - .3623^2)*(-.131)*(1)$.

Conclusions

I have reported on an observational study of what actually happened or, at least, of what was recorded by DNR and DOA. The reported results summarize years of experience for PF fields in the Illinois Permanent Program. When I started, I expected to find that very few PF fields had passed the yield tests. I found, instead, that about 41% of the PF fields had passed the three yield tests in the 10 year liability period. The 41% is still disappointingly low, but the pass rate is higher than I expected. My results, based on observational data, confirm what other studies using experimental data have shown. The policy relevant results include: Low compaction methods of soil replacement and grading reduce the seasons elapsed by a PF acre in the testing program by about nine months and increase the probability of passing the tests by .29. High compaction methods add at least one season elapsed in the testing program. Deep tillage increases the probability of PF fields passing the yield tests and shortens the time to passage by about one year. Such results give state and federal regulators, concerned citizens, and mine operators an opportunity to assess this important regulatory program in ways not possible without comprehensive data. All parties may check the results of this observational study against what they expected based on their experience and the results reported from, for example, controlled experiments done at agricultural research stations, Is the response of PF fields to compaction more or less than expected? Is the response to deep tillage more or less than expected? Which mine operators are least successful at passing fields? Why? Which are the most successful? Why? Do the results suggest modifications to mine and regulatory practices?

Because I have not explored the entire data set (in particular the average yields per acre for each field) and because parts of the data set are incomplete, I urge that the results reported here be treated as preliminary. Much remains to be done and can be done. I intend to ask the DNR and DOA for more information in order to complete the data set before I re-edit it for accuracy. After completing the work started in this report, I intend to investigate how pass rates varied by crop, compaction, and deep tillage as well as how yields varied with location, compaction, deep tillage, and so on. When I'm done, I hope that the results of these future investigations, like the results reported here, will provide useful information to mine operators and regulators-information that helps them to make better decisions in pursuing the goal of restoring mined farmland to pre-mining crop productivity.

Appendix 1

Required Number of Passes in 10 Seasons and by Crop

		Number of Required Seasons Passing Target Yields by Crop			
Capability/Liability of Soil in Mining Permit	Total Required Passes in 10 Seasons	**Corn**	**Beans**	**Wheat**	**Hay**
Prime Farmland PF	3	1 or more	at most 1	at most 1	at most 1
High Capability HC	2	1 or more	no limit	at most 1	at most 1
Low Capability LC	2	no limit	no limit	no limit	1 or more

Deep Tillers and Till Depths

Deep Tiller	Till Depth Range
DM1	48"
DM2	48" +
DM3	30"
DMI-TIGER2	18"
HDT	30" to 36"
MURAY	24" to 30"
RKP	24" to 30"
RM1	36"
STING	48"
TALON	30"
TLG12	30" to 36"

Appendix 2

Regression and Logit Results					
(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	**Regression Coefficients**		**Dependent Variable**	**Logit Coefficients**	
Seasons elapsed to Pass or to 1996			Indicator variable for Pass		
(1)	(2)	(3)	(4)	(5)	(6)
Independent Variables			**Independent Variables**		
intercept (t statistic)	3.5683 (11.100)	4.1483 (7.996)	same as in column 1	-2.871627 (-1.515)	-2.54056 (-1.452)
indicator variable for low compaction	-.73823 (-2.772)	-.73993 (-2.798)		1.203873 (1.563)	1.271279 (1.775)
indicator variable for medium compaction	1.7241 (3.200)	.672479 (0.939)		-5.622442 (-2.872)	-2.93286 (-1.335)
indicator variable for high compaction	1.66451 (5.862)	1.07737 (2.268)		-7.445314 (-2.872)	-5.705677 (-2.537)
indicator variable for northern Illinois field		-.58708 (-1.459)		-3.303361 (-1.815)	-1.875454 (-1.242)
indicator variable for deep tillage	-1.29222 (-2.725)				
depth of deep tillage in inches		-.02655 (-2.281)		.0940637 (2.032)	.1315627 (3.302)
attempts by operator to pass field	.37125 (4.552)	.37337 (4.595)			
attempts to pass divided by seasons elapsed				7.694291 (3.465)	5.396401 (3.024)
years elapsed due to deep tillage	1.09202 (8.534)	1.099067 (8.583)		1.073245 (2.554)	
season 10 year window starts	-.51627 (-9.835)	-.516093 (-9.992)		-.7731305 (-4.092)	-.6282835 (-3.987)
Summary Regression Statistics			**Summary Logit Statistics**		
(1)	(2)	(3)	(4)	(5)	(6)
number of observations	132	132		132	133
degrees of freedom	124	123			
F statistic	71.11	63.35	χ^2	95	88.04
P value for F statistic	0.0000	0.0000	P value of χ^2	0.0000	0.0000
R^2	.8006	.8047			
Adjusted R^2	.7893	.7920	Pseudo R^2	.5351	.4919
RMSE	1.0854	1.0785	specificity = 100 - %false neg.	83.65%	85.15%
			sensitivity = 100 - %false pos.	80.29%	81.4%

Bibliography

Darmstader, Joel, "Productivity Change in U.S. Coal Mining," Discussion Paper 97-40, Resources for the Future, Washington, DC.

Fehrenbacher, et. al., "Soil Productivity in Illinois," College of Agriculture, University of Illinois at Champaign-Urbana, 1978.

[3]Richard Stout, Associate Professor of Economics, Knox College; Ph.D. Economics, Indiana University; 17 years of teaching and research in various disciplines of economics; current research is the analysis involving data sets from over 700 fields in the Illinois mining reclamation program.

COMPACTION MEASUREMENT METHODS

C. L. Hooks[1]
Coal Research Center, Southern Illinois University

Abstract

Current reclamation practices include a variety of methods to reconstruct soils. The methods of excavation, transportation, and placement can affect the physical properties of the reconstructed soil. This is a major factor affecting crop performance. The relationship of compacted subsoils and poor crop performance has been identified, and deep tillage is used when compaction is suspected. Illinois researchers have investigated several methods to detect and quantify soil physical problems. Experience has shown that soil strength, as collected with the deep profile penetrometer, is the most efficient and reliable measure for reconstructed soils. A three dimensional view of the soil can be rapidly generated when this information is collected with a GPS database. Some mine operators are currently using soil strength to more efficiently prescribe the deep tillage, where needed, at the proper depths.

Introduction

Current reclamation practices include a variety of methods to reconstruct soils. The methods of excavation, transportation, and placement can affect the physical properties of the reconstructed soil. This is a major factor affecting crop performance (Jansen et al. 1985). The relationship of compacted subsoils and poor crop performance has been identified with deep tillage to relieve subsoil compaction and improve productivity, becoming an accepted practice in the industry. Deep tillage is commonly used in Illinois as the final step in the reclamation process for row-crop acres. The yield effects of tillage depth, reclamation methods, and time have been studied (Dunker et al. 1995; Hooks et al. 1992). In general, it has been concluded that productivity success is directly related to the physical condition of the soil or the level and extent of compaction. In the early years of Illinois reclamation research, it became apparent that, in addition to long-term yield testing, a more efficient method for evaluation of these soils was needed. Several parameters were considered and have been tested in varying degrees. A discussion considering advantages and limitations is presented in this paper.

Parameters Considered

Crop Performance

Annual crop yields have been measured since 1978 by Illinois researchers on various test plots and whole fields. Differences in yields are most dramatic in years of high moisture stress. In years of little stress, moderate, if any, yield differences can be measured. Hence, yield tests over several years are necessary to reliably detect a minesoil problem. Figure 1 illustrates this with yield differences between years within treatment sometimes greater than the differences between the compacted (Scraper) and a favorable (Wheel-Conveyor) minesoil.

Whole field yield comparisons (grain elevator weight ticket measurement) are easily tabulated but are only useful for a field to field comparison. Specific within field problem areas cannot be identified. GPS and yield monitors can be used to gather more specific information. Crop performance evaluations are subject to weather variability, and tests over time are required. Even then, it can be difficult to determine if yield differences are due to a soil problem, a management error, or a weather anomaly.

Visible Differences

Those who have been involved with monitoring crops during the growing season over time can attest to the fact that treatment or soil differences are easily detectable by plant moisture stress symptoms.

Signs of stress may occur for a long period of time or only a few days depending on the year. Symptoms may not be present in the early morning hours but are observable at midday. After long periods of stress, the symptoms remain through the night and are present in the morning. The plant response to soil differences is easily detected by

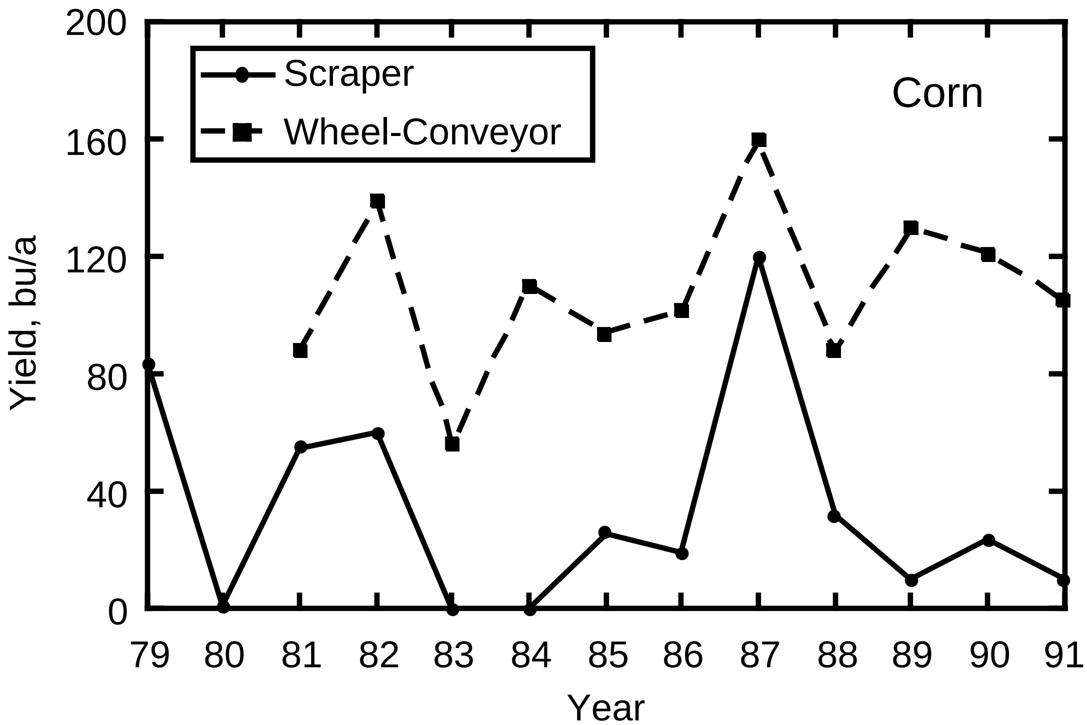


Figure 1. 1979 to 1991 Corn Yields: Compacted and Noncompacted Minesoils.

those who frequent the fields but it is difficult to quantify. The year, the time of year, and the time of day are critical to capture these observable differences. Well-timed visual and infrared aerial photography has been used by researchers for this purpose. Through digitization, this information can be quantified. Though costly and time consuming, differences can be measured and compared statistically. Canopy temperatures also were measured with a hand-held infrared thermometer (Thompson et al. 1984). This also generated measurable differences, but again the timing and the year were critical. With considerable effort and critical timing, observable differences can be measured. The quantification of visible differences is possible but it is impractical for the mine operator.

Soil Characteristics

A constant rate penetrometer was developed to serve the need to quantify physical properties of reconstructed soils (Hooks and Jansen 1986). Thompson (1987) studied the relationship of bulk density and soil strength to corn root length density on reclaimed soils. That study concluded that while both bulk density and soil strength correlated well with corn root length density, soil strength data was easier to collect in the numbers required to accurately assess reconstructed soils. Bulk density sampling by the core method is questionable on reclaimed soils, especially deep tilled soils. In some cases, there is a resultant fluff in the soil that may be as much as 20 inches. With this dramatic increase in macroporosity, percolation increases and the subsoil can be easily compressed. Another possibility is that the tillage shatters the subsoil but large peds of compacted material remain with large fissures and macropores between them. Some minesoils with bulk density levels higher than acceptable for natural soils are productive. Bulk density has proven to be an unreliable test across several minesoils. Figure 2 shows that there is a lack of correlation between bulk density and yield across several depths of tillage. The correlation of soil strength and yield from the same data set is significant (Figure 3).

The reliability of in situ soil strength measurements has been questioned (Mulqueen et al. 1977). Mulqueen also acknowledged the ease of sampling and suggested the measurement of moisture content. Perumpal (1983) presented a summary of many studies with the cone penetrometer. These studies relate the effects of moisture content, density, texture, and even organic matter to cone index. It appears that it is generally accepted that soil

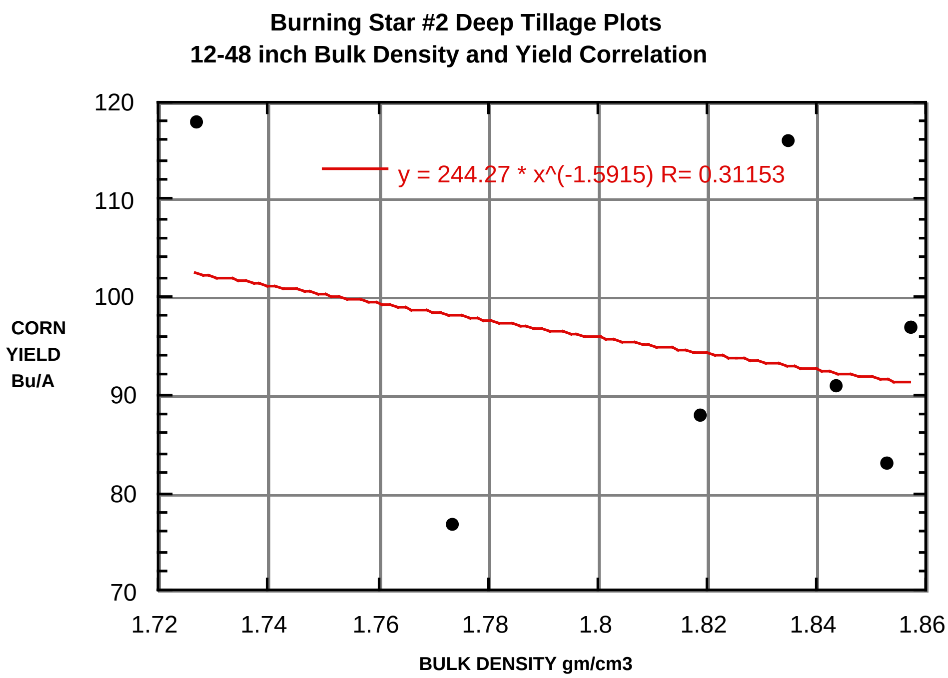


Figure 2. Subsoil Bulk Density vs 10 Year Corn Yield Means.

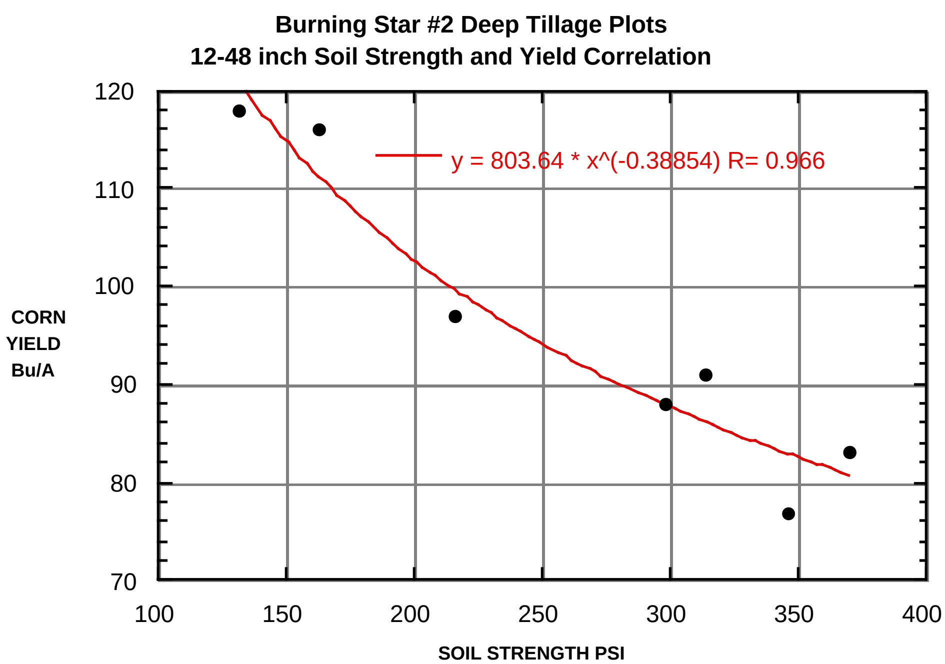


Figure 3. Subsoil Soil Strength vs 10 Year Corn Yield Means.

strength measurements are most reliable at or near field capacity. From an engineering or physical approach, soil strength is a true value that should be predictable with given values of moisture content, texture, density, etc. In this study, soil strength is approached as a relative value that is a composite of the effects of moisture content, texture, density, etc. Moisture content is a major factor in soil strength when it is well below field capacity. However, when the data is collected in the spring, when soils are the most uniformly moist, minor differences in soil moisture between treatments are considered to be a reflection of the soil/environment interaction and a valid part of the composite value “soil strength.”

Minesoil productivity is related to the level and extent of compaction. Soil strength can determine the level of compaction in PSI, which can be related to plant root penetration. Soil strengths above 300 PSI are highly restrictive to root growth and are an indication that a soil physical problem exists. The depth to a root limiting zone also can be determined, which relates to the available soil volume favorable for plant growth. When combined with a ground position database (GPS or surveyed) a three dimensional view of the reconstructed soil can be generated. This allows the identification of critical compaction levels, their extent, location, and depth in a field. The data is collected in real time with the computer and data acquisition system. Minimal effort and data manipulation is required to generate a three dimensional field compaction map. Figure 4 is an example for a 24 acre field on topsoil over wheel spoil. Depth "slices" were generated with 6 inch segment means. The west half of this field was deep tilled to 32 inches and the east half was not tilled. The 12 to 18 inch segment is just below the topsoil and indicates that the west side is uniformly favorable for plant root growth with PSI levels below 300. The east side is highly compacted and few roots will penetrate below this depth. The 24 to 30 inch segment indicates a similar distribution of compaction but excessive levels still exist on the east side. The 36 to 42 inch segment is below the depth of excessive compaction with fairly uniform PSI levels at 300 or less. This is below the depth of tillage on the west side and is typical of wheel construction with compaction below the topsoil to the depth affected by spoil grading. Compaction can be efficiently managed with this information that indicates the east half of the field is a problem area needing tillage to a depth not exceeding 36 inches.

Summary

Soil strength as measured with the deep profile penetrometer has proven to be the most efficient and useful parameter for the detection and evaluation of compaction.

References

Dunker, R.E., C.L. Hooks, S.L.Vance, and R.G. Darmody. 1995. Deep Tillage Effects on Compacted Surface-Mined Land. Soil Science Society of America Journal. 59: 192-199.

Hooks, C.L., and I.J. Jansen. 1986. Recording cone penetrometer developed in reclamation research. Soil Sci. Soc. Am. J. 50:10-12.

Hooks, C. L., R. E. Dunker, S. L. Vance, and R. G. Darmody. Rowcrop Response to Truck and Scraper Hauled Root Media Systems in Soil Reconstruction. 1992 National Symposium on Prime Farmland Reclamation, Aug. 10-14, 1992, St. Louis, Missouri.

Jansen, I.J., R.E. Dunker, C.W. Boast, and C.L. Hooks. 1985. Row crop response to soil horizon replacement. Symposium on the Reclamation of lands Disturbed by Surface Mining: A Cornerstone for Communications and Understanding. Science Reviews Limited, Middlesex, England p. 410-430.

Mulquween,J., J.V. Stafford, and D.W. Tanner 1977. Evaluation of penetrometers for measuring soil strength. J. of Terramechanics 14: 137-151.

Perumpral, J.V. 1983 Cone penetrometer application-a review Am. Soc. Agr. Engr. Winter meeting paper # 83-1549.

Thompson, P.J., I.J. Jansen, and C.L. Hooks. 1987 Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. Am. J. 51:1288-1293.

[1]Charles Hooks. Program Director, SIU/UI Cooperative Reclamation Research Center. Coal Research Center SIUC. MS 1976 Forest Science, U of I. 17 Years reclamation research.

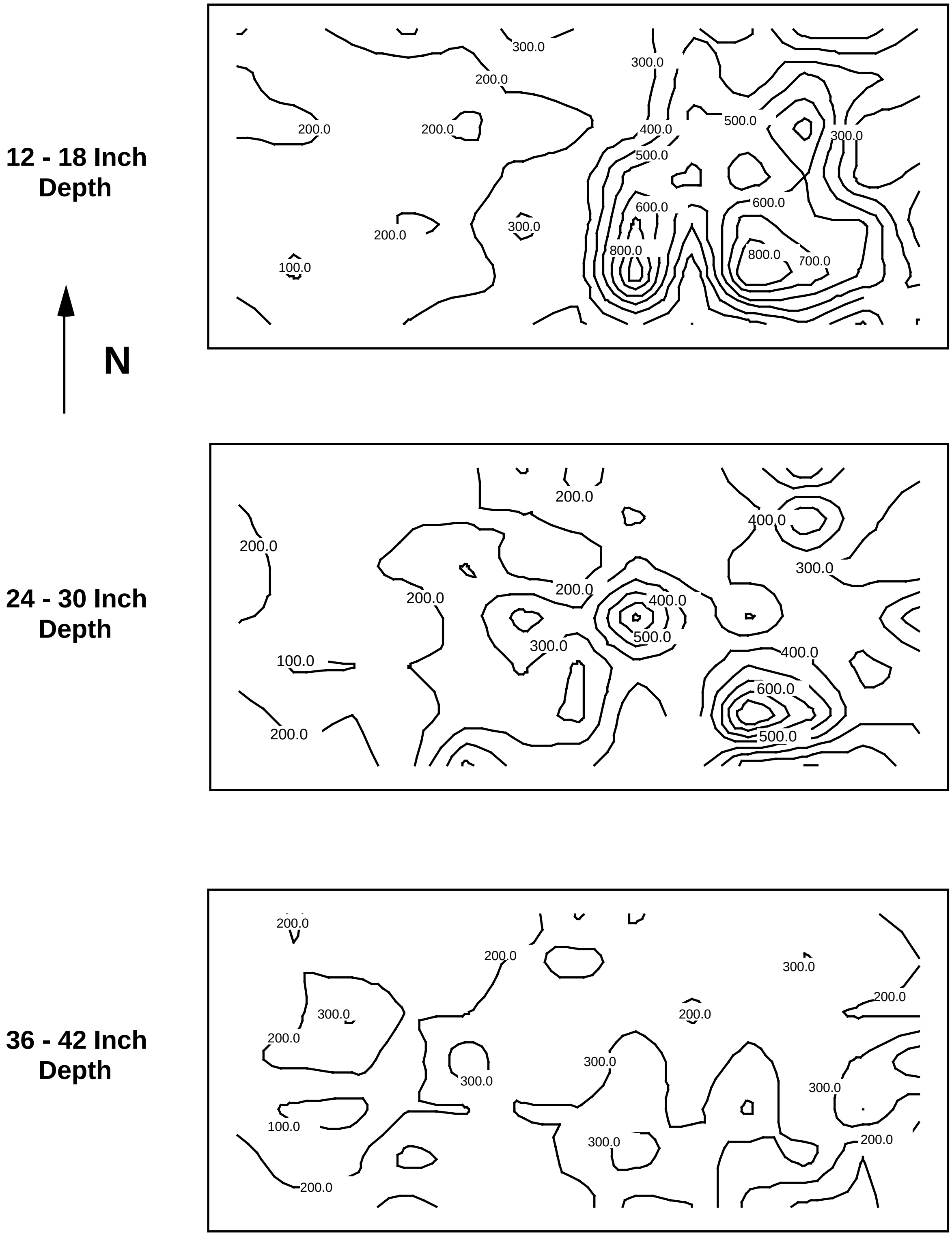


Figure 4. Soil Strength Depth Segment Contour Maps

EFFECT OF RECLAMATION METHOD ON MINESOIL PRODUCTIVITY IN ILLINOIS

R. E. Dunker', C. L. Hooks, and R. G. Darmody Department of Crop Sciences and
Department of Natural Resources and Environmental Sciences
University of Illinois at Urbana-Champaign

Abstract

Reclamation studies have shown that poor soil physical condition is the most limiting factor to successful row crop production on mined land. Critical to success are selection of the best available soil materials used in soil construction and a material handling method that will minimize compaction. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well as low stress years. Total crop failures have occurred on high strength soils in years of weather stress. Deep tillage practices have been successful in improving compacted soils, but it is preferable to avoid compaction when the soil materials are handled. Soil strength measurements with a cone penetrometer have proven to be useful tools in evaluating rooting media and reclamation practices.

Introduction

This paper will report and summarize to date research work done by the University of Illinois concerning rowcrop response to various reclamation practices. Discussion of results will focus on reporting yield responses, observations, and summary to date from the Illinois work. There will be little attempt to distinguish between prime and non-prime farmland, even though prime farmland is addressed separately in federal legislation. The principles of reclamation for rowcrops and, to a large degree, the potential for success are quite similar for prime and non-prime farmland. Most prime farmland must by law be reclaimed to row crop capability, but not all row crop reclamation is on prime farmland.

Selection of Soil Materials

Segregation and replacement of horizons from the premine soils is a practice that is required by law under many conditions. Early reclamation research was focused on the evaluation and characterization of selected soil materials to be used for soil horizon replacement or substitution, if the substituted soil material could be shown to be as productive as the natural soil horizon it replaced. Construction of minesoils with good quality soil materials and desirable physical properties is essential to attaining productivity levels necessary for bond release.

Greenhouse evaluation revealed that replacement or alteration of the claypan subsoils of southern Illinois would increase crop growth by enhancing the chemical and physical properties of mined land (Dancer and Jansen, 1981; McSweeney et. al., 1981). Topsoil materials generally produced somewhat greater plant growth than did mixtures of B and C horizons, but the B and C horizon mixtures were commonly equal to or better than the B horizon materials alone. The natural subsoils of this region are quite strongly weathered and acid, or are natric and alkaline (Snarski et. al., 1981). The alternative material mixed in or substituted was generally much higher in bases than the acid soils and lower in sodium than the natric soils. Liming and fertilizing of the soil horizon material produced a good yield response and reduced the need for material substitution. McSweeney et al. (198 1) also got a favorable greenhouse response to blending of substratum materials with B horizon materials from the high quality Sable soils (Typic Haplaquolls) in western Illinois, This response to blending was less pronounced than that observed with materials from the Alfisols in southern Illinois.

Most of the Illinois research has centered around field experiments to evaluate row crop response to soil replacement and various reclamation practices. Premine soils ranged from the highly productive deep loess soils developed under prairie vegetation (Mollisols) at the western Illinois sites to the lighter colored, more strongly developed Alfisols at the southern Illinois sites. Corn (*Zea mays* L.) and soybeans *(Glycine max* (L.) Merr) were grown on these newly constructed soils to evaluate productivity. Following up on the greenhouse studies, most of the early field studies addressed the issue of topsoil and subsoil horizon replacement.

Topsoil replacement has generally been beneficial for seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials (Jansen and Dancer, 198 1). Yield response to topsoil replacement has ranged from strongly positive to strongly negative. At the Norris Mine in western Illinois, scraper placement of 18 in, of dark prairie topsoil over graded wheel spoil resulted in a significant positive corn yield response in three of four years with irrigation and two of four when not irrigated (Table 1). Soybeans responded favorably to topsoil in one of the two years studied (Dunker and Jansen, 1987a). Significant negative yield responses to topsoil occurred in years of weather stress. Year to year variation in corn yield was considerably greater on the tmirrigated topsoil than the umrrigated wheel spoil. Compaction caused by the use of scrapers to replace topsoil is assumed to be the reason for low topsoil yields in years of weather stress. The zone directly below the topsoil has a bulk density of 1.7 to 1.9 Mg m3 and very low hydraulic conductivity.

Table 1. Corn yields in response to irrigation and topsoiling at Norris Mine in western Illinois.

Treatment	1979 bu/ac	1980 bu/ac	1981 bu/ac	1983 bu/ac	Mean bu/ac
Irrigated Topsoil/Wheel Spoil	191 a	166 a	175 a	193 a	181 a
Unirrigated Topsoil/Wheel Spoil	155 b	70 d	165 a	20 c	102 c
Irrigated Wheel Spoil	142 b	144 b	105 b	169 a	140 b
Unirrigated Wheel Spoil	100 c	89 c	109 b	70 b	92 d
Undisturbed Sable soil	156 b	124 b	173 a	70 b	131 b

Values followed by the same letter within a column are not significantly different at the 0.05 level.

At the Norris topsoil wedge experiment, A horizon material was replaced over wheel spoil by scrapers in thickness ranging from 0 to 24 in. There was a significant positive yield response to increasing topsoil thickness for corn, but not for soybeans. Year by year results showed positive relationships to topsoil thickness in years of favorable weather, but negative responses in years of moisture and temperature stress (Jansen et al., 1985).

At Sunspot Mine, in western Illinois, topsoil and B horizon replaced over dragline spoil was evaluated over an eight year period. Soil treatments consisted of 15 in. of topsoil replaced over replaced B horizon; 15 in. of topsoil replaced directly over dragline spoil; 36 in. of B horizon replaced directly over dragline spoil; and dragline spoil only. Bulldozers pushed the soil materials onto the plot areas; it is important to note that scrapers were never allowed directly on the plots at any time during construction. An undisturbed tract of Clarksdale soil (Udollic Ochraqualf) was used as an unmined comparison. Topsoil replacement resulted in significantly higher corn yields in four out of eight years when replaced over B horizon materials and six of eight years when topsoil was replaced directly over dragline spoil (Dunker and Jansen, 1987b). Corn grown on the topsoil replaced treatments had a higher percent stand at harvest, fewer barren stalks, and a higher shelling percentage than corn on the non-topsoil treatments. Soybean yields on the topsoil replaced treatments were significantly higher than yields from both non-topsoil treatments in six of seven years, The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale in five of seven years while the B horizon treatment without topsoil produced corn yields comparable to the undisturbed in only one year, The dragline spoil was unable to equal corn tmdisturbed Clarksdale yields in any of the years studied, regardless of topsoil placement (Table 2). Fehrenbacher et al., (1982)

Table 2. 198 l-86 average corn and soybean yields in response to topsoil and subsoil replacement at Sunspot Mine in western Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Topsoil/B Horizon	36 b	130 a
Topsoil/Dragline Spoil	31 c	110 b
B Horizon only	27 d	86 c
Dragline Spoil only	17 e	65 d
Undisturbed Clarksdale soil	40 a	135 a

Values followed by the same letter within a column are not significantly different at the 0.05 level.

found that corn roots penetrated significantly deeper in the B horizon materials than the dragline spoil and that bulk densities were significantly higher in the graded dragline spoil than the replaced B horizon at depths of 22 in. and deeper. Bulk densities between the B horizon material and the undisturbed Clarksdale were similar. It is not possible to determine whether the favorable response to the B horizon treatment was due to the B horizon material or to the lower soil strength that resulted from the careful handling.

Response to soil horizon replacement in southern Illinois has been less dramatic than has been observed at the western Illinois sites (Table 3). This is understandable considering that A horizons are more highly weathered and average 8 to 9 inches in depth compared to 15 to 18 inches in the highly productive western Illinois soils. At River King in southern Illinois, topsoil replaced by scrapers over wheel spoil significantly increased corn yields in only one of eight years and soybeans in three of six. Row crop yields were lower than productivity goals and soil physical problems became suspect.

Table 3. 1978-85 average corn and soybean yields in response to topsoil and subsoil replacement at River King Mine in southern Illinois.

Treatment	Soybeans bu/ac	corn bu/ac
Scraper Placed Topsoil/Wheel Spoil	18 a	54 a
Wheel Spoil only	13 b	52 a
Scraper Placed Topsoil & Root Media	13 b	33 b

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Soil horizon replacement and thickness of soil materials from southern Illinois has been studied at the Captain Mine where the natural soils have chemical and physical problems that limit productivity. The Captain wedge experiment was used to evaluate corn and soybean yield response to thickness of scraper placed rooting medium (0 to 48 in. thick) over graded cast overburden, with and without topsoil replaced. Yields of both corn and soybeans increased with increasing thickness of hauled material to about the 24 to 30 in. depth. Meyer (1983) found very few roots below the 24 in. depth and found that roots in the subsoil were largely confined to desiccation cracks. The subsoil physical condition can best be described as compact and massive with very high bulk density levels and poor water infiltration. Soybean yields on the scraper placed root medium with and without topsoil were significantly lower than a nearby undisturbed tract in all seven years of the study. Corn yields were comparable to the undisturbed site in three of the years that can be characterized as low stress years (Table 4).

Table 4. 1979-86 average corn and soybean yields in response to scraper placed topsoil and root media replacement at Captain Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Scraper Topsoil/Scraper Placed Root Media	13 b	33 b
Scraper Placed Root Media only	12 b	38 b
Undisturbed Cisne/Stoy soil	27 a	70 a

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Soil Physical Properties

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils. Indorante et al. (1981) in a comparison of mined and unmined land in southern Illinois, reported that reconstructed mine soils studied had higher bulk densities and they lacked any notable soil structure. Natural improvement in compacted mine soils is a slow process, Thomas and Jansen (1985) studied soil development in eight mine spoils ranging in age from 5 to 64 years looking at physical, chemical, and micromorphological properties. All eight minesoils showed some evidence of soil development, but depth of structure development ranged from only 1.5 in. at the 5 year old site to 14 in. at a 55 year old site. No evidence of clay translocation attributable to soil development was found. Color and texture pattern changes were determined to be a result of the mixing of materials rather than developmental processes.

Illinois has an abundance of high quality soil materials to use for soil construction, and row crop success on mine land has been as dependent upon the method by which soil horizons have been excavated and replaced as the quality of soil materials selected. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well as low stress years, Soil horizon segregation and replacement in Illinois has generally shown a moderate positive yield response in most cases; however, the soil physical condition that is established during soil construction is clearly a more significant concern (Jansen and Dancer, 1981).

McSweeney and Jansen (1984) studied the soil structure patterns and rooting behavior of corn in constructed soils. On a site that received extensive grading of the subsoil, the subsoil was severely compacted and massive. Root penetration into these subsoils was extensively horizontal instead of the normal vertical direction. Cross sections of the roots were noticeably flattened and compressed. McSweeney described a "fritted" soil structure in areas where soil materials were handled by a mining wheel-conveyor-spreader system where only minimal grading is necessary. Fritted structure was defined as an artificial soil structure consisting of rounded loose aggregates formed by the action of the wheel excavator and the subsequent tumbling at each drop point on the conveyor system. The soil conveyor system resulted in a low strength soil high in macropores. Although subject to compaction at the upper surface, the extensive void spaces between aggregates allow for excellent root penetration. Four year average corn and soybean yields on these plots with well developed fritted structure were equal to or better than yields obtained on nearby natural soils (McSweeney et al., 1987). By contrast, corn and soybean yields from a nearby set of plots with root media replaced entirely by scrapers were unable to produce comparable yields to the undisturbed soil in any of these four years. The rooting materials for both experiments were similar with the major difference being in the way the soil materials were replaced.

The Captain Mix Plots, constructed using the wheel-conveyor-spreader, were designed to follow up a series of greenhouse experiments which began in 1977. Greenhouse evaluation revealed that alteration of the claypan soils in southern Illinois would increase crop growth by enhancing the chemical and physical properties of the reclaimed land. The Captain Mix Plots consist of several treatments that are composed of differents depth mixes of the original soil profile replaced by the conveyor-spreader. Excellent corn and soybean yields have resulted on these low strength soils in high stress as well as low stress years. Penetrometer data from the Mix Plots reflect the excellent physical condition resulting from placing rooting materials with the wheel-conveyor system (Table 5). Rowcrop yields comparable to those obtained on nearby undisturbed soils were achieved in all eleven years of this study (Dunker et al., 1992). Topsoil replaced with the soil spreader on these plots only infrequently produced any significant yield response (Table 6).

Table 5. Mean penetrometer resistance values for soil treatments constructed with wheel-conveyor-spreader on the Captain Mix Plots.

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	36-44" Depth PSI
Topsoil/3 ' Mix	179 abc	97 d	77b	98 b
Topsoil/10' Mix	183 ab	136 bc	91 b	96b
Topsoil/15' Mix	210 a	161 ab	125 a	111 ab
Topsoil/20' Mix	219 a	176 a	117a	108 ab
10' Mix	135 c	103 b	100 ab	170 a
20' Mix	121 c	110 cd	101 ab	112 ab

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Table 6. 198 l-9 1 average corn and soybean yields in response to soil treatments constructed with wheel-conveyor-spreader at Captain Mine in southern Illinois.

Treatment	Soybeans bu/ac	corn bu/ac
Topsoil/3' Mix	29 a	113 a
Topsoil/10' Mix	27 ab	109 a
Topsoil/15 Mix	27 ab	111 a
Topsoil/20' Mix	27 ab	98 b
10' Mix	24 b	100 b
20' Mix	25 ab	102 b
Undisturbed Cisne/Stoy soil	27 ab	112a

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Although the mining wheel-conveyor-spreader system proved successful in constructing productive soils after surface mining, it does not offer a generally applicable solution to the problem of restoring land to agricultural productivity after mining. It is a very inflexible system which can not be used at most mine sites. Evident options are to either develop a method by which excessively compacted soils can be ameliorated to a significant depth or to develop other material handling options which will produce soils with good physical characteristics and will be more cost competitive and applicable than the conveyor system.

As an alternative to the wheel-conveyor system, corn and soybean response to mine soil construction with rear-dump trucks and scraper pans was studied from 1985-91 at the Denmark Mine in southern Illinois (Hooks et al., 1992). Two truck-hauled treatments, one which limited truck traffic to the spoil base only, and one which allowed truck traffic on the rooting media as it was placed were evaluated. A third treatment consisting of entirely scraper hauled rooting media was included. The rooting media was comprised primarily of the B horizon of the natural unmined soil and all treatments had 8 inches of topsoil replaced on the rooting media using dozers to prevent wheel traffic compaction. Significant differences in soil strength, a measure of soil compaction, and rowcrop yields were observed among treatments over the five year period. The lowest soil strength and highest rowcrop yields occurred on the truck without traffic treatment. Soil strength and yield response were similar for both the truck with surface traffic and the scraper treatments (Table 7 and Table 8).

Table 7. Mean penetrometer resistance values for soil treatments on the Denmark Plots.

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	36-44" Depth PSI
Truck Placed Root Media w/o Traffic	182 b	189 b	161 b	172 b
Truck Placed Root Media with Traffic	223 ab	227 ab	213 ab	217 ab
Scraper Placed Root Media	272 a	275 a	258 a	258 a

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Table 8. 1985-91 average corn and soybean yields in response to rear-dump truck placed and scraper placed root media at Denmark Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Truck Placed Root Media w/o Traffic	20 b	99 a
Truck Placed Root Media with Traffic	16 c	71 b
Scraper Placed Root Media	16 c	63 b
Undisturbed Cisne/Stoy soil	26 a	103 a

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Severe compaction and compacted interfaces between soil layers have proven to be major problems which can limit the productivity of reclaimed soils. A truck handling system, which handles both topsoil and subsoil in one operation, was evaluated at Cedar Creek Mine in western Illinois from 1992-94. During plot construction, each rear-dump truck was loaded with the equivalent of 36 in. of subsoil and 12 in. of topsoil on top of the load. Subsoil and topsoil dumped in one operation eliminated the need for topsoil replacement by scapers. Some mixing of the topsoil and subsoil occurred but the majority of topsoil remained at the soil surface. Thin lenses of topsoil extended into the subsoil material. These lenses could actually encourage root exploration into the subsoil below. Two other treatments, one being rear-dump truck placed subsoil with scraper placed topsoil and the other rear-dump truck placed subsoil without topsoil, were included in the evaluation. Penetometer resistance data collected in 1994 indicated that wheel traffic from the use of scrapers to replace topsoil had a negative impact on the underlying placed subsoil. Soil strength values increased due to scraper traffic by 82% over that of the one operation rear-dump system. The 1992-94 mean yields indicate the system using rear-dump trucks to simultaneously replace both rooting media and topsoil is superior to using scrapers to replace topsoil over hauled rooting media. Results also show a significant response to topsoil replacement using this system (Table 9).

Table 9. 1992-94 average corn yields in response to rear-dump truck placed root media and topsoil and scraper placed topsoil at Cedar Creek Mine in western Illinois.

Treatment	**Corn bu/ac**
Truck Placed Root Media with Topsoil	159 a
Scraper Placed Topsoil over Truck Placed Root Media	131 b
Truck Placed Root Media w/o Topsoil	**130 b**

Values followed by the same letter within a column are not significantly different at the 0.05 level.

Thompson et al. (1987) used root length and root length densities to evaluate how bulk densities and soil strength values are predictors of root system performance. Because root restriction is generally the factor most important in limiting crop performance in mine soils, determining the suitability of soils for root system development could be a useful method of evaluating reclaimed soils. Soil strength was evaluated with the use of a constant rate recording cone penetrometer developed by Hooks and Jansen (1986). Results indicate that both penetrometer resistance and bulk density are useful predictors of root system performance in soils. They are especially useful in predicting root extension into deeper regions of the root zone. Penetrometer resistance and bulk density were highly correlated in the lower root zone, but poorly correlated nearer the soil surface.

Penetrometer data has proven useful for evaluating the soil strength effects of several reconstruction methods, of high traffic lanes on reclaimed areas, and of tillage methods for alleviating compaction (Vance et al., 1987). Soil strength values decreased with decreasing traffic. Scraper soil material handling systems produced the highest soil strengths; soils from truck-haul systems were intermediate; and soils built by a wheel-conveyor-spreader system had the lowest soil strength.

The relationship between soil strength levels measured with a recording cone penetrometer and five-year corn and soybean yields of four reclamation methods was studied at two mine sites in southern Illinois (Vance et al., 1992). Reclamation treatments included the wheel-conveyor system, truck-hauled root media with and without surface traffic, and a scraper-hauled rooting media system. Penetrometer measurements have resulted in wide ranging values between reclamation treatments and corresponding wide ranging values in crop yield. Correlation of penetrometer resistance with crop yield has been significant within most years for both corn and soybeans. Reclamation treatments with the highest soil strength had the lowest yields; those with the lowest soil strength had the highest yields. Average soil strength over the 9 to 44 in. profile depth was highly correlated with five-year mean yields across reclamation treatments.

Summary

In summary, results from the Illinois work shows that achieving mine land productivity is possible if reclamation plans are designed to minimize compaction, use good quality soil materials, and use high management levels (herbicides, fertility, adapted crop varieties) in rowcrop production. Illinois has an abundance of high quality materials to use for soil construction and row crop success on mined land has been dependent upon the method by which soil horizons have been replaced and the quality of the materials selected. Excellent corn and soybean yields have been achieved on low strength soils in high stress as well as low stress years. However crop failures have occurred when reclamation methods result in mine soils with high soil strength. Truck handling of rooting media with limited surface traffic has resulted in a more productive and less compacted soil compared to a high traffic scraper haul system for replacing root media. Compaction may be unavoidable in some reclamation systems. Illinois has continued deep tillage studies since 1984 to address this issue.

Literature Cited

Dancer, W. S. 1984. Soil tests for predicting plant available phosphorous in newly reclaimed alkaline minespoil. Commun. in Soil Sci. Plant Anal. 15(11), 1335-1350.

Dancer W. S. and I. J. Jansen. 1981. Greenhouse evaluation of solum and substratum materials in the southern Illinois coal field. I. Forage crops. Journal of Environmental Quality. 10:396-400.

Dunker, R. E. and I. J. Jansen. 1987a. Corn and soybean response to topsoil replacement and irrigation on surface-mined land in western Illinois. J. Soil and Water Cons. 42:277-28 1.

Dunker, R. E. and I. J. Jansen. 1987b. Corn and soybean response to topsoil and rooting medium replacement after surface miming. Proceedings, National Symposium on Mining, Hydrology, Sedimentology and Reclamation. Springfield, Illinois. December 6-11, 1987. Pp 83-89.

Dunker, R. E., I. J. Jansen, and W. L. Pedersen. 1988. Corn hybrid responses to reconstructed mine soils in western Illinois, Agron. J. 80:403-410.

Dunker, R. E., C. L. Hooks, S. L. Vance and R. G. Darmody. 1992. Rowcrop resonse to high traffic vs low traffic soil reconstruction systems. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 1 l-18.

Fehrenbacher, D. J., I. J. Jansen and J. B. Fehrenbacher. 1982. Corn root development in constructed soils on surface mined land in western Illinois. Soil Sci. Soc. Am. J. 46:353-359,Hooks, C. L. and I. J. Jansen. 1986. Recording penetrometer developed in reclamation research. Soil Sci. Soc. Am. J. 50: 10-12.

Hooks, C. L., R. E. Dunker, S. L. Vance, and R. G. Darmody. 1992. Rowcrop response to truck and scraper hauled root media systems in reconstruction of surface mine soils. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 19-24.

Indorante, S. J., I. J. Jansen, and C. W. Boast. 1981. Surface mining and reclamation: Initial changes in soil character. J. Soil and Water Conserv. 36:347-351.

Jansen, I. J., and W. S. Dancer. 1981. Row crop response to soil horizon replacement after surface mining. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, Lexington, Kentucky. Dec 7-l 1, 1981.

Jansen, I. J., R. E. Dunker, C. W. Boast, and C. L. Hooks 1985. Rowcrop yield response to soil horizon replacement. Symposium on Reclamation of Lands Disturbed by Surface Mining: A Cornerstone for Communication and Understanding. Science Reviews Limited. Middlesex, England. Pp. 410-430.

McSweeney, K., I. J. Jansen and W. S. Dancer. 1981. Subsurface horizon blending: An alternative strategy to B horizon replacement for the construction of post-minesoils. Soil Sci. Soc. Am. J. 45:795-799.

McSweeney, K. and I. J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. Soil Sci. Soc. Am. J. 48:607-612.

McSweeney, K., I. J. Jansen, C. W. Boast, and R. E. Dunker. 1987. Row crop productivity of eight constructed minesoils. Reclamation and Revegetation Research. 6: 137-144.

Meyer, J. J. 1983. Corn root behavior in soils constructed after surface mining for coal in southern Illinois. Unpubl. M.S. Thesis, Univ. of Ill., Urbana, Illinois.

Peck, T. R., W. M. Walker, and L. V. Boone. 1969. Relationship between corn (Zea mays L.) yield and leaf levels of ten elements. Agron J. 6 1:299-30 1.

Public Law 95-87. 1977. Surface Mining Control and Reclamation Act. U. S. Code Vol. 30, Sec 1265.

Snarski, R. R., J. B. Fehrenbacher, and I. J. Jansen. 1981. Physical and chemical characteristics of pre-mine soils and post-mine soil mixtures in Illinois. Soil Sci. Soc. Am. J. 45:806-812.

Thomas, D. and I. J. Jansen. 1985. Soil development in mine spoils. J. Soil and Water Conserv. 40:439-442.

Thompson, P. J., I. J. Jansen, and C. L. Hooks. 1987. Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. Am. J. 5 1: 1288-1293.

Vance, S. L., I. J. Jansen, and C. L. Hooks. 1987. A comparison of soil construction methods used after surface mining for coal. Proceedings, National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. Springfield, Illinois. December 6-11, 1987. Pp. 149-152.

Vance, S. L., R. E. Dunker, C. L. Hooks, and R. G. Darmody. 1992. Relationship of soil strength and rowcrop yields on reconstructed surface mine soils. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 35-42.

'Robert Dunker, Manager, Crop Sciences Research and Education Center, University of Illinois. MS Agronomy 1986. 17 years with Illinois Reclamation Research Program.

SMALL MINES AND FUTURE TECHNIQUES

Mark Yingling[1]
Black Beauty Coal Mine
Evansville, Indiana

Abstract

Many of the remaining surface mineable coal reserves of the Midwest are located in small non-continuous arms (“pods"). In order to economically recover these resources while providing for proper reclamation, it will take innovative approaches that incorporate many factors. Some of these include planning in the property control; forethought in the permitting process with regards to soil handling land uses, drainage control, blending to unaffected areas, etc.; engineered mine plans that incorporate the overall reclamation requirements; and flexibility/understanding by the regulatory agencies.

Introduction

Black Beauty Coal Company started mining in the late seventies on both small and mid-sized reserve blocks consisting mostly ofleased property on prime farmland. Over the yeas, activities have taken place at more than 40 locations using both Company mining and Contract mining. Many of these mines have been made up of small noncontinuous mining areas (pods). In most cases these pods are defined by topographic ridges with multiple landowners where the coal subcrops on three or four sides. Each area is divided into various land units (landowner/soil capability/land use). Prime farmland/cropland at 0% - 5% slopes will lie along the top and sides of the ridge. This then transitions to less capable soils (cropland, pasture, or forest/wildlife) at the edges (6% - 15%), then on into the subcrop that includes highly eroded upland drainage ways (noncropland capable/pasture, forest, or wildlife) where the soil depths are shallow and slopes are steep (15% - 30%).

Pod mining is particulary challenging in that it involves all of the details of area mining then adds the intricacies of multiple land units (landowner/land capability/land use) all within a much smaller reserve base. Given the small reserve base, cost control measures are extremely important. This not only affects the mining method but also involves all other aspects of the mining process, i.e., land leasing, permitting, mine operations, reclamation, and bond release.

Property Control

In pod mine situations, property is usually not owned since the mining is relatively short-lived and the landowner usually wishes to retain ownership. Land is normally controlled under some lease agreement where the landowner is compensated for coal mined and temporary loss of the use of land. In evaluating this cost, companies must keep in mind not only the area to be mined but also the support area required (basins, diversions, stockpiles, roads, etc.) since support and mined land is treated (regulatorily) the same. Regarding reclamation and prime farmland, the lease needs to specifically address post-mine land use comments (changes that the landowner may want to see in the permit) and farming arrangements. Once all the property is controlled to support the mining of the pod, considerable planning must go into how the different properties interact. This will include pre-mine vs. post-mine considerations for drainage, erosion control, field layouts, and property access.

Engineering/Permitting

From a reclamation standpoint, the areas of engineering/permitting for which pod mines are especially sensitive include soils, contours and land units (landowner, land capability, and land use).

Soils

Pod mines will usually run along ridges where soil types will start with prime farmland (0%-5 %) at the top and sides, then go to less capable soils (6% - 15%) at the edges, and end up at the sub-crop with highly eroded steep slopes (15% - 30%). Once the various soil capabilities are mapped (SCS soils map), existing soil quantifies and qualifies must be evaluated for the areas to be mined. At this point it must be fully understood that the area will not be mined or reclaimed according to the Soils map but that with planning, the overall capability of the affected land will be improved. Given this understanding a plan must be prepared that permits mixing of various soils, provides flexibility in soil handling and allows for the use of soil substitutes.

Soil mixes/substitutes and rooting media may include the original B horizon, a prime, B/C horizon mix, or a non-prime A/B horizon mix. The goal is to use the best rooting media available (within reasonable time and distance constraints) for all the areas to be reclaimed. In most cases there will be a sufficient amount of prime B/C horizon mix to provide all the rooting media for prime and non-prime areas. If a limited amount of higher quality roofing media exists, the better material should concentrated in areas to be reclaimed as prime; areas to be reclaimed to a lesser capability should receive lesser qualifies/quantities. As to soil replacement, as much area as possible should be replaced to prime standards. This will allow for much more flexibility in the post mine land unit placement. This also holds tree for post mine contours.

As to soil handling the permit must allow for removal and placement of soils in a very flexible manner. The plan should allow for disposal of poorer quality rooting media to allow for the use of better. It should also provide for a timing variance when better materials lie ahead of the current mining strips. (This may take added bond to satisfy the regulatory authorities.) The permit needs to allow for loading of upper soil horizons from within the pit and should also allow for removal of B and C horizon benches where a rooting media mix has been approved. The permit should address minimal stockpiling of rooting media in lieu of direct resoiling.

Contours

The permit needs to include planning for swell of mined areas, filling of highly eroded drainage ways, and blending to surrounding unaffected property. A balance must be kept for the various post-mine capabilities. In most cases, post-mine contours can be constructed that allow for maximizing prime farmland slopes while still maintaining pre-mine drainage patterns. These contours can also be planned to provide flexibility in the placement of post-mine land units.

Land Units

As noted earlier, land units are made up of three categories: landowner, land capability, and land use. These three categories thoroughly describe a piece of property. For each landowner there will be various land capabilities (prime, high capacity-Illinois, non-cropland/alt. topsoil) and various land uses (cropland, pasture, wildlife, forest, water, residential, roads and industrial). This gives up to 24 possibilities per landowner and with multiple landowners leads to a very complicated set of data. These pre-mine land units are not geometrically uniform. Instead, they look like a jigsaw puzzle (the Soils map). In the pre-mine situation, landowners do not manage these land units as such - they square the field and take the average. In the post-mine state, the regulations require a separation of these land units by landowner and separate management as to revegetation and bond release requirements. As such, in the permitting process the land units must be precisely quantified.

Operations

Leasing and engineering/permitting provide much of the directions. Operations is where the product is made. One cannot function without the other.

Spoil Placement

The pre-mining condition of many pod areas includes highly eroded drainage ways along the edges. As mining starts at the box-cut then progresses along the ridge, it will begin at, then pass through, many of these draws. During mining and reclamation, these highly eroded areas can be filled, flattened, and blended, then prepared for use in the post mine planned erosion control. These filled areas can also provide flexibility in the post-mine land unit locations. As with soil depths, post-mine contours should be planned to provide as much prime farmland as possible. This will provide for both increased land unit flexibility and reduced erosion control problems/costs. One drawback with increased amounts of prime farmland slope is that the overall slope-length may increase. Regarding prime slopes, these need to be in the 2% - 3% range if at all possible. This will provide for both drainage and moisture retention and allow for settlement without having excessive wet areas. Final grades should always be established in the spoil material to minimize traffic and grading in the rooting media. This will also give a better overall grade and smoother transitions.

Soils Handling

Handling should occur such that the best soils are used for the entire mined areal. This may cause periods of increased graded spoil area but will be balanced by a better final product. Soils should be removed and placed such that compaction is minimized regardless of the post mine capability. Compaction reduction is accomplished by reducing traffic over the rooting media and grading the materials during more favorable conditions. Traffic and grading on the rooting media is reduced by starting with the proper spoil grade.

Reclamation

Reclamation begins during operations. The final grade, soil handling, soil quantities, and soil quality will dictate the efforts required during reclamation.

Planned Erosion Control

Final grade should be planned to accommodate erosion control that compliments the field layouts. Erosion control begins where water initially meets the soil. Erosion is most easily controlled here. Once water is concentrated it becomes harder and more costly to control its affects. In nearly all cases it is best to intercept the flow in holding areas then convey it in a nonerodable material to its outfall point. The use of parallel tile outlet terraces and dry dams is highly recommended. One drawback to these is that under some state regulations terraces must be directed to sediment basins (increased amount of pipe). This seems odd since properly designed terraces have a greater standard retention time and a larger sediment holding capacity than sediment basins.

Revegetation

This is a process that starts with initial reseeding for erosion control, moves through the productivity stage, and ends in final bond release. Given the number and variety of land units and different requirements for each, considerable detailed management must be undertaken. Again, this is a process where the soil fertility and structure is developed, vegetative cover is established, and crop productivity is proven.

Field Layout

Post-mine field layout is based on pre-mine land units. In the pre-mine state these are irregular shaped areas based on soil capability lines, land use boundaries, and property lines. This is exaggerated in pod mines with multiple landowners, especially if each landowner is farming his own property. What is particularly difficult is that the regulations require a miner to reclaim to approximate original contour but also requires the miner to manage these land units separately even though no farmer has ever done this historically. OSM and most states have remedied this situation by allowing certified test plots to represent larger areas. This facilitates proper field layout, better erosion control, and more manageable crop productivity logistics. In addition, in most cases the land that is not being used as a test plot is returned to the landowner to manage under the miner's direction.

Crop Productivity and Bond Release

In the case of prime farmland, bond release is based on minimal grading and soil depth requirements and crop productivity. Crop productivity includes a target yield verses actual productivity. As to the target yield, OSM and most states use a weighted SCS yield by soil type based on the entire permitted area or allow for the use of an adjacent reference area. Illinois, on the other hand, uses a complicated and subjective formula that takes months to calculate and is based on some assumed variables and other uncorroborated information. As to actual crop productivity, as stated previously, OSM and most states allow the use of certified test plots to represent larger land units. This makes multiple landowner pod mining more workable. Illinois does not allow test plots but instead requires whole field harvest and state sponsored crop sampling. This makes multiple landowner crop management extremely complicated and a severe logistical problem.

Opportunities and Challenges

Pod mining can be a legitimate method of mining. Landowners can receive me income for a temporary use of the land that far surpasses normal farming. The property is then returned to its former use or an alternative as agreed upon by the landowner. Given some latitude and regulatory understanding, overall capability of affected areas can also be improved. Several areas that could improve the ability to further develop this type of mining include:

- Less complicated landowner differentiation and more control of the final product by landowner consent.

- More emphasis on overall soil quality, replaced soft depth, and soil handling. This should replace the costly, long and burdensome crop productivity process. Fifteen to 20 years of data has shown that properly handling the right type and amount of soil will lead to a product equal to or better than the pre-mine.
- An averaging of prime, high capability, and lesser capabilities for reclamation and bond release purposes.
- Actual reclamation and bond release credits/incentives for increasing overall capability of affected areas.

---

[1]Mark Yingling is Director of Reclamation and Regulatory Affairs at the Black Beauty Coal Company in Evansville, Indiana. He received his B.S. in Agricultural Engineering in 1984 from the University of Illinois. He has 16 years of reclamation experience.

SURFACE MINING - PRIME FARMLAND SOILS USING MIXED OVERBURDEN

Eddie D. Bearden'
TU Services
Dallas, Texas

Abstract

Mining companies are required by regulation to replace prime farmland by, sequential soil horizon during the reclamation phase of mining. However, by the use of selective handling techniques, prime farmland soils can be produced using mixed overburden. Overburden characterization is performed using gridded geophysical logs and cores to determine the best material available to use during reclamation, A postmine soil mapping project indicated the Grayrock, Grayvar, and Bigbrown soil series at two mine sites in Texas could meet the criteria for prime farmland soils. At the Monticello Winfield Mine, the Grayrock and Grayvar soils on 1 to 5% slopes were declared as prime farmland by the U. S. Soil Conservation Service (SCS) in 1991. The Bigbrown soil series on 1 to 5% slopes was declared a prime farmland soil by the SCS in 1993 at the Big Brown Mine. Postmine prime farmland soils at Monticello Winfield Mine compose 65.9% of the mined area, compared to 38.8% prime farmland soils within the permit area prior to mining. Prime farmland soils at the Big Brown Mine made up 4.7% of the area before mining but 58.6% of the postmine soils. Use of selected overburden material, especially in areas where native soils have low to moderate productivity, is considered a viable alternative based on this and other studies.

Additional Key Words: stratigraphic units, postmine soil mapping, overburden evaluation.

Introduction

Mining companies are required by regulation to replace prime farmland soils by sequential horizons (A and B or C horizons) if the soils have historic cropland use. Regulatory authorities in most states may approve substitute materials in the top four feet of reclaimed soil if this material will produce a soil having as good, or greater, productive capacity as the native prime farmland soils. Productivity of the replaced prime farmland soil must also be proven.

The development of the prime farmland soils concept occurred in the 1970s because of the covering of the nation's best farmlands by concrete as urban areas spread across former cropland. A brief discussion of the criteria for prime farmland soils follows.

Criteria for Prime Farmland Classification

Prime farmland is land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and is available for these uses (the land could be used as cropland, pastureland, rangeland forest land, or other land, but not urban built-up land or water). It occurs in an area which has an adequate growing season and has the soil quality and available water capacity needed to economically produce sustained high yields of crops when treated and managed, including water management, according to acceptable fanning methods. The best farmlands typically are those derived from loessial materials or the grasslands of the Great Plains.

The Natural Resources Conservation Service's State Conservationist in each state has developed criteria for prime farmland soils specific to that state's climate and soils. There are requirements for soil moisture, temperature, pH, drainage and water table, salinity, flooding, slope and erosion, permeability, rock fragments, and calcium carbonate equivalent. This paper will deal with the criteria associated with Texas soils.

Soil Moisture

Texas is divided into moisture zones but, basically, either available water capacity must be equal to or greater than 4 inches in the top 40 inches of soil, or the land must have a developed irrigation water supply that is dependable and meets minimum water quality standards for irrigation water.

Temperature

The soil temperature at a depth of 20 inches is greater than 32' F. All soils in Texas meet this criterion.

Hydrogen Ion Concentration (pH)

The soil has a pH between 4.5 and 8.4 in all horizons within a depth of 40 inches or in the root zone if the root zone is less than 40 inches deep.

Drainage and Water Table

The soil drainage class is either somewhat poorly drained, moderately well drained, or well drained, or the soils lack a high water table that adversely affects production of crops commonly grown in the area or has an installed drainage system that prevents a high water table or poor drainage from adversely affecting the production of crops commonly grown in the area.

Salinity

The soil can be managed so that electric conductivity is less than 4 mmhos/cm in all horizons, and the soil lacks a natric horizon.

Flooding

The soil surface is flooded less than once in two years or for less than two days during the growing season of crops commonly gown in the area.

Slope and Erosion

The soil is not presently gullied, eroded, or severely eroded. The soil has a slope of less than or equal to 5%.

Permeability

The soil has a permeability rate of at least 0.06 inches per hour in the most restrictive horizon in the upper 20 inches.

Rock Fragments

Less than 35% by volume of gravel; less than 10% by volume of cobbles; no stones greater than 10 inches in diameter; or too few stones to interfere with tillage.

Calcium Carbonate Equivalent

The soil has a weighted average calcium carbonate equivalent. in the fraction less than 2 cm in diameter, of less than 40% in the root zone.

Problems with Existing Regulations

As stated earlier, regulations require the sequential removal and replacement of soil horizons, and soil productivity shall be returned to equivalent levels of yield as nonmined land of the same soil type in the surrounding area under equivalent management.

This sounds very good in theory; however, it is considerably more difficult to accomplish in the field. The method frequently used to replace native soil horizons sequentially is by, the use of scrapers or end dumps. Either method may result in soil compaction. Soils replaced using scrapers would often make better streets or parking lots than cropland due to the amount of compaction that was induced during the placement phase by loaded scrapers going over them.

Methods

The method which Texas Utilities Mining Company (TUMCO) employs for reclamation is the use of selected mixed overburden materials in mining. This approach was based at least in part, on a study (Angel, 1973) which found that east Texas overburden materials are favorable for vegetation. Selection of overburden for placement in the top four feet of reclamation is guided by the geologic studies required to obtain the permit for mining. Stratigraphic units are mapped and correlated throughout the mine area by use of gridded geophysical core data and electrical logs. Stratigraphic units are defined as strata within the overburden which exhibit distinctive textural composition., a reasonably consistent and predictable stratigraphic relationship with mineable lignite seams in the permit area, a recognizable geophysical log signature, and a mappable thickness and geographic extent (DeMent, et. al., 1992). Weighted averages of the major parameters (pH, ABA, texture, and trace elements) are obtained for each stratigraphic unit. These averages are then compared to the values in the native soils and the criteria set out by the state's regulatory agency to determine the best material for use in reclamation. The overburden is selectively handled by draglines or cross-pit spreaders during the mining, with unsuitable materials placed low in the spoil. The suitable strata are placed so that they are the only materials occurring in the leveled postmine topography from which minesoils could develop.

Texas Utilities, in cooperation with the Natural Resources Conservation Service (formerly Soil Conservation Service), developed a postmine soil mapping and classification program. Postmine soil mapping provides a valid procedure for comparing premine and postmine soil quality. The results of this program suggested that minesoils developed from mixed overburden could potentially meet all the criteria for prime farmland soils. Several years of field trials and data collection went into the effort. The NRCS, in 1991, declared the first mixed overburden prime farmland minesoil at the Monticello Winfield Mine in northeast Texas.

Results

Postmine Soils

The native soils of east Texas are mostly either deep sands (>40 inches of sand or very fine sand) or have a claypan at shallow depths (<20 inches). Both tend to be very droughty soils, either because of the high sand content throughout or because of the abrupt textural break at shallow depths causing a boundary across which water, air, and roots have difficulty passing. Most native soils in Texas have low pH and low acid-base account (ABA) values (Smith and Sobek, 1978). Postmine soils where selective overburden handling is practiced tend to have higher mean values for these parameters and more consistent textures throughout the minesoil profile (Table 1).

The mining operation, in which selected geologic materials are used in the top four feet of reclaimed soil, breaks up the claypan where it exists and removes the deep sand layer where it occurs. The minesoils produced exhibit a much more uniform texture throughout than most of the native soils in east Texas. The surface of most of the reclaimed soils is more clayey, which allows for higher water-holding capacity and higher cation exchange capacity. The lower layers of these reclaimed soils are usually less clayey than the native soils, allowing freer movement of roots, water, and air.

At the Monticello Winfield Mine, the Grayrock soil series (fine-silty, mixed, nonacid, Typic Udorthents) on I to 5% slopes and the Grayvar soil series (fine-loamy, mixed, nonacid, thermic, Typic Udorthents) on I to 5% slopes were declared as prime farmland soils by the Natural Resources Conservation Service in 1991. The Grayvar series is a proposed series but meets the prime farmland criteria. The Bigbrown soil series (fine-silty, mixed, nonacid, Typic Ustorthents) on I to 5% slopes was declared a prime farmland soil by the NRCS in 1993. Table 2 presents a comparison of areal extent of prime farmland soils between premine and postmine areas.

Table 1. Mean values of premine and postmine soils

	Native Soils	Postmine Soils	Native Soils	Postmine Soils
	0-12"		12-48'	
Big Brown				
pH	5.6	6.5	5.4	6.4
ABA	0.5	3.2	-0.3	2.7
Sand	69	35	44	34
Clay	17	27	41	28
Monticello Winfield				
pH	4.9	6.9	4.9	7.0
ABA	-0.5	5.9	-2.7	5.3
Sand	72	31	54	30
Clay	12	28	30	28

Table 2. Percentage of prime farmland soils.

	% of premine area	% of postmine area
Big Brown	4.7	58.6
Monticello Winfield	38.8	65.9

Productivity

Estimated yield comparison for major forage crops such as coastal bermuda grass (Cynodon dactylon (L.) Pers.) and winterwheat (*Triticum aestivum* L.) are provided in Table 3 for the Grayrock soil series. Native soil yield estimates were made by the Natural Resources Conservation Service (USDA-SCS, 1989) for a low level of management and are based mainly on the experience and records of farmers, conservationists and extension agents from the area. These can vary in any given year depending on weather, management practices, and the presence or absence of disease and insects. Yields for costal bermuda grass for Grayrock series come from production averages over a number of years in compliance with regulatory requirements (TUMCO, 1996).

Estimated wheat yield were summarized in 1989 following three years of study on a 10-acre plot of Grayrock silty clay loam, 1 to 5% slopes. Management on the study area conformed to normal farming practices within the area. Due to variances in weather and damage from migratory geese, annual yields ranged from 29 to 59 bushels per acre. The estimated wheat yield shown in Table 3 is an average of the three-year study.

In addition to the above information, a 5-acre plot of alfalfa (*Medicago sativa L*.) planted in 1989 continued to produce a healthy crop through the 1996 growing season, producing four hay cuttings. This is in an area of the state where native soils are not adapted to alfalfa production.

Table 4 provides the estimated yield information for the Bigbrown soil series for coastal bermuda grass (TUMCO, 1997) and wheat. The wheat yield is based on one year's data on Bigbrown.

Table 3. Premine/postmine yield comparisons - Monticello Winfield Mine.*

	Yields	
Soil	Coastal Bermuda	Wheat
	(tons/ac)	(bu/ac)
Bernaldo	3.1	-
Freestone	3.1	35
Nahatche	2.9	-
Wolfpen	2.6	-
Woodtell	2.8	35
Grayrock**	3.4	39

*A dash means not commonly grown. See text for source of estimates.
**Minesoil; remainder are native soils.

Table 4. Premine/postmine yield comparisons - Big Brown Mine.*

Soil	Costal Bermuda	Wheat
	(ton/ac)	(bu/ac)
Crockett	2.0	35
Edge	1.9	28
Gasil	2.2	28
Gredge	2.0	-
Nahatche-Hatliff	2.1	-
Padina	1.8	-
Silawa	1.9	-
Silstid	1.9	-
Bigbrown**	3.0	52

* A dash means not commonly grown. See text for source of estimates.
** Minesoil; remainder are native soils.

These studies have not received statistically valid testing but support the conclusions of the NRCS that the yield potential is equal to or greater than that of native soils of the area.

Conclusions

The general consensus among many people in the general public today, as in the past, is that surface mining is an aberration and should be brought to an abrupt halt. Although it is true that mining may have caused environmental damage before mining regulations were promulgated in the mid-1970s, the reclamation work done by current mining techniques is proving beneficial to wildlife and soils in many instances. It is also furnishing a valuable soil resource for current and future users of the land. Many people in east Texas have sought for years a method to break up the claypans so prevalent in that part of the state. Surface mining has provided that method, and has even given an increase in the percentage of the landscape occupied by soils meeting the criteria for prime farmland soils. Flexibility to use techniques such as this should be encouraged as much as possible in applicable situations. Where overburden materials are as consistent and desirable as those in this study, the results can be very beneficial.

References

Angel, P. N. 1973. A Soil Analysis of the Strip Mine Spoil Bank at Fairfield, Texas. M.S. Thesis, Stephen F. Austin Univ. Nacogdoches, TX. 75 pp.

DeMent, J. A., S. Cooney and J. Denman. 1992. Development of a Prime Farmland Minesoil in Selectively Cast Overburden in Northeast Texas. Proceedings of the 1992 National Symposium on Prime Farmland Reclamation. (St. Louis, MO, August 10- 14, 1992).

Smith, R. M. and A. A. Sobek. 1978. Physical and Chemical Properties of Overburdens, Spoils, Wastes, and New Soils. American Society of Agronomy, Madison, WI. In: Reclamation of Drastically Disturbed Lands.

TUMCO. 1996. Monticello Mine, 1,961 Acre Bond Release Application. Submitted Oct. 31, 1996.

TUMCO. 1997. Big Brown, 2,022 Acre Bond Release Application. Submitted May 30, 1997.

USDA-SCS. 1989. Forage Production Standards for Postmine Soils. In: Monticello Permit No. 30B Surface Mining Application, Section 145 Appendix D. Submitted 5-31-96.

'Eddie Bearden, Senior Environmental Specialist, Texas Utilities. BS Agronomy 74, MS Soil Science 84, Texas A&M. 23 years Soils experience.

RECLAMATION OF ANCILLARY SURFACE AFFECTED SOILS

Dean Spindler[1]
Land Reclamation Division
Office of Mines and Minerals
Springfield, Illinois

Abstract

The Surface Mining Control and Reclamation Act (SMCRA) requires the restoration of productivity for cropland affected by mining activities. Current Illinois reclamation directives require the planting and testing of the entire cropland areas that have been effected. Both surface and underground mines commonly affect small areas of cropland along the fringes of the mine. These areas are used for substations, stockpiles, minor roads, etc. These areas typically have only the topsoil removed and subsequently replaced during reclamation. The subsoil remains intact. Because of their small size and irregular shape, the cropping and testing of these parcels is proving to be an administrative burden. Regulations and procedures are being evaluated to address this problem.

Introduction

In 1986 the division adopted the Agricultural Land Productivity Formula (ALPF) as its method for establishing productivity yield targets, sampling procedures, and yearly adjustments to reflect local weather conditions. These regulations were a cooperative effort between the Illinois Department of Agriculture, USDA Crop Reporting Service, Natural Resources Conservation Service, citizen and agricultural groups, University of Illinois, and the Land Reclamation Division. In its simplest terms, it establishes a mathematical relationship between the actual productivity of the cropland in the county and the baseline productivity of the prime or high capability soils each year. A baseline productivity is also calculated for the permit area. If weather is very favorable and county yields are better than the baseline, then the permit targets are increased by the same percentage. Likewise, if the county yields are depressed then permit targets are decreased by the percentage. The end result of ALPF is the following formula.

Annual Adjusted Target Yield =

$$\textbf{Potential Yield for Soils in the Permit} \times \frac{\textbf{County Actual Yield}}{\textbf{Potential Yield for Soil in the County}}$$

ALPF also established a random sampling procedure based on whole field planting. Sampling is contracted to the crop enumerators in the employ of the Illinois Agricultural Statistic Service and the Illinois Department of Agriculture. This system has worked on mined land since its adoption. The number of fields tested varies from year to year but typically involves several thousand acres. To date, approximately 2,000 field test-years have been in the system. Annual costs to run the testing program are approximately $40,000 and involve numerous man-hours digitizing maps, determining random sample points, taking the samples, weighing the samples, and gathering county statistics.

The system works fine for fields greater than four acres in mined areas. Sampling can be done throughout the mining areas during the time span of crop maturity until harvest. Smaller fields currently require a whole field harvest sample that must be times to coincide with the harvesting of the remainder of the adjoining fields. Care must be taken to ensure the combine only harvests from the small field. It is very common that small, irregularly shaped pieces of surface-affected land occurs on the fringes of surface mines and underground mines. Examples of this include areas used for electrical substations, minor roads, soil stockpiles, or boreholes to underground works. By surface affected, I mean areas where the topsoil was removed and replaced and the original subsoil largely remains in place. As these areas may have a post mining land use of cropland, they are subject to productivity requirements. From an administrative point of view, the hardest case to deal with is a quarter acre piece of affected land that was used as a bore hold to deliver power or rock dust to an underground mine. This site may sit in the middle of a cornfield and represent the entire area affected for a mile. As the site is too small to use a combine, hand harvesting of the entire site is the only current option.

New Initiatives

The Department has been exploring a number of alternatives to deal with these small isolated areas, while at the same time to ensure the areas are returned to their premining capability. The current draft is:

1. limit the sites to those less than four acres,
2. limit the sites where the majority of the subsoil was left in place,
3. limit the sites where no toxic materials were present onsite,
4. require other contaminants (rocks) must be removed,
5. require compaction alleviation where appropriate, and
6. visually compare these areas with adjacent cropland using persons experienced in agricultural practices for the required number of years.

Once approved and implemented, the division will have a mechanism to document the reestablishment of productivity on small ancillary areas.

[1]Dean Spindler, supervisor of Operations/Soil Scientist, Illinois Office of Mines and Minerals, Land Reclamation Division; M.S. Plant and Soil Science, Southern Illinois University; Registered Professional Geologist, Certified Professional Soil Scientist; 22 years with the Land Reclamation Division.

LONG-TERM EFFECTS OF DEEP TILLAGE

C. L. Hooks, Southern Illinois University, Carbondale, Illinois
R. E. Dunker and R. G. Darmody, University of Illinois at Urbana/Champaign

Abstract

The effects of seven tillage treatments ranging in depth from 9 to 48 inches applied to a reconstructed surface mine soil were evaluated over a ten year period beginning in 1988. The southern Illinois mine soil consisted of 8 inches of scraper-placed topsoil over 40 inches of scraper-placed rooting media. The pre-tillage physical condition of this mine soil is described as compact and massive. A nearby tract of Cisne silt loam (fine, montmorillonitic, mesic Mollic Albaqualf) was used as an unmined comparison. Significant differences in corn and soybean yield, soil strength, and net water extraction were observed among tillage treatments. Depth of tillage needed on the mine soil to achieve productivity comparable to permit target yields were found to be affected by initial levels of soil strength. Soil strength and depth of tillage were highly correlated to long-term yields.

Introduction

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils (Fehrenbacher et al., 1982). Newly constructed soils commonly lack a continuous macropore network necessary for water movement, aeration, and root system extension. Also, plant root growth is often severely inhibited by excessively high soil strength (Thompson, et al., 1987; Meyer, 1983).

There are two sources of the physical condition problem in man-made soils. One is the use of severely compacted, high strength soil materials that are naturally present in the lower horizons of many southern Illinois soils. If this is not adequately disrupted in the excavation process, the soil may maintain high strength. This "transportation" of compaction is generally associated with scraper placed subsoils. In that process, large monoliths of intact subsoil are sheared out and folded into the scraper pan. The resulting subsoil is largely massive with interfaces between the monoliths and where they were broken and folded together. Mottling and other characteristics of the original soil remain detectable with varying degrees of distortion. Secondly, and more common with all placement methods, is compaction induced by earth moving equipment in the process of moving, placing, and grading the soil material.

In natural soils, a physical condition problem can be improved by growing forage legumes for an extended period or at least within a crop rotation. Illinois has completed two experiments over the last ten years to evaluate its efficacy in solving the deep compaction problem of reconstructed soils. The practice, though having some merit, has proven inadequate. Soil strengths are commonly just too high to allow diffuse distribution of even alfalfa root systems. The roots tend to form mats in desiccation cracks and leave much of the soil volume largely unaffected. Physical improvement is slow, if detectable, especially in the lower horizon. Perhaps that should not be surprising, as severely compacted glacial till layers in some natural soils have also remained intact, even after one or two centuries of agriculture.

A logical approach would be to reduce compaction by limiting the moving of soil materials to periods when they are dry. This approach has some merit, but is also inadequate. The reality is that the mines simply do not have that option. Experience has also shown that, even though moving materials dry does help substantially, the finished product still has excessive soil strength and bulk density. Research should continue to be directed towards finding soil construction methods that will prevent the problem, but meanwhile, means for amelioration of deeply compacted soils must be investigated.

There are many tillage options that have been proven effective to 12 to 15 inches depth for ameliorating wheel traffic effects of farm machinery on undisturbed soils. Standard agricultural tillage equipment cannot reach the depths of the compaction problem in reconstructed soils. A deep ripper, the Kaeble Gmeinder TLG-12, which has an effective depth of 32 inches, has been tested in preliminary studies in southern Illinois (Hooks, et al. ,1987) and western Illinois (Dunker, et al., 1989). Results from both studies were very encouraging with significantly increased yields and reductions in soil strength to the depth of tillage. This experiment was designed to continue and expand the investigations of the effects of deep tillage.

Objective

The objective of this experiment was to determine the effectiveness and longevity of deep soil tillage methods for improving soils with poor physical condition.

Materials and Methods

The Site

The site for this experiment was at the Consolidation Coal Company Burning Star #2 Mine located near Pinckneyville in Perry County, Illinois. The agricultural soils disturbed by surface mining for coal in this permit area primarily belong to the Ava, Bluford, and Blair soil series. The Alfisols of this region are formed on thin loess overlying silty sediments and/or Illinoian glacial till. Most of these soils have highly weathered acidic subsoils which are high in clay, highly plastic, and poorly aerated when wet. These subsoils tend to be only slowly permeable and, when dry, restrictive to root penetration. The C horizon consists of calcareous loess and calcareous glacial till and is chemically suitable for supporting plant growth.

The mine soil at this site was constructed in 1983 using a scraper-haul system to replace 40 inches of rooting media and 8 inches of topsoil. Texture of rooting materials ranged from silt loam to clay loam, but clay content never exceeded 30%. Physical characteristics of this mine soil can best be described as compact and massive. Preliminary soil samples were taken to determine levels of soil fertility. Required amounts of inorganic fertilizer and limestone were applied prior to the application of deep tillage treatments.

Experimental Design and Layout

A randomized complete block experimental design providing for six replications of seven treatments was prepared for the site. The plots were surveyed and staked out in April, 1987. Experimental plots have two rows of three blocks each, aligned in roughly a north-south direction. Each of the 42 plots is 50 feet wide and 250 feet long, to provide two 50 foot by 100 foot subplots for corn and soybeans, separated by a 50 foot turn strip.

Pre-treatment Evaluation of Soil Strength

A deep-profile penetrometer (Hooks and Jansen, 1986) was used to measure soil strength to a depth of 44 inches prior to the application of tillage treatments (Table 1). Soil strength was highly variable, but the pattern did not compromise the experiment. Analysis of this pre-tillage penetrometer data revealed that while there was no soil strength difference between pre-treatment plot means, there were significant differences in soil strength between blocks. Soil strength levels of the west three blocks (1-3) are significantly higher (0.05 level) than soil strength levels of the three east blocks (4-6) for each depth segment of the soil profile.

The difference in soil strength between the east and west sides was initially unexplainable with limited reclamation history available. There was a time difference in grading. There was a one year delay in grading of the cast overburden between the east and west sides, but all of the root medium and topsoil materials were placed during the June-August period of 1983. Aerial photography from early June 1983 indicated a scraper haul road along the west side of the site.

Application of the Deep Tillage Treatments

The plot areas at the site were sprayed in early August 1987 with one quart of Roundup and one pint of 2,4-D per acre to kill the dense, foot-tall stand of the initial crop of legumes. This was done to reduce the amount of plugging with green trash during tillage and to reduce control problems in the row crops to be planted in 1988.

Five of the tillage treatments were completed during the next month in 1987. Additional treatments were completed in 1988 and 1990. The treatment descriptions are as follows:

TLG Kaelble Gmeinder TLG-12. The TLG uses a cut-lift operation to shatter the soil to a depth of about 36 in. A wide, moving foot is attached to each of the three shanks to cut and lift the soil as the machine moves forward.

RM1 RM1 Processor by Harry Jones. The RM1 Processor has four curved, vibrating shanks cut from 1.5 in. steel. The shanks do not have expanded points or wings. Two hydraulic vibrators are used each operating two of the four shanks. It has an effective tillage depth of about 36 in.

DM1 DMI, Inc., Deep Ripper (DMI) (prototype). This machine is a two-lift, solid shank ripper. Two "Turbo" chisel shanks are used to fracture the soil to an 18 in. depth ahead of the main shank. The main shank is cut from 4 in. steel. It is parabolic and has a winged point, 32 in. wide with a 7 in. lift. The point of the main shank is designed to run 50 in. deep. The machine incorporates a hydraulic trip/reset mechanism to prevent breakage. Successive passes are separated by 48 in. Under favorable moisture/tilth conditions, the floor of the tilled zone shears nearly horizontally, yielding a minimum tilled depth of 48 in. Moisture content at that depth was a bit high at the time of treatment, and a pronounced ridge of unloosened material was left between shank passes.

DM2 The final prototype of the DMI treatment. It incorporates a new design point and tongue to improve draft control. A larger tractor is used to increase ground speed and allow more consistent depth control.

DM3 A static-shank ripper similar to the DMI in point design but smaller. It tills to a depth of 36 to 38 in. and is pulled by a rubber-tracked tractor.

TG2 Tiger-two chisel by DMI, Inc. This is a commercially available chisel used in commercial agriculture for tillage in the 12 to 18 in. depth range. It is not really considered adequate for the needed loosening in reclaimed soils because of its depth limitations. It was included for comparison since its tillage depth should at least include the topsoil/root media interface, which can be a problem with water movement and root growth.

CHS Standard agricultural chisel plow with an effective depth of 9 to 10 in. This treatment is considered the tillage control treatment.

Table 1. 1987 Soil Strength Before Tillage at Burning Star #2.

	Soil Strength (PSI) by Depth Segment			
Treatment	**9 - 18"**	**18 - 27"**	**27 - 36"**	**36 - 44"**
1	332.5 a [1/]	369.9 a	327.9 a	260.6 c
2	365.7 a	420.0 a	350.4 a	319.9 ab
3	358.6 a	391.8 a	335.5 a	314.2 ab
4	336.5 a	391.9 a	352.4 a	327.2 a
5	348.1 a	411.2 a	338.2 a	283.6 bc
6	316.0 a	386.3 a	350.5 a	322.3 ab
7	353.0 a	396.9 a	307.4 a	301.3 abc
LSD (0.05)	59.9	61.9	62.5	41.2
Block				
1	435.0 a	571.3 a	477.1 a	432.1 a
2	498.8 a	574.2 a	440.8 ab	393.0 a
3	477.1 a	478.5 b	378.5 b	322.1 b
4	246.5 b	236.4 c	208.8 c	195.8 c
5	217.5 b	272.6 c	281.3 c	239.3 c
6	191.4 b	240.7 c	237.8 c	230.6 c
LSD (0.05)	71.1	87.0	71.1	58.0

[1/] Values followed by the same letter within a segment are not significantly different at the 0.05 level.

Tillage treatments were applied to plot areas only once, except for fall tillage in which the chisel plow is applied across all treatments. Consequently, both initial tillage effectiveness and longevity of tillage effects can be evaluated.

A nearby tract of Cisne silt loam (Mollic Albaqualf) was used as an unmined comparison. This is a prime soil compared to the high capability soils of the mine area. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation in the area. Corn (*Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental design. A minimum tillage management system was used to minimize traffic on the plots. Soil moisture was monitored during the growing season of the first two years of the experiment using a neutron probe.

Grain yield samples for corn were harvested after black-layer formation indicated physiological maturity, and soybeans were harvested when all pods were brown. Grain yield estimates were based on the amount of shelled grain after adjusting for variation in moisture content of grain to 15.5% for corn and 12.5% for soybeans.

Results and Discussion

Effects of Deep Tillage on Soil Strength

Soil strength measurements using the deep-profile penetrometer were taken prior to planting in 1988, 1989, 1991, and 1993 to evaluate tillage effects. Analysis of these data are presented in Table 2. Soil strength measurements taken in April 1991 indicate that tillage effects remain consistent to initial post-tillage soil strengths 42 months after application of tillage treatments. In summary, using the chisel treatment (CHS) as the control treatment, the Tiger II (TG2) was successful in lowering soil strength down to Segment 2 (9 to 18 inches). The TLG and RM1 significantly lowered soil strength to Segment 3 (18 to 27 inches) and was numerically lower than the CHS or TG2 in Segment 4 (27 to 36 inches). Both the DM1 and DM2 deep plows were successful in significantly lowering soil strength to the 44 inch depth. First year measurements of the DM3 treatment show it had similar effects to the RM1 and TLG treatments.

It is important to note that even though the magnitude of soil strength values are different for 1988, 1989, 1991, and 1993 results, the significant groupings of treatments are essentially the same for all years. This is probably due to differences in soil moisture content at the time data was collected.

Figure 1 shows graphically the effects of tillage on soil strength over the entire soil profile to a depth of 45 inches in 1993. The plotted curves data reveal that the effective tillage depth of each treatment is representative of the designed depth of tillage for each piece of tillage equipment. These soil strength curves represent the average curve across the six replications of each treatment. The pronounced high strength peak on the soil strength curve for the conventional chisel plow (CHS) is probably due to traffic induced compaction by scrapers from the topsoil replacement operation. The Tiger II (TG2) treatment has successfully eliminated this effect, but the soil strengths of the TG2 and CHS treatments remain high throughout the soil profile. Soil strength profiles of the RM1 and TLG are similar to the DMI deep plow treatments to a depth of about 30 inches. Below this depth soil strength increases with depth until resistance levels are comparable to the TG2 and CHS treatments. Both the DM1 and DM2 deep plow (48 in. effective depth) show relatively low soil strength throughout the soil profile.

Rowcrop Yields

Tillage treatments significantly influenced corn and soybean yields in all years (Table 3). Significant block differences have occurred for both corn and soybeans. In general, the three blocks on the west side of the experiment (Blocks 1-3) yielded lower than the three blocks on the east side (Blocks 4-6).

Grain yields from 1988 through 1997 growing seasons indicate a consistent trend over time. The DMI deep plow treatments produced corn yields significantly higher than any of the other mine soil tillage treatments for the ten years studied. The DM3, TLG, and RM1 corn yields were comparable, while the Tiger II (TG2) and conventional chisel (CHS) treatments yielded the lowest. Corn yields from the DMI Super Tiger deep plow (DM2) treatment were comparable to those obtained on the nearby tract of undisturbed Cisne soil in most years

Table 2. Soil Strength from BS#2 plots after tillage.

Soil Strength (PSI) by Depth Segment

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	9-18"	**18-27"**	**27-36"**	**36-44"**
		1988		
Spare B1/	804.1 a2 /	603.6 a	417.1 a	446 4 a
Spare C	768.8 a	584.4 a	415.8 a	432.8 ab
CHS	712.8 a	554.6 a	405.9 ab	434.5 ab
TG2	568.7 b	582.3 a	416.4 a	379.0 b
DM1	235.9 c	193.6 b	180.7 c	210.6 c
RM1	218.7 c	266.7 b	345.0 b	387.9 ab
TLG	193.4 c	219.1 b	338.9 b	390.2 ab
LSD (0.05)	99.5	123.9	67.1	61.5
		1989		
Spare B	521.9 a	515.8 a	419.7 a	381.6 a
CHS	457.4 ab	433.4 a	374.5 ab	350.5 a
TG2	400.4 b	457.7 a	394.5 ab	350.6 a
RM1	200.1 c	195.3 b	320.9 b	346.3 a
TLG	192.0 c	181.3 b	323.5 b	388.5 a
DM1	188.9 c	160.2 b	148.0 c	176.4 b
DM2	151.8 c	179.5 b	173.2 c	138.3 b
LSD (0.05)	71.0	135.6	87.3	62.9
		1991		
CHS	402.5 a	459.5 a	423.6 a	369.4 a
TG2	343.6 b	448.9 a	411.0 ab	349.9 a
DM3	218.8 c	231.4 b	290.6 c	370.3 a
RM1	210.4 c	240.2 b	320.0 bc	355.2 a
TLG	203.7 c	189.5 b	382.8 abc	427.0 a
DM1	188.9 c	211.0 b	179.4 d	159.6 b
DM2	181.1 c	175.1 b	156.5 d	140.2 b
LSD (0.05)	56.3	109.0	96.3	91.6
		1993		
CHS	406.0 a	453.9 a	411.8 a	349.5 a
TG2	381.4 a	430.7 a	349.5 ab	311.8 a
DM3	216.1 b	184.2 b	262.5 b	329.2 a
RM1	194.3 b	255.2 b	375.6 ab	342.2 a
TLG	192.9 b	214.6 b	361.1 ab	311.8 a
DM1	152.3 b	146.5 b	130.5 c	146.5 b
DM2	114.6 b	114.5 b	129.1 c	146.4 b
LSD (0.05)	103.0	161.0	113.1	69.6

1/ Soil treatments are: Spare, nontilled plot held in reserve for future application; CHS, conventional chisel plow, 8" tillage depth; TG2, DMI Tiger II Coulter, 16" depth; RM1, Harry Jones RM1 soil processor, 32" depth; TLG, Kaeble-Gmeinder TLG ripper, 32" depth; DM1, DMI deep plow (first design prototype, 48" depth; DM2, DMI deep plow (second design), 48" depth; DM3, DMI deep plow, 38" depth.

2/ Values followed by the same letter within a segment are not significantly different at the 0.05 level.

which indicates prime yield levels from reclaimed high capability soils. Significant differences have occurred between treatments within and across years. Significant differences across treatments between years due to weather variations are also apparent. Soybean yields for the DMI deep plow treatments were significantly higher than the other mine soil tillage treatments in most years. Few soybean yield differences occurred on the other tillage treatments.

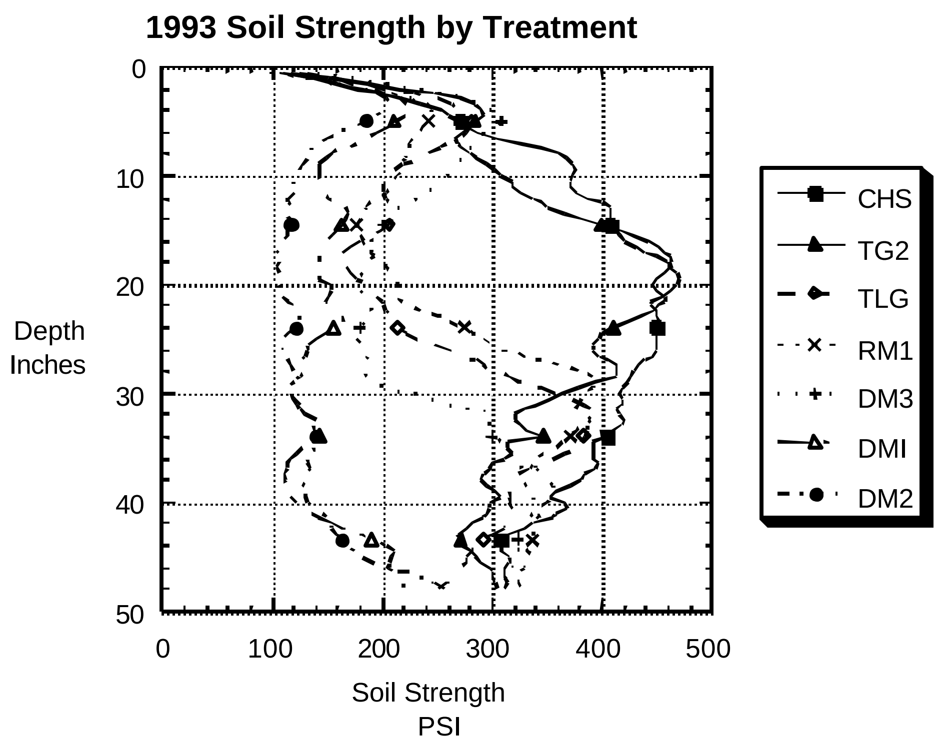


Figure 1. Soil Strength Profiles

Measurement of agronomic variables for corn indicate significant 1988-1997 mean differences among tillage treatments for % barren plants, shelling percentage (ratio of shelled grain per total ear weight), average ear weight, and test weight (a measure of grain density). Corn planted on the DMI deep plow treatments (DM1, DM2) produced a significantly lower percentage of barren plants, greater average ear weight, and grain with significantly higher test weights than the other tillage treatments.

Subsoil Differences and Productivity

Significant differences in yields of the experimental blocks have occurred. Blocks 1 to 3 on the west side have yielded lower than blocks 4 to 6 on the east side. Pre-tillage evaluation with the cone penetrometer showed significant initial differences in soil strength between the east and west sides of the plots. Soil strength levels of the west side were significantly greater than the east blocks for each depth segment. Post-tillage penetrometer data shows similar trends. The relationship of soil strength and tillage depth is consistent on both sides. Reduction of soil strength with increasing tillage depth is occurring at the same rate, only the magnitude of soil strength is different. This data suggests that the effect of tillage in reducing soil strength levels is affected by initial levels of soil strength.

Soil texture analysis reveals dramatic differences between the two sides (Table 4). The west side has higher sand, lower silt, and a high percentage of coarse fragments throughout the profile. This loamy subsoil is quite different than the silty material of the east side. The subsoil material of the west side can be identified as calcareous till while the subsoil materials of the east side are from Peorian loess and Roxana silt. The high soil strength of the west side is more a result of transported compacted till with minimal disturbance than equipment traffic, which is equal on both sides. The soil materials originated from different premine soils or from different depths of excavation.

Table 3. 1988 - 1997 Yields

Soil Trt	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	88-97 Mean
	Yield, bu/ac (2/)										
	Corn										
CHS (1/)	38 e	61 d	70 b	8 c	122 c	128 cd	96 cd	63 abc	35 c	70 c	67 c
TG2	43 de	53 d	85 b	6 c	122 c	115 d	88 d	56 c	22 c	75 bc	65 c
RM1	56 cd	86 c	79 b	22 b	111 c	154 ab	108 bcd	62 abc	66 b	93 ab	82 b
TLG	68 c	83 c	76 b	22 b	120 c	143 bc	96 cd	57 bc	60 b	77 abc	79 bc
DM3				30 b	127 bc	152 ab	112 bc	62 abc	74 b	74 bc	90 b
DM1	87 b	127 b	113 a	67 a	150 ab	167 a	117 bc	77 ab	115 a	96 a	110 a
DM2		143 a	124 a	57 a	161 a	170 a	121 b	83 a	112 a	90 ab	117 a
Cisne	136 a	142 a	130 a	68 a	158 a	160 ab	154 a	(4/)			
	Soybeans										
CHS	14 b	13 c	(3/)	(3/)	17 de	29 c	(3/)	(3/)	(3/)	36 de	
TG2	13 b	14 c			16 e	32 bc				34 e	
RM1	14 b	14 c			21 cd	30 c				40 cd	
TLG	14 b	14 c			18 cde	30 c				42 bc	
DM3					22 c	38 abc				39 cd	
DM1	21 a	24 b			27 b	40 ab				45 ab	
DM2		30 a			33 a	41 a				46 a	
Cisne	19 a	24 b			34 a	31 c					

1/ Soil treatments are:CHS, conventional chisel plow, 9" tillage depth; TG2, DMI Tiger II , 14" depth; RM1, Harry Jones RM1 soil processor, 32" depth; TLG, Kaeble-Gmeinder TLG ripper, 32" depth; DM3, DMI prototype ripper, 36" depth; DM1, DMI deep plow (first design prototype), 48" depth; DM2, DMI Super Tiger, 48" depth.

2/ Yields followed by the same letter within a crop are not significantly different at the 0.05 level.

3/ Soybeans were not harvested in 1990, 1991 and 1996 and not planted in 1994 and 1995.

4/ Cisne not included in 1995 or later comparisons.

Table 4. Soil Texture by Depth

	WEST				**EAST**			
DEPTH	**SAND**	**SILT**	**CLAY**	**C F**	**SAND**	**SILT**	**CLAY**	**C F**
Inches	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
0>6	8.1	70.9	21.0	1.0	11.8	69.4	18.9	0.1
6>12	9.8	68.5	21.8	1.3	11.5	68.7	19.9	0.3
12>18	20.5	52.8	26.7	2.5	11.5	64.1	24.3	0.3
18>24	27.9	45.0	27.0	4.2	9.6	61.0	29.4	0.9
24>30	30.4	47.2	22.6	6.1	9.9	58.6	31.5	0.3
30>36	30.4	40.8	28.7	4.5	9.9	59.3	30.9	0.2
36>42	30.0	42.1	27.8	4.1	9.7	59.7	30.7	0.2
42>48	29.8	40.6	29.7	4.3	10.4	58.6	31.0	0.2

Table 5 is a summary of differences between the two sides. **Till Depth** is the mean measured depth of tillage from soil cores. **12-48 SS** is the mean soil strength (PSI) of the 12 to 48 inch profile (below the depth of normal agricultural tillage. **12-48 BD** is similarly the subsoil mean measure by the core method. **88-97 Yield** is the mean corn yield in bushels per acre. **% Target** is the mean yield converted to a percentage of the target yield calculated by the Illinois Department of Agriculture for the mine permit area. This target is generated from the percent of the different natural soils affected and their productivity. **TS Depth** is the mean topsoil depth measured from soil cores.

Table 5. Tillage Treatment and Soil Effects on Productivity

SIDE	TRT	TILL DEPTH	12-48 SS	12-48 BD	88-97 YIELD	% Target	TS DEPTH
E	CHS	11.3	219	1.75	77.0	75.2	13.8
E	TG2	15.3	201	1.71	76.2	74.4	12.5
E	TLG	25.3	207	1.79	90.9	88.8	10.3
E	RM1	27.3	194	1.80	93.0	90.8	11.7
E	DM3	32.7	193	1.81	98.7	96.3	13.0
E	DM1	42.0	126	1.81	119.8	116.9	11.8
E	DM2	42.2	101	1.69	123.7	120.8	9.0
EAST MEAN		**28.0**	**177**	**1.77**	**97.0**	**94.7**	**11.7**
W	CHS	8.0	520	1.96	57.5	56.1	12.2
W	TG2	13.0	491	1.84	53.9	52.6	15.8
W	DM3	24.5	238	1.90	78.7	76.8	14.2
W	TLG	26.8	389	1.84	66.2	64.7	14.5
W	RM1	31.7	432	1.89	70.8	69.1	14.2
W	DM2	36.3	161	1.76	110.6	107.9	14.5
W	DM1	38.3	199	1.86	99.7	97.3	15.8
WEST MEAN		**25.5**	**347**	**1.86**	**76.8**	**74.9**	**14.5**

The table is sorted by tillage depth and shows that the same equipment could not till as deep on the west side due to the high strength materials encountered. This is a difference in the depth to a densic contact or the available rooting volume not only between treatments but also between sides. The soil strength after tillage is different within treatments between sides. While bulk density has not correlated with yield in any of the ten years of this study, it is higher on the west side. Yields increase with the depth of tillage on both sides. The yields achieved with the same tillage tool are lower on the west side. The productivity goal for high capability soils is to statistically meet 90% of the target. The intermediate depths of tillage appear to be adequate for this on the east side. The deepest tillage (DM1 and 2) is necessary to meet productivity on the west side. No relationship is apparent between topsoil depth and productivity in this experiment.

Since the two sides are different soils regardless of tillage, productivity modeling has combined tillage and soils providing 14 treatments. Figure 2 is a logarithmic correlation of mean 12 to 48 inch soil strength and 1988-1997 corn yield means. This is consistent with previous years results; yields decrease as soil strength increases (r=.93). Figure 3 is a linear correlation of tillage depth and 1988-1997 corn yield means. This is also consistent with previous findings; yields increase with increasing depth of tillage or available rooting volume of soil (r=.82). The combined effects of these two parameters are shown in the multivariate model in Figure 4. This is a highly significant model (r^2=.96), using natural log conversions, explaining 96% of the variability in yield with two soil parameters. Both soil parameters can be measured with the penetrometer. Soil strength measurements will be a major factor in the development of a soils based productivity model for this region. With the results of this experiment, the pursuit of this effort is certainly warranted.

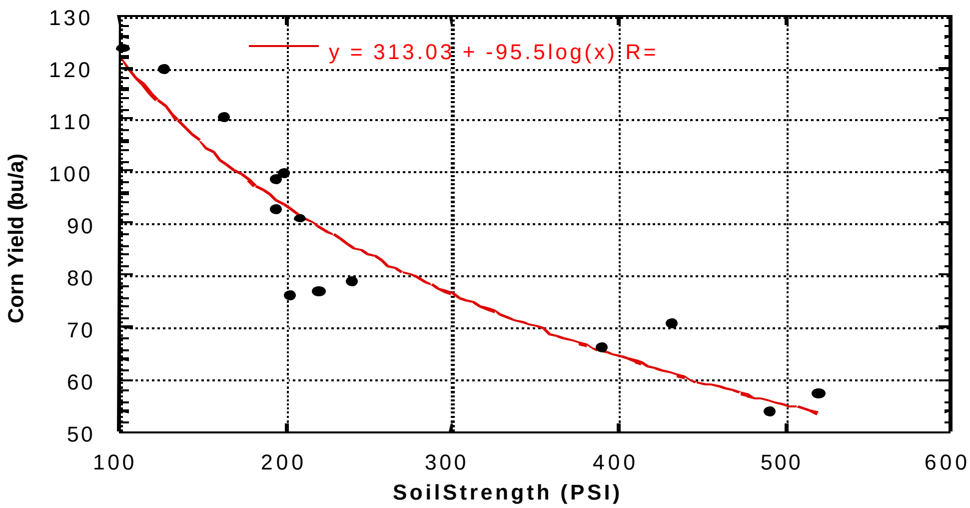


Figure 2. Soil Strength and Yield Correlation

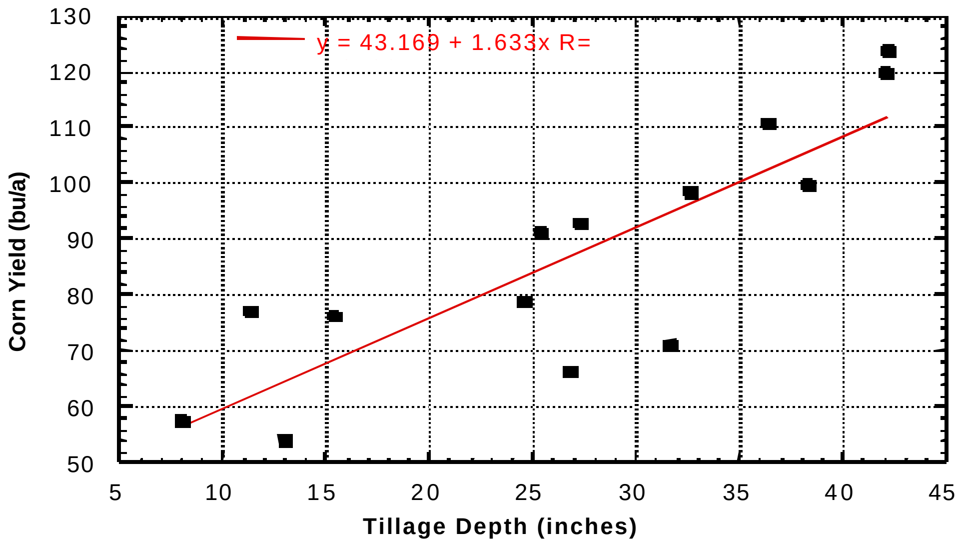


Figure 3. Tillage Depth and Yield Correlation

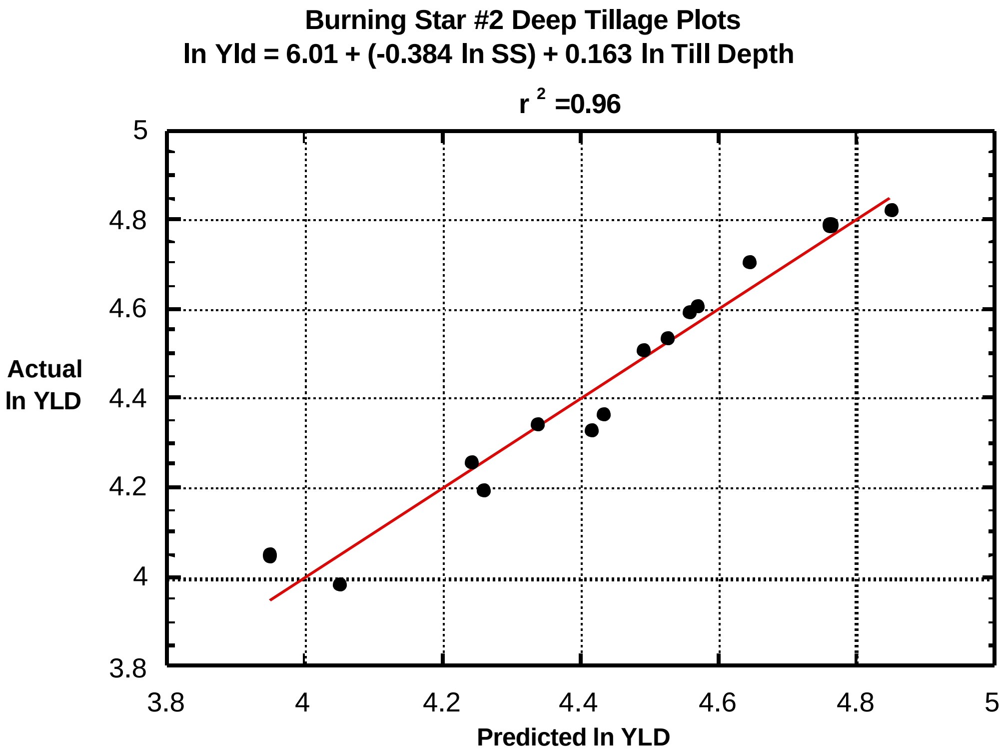


Figure 4. Soil Strength and Tillage Depth Correlation with Yield

Summary

Data from this study support the following general conclusions:

1. Tillage treatments significantly affected crop yields, soil strength levels, net water extracted by growing crops, and measured agronomic variables.

2. Corn yield increased with increasing tillage depth and decreasing soil strength within and across years. The only treatment response to tillage for soybeans occurred from the DMI deep plow (48 inch) treatments (DM1 and DM2).

3. Post-tillage penetrometer and yield data indicate that amelioration effects of tillage remain at least ten years after initial application of tillage treatments.

4. Depth of tillage needed to achieve productivity comparable to target yield levels will be affected by initial levels of soil strength.

5. Productivity can be reliably predicted with soil parameters measured by the deep profile penetrometer.

Acknowledgments

This work was supported by funds from Amax Coal Co., Arch of Illinois, Inc., Consolidation Coal Co., Cooperative States Research Service (USDA), Freeman United Coal Co., Illinois Agricultural Association, Illinois Agricultural Experiment Station, Peabody Coal Co, Illinois Department of Commerce and Community Affairs, and the Coal Research Center at Southern Illinois University.

Previous findings from this experiment have been reported in the following publications:

Dunker, R.E., C.L. Hooks, S.L. Vance, and R.G. Darmody. 1995. Deep Tillage Effects on Compacted Surface-Mined Land. Soil Science Society of America Journal. 59: 192-199.

Dunker, R. E., C. L. Hooks, S. L. Vance and R. G. Darmody. Effects of Deep Tillage on Surface Mined Land in Southern Illinois. 1992 National Symposium on Prime Farmland Reclamation, Aug. 10-14, 1992, St. Louis, MO.

References

Fehrenbacher, D.J., I.J. Jansen, and J.B. Fehrenbacher. 1982. Corn root development in constructed soils on surface-mined land in western Illinois. Soil Sci. Soc. Am. J. 46:353-359.

Dunker, R. E., I. J. Jansen, and S. L. Vance. 1989. Corn response to deep tillage on surface mined prime farmland. American Society for Surface Mining and Reclamation (ASSMR) and Canadian Land Reclamation Association (CLRA) Symposium: Reclamation, A Global Perspective. August 28-31, 1989. Calgary, Alberta.

Hooks, C. L. and I. J. Jansen. 1986. Recording penetrometer developed in reclamation research. Soil Sci. Soc. Am. J. 50:10-12.

Meyer, J. J. 1983. Corn root behavior in soils constructed after surface mining for coal in southern Illinois. Unpubl. M.S. Thesis. University of Illinois, Urbana, IL. 61801

Thompson, P. J., I. J. Jansen, and C. L. Hooks. 1987. Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. Am. J. 51:1288-1293.

Hooks, C.L., I.J. Jansen, and R.W. Holloway. 1987. Deep Tillage Effects on Mine Soils and Row Crop Yields. National Symposium on Mining, Hydrology, Sedimentology and Reclamation, Springfield, Illinois. December 6-11, 1987.

SOILS BASED PRODUCTIVITY EVALUATION

C. L. Hooks[1]
Coal Research Center, Southern Illinois University
R. E. Dunker[2]
University of Illinois

Abstract

Since the passage of SMCRA, reclamation success on agricultural lands has been determined by long-term yield testing. This required a long bond release period lasting ten years or more. Recently, needs have been voiced from landowners, mine operators, and regulators for methods to expedite the bond release process. The financial burdens of annual cropping and field maintenance by mine operators and monitoring by regulators are of major concern. Landowners need to have the land returned to their production operations instead of being locked in the bond release process for a decade or more. A soils based formula could relieve these financial burdens and ensure the most efficient process to return the productive soil resource to the landowner. In addition, this method also will identify problem fields immediately after reclamation. Currently, some undergo 10 years of yield testing before a problem becomes evident. Then, after further remediation, another long period of testing is required. A soils based productivity index is currently being developed in Illinois. This includes the basic concepts and findings from earlier research. Two reliable approaches have been developed for southern Illinois. Additional information from the Mollisol region of the state will be included before final validation tests.

Background

In the first years following the passage of SMCRA, Illinois developed a regulatory program to insure the preservation of our valuable soil resource while continuing the development of our coal reserves. The Illinois program is superior to many in our neighboring states and it should be, since much of the reserves underlie some of the nations most productive farmlands. The Agricultural Lands Productivity Formula (ALPF) was developed as a part of this program to determine reclamation success. While it is superior to methods used in neighboring states, it is not without problems. ALPF does not consider within county weather variability or crop management practices. In some cases, it is difficult to determine whether success or failure to meet productivity is due to soil effects, a weather anomaly, or management practices. These limitations were accepted with the program, and tests with several crops over time can reduce these errors. The sampling method has been questioned, and a comparison of side by side corn yield measurements was conducted by the SIU/UI Cooperative Reclamation Research Station. The test correlated university measurements with those from state enumerators. Results yielded a high correlation (r=.93) indicating that the yield measurements are not different and statistically reliable.

Considerable time and effort is required from regulatory agencies and mine operators to implement and monitor the program. Recently, landowners, mine operators, and regulators have voiced the need for a method to expedite the bond release process. Landowners need to have the land returned to their production operations instead of being locked in the bond release process for a decade or more. A soils based formula to determine productivity capability could relieve these burdens and ensure the most efficient process to return the productive soil resource to the landowner. In addition, this method will allow the identification of problem fields soon after reclamation. Currently, fields undergo 10 years of yield testing before a problem becomes evident. Then, after remediation, another long period of testing is required.

The acres of land affected by surface mining in southern Illinois has declined in recent years; however, thousands of acres still will be in the bond release process for the next 10 to 15 years. More small off-site areas (substations, beltlines, etc.) are being reclaimed as mines continue to close in southern Illinois. The largest acreage of remaining strippable reserves are in the western part of the state. The development of these reserves is expected to continue for several years. Much of the remaining acreage will be affected by small "pod" mines that are different from the "classic" large mines of the southern part of the state. The pod mines may only cover 100 acres, more or less, as opposed to the vast areas covering several square miles. Individual fields may be much smaller and the mines are opened and reclaimed in a matter of months instead of years or decades. As the time required for resource extraction and reclamation is shortened, a method to validate productivity and return the land to the owner as soon as possible will be of great value. Currently, the time required for productivity validation with yield tests over time may be ten times that required for extraction and reclamation. A soils based method of productivity validation will provide the shortest period of time that the land will be out of the landowners normal production.

When it was developed, ALPF was the best measure possible for productivity over time. The reclamation research was also in its infancy, and the relationships of minesoils and crop productivity were not known. Today, after 18 years of reclamation research, the idea of a soils based productivity formula for bond release could be a reality in the near future. This will result in reduced time and effort from all involved while not compromising the accuracy of productivity testing. Most of the work is complete for southern Illinois, but additional reclaimed soils information is needed from western Illinois.

Methods

The basic approach to the soils based productivity concept is a comparison only of soil physical attributes. This determination does not consider controllable management factors such as fertility, pH, tillage practices, etc., since they are considered to be part of a sound, high level, crop management program. Soil attributes will be correlated with long-term yields from tests plots and field studies. Yields are converted to a percent of the expected target for the premine soils in the area of each soil tested. The initial approach is that potential productivity is a function of measurable soil properties and is summarized below:

Yield Potential = ASV + SUB + TS

ASV - Available Soil Volume relates to the physical rooting environment for the plant. Soil strength, depth to root limiting zones, and thickness of root limiting zones will determine this factor.
SUB - Subsoil Quality relates to the ability to hold water and provide it to the plant, and the favorability of the subsoil chemistry and drainage. Soil texture, reclamation method, and premine soils will affect this factor.
TS - Topsoil Quality relates to the volume of surface soil and its ability to hold and provide nutrients to the plant. Topsoil depth, texture, cation exchange capacity, and organic matter will determine this factor.

The database for this study includes yields in a period from 1979 to 1997 at various research plots and field tests. Periods of time for individual test sites varies from 3 to 10 years. The data represents 29 minesoils at five southern Illinois mines. Reclamation methods included are scraper haul, shovel/truck, cross pit wheel, and wheel/beltline, with and without various deep tillage methods. It is unique in that it contains a wide range of productivity: success and failure from long-term test plots. Soil attributes measured include % organic matter, topsoil depth, tillage depth, soil strength, bulk density, texture, and coarse fragments.

Southern Illinois Results

The database is near complete and the initial analysis has yielded encouraging results. Soil texture has not been completed on seven soils. Texture results from the 22 soils show major differences in subsoils. Figure 1 shows a loamy subsoil originating from calcareous till. Texture is somewhat variable with depth resulting from scraper placement. Figure 2 shows a silty subsoil originating from Peorian loess and Roxana silt. Texture is more uniform with depth representing shovel/truck reclamation. These are the dominant parent materials in this region and occur in varying degrees in the minesoils depending on the natural soils being reconstructed and the method of excavation and placement. Tests indicate no significant texture influence over the wide range of minesoil productivity.

Initial results clearly confirm that subsoil soil strength and depth of tillage (or depth to a densic contact) are the dominant independent variables over the wide range of productivity. Figure 3 is the correlation of the natural log of mean soil strength in psi (12 to 48 inch depth) and % target success. The dependent variable (% target) is the ratio of long-term yield means from university tests and the ALPF calculated target for the permit area of each minesoil in the test.

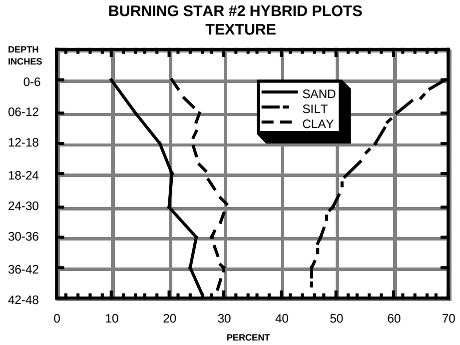


Figure 1.

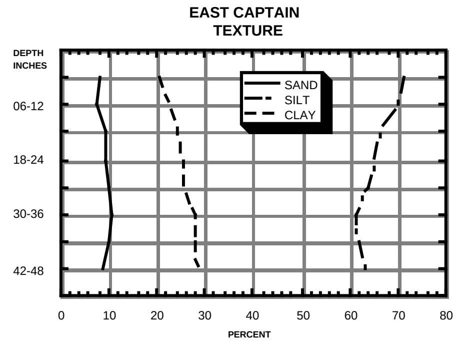


Figure 2.

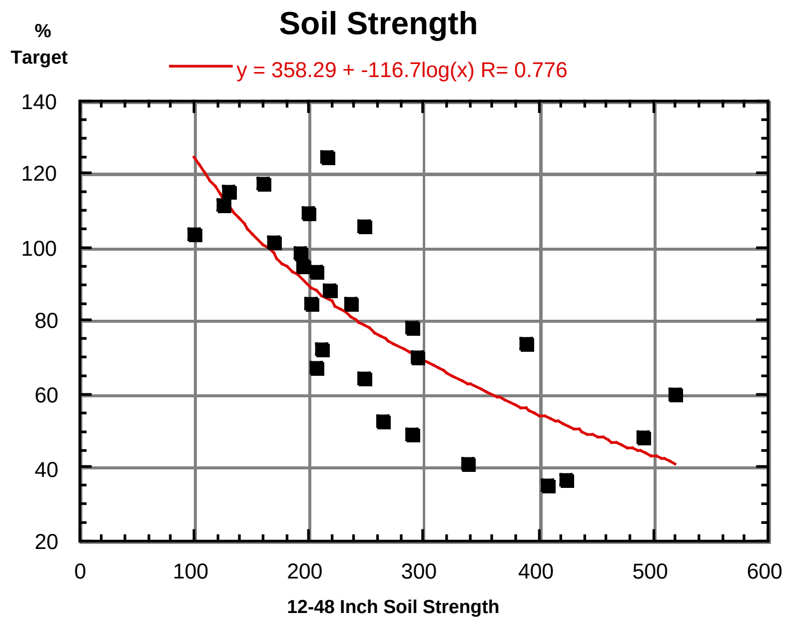


Figure 3.

This illustrates the same relationship discovered in earlier small plot research: yield decreases as soil strength increases. Soil strengths above 300 psi are limiting to root growth. In this area of the relationship, soil strength is the dominant factor determining yield. As soil strength decreases below that level, the soil becomes more favorable to root growth to the point where maximum rooting volume is available and soil strength is less important. In this transition zone, other factors begin to play a significant role in productivity.

Depth of tillage also plays a role in the minesoil evaluation. This represents the depth to a densic contact or a root limiting zone. It relates to the available soil depth or soil volume favorable to support plant growth. Mean subsoil soil strength below 300 psi may indicate a uniform but marginal subsoil environment. It could also indicate a very favorable upper profile over a high strength lower profile, which could have superior productivity. While both values can be measured with the penetrometer, subsoil soil strength alone may not be adequate for the productivity formula across a wide range of minesoils.

Stepwise analysis provides the best fit for the data in southern Illinois. A significant multivariate model is represented in Figure 4.

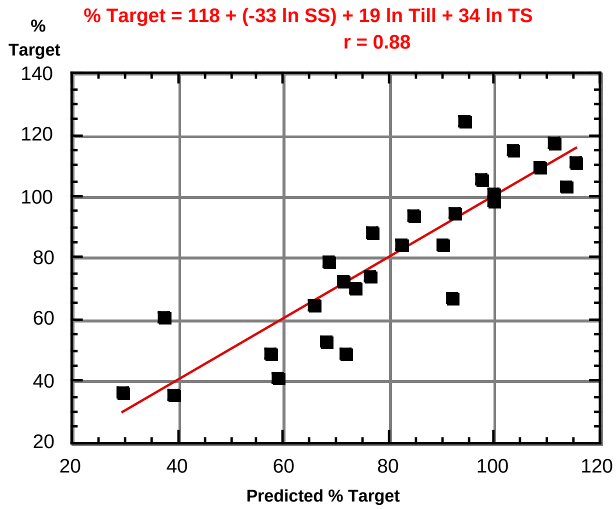


Figure 4.

In this model, % target is predicted from the combined effects of soil strength in psi, tillage depth or depth to a densic contact in inches, and topsoil depth in inches. It is a significant correlation that explains 78% of the variability in % target in this southern Illinois data set. Another approach to further improve the accuracy has been considered in Figure 5.

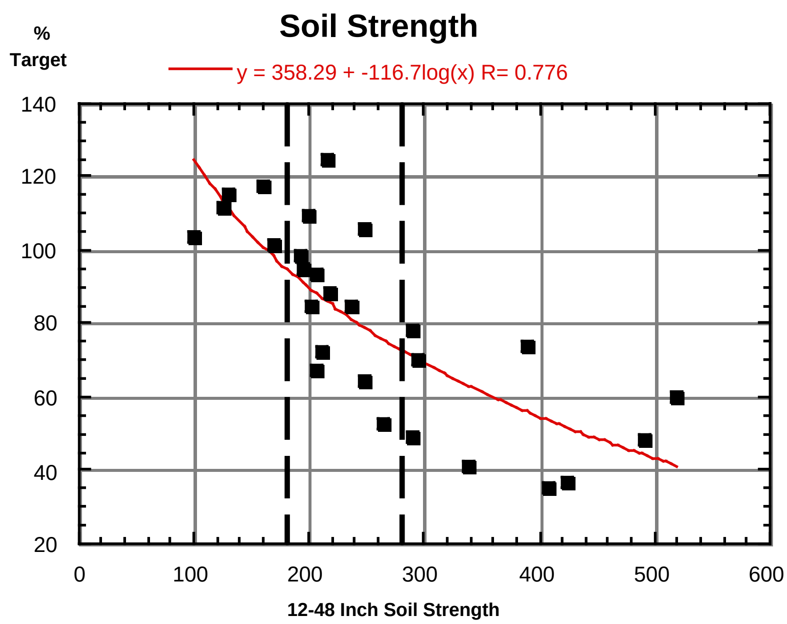


Figure 5.

In this approach, lower and upper thresholds are set at 180 and 280 psi. The lower limit indicating a minimum of 100% success and the upper limit indicating less than 80% of target (augmentation needed to increase productivity). Many Illinois minesoils are in the "transition zone" in the middle. Soil texture is needed on all but nine of the soils tested in that range. A significant correlation (r=0.96) from the nine soils with texture data suggests that yield is a function of soil strength, tillage depth, % clay, and bulk density. Completion of the data set will improve the accuracy of the formula.

Summary

Initial results from this study support the following conclusions:

1. A valid soils based productivity formula for southern Illinois minesoils is near completion.

2. The two-stage approach utilizing upper and lower thresholds will be most efficient.

3. The database should be expanded to include the Mollisol region of western Illinois.

4. The final formula will have to be validated and equal the reliability of the ALPF results.

Acknowledgments

This study represents the continuation of prime farmland reclamation research by the Southern Illinois University/ University of Illinois Cooperative Reclamation Research Station through the Coal Research Center, Southern Illinois University, Carbondale. It is a continuation of research, published and unpublished, from both universities.

---

[1]Charles Hooks, Program Director, SIU/UI Cooperative Reclamation Research Center. Coal Research Center SIUC. MS 1976 Forest Science, U of I. 17 years reclamation research.
[2]Robert Dunker, Manager, Crop Sciences Research and Education Center, University of Illinois, MS Agronomy 1986. 17 years with Illinois Reclamation Research Program.

MINE SOIL MAPPING, CLASSIFICATION, AND CHARACTERIZATION IN ILLINOIS

S. M. Wiesbrook[1]
R.G. Darmody[2]
Department of Natural Resources and Environmental Sciences
University of Illinois

Abstract

Surface mining for coal completely disturbs the soils and geologic materials overlying the coal. The soils and landscapes left after surface mining are a result of what the miners did with the materials they encountered. At one time, the spoil was left as it was deposited by the mining activities, but through the years, increasing attempts have been made to purposely place materials to accommodate reclamation requirements. If mined areas are to be used, a soil survey is needed to describe the landscape to guide wise land use decisions. Existing mine soil series and map units in Illinois, as elsewhere, are insufficient to describe their diversity adequately. Most of these soil series were developed before reclamation requirements took full effect and others were too broadly defined. The official series descriptions did not adequately recognize soil attributes, such as compaction, produced by new techniques of material handling and placement. The purpose of this study was to address these shortcomings by developing new soil series and by refining existing soil series. Proposed soil series were characterized in the field and existing series were redefined to reflect field conditions better. Standard soil survey techniques were used. In addition, depth to compaction was estimated with a recording cone penetrometer. Alterations of existing soil series were proposed to restrict them to a better range of sod properties and recognize important soil features. The descriptions, along with the existing mine soil series, will be used as a guide to map reclaimed mine sods in Illinois.

Introduction

Surface mining for coal entirely disrupts a landscape, sometimes to a depth as great as 170 feet. While many surface mines are not that deep, they all disturb the entire soil profile and the portion of the underlying geologic profile above the coal regardless of depth. Reclamation methods used in Illinois range from none at all, to a variety in response to "intermediate" legislation, to the standards in place today, under which a reclaimed soil must have equal or greater productivity than the pre soil. Mined lands need an accurate soil survey to guide post mining land use decisions. However, soil series descriptions have not kept pace with the strides made in reclamation technology. Consequently, many mine soils are mapped improperly, if at all. There is a need for a more refined system of mine soil classification and mapping in Illinois as elsewhere today to rectify these problems.

History of Surface Coal Mining and Reclamation

Surface mining for coal over the last one hundred fifty years has affected approximately 257,000 acres in forty counties in Illinois (Table 1, Fig. 1) (IDMM 1995). The distribution throughout the state clearly indicates the geologic spoon shaped Illinois coal basin. Surface mines are confined to the margins where the coal is shallow. Deep mines occupy the center of the basin. Slightly over two-fifths of the surface mined area was never reclaimed and the remainder was reclaimed to meet the regulation standards of the day (Table 1). Regulations have changed a great deal over time; consequently, so have the post-mine soils. Both reclaimed and nonreclaimed mine soils present problems to a soil classifier and mapper. Over the years, surface mined land has undergone more careful consideration, but the mapping and classification of mine soils has not been conducted with the care given to unmined areas.

Coal mine reclamation in Illinois has taken on many forms over the years. Mine soil reclamation in Illinois is now conducted to meet the standards set forth in the Surface Mining Control and Reclamation Act (SMCRA, PL 95-87) (United States, 1977). This act mandates the replacement of a minimum of four feet of soil after mining. This includes all of the original topsoil to a minimum of 6 in. of surface soil, and a rooting media of equal or better quality than the original subsoil. The methods by which these soil materials are placed can create large differences in the post-mine soils.

Compaction is a common consequence of soil placement. Soil materials placed with scrapers or end-dump trucks driving on the surface become densely compacted (Jansen, 1982). This greatly reduces the exploitable root volume for plants, leading to reduced nutrient and moisture availability. This method of replacement was common for years in Illinois, causing many acres of compacted soils that are not recognized in the existing series. Compaction can be avoided or ameliorated by more careful material handling methods or the use of deep tillage (Dunker et al., 1995). Deep tillage of compacted reclaimed soils can result in corn and soybean yields equal to native soils (McSweeney et al., 1987; Dunker and Jansen, 1987). Soils that have been carefully placed or deep-tilled are also not accounted for by the current soil series.

History of Mine Soil Classification and Mapping

Soil maps have not shown much detail m areas that have been surface mined. Originally, mined areas were identify ed as MD (Mine Dump), SM (Surface Mine), or NE (Made Land) (Table 2). From about 1960 through 1982, mine soils were mapped with the generic Orthent or Udorthent labels. Ironically, in the quest to apply a taxonomic name to these soils, the counties mapping them as Orthents lumped them with other disturbed soils as well as natural Orthents. Valuable information about the soils' formation that the strip mine label indicated was lost. Beginning in 198 1, five soil series were used to describe mine soils. In Illinois there are two series into which an unreclaimed surface mined soil may be placed, Lenzburg and Morrisstown. There are currently three soil series, Swanwick, Schuline, and Rapatee, which may be used in Illinois to identify reclaimed surface mined soils.

These five soils are all classified into mixed, mesic families of Entisols. However, there has been debate about the higher categories into which these soils should be placed. Lenzburg and Morristown are well drained and are classified as Typic Udorthents. They are composed of cast overburden with no or minimal reclamation (Fig. 2). The main difference between these two soils is at the family level; Morristown is loamy-skeletal, while Lenzburg is fine-loamy. The three series representing reclaimed mine soils differ mainly in terms of soil materials replaced. The parent materials for Schuline are topsoil replaced over cast overburden. There is no root media replaced, as Schuline is an intermediate reclamation law soil. Swanwick and Rapatee both have root media and topsoil replaced. Rapatee soils have a dark colored surface horizon, while Swanwick and Schutine soils have a light colored epipedon. Schuline and Rapatee are both classified as Typic Udorthents, while Swanwick is classified as an Oxyaquic Udorthent. Swanwick and Rapatee are in the fine-silty family, and Schuline is in the fine-loamy family.

Mapping and classification of these soils are difficult. Mine soils are inherently heterogeneous which complicates classification and mapping. In addition, there is no natural soil-landscape model which one can apply across a mined landscape as is done to map natural soils. Premine soil(s), mining method(s), reclamation method(s), and the premine geologic column must be used to map these soils (Indorante and Jansen, 1984). The field researcher must be careful to determine whether a particular soil property is inherited from the premine soil, or is an actual indicator of pedogenesis experienced by the soil in place. This is especially important when interpreting subsurface colors. There may be relict materials and colors that would lead a researcher to believe there were reduction-oxidation processes associated with excessive wetness in the soil. These soils also may not exhibit the natural trend of decreasing organic matter with increasing depth, due to relict concentrations of organic matter (Ammons and Sencindiver, 1990). Perhaps the most easily identifiable feature of these soils is the erratic nature of curves plotted from physical data for the soils.

Reclaimed soils present unique challenges to classification as well. They may retain the materials from their original horizons, but without their original structure, which is a very important physical property of a soil. They also may show layering effects and abrupt boundaries that are due to placement of the materials. The physical property of compaction and the disturbance of the entire profile are reasons enough to warrant new series for these soils.

Problems With Existing Soil Series

The existing soil series are extremely broad in scope and do not adequately describe the diversity of mine soils. There are some very different soils that must be included in the same mapping unit because of the limited suite of soil series from which to choose. In southern Illinois, reclaimed mine soils with light colored surface horizons must be mapped as Swanwick if root media was replaced; if not, they must be mapped as Schuline. Currently, reclaimed mine soils with dark surface horizons must be mapped as Rapatee. Alternatively, a new soil series must be developed to allow for additional soils. When comparing profile descriptions from one county to another, it becomes evident that very different soils have been mapped the same because of lack of alternatives (Elmer and Zwicker, 1996; Walker, 1992; Windhom, 1986).

There is a need for soil series that will include more recent reclamation techniques and recognize the materials used. Modem reclamation places topsoil on root media on graded cast overburden (Fig. 2). Topsoil and root media are taken from the premining soil A horizon and the B or C horizons and are of Pleistocene age. Cast overburden is generally Pennsylvanian in age, although it can be any material removed in the process of mining, dumped, then leveled. Replacing 48 in. of root media on top of graded cast overburden often greatly increases the volume of soil available for root exploitation and water storage. This practice is required for all reclamation since the SMCRA took effect, but only two of the current soil series recognize this.

Unrecognized in existing soil series is compaction. Compacted soils, or soils with densic layers, have massive structure, high soil strength, and high bulk density. Compaction slows water flow, and root growth is restricted to fractures between large fragments of compacted soil. This causes poor crop growth. A penetrometer can be used to detect densic soil layers (Fig. 3). These devices measure the resistance of a soil to penetration. Densic layers occurring within 50 cm of the surface can be detected with a hand-held penetrometer; deeper ones require a tractor or truck mounted penetrometer. Densic layers are now recognized in soil taxonomy (Soil Survey Staff, 1996) as Cd horizons. The label Cd was not available when the existing reclaimed mine soil series were established. Consequently, the official series descriptions for these soils do not include Cd horizons, although compaction was indicated by the consistent descriptions.

Another shortcoming of the existing soil series lies in the lack of recognition of lithologic discontinuities. The topsoil and underlying root media are of Pleistocene age, while the cast overburden is a mixture of predominantly Pennsylvanian age materials. The Pleistocene materials are typically neutral to slightly acidic and lack coarse fragments; the Pennsylvanian materials are typically calcareous and contain a large percentage of coarse fragments. The Pennsylvanian age cast overburden should be recognized as a second parent material and indicated with an Arabic number two (2) in front of the horizon designation (Soil Survey Staff, 1996).

Mine Soil Characterization

Characterization of these soils involves studying the soil properties that make them unique. These soils usually have very similar chemical characteristics to the premine soils, since they are usually made from them (Snarski et al., 1981). Reclaimed mine soils differ from premine soils primarily in physical properties. Structure is destroyed during material handling, and a dense, massive structure may be imparted during material replacement (Thomas and Jansen, 1985; Dunker, et al., 1995). These dense layers have high soil strength.

Soil Strength

Soil strength is an important property of mine soils. Roots cannot enter soils with excessive strength, and crop yields consequently suffer (Dunker et al., 1995). There are many measurements of soil strength, including bulk density, shear strength, compressive strength, and resistance to penetration, among others. Bulk density is the most commonly reported measurement, but it does not adequately describe the strength of reclaimed mine soils.

We sampled selected horizons at seven locations to determine bulk density by the coated clod method (Blake and Hartge, 1986). Included were samples from densic Cd horizons and non-densic C horizons (Soil Survey, Staff, 1996). Clod bulk densities were not consistently higher in the Cd horizons (Table 3). Field differentiation between densic and non-densic horizons was based, in part, on ped size. Horizons labeled densic were composed of large, dense clods of replaced compacted soil. The non-densic horizons originally were similar, but were modified by deep tillage that shattered the clods into smaller pieces. The result of deep tillage is that roots are able to penetrate between the smaller pieces to a greater depth and extent than through the original material, even though the clod bulk density of the material was not altered.

Based on these findings, we believe that clod bulk density should not be used to separate densic (Cd) horizons from non-densic C horizons in reclaimed mine soils. We feel that a much better indicator of root penetration is the penetrometer. Penetrometer resistance can be used to determine depth of tillage and is correlated with crop yields on reclaimed mine soils (Dunker et al., 1995; Thompson et al., 1987). Penetrometer resistance can also be used to determine topsoil this root media thickness, or depth to cast overburden (Fig. 3). Cast overburden is composed mainly of impenetrable shale fragments that increase penetrometer resistance.

Proposed and Revised Series

New soil series are needed to encompass the diversity of mine soils in Illinois sufficiently (Indorante et al., 1992). We have refined existing soil series and proposed five new series to accommodate reclaimed mine soils now found in Illinois.

Unreclaimed mine soils are adequately covered by the existing soil series with the exception of wet Lenzburg soils. Lenzburg is defined as a well-drained soil; however, they include areas that are not well drained. These have been mapped as inclusions within the Lenzburg map unit. There needs to be a wet phase of Lenzburg recognized for these areas. They have similar profiles to a typical Lenzburg, but occupy landscape positions that cause poor drainage.

Changes are also needed in the existing reclaimed mine soil series official descriptions to narrow their range in characteristics. Because of root media and topsoil replacement, Rapatee soils have a very dense layer starting at about 18 in. (Windhorn, 1986). Swanwick soils have a very hard layer starting at 27 in. (Miles, 1988). These should be recognized as Cd horizons. Recognition of these Cd horizons will separate the early, non deep-tilled soils from the more recent, carefully placed or deep-tilled soils.

Proposed mine soil series include three soils with light colored surface horizons: Pyatts, Burningstar, and Captain (Fig. 4). These soils were formed in areas where Alfisols were the dominant premine soils. In these soils, the original light colored surface horizons have been replaced over root media for a total of 48 in. of replaced material. Two of them do not have densic contacts within the top 50 cm. They are the fine-silty Captain and the fine-loamy Burningstar. The third proposed light colored surface soil is Pyatts, which has a fine-loamy texture with a densic contact. Pyatts is a loamy analogue of Swanwick.

There are also two proposed soils with dark colored surface horizons (Fig. 4). These soils were formed in areas where Mollisols were the dominant premine soil type. The original dark colored surface horizons have been replaced, almost re-creating a mollic epipedon. These two soils both have fine-silty textures. Fairview is a proposed series that is similar in most respects to Rapatee, although it also does not have a densic contact within 50 cm, because of better material placement methods or deep tillage. Rupp is an intermediate-la* sod, similar to Schuline, but with a dark colored surface replaced directly on top of cast overburden. Soils that meet the criteria for Rupp have been mapped in Stark and Peoria counties as Rapatee (Elmer and Zwicker, 1996; Walker, 1992).

Future of Illinois Mine Soil Mapping

There is still much work to be completed before mine soils in Illinois are mapped adequately. The five soil series and revisions to existing series proposed will allow much greater accuracy in assigning soil series to these disturbed lands. Soils will be classified more accurately than they are by the five existing soil series, but there are still limitations.

Counties will need to re-map areas that have already been mined. As part of this objective, more studies will be needed to determine approximate crop yields for both the proposed series and the revised existing ones. This could have a significant effect on the tax base for the more effectively reclaimed sites whose productivity should be far superior to that of the earlier attempts at reclamation. As areas of compacted mine soils, such as Rapatee, are deep tilled to improve crop yields, re-mapping of the areas, as Fairview, will be necessary. Deep tillage is an expensive, high energy input event with persistent effects (Dunker et al., 1995). It permanently and significantly changes soil properties throughout the solum.

Soil scientists will need to use a penetrometer to detect densic contacts to identify compacted soils. One possibility is to mount a penetrometer on an all-terrain vehicle to assist the mapper. There are also hand-held constant rate recording cone penetrometers that are suitable for detecting densic contacts within 50 cm. Mappers will also need to become accustomed to the fact that unlike natural soils, many mine soil mapping units will have regular boundaries as a direct result of the reclamation methods and mining permit boundaries.

Conclusion

Surface coal mining dramatically alters soils and landscapes. Some areas were reclaimed to various extent over the years, while others were not. There is a need for more soil series to describe the variability found in mine soils adequately. New technology and approaches, such as measurement of penetration resistance, will aid in detecting soil compaction, the most important crop yield limiting property of mine soils. Soils already mapped will need to be reexamined to place them into the most suitable series. More work needs to be done to characterize specific soil properties of mine soil series in Illinois.

References

Ammons, J.T. and J. C. Sencindiver. 1990. Minesoil mapping at the family level using a proposed classification system. J. of Soil and Water Conservation, 45:567-571.

Blake, G.R. and K.H. Hartge. 1986. Bulk density. p.363-375. *In* A.L. Page, R-H. Miller, and D.R. Keeny (ed.). Methods of soil analysis. Part 1. ASA and SSSA Publ., Madison, WI.

Dunker, R.E., and I.J. Jansen. 1987. Corn and soybean response to topsoil replacement and irrigation on surface-mined land in western Illinois. J. of Soil and Water Conservation, 42: 277-281.

Dunker, R.E., C.L. Hooks, S.L. Vance, and R- G. Darmody. 1995. Deep tillage effects on surface-mined land. Soil Sci. Soc. of Am. J., 59: 192-199.

Elmer, S.L. and S.E. Zwicker. 1996. Soil survey of Stark County, IL. U.S.D.A. Natural Resources Conservation Service. Superintendent of Documents, Washington, D.C.

Illinois Department of Mines and Minerals (IDMM. 1995. Ann. Rpt. FY94. Springfield, EL. 45 p.

Indorante, S.J., and I.J. Jansen. 1984. Perceiving and defining soils on disturbed land. Soil Sci. Soc. of Am. J., 48: 1334-1337.

Indorante, S.J., D.R. Grantham, R.E. Dunker, and R.G. Darmody. 1992. Mapping and classification of minesoils: Past, present and future. In Dunker, R-E., R.I. Barnhisel, and R-G. Darmody (Eds.) Proceeding of the 1992 National Symposium on Prime Farmland Reclamation. University of Illinois, Urbana, IL 6180 1.

Jansen, I.J. 1982. A pedologist's perspective on reclamation. Proceedings of the Illinois Mining Institute Annual Meeting. Springfield, IL. p. 59-64.

Mc Sweeney, K., I.J. Jansen, C.W. Boast, and R-E. Dunker. 1987. Row crop productivity of eight constructed minesoils. Reclamation and Revegetation Research, 6: 137-144.

Miles, C.C. 1988. Soil survey of Randolph County, IL. U.S.D.A. Natural Resources Conservation Service. Superintendent of Documents, Washington, D.C.

Snarski, R.R., J.B. Fehrenbacher, and I.J. Jansen. 1981. Physical and chemical characteristics of pre-mine soils and post-mine soil mixtures in Illinois. Soil Sci. Soc. of Am. J., 45: 806-812.

Soil Survey Staff. 1996. Keys to Soil Taxonomy, Seventh Ed. U.S.D.A. Natural Resources Conservation Service. Superintendent of Documents, Washington, D.C.

Thomas, D.W. and I.J. Jansen. 1985. Soil development in coal mine spoils. J. of Soil and Water Conservation, 40: 439--442.

Thompson, P.J., I.J. Jansen, and C.L. Hooks. 1987. Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. of Am. J., 51: 1288-1293.

United States. 1977. Public Law 95-87. Surface mining control and reclamation act. United States Statutes at Large. Code Vol. 30, Sec. 1265. U.S. Government Printing Office, Washington, D.C.

Walker, M.B. 1992. Soil survey of Peoria county, EL. U.S.D.A. Natural Resources Conservation Service. Superintendent of Documents, Washington, D.C.

Windhorn, R-D. 1986. Soil survey of Knox county, EL. U.S.D.A. Natural Resources Conservation Service. Superintendent of Documents, Washington, D.C.

---

[1]Scott Wiesbrook, Graduate Research Assistant, Department of Natural Resources and Environmental Sciences, University of Illinois. MS Pedology 1998.

[2]Robert G. Darmody was born in Washington, D.C. IN 1949, and grew up in the Washington suburbs. He received from the University of Maryland a B.S. in Natural Resources with a minor in Botany (1972) and a M.S. (1975) and Ph.D. (1980) in Soils with a minor in Geology. From 1975 to 1977 he taught introductory soil science as an instructor in the Agronomy Department, University of Maryland. In 1981 he was hired by the University of Illinois Department of Agronomy as an Assistant Professor of Pedology to conduct research and teach soil science. Research interests include reclamation of surface mined soils and the agriculture and environmental impacts of mine subsidence and coal combustion. He is married and lives in Champaign, Illinois with three children, one dog, and one mortgage.

Table 1. Acreage disturbed by surface coal mining in Illinois.

County	Acreage Affected				Area Affected %	Acres in County
	Prior to '62 Law	1/1/62 - 6/30/93	% Pre Law	Total		
Adams	177	51	78	228	0.04	556,160
Brown	19	761	2	780	0.40	196,480
Bureau	2,910	225	93	3,135	0.56	558,720
Clark	3	0	100	3	0.00	322,560
Crawford	4	17	19	21	0.01	282.880
Edgar	51	450	10	501	0.17	296,160
Fulton	25,293	28,016	47	53,309	9.53	559,360
Gallatin	208	3,460	6	3,668	1.74	211,200
Greene	50	6	89	56	0.02	349,440
Grundy	6,162	1,128	85	7,290	2.66	273,920
Hancock	101	0	100	101	0.02	510,080
Henry	2,676	0	100	2,676	0.51	528,640
Jackson	4,080	5,168	44	9,248	2.40	385,920
Jefferson	72	3,435	2	3,507	0.94	373,120
Jersey	1	0	100	1	0.00	241,280
Johnson	1	81	1	82	0.04	220,800
Kankakee	2,097	63	97	2,160	0.49	437,760
Knox	11,434	10,359	52	21,793	4.73	460,800
LaSalle	1,213	0	100	1,213	0.16	737,920
Livingston	46	0	100	46	0.01	668,800
Madison	7	0	100	7	0.00	476,160
Marshall	1	0	100	1	0.00	255,360
McDonough	6	2,057	0	2,063	0.55	372,480
Menard	0	6	0	6	0.00	202,240
Mercer	25	0	100	25	0.01	364,160
Morgan	4	0	100	4	0.00	366,080
Peoria	1,265	8,413	13	9,678	2.40	403,840
Perry	13,084	37,506	26	50,590	17.84	283,520
Pike	1	0	100	1	0.00	540,160
Pope	0	53	0	53	0.02	238,080
Randolph	2,387	12,913	16	15,300	3.96	386,560
St. Clair	5,948	8,330	42	14,278	3.24	440,960
Saline	5,584	12,032	32	17,616	7.11	247,680
Scott	1	0	100	1	0.00	161,280
Schuyler	1,327	3,039	30	4,366	1.57	277,760
Stark	239	2,447	9	2,686	1.45	184,960
Vermilion	4,208	1,152	79	5,360	0.93	575,360
Wabash	6	4	60	10	0.01	145,280
Will	4,698	1,624	74	6,322	1.17	540,800
Williamson	7,792	11,377	41	19,169	6.79	282,240
Total	103,181	154,172	40	257,353		

Source: Illinois Department of Mines and Minerals, 1995 Annual Report.

Table 2. Soil map used on Illinois mine soils.

Map Unit					
Number	Name	Established	Texture	Reaction	Classification
MD, ML, SM	Strip Mine	Pre 1978	*Undifferentiated strip mined and other made land*		
801	Orthents	1978	silty	--	Udorthent
802	Orthents	1978	loamy	--	Typic Udorthent
803	Orthents	1978	--	non-acid	Udorthent
804	Orthents, acid	1978	loamy-skeletal	acid	Udorthent
821	Morristown	1978	loamy-skeletal	(calcareous)	Typic Udorthent
871	Lenzburg	1981	fine-loamy	(calcareous)	Typic Udorthent
823	Schuline	1983	fine-loamy	(calcareous)	Typic Udorthent
824	Swanwick	1983	fine-silty	non-acid	Oxyaquic Udorthent
872	Rapatee	1983	fine-silty	non-acid	Typic Udorthent
806	Orthents	1988	clayey-skeletal	--	Udorthent
825	Lenzburg	1988	871, *Acid sub-stratum phase*		Typic Udorthent

Note: All taxa are members of mixed, mesic families of their respective subgroups.

Table 3. Bulk density of selected horizons of Illinois mine soils.

Pedon (g/cc)	Horizon	Depth (cm)	Bulk Density
S72	C	17-49	2.08
S72	Cd1	49-100	2.14
S72	2Cd2	100-110+	2.00
S74	C2	35-75	1.97
S74	Cd1	75-107	1.97
S74	2Cd2	107-112+	1.99
S75	C2	46-80	2.00
S75	Cd4	138-160+	2.05
S76	C1	21-51	2.08
S76	Cd1	91-121	1.95
S77	C	25-74	1.95
S77	Cd1	74-122	1.90
S77	2Cd2	122-140+	2.07
S78	Cd1	56-99	2.08
S79	C1	18-68	1.75
Mean	Cd		2.02†
Mean	C		1.97

†No difference at =0.05

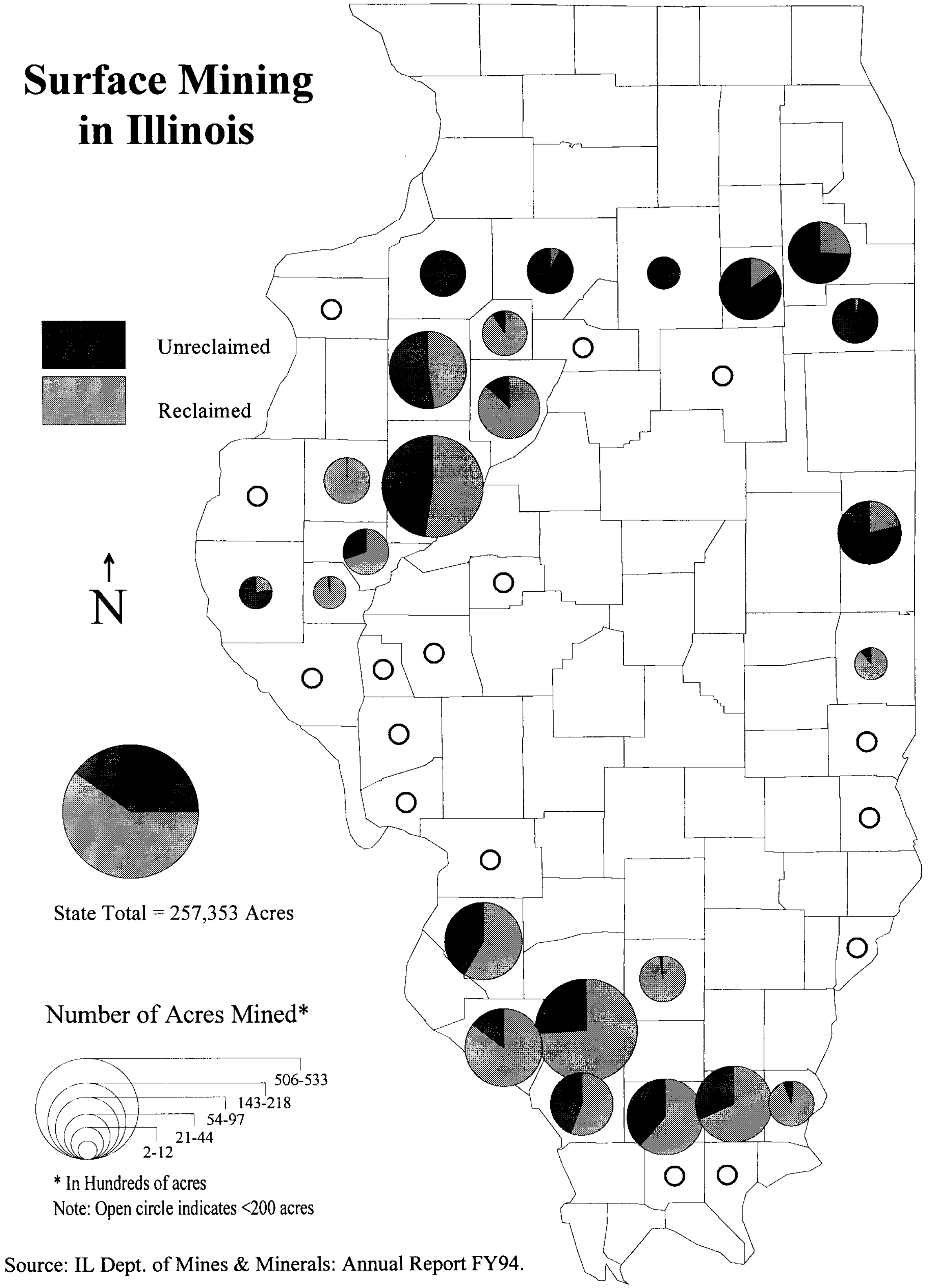


Figure 1. Distribution of surface mining in Illinois.

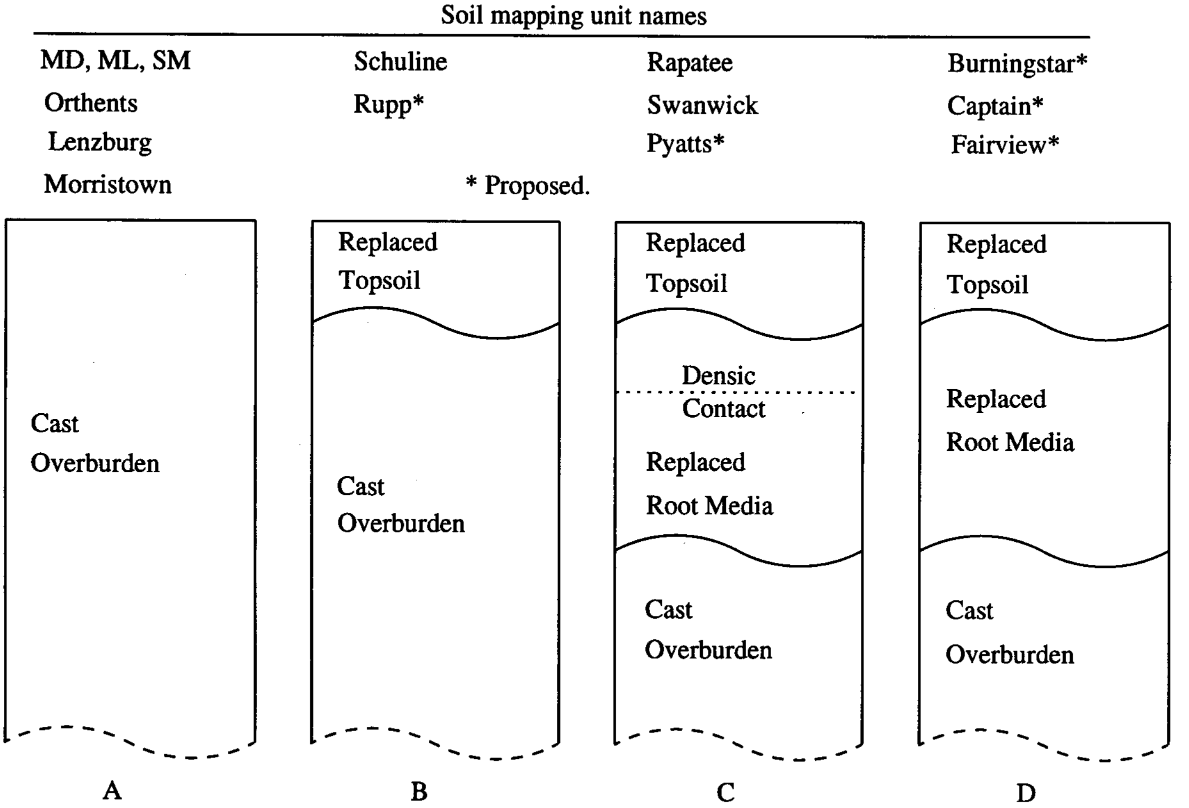


Figure 2. Idealized post-mine material placement profiles showing soil mapping unit names.

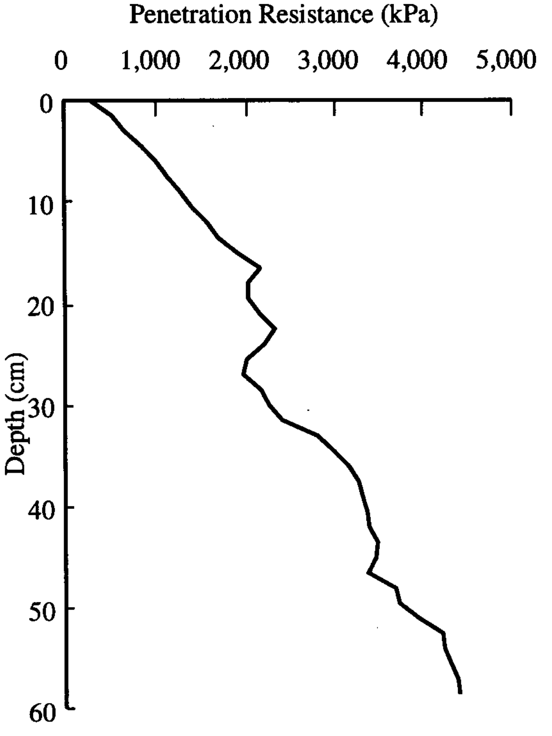


Figure 3. Penetration resistance in a soil mapped as Rapatee, 30 cm topsoil replaced over rocky cast overburden. This soil meets the guidelines for the proposed Rupp series.

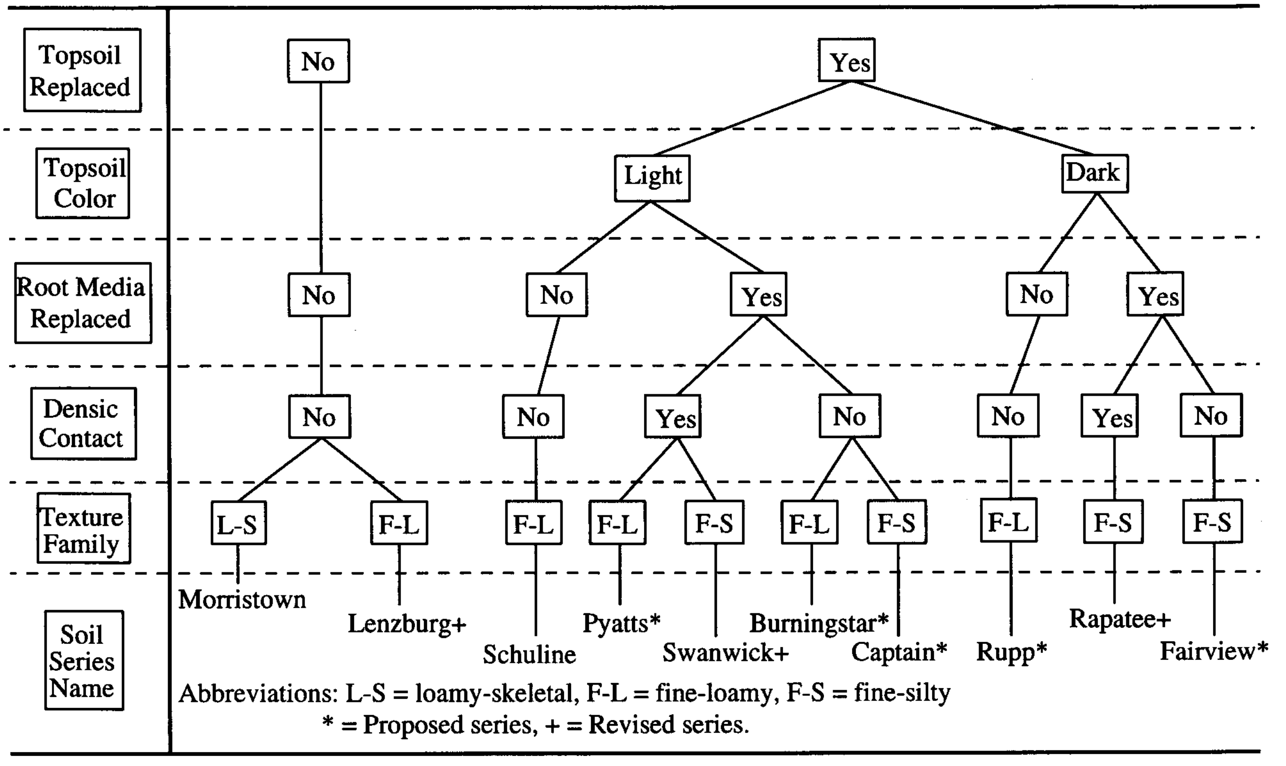


Figure 4. Key for Illinois minesoils including proposed and revised series.

GLOBAL POSITIONING SYSTEMS (GPS) AND SITE SPECIFIC MANAGEMENT

Richard 1. Barnhisel[1]
University of Kentucky,
Lexington, KY

There are several items of equipment necessary in order to use GPS for managing surface-mined soils. The most important is a DGPS (Differential) receiver that ranges in price from $2,500 to $5,000 depending on the brand and its capability, For example, the Starlink Invicta has a suggested retail price of $4,200, capable of receiving 10 satellites and two U.S. Coast Guard (USCG) signals. DGPS receivers are those which obtain free signals from the U.S. Coast Guard radio beacons that correct the built-in efforts of the GPS satellites. Most DGPS receivers obtain signals from at least eight satellites and at least one USCG correction signal. Others may receive up to 12 satellites and two USCG beacons. Only the strongest four satellites and one USCG signal are used to compute the position of the DGPS antenna in the field.

Depending on the cost of the instrument, DGPS positions are within plus or minus I to 2 meters, as a worse case. In general, the more expensive the instrument, the more precise the position. Some of the receivers can provide sub-meter accuracies. A survey grade instrument, which may cost several tens of thousands of dollars, can deliver positions within I or 2 centimeters in the X-Y direction. In general, elevation or the Z direction is 3x poorer than those of the X-Y direction.

A second piece of equipment needed is some method of recording the position in the field so that maps can be produced. This may range from a palm-top computer that costs around $500 to a lap-top that ranges from $1,500 and up, depending on what accessories it may have and how rugged it may be. Ordinary lap-tops will serve this purpose, but remember they are not designed to bounce around in the field especially under dusty conditions. If such a computer is used, it is highly recommended to down-load all data each day to a more stable computer as a “crash” is likely to occur sometime during its use.

Software is the third component. The cost ranges from $500 to as high as $8,500, Cheaper software packages can do only simple mapping and generate output to a printer. The more expensive software packages have Geographic Information Systems (GIS) components that allow the user to link information to points or features of a map. In the case of surface-mining, this may range from simply linking the permit data to an area or a polygon. This data can be as large as desired as long as it is within the space limitations of the computer. One can link seeding and fertilizer rates applied, yields taken as a part of productivity measurements, and even data from individual soil or plant sampling locations within the permitted area. Location of areas where reseeding is needed, where gullies are found. diversion structures, sediment basins, etc., are other components that may be included in the GIS database. Essentially, the database can include any kind of GIS data that can be linked to the map or GPS position from the very first time the boundaries are defined, through the mining phase, to when the bond is released and beyond if record keeping is needed.

Sources of Field Variations

Most of my personal use of GPS on surface-mined lands is related to recording yields associated with prime farmland. Yields are subject to many components, some of which are the results of physical and chemical properties of the soil. Yield maps from a combine can show zones within a field that have good to poor yields. These areas can be linked to physical properties through GPS and GIS databases.

Prior to planting a permitted area, one should sample the soils or spoils within the area. Grid sampling is one method to detect regions within the permit area that may need special treatment to bring conditions to a level where yield goals can be met. The first step in preparing to grid sample is to determine the increment or field boundary within the permit. This is simply driving the perimeter with an ATV vehicle equipped with GPS, or it may be established by scanning the permit map and linking latitude and longitude positions to this map. An example of a boundary map is given in Figure 1. Superimposed on such a map, as is the case in Figure 1, are grid sampling points. In this case, I started with sample #26 in the upper left hand corner and ended with #87 in the lower right hand comer. This illustration of a grid map is perhaps much more intensively sampled than is usually, necessary, and it has a spacing of 150 x 200 feet. The spacing used in this study, allowed for a slightly more intense sampling interval in one direction due to change in slope. It also allowed for the determination of how frequently should one sample reclaimed land. More commonly grid sampling is done on 330 x 330 or 445 x 445 feet or 2.5 or 4.5 acres per sample.

Physical and chemical properties could be determined for the soil samples at each location. In this case, I determined only soil fertility values, but since GPS positions were recorded, I can always return to these positions,, within plus or minus one yard, and collect other data such as compaction or bulk density, soil strength. or soil depth. It is planned to collect physical data only where the yield map for corn indicates possible problems may be limiting yield. These yield data will be collected in the future.

Soil Fertility Variations

Another grid soil sampling study will be presented in the next few figures as an example of soil nutrient variations. This study is not from a mdace-mined field, but is adjacent to where a surface-mine occurs. It was my hope to have the data from the previous area completed and included in this paper, but soil sampling and data analysis are not complete.

This field shown in Figure 2 is bordered on both of the long edges by open ditches. On the right side ', the soil from this ditch was placed within the field. Although this had minimal effect on pH, it did influence other nutrients. The bottom of this field has a road running along its edge.

Figure 2 illustrates the variation of pH within this 20 a field. This field is of one soil type, yet the pH varied from <5.4 to >7.5. Although such maps are more vivid in color, the contour lines surrounding the dark shading illustrate pH boundaries where the pH is low. Through the center section is a zone of higher pH, more or less parallel to the field's longest axis. The pH in this area is greater than 6.6, with two small points where the pH was greater than 7.5.

The Mehlich III Ca data are plotted as Figure 3. There is a similar pattern in this Ca data as that for pH, as one would expect. In general, regions low in pH arc also low in Ca, and vice versa. The degree of fit between two figures, as a general rule, can be manipulated by changing the scale or range in values. However, I did not attempt to manipulate these ranges to produce a better fit, but generally tried to keep the number of shades at the same level, or to represent differences for recommendation of nutrients.

For the Ca data, there tended to be higher levels along the ditch on the left side of this figure. The soil that was spoiled along this portion of the field is higher in clay and had been spread onto this soil for the first 50 feet.

Figure 4 illustrates the level of Mg in this field. Essentially, the Mg is uniformly low and below 300 lbs/a, except along the open ditch, especially up to about the first 1,400 feet. Along the ditch, Mg levels were about 5x greater than the rest of the field. In all cases, however, Mg levels were adequate.

Figure 5 gives the Mehlich III P data. This pattern does not match any of those presented earlier. There arc "islands" of high levels throughout this field that are 4x greater than the low areas. Near the top of this figure are a couple low areas that are <20 lbs/a, which occur within 200 ft from a level between 70 and 80lbs/a.

It appears that P levels are high along the road at the bottom of this figure. It is likely (my speculation) that extra fertilizer (both P and K) has been applied here in order to empty the spreader truck prior to its departing the field.

Figure 6 presents the Mehlich III K data. Again, this nutrient has a different pattern, with the exception of being high along the road. The majority of the K was in the medium range between 140 and 220 lbs/a.

Conclusions

It may appear that perhaps grid sampling presents more data than one can manage. In the examples given here,, all elements except for Mg are candidates to be managed separately by variable additions of these nutrients. Since these patterns vary widely and present large differences in nutrient levels', variable fertilizer application would challenge most computer driven spreader trucks. In fact, the sampling frequency in this field was more intense than given in the first figure, being at 75 x 75 ft. We used this pattern since many available spreader trucks could spread nutrients at such a spacing. On an average, and if only applying P and K. adjustments in either of these elements would need to be made four or five times across this field of 2,000 ft in length. Since there are about eight passes of the truck, 40 adjustments would be needed for each element, or a total of 80. This is not beyond the capability of commercially available trucks. It is not known if applying nutrients according to these maps would be economical, but if this were a surface-mined field, this may be important to a coal operator to insure a timelv bond release, at least the first couple of years for corn production. Hopefully with time, the fields will become more uniform and variable rates would no longer be needed or advantageous.

Preliminary data from a grid-sampled, surface-mined field indicates a wider degree of variability than seen for this non-mined field. This is not surprising since, as you will recall, the field illustrated in figures 2 to 6 were all from the same soil series.

---

[1]Richard Barnhisel, Professor of Agronomy and Geology. Department of Agronomy. University of Kentucky. PhD. Virginia Tech. 64. 25 years reclamation experience.

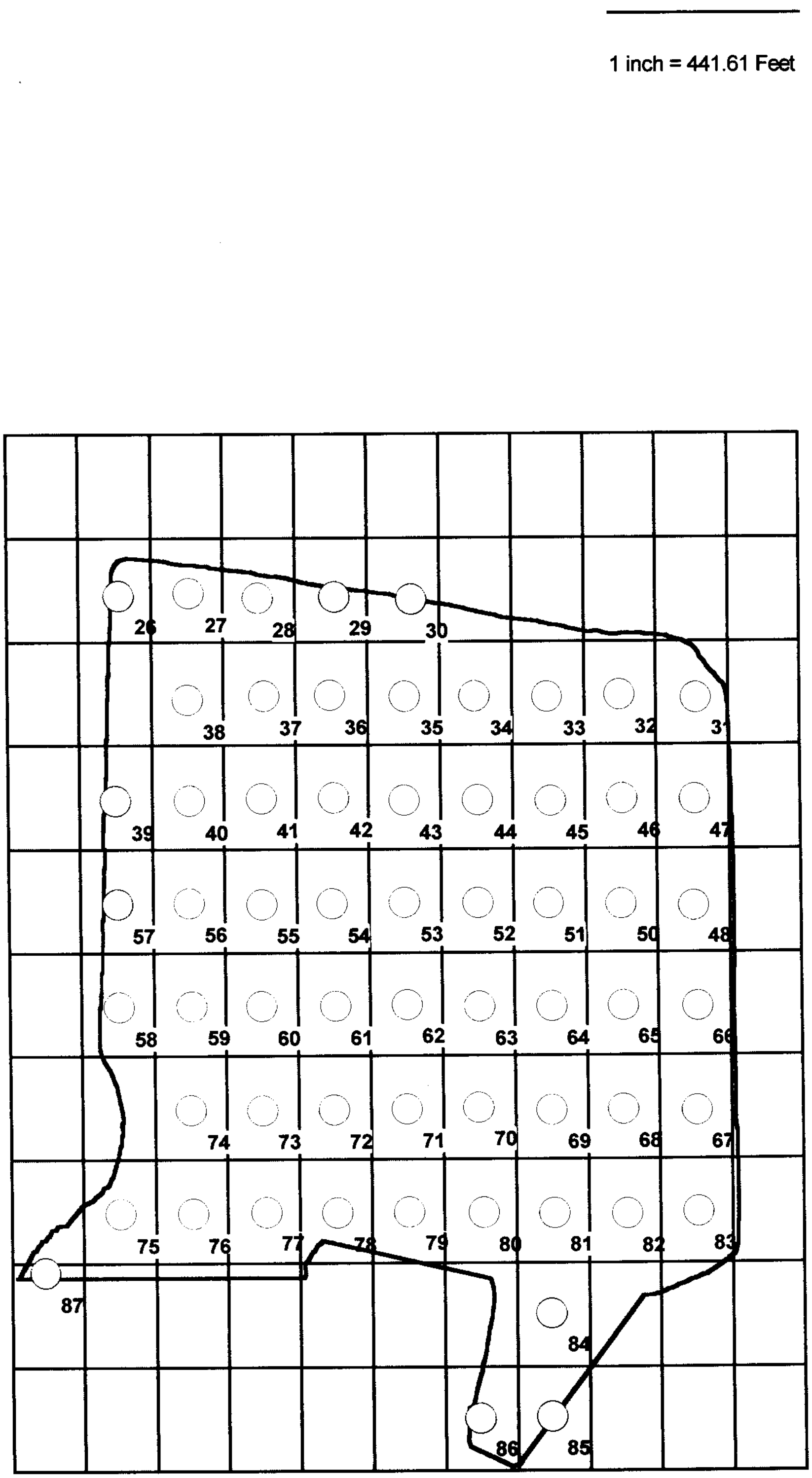

1 inch = 441.61 Feet
26
27
28
29
30
38
37
36
35
34
33
32
31
39
40
41
42
43
44
45
46
47
57
56
55
54
53
52
51
50
48
58
59
60
61
62
63
64
65
66
74
73
72
71
70
69
68
67
75
76
77
78
79
80
81
82
83
87
84
86
85

Figure 1.

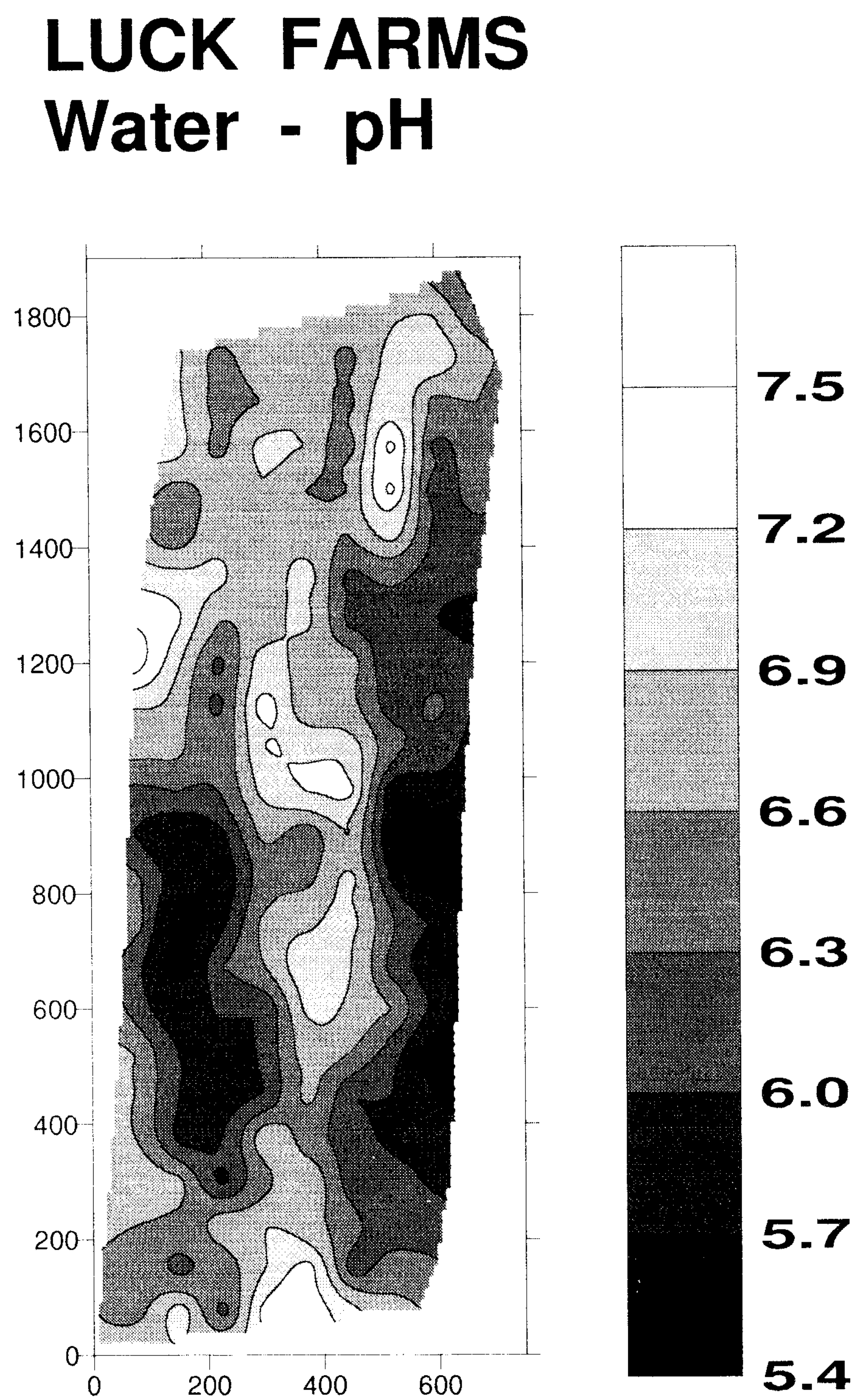

LUCK FARMS
Water - pH
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
7.5
7.2
6.9
6.6
6.3
6.0
5.7
5.4

Figure 2.

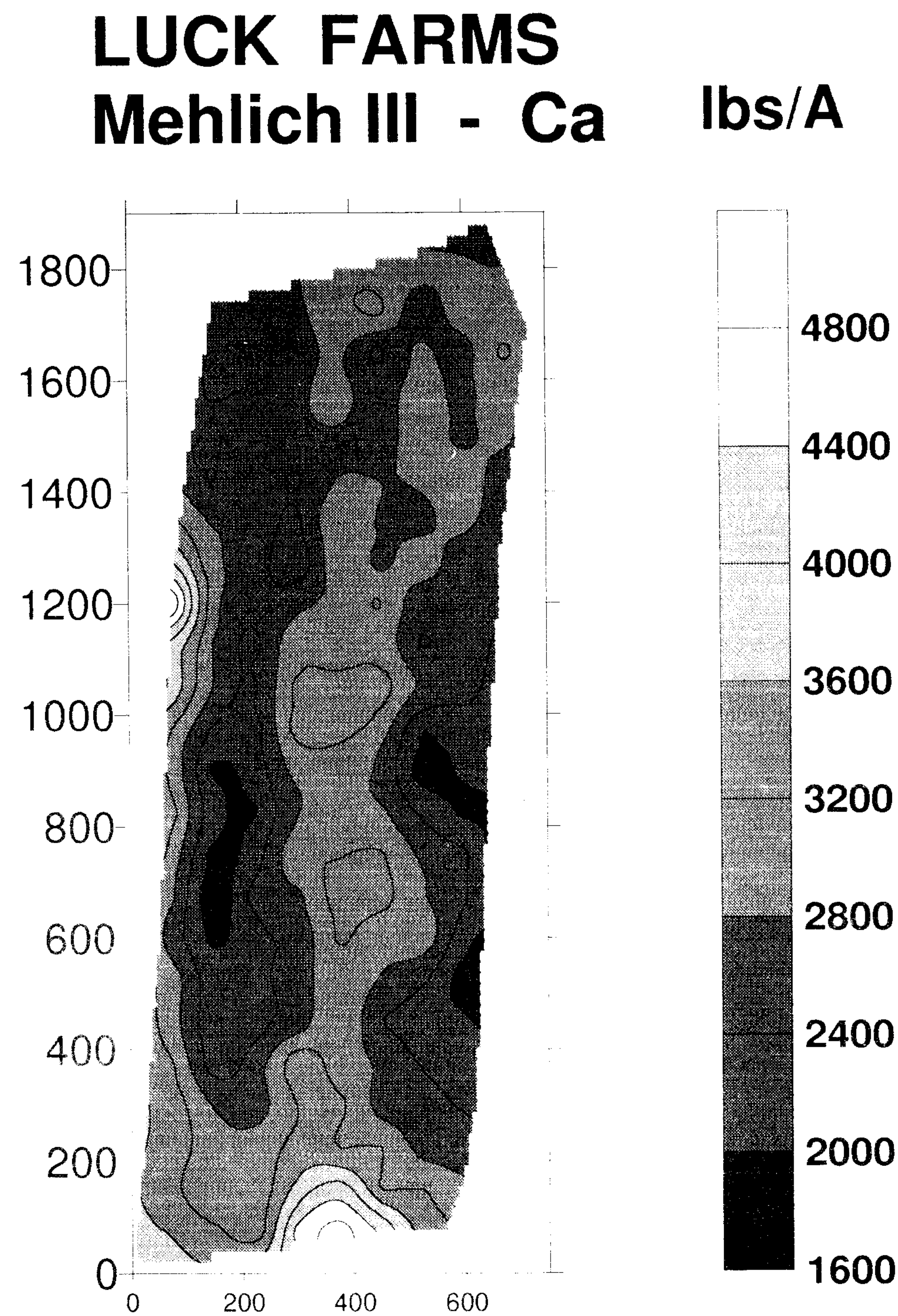

LUCK FARMS
Mehlich III - Ca
lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
4800
4400
4000
3600
3200
2800
2400
2000
1600

Figure 3.

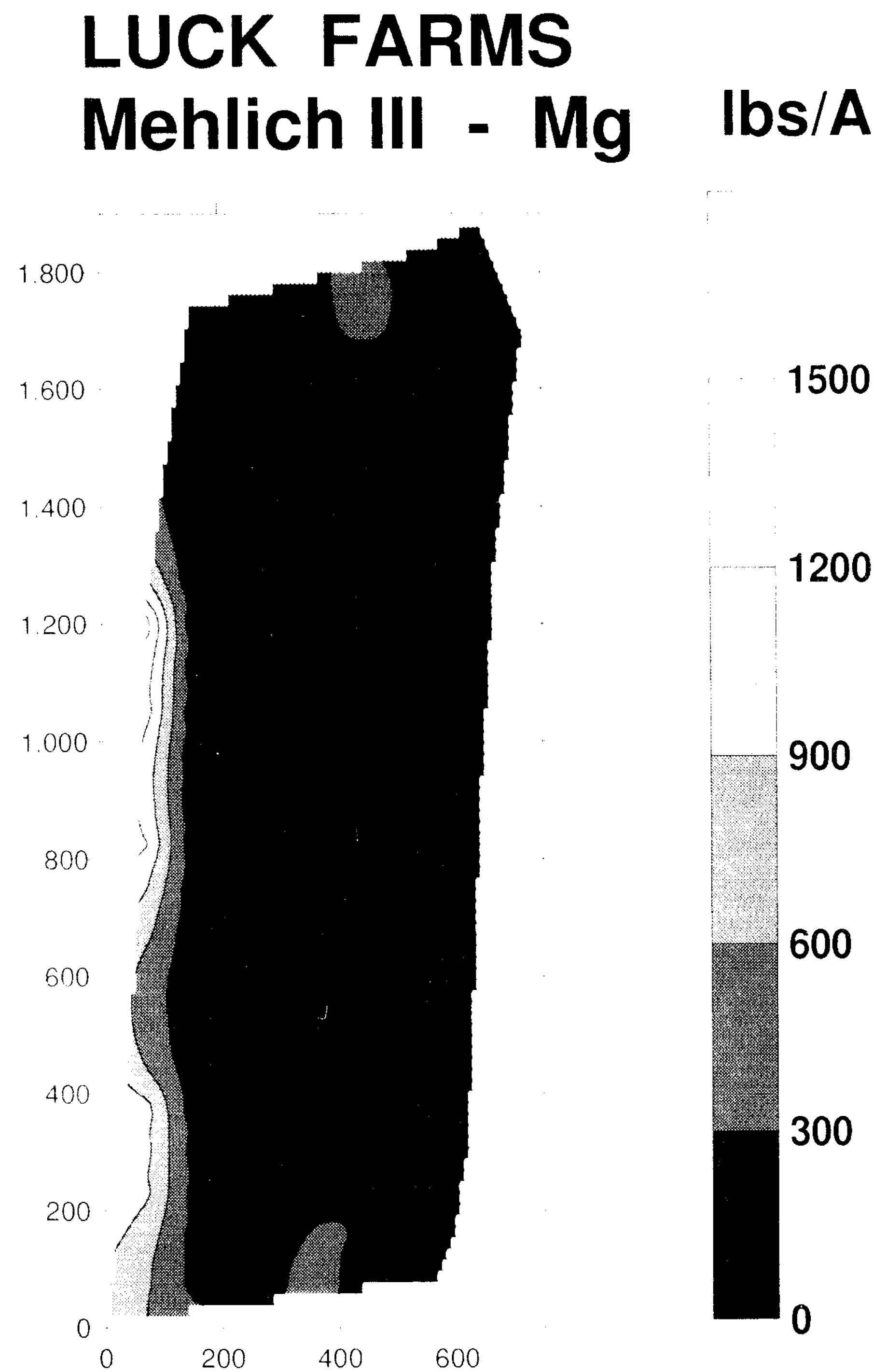

LUCK FARMS
Mehlich III - Mg
lbs/A
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
200
400
600
1500
1200
900
600
300
0

Figure 4.

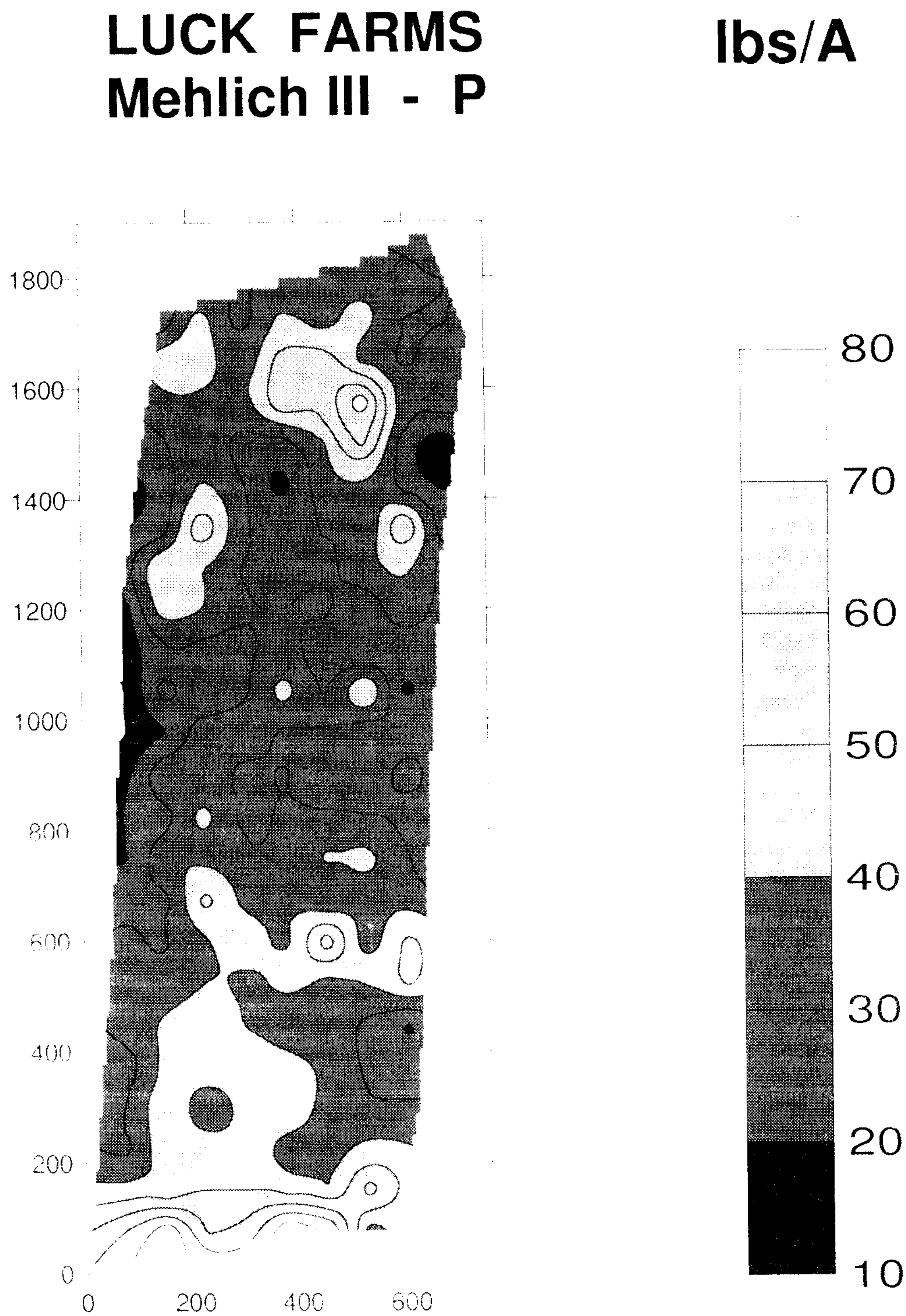

LUCK FARMS
Mehlich III - P
lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
80
70
60
50
40
30
20
10

Figure 5.

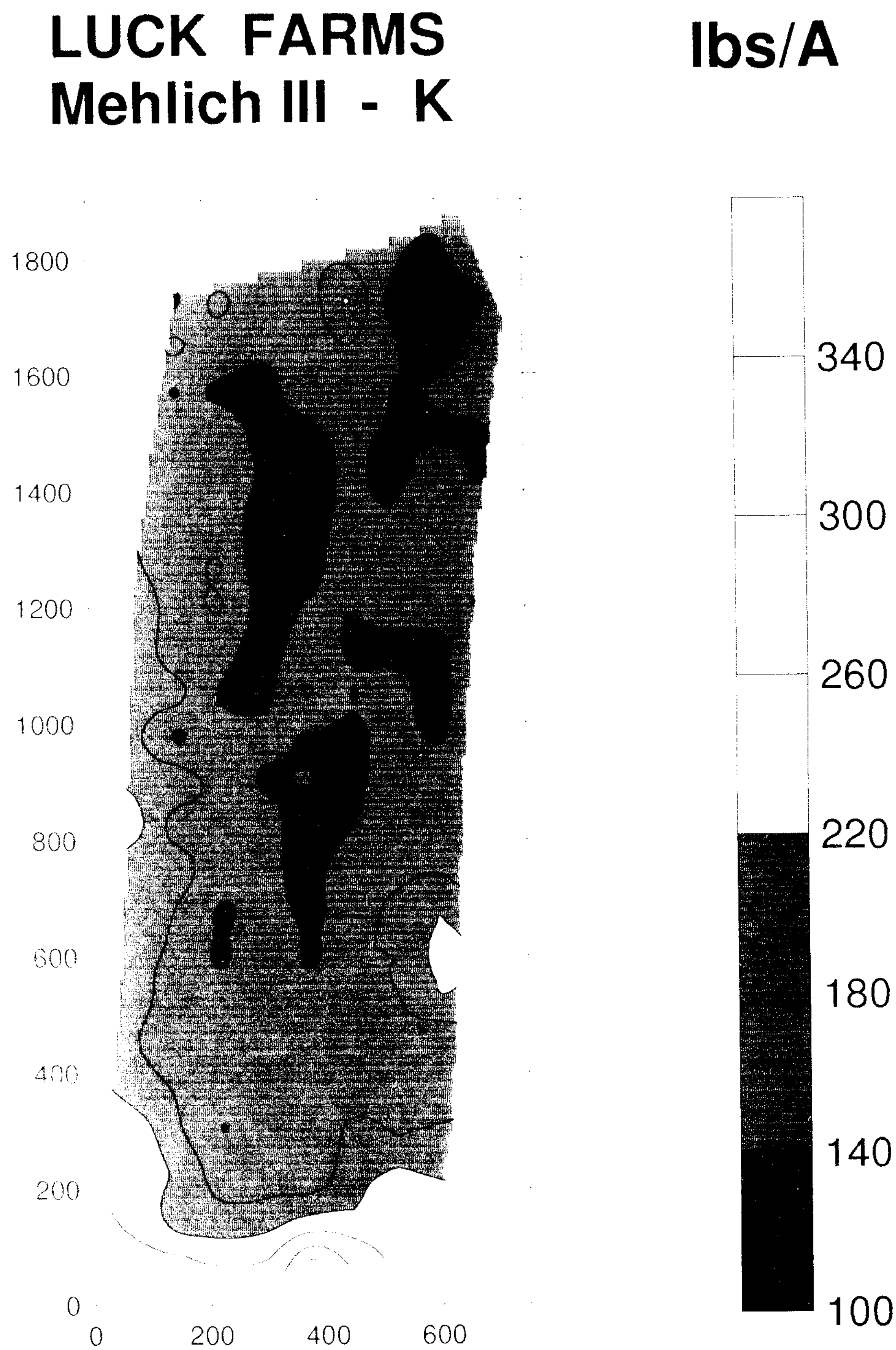

LUCK FARMS
Mehlich III - K
lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
340
300
260
220
180
140
100

Figure 6.

LAND USE AND VALUE AFTER RECLAMATION

William R. Phelps[1]
ARK Land Co.
St. Louis. Missouri

Abstract

This presentation discusses the process of analyzing the size and condition of producing land parcels concerning management and income relationships, tract location., and soil and water conservation structures. It reviews production schemes for crops such as corn, soybeans. wheat, alfalfa hay, and warm season grasses, as well as use for recreation. Management of tenants and leases is discussed concerning evaluation of crop share leases, cash renting, custom farming, and tenant selection. Issues related to planning for and management of taxes, long-term improvements, and other land costs are presented.

Introduction

I have been with ARCH Coal for five years. My responsibilities include managing and leasing all of ARCH's properties that are no longer under bond, as well as lands that are undisturbed by mining. I am going to talk about management of property in terms of (1) building asset values, (2) current property values of reclaimed lands in southern Illinois where we have tested the market, and (3) some future trends, such as some nonconventional uses of these properties, both those that are emerging and those that may become more important in the future.

Property Management

Concerning property management, management of both the reclaimed and undisturbed areas are key to unlocking the maximum values of these properties. We had been looking at the property as a leftover from mining rather than as an asset. Internally we had to change our mind set and start looking at this property as an asset. We had to start looking at it on an individual tract-by-tract basis, both in terms of sales potential and as a management responsibility. Instead of acting like one of the largest landowners in southern Illinois, we had been acting like a coal mine, until recently.

ARCH has reduced the number of operators that we have working on these properties from 55 to 23 individuals over the last five years. Tenant selection is very important in this process. One of the first things we did was to significantly raise the tenant rent for cash renting and custom farming. Although not popular initially, the benefits were more than we had anticipated. We ended up working with a much higher quality of tenants that were more successful land managers. We eliminated rental of small tracts of land and ended up with fewer but larger tracts of 2,000 to 5,000 acres. This gave us more bargaining power in the market. This was done both for agricultural tracts as well as for the hunting rights. In order to manage this successfully, we had to ensure that our tenants who were raising crops, those raising cattle, and our hunters were all working together.

Land Values

We also had to look closely at those enterprises that were actually making us the most money. We looked at corn production and saw that this was our most risky enterprise. We found that wheat and hay production were the least risky and many times the most profitable crops. We have been very aggressive at matching our cattle producers with the right hay ground. This combination added value to both operations. We also greatly increased our control over the properties in order to reduce our problems from trespassing.

We knew that some day we would want to sell these properties, and we knew approximately what the value of the properties were. We looked at the market for land in this area. We projected that the land values would increase with time because people were moving out of the St. Louis, Missouri area and moving into the country. We were getting a lot of calls from people who wanted to hunt on our property. Pressure for land in this area was going up rather than down.

We determined that in our area, the market for hunting is what is going to drive the price of these properties up. In response to this hunting pressure, we established hunting clubs on the properties to develop the hunting resource and stopped all of the trespassers and other individuals that wanted to hunt on these areas. This has allowed our populations of deer, turkey, and other game animals to increase. We actually plant crops in the area just to encourage water fowl to utilize the area so they will be present when we show the properties to potential land buyers.

We also had to change the mind set of the locals in the community. One thing about land value is that 70% of all land sales in the Midwest will be to local buyers within two to three miles from the property. We had to change the property potential in the minds of the patrons of the local coffee shop. Prior to this, the locals would only value previously mined land at $200 to at most $400/acre.

In order to do this, we had to set some standards for land values and stick to them. We determined that the hunters were going to drive the market. We were about 90 miles from St. Louis, Missouri and about 50 miles from Carbondale. Illinois. We knew that there would be people coming from these urban areas that would drive the demand for our properties. Although 70% of our sales have been to local people, it has been the pressure from this urban hunter market that has allowed for the increase in land values.

We have worked with our local real estate brokers in order to change their mind sets about the value of these lands. It is very important that the real estate broker actually feels that land is worth the asking price for the land. If he truly feels the land is only worth $400/acre, he will have little success trying to get $800/acre. If the buyer says the price is too high, then the broker will agree with the buyer because that is what he believes.

One thing that has helped us to raise the per acre value of the property is to divide it up into more marketable tracts prior to sale. We take an area that has 1,000 acres and has water on it, and subdivide it into two 500 acre tracts. You need to make logical divisions that increase the value of the land. You need to make sure that you have access to the property so that people do not have to build roads to get to their property.

We plan to market the ground at least one year in advance. Although most buyers can not tell what 60 bushel soybean land looks like, they can tell whether or not the road ditches have been mowed. If the row ditches are mown, then they think you are doing a good job taking care of the land. Another thing we do is to ensure that the tenant farmer who rents the property does not go the local coffee shop and bad mouth the property. We make it very clear to the tenant farmer that this will not happen. If he doesn't like some particular feature of the property, such as he thinks the water way should be in some other place or there are some rocks he does not like, that is just between us and him. You can not afford to have him not speak well of the property as he will get asked frequently.

We have sold about $11 million worth of land over the last 13 months. The market has come up significantly in the last two years and will probably level out soon. In 1995, we sold some, what I would call nuisance acres, pre-law ground with spoil ridges still standing that had a pretty good coverage of pine trees. We had a terrible trash dumping problem on this property. After trying hard for six months, we finally sold it for $325/acre and were happy to get it at that point. We learned a lot in this process. Even though we cleaned it up just prior to the sale, we and everyone else knew that trash dumping was a problem. After changing our management practices in 1997, we sold 550 acres of mostly reclaimed land that had about 30 acres of water, 62 acres of cropland, and the remainder in scrub woodland with a lot of rocks for $530/acre. In our best sale this year, we sold 1,035 acres with 150 acres of crop land, with the remainder in water, timber, and pasture that made a very good hunting area for $800/acre. It had a county road on three sides and we really marketed it well. We have had several other sales in the $750/acre range.

We figure that reclaimed crop land is worth about 75% of un land currently. This is the best price assuming that you manage it and market it properly. Areas that have been planted with trees that are six to eight years old are worth within $50/acre of undisturbed forest properties. Reclaimed pasture is worth about $700 - $800/acre. This depends upon the number and condition of the fencing and the number of separately fenced areas. The pre-law lands with standing spoil ridges are worth under $500/acre if they have water and water fowl will use them.

Maximum values are enhanced by subdividing the land. You increase the number of potential buyers by tenfold if the sale concerns a$300,000 tract of land rather than a $1,000,000 tract of land. By subdividing the land you transform a 5,000 acre parcel worth $500/acre into several tracts worth $700 to $750/acre.

Future Trends

Concerning future trends, the number of farmers in America are decreasing at 3.5% per year. Every time a farmer goes out of business, he usually has two to three people that use his land for hunting that are now looking for a new place to hunt. Also hunters are never satisfied with what they have and are always looking for new places to hunt Although I think that the hunting value of the land may not increases I do not think it will come down.

Another emerging market, if the property is large, is for a hog or poultry feeding operation. These operations are trying very had to find land that is remote from human populations. These people are looking for an isolated 40 acre tract of land with road access. I think the market for such property is in the $8,000 to $10,000/acre range. If you can arrange to obtain the hog manure and put it on surrounding crop land, it will increase the crop land value by $400 to $600/acre.

---

[1]William Phelps, A.F.M., Property Specialist, Ark Land Company. BS 88 Animal Science, University of Kentucky. 8 years experience Farmland Land Management.

ILLINOIS RECLAIMED SOIL PRODUCTIVITY: RESTORATION TECHNIQUES

Gene Smout[1]
Consolidated Coal Company
Sesser, Illinois

Consolidation Coal Co. (Consol) has nearly 8,000 acres of high capability and prime farmland reclamation responsibilities in Illinois. It has been involved in research in the area of restored soil productivity since 1976 with the University of Illinois and Southern Illinois University at Carbondale. Consol maintains an intensive internal program to demonstrate and test deep tillage equipment.

The research and in-house demonstrations identified soil physical strength (compaction) as the main limiting factor to restoring a soil's productive capacity. There are two primary ways to address this issue: prevention and amelioration. The former was not an option for Consol because many acres were already reclaimed and the company has a major scraper fleet. Along with other operators in Illinois, Consol started an aggressive search for equipment and techniques that could loosen compacted soils.

In 1987 Consol was the first to use the DMI-Super Tiger deep soil plow, originally developed and manufactured DMI, Inc. of Goodfield, Illinois. This plow is composed of a single parabolic, static shank with a 44-inch wide sweep weighing 1,200 pounds. It is capable of plowing 48 inches deep while leaving the topsoil in place. A Catapiller D9L tractor with 46.0 horsepower is used to pull the plow. In 1990 the decision was made to commit to this equipment as the best technology currently available. In 1994 Consol received a patent waiver from DMI to build its own plow. The Consol-built plow has been in use since the er of 1995. To date, Consol has plowed over 3,900 acres with a DMI plow.

In summary, Consol's program for deep tillage after topsoil replacement is as follows:

(1) Wheat is planted for the first two years. This allows for an intensive land leveling program following each harvest, During this time, the majority of surface water management structures (terraces and grass waterways) are constructed.

(2) Alfalfa is established and maintained for a minimum of two to three years. Just prior to the plowing, the remainder of the build-up fertility is applied, based on variable rate technology sampling and application. Alfalfa roots can penetrate the dense clays and dry out the subsoils. This is important because the action of the plow is significantly enhanced when the subsoil is dry. The lifting motion of the sweep combined with the ground speed of the tractor does an excellent job of shattering the large massive blocks of high density clay but only if the soil materials are dry.

(3) The plowing season is limited to the driest part of the southern Illinois summers Start-up is normally planned for the first two weeks in July, allowing time for the alfalfa to pump out the subsoil moisture gained during the last wet season. The plowing continues as late in the fall as possible. Consol plants to plow around 600 acres per year that normally includes one mobilization between mine sites. The best productivity for this combination of equipment has been around three quarters of an acre per hour. The contractor can usually ran the plow for 20 to 24 hours per day.

(4) After plowing, these fields are rough because the plow leaves a corrugated pattern in the soil surface. The soil peak in the plow path averages 21 inches above the original soil surface. The surface of the fields are re-leveled as quickly as possible through off-set discing and multiple passes with a field cultivator. If the field receives a three inch rain or less immediately following deep tillage, a long delay can result before an entry into the field is again possible.

The program, as described above, has been applied for over ten years, and the cropping results have been very good. On soils that have been plowed with the DMI, there have been 130 fields, with cumulative total of 4,000 acres, tested by the Illinois Agricultural Lands Productivity Formula. The results of this testing are as follows:

(1) com-96 fields tested and passed 83.3% of the time;

(2) soybeans-20 fields tested and passed 85% of the time; and

(3) wheat-14 fields tested and passed 78.6% of the time.

---

[1]Gene Smout, Project Engineer, CONSOL. MS 78, Forest Ecology Southern Illinois University. Over twenty years reclamation experience.

CHARACTERISTICS OF SUBSIDENCE FROM ABANDONED AND ACTIVE UNDERGROUND COAL MINES IN THE ILLINOIS COAL BASIN

Robert A. Bauer[1]
Illinois State Geological Survey
Champaign, Illinois

Abstract

In both active and abandoned coal mining in the Illinois Coal Basin, there have been and still are two fundamental mining types: ones that leave coal pillars behind to support the overburden and ones that remove the coal and support of the overburden at the time of mining. The later method has coal mine subsidence occurring at the time of mining and is considered planned coal mine subsidence.

Coal mining in the Illinois Basin has used four mining methods that left pillars behind to support the ground surface. The mining patterns have evolved from random directions and high percentage of extraction of coal (small amount of coal left to support the ground surface) to very systematic and a lower percentage of extraction to greatly insure supporting the ground surface. The higher the percent of coal removed, the greater the potential for subsidence, but review of case histories of subsidence associated with these mining methods shows no clear correlation with time. Individual subsidence events are not predictable, since there are too many variables of changes in thickness of weak floor materials, wet or dry mine conditions, exact size of pillars, amount of damage to pillars from blasting, etc. Therefore, it is felt that if an area is undermined by an old abandoned mine, there is always a possibility of subsidence.

The other coal mining type either extracted pillars or all of the coal and lowered the ground surface at the time of mining. Each of these three methods had predictable subsidence patterns on the ground surface. Subsidence characteristics for all the mining methods are reviewed along with the results of studies investigating subsidence impacts on groundwater.

Introduction

Underground mines were developed in the Midwest soon after the first settlers arrived. They mined coal, lead, zinc, fluorite, claystone, and limestone. During the early years, land over mining areas was sparsely populated. If the ground settled, little damage to structures occurred but at times settlement caused disruption of drainage on farmland. Many of the drainage problems were resolved through legal settlements and court cases. As towns and cities expanded over mined-out areas, subsidence impacted more structures and became a recognized problem.

Types of Subsidence

Researchers have learned much about the nature and causes of subsidence by studying the effects at the ground surface, drilling holes down to mines, lowering small television cameras down the holes to view mine conditions, and personally inspecting mines that are still accessible. In the Illinois Basin, subsidence of the land surface may take either of two typical forms: pit or sag (trough).

Pit Subsidence

Pits are usually 6 to 8 feet deep and range from 2 to 40 feet in diameter (Fig. 1), although most are less than 16 feet across. Newly formed pits have steep sides with straight or bell-shaped walls.

Pit subsidence usually occurs over mines less than 200 to 300 feet deep. The mine roof collapses and the void works up through the overlying bedrock and surficial layers of glacial deposits and loess to the surface, where a hole forms over one or two days. If the bedrock is only a few feet thick and the surficial deposits are loose, these materials may subside and wash into adjacent mine voids so that they produce a surface hole deeper than the height of the collapsed mine void.

When pits develop, the ground only moves in one direction-it drops vertically. Pits are most likely to form at the surface after heavy rainfalls or snow melts. Water does not usually accumulate in the pits but drains down into the mine. A common treatment is to fill the pit with sand or clay, cap the fill with a clayey soil, and compact the clay tightly so that its permeability is very low. Many pits have been permanently filled this way.

Structures can be damaged if pit subsidence develops under the comer of a building, the support posts of a foundation, or other critical spots. Otherwise, the probability of a structure being damaged by pit subsidence is low because most pits are relatively small, that is, only a few feet across. ff pit subsidence develops under foundation walls, it may not immediately affect the house because the foundation temporarily bridges the pit. Eventually, the "bridge" may become damaged.

Subsidence pits that are not filled pose a special danger for both people and animals. They are often deep and steep-sided. Anyone who falls in may find it very difficult to get out. Also farm equipment may partially fall into a pit if the equipment runs over it as it is in the final stages of reaching the ground surface.

Sag or Trough Subsidence

Sag subsidence forms a gentle depression over a broad area. Some sags may be as large as a whole mine panel--hundred feet long and a few hundred feet wide (fig. 2). Several acres of land may be affected. The maximum vertical settlement is usually 2 to 4 feet, as shown along the profile below the mine plan in Figure 2.

A major sag may develop suddenly (in a few hours or days) or gradually (over years). The profile in Figure 2 shows settlement that took place over 45 weeks.

Sags may originate over places in mines where the coal pillars have disintegrated and collapsed, or where the pillars have settled into the relatively soft underclay that forms the floor of most mines. Sags can develop over mines of any depth.

Tension cracks form as the ground is pulled apart by downward bending of the land near the outside edges of the sag. Generally the cracks parallel the boundaries of the depression and are a near surface feature going down 10 to 15 feet and decreasing in width with depth. Near the center of the sag, compression ridges form as the ground is squeezed by upward bending of the land. Ridges are observed less frequently than tension fractures because the area of compression is much smaller.

The ground moves in two directions during sag subsidence (Fig. 3). It drops vertically and moves horizontally toward the center of the sag. At the surface, the sag may be much broader than the collapsed part of the mine. For example, a failure in a mine 160 feet deep could cause minor surface subsidence more than 75 feet beyond the edge of the undermined area. The deeper the mine, the larger the area affected.

Sag subsidence has an orderly pattern showing tensile features surrounding possible compression features. Mapping of all the tensile features shows orderly movements toward the center of the sag.

Type and extent of damage to surface structures relate to their orientation and position within a sag. In the tension zone, any large cracks that develop in the ground may damage buildings and roads as well as driveways, sidewalks, pipes, sewers, and utilities. Houses in the tension zone may need to be supported until subsidence has ceased. Then repairs may be made.

In the comparatively smaller compression zone roads may buckle and foundation walls be pressed inward. The foundations of any houses in the center of the sag would be under horizontal compression. Although the area affected by compression is substantially smaller than the tension zone, buildings damaged by compression may need their foundations rebuilt. They may also need to be releveled.

Room-and-Pillar Mining-Unplanned Subsidence

The early coal mining efforts left enough coal m pillars to support the underground working area and therefore, the ground surface. The mining methods changed through time from unsystematic to systematic mine designs. These methods, frequently used before the early 1900s, were characterized by rooms that varied considerably in length, width, and sometimes direction (Fig. 4), forming irregular mining patterns. After about 1910, mining was conducted in a room-and-pillar pattern. In the production areas or panels, workers created rooms and crosscuts at right angles to form a grid pattern. These production areas (panels) were separated from main entries providing more support to the main en for their long-term use and improved Ventilation. This was the modified room-and-pillar or panel system (Fig 5). This system provided more regular configuration of production areas (panels) which had well-defined boundaries as a result of the broad barrier pillars or unmined areas left between panels. Two fairly modem room-and-pillar methods are the blind room and the checkerboard (figs. 6 & 7). Using the first method, miners bypass every sixth or seventh room of a production area. The unmined area (blind room) functions as a large pillar to support the roof and provide barriers to reduce the spread of any floor squeezes and fires. This method is still used today. The checkerboard system has evenly spaced square pillars in a checkerboard pattern of panels thousands of feet long and wide. In comparison to earlier mining, modem room-and-pillar mines have many main and secondary entries to provide for required ventilation.

No one can predict when or if the land above a room-and-pillar mine will sink. If any coal has been removed from an area, subsidence of the overlying geologic materials is always a possibility.

High Extraction-Planned Subsidence

High-extraction coal mining methods mine almost all the coal in a I area. They always result in the surface subsiding above a mine within several days or weeks after the coal has been removed. The sinking or subsiding of geologic materials lying over the mined-out area will continue for years, although movements will diminish rapidly after a few months. Once subsidence has decreased to levels that no longer cause damage to structures, the land can usually be developed or damaged structures can be repaired. In early longwall mines (Fig. 8), workers maintained the haulageways (entrances) by leaving areas of stacked rock, wooden props, and rock-filled wooden cribs to replace the support lost by the removal of coal. The mine roof, then the overlying bedrock and earth, settled onto the stacks of rock. When this occurred, a few feet of subsidence resulted at the ground surface.

Modem high-extraction systems are designed to achieve a high rate of production (figs. 9 & 10). Using the high-extraction retreat method, miners remove as much coal as possible in a small area until the roof starts to collapse; then they retreat to the next area. Using this method 80% to 90% of coal in the panel is removed. The size and number of pillars that must be left to maintain worker safety varies with underground geologic conditions (Hunt, 1980). The roof collapses in a manner that is controlled by temporary supports, and planned subsidence is initiated immediately. Using the modem longwall method, workers mine 100% of the coal along a straight working face beneath Artificial roof supports. The mine roof collapses immediately behind the working face, causing 4 to 6 feet of subsidence. This amounts to 60% to 70% of the mined height of the coal seam plus any roof or floor materials that have been removed.

Modern Longwall Mining

In the United States, mining companies began using the mechanized longwall method in the 1960s, although it was developed and used much earlier in England and Europe. Like high-extraction retreat, longwall mining begins at the outer edges and works toward entries that are used to haul the coal, mine personnel, and machinery. In the longwall system, all the coal is removed from a panel, but a few rows of pillars (called chain pillars) are left between panels. In Illinois, longwall panels may be 600 to 900 feet wide, up to several miles long, and 350 to 800 feet below the ground surface.

The effects of subsidence from longwall mining are uniform and anticipated. The surface over the center of the panel drops approximately 4 to 6 feet. The decline tapers off toward the edges of the panel and forms a gentle trough.

Subsidence of about 1 to 1.5 feet occurs over the entryways and chain pillars between mined out panels. The areas of surface subsidence go beyond the edges of the panel to a point of zero subsidence which is found at a distance of about 0.35 to 0.45 times the depth to the mine.

At one site, researchers in Illinois showed that subsidence movements continued for years after an area had been undermined by longwalls; this is called residual subsidence (Mehnert et al. 1992). These movements were measured six months to dm years after mining and amounted to 5% (about 0.3 ft) of mined-out height. Residual subsidence seemed to be fairly uniform over the panel and the pillars between panels. Residual subsidence caused no differential subsidence and no over the sides of the panel, two effects that would damage structures. This occurrence is similar throughout many areas of the world where residual subsidence may last six months to seven years, depending on the strength of the strata above the coal seam (Whittaker and Reddish 1989, Orchard and Allen 1975, and Fejes 1985).

Longwall Subsidence and Groundwater

A program in Illinois monitored the hydrology in the bedrock and near surface glacial materials and the amount and location of fracturing in the bedrock over several active mining areas. A high-extraction retreat panel and several longwall panels were studied. Water levels in deep and shallow test wells was monitored before, during, and after subsidence. Water levels were checked continuously by electronic recorders. Water chemistry and quality were evaluated. Results from several deep longwall panels show that rural wells in glacial materials (sand, clay, and silt) were unaffected by subsidence. Water levels in test wells in bedrock, where the water producing zone was very continuous across the area, were temporarily lower and recovered several months after mining (Booth 1992). In water bearing zones that were not continuous (limited in areal extent), water levels were lowered since fracturing of the zone produced a larger amount of void space for the quantity of water in the zone. Also there is speculation that the water yield of bedrock aquifers may be enhanced by longwall subsidence; however, this enhancement also depends on site-specific geologic factors that control the occurrence of groundwater. At the study sites, subsidence-induced fracturing improved the way water flowed through bedrock. The storage capacity of the bedrock aquifer was also enhanced.

Conclusion

The various forms of coal mine subsidence in the Illinois Basin have been cited in reports and publications for about one hundred years. During the past 20 years, systematic studies of the characteristics of each of the different gills of subsidence has led to an Understanding of their movements and impacts on groundwater.

Acknowledgments

This paper is a combination of text and figures from two previously published Illinois State Geological Survey publications: "Mine Subsidence in Illinois: Facts for Homeowners" and "Planned Coal Mine Subsidence in Illinois." This publication was published with permission of the Chief of the Illinois State Geological Survey.

References

Andros, S.O., 1914a, Coal Mining Practice in District I (Longwall): Illinois State Geological Survey, Champaign, Mining Investigation Bulletin 5, 42 p.

Andros, S.O., 1914b, Coal Mining Practice in District VI (Mines in Bed 6 in F Jackson, Perry, and Williamson Counties): Illinois State Geological Survey, Champaign, Mining Investigation Bulletin 8, 49 p.

Bauer, R-A., B.A. Trent, and P.B. DuMontelle, 1993, Mine Subsidence in Illinois: Facts for the Homeowners: Illinois State Geological Survey, Environmental Geology 144, 16 p.

Bauer, R.A., B.A. Trent B.B. Mehnert, and D.J. Van Roosendaal, 1995, Planned Coal Mine Subsidence in Illinois, A Public Information Booklet: Illinois Mine Subsidence Research Program VII publication, Illinois State Geological Survey, 32 p.

Booth, C.J., 1992, Hydrogeologic impacts of underground (longwall) mining in the Illinois Basin, in S.S. Peng, editor, Proceedings of Third Workshop on Surface Subsidence Due to Underground mining, Morgantown, AW, June 1-4, 1992: Department of Mining Engineering, West Virginia University, p. 222-227.

Fejes, P.J., 1986, The regulation of subsidence and underground coal mining in Illinois, in M.M. Singh, editor, Society of Mining Engineers Fall Meeting, St. Louis, MO., September 1986: Society of Mining Engineers, Littleton, CO, p. 97-100.

Hunt S.R., 1980, Surface subsidence due to coal mining in Illinois: Ph.D. dissertation, University of Illinois at Urbana Champaign, 129 p.

Mehnert, B.B., D.J. Van Roosendaal, and R.A. Bauer, 1992, Long-term subsidence monitoring over a longwall coal mine in southern Mining, in S. S. Peng, editor, Proceedings of Third Workshop on Surface Subsidence Due to Underground mining, Morgantown, WV, June 1-4, 1992: Department of Mining Engineering, West Virginia University, p. 311-316. -

Orchard, R-J., and W. S. Allen, 1975, Time-dependence in mining subsidence, in Proceedings of the Symposium on Minerals and the Environments, London, UK, 1974, Institute of Mining and Metallurgy, London, p. 1-17.

Whittaker, B.N., and D.J. Reddish, 1989, Subsidence: Occurrence, Prediction and Control: Developments in Geotechnical Engineering, Elsevier, New York, v. 56, p. 528.

---

[1]Robert A. Bauer has a Bachelor's degree from the University of Illinois at Chicago and a Master's degree from the University of Illinois at Urbana-Champaign in Engineering Geology with an emphasis on foundation and underground excavation. He has been with the Illinois State Geological Survey since 1976 after working at the McHenry County Section which is responsible for soil and rock mechanics testing and integration into other projects and seismic hazard assessment. He was Technical Manager and Director of the Illinois Mine Subsidence Research Program that investigated the impact of mine stability of all mining types and the impact of longwall mining on agriculture.

SUBSIDENCE: A REGULATORY PERSPECTIVE

Daniel Barkley[1]
Illinois Department of Natural Resources
Office of Mines and Minerals, Land Reclamation Division
Springfield, Illinois

Abstract

Underground coal mining in Illinois has shown an increasing percentage of total coal mined relative to surface mining. In the past 20 years, the percentage of underground to surface mine production has steadily increased. Underground mining is expected to continue to dominate coal production into the 21st century. Once the dust has settled from the clean air act, the drive for higher production and lower operating costs should increase the number of longwall and high extraction retreat mines. This will involve either conversion of existing room and pillar mines or the initiation of new underground mining operations,

As the industry continues to evolve, so do the environmental regulations that govern the mitigation of impacts. Federal regulations promulgated in 1992 under the Energy Policy Act (EPACT) mandated additional restrictions and regulatory requirements beyond those adopted in 1977 under the Surface Mining Control and Reclamation Act (SMCRA).

The regulation of subsidence mitigation in Illinois has developed through the years. Initial growing pains were experienced by both the coal operators and the Illinois state regulatory authority (RA) with lessons learned through experience. Today, subsidence permitting and mitigation are more standardized with clearer communications between the operators and the RA to achieve the goal of maintaining surface capabilities and making surface owners whole while m g the utilization of our coal resources. This paper describes the existing Illinois regulations, their impact on the coal industry and on the landowners above underground mining and how they have been implemented, and outlines currently proposed changes.

Introduction

Illinois underground production has captured an increasing percentage of total coal mined. In the past 20 years, the percentage of underground to surface mine production has increased from approximately 53% to 85% (Fig. 1). The production from longwall mining has also grown since its introduction in Illinois in the early seventies (Fig. 2). It is anticipated that underground mining will continue to dominate Illinois coal production into the 2lst century. The industry will continue to strive for higher production and lower operating costs and, therefore, the number of longwall and high extraction retreat mines should increase through conversion of existing room and pillar mines or initiation of new underground mining operations. The growth of underground mining in Illinois has been accompanied by the evolution of regulations governing underground mining effects over the past two decades.

On August 3, 1977, the Surface Mining Control and Reclamation Act (SMCRA) became law. The Act created the U.S. Department of Interior's Office of Surface Mining Reclamation and Enforcement (OSM). As suggested by both the name of the act and the regulatory body created to administer the act impacts of underground mining were not the primary focus or centerpiece of the legislation. In the infancy of SMCRA and at the beginning of state primacy, OSM left the choice of enforcement of subsidence repair and compensation of land and structures affected by mine subsidence to state law.

At one point m time, the surface property owner also controlled the mineral, oil, gas, and coal rights for a given land track. As far back as the early 1900s, companies began securing control of large blocks of coal reserves from surface owners not only for existing operations but also for speculation on future extraction. The contract severing the surface property from the mineral rights often incorporated language granting the entity obtaining the mineral property the right to extract all of the resource without liability for surface damage. This right is often referred to as the "right to subside." As the surface property changed hands through time, the knowledge of who controls the subsurface rights or even whether the property is already undermined could get lost.

The first specific protection afforded landowners occurred when the Illinois General Assembly created the Illinois Mine Subsidence Insurance Fund in 1979. The insurance fund was created to address the problems of old abandoned mines causing damage, but only provided insurance protection to homes and structures. Subsidence damage to surface lands such as farmland was not covered. From its inception, the Illinois regulatory program created as a result of SMCRA recognized the importance of Illinois farmland and the need to protect property owners from loss due to mine subsidence. Specific subsidence permitting and performance regulatory requirements were enacted at the state level to achieve the goal of balancing the lights of surface owners impacted by subsidence and the legal rights of the coal operators to extract their resource.

SMCRA and the Illinois Regulations of 1983

Although some form of Illinois mining reclamation law governing surface coal extraction had been in place prior to SMCRA dating back to 1962, no requirements for correction of subsidence impacts existed. Based on the expected trends of underground mining and planned subsidence operations, the Illinois state regulatory authority (RA) believed it necessary to protect both land and surface structures and therefore crafted the state regulatory program rules accordingly. The state of Illinois' Permanent Program Rules and Regulations were enforceable on February 3, 1983 and thus established coal operators' legal liability for subsidence. Underground coal extraction performed by any method after this date would be subject to subsidence control. To assist in determining jurisdiction to enforce the newly created requirements, operators were required to provide maps that define the specific location of underground operations on and after February 3, 1983.

Several legal challenges were launched by the industry contesting the mandate to mitigate, repair, or compensate for damages caused by subsidence. Certain companies contended that the transaction severing the surface and mineral rights also granted the right to extract all of the resource without liability for surface damage. The challenge contended that the right to subside without liability was acquired as part of a legal transaction. Therefore, the coal companies reasoned that it should be construed as taking of property rights if mine operators were mandated to provide compensation or execute repairs.

Illinois' ability to enforce subsidence repair and compensation was continually upheld by the courts. Coal operators must repair subsidence damage to land and structures regardless of any waiver. Mining maintains stringent subsidence requirements based on the potential for subsidence affecting not only structures but also land capabilities. Structures damaged by subsidence must be repaired, replaced, or compensated for, while surface lands must be mitigated to maintain the value and capability that existed prior to subsidence.

Subsidence Control Plans

Any underground mine active on or after February 1, 1983 must receive a permit to mine regardless of the method of extraction. Areas undermined after February 1, 1983 and projected areas to be undermined in the future are termed the "shadow area." The regulatory framework is divided into *permitting* requirements and *performance* requirements. Permitting requirements set the threshold of information required in an application to receive an permit. Performance requirements measure the effectiveness of the operation to achieve the regulatory goals. A key permitting element of an underground mining application is the mine subsidence control plan. The subsidence control plan must demonstrate that either maximum mine stability is being provided to prevent subsidence, termed "unplanned subsidence," or that mining will be carried out to produce "planned subsidence." Planned subsidence involves nearly total seam extraction and results in immediate surface subsidence in a predictable and controlled manner. Longwall mining and high extraction retreat room and pillar mining are examples of planned subsidence operations.

As part of the subsidence control plan, operators must provide information on the technique of coal removal, percentage of coal to be extracted, pillar sizes, extraction dimensions, and nature of the geologic strata above and below the mine. The subsidence control plan must include a survey of all structures and surface features. This is largely a general description of the land and surface features above the shadow area.

If planned subsidence is proposed, operators are required to define the extent and location of subsidence, damage expected to occur, and measures to be taken to mitigate any material damage to land and structures. Site specific monitoring of subsidence movements to verify the accuracy of subsidence predictions is required initially for a given area. Pre-subsidence surveys of all structures potentially impacted is also required. The surveys help document the pre-subsidence condition of the structures to distinguish damages attributable to subsidence clearly from preexisting conditions.

Subsidence Mitigation

The measure of the effectiveness of subsidence mitigation is found within the performance requirements of the regulations. Crops and coal are two very important components of the Illinois economy. Over the past 15 years, the effects of subsidence on cropland have been closely monitored for mitigation. Unlike the permit area, which is the bonded surface facilities of a mine, the shadow area is not bonded. Instead, the Department relies on the ability to impose violations when mitigation is not being accomplished. A pattern of violations could easily develop if a company became lax in their mitigation efforts. If a pattern of violations develops, a cessation order can be imposed with a show cause order for the operator to defend why the state should not revoke the permit. As a result the lack of a structured bonding mechanism has not hindered achieving land mitigation.

Subsidence from longwall or high extraction retreat mining creates a "sag" type subsidence on the surface. A low lying, bathtub shaped depression results that can be 1,200 feet m width and a mile or two long. The width and length of the surface area affected is controlled by the depth of overburden and longwall equipment specifications. This bathtub effect is experienced side by side as a series of longwall panels are mined over several years creating a washer board effect. The surface subsidence can create closed depressions and pond water. To successfully drain closed depressions, the surface can be or surface waterways can be installed to carry away water collected in the depressions. Cut and fill operations are also performed to help restore surface drainage. When suitable soils are present subsurface drainage tiles can be placed to aid drainage. Often, a combination of the above may be incorporated over several mine panels to successfully mitigate a watershed affected by subsidence.

A second impact that occurs to surface lands is a series of tension ground cracks. The ground movements that take place can create uniform and parallel cracking as the wall progresses. The cracking varies in width from an inch or less under most circumstances but can occasionally reach as much as a foot m width. Transverse cracks occur in a radial pattern in advance of the mining direction. The transverse cracks tend to close as the dynamic subsidence wave passes. Longitudinal cracks occur at the panel's edge in the tensional zone. The longitudinal cracks along the edge can remain open and require some form of mitigation (Van Roosendaal et al. 1992) (Fig. 3). In farm fields, narrow cracking is easily eliminated by plowing. Wider tension cracks can necessitate filling with appropriate soil, sand, or lime, then mulched to control erosion Sand and lime are used because they are inexpensive flowable fills that can efficiently seal ground cracks. It can also be beneficial to excavate larger cracks down to a depth where the separation has tightened before beginning to backfill and compact to ground level. Top soil should be removed and replaced upon completion of repairs.

The timing of mitigation repairs can often be complicated by several extenuating factors. Repairs to structures and land are not required until the subsidence movements have stabilized. Mitigation carried out before the am is stable would only have to be repeated later. Structures are more sensitive than farmland to the residual movements that can occur six months to a year or more after mutation of subsidence. Residual subsidence under farmland is only an issue in areas with very little relief. Adverse ground conditions due to precipitation can prevent drainage repairs and push the necessary construction work into the next growing season. Most farmers prefer that such work take place m the fall when the fields are dry and the crops have been harvested. Another delaying factor in farmland mitigation can be the need to allow a second or third panel to be mined and subsided to implement proper drainage repair to a larger watershed. Because of these unavoidable delaying factors, the Department has required a mechanism for crop loss compensation in planned subsidence permits. If acreage is inundated because mitigation has yet to be accomplished, the operator must compensate the landowner for the acreage that is unfarmable. This compensation is a temporary measure until mitigation is successfully completed.

Often, to meet the regulatory performance requirements associated with subsidence, operators must work with local road authorities and local drainage districts. It is sometimes necessary to deepen existing main branch drainage ways or road ditches to allow tiling or waterways to outlet properly. Culverts must sometimes be placed under a roadway where they did not exist before the subsidence altered topography. Communication and cooperation with the various local road and drainage jurisdictional bodies is essential to achieving drainage mitigation.

Energy Policy Act of 1992

The passage of the 1992 Energy Policy Act (EPACT) introduced federal legislation on subsidence repair and compensation to land and structures similar to the Illinois regulations. It also requires operators to replace drinking, domestic, and residential water supplies lost or contaminated by mine subsidence. OSM was required to promulgate rules under SMCRA within one year of the passage of EPACT. Controversy over the content of the regulatory language proposed by OSM delayed final promulgation until the publication of the March 31, 1995 Federal Register.

Most of the performance requirements now in place at the federal level through EPACT are being enforced in Illinois through existing regulations. One specific area of EPACT that was not previously a regulatory performance requirement in Illinois is the mandate to replace water lost or contaminated by subsidence. The requirement to replace water was apparently one of the driving forces behind the incorporation of subsidence language into the EPACT. Water loss due to subsidence tends to be a more prominent issue in the Appalachian coalfields than in the Illinois Coal Basin. Groundwater in much of the area of underground coal mining of the state of Illinois is not of sufficient quantity and/or qual4 to make it potable, and therefore much of the drinking water is derived from natural or man-made surface water bodies. When subsidence does affect groundwater, the geology of Illinois tends to be forgiving and allows most impacts to be short term (Van Roosendaal et al. 1992).

To bring water replacement requirements into the Illinois program, the Department took the initiative to promulgate water replacement language mining EPACT before the March 31, 1995 Federal Register. This regulation, 62 Ill. Adm. Code 1817.12 1 (c)(3), was eventually approved on May 29, 1996.

The March 31, 1995 Federal Register detailed permitting requirements envisioned by OSM to achieve the regulatory goal of subsidence mitigation of water, and es. Requirements such as bonding, timing, and content of pre-subsidence surveys, public participation, and level of detail in the permit application were described and contained in the rules. Currently, the nuts and bolts of carrying out the regulations are still being worked out on the state level. Many states are presently working through their own regulatory procedures to arrive at a counterpart rule.

Conclusion

Illinois has always regarded subsidence control and mitigation as a top priority. We believe Illinois's approved program under SMCRA has been highly successful in the regulation of mine subsidence. The regulations work to strike a balance between the coal company's legal rights and the rights of the surface owners. Illinois will continue to strive to protect the public and the environment while working with the industry to maximize the use of our coal resources.

References

Illinois Department of Natural Resources (IDNR). 1996. Annual Statistical Report, Office of Mines and Minerals.

Bauer, R.A. B.A. Trent, B.B. Mehnert, and D.J. Van Roosendaal. 1995. Planned Coal Mine Subsidence in Illinois: a Public Information Booklet. Illinois Mine Subsidence Research Program VU: Illinois State Geological Survey, Champaign, Illinois.

Illinois Department of Mines and Minerals (IDMM). 1993. Citizen's Guide to Coal Mining and Reclamation in Illinois, Springfield, Illinois.

Van Roosendaal, D.J., P.J. Carpenter, B.B. Mehnert, M.A. Johnston, and J. T. Kelleher. 1992. Longwall mine subsidence of farmland in southern Illinois: near-surface fracturing and associated hydrogeological effects, In R.E. Dunker, R.I. Barnhisel, and R.G. Darmody, eds., Proceedings of the National Symposium on Prime Farmland Reclamation: Department of Agronomy, Illinois Agricultural Experimentation Station, University of Illinois, Urbana, p. 147 158.

---

[1]Daniel Barkley is a mining engineer and a subsidence specialist. He works for the Office of Mines and Minerals, Land Reclamation Division of the Illinois Department of Natural Resources in Springfield, Illinois. He formerly worked for the Illinois Geological Survey in Champaign, Illinois on the Illinois Mine Subsidence Research Project.

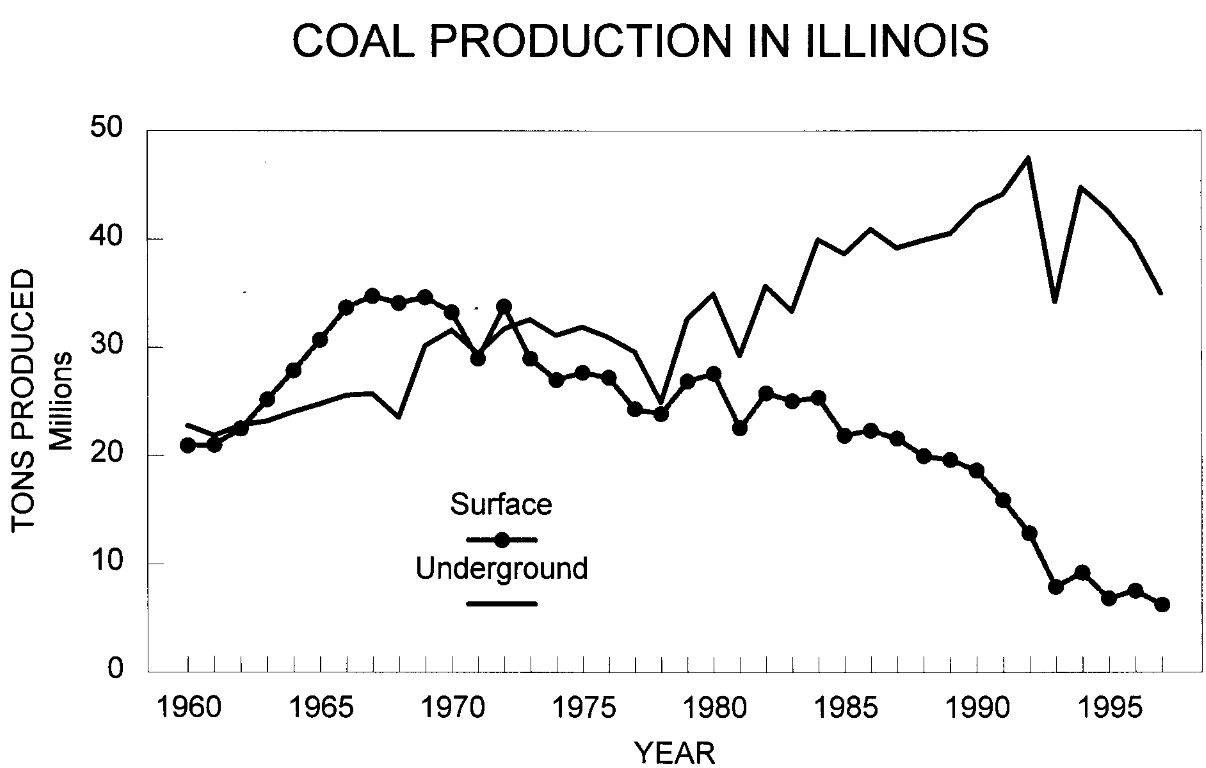

COAL PRODUCTION IN ILLINOIS
50
40
30
20
10
0
TONS PRODUCED
Millions
Surface
Underground
1960
1965
1970
1975
1980
1985
1990
1995
YEAR

Figure 1.

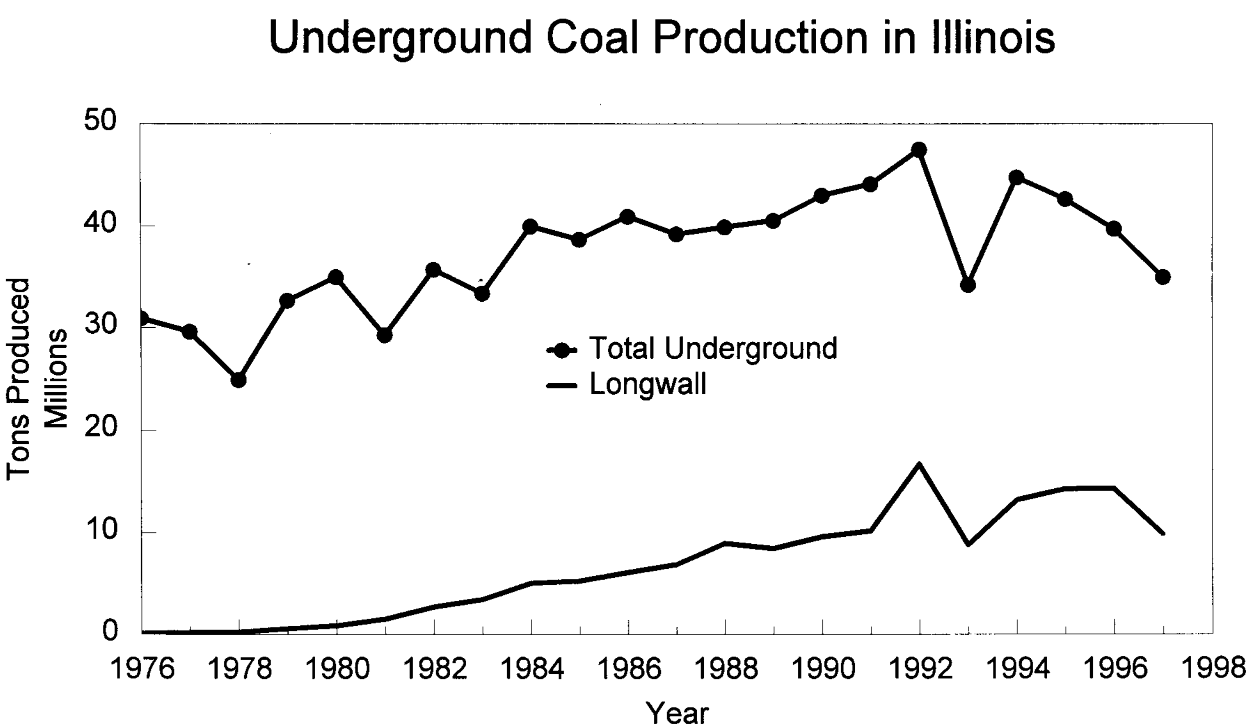

Underground Coal Production in Illinois
50
40
30
20
10
0
Tons Produced
Millions
Total Underground
Longwall
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year

Figure 2.

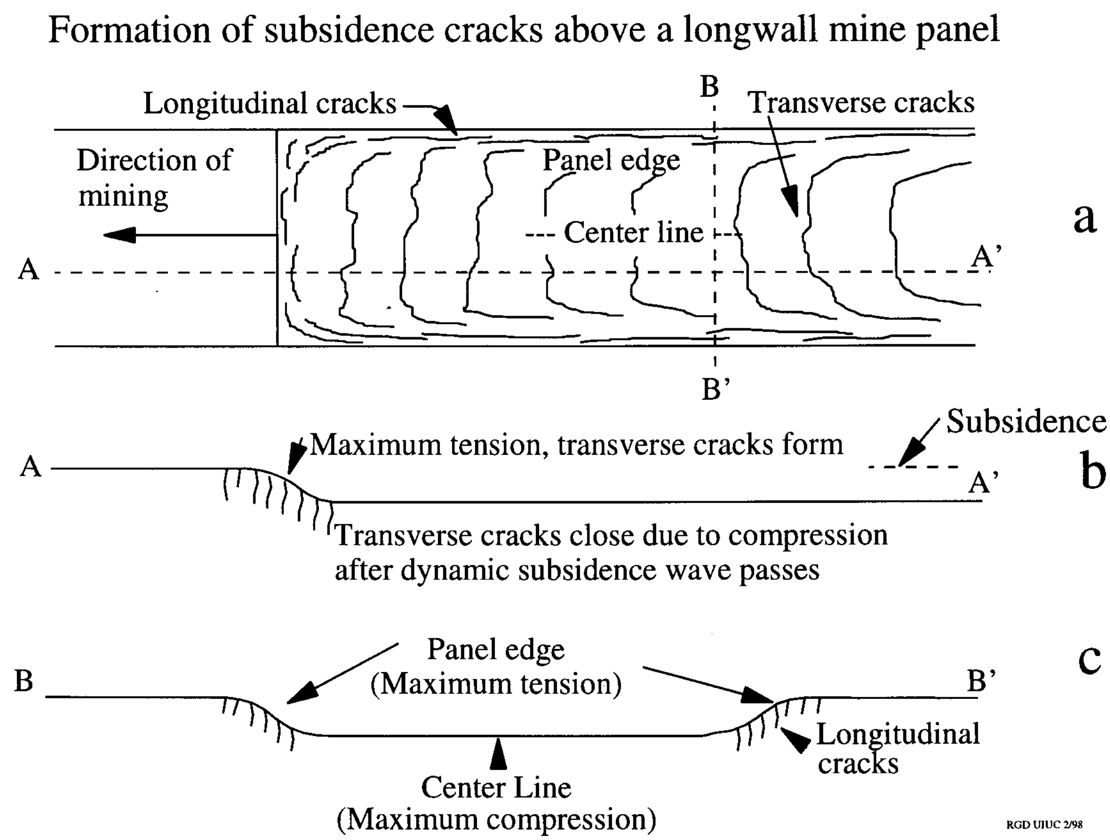

Formation of subsidence cracks above a longwall mine panel
Longitudinal cracks
B
Transverse cracks
Direction of mining
Panel edge
Center line
A
A'
a
B'
Subsidence
Maximum tension, transverse cracks form
A
A'
b
Transverse cracks close due to compression after dynamic subsidence wave passes
Panel edge
(Maximum tension)
B
B'
c
Longitudinal cracks
Center Line
(Maximum compression)
RGD UIUC 2/98

Figure 3.

IMPACTS OF MINE SUBSIDENCE ON GROUNDWATER

Colin J Booth[1]
Northern Illinois University
DeKalb, Illinois

Abstract

By changing the hydraulic properties of overlying aquifers through fracturing, mine subsidence affects ground-water levels, well yields, and water chemistry, independently of drainage to the mine. In the low-relief Illinois coalfield, the impacts of subsidence above two longwall mines differed according to the aquifer type. The shallow glacial-drift aquifer was not significantly affected, but water levels in bedrock sandstone aquifers fell considerably. At one site, the levels recovered and well yield improved because the aquifer was transmissive and well connected to recharge sources; however, the water quality deteriorated. At the other site, the sandstone was thin and poorly permeable; water levels did not recover from the subsidence effects except locally where the sandstone was in contact with an overlying drift aquifer.

Introduction

Underground coal mining affects aquifers in two ways. First, water may drain into the mine workings, depleting groundwater resources and lowering water levels. Second, mine subsidence fractures the overlying strata, changing the permeability and porosity and thus changing groundwater levels, well yields, and, through new flow patterns, groundwater chemistry. Although subsidence can affect aquifers over abandoned room-and-pillar mines, it is more significant over longwall mining, in which large rectangular areas (panels) of coal are completely extracted without the use of permanent roof support. This causes rapid subsidence of the overburden, accompanied by fracturing and bed separation and producing a subsidence trough at the ground surface.

Studies in the Appalachian Coalfield

Numerous case studies of the effects of longwall mining have been made in the Appalachian coalfield (e.g., I-fill and Price, 1983; Schulz, 1988; Dixon and Rauch, 1988; Walker, 1988; Matetic and Trevits, 1992). The region has considerable topographic relief, abundant minor sandstone aquifers, well-fractured strata, and outcropping bedrock, all of which favor relatively active groundwater flow systems.

Unlike room-and-pillar, longwall mining affects most overlying wells (Stoner, 1983 Tieman and Rauch 1987)-, water levels in bedrock aquifers decline considerably during subsidence. This impact is not generally caused by drainage of groundwater into the mine, which normally remains hydraulically separated from shallow aquifers by low-permeability confining units (Singh and Kendorski, 198 1), but by the sudden increase in fracture porosity within the strata. The water-level response is most severe over the panel and diminishes rapidly off-panel (e.g., Moebs and Barton, 1985). Water levels commonly recover within a period of months to years; Tieman and Rauch (I 987) observed recovery within one to three years in half the wells over their study panel and in all off-panel wells. However, changes in the fracture permeability can also produce permanent changes in groundwater levels, leakage between aquifers, and spring discharges as a result of altered hydraulic gradients.

The well response is strongly influenced by topography. Johnson (1992) found that hilltop wells were more affected and less liable to recover than valley wells, probably because they have smaller recharge areas and are more influenced by loss of water through fractures in underlying low-permeability layers. Similarly conclusions were made by Leavitt and Gibbens (I 992) from data on 174 wells (I 20 over panels and 62 deepened or replaced after mining).

Illinois

The Illinois Basin coalfield has low relief a cover of glacial sediments on top of the bedrock and a shale-dominated bedrock sequence of low overall permeability. These features produce a sluggish groundwater flow system and generally poor groundwater resources. Room-and-pillar mines in Illinois have usually been dry and had little effect on groundwater resources (Cartwright and Hunt 1981). The hydrologic effects of subsidence above abandoned room-and-pillar mines are not well documented, but seem to be minor, localized and permanent. For example, Booth and

Saric (1987) observed local water-level anomalies above two long-abandoned mines in southeastern Illinois.

In the first hydrogeological study over a longwall mine in Illinois, Pauvlik and Esling (1987) observed temporary water-level fluctuations and minor permeability changes in a glacial till aquitard due to subsidence. Over a 250-ft-deep high extraction retreat mine (comparable to longwall), Bauer et al. (1987) observed that water levels declined rapidly in the bedrock and gradually in the glacial drift.

This paper summarizes information from hydrogeological studies above longwall mines at sites in Jefferson and Saline counties in Illinois by the author and colleagues from Northern Illinois University and the Illinois State Geological Survey, presented in various reports including Booth and Spande (1992), Mehnert et al. (1994), Van Roosendaal et al. (1994), and Booth et al. (1997). Both sites have rolling landscapes with less than 50 ft local relief, mines into the Pennsylvanian Herrin Coal; overlying bedrock strata comprising mainly shale and siltstone with minor sandstone, limestone, and coal; and a cover of glacial drift comprising mainly till with minor sand and gravel. However, local geological differences produced markedly different impacts of mine subsidence.

Studies at the Jefferson County Site

Site Description

At the Jefferson County site, the mined Herrin Coal is about 10 ft thick and 725 ft deep. The overlying bedrock strata are mostly poorly permeable, but about 570 ft above the mine is the 80-ft-thick Mt. Carmel Sandstone aquifer. Above this is a shale, up to about 60 ft thick, overlain by 9 to 30 ft of glacial drift (till, minor sand, and gravel) and loess. Residential and farm wells tap the upper shale and the drift. The sandstone is used nearby, but not over the study site, although piezometers and a test well were installed for this study.

Four longwall panels, each about 600 ft wide and a mile long, were mined between 1987 and 1989. Our study (I 988-1995) focused on panel 4, which undermined the instrumentation in February 1989 and produced ground subsidence of 6 ft within six weeks and 0.67 ft more within three years. The strata were heavily fractured, especially by shear in the marginal tensional zone and bedding-plane separations in the central subsidence trough (Mehnert et al., 1994).

Response of the Drift Aquifer

Water sampled from large--(diameter wells in the shallow drift was fresh (total dissolved solids less than 600 mg/1) and mainly sodium-calcium-sulfate type, with relatively high nitrate levels that often exceeded the 10 mg/l US EPA potability limit The chemistry did not change noticeably due to mining; nor, except for temporary adjustments to changing ground levels, did the drift water levels. However, the water table in wells on topographic highs overlying barrier pillars had slight long-term declines, probably because the ground level and water table in the adjacent topographic lows had subsided.

Response of the Upper Shale

Water levels in shale wells over and next to the longwall panels were substantially lowered by mining, and took from several months to three years to recover. Shale wells 600 ft off the panel were unaffected. The shale water was brackish (1000 to 4000 mg/1) and of mixed cation, sulfate type, with some nitrate. Post-mining analyses showed a slight reduction in salinity that may reflect increased recharge from the drift.

Physical Response of the Mt. Carmel Sandstone

The sandstone at the site is 75 ft deep and 80 ft thick, but divided into hydraulically separate upper and lower benches by a shaly siltstone unit up to about 20 ft thick. Pumping tests showed that the upper sandstone receives some leakage from the overlying shale, but the lower bench behaves as a separate confined aquifer.
Sandstone piezometers over panel 4 were monitored from 1988 until damaged by subsidence in Spring 1989. Monitoring continued from 1991 to 1995 in two new piezometers, drilled into the lower sandstone bench in the central area and tension zone of the subsidence trough, and in centerline test well P350, open through the whole aquifer. Pre- and post-mining permeabilities were determined from slug and pump tests, and from packer tests in two centerline boreholes cored through the bedrock before and after mining. The permeabilities (i.e., hydraulic

conductivities) of the sandstone were between $10^{-6}$and 10^{-4}cm/s before subsidence, depending on test method and location, and increased approximately one order of magnitude in the central subsidence trough and two in the tension zone. Storage coefficients increased about one order of magnitude. These changes resulted in a 200% increase in specific capacity (indicating yield) of the test well.

The sandstone water levels responded systematically to subsidence (Booth and Spande, 1992; Mehnert et al. 1994; Booth et al., 1997). They declined gradually as the mine face approached, then fell rapidly to a minimum during the tensional early phase of subsidence. After a decline of about 30 ft due to the mining of adjacent panel 3, the water levels over panel 4 recovered briefly, declined as the panel 4 face approached, then dropped rapidly to about 135 ft (70 ft below initial values) during undermining (Fig. 1). The rapid head drop in the subsiding zone is due to the sudden increase in porosity caused by opening of fractures, joints, and bedding planes. The earlier gradual decline is a secondary drawdown effect transmitted through the aquifer from the approaching potentiometic low.

After a rapid partial rise during the compressional phase, the water levels recovered gradually over two years after mining to the initial levels about 65 ft below ground, and by 1995 to about 40 ft (Fig. 2). The long-term recovery reflects inflow of water from surrounding areas of the aquifer into the potentiometric depression over the panel.

Changes in Groundwater Chemistry in the Mt. Carmel Sandstone

The pre-mining chemistry of the sandstone water was indicated by early samples from well P350 and by later smwles from well W18 in the unmined area 3.3 miles to the east. The water was sodium bicarbonate dominant and fresh to slightly brackish (total dissolved solids (TDS) 900-1200 mg/1); sulfates were low in W18 but around 200 mg/l in P350. After mining, the water in P350 became more brackish (TDS 1990-2620 mg/1) with increased sulfates (over 800 mg/1), a significant deterioration in quality. The geochemical changes are evidently due to water flowing back into the aquifer from two possible sources: leakage of high-sulfate water from the overlying shale, and lateral flow, through the aquifer, of more oxidizing water that could liberate sulfate from sulfide minerals present in the sandstone.

Studies at the Saline County Site

Site Description

At the Saline County site, the mined Herrin Coal is about 6 ft thick. Several farms and homes around the site have large diameter wells tapping the shallow drift water-table aquifer, and a few have wells drilled into thin sandstone aquifers such as the Trivoli, typically 0-25 ft thick. None of the aquifers provides good yields and most homes are now connected to the water supplies of the nearby small towns.

Six longwall panels were mined between 1989 and 1994. Hydr6geological studies were conducted over panels I and 5. Because of the northward dip, the coal seam and bedrock units were about100 ft higher in elevation at panel 5 than at panel 1; also, the depth to bedrock (thickness of drift) decreased from about 90 ft at panel 1 to less than 65 ft at panel 5.

Panel 1 (669 ft wide, 400 ft deep) undermined the instrumentation in December 1989. Although the strata were fractured, the overburden generally subsided as a coherent mass (Van Roosendaal et al., 1994); maximum ground subsidence was about 4.7 ft. Panel 5 (943 ft wide, 318 ft deep) undermined its instrumentation in early January 1993, producing a centerline subsidence of 4.5 ft.

Shallow Drift ReMonse

The nearest shallow drift wells, several hundred feet from the panels, did not respond to mining. At panel 5, two study piezometers were screened in sandy gravels within 20 ft of the land surface. Except for fluctuations during subsidence, the water levels were not significantly affected by mining and have subsequently maintained normal seasonal variations in the range of 3 to 12 ft below ground.

Deep Drift Response

Piezometers at panel 1 were screened at depths of 63 to 73 ft in sand and gravel in the lower drift. Water levels fluctuated during subsidence then declined 8 to 11 ft. At panel 5, four piezometers were screened in the lower drift, which varied across the panel from a low-permeability clay till (permeabilities 10^{-7} to 10^{-6} cm/s) in the central panel area, to a permeable sand (10^{-5} to 10^{-4} cm/s) over the southern barrier. The permeabilities were not affected by subsidence. The water levels were initially 5 to 12 ft below ground and their responses varied with setting (Fig. 3). In the southern sand unit, which is in continuity with the underlying sandstone, they started to decline in December 1992 as the panel approached and dropped to 40 ft in the tension zone and 30 ft on the barrier during subsidence in early January. In the till over the central area, water levels fluctuated erratically during subsidence, then declined gradually a total of 10 to 15 R.

Response of the Bedrock Sandstones

Pre-mining hydraulic tests above both panels indicated very tight bedrock. Initial permeabilities in the Trivoli Sandstone were in the range 10^{-6} to 10^{-5} cm/s, and post-subsidence testing showed only minor localized increases probably related to discrete fractures. At panel 1, piezometers were screened into the sandstone at depths in the range 138 to 196 ft. The water levels were initially about 40 ft deep, and fell rapidly to 160 to 180 ft just before and during undermining (Fig. 4). Except for a slight rise during the compressional phase, the water levels did not recover during two subsequent years of monitoring.

At panel 5, the bedrock surface was about 65 ft deep, and the Trivoli Sandstone was locally in contact with the glacial drift. The pre-mining potentiometric surface in the sandstone was essentially flat, with water levels between 7 and 20 ft deep depending on topography. The levels started to decline when the mine face was 1,000 ft away, falling about 55 ft over the panel and 40 ft on the barrier by undermining (Fig. 5). The three bedrock piezometers over the panel were almost dewatered during subsidence, and subsequently maintained low water levels except for slight (10 ft) rises in winter 1994-1995. However, the water level in the piezometer on the southern barrier recovered quickly by about 13 ft in early 1993 and remained high, probably due to recharge from the overlying lower drift sand aquifer (which experienced corresponding head losses).

Groundwater Chemistry at the Saline County Site

The water in the off-panel private shallow drift wells was fresh to slightly brackish, mixed cation, bicarbonate-sulfate type, with nitrate widely present. The shallow drift piezometers over panel 5 contained similar but slightly more mineralized water. There was no apparent change in chemistry due to mining. Water in the deep drift piezorneters was similar but more brackish (TDS 1200-2000 mg/1) and had only minor changes due to subsidence, probably due to mixing of waters through local fracturing.

The Trivoli Sandstone over panel 5 contained slightly brackish sodium-bicarbonate water (TDS 1100-1400 mg/1) with relatively high sulfate. Changes from before to after subsidence were slight but there were consistent decreases in sodium and chloride, increases in calcium sulfate, and TDS; and the appearance of low levels of nitrates. These changes suggest the introduction of water from the overlying dnft into the sandstone.

Summary

At both study sites, subsidence had negligible impact on the water levels and chemistry of shallow drift aquifers. The water table fluctuated briefly during active ground movements, but long-term water-level changes were minor and probably due to readjustment to the local changes in topographic relief.

The response of confined sand-and-gravel aquifers in the deeper drift depended on the hydraulic connection to the underlying bedrock. In isolated aquifer zones, slight changes of water level were probably due to elevation changes and leakage through local fracturing. Significant water-level loss was observed only in a drift aquifer in good contact with underlying sandstone.

The impacts on bedrock aquifers are considerable. The primary mechanism is the increase in fracture porosity and permeability caused by fracturing and bedding-plane dilation. Bedrock water levels over longwall panels drop substantially to a low during undermining and active subsidence. The effects are more sudden, severe, and localized in fewer transmissive units. Recovery depends on the "rechargeability" of the aquifer-its transmissive characteristics plus continuity with sources of recharge water. At Jefferson County, the water levels in the Mt. Carmel Sandstone recovered within two years because the aquifer was moderately permeable, transmissive, and in good continuity with adjacent areas of the aquifer. The combination of increased permeabilities and water-level recovery increased the well yield. At Saline County (Fig. 6), the Trivoli Sandstone was thin, poorly permeable, and largely isolated from potential recharge sources by overlying confining units and by continued mining up-dip of the study sites. Water-level declines were severe, and recovery was negligible except for a localized area of recharge from an overlying drift aquifer.

Two processes apparently affect the groundwater chemistry. First, subsidence-related fracturing increases leakage from overlying to underlying units. At Jefferson, fresher drift water leaked into the shale, and brackish high-sulfate shale water leaked into the less-brackish bicarbonate water in the sandstone. Nitrate (or other) contaminants from shallow aquifers may leak to deeper aquifers. Second, oxidizing recharge water moving through the aquifer may mobilize sulfates from sulfide minerals present in the sandstone. At Jefferson, the deterioration in quality detracted from the physical enhancement of the aquifer. Nevertheless, it is neither inevitable (it depends on the local geochemistry) nor (given current point-of-use treatment systems) necessarily a bar to using the water.

Acknowledgments

These studies were supported by Illinois Department of Energy and Natural Resources through the Illinois Mine Subsidence Research Program, and by US Department of the Interior, Office of Surface Mining Reclamation and Enforcement, through agreementGR196171. This support does not constitute an endorsement by either DENR or OSM of the results, conclusions, and views expressed in this article, which are solely those of the author. The author acknowledges the contributions to the studies by R.A. Bauer and staff of ISGS and by former NIU graduate students E.D. Spande, C.T. Pattee, A.M. Curtiss, J.D. Miller, and L.P. Bertsch.

References

Bauer, R.A., E.M. Gefell, and D.W. Barkley. 1987. Characterization of Coal Mine Subsidence and Impacts on Bedrock and Near-Surface Hydrology over a Shallow High-Extraction Retreat Mining Operation m Illinois. Proc. National Symp. on Mining, Hydrology, Sedimentology and Reclamation, December 1987, Springfield, Illinois, p. 197-202.

Booth, C.J. and E.D. Spande. 1992. Potentiometric and Aquifer Property Changes Above Subsiding Longwall Mine Panels, Illinois Basin Coalfield. Ground Water 30: 362-368.

Booth C.J., P.J. Carpenter, and R.A. Bauer, 1997. Aquifer Response to Longwall Mining, Illinois. US Dept. of the Interior, Office of Surface Mining, Lib. Rept. No. 63 7, 400 pp.

Booth, C.J. and J.A. Saric. 1987. The Effects of Abandoned Underground Mines on Ground Water in Saline County, Illinois: Proc. National Symp. on Mining, Hydrology, Sedimentology and Reclamation, December 1987, Springfield, Illinois, p. 243-248.

Cartwright, K. and C.S. Hunt. 1981. Hydrogeologic Aspects of Coal Mining in Illinois: An Overview. Illinois State Geological Survey, Env. Geol. Notes EGN 90.

Dixon, D.Y. and H.W. Rauch, 1988. Study of Quantitative Impacts to Ground Water Associated with Longwall Coal Mining at Three Mine Sites in the Northern West Virginia Area. Proc. 7th Inter. Conf. on Ground Control in Mining, West Virginia University, August 1988, p. 321-335.

Hill, J.G. and DR. Price. 1983. The Impact of Deep Mining on an Overlying Aquifer in Western Pennsylvania. Ground Water Monitoring Review, v. 3, no. 1, p. 13 8-143.

Johnson, K.L. 1992. Influence of Topography on the Effects of Longwall Mining on Shallow Aquifers in the Appalachian Coal Field. Proc. 3d Workshop on Surface Subsidence Due to Underground Mining, Morgantown, WV, June 1992, p. 197-203.

Leavitt, B.R. and J.F. Gibbens. 1992. Effects of Longwall Coal Mining on Rural Water Supplies and Stress relief Fracture Flow Systems. Proc. 3d Workshop on Surface Subsidence Due to Underground Mining, Morgantown, WV, June 1992, p. 228-236.

Matetic, R.J. and M.A. Trevits. 1992. Hydrologic Variations Due to longwall Mining. Proc. 3d Workshop on Surface Subsidence Due to Underground Mining, Morgantown, WV, June 1992, p. 204-213.

Mehnert, B.B., D.J. Van Roosendaal, R.A. Bauer, P.J. DeMaris, and N. Kawamura. 1994. Final Report of Subsidence Investigations at the Rend Lake Site, Jefferson Co., Illinois. Illinois State Geol. Survey, Rept. to US Bur. of Mines, Coop. Agreement C0267001, 237 pp.

Moebs, N.M. and T.M Barton. 1985. Short-term Effects of Longwall Mining on Shallow Water Sources. Mine Subsidence Control, US Bureau of Mines Inf. Circ. IC 9042, p. 13-24.

Pauvlik, CM. and S.P. Esling, 1987. The Effects of Longwall Mining Subsidence on the Groundwater Conditions of a Shallow Unconfined Aquitard in Southern Illinois. Proc. National Symp. on Mining, Hydrology, Sedimentology and Reclamation, December 1987, Springfield, Illinois, p. 189-196.

Schulz, R.A. 1988. Ground-Water Hydrology of Marshall County, WV, with Emphasis on the Effects of Longwall Coal Mining. US Geol. Survey, Water Res. Inv. Report 88-4006.

Singh, M.M. and F.S. Kendorski. 1981. Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments. Proc. First Conf. on Ground Control in Mining, Morgantown, WV, July 1981: p. 76-88.

Tieman, G.E. and H.W. Rauch. 1987. Study of Dewatering Effects at an Underground Longwall Mining Site in the Pittsburgh Seam of the Northern Appalachian Coalfield: Eastern Coal Mine Geomechanics. US Bur. Mines Inf. Circ. IC 9137, p. 72-89.

Van Roosendaal, D.J., B.B. Mehnert, N. Kawamura, and P.J. DeMaris. 1994. Final report of Subsidence Investigations at the Galatia Site, Saline County, Illinois. Illinois State Geological Survey, Report to US Bur of Mines, Coop. Agreement C0267001, 230 p.

Walker, J. S. 1988. Case Study of the Effects of Longwall Mining Induced Subsidence on Shallow Ground water Sources in the Northern Appalachian Coalfield. US Bur Mines Report of Invs., RI 9198, 17 p.

---

[1]Colin J. Booth is a hydrologist and currently an Associate Professor in the Department of Geology, Northern Illinois University. He has a B.Sc. in Environmental Sciences from the University of East Anglia (UK), a Ph.D. in Geology from Penn State University, and has worked as a geologist in industry. His principal interests are coalfield hydrogeology, groundwater problems related to mining, and groundwater flow systems and their application in environmental hydrogeology. He also serves on the Illinois Low-Level Radioactive Waste Task Group.

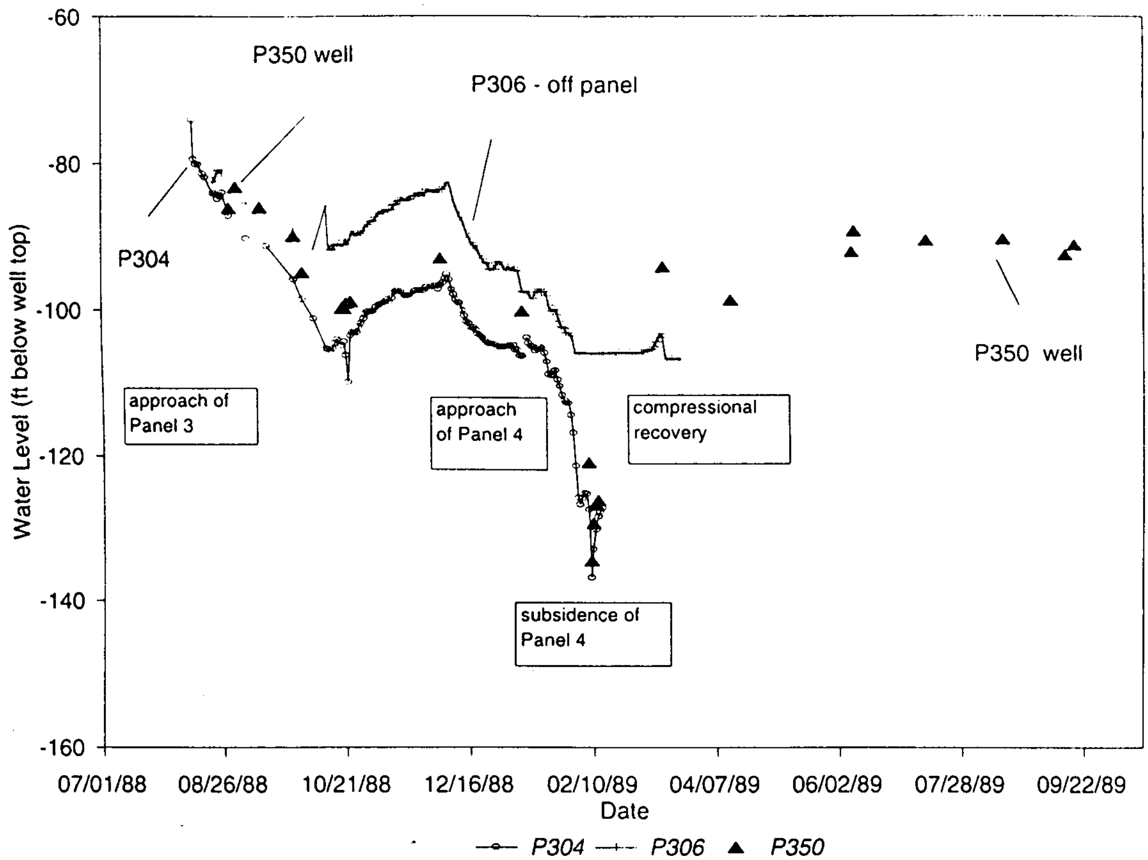


Fig. 1 Water Levels in Sandstone Aquifer During Mining, Jefferson Panel 4, 1988-1989.

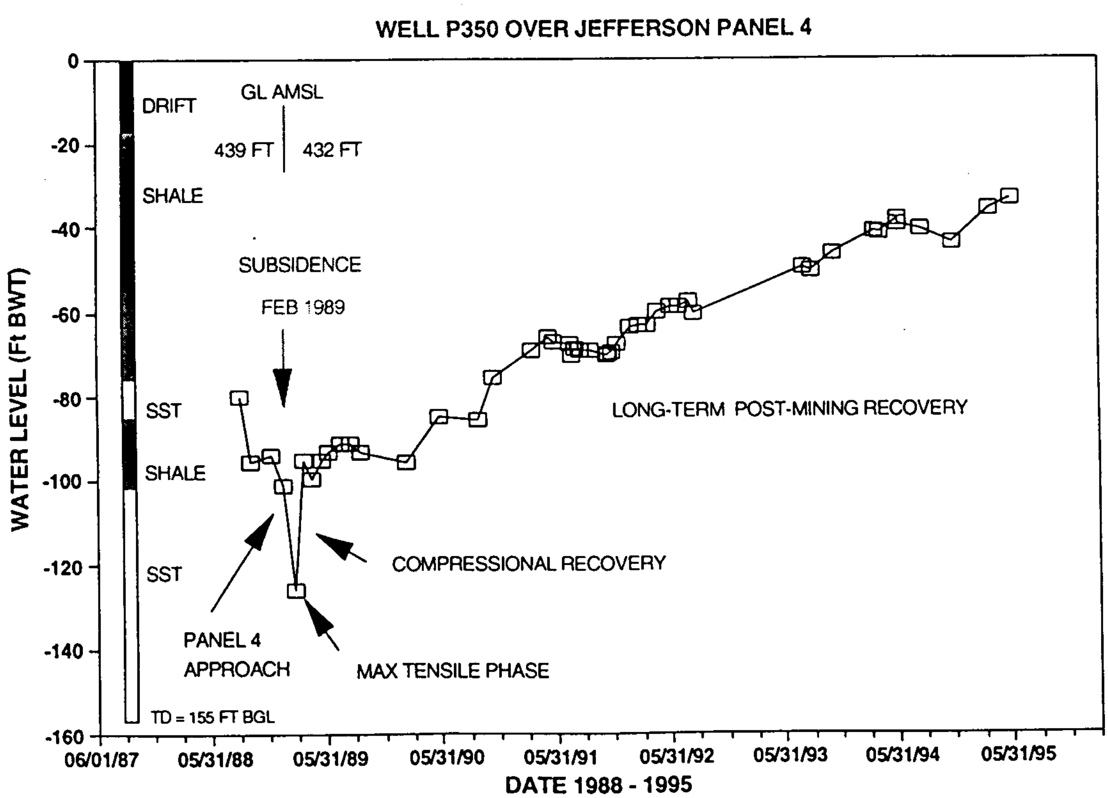


Fig. 2 Long-Term Recovery of Sandstone Water Levels Over Panel 4, 1991-1995.

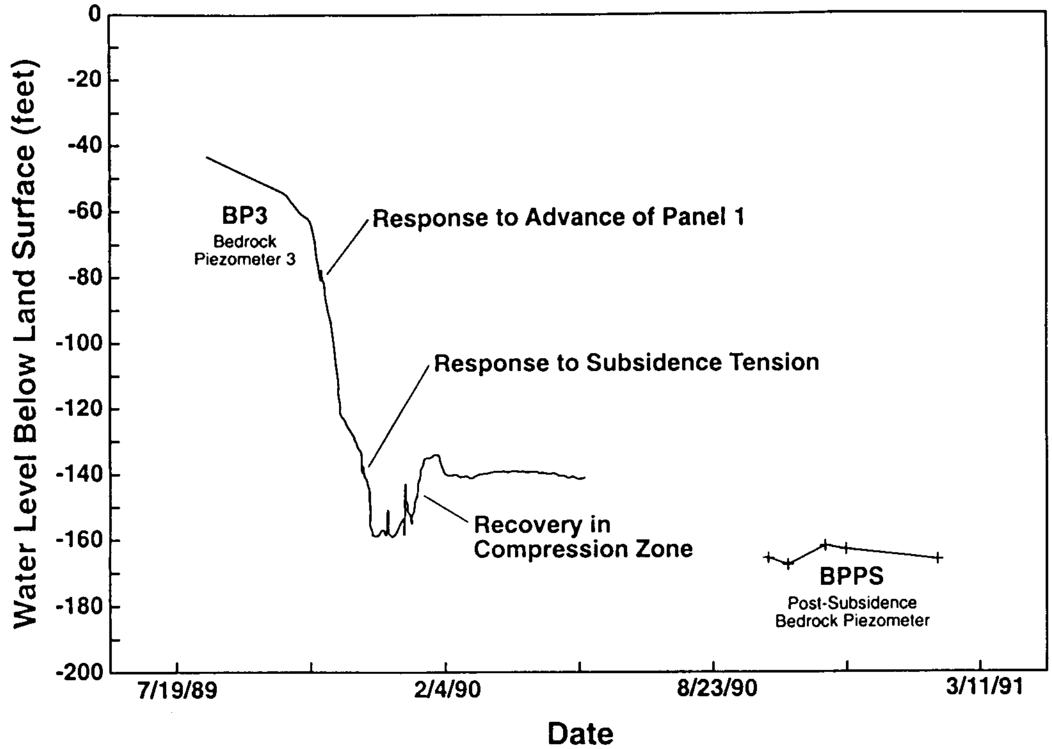


Fig. 3 Water Levels in Trivoli Sandstone Over Saline Panel 1, 1989-1991.

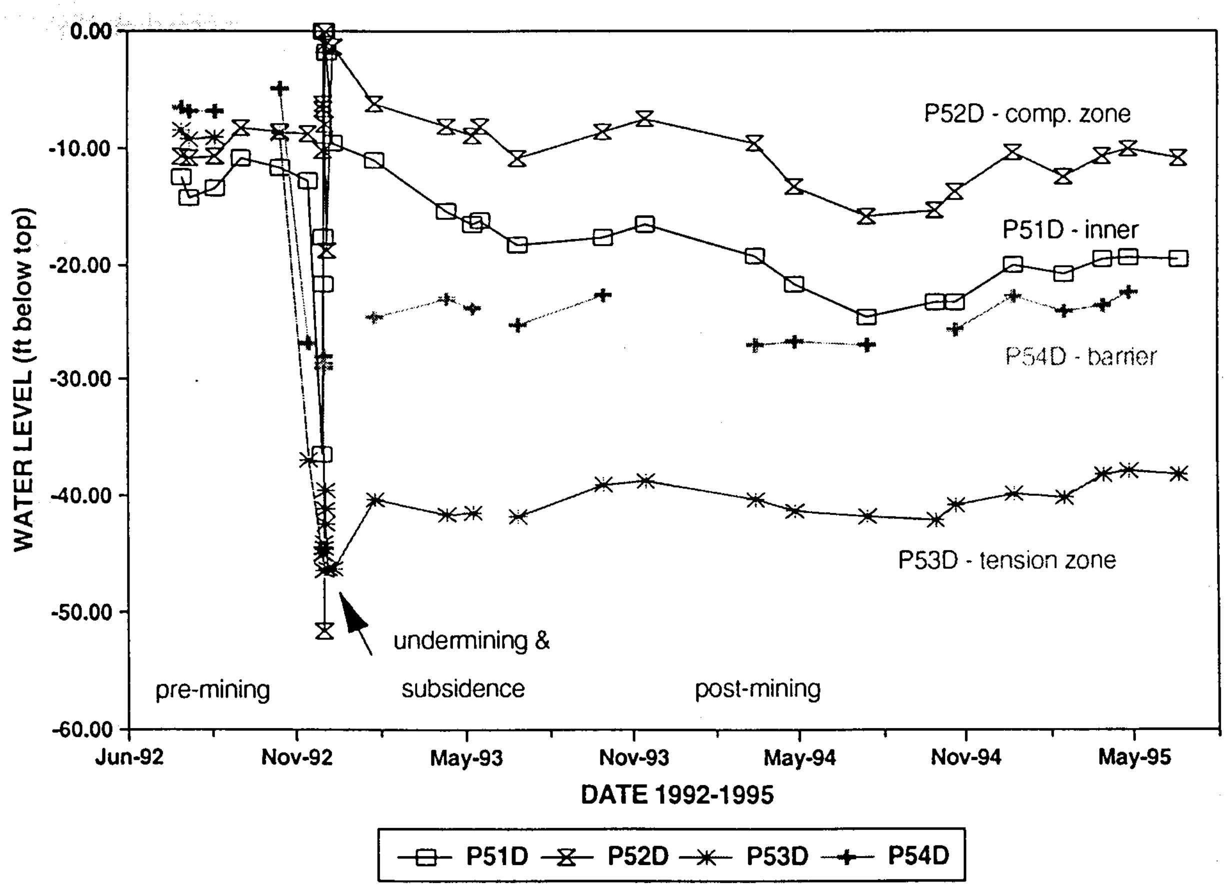


Fig. 4 Water levels in the Deep Drift Over Saline Panel 5, 1992-1995.

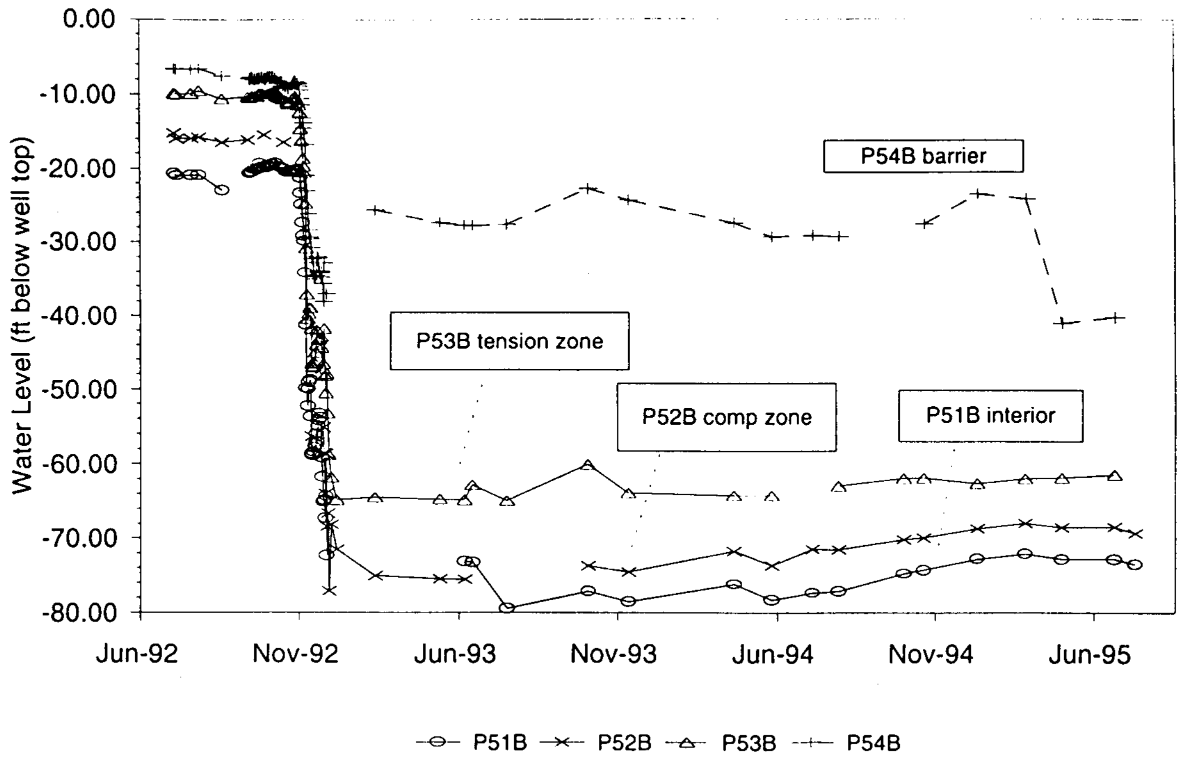


Fig. 5 Water Levels in the Trivoli Sandstone Over Saline Panel 5, 1992-1995.

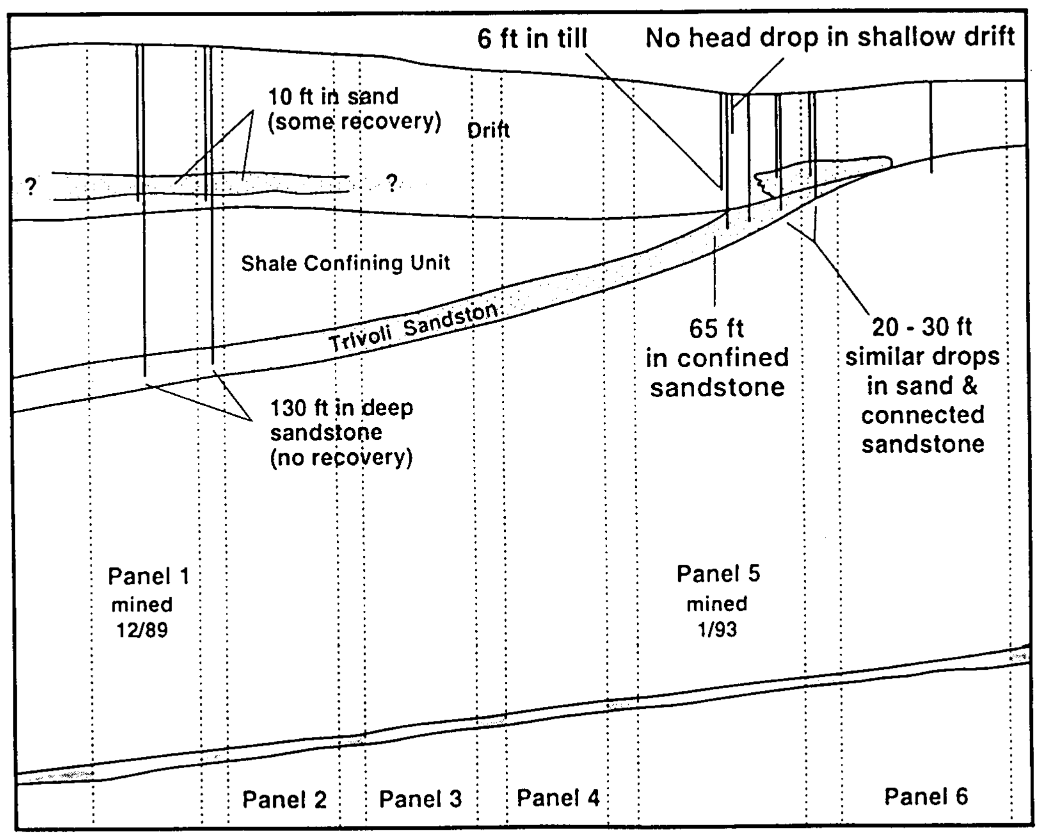


Fig. 6 Summary of Geologic Setting and Water-Level Response to Mining, Saline County Site.

RECLAMATION OF AGRICULTURAL LAND AFTER PLANNED COAL MINE SUBSIDENCE

R. G. Darmody[1]
Department of Natural Resources and Environmental Sciences
University of Illinois
Urbana, Illinois

Abstract

Underground coal mining, although not as as surface mining, can alter the surface and impact agriculture. Surface alterations include subsidence that disturbs and creates depressions. Subsidence has always been a potential long-term problem with conventional room and pillar mining, but newer forms of mining create certain and immediate subsidence. This difference is due to the amount of coal left behind to support the overlying soil. In conventional mines, about half the coal remains unmined as pillars, and subsidence is not expected to occur. In high extraction mining, all of the coal is removed and the surface subsides immediately. The advantage of high extraction mining is that less of the coal is left in the ground and subsidence can be planned for and mitigated shortly after subsidence. Subsidence is a problem particularly where water tables are near the surface and the landscape is of low relief. Under these conditions, ponds can form in the subsided areas. Research has shown that subsidence mi|igation, properly applied, can restore agricultural productivity to undermined areas in most cases.

Introduction

Coal mining and agriculture are large industries that require extensive land areas to be efficient and often compete for the same land. This is a problem wherever coal and agriculture coexist (Hu and Gu, 1995; Holla and Bailey, 1990). In the midwestern U.S.A., and in Illinois in particular, coal underlies areas of prime agricultural soils (Fig. 1). Both mining and agriculture contribute to the economic health of a region, but coal extraction must not be done at the cost of long-term agricultural productivity. Long after the economic benefit of coal has been realized, the soil will continue to be needed for food and fiber production. It is the goal of coal mining regulations and reclamation to provide the potential for both industries to contribute economically.

The trend in Illinois is toward underground coal mining. Over the last 30 years, underground mining has gone from 48 to 8 1 % of the total production, and it will dominate Illinois coal production into the 2 1st century (IDMM 1994). In addition, the underground coal mining industry of the Eastern Interior Coal Basin is moving away from conventional partial extraction mining methods, such as room and pillar, toward higher extraction mining methods. In room and pillar mining, coal is removed from the rooms, but about half the coal is left undisturbed as pillars to support the roof (Bauer et al., 1995). Room and pillar mining wastes much of the coal and is not absolutely guaranteed to prevent subsidence in the future. Subsidence can occur due to pillar, roof, or floor failure, particularly in older mines (Bauer et al., 1995). This type of subsidence can be gradual and long-term as the floor slowly heaves creating a subtle sagging on the surface; or it can happen quickly in relatively well defined areas long after the mine is abandoned. Subsidence of this nature is not predictable and is difficult to manage.

Higher extraction mining methods include retreat mining and longwall mining. High extraction retreat mining involves removing portions of the pillars from a room and pillar mine. Extraction ratios are about 80 to 90% within a mine panel (Hunt 1980). Maximum subsidence at the surface from this method is about 50 to 60% of the mined-out height underground (Bauer et al., 1995), but it can be unpredictable because local conditions in the mine influence the actual amount of extraction. In addition, pillars left standing as in conventional room and pillar mining may eventually fail. Subsidence effects at the surface above high extraction retreat mines are similar to, but less clearly demarcated than, effects caused by longwall mining (Darmody et al., 1989). Longwall mining is more efficient than either room and pillar or high extraction retreat mining. It involves removal of all of the coal within the mine panel with a continuous longwall mining machine. Consequently, with no pillars left in the panel to support the roof, subsidence occurs almost immediately at the surface (Bauer and Hunt 1992) (Fig. 2). Total subsidence in the center of the mine panel is typically 60 to 70% of the extraction thickness (Bauer and Hunt, 1992; Kahair and Begley, 1992). In nearly level terrain, a subsided longwall mine area appears as a series of troughs between low ridges. The troughs vary in size, but in Illinois they are typically about 1 to 2 m deep in the center with dimensions of 0.2 by 3 km (600 by 10,000 ft), and cover about 60 ha (150 ac) (Bauer et al., 1995).

The subsidence pattern at the surface is a reflection of the coal extraction pattern underground in the coal mine. Subsidence troughs are the result of fall extraction in the mine panels. The ridges between them are the partially extracted barrier pillars left standing between the panels. While the panel centers experience the most subsidence, some subsidence may also occur over the chain pillars (Mehnert et al., 1992). As a panel is mined, the surface begins to subside above the active mine face after the mining advances beyond a critical distance. Tension cracks at the surface open as the dynamic subsidence passes a given spot. Cracks at the advancing edge close due to compression after the area fully subsides. Cracks along the panel edges stay open because they are in a tensile-strained area between the unsubsided ground beyond the panel and the subsided panel center (Fig. 3). While most of the subsidence associated with longwall mining occurs rapidly, slight residual subsidence may continue as long as three years (Mehnert et al., 1992).

Subsidence from longwall mining is predictable, and damage to buildings and other civil structures can be prevented or moderated. Because of its efficiency, safety, and predictability, longwall mining is the method of choice for high extraction coal mining. Its use is increasing, but high start-up equipment costs, as compared with traditional room and pillar mining, and fears of planned subsidence hinder acceptance of this method (DuMontelle et al., 198 1).

Coal companies anticipating subsidence as a consequence of mining need to control the legal right to subside the surface. Subsidence rights were sometimes purchased by coal companies when the mineral rights were originally sold by the landowner. In other instances, if the coal company does not own the surface, subsidence rights are included in negotiations with landowners before the actual mining. Prior to the passage of SMCRA there were no federal regulations to control surface impacts of subsidence. SMCRA addressed subsidence mitigation, but deferred enforcement of that portion of the act to the states. Regulations were developed in Illinois by 1983 requiring coal companies to mitigate damage caused by subsidence (D. Barkley, IDNR, 1996, personal communication). Coal companies were required to compensate landowners or repair damage to structures and to restore land use capability to pre-mining conditions. This is different from regulations for surface mining of agricultural land that require restoration of agricultural productivity.

This presentation deals primarily with subsidence problems associated with longwall mining. Most research on agricultural impacts of subsidence has dealt with longwall mining. Subsidence from high extraction retreat mining is similar to longwall but generally not as severe because of the lesser amount of subsidence associated with that form of mining. Unplanned subsidence from room and pillar mining is unpredictable and site-specific which makes generalizations difficult. However, the general principles discussed here apply to all types of mine subsidence.

Subsidence Effects

Subsidence impacts on structures

Subsidence has deleterious effects on man-made structures. Nevertheless, because the subsidence from longwall mining is predictable and short-term, damage to structures can be reduced. Damage is most severe to structures that span the edge of subsided troughs (Boscardin, 1992). Structures toward the center of the subsidence trough are generally less prone to damage because they are let down more uniformly after the dynamic subsidence wave passes (Fig. 3). Repairs can begin soon after mining because most of the subsidence occurs within a few days after undermining, and the surface typically within three to six months (Mehnert et al., 1992).

To prevent subsidence damage, small buildings can be isolated from their foundations, or "floated," during the subsidence event and later placed upon new foundations. Railroads can be continuously regraded and leveled during subsidence so that traffic is not interrupted. Buried pipe lines can be exhumed to relieve soil pressure and allow flexing during subsidence. This reduces the chance of breakage and may allow uninterrupted use of the pipeline. Power lines can be subsided with no damage or interruption of service given sufficient slack in the lines and sturdy towers (van der Merwe, 1992). Roads also can remain open during subsidence; however, they need to be closely monitored during subsidence to prevent development of hazardous conditions. After subsidence, roads may need regrading and resurfacing; this is typically done a year after mining (Bauer et al., 1995). Subsidence can also lead to changes in springs, wells, and regional groundwater quantity and quality (Booth and Spande, 1992; Matetic and Trevits, 1992). These effects are site-specific and may be unpredictable.

Subsidence affects on soils

Research on the reclamation of lands subsided by longwall mining is limited. Subsidence effects on agriculture land have been documented in Illinois (Darmody et al., 1989; Guither, 1986; Guither et al., 1985; Guither and Neff, 1983), the United Kingdom (Selman, 1986), India (Kundu and Ghose, 1994), China (Hu and Gu, 1995), South Africa (van der Merwe, 1992), and Australia (Holla and Bailey, 1990; Ham, 1987). These effects include soil erosion, disruption of surface and subsurface drainage, wet or ponded areas, and reduction of crop yields. Much of the impact of subsidence on soils and landscapes is related to the pre-mining surface topography. Landscapes with erosive soils on long slopes may be subject to increased erosion potential because of slope increase or displacement of erosion control structures (Ham, 1987). In low areas with high water tables, ponding is a particular problem. This can be due to disruption of surface drainage patterns as runoff collects in the low portions of the subsidence troughs. In addition, the surface could subside below the elevation of the water table (Fig. 4). As subsidence progresses, and the surface lowers, it may appear that the water table is rising (Fig. 4a). What actually happened in this case was the water table maintained a constant elevation as the surface dropped (Fig. 4b). Soil drainage or seasonal groundwater fluctuations may mask this effect (Fig. 5). In some situations ponding might be viewed in a positive way because it creates wetlands beneficial to wildlife, but negatively when it reduces net returns to a food or fiber producer.

In areas of rolling topography or high relief, there may be little or no obvious subsidence effect. The noticeable exception to this, however, can be found in areas of very steeply sloping ground or cliffs. These areas may experience slope instability or rock falls (Shea-Albin, 1992). In addition, there may be a change in the local hydrology that may cause alterations in wells, springs, and ephemeral water supplies (Werner and Hempel, 1992).

Large cracks that develop at the soil surface after subsidence can pose a hazard and may alter soil hydrology. Most subsidence cracks are small and are quickly obscured by normal cultivation. Larger cracks are generally backfilled or graded to prevent them from posing a hazard to foot or wheel traffic. Along the panel edge, cracks remain open after the dynamic subsidence wave passes (Fig. 3). This may allow surface water to infiltrate more easily and may increase the hydraulic conductivity of some soil horizons (Fig. 6). These changes are in a very small portion of the mined area and may revert to the original conditions with time (Seils et al., 1992).

Subsidence affects on crops

Underground coal mining is generally not restricted by relief; however, agriculture is generally confined to areas of relatively low relief. Consequently, subsidence impacts on agriculture generally are more severe in areas with low relief and high water tables. Southern Illinois, for example, has abundant coal reserves and highly productive agriculture. It is characterized by nearly level to gently rolling topography, shallow water tables, and extensive areas of poorly drained, slowly permeable soils (Fehrenbacher et al., 1984). In this landscape, subsidence from underground longwall coal mining creates wet or ponded areas that delay and disrupt farming practices, causes low seed germination, and reduces crop growth and grain yields. Darmody et al. (1989) found a 4.7% average reduction in overall corn yields on subsidence-affected land in southern Illinois. In the same study, areas classified as moderately and severely affected by subsidence represented 2.3% and 5.3% of the mined land area and registered 42% and 95% corn yield reductions, respectively. These severe yield reductions were in unmitigated portions of the subsided landscape.

Subsidence Mitigation

Introduction to mitigation

Coal companies repair or mitigate areas adversely affected by subsidence by cutting drainage ditches or grass waterways, adding fill, recontouring the landscape, or a combination of these methods. Drainage ditches are typically constructed using small tractor-pulled scraper pans. Fill material either is excavated from existing ditches, borrowed in the construction of a pond, or moved from high spots in the field. Topsoil is usually pushed aside using low ground pressure bulldozers or stockpiled using scrapers in both the borrow area and the area to be mitigated. Subsoil from the borrow area is used as fill. Topsoil is then returned to both areas. Fill depths typically range from one-half to one meter.

Mitigation techniques can be classified into three Mm: (1) ditch, (2) fill, and (3) ditch plus fill. Site conditions dictate the amount and type of mitigation done. The success of mitigation in restoring grain yields is dependent on several factors including the amount of subsidence, the type of mitigation work necessary, the resources and materials available for the job, and the skill of the operators doing the work. Consequently, the impact of subsidence and the success of mitigation is site-specific.

There are many publications on reclamation of cropland after surface mining for coal. However, cropland reclamation after coal mine subsidence has not received much attention. Soil compaction caused by large earthmoving equipment used m subsoil and topsoil replacement has been identified as a major factor limiting crop productivity of reclaimed surface mined soils (Fehrenbacher et al., 1982). While the equipment used in subsidence mitigation tends to be smaller, the potential for soil compaction from scrapers excavating and placing fill and from bulldozers used for cutting ditches still exists. Soil compaction causes an increase in soil density and a simultaneous reduction in fractional air volume (Gupta, et al., 1989). Consequently, plant growth is altered due to poor soil aeration, low nutrient and water availability, slow permeability, and mechanical impedance to root growth (Indorante et al., 1981). Fehrenbacher et al. (I 982) found significant differences in corn yields and root densities related to different soil replacement techniques. Dunker et al. (1995) documented the success of mitigation of compacted reclaimed mine soils. Their research demonstrates the importance of sound soil replacement techniques.

<u>Subsidence mitigation effectiveness</u>

Effectiveness of mitigation to restore soils to their former productivity after longwall mining was studied in southern Illinois (Darmody et al., 1992). The research sites were located in farmers' fields and received varying amounts of subsidence and mitigation. Dominant soil series were Okaw (Fine, montmorillonitic, mesic Typic Albaqualf, Bluford (Fine, montmorillonitic, mesic Aeric Ochraqualf), and Cisne (Fine, montmorillonitic, mesic Mollic Albaqualf). The soils were classified as highly, moderately, and somewhat sensitive to subsidence damage due to their natural drainage and landscape position (Darmody, et al., 1989). A site consisted of the mitigation area, usually no larger than one-half hectare (1.2 acres), paired with an undisturbed reference area within the same field. The fields were planted to corn or soybean and managed by individual farmers. There was variability among sites in planting dates and other management practices; however, these variables were constant within each paired mitigated and reference site.

Selected physical and chemical measurements were made at the research sites to confirm consistency of soils and management within each research site pair and to help explain yield variability. These measurements included macro and micro-soil fertility levels, organic matter content, bulk density, saturated hydraulic conductivity, and particle-size distribution of the 0 to 23 cm depth. Penetrometer resistance of the upper 1 10 cm was also measured at selected sites to detect soil compaction (Hooks and Jansen, 1986).

Soil fertility could be adversely affected by subsidence mitigation in two ways. First, recontouring could expose less fertile subsoil and remove fertile topsoil. Second, fill material could be deficient in major or minor plant nutrients or organic matter, or could contain excessive amounts of sodium. To avoid soil fertility problems, topsoil is typically removed before adding fill and then replaced upon completion of the work. In the southern Illinois study (Darmody et al., 1992), organic matter and soil fertility estimates did not differ significantly within each paired site.

Subsidence mitigation may also influence soil physical properties. Mitigated sites tend to have massive or platy soil structure in added fill material (Hetzler and Darmody, 1992). Table 1 shows mean values for bulk density, penetrometer resistance, and saturated hydraulic conductivity at mitigated and reference sites. Soil compaction as measured by bulk density was not greatly influenced by mitigation. The lack of soil in fill material did not significantly change the bulk density from reference soils. This is due in part to similar textures between mitigated and reference areas sampled and perhaps the number of samples collected was not enough to detect statistically significant differences in bulk density. In addition, although the structure was massive in filled areas, it was not necessarily highly compacted throughout Compaction was mainly in traffic interfaces that may not have been sampled. Lower bulk densities were observed at sites reclaimed during dry conditions.

Penetrometer resistance measurements were taken in late spring when soil water content was approximately at field capacity throughout the sod profile. The penetrometer resistance of most mitigated and reference depth segment means were not different (a = 0.05). However, compaction from reclamation was detected at several sites (Fig. 7). Prominent points in the penetrometer profile identify traffic or scraper lift faces. These interfaces of high compaction disrupt internal drainage and may result in prolonged soil saturation. Root restricting soil strength values depend on soil texture, structure, moisture content, and method of measurement and, therefore, do not lend to direct comparison from other studies. Penetrometer resistance values between 2 and 2.5 MPa have been identified as potential root restricting values (Taylor and Burnett, 1964). These values are exceeded at some sites and may be causing root restriction. However, most often the mitigated values are statistically indistinguishable from reference areas (Table 1).

Soil hydraulic conductivity in filled mitigated areas tends to be lowered somewhat by mitigation because of the destruction of soil structure and compaction (Table 1). Also, inclusion of foreign material in the fill can impede conductivity; however, the changes are not of great significance if the undisturbed soil has slow to moderately slow permeability. In general, hydraulic conductivity did not vary by mitigation method. In the soils studied, which tend to be poorly drained, fine softly-textured, and slowly permeable, soil physical properties were not significantly influenced by mitigation.

Despite the similarities in chemical and physical soil properties, average crop yields were lower at mitigated sites (Table 2) (Darmody et al., 1992). Corn yield differences were significant, averaging 19% lower on mitigated sites. Soybean yields, however, were not statistically different averaged over the four years. Yields from individual years were influenced by weather. During the drier growing season of 1988, crops in the mitigated areas appeared to have benefitted from the extra water collected and held by subsidence troughs. In contrast, a wet spring in 1990 precluded planting or caused low seed germination in these same areas. The apparent better response of soybean to mitigation is attributed in part to a later planting date under typically better soil temperature and moisture conditions.

Crop yields at individual sites varied widely within a given year. Consequently, "best case" extremes or sites where mitigated yield was higher compared with reference yields were usually not statistically different (Table 3). In contrast, most "worst case" extremes are significantly different. This indicates productivity has been returned to pre-mined levels at some sites while at other sites significant yield reduction can still occur after mitigation. Table 4 shows crop yields for different mitigation methods. Crop yields at ditch type mitigation sites were statistically similar to yields at reference sites. In contrast, corn yields with the other two mitigation types, fill and ditch plus fill, were significantly lower than yields at reference sites. Soybean yields were restored in areas mitigated by the ditch method or by the fill method, but were not fully restored where the ditch plus fill method was used. These differences in success rates of the various mitigation methods is related to the extent of mitigation applied at each site. Ditch plus fill is used where subsidence impact is greatest and where probability of success is lowest. In contrast the ditch method is used where subsidence impact is slight and the probability of success is great.

Subsidence mitigation

Research demonstrates that all types of mitigation (ditch, fill, and ditch plus fill) can be successful in restoring land use and crop yields (Darmody et al., 1992). Rainfall and other factors may compound yield response at any site to cause significant yield reductions despite mitigation. Site-specific factors such as the amount of subsidence damage and, hence, the amount and type of mitigation necessary and field/landscape characteristics may bias measured mitigation success rate. For example, ditching may be done when subsidence creates a gentle and continuous trough, as opposed to a localized depression or "pit" which would require fill. The disadvantage of ditch mitigation is that waterways in fields take land out of production and require maintenance.

Results from this study indicate that soil physical properties were similar in mitigated and reference soils. Bulk density and saturated hydraulic conductivity tend to be somewhat lower and penetrometer resistance slightly higher at some mitigated areas. However, these small differences in soil properties are independently unlikely to affect crop yields. Field inspections revealed that yield differences were due to inadequate water drainage at poorly producing mitigated sites.

Because mitigated areas are relatively small (Fig. 8), a decrease in yield on one hectare will not significantly reduce overall field yields. However, it is important that mitigation is attempted on all mine subsidence damaged agricultural land not only from a productivity standpoint, but also to prevent associated agricultural problems such as weed and pest control and to maintain normal field patterns for planting and harvest.

The research indicates that the following practices may improve mitigation: 1) reduce soil compaction by working soil and adding fill when the soil is dry, 2) minimize traffic and use low ground pressure equipment, 3) apply deep tillage during and after mitigation work to alleviate compaction interfaces, 4) provide better water drainage by excavating existing drainage ways, and 5) add sufficient depths of fill to low areas. In addition, adding drainage tiles to mitigated areas may improve mitigation success. Drainage tiles are not commonly used in southern Illinois due to low soil permeability and siltation problems in high sodium soils. A single subsurface drain with surface inlets may be more economical than surface ditches for depressions in these soils (Drablos and Moe, 1984). In non-compacted fill material, a subsurface tile may provide adequate drainage for crop growth provided an outlet is available (Fig. 9).

Summary

Longwall mining causes immediate subsidence of the surface. Because essentially all of the subsidence occurs quickly, within a few weeks to months after undermining, most surface damage can be predicted and mitigated. This makes planned subsidence much more manageable than unplanned subsidence resulting from room and pillar mining. The most serious subsidence impact on agricultural soils is due to excess wetness. This is usually caused by disruption of surface drainage but can also be due to lowering of the land surface below the elevation of the seasonally high water table. Because of high water tables or inadequate surface drainage, wet soils are more difficult to manage for conventional agricultural crops, must be drained to increase productivity, and are more sensitive to subsidence. Subsidence mitigation as practiced in the Midwestern U.S.A. is largely in restoring land use and agricultural productivity. In some situations, however, subsidence may permanently alter land use and create wetlands. This is most probable in areas of poorly drained soils that may be marginally too wet for agriculture. In this instance, subsidence may be viewed as beneficial because it creates wetland wildlife habitat.

References

Bauer, R-A. and S.R. Hunt. 1992. Profile, strain, and the time characteristics of subsidence from coal mining in Illinois. p. 207-218. *In* S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ., Morgantown, WV.

Bauer, R-A., B.A. Trent, B.B. Mehnert, and D.J. Van Roosendaal. 1995. Planed coal mine subsidence in Illinois, a public information booklet. Illinois Mine Subsidence Research Program VII. Illinois State Geological Survey, Champaign, IL 61820. 32 p.

Booth, C. J. and E.D. Spande. 1992. Potentiometric and aquifer property changes above subsiding longwall mine panels, Illinois Basin coal field. Ground Water 30: 362-368.

Boscardin, M.D. 1992. Subsidence effects on buildings and buried pipelines. p. 106-112. *In* S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Darmody, R ., I.J. Jansen, S.G. Carmer, and J.S. Steiner. 1989. Agricultural impacts of coal mine subsidence: Effects on corn yields. J. Environ. Qual. 18:265-261.

Darmody, R.G., R.T. Hetzler, and F.W. Simmons. 1992. Coal mine subsidence: effects of mitigation on crop yields. International J. of Surface Mining and Reclamation 6:187-190.

Darmody, R.G. 1994. Effects of coal mine subsidence on agricultural soils and hydrology. p. 130-141. *In* B.A.

Trent, R-A. Bauer P.J. Demaris, and N. Kawamura (ads.) Guidelines resulting from the Illinois Mine Subsidence Research Program, 1985-1993. Final report to the Illinois Clean Coal Institute. Illinois. State Geological Survey, Champaign, IL.

Drablos, C.J. and R.C. Moe. 1984. Illinois Drainage Guide. Illinois Cooperative Extension Service. Circular 1226. 46 p.

DuMontelle, P.B., S.C. Bradford, R.A. Bauer, and M.M. Killey. 1981. Mine subsidence in Illinois: Facts for the homeowner considering insurance. M. St. Geol. Surv. Environ. Geol. Notes 99. 24 p.

Dunker, R.E. C. L. Hooks, S.L. Vance, and R.G. Darmody. 1995. Deep tillage effects on compacted surface-mined land. Soil Sci. Soc. Am. J. 59:192-199.

Fehrenbacher, D.J., I.J. Jansen, and J.B. Fehrenbacher. 1982. Corn root development in constructed soils on surface-mined land in western Illinois. Soil Sci. Soc. Am. J. 46:353-359.

Fehrenbacher, J.B., J.D. Alexander, I.J. Jansen, R-G. Darmody, R-A. Pope, M.A. Flock, E.E. Voss, J.W. Scott, W.F. Andrews, and L.J. Bushue. 1984. Soils of Illinois. Illinois Agricultural Experiment Station Bulletin 778. 85 p.

Guither, H.D. 1986. The mine subsidence threat to soils. J. Soil and Water Conservation. 41:21-23.

Guither, H.D. and S.A. Neff. 1983. Appraisal of farmland overlying underground coal mines. J. Am. Soc. Farm Managers and Rural Appraisers 49:49-50.

Guither, H.D., J. Hines, and R- Bauer. 1985. The economic effects of underground mining upon land used for Illinois agriculture. Doc. 85/01. B Dept. Energy and Nat. Resour. Springfield, 11. 179 p.

Gupta, S.C., B.P. Sharma, and S.A. DeFranchi. 1989. Compaction affects on soil structure. Adv. Agron. 42:311-338.

B.W. 1987. The impact of underground coal mining on farming. In Mining and Environment. Proc. Aus. I. M. M. annual conference. Brisbane, Australia. p. 33-40.'

Hetzler, R-T. and R-G. Darrnody. 1992. Coal mine subsidence mitigation: Effects on soils and crop yields. p. 129-135. *In* R-E. Dunker, R.I. Barnhisel, and R-G. Darmody (eds.) Prime Farmland Reclamation, Proc. National Symposium on Prime Farmland Reclamation. St. Louis, MO, August 10-14. Dept. of Agronomy, Univ. of Illinois at Champaign-Urbana.

Holla, L. and J.G. Bailey. 1990. Land subsidence due to coal mining. Nat. Conf. Pub. Inst. of Engineers. IE Aust, Barton, Aust. pt. 3. p 203-207.

Hooks, C.L. and I.J. Jansen. 1986. Recording cone penetrometer developed in reclamation research. Soil Sci. Soc. Am. J. 50:10-12.

Hu, Z. and H. Gu. 1995. Reclamation planning for abandoned mining subsidence lands in Eastern China: a case study. Internat. J. Surface Mining and Environment 9:129-132.

Hunt, S.R. 1980. Surface subsidence due to coal mining in Illinois. Ph.D. dissertation, University of Illinois at Urbana-Champaign. 129 p.

Illinois Department of Mines and Minerals (IDMM). 1994. Annual Report. Springfield, IL. 45 p.

Indorante, S.J., I.J. Jansen, and C.W. Boast. 198 1. Surface mining and reclamation: Initial changes in soil character. J. Soil and Water Conservation 36:347-351.

Kahair, A.W. and R-D. Begley. 1992. Mechanistic subsidence prediction model (MSPM). p. 56-65 *In* S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Kundu, N.K. and M.K. Ghose. 1994. Studies on the topsoil of an underground coal-mining project. Environmental Conservation 21:126-132.

Matetic, R.J. and M.A. Trevits. 1992. Hydrologic variations due to longwall mining. p. 204-213. *In* S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Mehnert B.B., D.J. Van Roosendaal, and R-A. Bauer. 1992. Long-term subsidence monitoring over a longwall coal mine in southern Illinois. p. 311-316. In S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Seils, D.E. R.G. Darmody, and F.W. Simmons. 1992. The effects of coal mine subsidence on soils macroporosity and water flow. p. 137-138. In R.E. Dunker, R-I. Barnhisel, and R-G. Darmody (eds.) Prime Farmland Reclamation, Proc. National Symposium on Prime Farmland Reclamation. St. Louis, MO, August 10-14. Dept. of Agronomy, Univ. of Illinois at Champaign-Urbana.

Selman, P.H. 1986. Coal mining and agriculture: A study in environmental impact assessment. J. Environ. Management 22:157-186.

Shea-Albin, V.R. 1992. Effects of longwall subsidence on escarpment stability. p. 272-279. In S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Taylor, H.M. and E. Burnett. 1964. Influence of soil strength on the root growth habits of plants. Soil Sci. 98:174-180.

van der Merwe, J.N. 1992. Experiences with undermining by coal in South Africa. p. 299-310 In S.S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

Werner, E. and J. C. Hempel. 1992. Effects of coal mine subsidence on shallow ridge-top aquifers in northern West Virginia. p. 237-243 *In* S. S. Peng (ed.) Proc. of third workshop on surface subsidence due to underground mining. Dept. of Mining Engr. West Virginia Univ. Morgantown, WV.

---

[1]Robert G. Darmody was born in Washington, D.C. in 1949, and grew up in the Washington suburbs. He received from the University of Maryland a B:S. in Natural Resources with a minor in Botany (1972) and a M.S. (1975) and Ph.D. (I 980) in Soils with a minor in Geology. From 1975 to 1977 he taught introductory soil science as an instructor in the Agronomy Department, University of Maryland. In 1981 he was hired by the University of Illinois Department of Agronomy as an Assistant Professor of Pedology to conduct research and teach soil science. Research interests include reclamation of surface mined soils and the agricultural and environmental impacts of mine subsidence and coal combustion. He is married and lives in Champaign, Illinois with three children, two cars, one dog, and one mortgage.

Table 1. Selected soil properties (45-100 cm) at subsidence mitigated and reference sites in Illinois

Mitigation Method	Bulk Density ($g\ cm^{-3}$)		Penetrometer Resistance (Mpa)		Hydraulic Conductivity ($cm\ d^{-1}$)		
	Ref.‡	Mit.	Ref.	Mit.	Ref.	Mit.	n§
Ditch	-†	-	1.6	2.3	3	7	1
Fill	1.48	1.41	2.0	2.3	21	18	4
Ditch+Fill	1.49	1.36	1.7 ¶	1.9 ¶	19		

‡Ref. for Reference, Mit. for Mitigated.
†No sample. ¶Means of 4 sites. Source: Hetzler and Darmody, 1992.

Table 2. Crop yields at subsidence mitigation research sites in Illinois.

Treatment	1988	1989	1990	1991	Mean
Corn	--------------------------Yield ($Mg\ ha^{-1}$)--------------------------				
Reference	5.96	7.84	7.02	6.65	6.87
Mitigated	6.02	7.27	4.95	4.64	5.72
Difference	0.06	-0.57	-2.07*	-2.01*	-1.15*
LSD	0.44	1.07	0.94	1.51	0.75
n†	6	7	11	4	28
Soybean					
Reference	1.75	1.95	1.88	2.08	1.92
Mitigated	1.68	2.42	1.61	1.68	1.85
Difference	-0.07	0.47*	-0.27	-0.40*	-0.07
n†	7	3	3	10	23

*Significantly different (a=0.05). †Means of n sites. Source: Darmody et al., 1992.

Table 3. Crop yield extremes at individual subsidence mitigation research sites.

	Year	Reference	Mitigated	Difference
Corn		---Yield (Mg ha^{-1})---		
Worst Case				
	1988	6.58	5.27	-1.31*
	1989	9.91	6.71	-3.20*
	1990	7.65	1.44	-6.21*
	1991	6.96	3.89	-3.07
Best case				
	1998	5.27	7.27	2.00*
	1989	4.64	5.71	1.07
	1990	4.95	4.70	-0.25
	1991	6.96	6.84	-0.12
Soybean				
Worst case				
	1988	2.26	1.76	-0.50*
	1989	1.88	2.20	0.32
	1990	2.01	0.94	-1.07*
	1991	2.32	1.25	-1.07*
Best case				
	1988	2.01	2.01	0.00
	1989	2.07	2.63	0.56
	1990	2.07	2.26	0.19
	1991	2.45	2.76	0.31*

* Significantly different at the 5 percent level.
Source: Darmody, 1994.

Table 4. Crop yields for different mitigation methods.

Mitigation Method	Crop Yield (Mg ha^{-1})	
	Corn	Soybean
Reference	6.90 a†	1.95 a
Ditch	6.08 ab	1.88 a
Fill	4.76 b	1.95 a
Ditch+Fill	5.58 b	1.54 b

†Means within columns followed by the same letter are not significantly different (a=0.05). Source: Darmody et al., 1992.

Figure 1. Distributions of coal reserves and prime agricultural soils in Illinois (source: IDNR and USDA

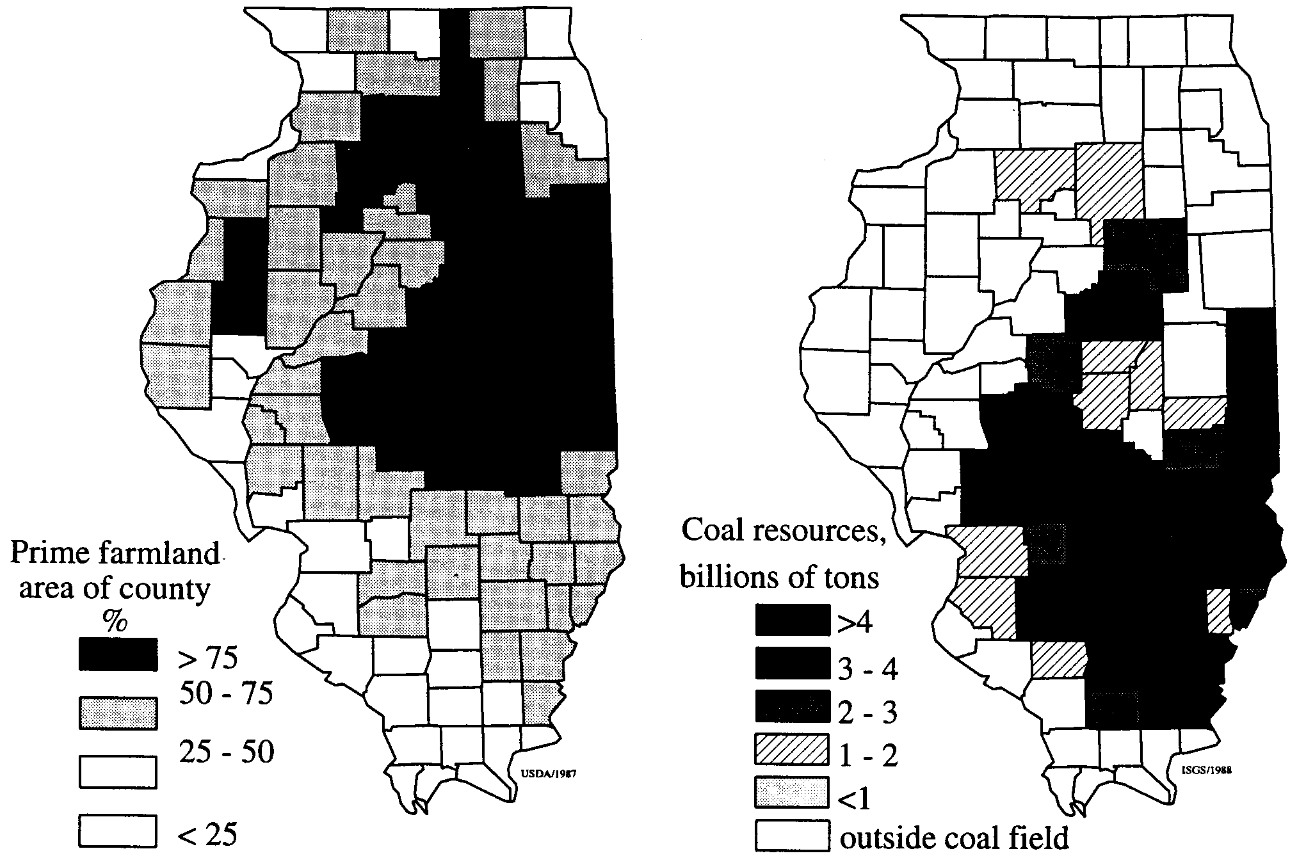


Figure 1. Distribution of coal reserves and prime agricultural soils in Illinois (source: IDNR and USDA NRCS).

LONGWALL COAL MINING SCHEMATIC

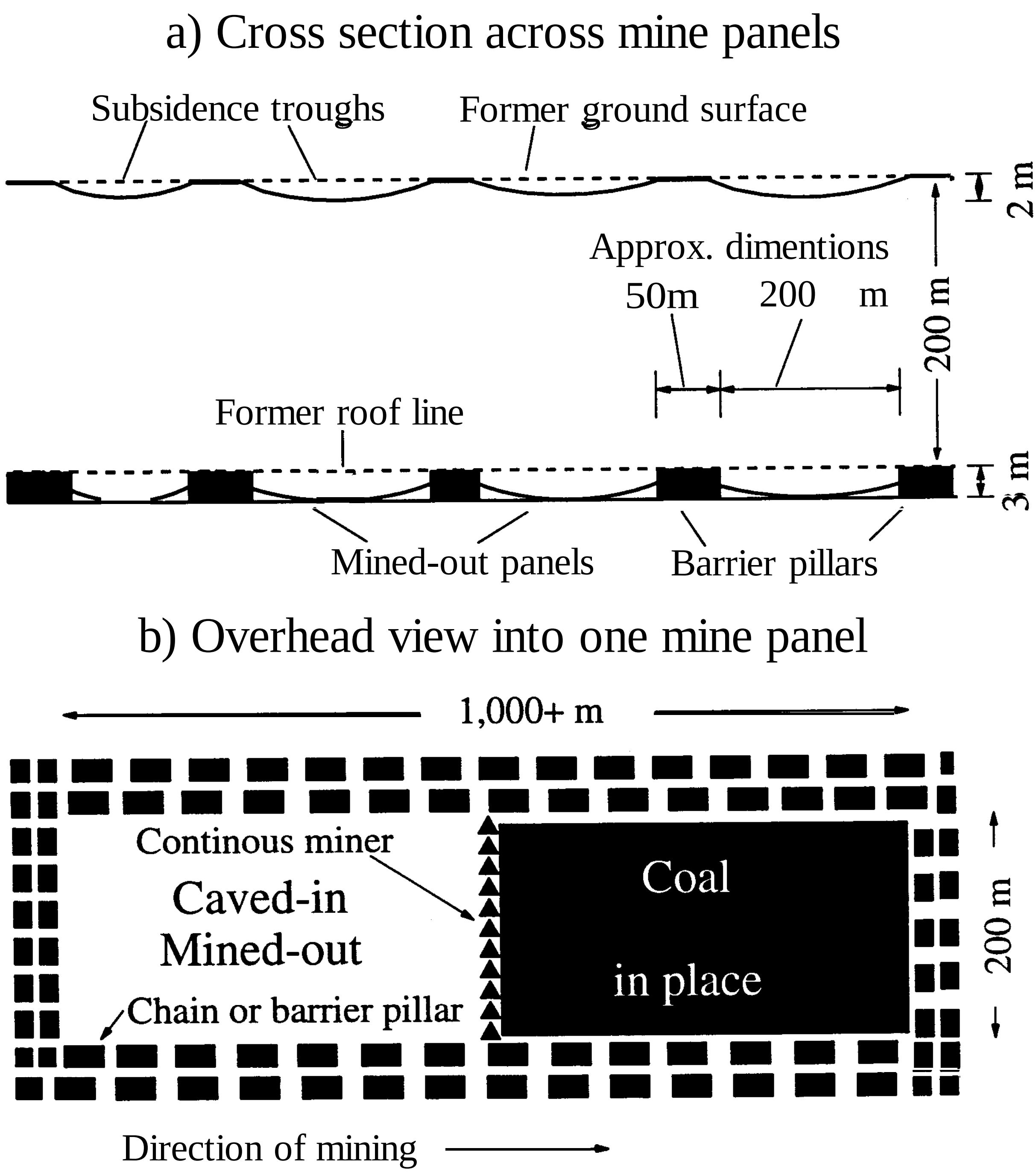


Figure 2. Schematic diagram of longwall mining, overhead view (a) and cross section (b).

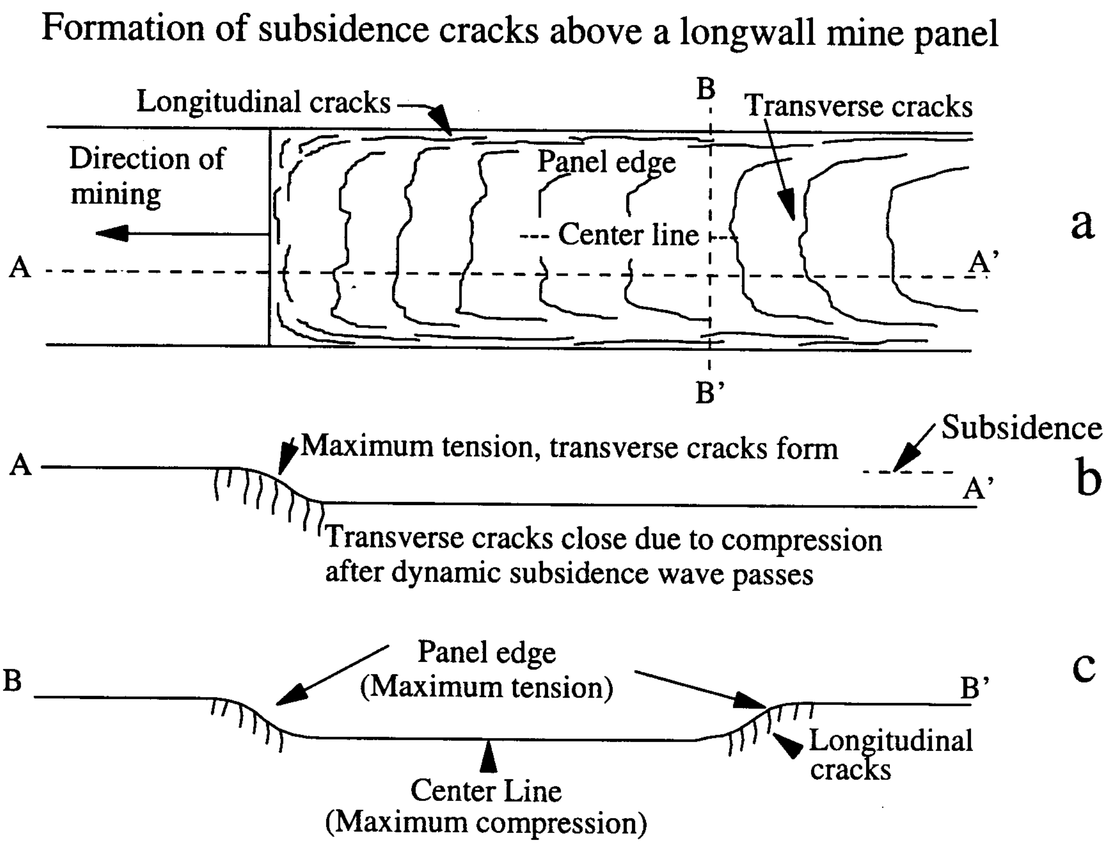


Figure 3. Formation of surface cracks above a longwall mine panel in a level topographic area.

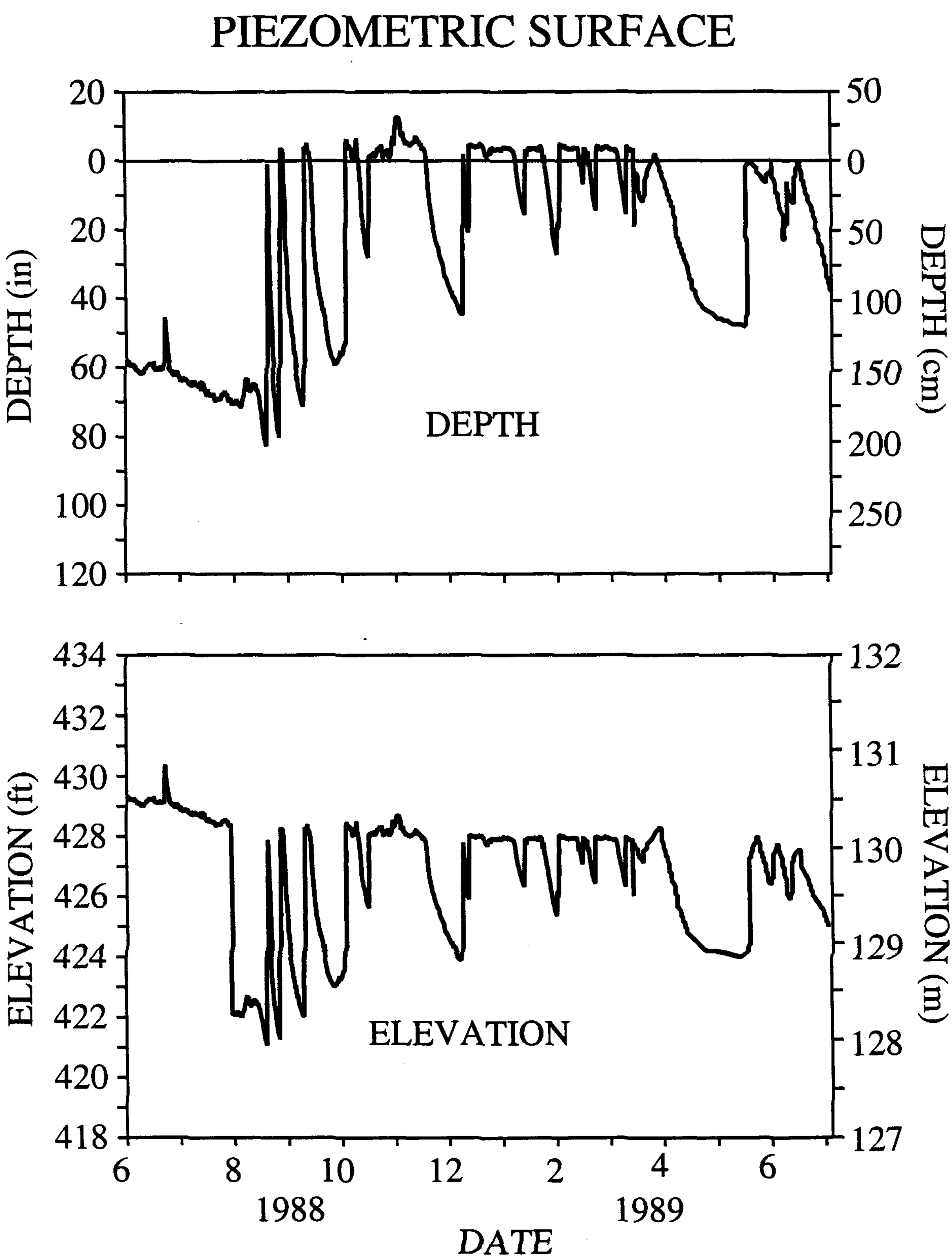


Figure 4. Piezometric response to subsidence above the panel centerline in a nearly level, somewhat poorly drained soil, as measured with reference;a)(upper) ground surface, b)(lower) elevation (Darmody, 1994).

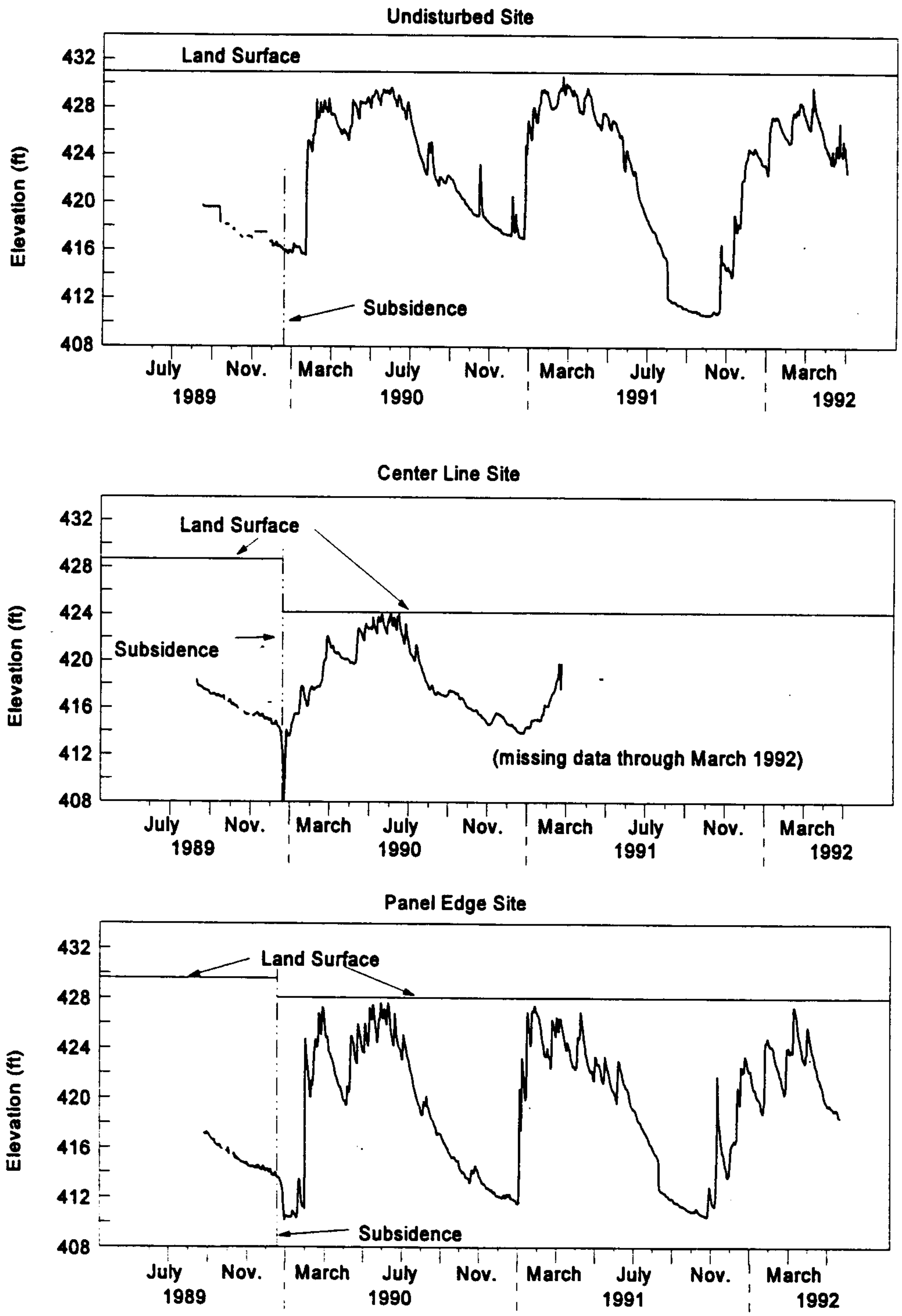


Figure 5. Piezometric elevations in a somewhat poorly drained soil at an undisturbed site and above the center line and edge of a nearby longwall mine panel (Darmody,1994).

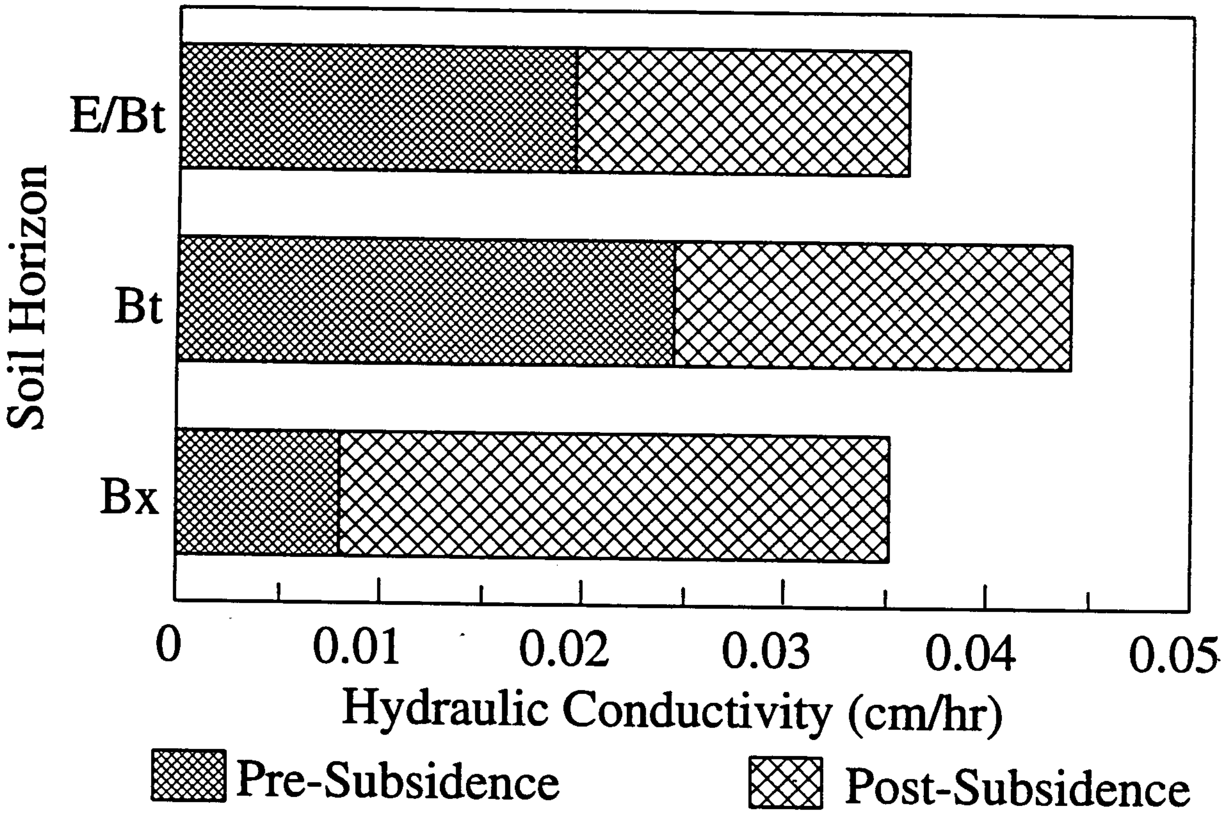


Figure 6. Effect of subsidence on soil saturated hydraulic conductivity (Darmody,1994).

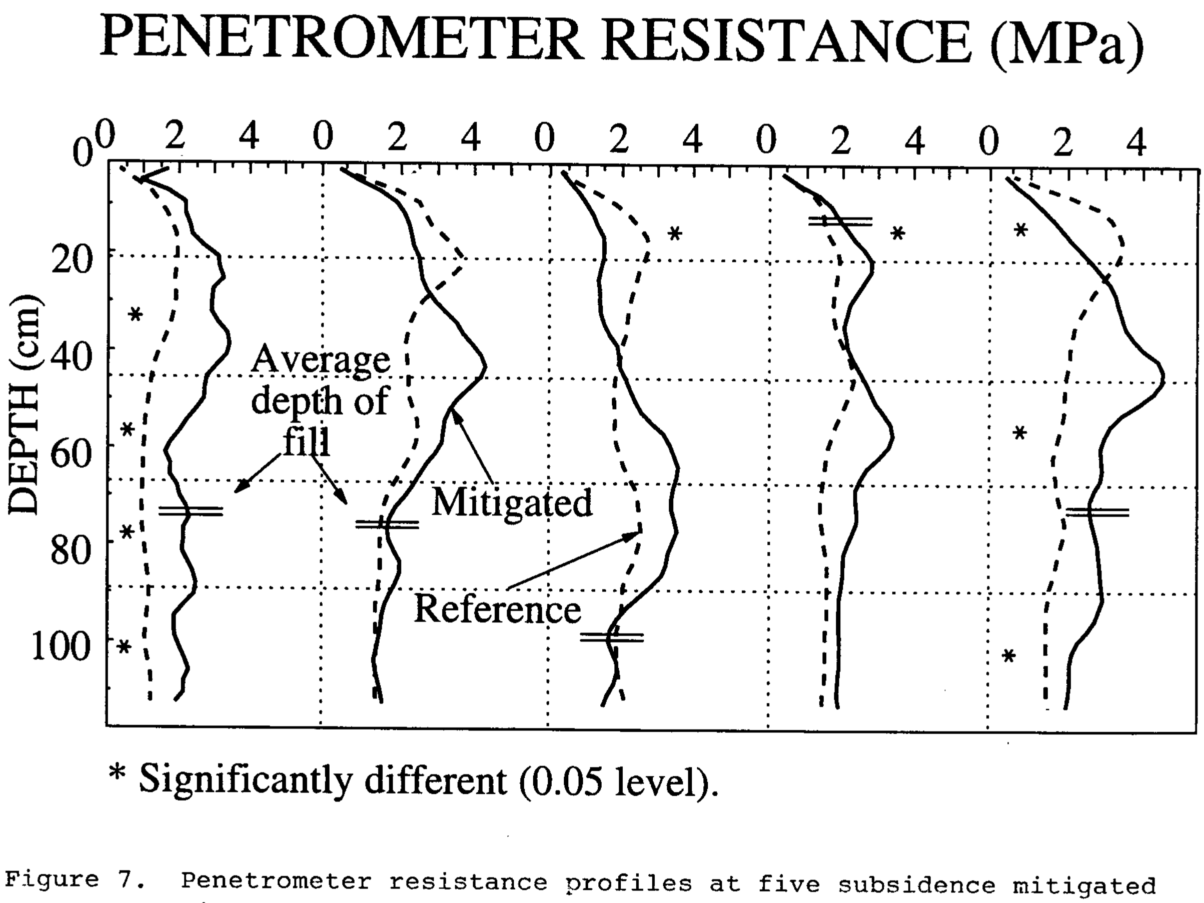


Figure 7. Penetrometer resistance profiles at five subsidence mitigated sites and at nearby reference sites (Hetzler and Darmody, 1992).

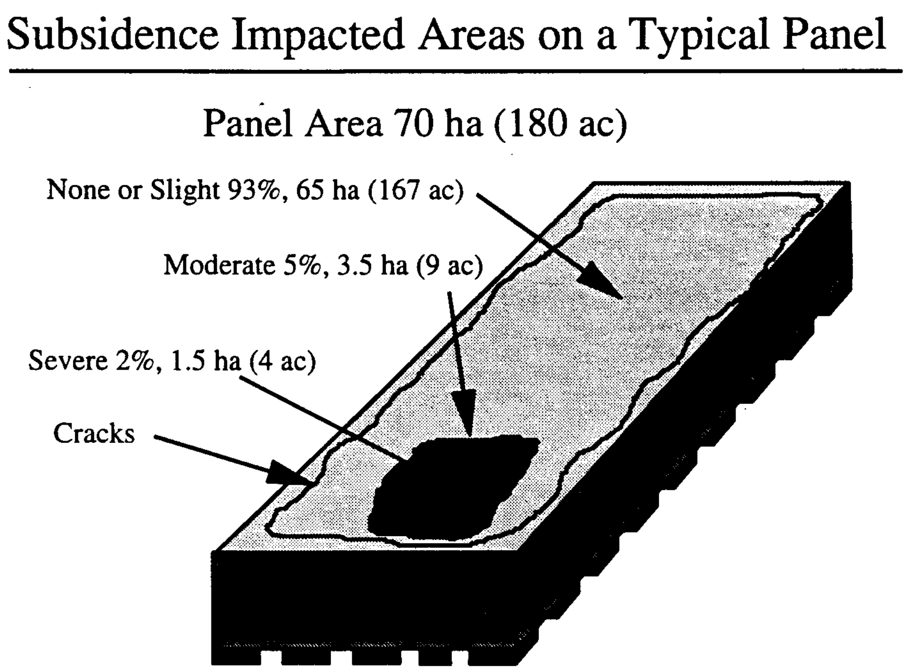
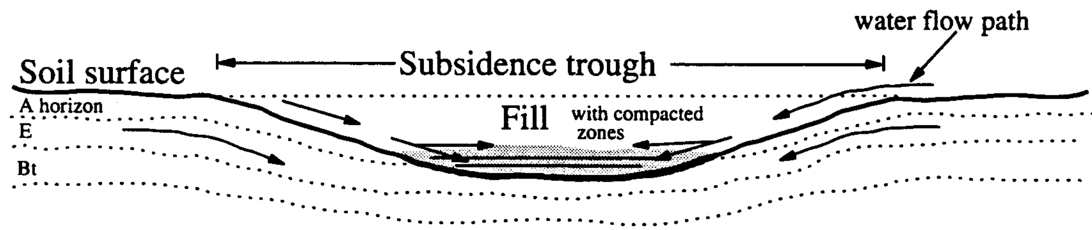


Figure 8. Schematic of the distribution of surface effects of longwall mine subsidence.

a. Subsidence troughs are run-on sites for both surface and subsurface water. This creates excessively wet or ponded areas. Compaction may be a problem within the fill and at the burried interface with the natural soil.



b. Adding sufficient fill, installing drain tiles, minimizing soil compaction, and tillage to eliminate compaction in fill and at the fill-soil interface should increase mitigate success.

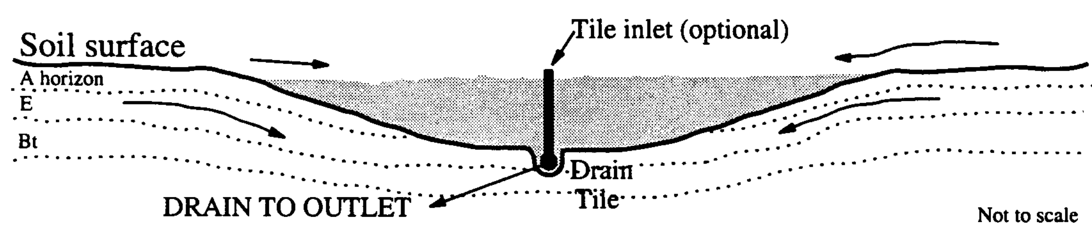


Figure 9. Schematic of proposed improved subsidence mitigation plan.

SURVEY RESULTS
PRIME FARMLAND INTERACTIVE FORUM
PARTICIPANT COMMENTS AND RECOMMENDATIONS

MOST USEFUL TALKS

SESSION 1 STATE PROGRAMS

PREFERENCE	PRESENTATION	TOTALS
1st	Indiana	15
	Illinois	8
	All State Reviews	4
	Kansas	2
	North Dakota	2
	OSM	2
	Public	1
2nd	Kansas	9
	Illinois	5
	Indiana	4
	Public	4
	North Dakota	2

SESSION 2 RECLAMATION AND SOIL RECONSTRUCTION

1st	Dunker/Reclamation Methods	16
	Hooks/Compaction Measurement	9
	Bearden/Prime Farmland with Overburden	3
	Yingling/Small Mines	2
	Spindler/Reclamation of Ancillary Soils	1
2nd	Bearden/Prime Farmland with Overburden	8
	Hooks/Compaction Measurement	7
	Dunker/Reclamation Methods	6
	Spindler/Reclamation of Ancillary Soils	3
	Yingling/Small Mines	2

SESSION 3 MINE SOIL MANAGEMENT AND STEWARDSHIP

1st	Dunker/Long Term Effects	12
	Smout/CONSOL Restoration Techniques	9
	Phelps/Land Value	6
	Hooks/Soils Based Productivity	4
	Barnhisel/GPS	1
	Wiesbrook/Soil Classification	1

PREFERENCE	PRESENTATION	TOTALS
2nd	Dunker/Long Term Effects	11
	Smout/CONSOL Restoration Techniques	5
	Barnhisel/GPS	5
	Hooks/Soils Based Productivity	3
	Wiesbrook/Soil Classification	3
	Phelps/Land Value	2

SESSION 4 SUBSIDENCE

1st	Darmody/Reclamation of Agricultural Lands	10
	Bauer/Characteristics of Subsidence	9
	Barkley/Regulatory Perspective	5
	Booth/Impacts on Groundwater	2
2nd	Darmody/Reclamation of Agricultural Lands	9
	Bauer/Characteristics of Subsidence	4
	Booth/Impacts on Groundwater	4
	Barkley/Regulatory Perspective	1

TOPICS OR SPEAKERS THAT PARTICIPANTS FELT THAT SHOULD HAVE BEEN INCLUDED AT THE FORUM

- Future methods of reclamation.
- Cost of current methods vs new technology costs.
- Reclamation of non-prime cropland.
- Reclamation in non-glaciated regions.
- Comparison of reclamation processes. New innovative processes.
- Comparison of material handling equipment.
- Reclamation for forest use.
- Crop yield data from different crops at different soil thicknesses.
- Is there any other research on reducing compaction?
- Have a lawyer discuss prime farmland soil capability.
- Panel of landowners/farmers who were currently working with reclaimed prime farmland on their experiences both pro and con.
- Panel of permittees to identify problems with permitting prime farmland.
- No speakers from Indiana universities. Are they not interested in mined land restoration?
- Indiana legislators; Indiana Farm Bureau; David Joest, Peabody Coal Company.
- We need to look to new technology for soil placement that eliminates compaction so we do not need to have costly deep tillage.
- Would have liked to hear the presentation from Tom FitzGerald. Hope his paper will be in the publication.
- Indiana seems to have some proponents that believe that 48 inches of prime farmland soil is not necessary. These people should be invited to present their evidence or data that supports this position.

ADDITIONAL RESEARCH NEEDS

SOILS BASED PRODUCTIVITY

- Soil based productivity methods for bond release.
- Develop crop yield predictive models.
- Relationship between soil properties (physical, chemical, biological) and productivity that would allow for bond release on this basis.
- Develop a system of bond release utilizing both soil properties and crop production.

PRECISION AGRICULTURAL MANAGEMENT

- Incorporating precision agriculture into the evaluation of reclamation techniques.
- GPS/GIS provides a new management system for mining operators and land owners to assess the success or short comings of reclamation.

COMPACTION

- Zero traffic soil reconstruction.
- New technology for root media and topsoil replacement that reduces compaction and is cost effective.
- Need more research on how to avoid compaction rather than compaction amelioration.
- More on amelioration of compaction in place and ways to prevent or minimize its occurrence.
- Other physical/chemical methods to reduce compaction (i.e., incorporation of recycled by-

products, injection of chemicals).
- C Impact of soil microorganisms on productivity.
- C Use of irrigation systems on these reclaimed lands during years of drought.

ECONOMICS
- C Need to see more research on the values of reclaimed prime farmland in comparison to undisturbed prime farmland.

POST BOND RELEASE YIELD AND MANAGEMENT
- C Crop yield and management following bond release.
- C Test crop varieties for productivity versus local varieties used by area farmers. If the farmers can not afford varieties used by operators, should the SRA limit the crop varieties to those used by farmers?

SOIL CLASSIFICATION OF RECLAIMED SOILS
- C Develop new soil series that could be utilized to adequately classify and remap reclaimed soils.

TOPICS FOR FUTURE INTERACTIVE FORUMS

RECLAMATION
- C Reclamation of non-prime cropland.
- C Reclamation in non-glaciated regions.
- C Reclamation for forest use.
- C Data on land capability of reclaimed areas from 1966-1977.
- C Prime farmland returned to corn or soybean production.
- C Potential for flue gas desulfurization sludge to replace or amend soils to reduce compaction and improve stability.

BOND RELEASE
- C Resolving barriers to bond release.
- C Management of bond released reclaimed areas.
- C Land values before and after reclamation.

SOIL CLASSIFICATION
- C Soil classification and productivity in non-glaciated regions.

HYDROLOGY
- C Water quality and runoff from acid spoil.
- C All aspects of reconstructed ground water in reclaimed areas and its impacts to soils.

WILDLIFE
- C Wildlife habitat reclamation.
  - C Successful tree establishment.
  - C Wetland reconstruction.
  - C Warm season grasses.
  - C Impacts to specific species (i.e., bats, raptors, game mammals, etc.).
- C Impact of compaction to tree growth and methods for amelioration.

PRECISION MANAGEMENT
- C Site specific management using GPS on mine soils.
- C Ways to utilize GPS in mining and reclamation.

SUBSIDENCE
- C Impacts of subsidence to water, land use and value, agriculture, etc.

APPENDIX 1: RECORDED DISCUSSIONS

Edited by Kimery C. Vories
USDI Office of Surface Mining

The following are the edited discussions that took place at the end of each speaker presentation and at the end of each session. The actual comments have been edited to translate the verbal discussion into a format that more effectively and efficiently communicates the information exchange into a written format. The organization of the discussion follows the same progression as that which took place at the forum. A topical outline has been developed to aid in accessing the information brought out in the discussions.

OUTLINE OF DISCUSSION TOPICS

Session 1: State Prime Farmland Programs

1. OSM
2. Illinois
   - ***Designation of Grandfathered Prime Farmland***
3. Indiana
   - ***Bond Forfeiture on Prime Farmland***
   - ***Capability to Grow Corn***
   - ***Grandfathering Definition***
   - ***Land Owner Notification***
   - ***Negative Determination on Prime Farmland***
   - ***Restoration of Soil Capability***
4. Kentucky
   - ***Extent of Grandfathering***
   - ***Restoration Standards for High Capability Crop land***
   - ***Soil Replacement Depths***
   - ***Soil Replacement Depth Verification***
5. North Dakota
   - ***Bond Release History***
   - ***Correlation of Soil Survey***
   - ***Proof of Productivity Limiting Factors***
   - ***Restoration Standard for Non-Prime Soils***
   - ***Standard for Non-Prime Soil Thickness***
6. Kansas
7. Public Concerns
   - ***Availability of yield Data when Crops Fail***
   - ***Variability Due to Rainfall***

Interactive Panel Discussion

- ***Adequacy of SMCRA in Prime Farmland Restoration***
- ***Variability in Farmer Expertise***

Session 2: Reclamation and Soil Reconstruction

1. Compaction Measurement Methods
   - ***Grid Density for Penetrometer Studies***
   - ***Use of Soil Strength and GPS Data***
2. Reclamation Methods Comparison
   - ***Best Methods for Reclaiming Prime Farmland***
   - ***Correlation of Soil Strength with yield***
   - ***Regulatory Use of Penetrometer Data***
   - ***Soils Based Productivity Index***
   - ***Use of Soil Measurements for Bond Release***
3. Small Mines and Future Techniques
   - Investigation ***of Crop Failures***
   - ***Land Owner Education about Regulations***

4. Surface Mining-Prime Farmland Soils Using Mixed Overburden
    - ***Applicability in Other Climates***
    - ***Bond Release History***
    - ***Bond Release Standard***
    - ***Land Use Trends***
    - ***Pasture Bond Release Standard***
    - ***Plans for Remining***
    - ***Relative Merits of Overburden to Original Soils***
    - ***Source of Clay Parent Material Related to Weathering***
5. Reclamation of Ancillary Surface Affected Soils
    - ***Comparison to Oil and Gas Regulations***
    - ***Length of Time to Publish Annual Yield Goal***
    - ***Response to New Proposed Regulations***
    - ***Time Frame for Proposed Regulations***

Interactive Panel Discussion

- ***Adequate Soil Depth Replacement for Prime Farmland***
- ***Cost of Deep Tillage***
- ***Positive Dialog for Problem Resolution***
- ***Possibility of Penetrometer Use during Dry Conditions***
- ***Prediction of Soil Compaction***
- ***Rate of Mining***
- ***Rate of Prime Farmland Creation***
- ***Seasonal Constraints to Penetrometer Use***
- ***Use of Hand Penetrometers***

Session 3: Minesoil Management and Stewardship

1. Long Term Effects of Deep Tillage
    - ***Bath Tub Effect of Deep Tillage***
    - ***Compaction Mitigation with Truck/Shovel***
    - ***Depth of Deep Tillage for Truck/Shovel***
    - ***Duration of Tillage Effects***
    - ***Effects of Deep Tillage***
    - ***Post-Deep Tillage Traffic***
2. Soils Based Productivity Evaluation
    - ***Data Gaps***
3. Mine Soil Classification and Mapping
    - ***Classification Concerns About In-Place Development of New A Horizon Material***
    - ***Classification Differences for Glacial and Non-Glacial Soils***
    - ***Productivity Values and Tax Base for New Soils***
4. Global Positioning Systems (GPS) and Site Specific Management
    - ***Calibration of Equipment***
5. Illinois Reclaimed Soil Productivity: Restoration Techniques
    - ***Duration of Settling on Reclaimed Areas***
    - ***Economics of Deep Tillage***
    - ***Row Spacing for Deep Tillage***
6. Land Use and Value after Reclamation
    - ***Incorporating Post-mining Land Values into Reclamation Planning***
    - ***Quantity of Permanent Program Crop Land Sold***
    - ***Speculation on Future Prime Farmland Sales***
    - ***Value of Subsided Agricultural Land***

Interactive Panel Discussion

- ***Acreage of Land that can be Deep Tilled per Year***
- ***Compaction Mitigation with Deep Rooted Plants***
- ***Effects of Excessive Rainfall***

- ***Effects of Prime Farmland Reclamation on Tree Growth***
- ***Land Value Related to Bond Release***
- ***Timing for Deep Tillage***

Session 4: Subsidence

1. Characteristics of Subsidence from Abandoned and Active Underground Coal Mines in the Illinois Coal Basin
   - ***Evidence for Sag Subsidence***
   - ***Evidence of Subsidence***
2. ***Coal*** Mine Subsidence/A Regulatory Perspective
   - ***Biggest Subsidence Mitigation Challenges***
   - ***Coal Production Trends***
   - ***Effects of Energy Policy Act***
   - ***Evidence of Subsidence***
3. Impacts of Mine Subsidence on Ground Water
   - ***Destination of Ground Water***
   - ***Time Frame for Taking Background Water Data***
   - ***Water Treatment Costs***
4. Reclamation of Agricultural Land After Planned Coal Mine Subsidence
   - ***Damage to Houses***
   - ***Differences Between Corn and Soybeans***
   - ***Remapping***
   - ***Tiling of Wet Areas***

Interactive Panel Discussion

- ***Correlation Between Subsidence and Depth of Mining***

DISCUSSION BY SESSION

Session 1: State Prime Farmland Programs

1. <u>The Surface Mining Control and Reclamation Act of 1977</u> Charles Sandberg, Office of Surface Mining, Alton, Illinois.

No questions recorded.

2. <u>Illinois Program Requirements, Experience, and Results</u> Dean Spindler, Illinois Office of Mines and Minerals, Springfield, Illinois

Question ***(Designation of Grandfathered Pime Farmland):*** What happens to grandfathered prime farmland in Illinois.

Answer: It is all treated as High Capability Land.

3. <u>Indiana Program Requirements. Experience, and Results</u> Steve Wade and Dave Kiehl, Indiana Division of Reclamation, Jasonville, Indiana

Consultant Question ***(Land Owner Notification):*** ***You have*** stated in your talk that prime farmland can be grandfathered prior to going through a permit application process. This would appear to be avoiding the permitting process that would require public participation. In this case, does the regulatory authority actively notify private land owners that their prime farmland acreage has been grandfathered.

Answer: There is no active disclosure until after the permit application is submitted.

Consultant Response ***(Land Owner Notification):*** As a result of this forum, I would like to see the Indiana program provide private land owners with this type of disclosure.

OSM *Question #1* ***(Capability to Grow Corn):*** I am concerned about the operator's capability to grow corn on prime farmland in Indiana. You have said that some operators in Indiana have stopped growing corn on mined lands. What is Indiana doing to restore the capability to grow corn on Indiana prime farmland?

Answer: *If the* operator provides proof of productivity by growing corn or soybeans for a Phase III liability bond release, we have to accept that. There is no continuing effort after bond release.

OSM Question #2 ***(Restoration of Soil Capability):*** Do you think that reclaimed prime farmland capability will be eventually restored after growing hay or pasture for 20 years or so?

Answer: I hope so. I don't know.

Real Estate Question ***(Grandfathering Definition):*** What does the term grandfathering actually mean?

Answer: The company had control of the land prior to the passage of SMCRA and could be exempted from the prime farmland standards of the law. SMCRA would require that prime farmland soils disturbed by mining receive a minimum replacement of 48 inches of soil materials. When prime farmland soils are grandfathered, then these soils are regulated as non-prime farmland soils. In Indiana, non-prime farmland soils would require a replacement of a minimum of 18 inches of soil materials for Crop land and 12 inches for non-Crop land. The productivity would be required to achieve 90 percent of the pre-mining yield rather than the 100 percent required for prime farmland.

State Question ***(Bond Forfeiture on Prime Farmland):*** ***Has*** Indiana ever forfeited bond on a permit containing prime farmland soils? If so, how has the Indiana program handled that situation in the reclamation of the site?

Answer: I am sure there has been this type of situation. Depending upon how the order is written, would determine the standards for reclamation at that site.

State Question (Negative ***Determination on Prime Farmland):*** Concerning negative determination of prime farmlands in Indiana, how are they handled? Is hayland considered Crop land?

Answer: A negative determination would not be allowed if the area was cut for hay.

4. Kentucky Program Requirements, Experience, and Results Gary Welbom, Kentucky Department of Surface Mining, Madisonville, Kentucky.

USDA NRCS Question #I ***(Restoration Standard for High Capability Crop land):*** **What are the** Kentucky standards for reclaiming areas classified as High Capability Crop land?

Answer: These lands would be classified as non-prime farmland crop land which, under Kentucky regulations, would be hayland and pasture and would require the proof of productivity for 2 years with a grass/legume hay mixture with a target yield based on 90 percent of a 3 year average of the previous 3 years of yield.

USDA NRCS Question #2 ***(Soil Replacement Depths):*** How much soil material does Kentucky require to be replaced on these areas?

Answer: The minimum requirement would be 6 inches of soil material.

State Question #I ***(Extent of Grandfathering):*** How much grandfathering of prime farmland has been done in Kentucky?

Answer: I don't have any hard numbers available to answer that question. There were quite a few acres that were grandfathered during the early stages of the Kentucky program. You would be talking in the thousands of acres but I don't know the exact amount. You don't see too much of this now.

State Question #2 ***(Extent of Grandfathering):*** Were most of the lands you now classify as non-prime crop land originally grandfathered prime farmland?

Answer: Kentucky has more acres removed from the prime farmland soil category due to historical use rather than the grandfathering process.

OSM Question ***(Soil Replacement Depth Verification):*** How does Kentucky verify the depth of soil materials replaced on prime farmland?

Answer: There is nothing specific in the Kentucky regulations that requires a specific procedure to be followed in that area. Generally, what we do after a prime farmland area has been restored and prior to a Phase I bond release, we will go out either with the operator or with a crew of State people and spot probe these areas. Many times the operator will provide equipment to assist in conducting this probing in order to insure timely Phase I bond release.

5. North Dakota Program Requirements, Experience, and Results Dean Moos, North Dakota Public Service Commission, Reclamation Division, Bismark, North Dakota

Industry Question **(Correlation** ***of Soil Survey):*** Was the ***2nd*** round of soils surveys (at a 1:4800 scale) you mentioned done by or correlated by the USDA NRCS?

Answer: No. It was done by consultants hired by the mining company and it was not correlated by the NRCS.

State Question *#I* ***(Standard for Non-Prime Soil Thickness):*** What is the total soil thickness standard for your non-prime soils?

Answer: From 2 to 4 feet of replacement depth depending upon the spoil quality. With a low SAR (sodium adsorption ratio) and low EC (electrical conductivity) it would be a 2 foot requirement. With a high SAR and high EC it would be a 4 foot replacement requirement. There are gradations in between these two values.

State Question #2 (Bond Release History: What has been your relative success on bond releases?

Answer: *North* Dakota has not received any applications for prime farmland bond releases to date. On non-prime farmland releases, we have not had a problem attaining proof of productivity.

State Question #3 (Proof of Productivity Limiting Factors): ***Have you*** been able to determine any limiting factors related to proof of productivity? In the Midwest we have noted problems with productivity on reclaimed soils during dry years.

Answer: I think that compaction is the one issue where we may experience problems. We have no problem meeting productivity on normal to above normal precipitation years but may have problems during below normal precipitation years. The reclaimed soils do not perform as well during dry years.

State Question #4 (Restoration Standardfor Non-Prime Soils): Your chart states that production on prime and prime farmland must be restored to 100 percent of pre-mining levels. Our program requires non-prime farmland to be restored to 90 percent of the pre-mining level. Why do you do that?

Answer: The North Dakota law requires 100 percent of productivity for all of our reclaimed lands, even native grassland.

6. <u>Kansas Program Requirements. Experience. and Results</u> Marlene Spence, Kansas Department of Health and Environment, Surface Mining Section, Pittburg, Kansas.

No questions.

7. <u>Public Concerns about Technical Aspects of State and Federal Prime Farmland Programs</u> Dr. Richard Stout, Knox College, Galesburg, Illinois.

State Question #I (variability due to Rainfall): ***Have you*** considered rainfall variability in your data analysis?

Answer: I tried but I determined that I would need rainfall data for each field for each year of testing. This was too much to incorporate into the analysis, so instead I tried to use some data provided by Dr. Keply at the Illinois Department of Agriculture and he sent me some data on ideal years, average years, and drought years. The problem with this is that State-wide precipitation data would not be representative of the actual precipitation conditions of the fields being tested. I tried using this data but it did not work. The end result was that I was not able to account for precipitation in the study.

State Question #2 (Availability of Yield Data when Crops Fail): Did you have data for a crop field that was planted but did not make its yield goal? When we have looked at this in Indiana, if a field does not make yield in a particular year we don't know about it because the data is not submitted. Is tbis type of data available in Illinois?

Answer: In this data set, I did not try to account for those cases. I do know that in past years a paper record has been kept but I have not been able to locate any electronic record.

<u>Interactive Discussion with all Speakers for Session 1</u>

Consultant Observation (Variability in Farmer Expertise): Dr. Stout, I have been involved in prime farmland reclamation for about 18 years, growing crops on both prime and non-prime farmland soils, and I have seen intense study of prime farmland soils up to the time the soils are replaced and then I don't see too much. One of the things I have observed is that there is a big difference in the expertise of the farmers growing crops on these lands. I have one farmer that only gets one or two successful crops over a period of 5 years while another farmer on a similar property obtains good yields every year. It all appears to be in the expertise of the individual farmer. They may actually use similar techniques but one farmer is better at using those techniques than the other. One farmer that grows corn on reclaimed land puts different varieties of corn in different hoppers of his planter in order to compensate for seasonal moisture stress. Purdue University has tried to quantify some of these things through a bulletin they put out called ID 152 and it tries to quantify these differences in farming practices. This is an aspect that needs to be brought into any evaluation of restoration effectiveness on reclaimed crop lands.

Another observation for OSM would be that in Pike County, Indiana, where the population is 12,000 we have experienced a net loss of prime farmland acres due to surface coal mining. That should be considered as an off-site impact in its oversight process. The resulting social/economic impact in loss of agricultural activity should have been prevented by SMCRA. It is hard to get an industrial business to come into the area because there is no infrastructure.

OSM Question ***(Variability in Farmer Expertise):*** Could we have the different states address their experience with the variability of expertise of people farming reclaimed crop land areas?

North Dakota Response: In North Dakota, we have the mining companies contract with farmers to come back on the land and farm that parcel of land. It has been our experience that the mining companies oversee this operation fairly closely. The end result is that those farmers that are good managers obtain bond release and those that aren't don't.

Indiana ***Response:*** In general, most of the coal operators have professional farmers tbat have the expertise to manage these lands well. Naturally some are better than others. For the most part, a very conscientious effort is being made to do everything possible to achieve successful bond release. Although we have good data on years where we achieved successful yields, we have no data on why certain crop years failed.

Illinois *Response:* Early in our program, a number of the operators attempted to have their own farm management programs. After several years, most of them decided they were better miners than farmers. They then shifted over to using tenant farmers. In two of our counties, I meet almost monthly with land owners where the land is leased by private land owners. These land owners continually complain that our standards for bond release are too high. Even though the reclaimed lands are out producing what these farmers had been able to produce before mining they are not achieving success. I don't tell them, but I feel that in many cases the farmers were not doing a very good job farming prior to the mining disturbance. There is a wide variety of pre- and post-mining management of these lands.

Kentucky Response: Most of the large operators do their own farming. The smaller operators seem to be better off using the land owner or hiring a contractor to do the work.

Kansas Response: In the case where the farmer is also the land owner, we see a high level of stewardship because they are interested in getting the land back and being able to use it. They are also able to get the coal company to provide funds for required fertilizer and other amendments. If the land owner hires a tenant farmer, then we do not see the same level of stewardship. The tenant farmer usually has his own land and takes care of it first and the coal companies land second.

The economics of mining coal in the Midwest is such that the coal companies have financial problems such that the reclamation and restoration of soil productivity suffers. Some of the operators are lucky to get their soils replaced let alone be able to afford to do the revegetation studies necessary to prove productivity success. If they have a vegetative ground cover established and are not receiving violations, then we see their level of effort to prove productivity fall off.

State Question ***(Adequacy of SMCRA in Prime Farmland Restoration):*** We have had SMCRA for 20 years now and we have had mining on prime farmland for at least that long. I would like to ask the panel if they believe that SMCRA has provided adequately for the restoration of prime farmland following mining? If there does need to be a change to SMCRA, what change would you recommend?

Kansas Response: *If* SMCRA is implemented correctly, I don't believe any changes need to be made. I was very interested in the survey utilized by Indiana and would be very interested in conducting a similar landowner survey in Kansas and find out what Kansas farmers feel about the productivity of these reclaimed lands.

Kentucky Response: Although I don't think I would make any changes, I would like to see more small land owner participation in the process so that they could better understand how the reclamation and restoration process works.

OSM Response: I do think that SMCRA is working, but I also think that we have learned a lot over the last 20 years. Based on the presentations this morning and talks to be given later by researchers in the field, we have seen that better reclamation methods and equipment have been developed. I am also now more hopeful than I was 10 years ago that progress is being made toward a soils based method for determining proof of productivity.

Dr. Stout Response: Compared to the bad old days, there has certainly been a lot of progress and SMCRA has helped a lot. Based on what I heard this morning, I think that Illinois has a pretty good program. I would still like to see the target yield for prime farmlands higher than they are. I think that passing productivity for 3 years out of 10 years is insufficient to satisfy me that the prime farmland has been reclaimed. The only way these types of changes occur are for concerned citizens to be informed and have access to scientific data to determine what levels of policy can be used to bring prime farmland back up to pre-mining levels of productivity.

Illinois Response: Overall, SMCRA has had a very positive influence on reclamation in our State. For the most part, the current laws adequately address the issues. I would like to see more progress toward soil modeling rather than actually raising crops. I think that all of the necessary authority to conduct successful reclamation is already in SMCRA. One area that is overlooked is the exempted prime farmland (either through grandfathering or negative determination) where there is a great deal of difference from state to state on how these lands are being reclaimed.

Indiana Response: I would agree that, if implemented correctly, SMCRA provides adequate reclamation of these lands. I would think that we have improved a lot over the last 20 years. Going to the replacement of soil materials with the truck/shovel method rather than scrapers has really helped. I would agree with Illinois that it would be nice to have a rule that treated exempted prime farmland as high capability crop lands. This would better address the restoration of soil capability for these lands.

North Dakota Response: I would agree with the other states that SMCRA adequately provides for the restoration of prime farmland. With regard to the special handling of prime farmland, we feel that the requirement to replace all of the original soil materials in sequence is overkill based on our successful experience of mixing prime and non-prime soil materials.

Session *2:* Reclamation and Soil Reconstruction

1. <u>Compaction Measurement Methods</u> Charles Hooks, Southern Illinois University/University of Illinois Reclamation Research Station, Percy, Illinois.

Academic Question ***(Use of Soil Strength and GPS Data):*** Who has been actually using soil strength measurements to better apply deep tillage or land use changes? Is anyone actually using GPS grid mapping to determine fertility levels?

West/Central Illinois Consultant Answer: We design constant rate cone penetrometers and have been using them in our business both in the mining industry and in the farming sector to detect compaction. We have been trying to predict the location of compacted areas to guide deep ripping efforts. We use GPS methodologies to map our findings in these efforts. We obtain the location coordinates every time we take a penetrometer reading.

Consultant Question ***(Grid Density for Penetrometer Studies):*** What intensity of a grid should we use to obtain accurate penetrometer readings for compaction?

Academic Answer: The actual grid spacing depends upon the variability of compaction levels in the soils being tested. In research applications, you may use a grid spacing as close as one acre. Most research applications, however use a ***five*** acre grid. You may have to use closer grid spacings on natural soils than you would use on a reclaimed mine soil because of the greater variability of compaction levels in natural soils. We would use a statistical analysis of variability in order to be assured that we have reduced the variability to an acceptable level.

2. Reclamation Methods Comparison Robert Dunker, University of Illinois, Urbana/Champaign, Illinois.

*Academic Question **(Best Methods for Reclaiming Prime Farmland):*** Assuming that money was not limiting, what would you do to reclaim prime farmland in order to meet the required production goals that the land owner would want following reclamation7

Academic Answer: I think the key to success of a good reclamation program is: (1) knowing the quality of soil materials you have to work with; and (2) knowing how you can take advantage of the qualities of those soil materials in order to replace them with a method that will reduce compaction, reduce compaction, and reduce compaction! If you can't reduce compaction sufficiently, then we need to look at alternative methods and we will have to look at deep tillage of the reclaimed soils. Deep tillage is becoming a common practice in the reclamation plans of the State of Illinois; however, quality of soils is still the key ingredient to reclaiming prime farmland soils. It is a site specific process. What may work at one mine will not necessarily work at another simply because they do not use the same techniques. The key in Illinois is to take advantage of the high quality of the soil materials and put them back in a manner that will promote and enhance root penetration and soil productivity.

*Regulatory Question **(Regulatory Use of Penetrometer Data):*** Is the cone penetrometer a practical tool to be used in a regulatory sense? Could it be used by the inspector to determine if prime farmland or high capability crop land had been properly reconstructed?

Academic Answer: The answer to that is that the penetrometer is a tool. As a tool it has to be used properly. Our penetrometer data has been collected under relatively controlled conditions. We take our readings in the spring when soils are uniformly moist. A penetrometer is highly sensitive to soil moisture, texture, and other physical soil variables. There needs to be work done to correlate a calibration curve under different soil moisture and texture conditions. However to compare the penetrometer method with taking bulk density cores, we feel that if the penetrometer data is taken at an optimum time, that we have a pretty good idea of what the reclamation treatment will result in over time. We find that bulk density measurements do not correlate nearly as well as penetrometer readings to actual crop yields. The penetrometer method is a quick, nondestructive methodology that will indicate to the operator the compaction variability in his field and whether or not he is likely to need deep tillage to meet his productivity goals.

My personal opinion is that the penetrometer readings, if done properly, could be used to determine whether or not the field would need deep tillage prior to beginning yield measurement for bond release.

*Regulatory Question **(Use of Soil Measurements for Bond Release):*** Concerning the need to prove productivity by growing crops, how far away is the science of compaction identification where you may not have to grow a crop in order to determine that the soils have been adequately reconstructed? To what extent is this science determined by the compaction issue? Are there any other soil factors involved in making this determination? If so, what would those factors be?

Academic Answer: There are still gaps in the data base that need to be filled in. Some of those gaps for Illinois are that we understand some soils in some parts of the State better than others. We need to increase our knowledge of textural and chemical conditions of soils in some parts of the State. One thing about a diagnostic test that could be ground truthed in the field, through comparison with long-term crop yields, is that "if we could determine that soil texture and chemistry are not limiting, then we would feel fairly comfortable about using soil strengths to make a qualitative assessment of good and bad reclamation." The real sticking point will be finding that part of the curve that says we will accept this level of reclamation but not that one. Currently, we can easily identify the low end and the high end of the soil strength curves. It is in the middle of these curves that we need to refine our methods and do additional research in order to fill in the data gaps, especially textural properties that correlate with medium levels of soil strength and how these relate to crop yield potential. We are seeing some very close relationships in our yield test plots but they need to be field tested over a field with high variability. It may not be that far in the future, but it will take a few more years assuming that research funds are provided to do the work.

Consultant Comment ***(Correlation of Soil Strength with Yield):*** I would like to tell the audience what we have been seeing on undisturbed farm ground in comparison to what you are finding on mined lands. We see a very close correlation between soil strength values and actual crop yields that tracks very closely with what you are seeing on disturbed mined lands. On undisturbed crop lands you start seeing a yield reduction at about 175 - 225 pounds/square inch (psi) of pressure. At 300 psi there is significant yield loss with soils that have man made compaction. In upland soils, we are finding vehicle traffic puts compaction in the zone of 14 to 16 inches of depth. In the river bottom soils along the Illinois and Mississippi rivers, we find compaction as deep as 30 inches. We have tracked this back to double incorporation of herbicides utilizing large discs. In some cases, we have seen compaction values even higher than what is found on the mine site.

Academic Comment ***(Soils Based Productivity Index): The*** issue of the use of the penetrometer to develop a soils based productivity index needs to be developed on a regional basis. What we would develop in Illinois may not be applicable for a comparable mining region in Kentucky because their soils are different in terms of soil development and also have differing soil chemistries. We would need to apply such a predictive model within the range of characteristics that the model was developed under. It is probably not feasible to come up with one model that would fit mining regions in such widely separated regions as Texas, Kentucky, and Illinois.

Academic Comment ***(Soils Based Productivity Index):*** Based on our experience at the University of Kentucky, we found in our efforts to develop a soils based productivity model that we had more variation in mining methods than in any thing else. We could develop a model that would work for a specific set of reclamation methods and equipment (i.e., scraper pans, truck/shovel, etc.). The model would not work when you tried to use it for a different set of reclamation methods and equipment. I think that with current reclamation methods being dominated by truck replacement in much of the Midwest, then the models that could be developed may be more likely to work across state lines.

3. Small Mines and Future Techniques Mark Yingling, Black Beauty Coal Co., Evansville, Indiana

State Question ***(Land Owner Education about Regulations):*** Could you describe the efforts that the company initiates to educate landowners about regulatory requirements related to proving productivity and obtaining bond release?

Answer: When we started our POD mining in Illinois, I am not sure that the bond release regulations were completed. Most of our leases were signed before the bond release requirements were known. Since the productivity formula has been completed, we have sent letters and we have sat down with the landowners to inform them that land has to be separated into different capability classes (i.e., prime, high capability, and non-crop land). It is hard for them to understand why they need a target level of 170 bushels of corn/acre when their average yield on a good year would be 120 bushels/acre.

State Question ***(Investigation of Crop Failures):*** I know you use primarily truck/shovel operations with some scraper pans, and you have had fairly good success at meeting the productivity requirement at Cedar Creek Mine, but when we have numerous repeated failures to make productivity, do you have any methods for determining what the problems are?

Answer: We look at fertility first with both macro and micro nutrient levels. Then we look at compaction by digging test pits and look at root penetration. We look for areas that might be holding water and not draining. Once we identify any problems then we try to alleviate them.

4. Surface Mining - Prime Farmland Soils Using Mixed Overburden Eddie Bearden, Texas Utilities, Dallas, Texas

OSM Question ***(Applicability in other Climates)*** : How would rates of precipitation relate to other parts of the country where this type of methodology would be useful'?

Answer: We typically get about 35 - 45 inches of precipitation per year depending on the location of the mines in the state.

State Question ***(Land Use Trends):*** ***Are*** most of your reclaimed areas going back to pasture rather than crop land?

Answer: *Yes.* We do not typically plant to crop land. We are now increasing the amount of land we are planting to forest land.

State Comment ***(Relative Merits of Overburden to Original Soils):*** Your soils seem to be very different from the soils we have in Indiana. Your soils seem to be very similar to your spoil materials, whereas our soils are very different from our spoil material. I don't know if it would be beneficial in our situation to substitute overburden materials for native soil materials.

Answer: In many of our situations, the overburden materials are better plant growth media than our native soils are. It is a site specific situation.

Academic Question ***(Source of Clay Parent Material Related to Weathering):*** Those clay soils that you showed on the slides might be smectitic or montmorillonic clays. Where is the source of the clays for the native soils? Is it possible that the overburden materials you are substituting will weather with time to something similar to the native soils you have now?

Answer: Most of the clays we deal with are montmorillonic although some are smectitic. I really don't know what the ultimate weathering of these overburden materials will be but it would take a very long time for them to weather into a clay pan soil.

OSM Question ***(Plans for Remining):*** Are there any layers of coal below the two seams that you are currently removing?

Answer: *I think* that there probably are but they are not economical to reach.

Academic Question ***(Pasture Bond Release Standard):*** What are your bond release requirements for pasture?

Answer: First we have five years to prove productivity, then we have to meet 90 percent of the yield standard for pasture. We graze the area, determine the animal unit months of forage harvested and convert that to tons/acre. In some areas, we also hay the area and convert that to tons/acre.

Academic Question ***(Bond Release Standard):*** ***You are*** starting with pasture land then you are converting it to prime farmland capability. Don't you get your bond release based on the productivity target yield for the pre-mining pasture condition?

Answer: That is correct. A lot of our land was previously native undeveloped vegetation. It is land that has been grazed and a lot was utilized to grow cotton during the late 1800s and early 1900s. The soil nutrients have been greatly depleted. They quit farming it because it was no longer economical to produce a crop. The erosion was severe. It has since been allowed to go back to native vegetation. After mining, we are either converting it to Bermuda grass pasture or forest land. We are also converting some land to wildlife habitat with mixed hardwoods and native grasses.

Academic Question ***(Bond Release History):*** ***Has any*** of this land that you feel now has prime farmland capability been released from bond and then had crops grown on it? If so, have any of the landowners developed a history of what its potential to produce crops is?

Answer: Some has been released. None, however, has been used to produce row crops. Partially because farmers in this part of the state no longer grow row crops. During my master's thesis I asked a farmer who had farmed some reclaimed land for some time, "If you had the choice between buying non-mined land or mined-land for the same price per acre, which would you buy?" He said that, "He would choose the reclaimed land every time." That is the kind of rating that most of our landowners give the land we reclaim.

5. Reclamation of Ancillary Surface Affected Soils Dean Spindler, Illinois Office of Mines and Minerals, Springfield, Illinois

State Question ***(Comparison to Oil and Gas Regulations):*** Does the Office of Mines and Minerals also regulate oil and gas?

Answer: Another Division in the Department of Natural Resources regulates oil and gas in Illinois.

State Question and Comment ***(Comparison to Oil and Gas Regulations):*** It is the same in Indiana. The requirement for reclamation on these relatively small areas are next to nothing. They put the soil back and grade the surface and apply seed and mulch and then they are done. These are very small areas and may provide a comparison for what we should be doing on small disturbed areas on mine sites. Since both programs are under the Department of Natural Resources and both under Federal regulatory programs, why do we do things differently in one industry over another?

Answer: The big difference is that the coal industry is regulated by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). I am not sure if there is any national legislation covering the environmental impacts of oil and gas development. When it comes to prime farmland under SMCRA "Thou shalt make it crop land in the post-mining landscape, and you need to measure productivity." Whereas in oil and gas you do not have a standard that you have to compare the reclaimed areas to. What we are attempting to do is to find some other way to assure that the requirements of SMCRA are met.

Industry Question ***(Response to New Proposed Regulations):*** What kind of response are you getting from other agencies on this proposal?

Answer: The bulk of this has not gone to the inter-agencies yet. This has been a multi-year discussion with OSM. Although we have had the general support of the Illinois Department of Agriculture and the NRCS on the initial proposals, the final details have not gone back to them yet.

Industry Question ***(Time Frame for Proposed Regulations):*** What is your time frame on enactment?

Answer: I will have to refer that one to OSM as it is currently under their review. We have been working closely with OSM and I expect to have something in place this year.

Industry Question ***(Length of Time to Publish Annual Yield Goal):*** On your adjustment factor for crop yields, how long does it take to come up with that adjustment7 It would seem that the mine operator would not know at the time of harvest whether he had made his yield or not.

Answer: This has caused some problems. It is normally not until around April of the following year before we can tell the operators what the yield data from the preceding fall harvest was. They are usually getting ready to plant for the next year before they find out whether or not they passed the previous year. The reason for this is the county statistics on the county average yields do not come out the until spring of the following year. This is an integral part of the formula that we use in Illinois.

Interactive Discussion with all Speakers for Session 2

OSM Question ***(Rate of Mining):*** Eddie Bearden, do you have a sense for how many acres per year that Texas Utilities mines?

Answer: Texas Utilities mines approximately 2,000 acres per year,

OSM *Question* ***(Rate of Prime Farmland Creation):*** How many acres of prime farmland would Texas Utilities be creating per year?

Answer: At the Big Brown Mine, it would be about 125 to 150 acres per year. At the Monticello Mine, it would be around 200 acres per year. Also, the soils that are developing from the cross pit or oxidized materials, I fully expect that it will also meet the NRCS criteria for prime farmland soils. NRCS has not yet finalized its work on classifying this as a new soil series.

State Question ***(Adequate Soil Depth Replacement for Prime Farmland):*** In the Illinois coal basin, what should the total thickness of soil horizon be in order to restore grandfathered prime farmland to its original productive capacity? We had proposed in Indiana at one time that 36 inches would be adequate but this did not pass. What depth of soil materials would you think would be adequate?

Answer: I will assume that we are not talking about fragipan soils, which would be a special case. In Illinois we have two mining districts and we have a varied soil replacement requirement from southern Illinois to northern Illinois. It is not uncommon for prime farmland restoration in western Illinois to have a total root zone requirement of five feet. In a situation were we have been covering refuse, we have had as much as a six-foot requirement. In the more common replacement situations, a four-foot root zone would be required in order to restore the pre-mining capability for most crop lands in Illinois and I would think that this would be the same for Indiana as well.

Academic Answer: From a pedologist standpoint, if we are going to return land capability, and we are going to be growing corn in Illinois, corn is a deep rooted crop. From our research, four feet of soil material is going to be necessary to return 100 percent productivity. Is that a combination of rooting media only or is it a combination of rooting media and high quality material below that? I think we need to have the capability to have four feet of rooting volume. If we are only going to have three feet of rooting material, yet the material below that is going to be severely compacted such that it will restrict root penetration, then we have made the decision to restore capability at 75 percent of its potential to produce a corn crop. We need to assess the rooting media, the quality of materials, and we need the total rooting volume that will support nutrient levels, water capability, and root penetration in order to achieve 100 percent productivity. I have a no till planter where I could plant corn in the carpet of this room, but that does not mean that we have restored the capability to produce a crop. We need to have the total rooting volume.

Academic Answer: Certainly in some of this you are relating to situations where the pre-mined soils had root zones shallower than four feet. A lot of the soils in this region of the country have a full rooting depth. Perhaps this conversation relates to the stewardship liability that we have as the current land managers. Concerning the productivity potential of our newly reconstructed soils, one of the methods of reclamation is deep tillage. If we look at the current research results, can the results we are obtaining on reclaimed soils be applied to our troubles with clay pan natural soils? By merely doing some soil mixing, we can significantly improve those natural soils. This type of technology may not be applied next year or in the next five years. But some day, the economics of agriculture may mandate that mixing of natural soils through deep tillage is economically viable. For that reason, we need to not only be thinking about replacing the necessary rooting volume but even if the natural rooting zone was shallow there may be a potential for creating a better soil given current technology.

Industry Answer: From an operations standpoint, we try to put back as much soil everywhere as possible, not just with prime farmland. This gives us a lot of flexibility from a land use standpoint. The answer of how much soil volume to replace is also dependent upon the replacement methods. If you are scraper placing all of your materials rather than using trucks this will limit root penetration. It also depends on the types of crops you intend to grow. Grazing land does not need as much soil depth as alfalfa. We grow a lot of alfalfa and have found as much need for total root depth as in a crop land situation. That is one reason that we try to put back four to five feet of soil materials everywhere. Since we have to handle all of the overburden material anyway, whether we put it on the top or bottom doesn't make that much difference.

*Academic Question (Cost **of Deep Tillage):*** I am interested in how much it costs to deep till. Could the other panelists respond to that?

Industry Answer: You need to look at where your compaction problems are occurring. If your compaction zone is within 16 to 18 inches from the surface, you will be needing a different tool than if the material has been scraper placed and the entire root zone is compacted. Breaking up compaction with a chisel plow or a Tiger II will cost about $20 - $30/acre For deeper compaction at the 24 inch depth, you will pay $60 - $100/acre depending upon whether you are hiring it done or you use your own equipment. Depths up to three to four feet could be costing $300 - $400/acre.

Consultant Answer: We contracted three years ago at $400/acre to do the DM II to four feet.

*Consultant Question **(Seasonal Constraints to Penetrometer Use):*** When measuring soil strength using a penetrometer, how many days in an average year have you been able to use this type of equipment?

Academic Answer: During the seasonal window we use, assuming similar low ground pressure equipment, we look for recharge and uniform moisture conditions. This could be from early March to the first of June through the middle of June. Another cut off indicator would be when the corn is at the five leaf stage is when the soil starts to dry out. When ever this happens, your accuracy begins to fall off.

*Industry Question **(Prediction of Soil Compaction):*** In predicting soil compaction, has anyone tried to map in advance areas at risk for soil compaction as a means of economizing on remedial work?

Academic Answer: Most of the areas we have looked at in our research were about 10 to 20 acres in size and the operator wanted to know how much variability in compaction existed on the site. We do not have any experience with large fields (i.e., 40-50 acres). Mostly we have done trouble shooting in potential problem areas.

Industry Answer: We have looked at different soil handling techniques and have asked the University of Illinois to look at soils when they are frozen or extremely dry and truck replaced material versus scraper placed. That gives us a subjective assessment of how and when we need to handle our materials.

*Academic Question **(Possibility of Penetrometer Use during Dry Conditions): Have you*** ever looked at a situation where you measured an area when moisture conditions are right and then come back later and reprobe the same area to try to build a working curve for less than ideal moisture conditions? Then you could use a moisture content measurement and the correction curve to adjust for less than ideal conditions.

Academic Answer: Whenever you start getting below field capacity moisture conditions (17 percent soil moisture) and begin to approach 15 percent soil moisture, the soil strength increases logarithmically and we jump from 100 - 200 psi to 500 psi in non-compacted areas to 1500 psi in compacted areas. In this situation, the limits of the penetrometer equipment will not allow you to take measurements at these soil strengths. Our equipment is designed to work up to a maximum soil strength of 1200 psi and is very accurate in the 100 - 500 psi range. The reality is that once moisture drops below field capacity, soil strengths shoot up so fast you can't get accurate readings or even force the probe into the ground.

*Academic Comment (Use **of Hand Penetrometers):*** I am concerned about the use of hand penetrometers. In this situation, you may not be considering the moisture content at the time the data is collected. The problem is that when the soil moisture is at field capacity you can't dig a soil pit very safely, yet that is when these measurements need to be made. I once probed a 60 acre field on a research farm. It had rained two days previously. When the probe reached a 6-inch depth, the soil strength increased and then later decreased as depth increased at what was assumed to be a lower compacted zone. I initially discounted the 6-inch high soil strength area as a product of low soil moisture because of the rain. It later turned out to be a compacted plow zone. I did not know that the field had been in wheat production six to eight years prior to the university acquiring it. The point is that you need to look at the data critically so that you correctly interpret it.

Industry Comment ***(Positive Dialog for Problem Resolution):*** I have been struck with the positive relationship between the industry, academia, and regulators in working through the problems that have been discussed today. I think this type of event is a very positive thing.

Session *3:* Minesoil Management and Stewardship

1. Long Term Effects of Deep Tillage Robert Dunker, University of Illinois, Urbana/Champaign, Illinois

Academic Question ***(Duration of Tillage Effects):*** What does your research indicate as far as how long the effects of deep tillage will last?

Answer: In our 1997 data, we were still seeing the same significant grouping between tillage depths that we saw in 1988. I will point out that these systems are subject to recompaction immediately after tillage. We need to employ a system that utilizes compaction avoidance techniques. High axle loads on these soils can recompact them. Our plots, however, have not shown any significant reconsolidation at the deeper depths. In the management zone in the upper horizons you will see some variability due to typical agricultural management systems. But there is no indication that the compaction that was alleviated below these zones has significantly reconsolidated after 10 years. The productivity levels have remained high over this same period of time.

OSM Question ***(Effects of Deep Tillage):*** Having seen these deep tillage machines operate, it appears that during deep tillage you actually are just creating deep fissures. You still have big chunks of material down there that would have very high soil strength. In this case, the roots would actually be penetrating the cracks between the chunks.

Answer: Depending upon the type of equipment used and the soil moisture conditions at the time of deep tillage, this could be true In heavily compacted mine soils, you will find that the material can break up in big chunks. At this point, them is no indication that the roots would penetrate into such chunks of highly dense material. What you have actually done is add a lot of areas for water and nutrients to become available for roots.

State Question ***(Compaction Mitigation with Truck/Shovel):*** If you were using a truck/shovel subsoil soil replacement system and replaced the topsoil with scrapers, what type of compaction alleviation system would get the job done? It does not seem that you would have to use quite as deep a tillage system when you have used the truck/shovel system of subsoil replacement.

Answer: There is no yes or no answer to that. You need to assess what the effects are. If I were going to use a shallower piece of tillage equipment, then I would want to actually measure the soils to determine that there was no significant compaction zones below the zone of tillage I was using. Truck/shovel operations create lower soil strengths than what is created with scrapers. But depending upon how the truck/shovel operation was actually carried out could change things considerably. Did the trucks drive on the rooting media? What were the moisture conditions? I would want to know the actual compaction results of using a particular method before making a final decision. In theory, you should be able to use a shallower piece of tillage equipment under such a system. In normal agriculture, you have the rule of thumb that you do not want to till any deeper than necessary in order to not disturb natural soil structure. In a mining situation you do not have natural soil structure.

State Question ***(Depth of Deep Tillage for Truck/Shovel):*** What would be the depth that you would typically need to deep till under ideal conditions for a truck/shovel system?

Answer: I don't know that I could give you an answer. I have seen a wide range of compaction in truck/shovel operations. You would really need to know the particulars about a given site and operation before you could say what deep tillage equipment you would want to use.

Consultant Question ***(Bath Tub Effect of Deep Tillage):*** In massive soils, what could you say about the bath tub effect where you would overload shallower depths with too much moisture?

Answer: *If you open these* soils up to large voids then subsoil moisture will tend to move downslope. Lower topographic areas will be in a moisture receiving condition. Just as in natural soils, landscape position will be a factor in the final conditions of the soils.

Academic Question ***(Post-Deep Tillage Traffic):*** What kind of traffic did you have on your research plots after the tillage treatments?

Answer: We did a lot of no till or minimal tillage treatments initially. We tried to use as light a tractor axle load as possible. We took the fluid out of the tractor tires.

2. Soils Based Productivity Evaluation Charles Hooks, Southern Illinois University/University of Illinois Research Station, Percy, Illinois

Academic Question ***(Data Gaps): Your*** regression equation for the intermediate set was quite different from the rest of your data set. Soil strength was positively correlated with yields. Could you comment on the differences?

Answer: Historically we have seen a negative correlation with soil strength and yield. As soil strengths increase, yield decreases. In the middle soil strength zone, this correlation does not play a major role and even has a slight positive correlation. This is the zone where we are going from a minimum rooting volume to an acceptable rooting volume and a lot of factors play a role. We have hypothesized that we are seeing soil texture differences playing a larger role in this middle zone than does soil strength. This is an area that needs to be more extensively investigated.

3. Mine Soil Classification and Mapping Scott Wiesbrook and Dr. Robert Darmody, University of Illinois, Urbana/Champaign, Illinois

NRCS Question ***(Classification Differences for Glacial and Non-Glacial Soils):*** Do most of the soil series that you have described have a glacial till component? Much of my experience has been in areas that do not have glacial till material. My observations in these areas is that they are highly variable. It concerns me that any attempt at soil classification with these materials will result in trying to make them fit into descriptions that assume more uniformity than what actually exists. In trying to put these reclaimed materials into soil series categories, I can see a lot of variation just based on things that we can see in the field (i.e., like depth or textural family), not even considering all of the factors that are not visually observable in the field. It seems that any attempt at classification would be much more difficult in non-glaciated geology.

Answer: Most of the areas we worked on in Illinois are glaciated. It is fairly easy to identify in the field whether you have Pennsylvanian (non-glaciated) or Pleistocene (glaciated) age materials. In our experience, the more glacial till material that was mixed in with the spoil the courser the soil texture. Glacial till soils tended to be more loamy in texture. Spoil materials, with a high proportion of glacial loess in the mixture especially northern Illinois, tended to produce a fine silty soil.

State Question ***(Classification Concerns About in Place Development of New A Horizon Material):*** Concerning your chart, I noticed you had a criteria of soil replaced or not replaced. What provisions are you going to have for soil A horizons that have developed in place and were not replaced in the reclamation process? As reclaimed soils without replaced topsoil develop an A horizon over time, how will this fit into your system of classification?

Answer: I don't think it matters so much *if* you have an A horizon develop in place. We are classifying them as Orthents. It is expected that they will follow a natural soil aging process and ultimately develop an A horizon and eventually a B horizon. At this point they will no longer be an Orthent and will have to be reclassified as Inseptisols. We have noted the development of A horizons in the field up to a depth of five to six inches. Although this can be recognized in the soil descriptions, I do not think this will make much difference in how these soils function in terms of agricultural uses.

OSM *Question* ***(Productivity Values and Tax Base for New Soils):*** Do you anticipate determining a range of potential productivity values for these soils? Would you expect this classification system to be used by county assessors in determining land values for tax purposes?

Answer: Yes we plan to do this as soon as Charles Hooks gives us the numbers. We do expect that eventually this information will be used by the county tax assessors.

4. Global Positioning Systems (GPS) and Site Specific Management Dr. Richard Barnhisel, University of Kentucky, Lexington, Kentucky

Academic Question ***(Calibration of Equipment):*** How often do you need to calibrate your equipment with actual grain test weights from the trucks?

Answer: From the yield monitor point of view, the most critical part of using a yield monitor for measurement of grain is calibration. I have a plot combine and we do not have the same mechanism that you would have in a large combine. We built a clean grain elevator in order to simulate the clean grain. That has not changed over time. In a standard combine, where the length of the chain increases with time you need to make adjustments by adjusting the chain at the bottom of the elevator and not the top. Farmers tend to go the other way. If you change it at the top you will mess up the calibration. It takes about five loads in order to get the AgLeader software yield monitor I use to work correctly. Green Star and MicroTrack only use one load. I have a problem with that because you might not have the same amount of variation from one field to the next. What I do is try to drive as fast as I can with the combine. At about 17 percent moisture in the grain, I can run at about 200 bushels/hour. Then I drive as slow as I can to get the next load. Then I try to get two to three loads at intermediate speeds. The software calculates a regression curve. This allows the monitor to compensate for varying rates of speed with the combine. Calibration is extremely important when using yield monitoring equipment in the field.

5. Illinois Reclaimed Soil Productivity: Restoration Techniques Gene Smout, CONSOL Coal Co., Sesser, Illinois.

State Question ***(Economics of Deep Tillage):*** I realize that in your operation you have shifted to soil replacement with trucks in recent years. From a purely economic point of view, is it economical to go ahead and do the full deep tillage to four feet rather than some type of intermediate tillage on less compacted soils replaced with trucks?

Answer: I don't know if I have the information to answer that question. What I can say is that we did a lot of penetrometer work before coming to the management practices that we have now. We looked at determining soil strengths pre-tillage. We did have wheel spoil at several of our mines and some truck haulage at others. We knew that we had soils that had been moved under a wide variety of circumstances including dry, wet, and frozen. We thought maybe we could use the penetrometer to save some money by using it to identify those areas where we would benefit from deep tillage Ultimately, we got our costs down in terms of tillage equipment to the point that deeper tillage was cheaper in many cases than intermediate tillage At that time, we decided to deep till all of our acreage so we would not have to worry about productivity. We felt that tillage less than 32 inches deep was less than adequate. Rather than worry about which equipment to use where, we can now apply one treatment to everything and don't worry about it.

State Question ***(Economics of Deep Tillage):*** Yesterday a question was asked about the cost of deep tillage with the DM II and a figure of $400/acre was an estimate. Would you find that to be a reasonable estimate of the cost?

Answer: I would think that would be accurate for some of the early stages of our work when we were leasing equipment and having contractors come in and do the work. Now by using our own equipment and manpower we are well under that figure.

OSM Question ***(Row Spacing for Deep Tillage):*** What is the distance between furrows with the deep tillage equipment that you use now?

Answer: The sweep is 44 inches wide and we are running on ***54*** inch centers. The right track of the dozer has to be up on the previous ripped rim. This leaves a V from the bottom of the plow of uncompacted material as the plow moves through the earth. On 54 inch centers, those V's overlap and leave a very small cone of compacted material between passes. Under ideal conditions that small cone will cleave off at the bottom as well. We feel that we are getting the best effect that we can from this type of application.

Academic Question ***(Duration of Settling on Reclaimed Areas):*** How long does differential settling continue on a remined area? How long would someone who wants to build a big shopping center have to wait to ensure that their foundations would be stable?

Answer: I don't have the answer to that one. Differential settling lasts for some time. It is a diminishing activity. Depending upon the type of overburden that you have, we will still see some pockets form five to six years after reclamation is completed.

6. <u>Land Use and Value after Reclamation</u> William R Phelps, ARK Land Co., St. Louis, Missouri.

State Question ***(Quantity of Permanent Program Crop Land Sold):*** Could you give us a ball park figure of how many acres of crop land that you have sold that has successfully demonstrated proof of productivity and completed the bond release process in Illinois?

Answer: We have not sold any of our best reclaimed crop land. My impression is that the value of crop land will be based on the actual crop yield that it is producing rather than what reclamation standard applied at the time of release.

State Question ***(Speculation on Future Prime Farmland Sales):*** ***Since you*** do not have any actual experience with selling significant quantities of crop land to farmers and most of your current sales emphasize the hunting aspects where soil quality is not really in question, could you speculate on what will happen when you actually start trying to sell reclaimed prime farmland as crop land to farmers?

Answer: I think you will see a lot of partnerships where a hunter and farmer will team up to buy the properties. I don't know if reclaimed prime farmland wilI ever achieve the original prime farmland values of undisturbed prime farmland. I think that people still have a stigma about mined land that would cause them to undervalue the reclaimed prime farmland. A lot of its value will depend upon the field configuration, the field size, its proximity to water, and the amount of non tillable acres that go with it. Many of these factors will overshadow factors related to soil capability.

State Question ***(Value of Subsided Agricultural Land):*** In Illinois, we like to think that land that has received mitigation after subsidence from underground coal mines is as productive after mitigation as it was before subsidence. Do you find that land owners still have the perception that it is of lesser value because it has been subsided?

Answer: *Yes* I do. The problem is that 70 percent of your buyers are from the local area and think of it as the Jones farm or the Smith farm. Most of the sales are in 100 to 200 acre lots. Is it the right size for a son or daughter to build a house on. With subsidence, you have limited the places on a tract of land that you can build a house and this does have a bearing on the market.

OSM Comment ***(Incorporating Post-mining Land Values into Reclamation Planning):*** I would like to see people involved with land sales get involved with the mine operator and reclamation planner so that the initial mine and reclamation plan could incorporate post-mining land values.

Answer: In order to maximize the post-mining land value, the reclamation plan should place the crop land next to water; put trees around the edge of the crop land so that the hunters can eventually set up their deer stands in the trees and hunt the area. Land values are based on what we know about how land is used now so these things should be set up the way they are perceived to be most valuable in terms of undisturbed land.

Interactive Discussion with all Speakers for Session 3

State Question ***(Acreage of Land that can be Deep Tilled per Year):*** How many acres can you deep till per year considering the seasonal window of opportunity for doing that?

Answer: Our budgeting considers between 600 - 700 acres per year as a normal season. The best year we ever had at CONSOL was about 750 acres in an ideal year.

State Question ***(Effects of Excessive Rainfall): Have you*** had a situation where, because of excessive rainfall, you decided it was not worth it to deep till in a particular year?

Answer: We usually stop some time in September or October because of the rain. It is usually more a consideration of what will happen to the areas that have already been deep tilled than the acres yet to be tilled. It becomes very difficult to get back on the area to get it ready for cropping.

State Question ***(Timing for Deep Tillage):*** How do make your decisions on when to begin deep tillage and when do you end deep tillage for a given year?

Answer: That comes with experience. Based on digging soil pits and determining if the stand of alfalfa is a strong or weak stand If you have had a vigorous stand of alfalfa on the area for three years, I am fairly confident that by the 1st of July we will be ready to go. But even then we dig a few soil pits and test the soil conditions. We normally reserve the right to stop the tillage contractor at any time or in any place if we don't think the soil moisture conditions are correct.

State Question ***(Land Value Related to Bond Release)*** : We find that our land acres under bond continue to climb. Do you carry land values on your books any differently for land that has been bond released as opposed to acres still under bond? Is there a point at which it becomes more economic to obtain bond release rather than leaving it under bond?

Answer: We try to carry the actual market value of the land on the books. We can actually market these lands before they are released and reserve the right to finish the bond release process. Prime farmland is harder to do than woodland because for woodland all you have to do is count trees.

Question ***(Compaction Mitigation with Deep Rooted Plants): Are there any native*** plant species that are particularly aggressive in dry situations in terms of penetrating the compacted soils other than the alfalfa and clovers that we already know about for the purpose of mitigating the compaction?

Answer: I would suggest that we wait for the next glacier. Clark Ashby has done some work with this at Southern Illinois University at Carbondale looking at woody species that have aggressive tap roots that could provide some mitigation of compaction. Normally for legumes you are looking at sweet clover or alfalfa. Clark Ashby has also looked at some of the deep rooting warm season grasses. But my point earlier is the time factor in terms of how long are you going to hold reclamation bonds on these areas waiting for them to meet the performance standards.

Answer: We have had a study in Kentucky where we looked at black locust trees, alfalfa, soybeans, fescue, and sweet clover. We found that black locust, alfalfa, and sweet clover were the best at loosening up the soil. On the black locust trees, we planted them very thick and brush hogged them every year. After two years we plowed up the areas and we did see a benefit to all three of these species as compared to continuous corn. Fescue and a wheat rotation was intermediate in effects. We also found an additive effect of ripping and cross ripping in combination with planting of deep rooted species.

State Question ***(Effects of Prime Farmland Reclamation on Tree Growth):*** One of the purposes of SMCRA is to restore the pre-mining land uses and soil capability. Is 48 inches of soil material necessary in all cases to restore pre-mining levels of soil capability for prime farmland soils in the Illinois basin? If prime farmland soils under SMCRA are replaced with the minimum soil depths and minimal compaction, is that a deterrent to tree growth?

Academic Answer: It is necessary to restore a minimum of 48 inches of soil material to restore prime farmland soil capability. I would answer the second question by saying that improper reclamation of prime farmland soils is detrimental to growing trees. Improper reclamation of prime farmland soils in a row crop application is also detrimental to trees. If you have a highly productive soil for crop land uses you will also have a highly productive soil for forest uses.

Industry Answer: The deeper we rip our soils at our mines, the farmers at our mines say that the productivity is better with the deeper ripped soils. They handle drought better and we have better crop success on these areas. Deep tillage at 40 inches is better than tillage at 36 inches. Our yield data would support this.

Academic Answer: In Kentucky, we have studied the effects of soil depths in a prime farmland situation over several years. If you are only going to grow wheat, about 18 inches of soil materials will produce the quality that you need. If you are going to produce soybeans or alfalfa you may only need two to three feet of soil materials to produce the quality you need. Three feet of soil material was not enough to grow corn productively even when the spoil material under the replaced soils was good material. We only looked at soil depths up to four feet, but at that depth we were able to get the crop production necessary to obtain bond release.

Academic Answer: Some of the soils that you mentioned have a significant rooting problem in their natural subsoil. Whether or not three feet of replaced soil materials would meet productivity levels, I don't have any data on that. However, looking at yield response of corn to depth of rooting media replacement for tillage alleviation, we are still on the curve going up in terms of soil depth. There is a considerable advantage to crop yield between three and four feet of soil depth related to rooting volume.

State Answer: I would take a simplistic approach. We have to grow corn in Illinois and corn is a deep rooted crop. I think that we need four feet of soil material. As far as the effects of soil depths related to tree growth, I would see that more as a compaction problem rather than a soil depth problem.

Consultant Comment: I would like to make a comment on the growth of trees. I have not seen where minimally graded soils pose a detrimental factor to trees as apposed to minimally graded spoils.

Session 4: Subsidence

1. <u>Characteristics of Subsidence from Abandoned and Active Undergound Coal Mines in the Illinois Coal Basin</u>
   Robert Bauer, Illinois State Geological Survey, Champaign, Illinois

Academic Question ***(Evidence for Sag Subsidence):*** If you are a land owner, with a farm that has a lot of wet bottomland, with a series of drainage ditches because you need to provide adequate drainage for crop production, and you suspect that there is sag type subsidence because the property has been underground mined, what evidence can you use to prove that you have sag subsidence as apposed to poor maintenance of your drainage ditches?

Answer: We have natural depressions on the Illinois landscape that have the same characteristics as sag subsidence. First, there may be some historical information or even aerial photography that would show that there was no depression features previous to mining. We will then map the sag features and place that over the mine map to see if it fits over the production panel. You can't look at an aerial photograph and look at every sag or depression feature you have on the landscape because we have a lot of them that are naturally there from past glacial actions.

OSM Question ***(Evidence of Subsidence):*** How can you tell if the features are actually caused by underground subsidence?

Answer: The sags are fairly large. They are usually hundreds of feet across with a maximum of two to four feet of downward movement. We do not find that normal soil settling will create a sag like this. I have been to farmers fields where the farmer points out 12 subsidence events. Upon investigation of the mine map, I will find that only three of them have been underground mined. The rest of them were natural depressions from when the glaciers were here.

2. ***Coal*** Mine Subsidence/A Regulatory Perspective Dan Barkley, Illinois Department of NaturaI Resources, Springfield, Illinois

State Question (Biggest Subsidence&litigation Challenges): What is the biggest challenge for subsidence mitigation from a regulatory perspective?

Answer: I think the biggest challenge is dealing with the surface owners that have subsidence problems. It can be very difficult in dealing with what they believe they have coming to them in terms of subsidence mitigation compensation. The contrast is between what the regulations require and their perception of the high standards that they have. In general, I think that mitigation has gone very well in the State. There are very few problems. Sometimes in the flatter areas we will have more problems than in rolling terrain where we have drainage. I have yet to see something that the companies have not been able to achieve in terms of mitigation.

State Question ***(Effects of Energy Policy Act):*** What is your impression of the positive or negative effects that have occurred with the new regulations under the Energy Policy Act?

Answer: There are some very positive things that has come out of the Energy Policy Act. There are some things that I think will need work in the actual implementation of the Act. The goals of the regulations were appropriate. Some of the mechanics to achieve those goals can be an implementation problem that we will have to work out over the next few years. We have been successful in this program in the past and I think we will have similar success in the future.

Academic Question ***(Coal Production Trends): You started your*** presentation with slides of the production of coal over the past few years, do you have any idea of what coal production is going to be doing over the next 10 years especially concerning increased long wall mining?

Answer: Although I have heard a lot of speculation, the problem we are dealing with is the Clean Air Act and what it has done to our higher sulfur coal. I expect the trend to continue toward underground mining. In the long run, once the dust settles from the clean air legislation, and every one gets on the same playing field, I think that Illinois coal production will begin to rise again. I think that long wall coal production will be a major part of that.

Academic Question ***(Evidence of Subsidence):*** What evidence does a home owner or landowner have to show that damage is a result of subsidence rather than poor structural design or natural sinks on their property?

Answer: With structures, planned subsidence mines are required to do pre-subsidence surveys. We feel that it is best to do those surveys within a short period of time prior to the actual mining. These surveys are the basis for our determining damage from mine subsidence. With land damage, it is a little more complicated. We will take pre-mining contours of the land and project post-subsidence contours in all permits that do long wall mining and high extraction retreat mining. They are expected to delineate where drainage problems are expected to occur. Then they must describe how they are going to mitigate these drainage problems. We have a feel for where we are going to have problems based on this mapping prior to the mining taking place. It is very uncommon for the mine to respond that the drainage is not their problem. Usually mitigation works out well between the land owner and the company.

For abandoned mines, the mine subsidence insurance fund is a private entity. They are regulated by the state, in the sense that it is a legislative act that created them, but they investigate on their own and no state agency goes out to investigate these claims. They have their own experts that monitor based on the types of damage and they monitor over time to see if they can pick up any downward trends in terms of movement. The state abandoned mine land program would only get involved if there is a public safety issue.

3. Impacts of Mine Subsidence on Ground Water Colin Booth, Northern Illinois University, Dekalb, Illinois

State Question ***(Destination of Ground Water): You*** indicated on the Saline County Site that there was recovery because it was cut off from its recharge. That water is going some place. Where is this water going?

Answer: First, the water level in the affected area is dropping. You have the same amount of water filling up a larger fracture space so that the water level drops. Outside of that area you may have some potential for recharge water flowing in but it will only flow in if there are permeable pathways. In the Jefferson county case, there seemed to be continuous pathways for that water to get into the affected aquifer. I think that is what you will see in most cases with reasonably productive aquifers. In the Saline county case, where you had a very poor tight aquifer, it may take 15 years for that to recover. The continued activity of the mining itself is blocking off that flow path as well.

State Question ***(Time Frame for Taking Background Water Data):*** Concerning the water replacement requirement of the regulations, what would be the appropriate time, for a long wall/ high extraction retreat mining operation that may affect a well or spring in terms of the time frame, to get good ambient background water quality data. Would it be best to obtain this information one year in advance of the long wall operation or five years or ten years.

Answer: Looking at the sites we have investigated, you start to see the effect of mining maybe a few weeks in advance of the actual mine face approaching. If you had no mining at all at the site, you should be getting some pretty good ambient water levels over the previous year which should give you the seasonal variation. At the first site I discussed, the initial water levels in the sandstone water aquifer were around 60 to 65 feet below ground and were probably already depressed by 20 feet or so because of mining of the earlier panels nearby. Ideally we should have been taking water levels probably two years in advance.

State Question ***(Time Frame for Taking Background Water Data):*** What problems would you see with taking water data five to ten years in advance of the mining operation?

Answer: The potential problem you would get in that situation would be if something else had happened after the data had been collected but before mining begins. If you have a representative natural water level and it was not taken in a drought year, providing something else has not happened, that should be the representative ambient level. I would be a little concerned about the addition of a pumping well starting up near by or changes in the hydrologic regime due to adjacent mining. You need to look at each site individually to see if there is any intervening stresses taking place.

OSM *Question* ***(Water Treatment Costs):*** You made a statement that on one of the aquifers the dissolved solids in the water was treatable. How much would it cost to treat this water?

Answer: I think the top line treatment systems can treat water up to about 3,000 milligrams per liter. I really don't know what the costs would be.

4. Reclamation of Agricultural Land After Planned Coal Mine Subsidence Dr. Robert Darmody, University of Illinois, Urbana/Champaign, Illinois

Consultant Question ***(Remapping):*** Do you see any effort in the future to remap these subsided soils?

Answer: I think the easiest way to handle that would be for the Natural Resources Conservation Service to use a spot symbol. Most of these very wet areas are around two acres or less. That is about as much detail as you can show on a soils map anyway. What they have done in some counties is to dash out the mine panel where they can show up on a topographic map. Generally, I would not vote for a new soils series but call them wet spots within a given soil series. The soil series should behave fairly uniformly with the exception of that low wet area.

Public Question ***(Damage to Houses): You talked*** about raising these houses to prevent structural damage. I saw a horror story from Pennsylvania recently of 33 houses splitting half in two from long wall mining. Does most long wall mining take place in rural areas or in residential areas where there would be more houses?

Answer: I can tell you what I have seen. If the coal companies are required to repair or mitigate damage, they are not going to mine where the costs are too high.

Answer: The Pennsylvania law is different than the law in Illinois concerning subsidence damage. They have provisions that are based on the age of the structures while in Illinois the age of the structure is not a factor.

Question ***(Diffences Between Corn and Soybeans):*** You showed that the corn was lower than soybeans, is this from the compaction with equipment?

Answer: ***One*** place where corn is different from soybeans is that corn is a determinate crop. There is a very small window of opportunity where everything has to be right in order for the yield to be maximum. If things are off during the two week period when it is silking things will not turn out like they should. Soybeans are indeterminate, they grow throughout the year and can take advantage of good and bad weather. So you are really seeing a difference in physiology. In most cases, this is due to water. On sites that have been mitigated, the ones that were bad were just not mitigated well enough.

OSM Question ***(Tiling of Wet Areas)*** : Have you seen any cases where the mitigation included tiling of the wet areas to lower the water table?

Answer: Generally, water control in Southern Illinois, because of the clay pans, is on a surface drainage ditch basis. One of the problems with mine subsidence is that if you do have drain tiles, they will run backwards as the area subsides and will make the situation worse. The area I have worked in is not suitable for tiling. Tiling could work if you had the right soils.

Interactive Discussion with all Speakers for Session 4

State Question ***(Correlation Between Subsidence and Depth of Mining):*** We have a lot of citizens that call us in Southern Illinois where the coal is quite shallow (withing 30 feet of the surface). After a heavy rain over the weekend we need to check the telephone recorder to see who called. Do you see any correlation between depth of coal and subsidence?

Answer: We usually tell people from this ares that if the coal is deeper than 200 feet we really don't expect to see much pit subsidence.

Answer: We have seen one where the subsidence was from 300 feet, but its not the depth that controls the subsidence but how much and what type of rock is above the coal. The thing that develops the pit subsidence is that a roof fall develops up through a shale type material and then it intersects the glacial material and soil. This then falls into the void.In the case where we had the mine that was 300 feet deep, we only had about 20 feet of roof rock with the rest being looser materials. In the cases where we have a limestone layer above the coal that is about two feet thick, the roof fall does not go past the limestone. We had one town in Illinois where we had pit subsidence in half of the town but not in the other half. When we drilled the sites, we found that where the pit subsidence was occurring, there was no limestone above the mine. Where there was no subsidence there was a one foot limestone layer above the mine. This is why it is hard to make a general rule correlating overburden depth with frequency of subsidence.

STATE PROGRAMS

- Caparison of state programs in other topic areas.

OVERALL VALUE OF FORUM

	TOTAL PERCENTAGE
EXCELLENT	53
GOOD	47
FAIR	0
POOR	0

COMMENTS ON VALUE OF FORUM:

- **Excellent presentations!**
- **Great information meeting!**
- **Good content and organization in all sessions!**
- **OSM Director Kathy Karpan's comments were very good!**
- **Excellent format! Very informative! Excellent questions from participants!**
- **Provided very informative information. Encompassed all affiliations to show all sides of reclamation. Displayed the applied technology in current mining operations**.
- **This was the most useful conference I have been to since getting into the field nearly 4 years ago! I especially liked seeing what other states do and how to eliminate or ameliorate compaction! Very helpful!**
- **This forum has been well worth my time to attend. My knowledge of this information was very low but I believe I am going away with a better working knowledge.**
- **The forum was perhaps the best for providing me the information I can use immediately in the course of my job duties.**
- **Had excellent speaker and audience participation!**
- **Good speakers who were well prepared!**
- **Enjoyed the forum very much. A good review and overview. Good to see what is happening in other states.**
- **Really good mix of topics.**
- **Although there were differences of opinion, all topics were professionally and factually handled. Moderators kept the flow going smoothly.**