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Project Summary

Planning Study to Model and Monitor Coal Pile Run-Off

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This report describes a planning study for predicting and monitoring the hydrologic and chemical characteristics of drainage from the open storage of coal with focus on the developments of a mathematical model. The project report contains four main sections: 1) The results of a questionnaire survey of members of the Edison Electric Institute in which recent information was gathered concerning coal pile characteristics and coal pile run-off treatment systems, 2) a report on the development of a coal pile drainage model with both hydrologic and qualitative components, 3) a detailed field program with work plan which itemizes those tasks necessary to describe the physical, chemical and hydrologic characteristics of a coal pile, the meteorological conditions relative to that pile, and the framework for conducting an intensive run-off sampling program, and 4) a field procedures manual which details all the steps necessary to monitor coal pile run-off from the training of field personnel to the analysis of run-off samples. This field program will be used to gather data for calibration and verification of the model.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC to announce key findings of the research project which is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In August 1979, TRC Environmental Consultants, Inc. began Phase I of a multiphased effort to predict the quantity and quality of coal pile run-off from utility sites by development of a verified mathematical model. This predictive tool will be used to design collection and treatment facilities for coal pile run-off without use of arbitrary and often overly conservative storm frequency parameters. In addition, the resulting pollutant loads, under different precipitation events, can be assessed.

Phase I began with a literature search and industry survey to research the desired capabilities for the model, review the most recent developments in treatment and characterization of coal pile run-off, and assess the theoretical research in quantifying and qualifying coal pile run-off. Based on the information gathered, TRC developed a preliminary model structure able to predict both volume and quality of drainage from any coal storage area. Along with the model format an outline was developed for the field monitoring program and data collection procedures which will provide input as well as verification data to the model.

Utility Industry Survey

To compile recent (1979-1980) information necessary to both plan a field study and develop a predictive model, TRC designed an independent poll of coal-burning utilities owning plants with a generating capacity greater than 25 megawatts (MW).

TRC received completed or partially completed questionnaires from 81 one plants with a total of 109 bituminous coal piles.

Data was tabulated using a total of 81 responses. From the data received, mean plant operating characteristics, coal pile characteristics, and treatment methods were determined. A list of the parameters tabulated is given in Table 1.

Coal Pile Drainage Model Development

Initial Model Research

In 1977, TRC completed a monitoring and modeling study of non-point sources at two coal-fired utilities. In this program, TRC utilized the Short Stormwater Management/RECEIV-II Model (SSWMM-RECEIV-II) to address sheet wash-off from coal storage piles. At the completion of this modeling program a number of shortcomings in the SSWMM-RECEIV-II Model were identified. For example, the model could not address:

- storm erosion of material from the coal storage pile
- stormwater percolation through the coal pile
- pyrite oxidation/acid production in the coal pile.

It was decided to try to include these aspects in a newly developed coal pile drainage model.

In addition to the industry survey, TRC undertook a literature search of coal pile drainage. In this search, TRC determined what physical/chemical phenomena associated with coal piles would be valuable in characterizing coal pile drainage in a modeling effort. The phenomena researched can be divided into quantitative and qualitative aspects.

Table 1. *Parameters Tabulated In Project Report*

Sulfur and pyritic sulfur content of active and reserve coal piles
Sizes, densities, heights, and slopes of active and reserve coal piles
Active and reserve piles with multi-state coal sources
Percentage ash and moisture in active and reserve piles
BTU values of active and reserve coals
Generating capacities of responding utility plants
Percentage of coal usage
Types of coal pile construction bases
Treatment methods used for run-off and year of system start-up
Design storms and run-off coefficients used in system design
Number of plants treating specified chemical parameters

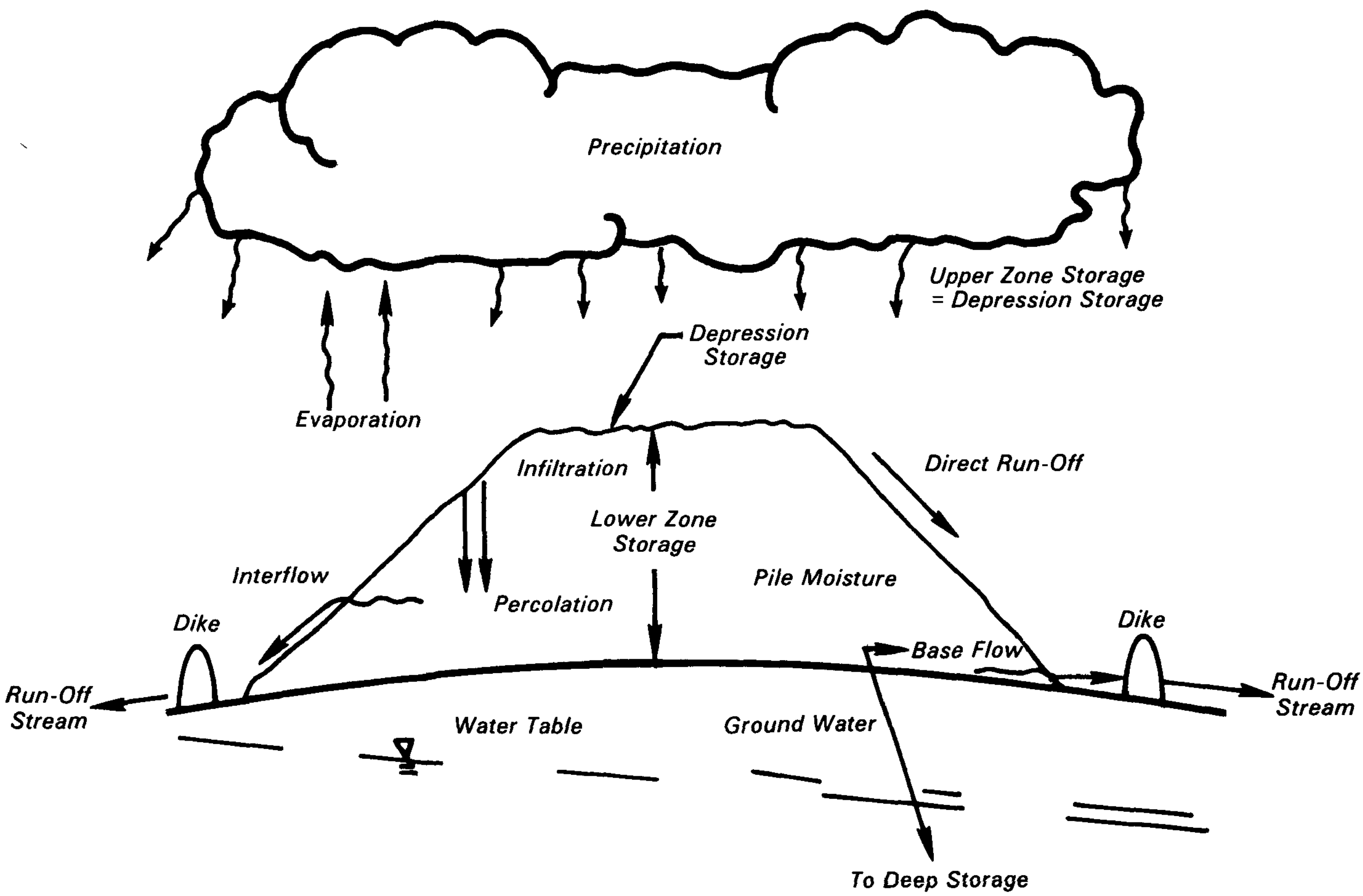

Figure 1. *Schematic of hydrologic cycle of coal storage pile.*

1) Quantitative
   a) Precipitation (rain/snowfall)
   b) pile surface run-off/infiltration
   c) percolation through the pile
   d) snow-melt
   e) infiltration into ground water beneath the pile
2) Qualitative
   a) oxidation of pyrite in coal, production of acid
   b) freeze/thaw of coal to expose surface areas
   c) erosion of gullies down the sides of the coal pile
   d) wash-off of pollutants from surface of the pile

Few models have been developed to describe industrial stormwater run-off situations and none have been developed specifically for material storage piles. The existing run-off models were researched to ascertain which one could best be utilized as the basis for the coal pile drainage simulation effort.

The Ohio State University (OSU) version of the Stanford Watershed Model was selected as the base model. The OSU model simulates overland run-off in a rural area. TRC also used the OSU co-model for acid production in coal refuse piles as the basis for the qualitative modeling work.

A number of modifications were made to the OSU models to make them applicable to coal storage piles. The physical/chemical reactions included in the models are described in more detail in the project report. In addition, the models were altered so that a standard NOAA magnetic tape of historical meteorlogical data can be utilized as data input instead of requiring the user to create his own data file.

The resulting TRC coal pile drainage model is actually two models - a hydrological model, termed TRCH2 O, and a qualitative model, TRCCOAL.

Quantitative Model - TRCH2 O

The TRCH2 O model reads hourly precipitation data in the form of rain or snow from the input meteorological tape. The phenomena of direct infiltration, gully erosion, delayed infiltration, direct run-off, snow accumulation, and snowmelt are hydrologic surface reactions to precipitation. The relationship is shown in Figure 1.

The amount of rainwater which immediately enters the pile is known as direct infiltration. It is dependent upon input factors of pile moisture and pile moisture storage capacity as well as time and adjustment factors. Some rainwater is retained by depressions in the coal pile surface and this infiltration is delayed. The depression storage is considered to be the upper zone of the coal pile. The amount of depression storage on the pile surface is estimated by the model user. The entire coal pile is considered pervious.

The rainwater which does not infiltrate into the coal pile becomes direct run-off. The Chezy-Manning equation for turbulent flow was utilized in the model to derive this relationship. Input variables are slope of the coal pile, length of the slope, and roughness coefficient.

In addition to rainwater, the model considers the effect of snow on the coal pile. The model reads the meteorological tape and determines the amount of snow which falls on the coal pile. The snow pack accumulates over time, and snow is converted to its liquid component by snow-melt. In this model snow-melt is estimated by the air temperature above freezing and a degree-day melt factor. Once snow is melted, it is handled in the model as rainwater for infiltration and run-off purposes.

The impact of rain on the coal pile causes solids to erode and creates gullies on the side of the coal pile. Using measured data on pile slope, length, and rain intensity, as well as erosion coefficients, the model calculates the pounds of coal solids moved to the base of the pile per day during a day with rainfall.

The moisture which percolates from the upper zone of the pile is stored in the lower zone. Some of the moisture erupts from the side of the coal pile and is termed inter-flow. In addition, some moisture percolates through the pile to the ground water. The amount of rainwater which emerges as inter-flow is proportional to the amount of rainwater which infiltrates from the surface, and the current in-pile moisture storage.

While some water is retained in the coal pile, some infiltrates into the interface that consists of the layer immediately beneath the coal pile. For the purposes of the model, moisture in this layer is termed ground water, and moisture below the interface is deep storage. The moisture in the ground water can be routed to deep storage or emerge from the base of the pile as a flow stream. The amount of seepage or base-flow from the pile is dependent upon the ground water storage, the ground water slope, and flow recession constants. Infiltration into the ground water increases the slope and the resulting base-flow emerging from the coal pile.

Percolation to deep, inactive ground water storage or ground water flow out of the basin is modeled by allowing a fixed portion of inflow to ground water storage to bypass the active storage that contributes to base-flow.

Qualitative Model - TRCCOAL

Qualitatively, during dry weather the surface of the coal pile undergoes the physical/chemical processes of pyrite oxidation: acid, iron, and sulfate production as well as the dissolving of trace materials. During wet weather these materials are washed off the surface and out of the interior of the coal pile. Seepage is generated during both wet and dry weather. These phenomena are simulated in TRCCOAL using the hydrologic balance developed in TRCH2 O. The block diagram for TRCCOAL is shown in Figure 2.

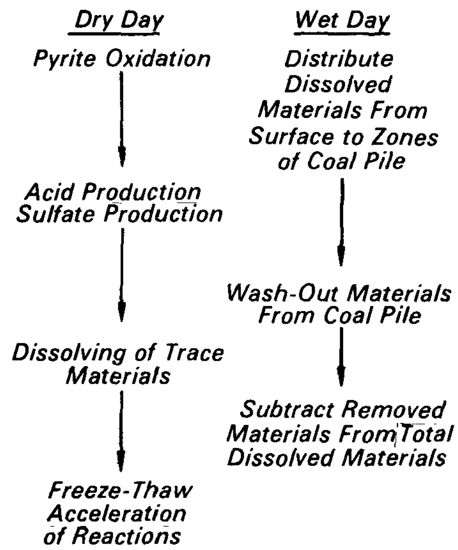

Figure 2.
Block diagram of qualitative model for coal pile drainage.

During non-rainfall periods the coal pile is subjected to atmospheric conditions which break up the coal lumps and the moisture and oxygen in the surface of the pile cause oxidation of the pyrite in the coal. The products of pyrite oxidation are acid, sulfates, and iron. The acid further acts to dissolve trace materials.

In TRCCOAL the user inputs data on coal characteristics and reaction rates. The model simulates the total amount of pollutants in the coal and the total amount of pollutants in a dissolved state during a dry weather period. The number of freeze/thaw cycles calculated in TRCH2 O is used to simulate the breaking up of coal and the subsequent pyrite oxidation in TRCCOAL. The dissolved material is then available for wash-off during the next storm event. Also during dry weather, the model simulates moisture being emitted from the lower zone as seepage.

The model conducts a wet/dry test to determine if the wet weather mode of wash-off or the dry weather mode of acid production, and seepage will be utilized for a given day. If the total rainfall is less than 0.1 inches, then the model considers it a dry day and only acid production and seepage generation takes place.

During wet weather, rainfall entering the pile distributes a portion of the dissolved metals, sulfates, and the acid on the surface to the interior of the pile and to direct run-off. In addition, the acidity of the rain is added to the available acid in the pile. The amount of pollutants that is distributed to the upper zone (depression storage), lower zone (pile interior), direct run-off, and inter-flow is proportional to the solubility of the pollutants and an adjustment factor. The material stored in the lower zone is further distributed to deep storage and the base-flow.

The amount of acid, metals, and sulfate in storage zones that is washed out of the pile can be linearly or exponentially related to the available material. EXPO-1 simulates an exponential decay rate. This relationship is best demonstrated by the "first flush" effect and considers the removal of both dissolved and suspended material. The transport of suspended solids is simulated either by the exponential wash-off function in TRCCOAL or by the erosion routine of TRCH2 O, but not both.

Input and Output of Models

The input data required by TRCH2 O consists of a card deck of site specific parameters, a magnetic tape of meteorological data and a card deck of data for the plotter. TRCCOAL uses the output disk file of hydraulic data created by TRCH2 O and a small card deck of qualitative site specific parameters. The output of the coal pile drainage modeling effort is the simulation of daily, monthly, and annual run-off flows and loadings of pollutants such as acid, iron, sulfate, and trace metals. In addition, there is the optional output of detailed storm events with subhourly flow and loadings. Figure 3 is an example output plot showing run-off flow and acid loadings for a three-month period.

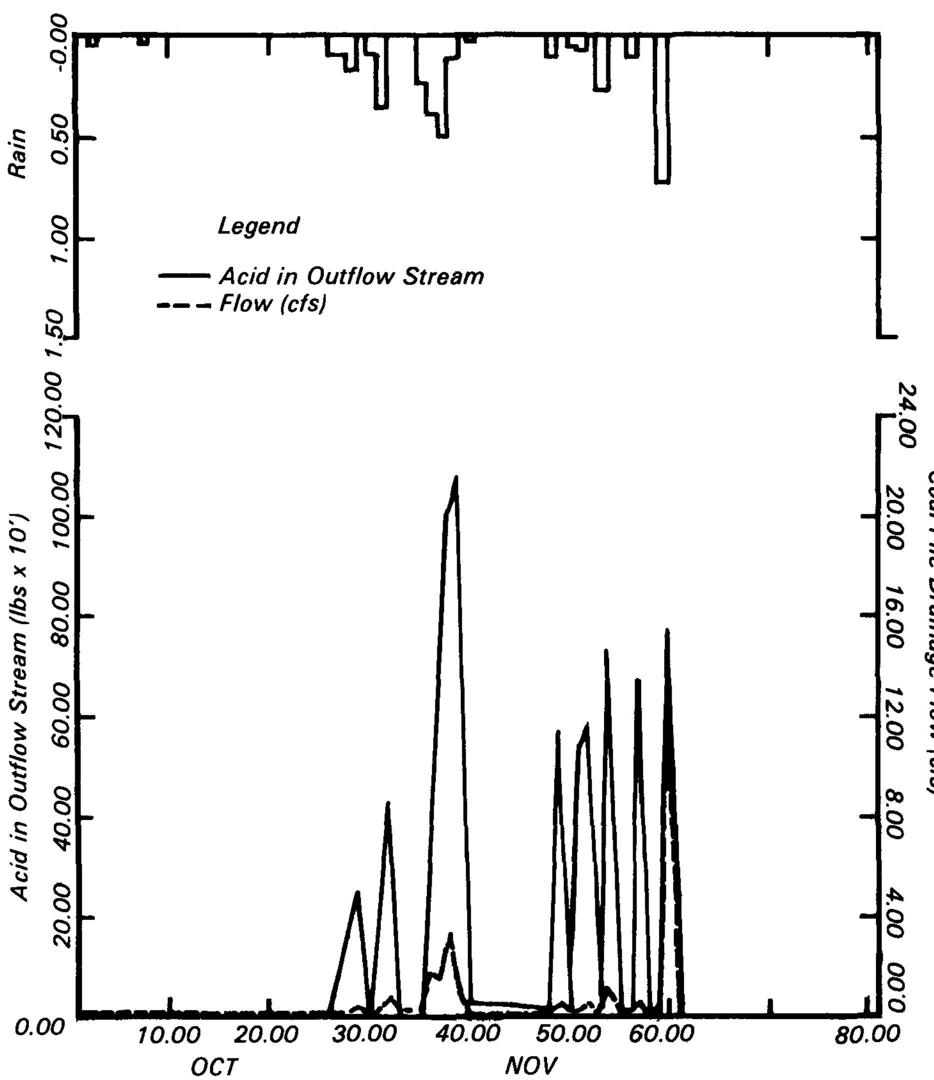

Figure 3. Example output plot- acid

Following preliminary model development a sensitivity analysis of selected input parameters was conducted. In TRCH2 O the most sensitive parameter analyzed was the infiltration parameter, CB. Increasing the coefficient CB, increased the pile moisture and significantly reduced run-off flows. For the qualitative model the most sensitive parameters were those dealing with the wash-out of pollutants during wet weather, not the accumulation of dissolved pollutants in the pile.

The report also discusses, in detail, limitations of the coal pile drainage model as designed. For example, the hydrologic model, TRCH2 O, concerns the flow from one run-off drainage point from the coal pile under consideration. When there is more than one run-off stream, the simulation must be run multiple times. In addition, the modeling of snow-melt is an approximation based on limited input data.

Field Work Plan and Procedures

In order to obtain representative data to modify the model as well as to generate a data base for study purposes, a well designed field program must be carried out. As part of Phase I the proposed field program strategy and procedures were outlined.

The field program is divided into two phases and is based on monitoring coal pile run-off from 12 different coal fired utility plants. The selection matrix of 12 sites is based on testing 3 sizes of generating plants and 4 coal sources representing different coal characteristics.

The first phase of the field program will involve sampling two medium size plants, one using low sulfur coal and one using high sulfur coal. These sites will serve as "test" sites to fine tune sampling procedures and modify and calibrate the mathematical models. The sampling program at each "test" site will be approximately 10 weeks duration.

The remaining 10 sites will be used to test the run-off model for a variety of climatic regimes, coal pile configurations, and coal characteristics, as well as to generate a substantial data base on coal pile run-off.

All data collected in the field will be put in a form which is compatible for use in the run-off model. In addition, this data will be digitized and made easily accessible through magnetic tape. The data tape will contain information on site description, meteorological conditions, run-off flows and pollutant loadings as well as statistical summaries.

The field program plan detailed in the report, addresses the following components:

1) Selection of 12 utility sites.
2) Initial site visit including background data acquisition. Examination of pile run-off streams and existing weirs and flumes.
3) Preliminary work, including acquisition of coal samples, and coal pile and ground water testing.
4) Laboratory testing of the coal samples to determine variability.
5) Choice of pollutant parameters for analysis.
6) Determination of sampling frequency.
7) Selection of sampling, flow monitoring and meteorological equipment.
8) Development of a plan for shipping samples for analysis.
9) Laboratory analysis of the run-off samples.

The sampling strategy will reflect greater frequency during wet weather periods than sampling during dry weather seepage. Sampling will also represent the 2-hour, 4-hour, 12-hour, and 24-hour frequency storms.

Two other uses for the field data will be to form a referral bank for utility use and to develop simpler tools, such as nomograms, charts, and/or tables to assist those without computer resources in designing treatment for coal pile run-off.

The field program at the 12 utility sites should take 2-3 years to complete.

Recommendations

The collection of coal pile run-off data should begin soon at two test sites. This data will be used for model modifications and calibration.

Following model verification, the model can be used to simulate run-off using local site specific data. Initial runs should be made with several days of precipitation data. Following any parameter adjustments simulations can be run for several years of historical meteorological data or a specially formulated design storm.

Conclusions

From the survey of EEI member utilities it is apparent that, in order to meet the effluent limitations for pH and suspended solids, most utilities have incorporated treatment for run-off from coal piles. In fact, from the questionnaire, it is shown that 85% of the plants responding have some form of treatment. The design criteria for collecting the coal pile run-off for the majority of plants is the 10 year, 24-hour storm taken from either local data or the National Weather Services Technical Paper #40. This design storm is an arbitrary parameter used by many states without regard to the dynamic nature of coal pile run-off. It appears from the survey that most utilities are relying on such rudimentary techniques to design a coal pile run-off treatment system.

The coal pile drainage model, after calibration and verification, can become an effective tool to design collection basins and treatment systems. For example, it may be possible to collect and treat only the first flush of the storm run-off with higher level of contaminants and discharge the subsequent "clean" run-off which meets NPDES limitations. Using historical meteorological data or simulated storms the model could be used to determine when the transition from collection of run-off to bypassing of run-off could take place during a storm event.

The quantitative and qualitative models in this program must now be calibrated and verified by a field data program.

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***D. B. Harris** is the EPA Project Officer (see below).*
The complete report, entitled "Planning Study to Model and Monitor Coal Pile Run-Off," (Order No. PB 81-152 530; Cost: $17.00, subject to change) will be available only from:
National Technical Information Service
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