QUAL II SIMULATION ANALYSIS FOR TREATING ACID MINE DRAINAGE PROBLEMS IN THE MONONGAHELA RIVER BASIN

Thomas E. Holland
Donald L. Gochenour, Jr.
Alfred W. Pappano

ABSTRACT

A computer simulation model to examine wasteloads (active mines, inactive mines and industrial wasteloads) and their effects upon river quality was used for evaluating acid mine drainage treatment alternatives, because of reduced costs, and no hazards of adverse environmental impact due to the treatment itself. The QUAL II simulation program was chosen as best for the needs of this study because it has been used successfully in other areas of the country which had similar river basin characteristics.

A data base containing information on the current state of the Monongahela River (West Virginia) study basin (with respect to needed parameters about water pollution sources, river flows, hydraulics - such as slope, Manning's Coefficient, etc.) was also developed to complement the simulation model. This data base was used to give a complete picture of the environment with respect to the river basin being studied. The information in the data base was constructed in such a way as to facilitate its use in both statistical studies as well as input to the QUAL II program.

Using information from the data base, the effects of various acid mine treatments were provided as output from the simulation program. The wasteloads (acid mine drainage locations or other types of industrial or municipal wasteloads) were "treated" by a particular type of treatment in a subroutine that modeled the alternative. The "treated" wasteloads were then input to the simulation program and their simulated effects printed out.

This approach has proven to be a low cost, highly flexible, low risk method of evaluating secondary impacts of types of treatments for controlling acid mine drainage. As an extra benefit, it provides a method for determining the most appropriate locations for treatment facilities.

INTRODUCTION

With increasing concern in the United States about the environment, more and more attention is being directed to the effects of man's progress on nature. While everyone, including government, business, and the public-at-large, is guilty of pollution, of primary concern are the effects of different industrial wastes on the land, air, and water resources. This stems from the fact that industries discharge the largest volume and most toxic of pollutants (1). Realizing this problem, President Nixon, in his State of the Union message in 1970, said, "The great question of the 70's is: shall we surrender to our surroundings or shall we make peace with nature and begin to make reparations for the damage we have done to our air, to our land, and to our water?" In addition, Senator Edmund Muskie has pointed out that "In the past, we had to fight against all kinds of political pressure, public apathy and ignorance. Now the wind is blowing at our back." (2).

Experts estimated in 1970 that it would cost nearly $100 billion dollars in the next five years (1970-1975) to prevent the U.S. from becoming a wasteland (2). This estimate can only be raised upward as inflation coutinues. The cost of curbing air pollution in the U.S. was estimated to be around $60 billion for a five year period beginning at the same time, and water pollution clean up costs were set at between $30-$50 billion.

The U.S. produces almost 50% of the world's industrial pollution. "How to Remove Pollutants and Toxic Materials from Air and Water - A Practical Guide" by Marshall Sitting, Noyes Data Corporation, takes 620 pages just to list condensed information on patented methods for preventing everything from acetone cyanohydrin to zinc smelter effluents from polluting the environment. Industry, by comparison with government and the public at large, has a relatively less expensive problem on its hands. The same experts that estimated $100 billion for municipal and governmental cleanup programs, gave an estimate of $600 million a year to clean up sulfur dioxide emissions and other air pollutants. They also predicted it would cost $3 billion to treat wastes to meet water quality standards, $2 billion to handle thermal pollution, and $6 billion to bring sediment and acid-mine drainage under control.

WATER POLLUTION IN THE APPALACHIAN AREA

Tourism has even been affected in the Appalachian states due to acid mine drainage reaching the water table level, affecting drinking, industrial, and recreational water sources. About 60 percent of the mine drainage pollution problem is caused by mines which have been abandoned. Mines that have been idle for 30 to 50 years may still discharge large quantities of acid waters. The total unneutralized acid drainage from both active and unused coal mines in the United States is estimated to amount to over 8 million tons of sulfuric acid equivalent annually, roughly one half of which is neutralized by natural alkalinity in mines and streams. In Appalachia alone, where an estimated 75 percent of the coal mine drainage problem occurs, approximately 10,500 miles of streams are reduced below desirable levels of quality by acid mine drainage.

Processing and treatment facilities also contribute to pollution by indirect means. For many minerals, such as phosphates, the pollution from processing operations exceeds that resulting directly from the mining operations.

While more than one method of treatment of acid mine wastes exists, the most common method is to use lime to neutralize the acid. Even this method has potential drawbacks to its use, one of which is the possibility of increasing the hardness of receiving streams to such a point that industries incur problems in using the water.

In order to provide information on water quality and locate possible violations of standards, the Environmental Protection Agency (EPA), as well as other state and federal agencies, have monitoring stations to measure water quality located in various places along many of the rivers of the United States. They have developed a computer storage and retrieval system for the information which has been in use for several years. This information is open to any who need it and when completed, should provide the federal government a much better picture on the extent of pollution in the entire country. Unfortunately, for various reasons (such as lack of manpower or no established standards as yet on some pollutants) these data are sketchy and incomplete.

Another important aspect to consider is that measuring water quality, while it provides needed and useful information, still provides information about a treatment's effectiveness only after the cost of putting the treatment into effect has been incurred. A means of evaluating the primary and secondary impacts of controls and treatments before their implementation is badly needed.

PREVIOUS STUDIES

More than one technique has been applied to try to solve this very problem. The methods have ranged from actual construction of physical models of a system, to analytical or mathematical models, and finally to various computer modeling schemes.

A physical prototype procedure for river modeling was used in 1963 when the U.S. Corps of Engineers developed and constructed a physical model of the San Francisco Bay.

Streeter and Phelps (1925) modeled the Ohio River through analytical methods by using "plug in"flow first order reaction equations. The Thames River was modeled using a probabilistic approach in 1964.

FWQA (Dr. Gerald T. Orlob largely the developer) modeled the San Francisco Bay two-dimensionally in 1968 by a junction method that included the effects of tidal motion.

In the 1970's development and use of finite elements approach was added to the tools of the trade. Rather than solving or approximating the differential equations, the solution is approximated by a piecewise continuous function that is adjusted to give a "best fit" to the exact continuous solution. This method is the crux of Dailey and Harleman's (1972) Numerical Model for the Prediction of Transient Water Quality in Estuary Networks at MIT.

Part of the Texas San Antonio River basin was modeled by a computer model entitled QUAL I (Texas Water Development Board, 1971). Ward-Espey conducted a case study in 1971 and reported that the Delaware in 1966, Potomac in 1967, and Hillsborough Bay in 1969 were modeled by what was called DECS (Delaware Estuary Comprehensive Study) (Environmental Protection Agency, 1971). In 1968, the Galveston Bay was modeled by the Texas Water Development Board (principal work by Reid and Bodine) utilizing the time-dependent vertically integrated equations of motion and continuity in finite-difference form (Environmental Protection Agency, 1971.

The characteristics examined in the above studies ranged from river flows (what causes them to change), to dispersion of suspended solids, through the investigation of how oxygen and nitrogen levels are affected by changes in other parameters. The results have generally been very informative though most of the studies have been directed toward specialized areas of interest resulting in only a few constituents in a whole range of pollutants being considered.

The computer simulation approach used in these studies, while delivering reasonable accuracy from the data available was also very flexible in its ability to handle large regions of varying physical (or environmental) composition. Thus it was decided for the study initially described that a simulation approach would allow a preliminary evaluation of controls and treatments without the risk of possible adverse effects resulting from their implementation. It would also allow the evaulation of more alternatives in a much shorter time span than trial-and-error implementation, and at much lower cost.

Along with the evaluation method, it would be necessary to supply accurate, up-to-date, organized data on the environment to be studied. With more accurate and current data, the technique would provide much better results then previously possible. Thus, a method of data presentation and assimilation that can keep abreast of current acid mine drainage conditions is a must for accurate results to be obtained from the evaluation technique.

In summary, the objectives of this paper are
(1) to report on the simulation model used for evaluating the secondary impact from treating acid mine drainage;
(2) to discuss the data base developed and used to complement the simulation analysis identified in (1).

PROCEDURE

The steps identified to complete the objectives set forth above are shown in Illustration 1.

The first step is to identify the types of data needed to fully represent the river system and the treatment methods to be modeled. Also, any particular data needs of the simulation model must be identified.

After all parameters to be collected have been identified, the next step is to locate the sources available that contain these parameters and acquire the information. The information must then be coded onto cards (or card images on a CRT), edited for accuracy, and input to their proper file.

After the two files of information have been completed, they must be merged into a master file to be usable as input to the simulation model. Once this is accomplished, decisions on what type of wasteloads to treat, what pollutants to study the treatment effects upon and where the treatments are to be made are all input to the interfacing program. This program models the treatments, mass-balances the wasteloads, and generates the input data for the model.

Using this data, the simulator outputs the effects of the treatments on pollutant concentrations for the entire river section studied. With these outputs, decisions on alternate treatment locations can be made, and their effects studied in subsequent runs of the model. Decision makers can thus find both the best treatment and the best combination of locations, amounts, and number of treatments to be used for the dollars and resources available to be invested.

STUDY AREA

The Monongahela River basin in West Virginia was found to be a good choice for a study region. The river basin is heavily congested with both active and inactive surface and deep mines. Pollution from mines in this area is, at times, very heavy. Compounding the problem is that many of the streams are not large enough to handle the waste load that is being placed upon them by population centers, not even considering the mine pollution inputs. A recent government publication states "Mine drainage is the major water quality problem in the basin. Over the last one hundred years, coal mining has caused increased amounts of acid, sediment, sulfates, iron, manganese, and hardness in the basin's streams, thereby substantially altering the water quality. Of the approximately 6400 miles of streams in the Monongahela Basin, 1400 miles are affected by acidity. Abandoned underground mines are the largest contributor of acidity in the basin. Of the active mining operations the underground mines produce the maximum acid load. Overall, about 80% of the acid load comes from underground operations (active and abandoned). Abandoned sources contribute about 65% of the total load." (3) In summary, it has been stated that "The Monongahela River is more intensely polluted by mine drainage than any other river basin in the United States. Only minor areas are free from the pollutional effects of mine drainage." (4)

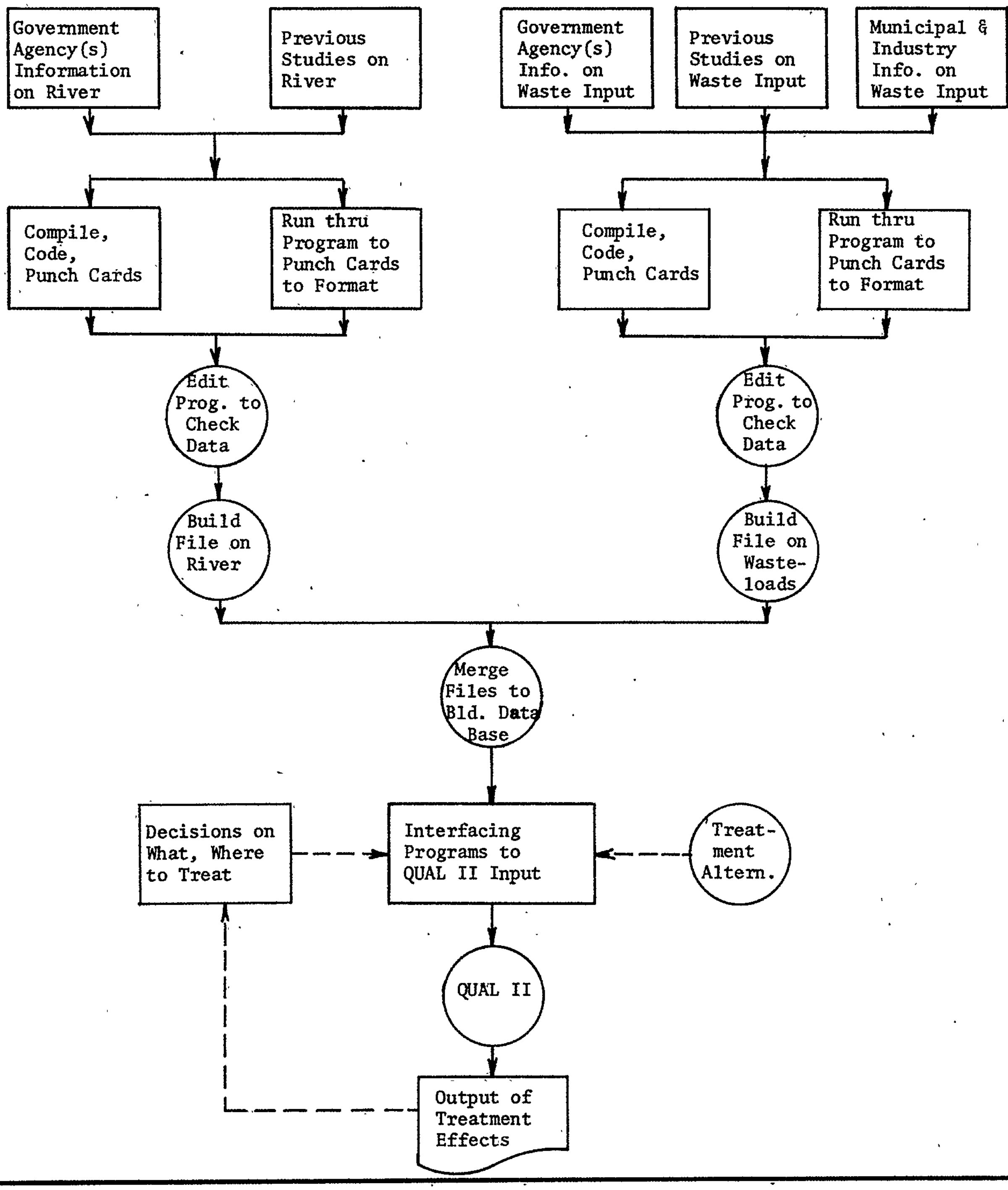
SIMULATION MODEL

The QUAL II simulation program, developed by Meta Systems Inc., for the Pennsylvania Region of the Environmental Protection Agency, was used for modeling purposes in this study (5). QUAL II is a refinement of the original QUAL I river simulation model as developed by the Texas Water Development Board, Austin, Texas, for the EPA in 1970.

It has the capacity of both dynamic and steady-state simulation of many parameters involved in describing the flow of a river. In addition, the program has been designed for ease of modification. It has one main section with all other parts of the program, such as for inputs, outputs and modeling of various chemical/biological parameters, being handled by subroutines written to do specific

ILLUSTRATION 1

Flow of Logic to Complete the Study



tasks. There are over twenty subroutines in the model, but only one subroutine is called by any other subroutine, making it very easy to use/modify. Most are called only the main program. This makes additions, deletions, and modifications of subroutines easier to accomplish. Illustration 2 shows the general structure of QUAL II.

QUAL II requires data on the physical makeup of the river channel(s) to operate. It divides a river channel into "reaches" of a predetermined interval and uses these reaches as building blocks to model the entire river.

For each reach of the river, the following information is required: (1) data on flow per square mile of drainage area; (2) Manning's coefficient; (3) temperature; (4) coefficients to relate velocity to flow and depth to flow: (5) inputs and withdrawals of water; (6) river junctions; (7) slope; and (8) concentrations of pollutants in mg/l for inputs or withdrawals. With these inputs, QUAL II will output (in three different formats) calculated measures on how these pollutant concentrations change as flow progresses downstream and encounters runoff, dispersion, and other wasteloads.

Due to special requirements of QUAL II, such as allowing only one input or withdrawal per reach, an interfacing program was developed to allow the computerized data base to be used with QUAL II. This program performed such functions as mass-balancing wasteloads in one reach into one combined, representative wasteload for input to QUAL II. It also contained, as subroutines, the modeling programs for the treatments to be studied. Having the treatments set up as subroutines following the same logic as the QUAL II model, allows more treatment alternatives to be added to the main program as subroutines in the future with little or no modifications needed to the main program logic.

DATA BASE

The basic requirements of the data base are:

1. The format of the data should be easy to understand and use.
2. The data base should be relatively easy to update.
3. The information contained should be accurate, current, and complete enough to be of use in more than one application.
4. A method should be developed to differentiate between parameters that had a measured value of zero and parameters that had not been measured, and thus, had no value entered.
5. For use in this particular project, the data base should fulfill the data requirements for the study and the requirements for use in the QUAL II simulation program.
6. The units of measurements should be as consistent as possible to avoid errors and confusion.

The data base design consists of two separate files of information. One file contains information about the physical environment of the selected river basin. This includes such items as slope, drainage area, average flows, location of recording stations and/or locks and dams, etc. for each half mile element of a river, tributary, or stream. The other file holds information about wasteload inputs to, or withdrawals from, the river system. Here "wasteload" means anything from an abandoned mine to a municipal sewage treatment outlet. A wasteload withdrawal would be any industrial or municipal water diversion point. These points would have two methods of location utilized -- by latitude and longitude, and to the nearest half mile on a given river. A wasteload on a tributary, for example, would be located by the river mile to the nearest half mile that the tributary intersects the main river, and then the mile point to the nearest tenth (measured from the mouth of the tributary) that the wasteload is located on the tributary.

The two files would be indexed identically on river basin and river, tributary, and stream half mile points so that they could be merged to give a complete picture of each river at each half mile increment.

A list of the information contained on each file can be seen on Tables 1 and 2.

RESULTS AND CONCLUSIONS

(1) Using the QUAL II simulation model and the computerized data base (along with the mass balancing program) the acid mine drainage problem on the Monongahela River Basin has been analyzed in detail. Specific results will be reported on in detail at the 1978 Winter Simulation Conference. However, in general, three different types of neutralization were used to treat mine drainage and wasteloads. They were lime, osmosis, and foam. In addition, limited resources (dollars and neutralization material) were strategically placed at various locations on the river basin to have the greatest effect on the total treatment process.

(2) The QUAL II program can model as many as ten different parameters. It is a large program, over 3600 lines in FORTRAN, and does require a large amount of core space to be run. For this reason, an overlay program was developed to cut core requirements and execution time for the program. To use QUAL II with this data base, the non-changing inputs to QUAL II describing the physical aspects of the river system can be saved on cards, disk, or tape. It is then necessary to run the data base through the interfacing program to generate the wasteload input to QUAL II. Depending on how the read statements in QUAL II have been modified to accept the data, these wasteload inputs can be output onto cards, disk or tape. The total input package can then be run to simulate the effects of treatments and their locations on the river system.

ILLUSTRATION 2

General Structure of QUAL II

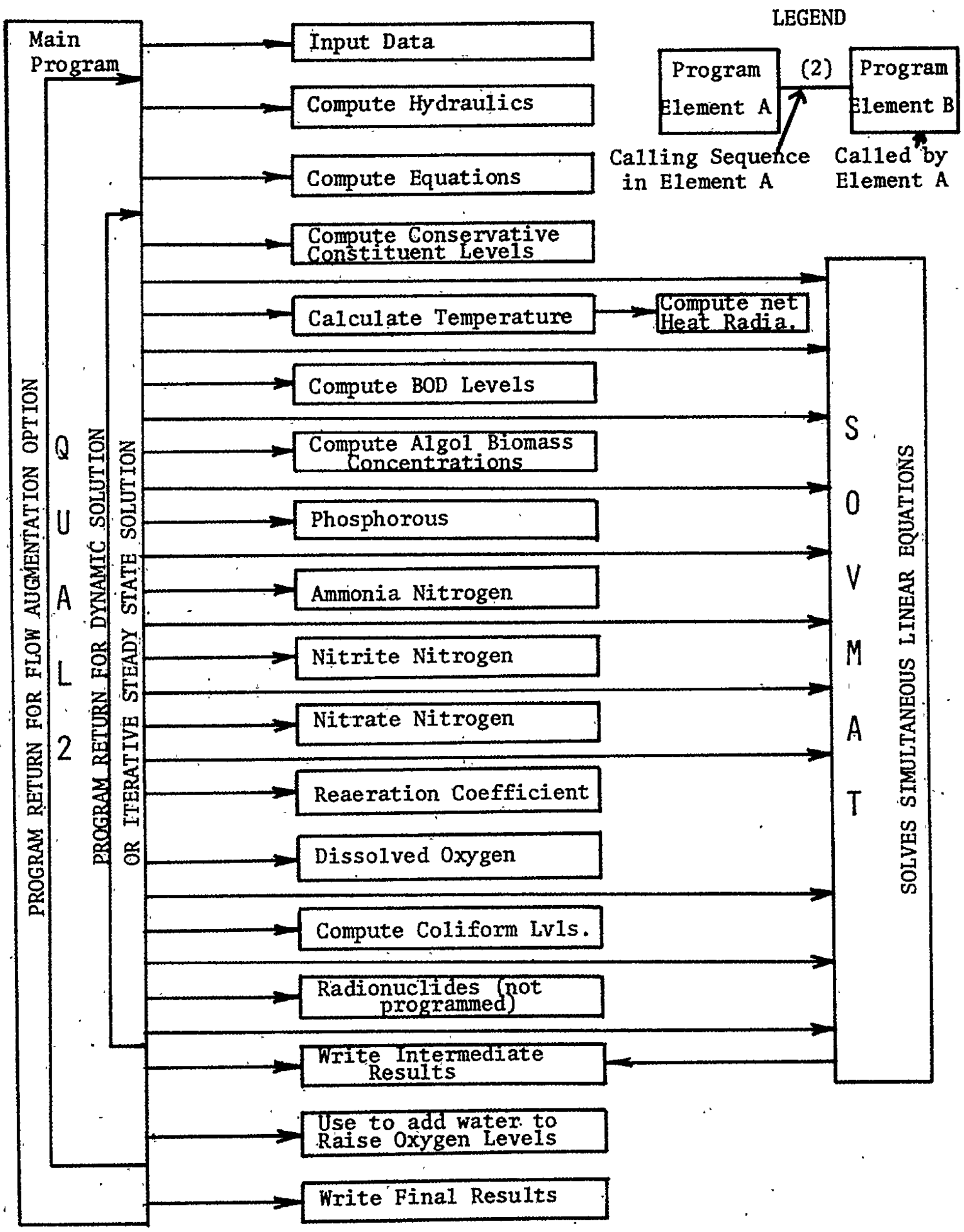


TABLE 1

Data Base Information

General Information Per River Segment

Code Number for Type of Record

Code for River

River Mile

Latitude

Longitude

River Name

County

USGS Station (Name)

Locks and/or Dam (Name)

Lock Lift (ft)/Dam Height (ft)

Hydraulic Data

- Average Flow - (ft^3/sec)
- 7Q10 Flow - (ft^3/sec)
- Average Depth (ft)
- 7Q10 Depth (ft)
- Slope (ft/mile)
- Manning's Coefficient
- Drainage Area (sq. mile)

Water Quality Information

- Code for Primary Source
- Secondary Sources/Comments

TABLE 2

Data Base Information

Wasteload Information

Code for Type

Name

Latitude and Longitude

Flow (cps)

Alkalinity $CaCo_3$ Mg/l (unless otherwise indicated)

Acidity - $CaCo_3$

pH

Total Hardness

Calcium (Ca)

Magnesium (Mg)

Iron (Fe)

Sulfates (SO_4)

CI

Phosphorous (P)

Total Dissolved Solids (TDS)

Suspended Solids (SS)

Biological Oxygen Demand (5 day period) (BOD_5)

Total Kjeldahl Nitrogen (TKN)

Ammonia Nitrogen (NH_3)

Organic Nitrogen (Org-N)

Fecal Coliform

(3) The data base is large, containing information on hydraulics and wasteload inputs for over 475 miles of riversand streams. These rivers were broken down into half-mile elements and information (such as contained in Tables 1 and 2) was gathered for as many elements as could be found. Due to the lack of monitoring stations on many of the streams, information on some of the parameters was very sketchy. As a measure of the volume of the data, there are over 1900 abandoned deep mines alone in the Monongahela River Basin. The exact number is still open to question.

(4) The interfacing program was developed due to a restriction imposed by the QUAL II model. It allows only one wasteload input or withdrawal per modeled element in a river. Thus, if a half-mile element contained more than one wasteload, it would require mass-balancing the wasteloads to get one representative wasteload as an input to QUAL II. The interfacing program takes inputs including mile point to be treated, type wasteload to treat, and type treatment and reads the data base, mass-balancing and outputting wasteload inputs to QUAL II until it reaches a mile point to be treated. It then sends the mass-balanced wasteloads on that mile point through the appropriate treatment model before outputting the wasteload as an input to QUAL II. Using this technique many mile points can be entered in one run of the program to simulate treatments at different locations on a river. This prevents having to actually perform the tedious assembling of data on time-consuming mass-balancing technique by hand.

BIBLIOGRAPHY

1. Lehman, P. John, "Industrial Waste Disposal Overview" Industrial Waste Management Seven Conference Papers (SW-156), U.S. Environmental Protection Agency, 1975.

2. Shavitz, Burt, "Fighting to Save the Earth from Man", Time, February 2, 1970.

3. "State of West Virginia Basin Water Quality Management Plan for the Monongahela River Basin", Department of Natural Resources, Division of Water Resources, April, 1976, pp. I-3, I-4.

4. Enforcement Conference - Monongahela River and Its Tributaries, Summary Report, EPA, 1971, pp. 9.

5. QUAL II User's Manual, Prepared by META Systems Corporation, Cambridge, MA, for Pennsylvania Region Environmental Protection Agency, December, 1973.