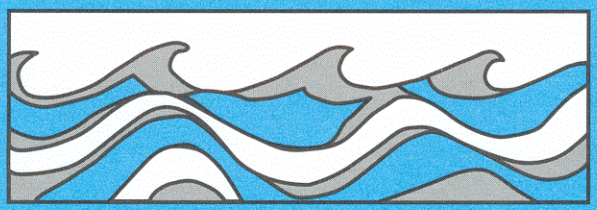
University of Washington
Department of Civil and Environmental Engineering

RISK-BASED SELECTION OF MONITORING WELLS FOR ASSESSMENT OF AGRICULTURAL CHEMICAL CONTAMINATION

Timothy D. Scheibe
Dennis P. Lettenmaier



Water Resources Series
Technical Report No. 101
April 1986

Seattle, Washington
98195

Department of Civil Engineering
University of Washington
Seattle, Washington 98195

RISK-BASED SELECTION OF MONITORING WELLS FOR ASSESSMENT OF AGRICULTURAL CHEMICAL CONTAMINATION

Timothy D. Scheibe
Dennis P. Lettenmaier

Water Resources Series
Technical Report No. 101

April 1986

Department of Civil Engineering
University of Washington
Seattle, Washington, 98195

RISK-BASED SELECTION OF MONITORING WELLS FOR ASSESSMENT OF AGRICULTURAL CHEMICAL CONTAMINATION

by

Timothy D. Scheibe

and

Dennis P. Lettenmaier

Water Resources Series
Technical Report No. 101

April 1986

Project Completion Report: A Risk-based Hierarchical Strategy for Assessing EDB and EDB-like Contamination of Groundwater

Prepared for: U.S. Department of the Interior, Geological Survey, through the State of Washington Water Research Center

USGS Agreement No.: 14-08-0001-G1051

State of Washington Water Research Center Contract No.: A-139-WASH

Project Period: May 1, 1985 - April 30, 1986

Principal Investigator: Dennis P. Lettenmaier, Research Professor
Department of Civil Engineering
University of Washington

ABSTRACT

Public health agencies that are charged with assuring the safety of potable water supplies have long had well monitoring programs. Usually, sampling has been restricted to indicators of bacterial contamination. Current concerns about the health effects of agricultural chemicals have created a dilemma, since sampling costs are much higher than for bacteriological assessments. Because of the high cost of sampling, it is essential to sample those wells that are most susceptible to contamination, while protecting against incorrect prior assumptions about contamination risk. The monitoring of ethylene dibromide (EDB), a highly toxic soil fumigant whose registration was suspended in 1983, is a useful case study in the design of a monitoring program for agricultural drinking water contamination. A three-tier strategy for assessing EDB contamination risk is proposed. At the first level, a determination is made of data needs and availability, problem objectives are defined, and the appropiate scope of the monitoring program is established. At the second level, a prioritization of wells within the study area is developed based on estimated risks. At the third level specific wells to be sampled are identified based on an objective of minimizing the aggregate health risk. The procedure has been implemented for interactive decision making using a microcomputer-based geographic information system approach. The evaluation of EDB contamination of domestic wells in Whatcom County, Washington is used as a demonstration study.

ACKNOWLEDGMENTS

The authors are grateful to those employees of the State of Washington Department of Ecology and Department of Social and Health Services, Whatcom County Health Department, and the Whatcom County Agricultural Extension Office, who provided valuable information and insight during the course of the study.

Computing resources were provided by The University of Washington Academic Computer Services. The report was typed and edited by Kimlan Nguyen and Margo Behler, whose assistance is greatly appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I: INTRODUCTION

I.1 BACKGROUND

Groundwater is an important source of drinking water for much of the United States. The U.S. Geological Survey (1984a) estimates that 35 percent of the nation's public water supply is derived from groundwater. The equivalent figures for the State of Washington (37 percent) are similar. It has long been known that well water is susceptible to bacterial contamination, and most states have regulations restricting the proximity of domestic wells to septic tanks and other possible sources of bacterial contamination. However, these problems have historically been viewed as affecting the type, and level, of disinfection required for the use of well water for domestic supply, and not as restricting water availability. More recently, a number of more serious threats to groundwater, which are largely related to carcinogenicity of synthetic organic compounds used in industrial and agricultural applications, have been discovered. Recognition of the potential for groundwater contamination from industrial and agricultural sources led, in part, to the Federal Safe Drinking Water Act of 1984, and the adoption of drinking water standards for a number of contaminants by the U.S. Environmental Protection Agency.

In Western Washington, much of the most readily available groundwater comes from shallow, unconfined aquifers comprised of fairly permeable sediments. This results in relatively inexpensive drilling and pumping costs compared to deep wells, but makes the source more vulnerable to contamination. Common sources of contamination may include domestic

sewage treatment systems, landfill leachates, and infiltration of contaminated storm runoff. However, agricultural pesticides and herbicides are also potential contaminant sources of concern for well water.

Periodic testing of drinking water wells is conducted in most states to assure that the public is protected from contamination of drinking water sources. For instance, in Washington, the Washington Department of Social and Health Services (DSHS) periodically monitors domestic water supplies for coliform bacteria and other conventional pollutants. The frequency of monitoring depends on the size of the water system and the pollutant under consideration. The number of bacteriological samples to be taken from a water distribution system ranges from one every twelve months for systems with 3-9 permanent service connections to 29 per month for a system serving a permanent population of 25,000 persons (and even more as the size of the system increases). Similar requirements apply to monitoring for inorganic chemical and physical contaminants, turbidity, trihalomethanes, corrosivity, pesticides, and radionuclides (Washington Administrative Code, 1983). Because the tests for conventional pollutants and coliform are relatively inexpensive, it is possible for agencies such as DSHS to assure the absence of public health problems from traditional contamination to a fairly high reliability.

The problem posed by trace contaminants, such as synthetic organics, is much more difficult for public health agencies to address. Laboratory test results suggest that there is a health risk (expressed, for instance, in the number of expected cancers per 10,000 population) associated with long-term consumption of drinking water having trace

concentrations (often in the parts per trillion range) of some synthetic organics. Problems exist in the estimation of such health risks, since they often involve extrapolation of high doses given to test animals over short time periods to low human exposure levels over long time periods. However, public health agencies are faced with few alternatives in assessing the health risks. A further complication is that while tests for bacterial contamination are relatively inexpensive, detection of trace concentrations of organic compounds usually requires gas chromatograph-mass spectroscopy (GC-MS) analyses, which can be quite expensive (typically in the range of $500-2000 per sample). When it is considered that there are over 10,000 drinking water wells in the State of Washington, agencies such as DSHS clearly cannot rely on blanket sampling. Nor is it feasible to assess users of small domestic wells (which make up the great majority of drinking water wells statewide) the cost of sampling. While the cost of trace contaminant sampling represents a relatively minor portion of the operating cost for large water purveyors, it is a potential burden for owners of small domestic wells, who may feel that the chances of detecting trace contaminants are slight, and, if present, the contamination (and sampling) is the responsibility of the producer and/or the user of the contaminant.

I.2 OBJECTIVES

The objective of this research is to formulate and demonstrate a framework for risk-based selection of monitoring wells, for the purpose of assessing the extent of groundwater contamination by agricultural chemicals. The term risk is used in two ways in this report. The term "aggregate public health risk" is used in a general sense to refer to the

increased number of expected cancers (per 10,000 population) due to the domestic use of well water contaminated by a specific agricultural chemical. The term "contamination risk" refers specifically to the estimated probability that a given well is contaminated by a certain agricultural chemical.

The issue that must be addressed by public health agencies is how many, and which wells to sample to best assure the protection of public health. This problem can be viewed as one of aggregate health risk minimization. Clearly, if funds were available to test all wells, this risk could be reduced to zero (assuming no field or laboratory sampling error, and ignoring the problem of contaminant migration). This would be an excessively expensive undertaking, since it is known without sampling that most wells are extremely unlikely to be contaminated, if there is no evidence of contaminant application in the area. Therefore, the problem can be posed as a risk-cost optimization, in which either the risk is minimized subject to a budget constraint, or the cost minimized subject to a risk constraint. In this context, the risk, as suggested above, is the result of the failure to identify contaminated wells; it should be noted that there may be some wells where the likelihood of contamination is so high (for instance, because all surrounding wells are contaminated) that contamination can be assumed without sampling, in which case the risk can be reduced without sampling by discontinuing use. The costs take the following forms: 1) the sampling costs, for those wells that are monitored, and 2) the costs of providing an alternate water supply source for those wells that are identified as contaminated.

The objective of the research reported herein is to develop a hierarchical risk-cost optimization framework for drinking water contaminant monitoring design. The three levels of the proposed hierarchy are:

1) To gather information and data, define project objectives, and eliminate areas where contamination risk is negligible from consideration;

2) To devise a method for estimating the contamination risk of specific wells in the study area based on information and data gathered in Level One; and

3) To formulate an optimization algorithm that uses the estimated contamination risk values to guide future sampling with the objective of minimizing the aggregate health risk.

The research reported herein makes no attempt to define an acceptable aggregate health risk level; this choice is a public policy issue. However, the development of a monitoring optimization method is expected to provide a tool both to allow the determination of the expenditure levels required for given levels of aggregate risk, and to assure that, for a given expenditure level, public funds are spent in the most efficient manner.

The drinking water contaminant on which this work is focused is ethylene dibromide (EDB), a soil fumigant that has been found to be acutely toxic by the U.S. Environmental Protection Agency (EPA, 1983b). EDB was

applied to strawberry fields throughout Western Washington prior to suspension of its registration by the U.S. Environmental Protection Agency (EPA) in 1983. DSHS has verified a number of instances of well water EDB contamination (DSHS, 1985). Chapter II provides background information on the characteristics of EDB, and what is known of its application history in Washington. However, the general monitoring design methodology developed in this report is applicable to any trace drinking water contaminant, and is not limited to EDB.

CHAPTER II: LITERATURE REVIEW

II.1 PROPERTIES OF EDB

Halogenated hydrocarbons are a class of synthetic organics that have been the subject of considerable recent public health concern. The family is so named because it has one or more of the hydrogen atoms replaced by an atom from the halogen family (of which chlorine, bromine, and iodine are the most common). This class of synthetic compounds has been of concern to regulatory agencies because a number of laboratory studies (Smith, and Goldman, 1983; Fanini, Legator, and Adams, 1984; Short, et al. 1978; Short, 1979), and, to a lesser extent, epidemeological studies (Ott, 1980) have shown that some chemicals in this class are mutagenic and/or carcinogenic, even at low concentrations.

This review focuses on one specific member of this class, ethylene dibromide (also known as 1,2-dibromoethane, or EDB). Production of EDB began in the U.S. in 1923, and increased to a peak of 350 million pounds per year in the early 1980's. About 80 percent of EDB made in the U.S. has been used as an anti-knock additive for gasoline. Most of the remainder of the EDB use has been in pesticides, with the majority of pesticide use as a soil fumigant to control nematodes. Common applications were for fumigation of potatoes and other root crops, and, in Washington, for nematode control in strawberries and raspberries. EDB was also used to fumigate fruits (especially citrus and tropical fruits) and grain and cereal products.

Laboratory studies conducted on animals since the early 1970's have shown that EDB is acutely toxic (Brown, 1984). Table 1, reproduced from unpublished documents cited by Brown (1984) gives carcinogenic potency for EDB and other trace organics. The numerical scale can be considered arbitrary; it is the relative ordering of the various carcinogens that is of interest. For instance, the carcinogenicity of EDB is greater than that of PCB (which has caused widespread public concern), about the same as arsenic, and slightly less than DDT (use of which was banned in the U.S. in the early 1970's).

Table 1. Relative Carcinogenic Potencies of Selected Environmental Toxins (from Brown, 1984)

Compound	Potency Index
Tetrachlorodioxin	$1x10^{8}$
Bis(chloromethy)ether	$1x10^{6}$
Aflatoxin B1	$9x10^{5}$
Benzidene	$4x10^{4}$
N-nitroso-N-methylurea	$3x10^{4}$
Dieldrin	$1x10^{4}$
Chromium	$4x10^{3}$
DDT	$3x10^{3}$
Arsenic	$2x10^{3}$
**********	**********
EDB	$2x10^{3}$
**********	**********
PCB's	$1x10^{3}$
Heptachlor	$1x10^{3}$
Chlordane	$7x10^{2}$
Toxaphene	$5x10^{2}$
Ethylene Oxide	$3x10^{1}$
Carbon Tetrachloride	$2x10^{1}$
Benzene	$4x10^{0}$
TCE	$2x10^{0}$
Vinyl Chloride	$1x10^{0}$
Formaldehyde	$6x10^{-1}$

In 1983, the U.S. Environmental Protection Agency (EPA) published information describing EDB's mutagenic and carcinogenic effects (EPA,

1983a). The initial concern was over residual levels of organic bromides (a product of the biological breakdown of EDB) in grain and grain products fumigated by direct application of EDB, which was then standard practice. Based on the evidence of health risk, and discovery of high concentrations of EDB in raw grain, EPA suspended the registration of EDB as a pesticide in September, 1983. About the same time as the EPA suspension, there was considerable publicity about discovery of EDB in processed grain products and citrus fruits. In February, 1984 EPA issued revised guidelines for acceptable concentrations of EDB in raw grain and processed grain products (EPA, 1984). This action was followed by additional regulation of EDB in grain products in some states.

Although it did not receive as much publicity, contamination of well water by EDB concentrations of up to 100 ppb was found in Georgia, Florida, and California (Holden, 1986; USGS, 1984b). The sites studied in these states were primarily in agricultural areas where there was a history of heavy EDB application rates. In 1984, the State of Washington Department of Social and Health Services (DSHS) began a study of EDB incidence in groundwater in those parts of Washington where agricultural records showed extensive EDB application. The DSHS analyses showed EDB was present in drinking water wells in several agricultural areas in Western Washington (DSHS, 1985). The DSHS study, and other information on historic application of EDB in Washington, are reviewed in Section II.2.

The relative health risks of various sources of exposure to EDB, and like contaminants, is of interest. EPA (1983b) reported such information as increased cancer risk for selected EDB exposure scenarios. While care

should be taken in interpreting the estimated risks, for the reasons noted earlier, the relative values are of interest. The most significant of the EPA estimates is that the lifetime consumption of drinking water with 1 ppb EDB (this level was exceeded in approximately one-third of the wells with detectable EDB in the DSHS study) would result in increased cancer risk of 2 in 1000. By comparison, lifetime exposure to EDB in wheat products with then-common (1983) concentrations would result in risk of only 1 increased cancer in 10,000, and consumption of EDB-treated citrus fruit would result in increased lifetime cancer risk of 2 in 100,000. It is important to note that the food consumption estimates, which are already lower than for drinking water consumption, assume continued lifetime exposure. The 1983 EPA rescission of registration for EDB assures that this will not be the case; EDB has now been essentially removed from dietary consumption, as it can no longer be used in the manufacturing and processing of foods. On the other hand, EDB consumption through drinking water contamination is likely to remain a long-term concern, since it is believed that the compound does not have a mechanism for natural degradation in groundwater systems.

Ethylene dibromide is relatively insoluble, volatile, and unreactive (State of Washington Department of Ecology, 1986). While it does appear that volatilization transfers a large portion of the applied compound from the soil to the atmosphere (where it is rapidly degraded by oxidation), this process apparently is not complete or rapid enough to prevent the extremely small amounts which cause concern from being dissolved in the groundwater.

II.2 MONITORING NETWORK DESIGN

Monitoring network design can be considered to encompass the entire range of decisions required to implement a data collection program. These include determination of the number, location, sampling frequency, and collection schedule for field sampling, the process of converting field samples to a quantitative representation of environmental conditions (e.g., field data collection procedures, sample transportation, and laboratory analysis), and data handling (storage and retrieval) and reporting. Hydrologic network design was the subject of an American Geophysical Union Chapman Conference in 1978. In the keynote address for that conference, Moss (1979) pointed out that "Hydrologic information almost always is measured in a parameter-specific sense, that is, information is inversely related to the error of estimation ... Nevertheless, the engineer, planner, or policy maker is more interested in the integrated measure of information -- what impact does the lack of hydrologic knowledge have on the decision?" In a drinking water monitoring program, the parametric information measure is the presence or absence of contamination. The application of that data is the decision as to whether or not a particular well or wells are safe, which is based on an interpretation of the public health risk (see Chapter IV).

Because the uses of hydrologic data differ, there is no single algorithm that can be used to design a hydrologic data collection network. However, there is a general process that is common to most network design problems. The first step in the process is to define the network objectives. For a well monitoring program, the appropriate objective, as noted in Section I.2, might be the minimization of public health risk.

The next step is to identify the constraints on the design. Usually, one constraint is budgetary resources, although there may be other constraints, such as possible sampling locations and times of year during which samples can be collected. The next step is to develop an equivalent technical statement of the objectives, and to identify the decision variables. In the case of the well monitoring program, the suggested technical objective function is an aggregate risk measure. The specific form of the aggregate risk measure is described in Chapter IV. Finally, a selection process is implemented to identify the preferred network alternative (combination of decision variables) subject to the constraints. This selection may be done in either an ad hoc fashion, or an optimization algorithm may be employed.

There have been a number of network design examples presented in the literature that follow this general approach. For instance, Rodriguez-Iturbe and Mejia (1974) and Bras and Rodriguez-Iturbe (1976) describe methods for designing rainfall networks where the objective is either to minimize the standard error of the estimate of the long-term areal mean rainfall, or the standard error of the estimate of areal mean rainfall for a given (storm) event. Moss and Karlinger (1974) describe a method for the design of surface water networks based on the transfer of information between correlated stream gauges where the objective is to estimate the long-term mean runoff. Ward and Vanderholm (1973) describe a sampling method for the detection of stream quality standards violations. Bogardi et al. (1985) describe a generalized method for locating stations in a spatial network, given the spatial (statistical) structure of the data. Lettenmaier et al. (1984) suggest an approach to

reducing the number of stations in a stream quality monitoring network designed to provide baseline data in an urban or urbanizing area.

Monitoring network design problems generally fall into two categories. The first is the redesign of an existing network, either for the purpose of improving cost effectiveness or reducing cost. Examples of such studies are Lettenmaier et al. (1984) and Wood (1979). The second type of problem is to initiate or expand a data collection network either to satisfy a new objective or to enhance the information yield of an existing network. DSHS's groundwater EDB monitoring program is an example of the second type of problem. In many respects, the network evaluation, or consolidation, problem is easier, because there is an existing data base from which the information yield and redundancy can be evaluated. In the design of a new network or network expansion, the designer is faced with the dilemma that some of the information needed to design the network is not available, because it is the very information the network is to collect. In the EDB monitoring problem, for instance, if the spatial distribution of EDB in groundwater were known, determination of which wells to sample, and how to estimate EDB contamination risk for unsampled wells, would be straightforward. In the absence of background data, though, it is difficult or impossible to optimize the network design aprior! . One way around this problem is to employ an iterative data collection strategy, where the initial data (which may be collected in an essentially ad hoc manner) are used to design the next data collection stage. A modification of this approach is pursued in Chapter IV.

CHAPTER III: DATA ANALYSIS

III.1 APPLICATION HISTORY - GENERAL

Groundwater contamination problems related to the use of EDB as a pesticide are not unique to Washington. Brown (1984) reported that about 20 million pounds of EDB were incorporated annually into more than 100 different pesticides in the United States prior to EPA suspension of its registration in 1983. Of this quantity, about ninety percent was used as a soil fumigant for nematode control. In addition to the groundwater contamination problems identified by DSHS in its 1985 study (DSHS, 1985), several other states, including California, Florida, and Georgia, have experienced EDB contamination of groundwater supplies (Holden, 1986). A brief summary of problems experienced elsewhere is given in this section.

In 1983, the California Department of Food and Agriculture (1983; 1984) reported detection of EDB in 35 wells with a maximum concentration of 140 ppb. In addition, over 2000 wells were found to be contaminated with dibromochloro-propane (DBCP), another halogenated hydrocarbon used as a soil fumigant. The application rates reported for DBCP ranged from 20 to 80 pounds per acre.

Holden (1986) reported use of EDB in Florida on citrus crops, peanuts, and soybeans. In addition, it was used extensively on golf courses in the state. The state government in many cases had promoted the application of the pesticide, since it was involved in a pest eradication program related to the state's citrus industry. Florida began sampling wells for EDB in 1983; by February, 1985, EDB had been detected in over 800 wells (out of over 7500 wells which were tested).

The United States Geological Survey (USGS, 1984b) reported the discovery of EDB in groundwater in Georgia in 1984. Six of nineteen wells sampled in an exploratory sampling program were found to be contaminated. The application rate reported for EDB usage in the area was 15 to 30 pounds of active ingredient per acre, which corresponds to one to two gallons of pesticide formulation per acre.

As noted earlier, very little information is available regarding the historical use of EDB for pest control. The keeping of records was not required prior to 1981 for two reasons. First, although scientific studies had been performed which demonstrated EDB's acute toxicity as early as 1973 (Olson, et al. 1973), the regulatory agencies did not perceive EDB as a problem. In addition, EDB is a highly volatile substance, which led manufacturers and users to believe that it would evaporate rapidly and thus pose no contamination risk. As a result of the lack of data, the long term trend in the extent of EDB use is poorly known. It is known, however, that registration of DBCP as a soil fumigant was rescinded in August 1977 and this action is thought to have led to a large increase in EDB usage as a replacement for DBCP from 1978 until EDB use was banned in 1983.

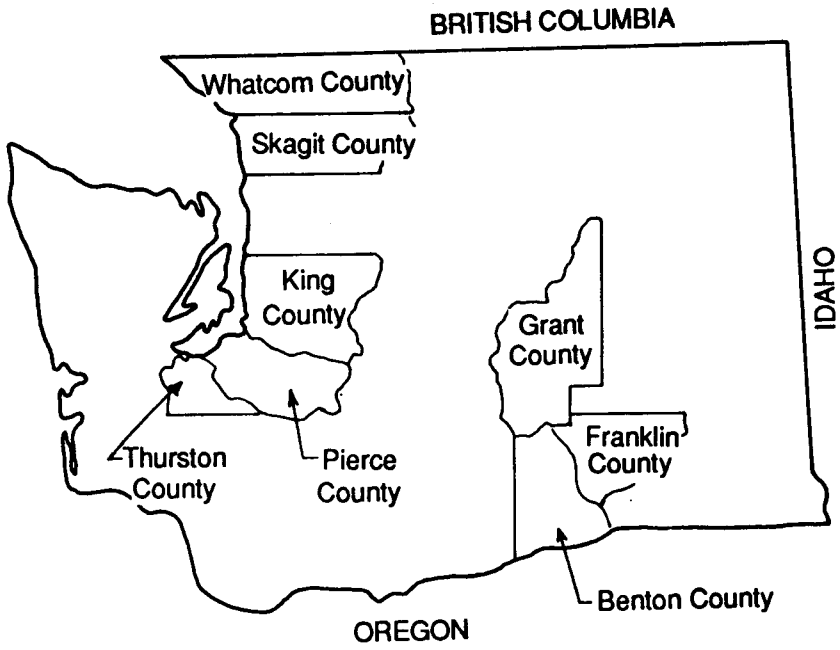


Figure 1. Map of Locations of Washington State Counties with Recorded EDB Usage from 1981-1983.

III.2 APPLICATION HISTORY - WESTERN WASHINGTON

In Western Washington, EDB was used primarily as a soil fumigant for strawberries and raspberries; these crops are most commonly grown in the lower reaches of the region's large river valleys. Data supplied by the Washington State Department of Agriculture regarding EDB use in Washington from 1981 to 1983 are summarized in Table 2. Figure 1 shows the locations of the eight counties in which EDB use was recorded.

TABLE 2. Historical Agricultural Use of Formulations Containing EDB in Washington State by County[a]

	1981		1982		1983		Total	
	Gals.	Acres	Gals.	Acres	Gals.	Acres	Gals.	Acres
Western Wash.								
Whatcom	1,060	69	2,356	124	4,237	223	7,653	416
Skagit	1,450	92	1,700	131	4,500	317	7,650	540
Pierce	----	--	165	11	348	29	513	40
Thurston	825	75	682	62	836	76	2,343	213
King	----	--	----	--	444	37	444	37
Eastern Wash.								
Benton	----	--	----	--	275	25	275	25
Franklin	----	--	----	--	3,350	306	3,350	306
Grant	----	--	----	--	1,590	145	1,590	145
						TOTAL	23,818	1,722

[a]source: Washington State Department of Agriculture. Blanks indicate no data available.

These figures indicate an average application rate of 14.9 gallons per acre (or about 300 to 700 pounds of active ingredient per acre). This application rate is high in comparison to application rates reported in other states. According to DSHS information, 63 known application sites exist in Western Washington.

III.3 MONITORING RESULTS TO DATE

Data have been compiled for 134 wells sampled for EDB in Western Washington. Efforts were concentrated in Skagit, Whatcom, Thurston, and Pierce counties (see Figure 1) since the greatest use of EDB occurred in these four counties. Approximately 100 wells were sampled under the initial DSHS sampling program. Details of the program are given in DSHS (1985). The remaining wells were sampled by individual county health departments in an ongoing study coordinated by the State of Washington Department of Ecology (DOE).

EDB was detected in 33 of the 134 wells sampled; DSHS conducted a second round of sampling which confirmed EDB in twelve wells, failed to confirm in three wells, and was not performed for the remaining eighteen wells. Figures 2a and 2b (based on United States Department of Agriculture, 1953) are typical of the density and spatial distribution of sampling and detection in the four counties tested. These two figures represent two small areas in Whatcom County (approximately 16 square miles each) which contain soil types which support crops to which EDB was often applied. At least four other similarly sized areas exist in Whatcom County alone, these aditional areas had similar or sparser sampling densities than those indicated in Figures 2a and 2b. These figures indicate that sampling was primarily concentrated in small areas, and that some potentially susceptible areas were unsampled. In addition to testing for EDB, other information was compiled for several of the wells. Included in these data is information regarding

- depth of the well

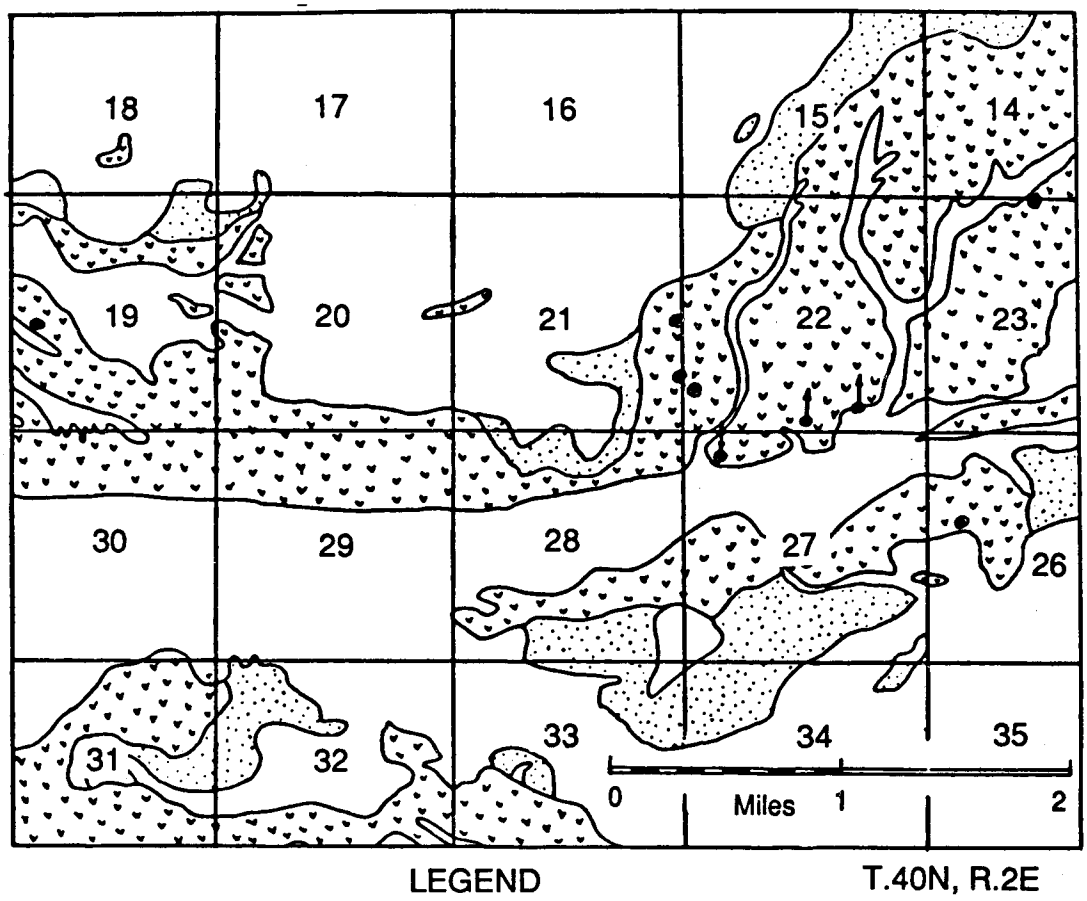


Figure 2a. Locations of Wells Sampled for EDB in the 1985 DSHS Study in Whatcom County, Washington (T.40N, R.2E).

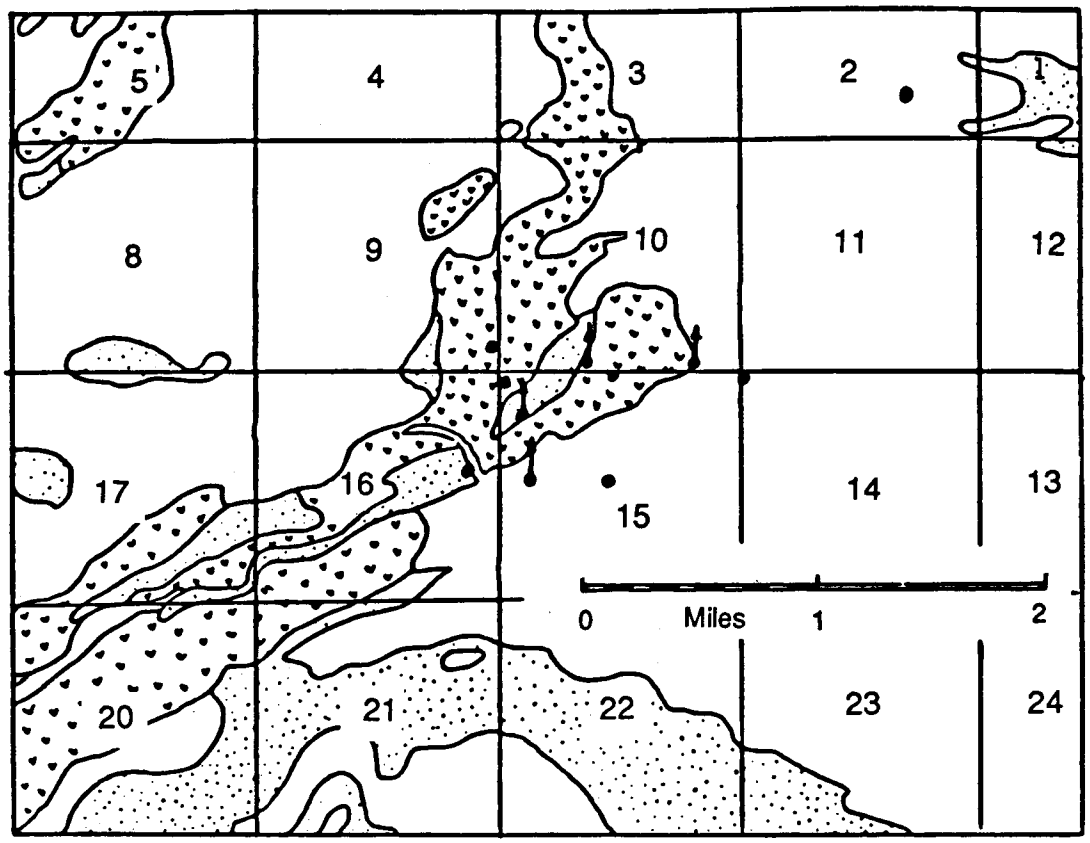


Figure 2b. Locations of Wells Sampled for EDB in the 1985 DSHS Study in Whatcom County, Washington (T.40N, R3E).

- o location of the well with respect to possible sources of contamination
- o results of analysis of water samples for nitrates and bacterial contamination
- o well driller's logs

However, the data collected are far from comprehensive; many gaps and apparent contradictions are present.

III.4 PRELIMINARY DATA ANALYSIS

In order to demonstrate the possibility of informative trends existing in the data, the relationship between observed nitrate and EDB concentrations was explored. Nitrate was examined because its presence in groundwater may indicate that substantial aquifer recharge had occurred through agriculturally utilized soils (nitrate is present in most fertilizers and generally is not attenuated greatly by passage through the unsaturated zone). Figures 3 through 5 show the results for wells which were analyzed for nitrate in conjunction with EDB, by county.

In Thurston County, there appears to be a direct relationship between nitrate levels observed and the potential for contamination by EDB. In cases where the nitrate level exceeded 3.0 mg/l, fifty percent of the wells also contained EDB; in contrast, none of the wells with nitrate levels lower than 3.0 mg/l contained EDB. In Whatcom County as well, none of the wells with nitrate levels lower than 3.0 mg/l contained EDB; however, only three wells in Whatcom County actually contained low nitrate levels, and a smaller fraction (only 30 percent) of the high-nitrate wells contained detectable EDB levels. In Skagit County, the

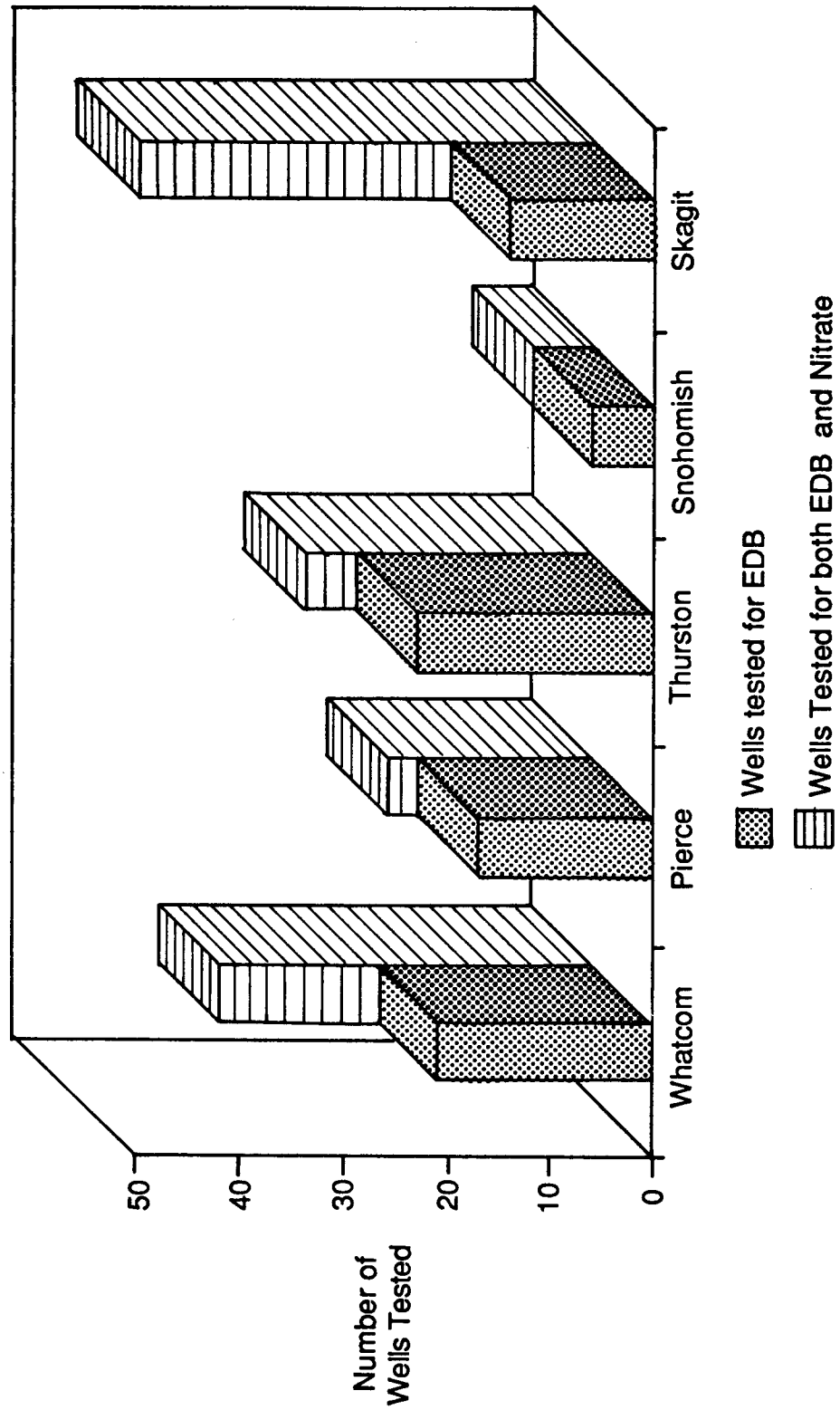


Figure 3. Proportion of Wells Tested for EDB and Nitrate Simultaneously in Five Western Washingtoun Counties.

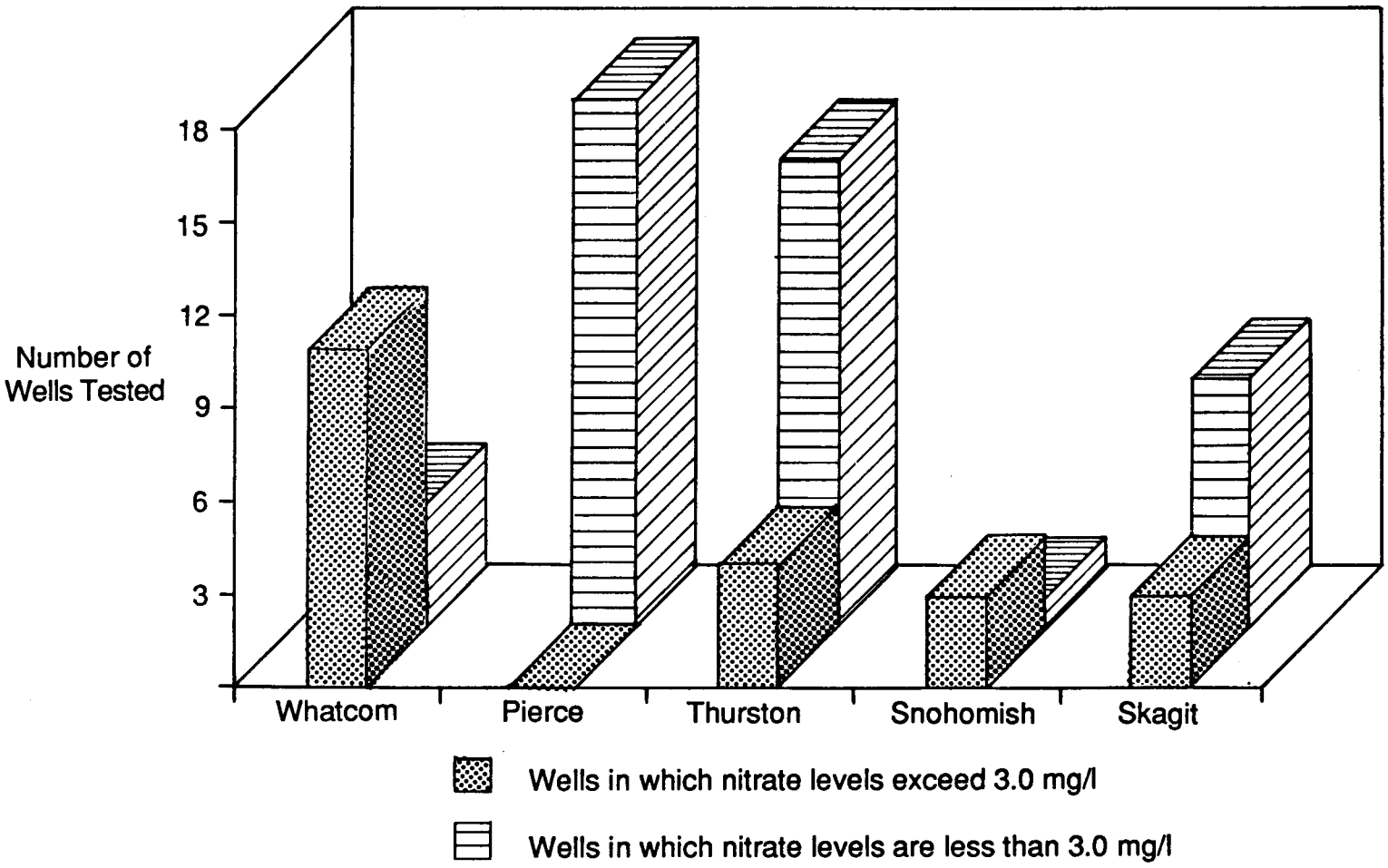


Figure 4. Nitrate Levels in Wells Testing Negative for EDB Contamination in Five Western Washington Counties.

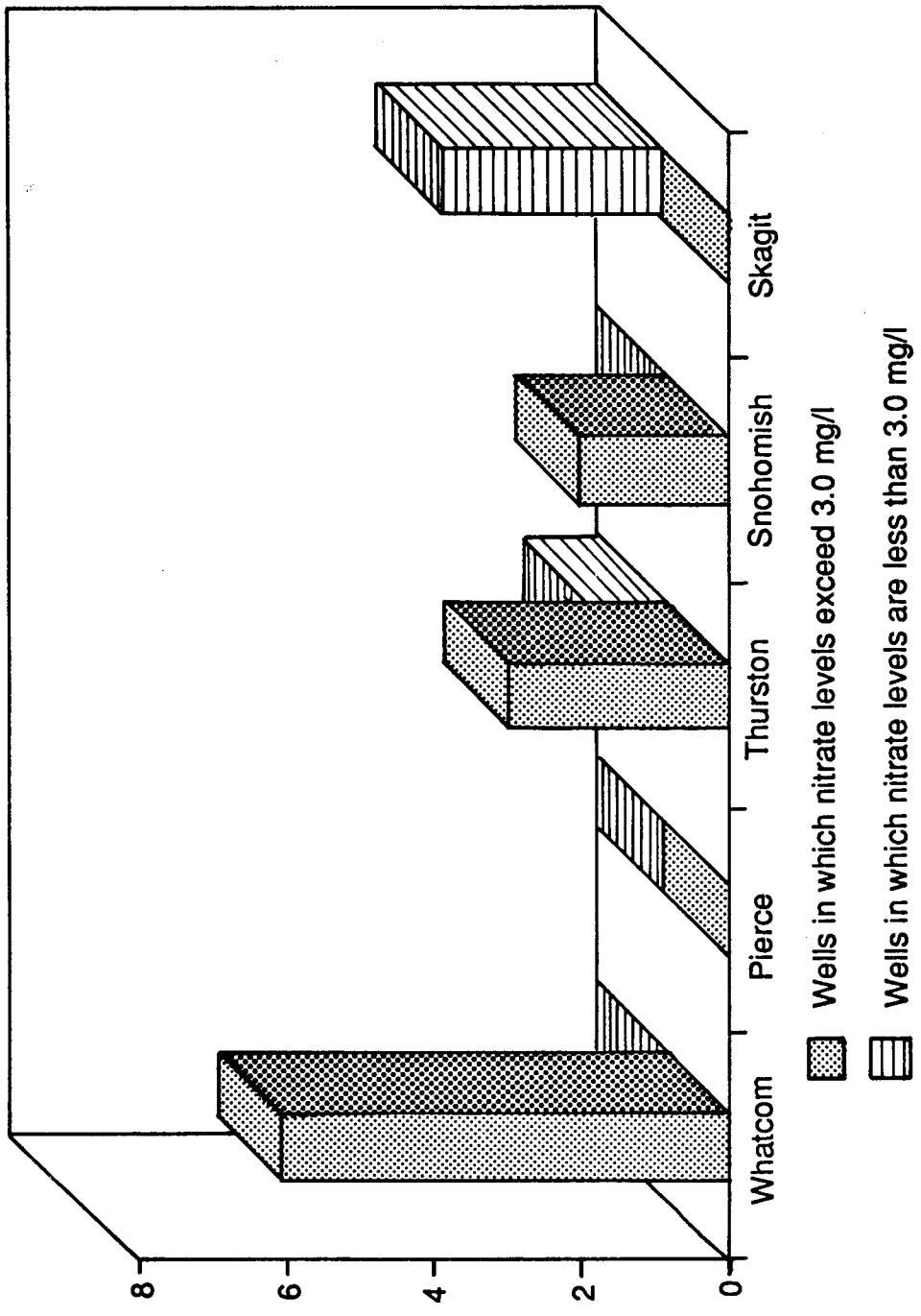


Figure 5. Nitrate Levels in Wells Testing Positive for EDB Contamination in Five Western Washington Counties.

trend appeared reversed, as all wells containing EDB contained less than 3.0 mg/l of nitrate and only twenty percent of the wells analyzed contained greater than 3.0 mg/l of nitrate. In Pierce County, where no EDB contamination was found, the nitrate levels were below 3.0 mg/l in all wells sampled.

In order to draw a rational conclusion from this information, it is important to note that in Thurston and Pierce Counties, relatively deep aquifers were tested, whereas the aquifers tested in Whatcom and Skagit Counties are shallow and unconfined. In the deep aquifers, where direct contamination from surface sources is less likely, it is reasonable to expect a strong correlation between observed nitrate levels and the potential for EDB contamination. In shallow aquifers where nitrate contamination is common (such as in Whatcom County), high nitrate levels may not be correlated to EDB, although the absence of nitrate may indicate low potential for EDB contamination. Where shallow aquifers predominate (such as in Skagit County) low nitrate levels offer little information about EDB contamination susceptibility, and may be indicative only of variations in farming practices from area to area. Unfortunately, most of the wells which tested positive for EDB in Skagit County were not tested for nitrate, so this conclusion is tentative.

The above discussion and Figures 3 through 5 indicate that the potential exists for correlation of nitrate levels to EDB contamination potential, at least in some areas, but that a broad generalization cannot be made for all areas. Factors such as the aquifer type and depth, spatial frequency of nitrate contamination, and farming practices must be considered as well.

Although the discussion in this section has so far been limited to the possible use of nitrate as an indicator of well contamination risk, other factors could be considered in a similar manner. Nitrate has been used here to provide an example of the potential for the use of indicator data as a low-cost method for estimation of well contamination risk; nitrate was chosen primarily because more complete data existed for nitrate in the DSHS study than for any other possible contamination risk indicator (such as, for example, soil type, soil pH, and distance from known or suspected application sites). These data have also been presented to demonstrate the value of collecting ancillary data; the cost of collecting such data is small compared to costs of EDB sampling, and such data may well allow extrapolation of data for tested wells to untested wells with greater confidence.

CHAPTER IV: FORMULATION OF A MONITORING STRATEGY

IV.1 INTRODUCTION

The objective of a monitoring program for detection of EDB or like contaminants in drinking water is to minimize the aggregate public health risk due to consumption of contaminated drinking water. The U.S. Environmental Protection Agency has stated that a public health risk exists from consumption of water with any measurable (>0.02 ppb) concentration of EDB. In this work, we use this criterion to determine whether or not contamination exists, and do not distinguish between the magnitude of the health risk for concentrations above this threshold, since all such waters are considered to be unfit for potable water supply.

The monitoring strategy that will be pursued was described briefly in Chapter I. It is a three level hierarchy, where the first level is definition of problem objectives and study area boundaries as well as development of an information base, the second level is development of a scheme for prioritization (or contamination risk ranking) of wells within the study area, and the third level is employment of an optimization algorithm to determine which wells should be sampled.

In Chapter III, existing knowledge about historic application of EDB, both nationally and within the Washington, state was described, along with information currently available about the extent of EDB contamination of well water from a DSHS reconnaissance study (DSHS, 1985). Given this information, there are two general approaches that could be used to evaluate, or prioritize, contamination risk. The first is to make use of

known physical and chemical properties of EDB, as well as general knowledge about the hydrodynamics of contaminant transport and specific knowledge about the groundwater flow field in areas of highest historic application of EDB, to predict the contamination hazard for given areas and/or specific locations (wells). The alternative approach is to base the contamination risk assessment entirely on sampling data. Finally, the two strategies could be combined, using statistical relationships which might describe (not explain) contaminant incidence.. The merits and liabilities of each approach are described in detail in Section IV.2. Subsequently, in Section IV.3, the approach we feel is best suited to the problem of EDB well water monitoring, which is primarily data-based, is described.

IV.2 ALTERNATIVE RISK EVALUATION STRATEGIES

IV.2.1 Predictive Methods

Although prediction is often associated with a specific algorithm, or collection of algorithms, to be applied in an input-output sense, our definition is somewhat broader. We consider any evaluation process that considers cause-effect factors, whether quantified or not, to be prediction. Therefore, at the one extreme one might apply a fairly sophisticated numerical model. Such a model might require knowledge, for instance, of boundary and (if transient behavior is allowed) initial conditions describing the groundwater flow field, as well as transmissivities and descriptive information about the dispersive properties of the (generally dissolved) chemical of interest. Given this information, the concentration field would be predicted. From such a prediction, a contamination risk evaluation could be made directly; this

evaluation would, however, be conditioned on the underlying assumptions about the form of the predictive model. At the other extreme, a hydrogeologist might make a subjective determination of the likely transport of a contaminant, given only information about the groundwater flow field. Rather than quantifying the expected concentrations, he might only designate areas where there was essentially no likelihood of the contaminant being detected. Such information would be useful for designation of high and moderate contamination risk areas, but would be less useful in evaluating the contamination risk within each area. Even in this case, which might be considered a lower level of prediction, certain assumptions are implicit. Among these are knowledge of the areas where the contaminant was historically applied (although not necessarily knowledge of application rates) and presumptions about the form of the groundwater flow field (for instance, that presumed impervious boundaries are in fact impervious).

Many numerical models for the prediction of groundwater contaminant transport have been proposed. Strecker, et al. (1985) review several of these. The most common assumptions are that the contaminant is soluble and nonreactive. The effect of these assumptions is that the transport of the contaminant is governed by advection (movement with the groundwater flow field) or dispersion (molecular diffusion, and, more importantly, mechanical mixing). Movement of the contaminant as a separate phase (that is, not dissolved) or nonconservative behavior (chemical reaction, or either physical or chemical uptake or release by the media) is not permitted. Contaminants such as EDB, which have relatively low solubilities, and densities much different than water, are generally

assumed not to meet these criteria. Mackay et al. (1985) provide some insight into the physical processes governing transport of organic, dense nonaqueous phase liquid (DNAPL) chemicals such as EDB. The conceptual characterization of the process of DNAPL transport in groundwater is as follows:

1. As initial movement by gravity occurs through the soil column, some of the substance is trapped in the vadose zone by adsorptive and capillary forces.

2. As the substance moves into the phreatic zone (if it is not all trapped in the vadose zone), it continues to be trapped in pore spaces and adsorbed to soil particles. As groundwater moves through the contaminated soil, some small amount of the chemical dissolves and is advected as solute. The immiscible phase may also be advected with the groundwater flow.

3. If the immiscible phase continues to move down far enough to reach a less permeable layer (the bottom of the aquifer), it may then travel by gravity along the surface of the impermeable soil. In fact, if the dip of the confining soil unit is contrary to the groundwater flow direction, the chemical pollutant may actually move against the groundwater gradient and contaminate wells hydraulically up-gradient of the contaminant source.

Thus, it is understood that standard aqueous phase solute transport models may not, in general, be used to describe the movement of high density, non-

aqueous phase groundwater contaminants. If the application rates of the contaminant are small enough, however, multiphase transport may not be an issue. For instance, based on a (typical) average application rate of 14 gallons/acre per year, and assuming one application per year, the average depth of application is approximately 0.0005 inches. Therefore, it is unlikely that the contaminant would travel through the soil column as a distinct mass of nonaqueous phase liquid; instead this very small amount should be dispersed rapidly, trapped in pore spaces, and adsorbed to soil particles within a short distance of the application point.

How, then, is EDB reaching the water table, if not as a distinct non-soluble mass? Three possible modes of transport are:

1. Rainfall or irrigation water moving down the soil column may force a "front" of immiscible liquid downward.

2. EDB contamination may be caused only by concentrated, localized spills of quantities of the chemical formulation large enough to travel to the water table as a single mass.

3. Water infiltrating into the soil from rain or irrigation may dissolve small amounts of EDB as it passes through the soil and carry the chemical to the water table as a solute.

A quick calculation shows that as little as one quarter inch of excess infiltration water is enough to dissolve 0.0005 inches of EDB. Therefore, because of the very small quantities of EDB involved, the low solubility becomes fairly unimportant; in addition, the very dilute solute (on the

order of 1980 ppm as an absolute maximum, and probably much less) has only minimally higher density than "pure" water, eliminating the effect if EDB's high density. The conclusion drawn, then, is that perhaps existing contaminant transport models could be successfully applied to the modeling of EDB, at least with regards to its use as a pesticide.

While this may simplify the effort needed to build a physical model, there are still limitations regarding the application of such a model for monitoring design. In order to model the transport of EDB accurately, the following information would be required:

1. Detailed geohydrologic information for each potentially contaminated site, such as groundwater flow velocities, aquifer transmissivities, water table surface elevations, and subsurface soil profiles.

2. Information regarding the adsorptive capacity of the soil column (which controls how much and when EDB actually reaches the ground water as solute). Soil borings and analysis for EDB residual content would be required to provide this information.

3. Data on timing and volumes of infiltrated rainfall/irrigation water (in excess of evapotranspiration) which moves through the EDB-contaminated soil column to recharge the water-supply aquifer.

The cost to obtain such information would be high, given that the application areas span a large region. In addition, the modeling approach

does not provide either a means for estimating the contamination risk explicitly, nor does it provide a means for determining the reliability of the predictions.

Development and application of predictive models on a small (site-specific) scale might, however, provide insight into several questions related to the large-scale monitoring problem. These include the impact of such factors as soil type, clay and organic content, and permeability of the amount of EDB available to be transported through the unsaturated zone to the groundwater, and time scale for EDB transport. For instance, the question as to whether there might be variations in EDB concentration in a shallow aquifer in response to individual rainfall events could be answered by such a study.

IV.2.2 Sampling Strategies

Ignoring such complicating factors as measurement error and long-term migration of contaminant plumes, EDB contamination risk could be reduced virtually to zero by monitoring all drinking water wells, and requiring that drinking water withdrawals be ceased from contaminated wells. This approach would eliminate many of the uncertainties encountered when predictive strategies are used to assess contamination risk, such as uncertainty about the predictive model structure itself, incomplete knowledge of boundary and/or initial conditions and errors in model parameters as well as the driving variables (e.g., application rates).

Monitoring of all wells is clearly infeasible because of the high cost. During the survey made by DSHS in 1984 (DSHS, 1985), 131 samples were taken

at 96 sites throughout five Western Washington counties. DSHS expenditures for this survey were $31,000 (sample analysis costs) plus three person-years of effort. This implies a total cost of approximately $1000 per site tested. In this study only a small number of wells considered most likely to be contaminated were tested; to sample all drinking water wells in the state would cost on the order of $10 million. Even limiting the scope of the testing program to all wells in agricultural areas could conceivably cost millions of dollars. Perhaps more importantly, the testing would have to be repeated at some interval to ensure that new contamination has not occurred, since the time variability and movement of EDB contamination is not well understood.

A more reasonable approach is to target the sampling to those areas that are most likely to be affected and accept the possibility of failing to identify all affected areas. Some variation of this approach has been employed in all studies to date. The general evolution of the studies of EDB or other agricultural contaminants of drinking water has typically been:

1. Existence of the problem comes to the attention of agency personnel. In the case of EDB in Washington, the problem was first brought to light as a result of a test analysis performed as part of a private real estate transaction.

2. Concern arises leading to mobilization of agency personnel and funds.

3. Goals of the testing program and funds available are outlined

and established.

4. Specific criteria are established based on experience of agency personnel and fundamental understanding of geohydrologic processes. For example the criteria set up by the DSHS (1985) for prioritizing which wells to sample were as follows:

   A. Type of Supply

      1. Priority goes to public supplies
      2. Private supplies will be sampled if information can be gained to protect the public

   B. Location of well

      1. Less than one-half mile from known application site.
      2. Downgradient of the application site
      3. Fifteen percent of the samples should be taken upgradient of the application site.

   C. Aquifer/soil characteristics

      1. Shallow, unconfined aquifers (depth less than 40 feet)
      2. Permeable soils

5. Sample analysis is performed on priority wells according to the criteria given above until available funds are exhausted.

6. Persons affected by wells found to be contaminated are notified and advised of possible health hazards. In addition, assistance is given in finding alternate sources of drinking water for affected persons.

Advantages of this approach are:

1. Agency personnel (particularly county health agents) may have

extensive experience within a local area and understanding of the local geohydrologic regime. This approach makes use of their knowledge.

2. Detailed data are not required to evaluate criteria.

3. Criteria can be implemented within a short time frame; results of the tests can be known quickly.

4. The approach gives leeway for change based on experience as the testing program proceeds.

5. Water supplies most likely to be contaminated will be tested; the health risk associated with those wells can then be eliminated.

6. Compared to an exhaustive testing program, this approach entails less budgetary expenditure.

The primary disadvantage of this approach is that it gives no indication of the aggregate health risk which remains due to wells which are untested after completion of the testing program. This is a particularly acute problem with contaminants such as EDB where application histories are not well known. For instance, a review of the data obtained by DSHS (1985) shows that while EDB usage by county was known for the period 1981-83 (essentially no pre-1981 data exist) application information for particular farms is entirely anecdotal. This is because the individual farmers generally contracted for the application of soil fumigants such as EDB, and only the contractor (typically a nonprofit cooperative) maintained

application records. The apparent discrepancy between application rates reported elsewhere (see Section II.2) would indicate that perhaps total usage volumes are accurate, but records of application may underestimate the acreage of application sites (probably due to failure to record site-specific data). Another problem with selective sampling strategies is that they do not address the contamination risk associated with areas where EDB was used but not recorded. While the most critical problems appear to have been addressed, there remains some contamination risk for unsampled wells, and at present there is no method for evaluating this risk, or of determining where additional samples should be collected, if needed.

IV.2.3. Combined Predictive and Sampling Strategies

For the reasons noted in Section IV.2.1, sophisticated predictive methods that make use of computerized numerical models are probably not applicable to the design of a large-scale monitoring program for drinking water contamination. The logistics of model implementation would clearly overwhelm the monitoring budget, and in fact it is quite likely that it would cost less to monitor all wells exhaustively. Further, predictive models cannot be applied in the absence of data; field measurements are required for model calibration and verification. This is not to diminish the applicability of numerical models to more specific problems, for instance, in areas where "hot spots" are detected through a monitoring program. Where the potential exists for future contamination of wells serving a substantial population and development of mitigation strategies is considered, numerical prediction models may be an integral part of the evaluation of alternate design strategies. For the present problem,

however, the most feasible approach is to rely primarily on field sampling data for the estimation of contamination risk.

Nonetheless, it is necessary to develop some method of extrapolating the results of field sampling data to avoid the necessity for exhaustive sampling. One approach, which will be employed at the second level of the suggested design hierarchy, is to estimate (using techniques similar to multiple regression) contamination risk given certain predictor variables (for instance, depth of well, distance from a known contaminated well, and distance from contaminant source). While this approach is relatively straightforward, and has the advantage that it incorporates the observed data directly, it does not necessarily consider all the relationships which affect the likelihood of well contamination. For instance, such indices as distance from a known contaminant source may be irrelevant if there is an intervening impervious boundary, or if the contamination source is down-gradient of the potentially affected well. Concerns regarding the amount and accuracy of available data as well as the scale on which such data are applicable also arise, further decreasing the confidence in the predictive ability of such relationships. It is important, therefore, to understand that such a model is predictive in a probabilistic rather than a deterministic sense. For this reason, this approach will henceforth be referred to as a contamination risk estimation procedure rather than a prediction procedure.

A strategy which combines field sampling with probabilistic estimation of contamination risk has three primary advantages over the approaches described in previous sections. First, all of the advantages of a field sampling program (as outlined in Section IV.2.2) still apply; however, the

primary disadvantage of such an approach is eliminated. A contamination risk estimation scheme does, if properly employed, provide some estimate of the remaining health risk due to unsampled wells, and may provide a means for quantifying the uncertainty in this estimate. Second, such a strategy provides for a clearer definition of sampling goals, data needs, and procedures to be employed. A framework is provided which allows flexibility in application but which encourages greater organization and thought regarding the fundamental nature of the problem. Finally, such a strategy provides more explicit guidance for selection of sampling wells by employing monitoring network design techniques and ideas in order that sampling monies may be efficiently expended.

Because of these advantages, the thrust of this research has been toward development and application of a combined sampling and contamination risk estimation strategy. The remaining sections of this chapter describe the general methodology of development of such a strategy.

IV.3 OVERVIEW OF PROPOSED STRATEGY

IV.3.1. Introduction

Before describing the details of the proposed strategy, it is useful to review the objectives. The desired result is the reduction or elimination of public health risks due to drinking of contaminated groundwater. In order to achieve this goal, it must be known which wells are contaminated so that replacement drinking water sources can be sought. Of course, this requires sampling of water supplies and testing for contaminant presence.

However, budget constraints limit the number of samples which can be analyzed. Therefore, the goal of a sampling program is to use available information to:

1. Guide sampling such that those wells most likely to be contaminated and with the largest number of users are sampled,

2. Be able to make some statement regarding the estimated health risk due to wells which remain unsampled, and

3. Perform these tasks in the most efficient manner possible.

Having clearly defined the goals of the strategy, it is possible to begin the development of the strategy as a framework within which specific problems can be formulated and addressed. The structure of the framework is three-fold, with each of the three levels (or stages) of the strategy described below.

IV.3.2 Level One - Reconnaissance

The first level of the proposed strategy can be seen as a reconnaissance step; that is, a broad overview of the problem, gathering of initial information, and prioritization of the allocation of effort. Although this is the least analytical of the three levels, it is perhaps the most critical. The organizational skills and thought processes employed at this stage will determine the extent to which accurate contamination risk assessments can be made in later stages, and thus determine the extent to which the goals of the sampling program are met. The subjective nature of this stage (in conjunction with the unique character of each specific

application case) makes it impossible to provide a step-by-step methodology which can be followed in recipe fashion. However, general tasks to be performed at this stage and possible sources of information can be defined. These are:

1. Define compound(s) to be sampled and determine what magnitude of sampling and analysis costs can be expected per sample analyzed.

2. Determine (in a general sense) what the sources of contamination may be (i.e., to which crops the compound(s) is or was applied, and the application procedure).

3. Determine the physical properties (such as solubility and density) of the compound(s). Consider how these factors may affect the mode of transport through the soil medium.

4. Determine what types of information are available and where.

5. Based on the properties of the compound(s), geohydrologic information, and other preliminary information gathered, compile a list of factors that may affect the likelihood of well contamination.

The delineation of the area of interest is one of the initial tasks. The area boundaries should be chosen to avoid discontinuities in geohydrologic regime or other controlling factors within the area. This is because a contamination risk estimation equation must later be developed based upon such factors; it may not be possible to develop a single relationship which

is applicable over a wide range of conditions. For example, EDB contamination in Thurston County, Washington was discovered primarily in deep, confined aquifers whereas it was found in shallow unconfined aquifers in Whatcom County; application of a single equation over this wide range of conditions would be impossible. Generally, this consideration dictates that the size of the area be roughly that of a county. Within the area of interest, it should become clear through the initial investigation that there are areas which can be eliminated from further consideration, thus reducing the number of wells requiring full analysis in levels two and three of the hierarchy.

When performing these tasks, all possible sources of data should be explored. Given in Table 3 are a number of information sources relevant to the state of Washington; similar or equivalent sources exist in other states. This list is not intended to be inclusive, but rather to show the wide variety of potential information sources and types of information available. Most of these were used in the case study to be presented in Chapter V.

Table 3. Sources and Types of Information Used In Level One

Source	Agency	Type of Information
State Government Departments	Department of Agriculture	Pesticide usage information
	Department of Natural Resources	Survey maps and cross-sections
	Department of Ecology	Well locations and drillers' logs
	Department of Social and Health Services	Hazardous materials policies and results of previous studies
	Department of Transportation	
Federal Government Agencies	U.S. Geological Survey	Geological and hydrologic data
	U.S. Environmental Protection Agency	Hazardous materials policies
	U.S. Department of Agriculture	Surficial soil maps and general crop information
Local Government Agencies	County Health Departments	Local water concerns, previous study results, well locations, and other specific (local) information
Other Sources	Libraries	General information
	Agricultural Cooperatives	Pesticide usage information
	University Agricultural Extension Offices	Local crop patterns, pesticide usage.

IV.3.3 Level Two - Estimation of Contamination Risk

In the second level of the hierarchy, well contamination risk estimation equations are developed based on information gained in level one. These can be similar in form to multiple regression equations. For instance, let X_1, X_2, ..., X_n be n factors which affect the contamination risk of a drinking water well. A contamination risk relationship might then be defined as

$$R = A_1 X_1^{C_1} + A_2 X_2^{C_2} + \ldots + A_n X_n^{C_n} \qquad (4\text{-}1)$$

or

$$R = \sum_{i=1}^{n} A_i X_i^{C_i} \qquad (4\text{-}2)$$

where

R = the estimated probability of contamination of a given well

A_i = Regression coefficients

C_i = Regression exponents

i = 1, 2, ..., n (factor index)

The most commonly used form is multiple linear regression, where all the regression exponents are assumed to be 1.0. In this case,

$$R = \sum_{i=1}^{n} A_i X_i \qquad (4\text{-}3)$$

However, two serious problems preclude the use of multiple regression techniques in the forms shown above. First, there is difficulty in defining factors X_i for the problem under consideration which can be expressed as continuous numerical functions. Even more importantly, such an equation is impossible to develop, since little or no data are available upon which to base the determination of coefficients and exponents.

A modified approach which overcomes these difficulties is as follows:

1. For each factor which is believed to control or affect contamination risk, develop a method whereby the raw data can be transformed into a contamination risk rating on a scale of 0 to 100. This will usually necessitate the use of some generalized equation forms with assumed parameter values. Examples of how this can be done are presented in the application study in the following chapter.

2. Establish relative weights for each of the factors (based on judgment as to their relative importance).

3. Define the contamination risk for well j as

$$R_j = \sum_{i=1}^{n} A_i X_{ij} \qquad (4\text{-}4)$$

where

n = the number of predictive factors

X_{ij} = the contamination risk rating (0-100) for the ith factor and the jth well

A_i = the weight for factor i

R_j = the estimated risk of contamination for well j

Using the above equation, an estimated contamination risk, expressed as a percentage (0-100), can be calculated for each well within the study area. Note that the following condition must be satisfied:

$$\sum_{i=1}^{n} A_i = 1.0.$$

It should be noted that the weights A_i are based entirely on the judgment of the user as are and the equation forms and parameters used to transform the raw data onto a contamination risk rating scale.

IV.3.4 Level Three - Sample Design

In Level Two, the information gained in Level One investigations was used to develop contamination risk ratings for each well within the study area. In Level Three of the hierarchy, these contamination risk ratings are used to develop a staged sampling program design as well as to modify and verify the contamination risk rating relationships.

Again, consider the objective of minimizing the aggregate health risk posed by drinking contaminated well water. This can be expressed mathematically as

$$\text{Min } Z = \sum_{j=1}^{W} R_j U_j \qquad (4\text{-}5)$$

subject to the constraint $\sum_{j=1}^{W} C_j \leq B$

where

Z = the estimated aggregate health risk due to drinking contaminated water from unsampled wells

R_j = estimated contamination risk for well j (Eq. 4-4)

U_j = number of users of well j

N = total number of drinking water wells in study area

C_j = cost of sampling well j (zero if not sampled)

B = total sampling budget

The objective as expressed above is valid if the values of all variables as defined are known. This is a reasonable assumption for the U_j's and C_j's. However, as discussed previously, R_j is based on subjective information and little or no data. Therefore, we may choose to rewrite the objective function as

$$\text{MIN } Z = \sum_{j=1}^{W} (R_j + E_j)U_j \qquad (4\text{-}6)$$

where

E_j = a description of the magnitude of uncertainty in R_j

While this is a useful conceptual model, it remains to define E_j. Nevertheless, arriving at any numerical definition of E_j is impossible without much more information than is available. If extensive sampling data were available, E_j could be defined, at least probabilistically. However, this is not generally the case, since it is the sampling scheme itself that is to be designed.

The scheme to be developed must address the objective of aggregate health risk minimization while adequately reflecting the uncertainty in the estimated contamination risks. In the following sections, three different formulations of the objective function (given by Eq. 4-5) are presented. Each is based upon different assumptions and deals with the uncertainty in a different manner; the case study portion of this work will be used in part to compare the validity and usefulness of each of these approaches.

IV.3.5 No Error Characterization

The simplest approach is to assume that the error term E_j in Eq. 4-6 is negligible (which implies that the judgment used to choose the equation forms, parameters, and weighting factors was good). This assumption reduces the objective function to the special case given by Eq. 4-5. The uncertainty can then be addressed in the following manner:

1. Determine the total number of wells (N_T) which can be sampled within the budgetary constraint.

2. Choose some subset of wells ($N_S < N_T$) to sample in an initial stage.

3. Apply Eq. 4-5 to determine which N_S wells to sample (which amounts to choosing the N_S wells with the highest product of contamination risk factor R_j and number of users U_j and sampling them).

4. Evaluate the accuracy of the predicted contamination risks. The relative frequency (or observed contamination risk) is simply the fraction of wells in a given estimated contamination risk interval which tested positive for contamination (see Figures 7 for example histograms). A "good fit" would be indicated by relative frequencies falling along a line of slope 1.0.

5. If necessary, adjust equation forms, parameters, and weighting factors used in the contamination risk estimation scheme until a good fit is achieved. This can be viewed as a calibration step.

6. Repeat steps 2-5 until all N_T wells have been sampled.

Although the uncertainty is not explicitly quantified, the investigator can develop a sense of the accuracy of the analysis by seeing progressively how well the observed results fit with the predicted contamination risks. In each stage of sampling, the contamination risk estimation relationship should become more refined. At the end of the sampling program, the values of R_j for those wells which remain unsampled give a measure of the remaining contamination risk; the extent to which the observed results agreed with predictions gives a sense of the uncertainty in that measure. Further statistical tests (such as the Kolmogorov-Smirnov goodness-of-fit test) could be performed to quantify the level of agreement between predicted and observed contamination risk levels.

However, there is one serious problem with this approach. Because the method leads to sampling of only those wells with a high estimated contamination risk level, there will tend to be little data by which to verify the estimated contamination risk of the (perceived) low risk wells. In other words, there is no incentive for sampling wells with low estimated risk of contamination, and thus no way to verify if the contamination risk of those wells is, indeed, low. A very good agreement may be achieved between sampling results and prediction estimates for assumed high-risk wells, yet no measure of the uncertainty of risk estimates for assumed low-risk wells can be obtained. In fact, the investigator may be falsely led to believe that the uncertainty is fairly low when in fact no verification has been made as to the uncertainty in the lower end of the contamination risk estimation relationship.

IV.3.6 Binomial Error Characterization

Assume, as an example, that exactly one half of a given group of wells are contaminated. If n wells are randomly sampled from this group, the probability of k of the n wells being discovered to be contaminated is described by the binomial distribution, written as:

$$P_X(k) = \binom{n}{k} p^k (1-p)^{n-k} \qquad (4\text{-}7)$$

where

$P_X(k)$ = the probability of k wells being contaminated in a sample of size n

p = the probability that a given well is contaminated ($p = 0.5$ in this example)

$$\binom{n}{k} = \frac{n!}{k!\ (n-k)!}$$

To continue the example, imagine that ten wells are sampled. The probability that 3, for instance, would test positive is then

$$P_X(3) = \binom{10}{3}\ (0.5)^3(0.5)^7 = 0.1172$$

Similar probabilities can be calculated for each value of k from zero to ten. This calculation assumes that the probability of contamination (p) is known and that it is desired to predict the number of contaminated wells in a given subset.

In the monitoring design problem, however, what is known is the actual number of contaminated wells in a small pilot sample; the desired goal is to estimate the overall (or population) well contamination risk. Therefore, the example is presented again, this time with k, rather than $P_X(k)$, given.

Assume that a set of 10 well samples have been taken and that 3 of them tested positive. Given this information, a simple estimate of the population well contamination risk (that is, p) is 3/10 or 0.3. However, the true value of p could be quite different from 0.3. The variability of p (an estimate of the actual value of p) can also be described using the binomial distribution, in conjunction with conditional probability theory, as follows. If the actual population contamination risk (p) was, for instance, 0.2, then the probability of obtaining the sample results seen (3 positives in 10 samples) would be

$$P_X(3) = \binom{10}{3} (0.2)^3(0.8)^7 = 0.2013$$

Let A represent the observed event (in the example, obtaining 3 positives in 10 samples). Then, the above calculation can be represented in conditional probability notation as

$$P(A|p=0.2) = 0.2013$$

Similar calculations can be performed for any assumed value of p between zero and one. Now, according to Bayes' theorem,

$$P(p_r|A) = \frac{P(p_r)P(A|p_r)}{\sum_{i=1}^{n} P(p_i)P(A|p_i)} \qquad (4\text{-}8)$$

where n is the number of assumed discrete values of p, one of which must be the actual value. Returning to the example, assume that the actual value of p can be represented by one of the numbers 0.0, 0.1, 0.2, ..., 1.0. Since there is no prior knowledge as to which of these values is, in fact, representative of the actual value of p, the further assumption will be made that each value is equally probable (in Bayesian nomenclature, this is known as a noninformative prior). This assumption allows reduction of Eq. 4-8 to the following form:

$$P(p_r|A) = \frac{P(A|p_r)}{\sum_{i=1}^{n} P(A|p_i)} \qquad (4\text{-}9)$$

Eq. 4-9 can be used to obtain a probability distribution of p conditioned only on the sampling results observed. Table 4 shows the probability distribution of p for the example considered above.

TABLE 4. Tabulation of the Probabilities of Various Trial Values of p, Conditioned on Observation of Three Positive Results in Ten Samples

p_r	$P(A\|p_r)$	$P(p_r\|A)$
0.0	0.0000	0.0000
0.1	0.0574	0.0631
0.2	0.2013	0.2212
0.3	0.2668	0.2932
0.4	0.2150	0.2363
0.5	0.1172	0.1288
0.6	0.0425	0.0467
0.7	0.0090	0.0099
0.8	0.0008	0.0009
0.9	0.0000	0.0000
1.0	0.0000	0.0000
	0.9100	= 1.0000

From column 3 of Table 4 it can be seen that the most likely single value of p is 0.3, which verifies what was stated intuitively. Note, however, that there would be greater likelihood of obtaining the observed results if p were 0.4 than if p were 0.2; consequently, $\hat{p} = 0.4$ can be considered a better estimate of p than $\hat{p} = 0.2$. A weighted average value of p can be calculated by multiplying each value of p_r by its probability as shown below:

$$\hat{p} = 0.1(0.0631) + 0.2(0.2212) + \ldots + 0.8(0.0009) = 0.333$$

How can this be applied to the monitoring sample design problem? First of all, it should be noted that $\hat{p}$, as used in the example above, is

simply the estimated contamination risk of a well in the general population, given the results of the 10 samples taken. If these 10 samples are chosen such that they are similar with regard to the assumed controlling factors X_j, then $\hat{p}$ provides an estimate of R_j (see Eq. 4-4) for that set of conditions.

If $\hat{p}$ is used as an estimate of R_j in Eq. 4-5 and in the 6 step procedure given in Section IV.3.5, two things will occur. First, because of the skewed shape of the binomial distribution for all values of p other than 0.5, $\hat{p}$ will bias the estimate of R_j upward for $R_j < 0.5$ and downward for $R_j > 0.5$ if a noninformative prior is used for p. Second, the form of the distribution will cause this effect to be accentuated for small values of n. That is, if few samples have previously been taken in a certain R_j interval, the uncertainty is large in that estimate of R_j; the larger skew in the distribution of p reflects the larger uncertainty. The overall result of these two effects is to provide greater incentive for sampling of wells with

a) low values of R_j, and

b) low incidence of previous sampling in wells with similar R_j values.

This modification will overcome, or at least reduce the effect of, the problem associated with the approach described in the previous section, where sampling tends to be focused on wells with assumed high contamination risk and no incentive is provided for sampling of assumed low risk wells for verification purposes.

However, this approach assumes that error in estimation of R_j is due only to random sampling variation, whereas it may be hypothesized that systematic error (i.e., improper choice of equation forms and parameters) is an equally or more important source of error in R_j estimation. Therefore, while this approach is an improvement over the first approach, because it accounts for parameter estimation uncertainty, it does not fully account for the uncertainty in the estimation of R_j, which includes model error as well.

IV.3.7 Information Content Characterization

Consider again the objective function form as given in Eq. 4-6.

$$\text{MIN} \quad Z = \sum_{j=1}^{W} (R_j + E_j)U_j \qquad (4\text{-}6)$$

Although E_j cannot be directly quantified, it can be stated that the magnitude of E_j is related inversely to the amount of information (or data) used to estimate R_j. In other words, if a large number of wells over a wide spectrum of conditions (within the range applicable to the assumed contamination risk relationship) have been sampled and a good match between the predicted and observed results obtained, E_j should be relatively small. E_j should be relatively large if only a small number of wells have been sampled, or if sampling has been concentrated only in a narrow band of conditions.

Therefore, the objective can be reformulated as a dual objective; that is to minimize total aggregate health risk (as formulated in equation 4-6) while also maximizing the information content of the wells sampled.

One way in which to quantify the information content of a well sample is to create a second index, I_j, again on a scale of 0 to 100. Each factor which contributes to the contamination risk estimate R_j can be broken into classes; if a well under consideration falls into a class into which few or no previously sampled wells have fallen, this well would receive a high rating for that factor. The ratings under each factor can then be combined to obtain the total rating I_j.

Our objective is to sample those wells with some combination of high estimated contamination risk, large number of users, and high information content. Let U_{max} be the number of users supplied by the largest well in the study area. Then, an overall well rating can be defined as

$$S = C(R_j U_j / U_{max}) + DI_j \qquad (4\text{-}10)$$

where C and D are non-negative relative weighting factors with $C + D = 1.0$

The use of U_{max} normalizes the first term onto a scale of 0-100 to match the scale of the second term; the coefficients C and D allow combination of the first and second terms into a single overall rating on a scale of 0 to 100.

Now, a multi-stage sampling process can be employed similar to that outlined in steps 1-6, Section IV.3.5. The only difference is that, in

step 3, those wells chosen for sampling will be the N_S wells with the highest rating as calculated using Eq. 4-10.

The choice of coefficients C and D depends on the relative importance of the two sub-objectives, and will vary as the sampling program proceeds. At first, when the uncertainty in R_j is large, the primary objective is to gather information to refine and verify the estimation scheme for R_j, and thus D should be made larger than C. As the sampling program proceeds, enough information will be gathered that the confidence in the contamination risk estimation scheme will increase. As a result, more effort can then be put into aggregate health risk reduction (i.e., sampling of wells with large values of R_jU_j) and less into gathering a wide spectrum of information; the user will therefore want to increase the magnitude of C and reduce the magnitude of D. The choice of C and D, although somewhat arbitrary, allows the user to specify explicitly the relative value of immediate aggregate health risk reduction as opposed to information maximization which will aid in reduction of aggregate health risk (and uncertainty) in the long term.

This third approach does not have the disadvantages of the first two, as it does not make any assumptions regarding the mode of error propagation (random or systematic), and also provides incentive for some sampling effort to be placed in wells with low estimated contamination risk values. In the next chapter, each of the three approaches is illustrated in a case study example.

CHAPTER V: APPLICATION STUDY

V.1 INTRODUCTION

The sampling strategies developed in Chapter IV were tested in an application study. The application study is based on data gathered during the 1985 DSHS study (DSHS, 1985) described in Chapter III. Due to the large area covered by the DSHS study (four counties) and the wide variation in geohydrologic conditions encountered and types of data available, it was necessary to narrow the scope of the application study. One of the four counties, Whatcom, was chosen as the study area. After some research into soil types and pesticide usage, the study area was further narrowed to parts of four townships in Whatcom County near the town of Lynden (Townships 40 and 41 N., Ranges 2 and 3 E., W.M.).

V.2 LEVEL ONE IMPLEMENTATION

Section IV.3.2 defines five tasks which are to be performed in execution of level one of the hierarchical approach. The performance of tasks one, two, and three in the case study was fairly straightforward; this information has been discussed in previous chapters. The compound of interest is ethylene dibromide (EDB); its properties and use were described in Chapter II.

Task four was more difficult. In an ideal situation, the strategy as outlined would be formulated and employed from the beginning of the study. In this case, however, the choice of which wells to sample initially, what types of data to collect, and how to organize the data

was made by DSHS personnel. Because the DSHS investigators were not attempting to employ the strategy proposed here, but rather had their own set of objectives, much information which might have been useful in this work was not collected. As a result, the demonstration study had to be accommodated to the types and amount of data that were collected during the DSHS study, or which could be obtained independently of the DSHS study. Additional information was obtained from the literature and from interviews with personnel from various government agencies. Some of the most important information collected, the sources, and treatment of the data are listed below:

- o Soil Maps: Published surveys of Whatcom County soil types, with accompanying maps, were obtained from the U.S. Soil Conservation Service. These data were useful in several ways. First, the maps were digitized and converted into array form for use in the contamination risk estimation model. Also, the soil surveys provided important information regarding typical crop patterns for various soil types and soil properties which were useful in developing contamination risk factors.

- o Pesticide Use Information: EDB use data was compiled by the Washington State Department of Agriculture Pesticide Office as part of the DSHS study; this information was made available for use in this study.

- o Well Log Information: Well records were searched to attempt to determine physical characteristics of the wells of interest. Unfortunately, well logs are required only of recently drilled

wells (since 1973) resulting in a somewhat incomplete record. Typical well depths and pumping rates, as well as actual values for some wells, were obtained using data from recently installed wells.

- Results of Initial Sampling: The wells sampled for EDB during the DSHS study provide the most vital information, as they represent some actual results by which some comparisons can be made and conclusions drawn.

- Informal Interviews/Discussions: Insight into the nature of the problem, as well as valuable information regarding local conditions and previously collected data, was gained through conversations with county health agents, agricultural extension agents, and state government employees. Although much of this information was qualitative, it helped in guiding the direction of the study as well as formulation of the sampling strategy.

Finally, consideration as to what factors to include in the contamination risk estimation analysis in Level Two was undertaken. It was observed that most of the soils upon which EDB was commonly used are freely draining, sandy soils without high organic content. It was hypothesized, therefore, that the most important factor in determining contamination risk was whether or not EDB was applied near a well. Five factors were hypothesized to affect the motion of contaminant to a well. These included well depth, soil type and organic content, groundwater flow gradient, and aquifer transmissivity.

The ordering of these five steps is not intended to imply that they are to be performed sequentially. For instance, the Level Two factors should affect the types of data sought and compiled; conversely, the types of data available should affect the manner in which the risk-controlling factors are formulated. Both data collection and contamination risk factor definition must take into consideration the mode of use of the chemical as well as its properties. In addition, it should be emphasized that there is no fixed "recipe" to be followed in the level one implementation; instead level one should be viewed as the problem formulation stage. It is significant that by far the largest portion of time and effort was allocated to Level One.

V.3 LEVEL TWO IMPLEMENTATION

V.3.1. Introduction

As discussed in the previous section, several factors may be expected to control the movement of EDB through a porous media, such as distance from source, depth, aquifer transmissivity and head gradient, soil type and organic content, evaporation, and rainfall rates. Many of these factors are unknowns in the characterization of a large number of sites, as determination of values of such physical parameters requires much effort. It is therefore impractical to include these factors directly as predictors of contamination risk.

However, several important observations can be made given the nature and use of the substance under consideration. Ethylene dibromide was used as a soil fumigant to control nematodes or root worms. As such, it was

only applied to certain types of crops which are susceptible to root worm infestation. Further, EDB was applied by a large-scale injection process; this process requires that the receiving soil be fairly porous. Finally, the crops on which EDB was typically used (primarily strawberries, raspberries, and seed potatoes) require well drained soils for good crop yields. As a result of these conditions, EDB was most commonly applied to soils that are well-drained, porous, and can support certain crop types. In Whatcom county, these soils tend to be glacially formed, with shallow, unconfined water tables, and located morphologically on or near gradually sloping river terraces.

The important conclusion to be drawn from the above observations is simply that several of the controlling factors initially listed are actually relatively uniform in areas where there is the greatest likelihood that EDB was used. In other words, those soil types on which EDB tended to be used have, relatively speaking, low variability of the physical factors which may be presumed to control the risk of EDB contamination. This statement should be conditioned in the following sense: for a glacially formed (outwash) soil, the local variability (on the scale of feet) of such parameters as permeability and porosity might be actually quite high. Only on a larger, spatially averaged scale can the assumption of uniformity be considered valid. This, of course, is one reason that a risk-based statistical approach is more valid than a physically-based deterministic modeling approach.

The result of the above discussion is quite important in formulation of contamination risk factors. Since the subsurface transport conditions are generally similar, the most important factor controlling

contamination risk should be whether or not EDB was applied upgradient in amounts sufficient to penetrate the vadose zone and reach the well. As noted previously, actual EDB application sites were not recorded prior to 1981. However, the types of crops on which EDB was commonly used and the soils on which these crops are typically grown can be fairly well defined. Therefore, it was proposed to use soil type as an index to the likelihood of EDB application, and thus as a prime indicator of contamination risk. The manner in which this was done is described below.

V.3.2 Soil Type Well Contamination Risk Factor Definition

As described in Section IV.3.3, it is necessary to develop a method of transforming the raw data into a numerical contamination risk rating on a scale of 0 to 100. Assume that some probability of EDB use can be assigned to various soil types in the study area. This probability can be further conditioned by whether the soil is in an area commonly used for EDB crop types and whether or not any known EDB use or known EDB crop type growth has occurred at a given location.

Given an estimate of the regional groundwater flow direction and velocity, and given the average pumping rate of the well, a parabolic "capture zone" can be defined which represents that portion of the aquifer from which water particles move into the well bore and are withdrawn (see Javendal and Tsang, 1985).

The method used to compute the contamination risk factor due to soil type, then, is:

1. Define the capture zone of the well

2. Calculate a weighted EDB application probability, averaged according to the areas within the capture zone occupied by the various soil classifications, and weighted according to the distance from (or travel time to) the well, as follows:

$$X_1 = \sum_{i=1}^{n} w_i/m_i \left(\sum_{j=1}^{m_i} S_{ij} \right)$$

where

n = the number of sub-areas of the capture zone (user-specified), divided according to distance from the well

w_i = a non-negative weight assigned to sub-area i;

$$\sum_{i=1}^{n} w_i = 1.0$$

m_i = the number of array cells which are located in sub area i

S_{ij} = the assumed probability of EDB use for the soil type existing in array cell j, sub- area i

Digitizing of the soil data into uniform array cells (in this case of approximate size 150 feet by 150 feet) allowed computer calculation of the factor value (given user-input probability estimates) although this process might have been performed manually.

V.3.3. Well Proximity Factor Definition

Another indicator of the risk of contamination of a given well is whether or not nearby wells are contaminated. Therefore, if a nearby well has

been sampled for EDB, the result of that sample should affect the perceived contamination risk of nearby wells. Also, the correlation between the contamination state of two wells may be expected to be a function of the distance between the two wells. As a result, a second contamination risk factor was defined as follows:

$$X_2 = \begin{cases} C*(((D_{max} - D)/D_{max})^{\alpha})*100 & \text{for } D \leq Dmax \\ 0 & \text{for } D > D_{max} \end{cases}$$

where

D = the distance between the wells

D_{max} = a threshold distance (user-defined) beyond which it is assumed that there is no correlation

α = an exponent (user-defined) which allows the user to specify a non-linear correlation function

C = a coefficient, equal to 1 if the sampled well is contaminated, -1 if it is not.

V.3.4 Well Depth Factor Definition

Since well depth information is fairly easily obtained from well logs or by inspection, and since deeper wells should intuitively have a lower risk of contamination by surface contaminants, a third contamination risk factor was defined as follows:

$$X_3 = \begin{cases} (((d_{max} - d)/d_{max})^{\beta})*100 & \text{for } d \leq d_{max} \\ 0 & \text{for } d > d_{max} \end{cases}$$

where

d = well depth

d_{max} = a threshold well depth (user-defined) beyond which the risk of contamination is assumed negligible

β = an exponent (user-defined) which allows the user to specify a non-linear relationship between well depth and contamination risk

The relative importance of this factor was low in the case study; since the well depth within the study area is relatively uniform. However, well depth may have a larger impact on contamination risk in other cases.

V.4 LEVEL THREE IMPLEMENTATION

Three approaches to determining an appropriate staged sample design were described in Sections IV.3.5 through IV.3.7. All three approaches were used in the demonstration study, thus allowing comparison of the sample design recommended using each approach. The three approaches were implemented as described in the earlier sections. No further description is necessary, as methods of implementation of Level Three are not unique to each case, as are those of Levels One and Two.

V.5 COMPUTER IMPLEMENTATION AND CODE:

A set of computer programs and data files were developed for application of the proposed strategy to the case study.

V.5.1 Computer Programs

Five separate programs were developed to accomplish implementation of Level Three. These programs were developed on an IBM PC-AT using the FORTRAN 77 and BASIC programming languages under the MS-DOS operating

system. The five programs can be executed as a group (in a pre-specified sequence) using a batch file, or they can be executed individually as directed by the user. The five programs and their functions are as follows:

1) DATIN.BAS - Interactive input and/or modification of contamination risk relationship parameters.

2) WELLDAT.BAS - Interactive input and/or modification of well data.

3) MODEL.FOR - Calculation of estimated contamination risk for previously sampled wells and comparison of estimated risks to observed sample results.

4) HISTO.FOR - Presentation of results from MODEL.FOR in graphical (histogram) form.

5) SAMOPT.FOR - Calculation of estimated contamination risk for unsampled wells and optimal design of the next stage of sampling to be performed.

A listing of each program is provided in Appendix A. Programs with filename suffix "BAS" were written in the BASIC programming language; those with suffix "FOR" were written in FORTRAN 77. The program HISTO.FOR makes subroutine calls to the graphics package HALO (Media Cybernetics, Inc., 1986). A batch file EDB.BAT was also developed which allows sequential execution of all five programs (in the order given above) with a single command.

V.5.2 Data Files

Two important data files have been created for use with the programs described above.

The file SOIL.DAT contains 83780 (236 X 355) characters. Each character represents a land surface cell within the study area, 147.12 feet on each side, and is assigned a value of 1-9 according to the classification of the soil type contained within. The classifications established for this study are as follow:

1) Known EDB application site
2) High contamination risk soil type within crop growth area
3) High contamination risk soil type outside crop growth area
4) Medium contamination risk soil type within crop growth area
5) Medium contamination risk soil type outside crop growth area
6) Low contamination risk soil type within crop growth area
7) Low contamination risk soil type outside crop growth area
8) Known EDB-type crop growth site
9) Surface water area

Appendix D includes a listing of the soil types (in SCS nomenclature) which were assigned to each of the above categories in the demonstration study.

The crop growth area is defined as those portions of the study area where growth of EDB-application crops tends to be focused. Note also that the contamination risk is not represented by the assigned character (1-9), but rather is variable and is set by the user (in DATIN.BAS).

The development of the file SOIL.DAT was a multi-stage process; the steps used are outlined below:

1) The Soil Conservation Service soil map of the study area (U.S. Department of Agriculture, 1953) was digitized using digitizing equipment owned by the University of Washington Department of Geography.

2) The digitized data are then processed using the geographic information systems package SAGIS (U.S. Fish and Wildlife Service, 1974). This provided an on/off sequence for each soil type in the study area.

3) A FORTRAN program ("CONVERT") was written and used to convert the on/off sequences into a single character data array, with different characters representing each soil type.

4) A FORTRAN program ("SETUP") was written and used to assign contamination risk classifications (i.e., high, medium, or low) to each soil type and to convert the associated characters into a numerical representation. This program was also used to overlay known EDB application sites, known crop growth sites, and crop growth areas onto the soil type classifications.

Step 1 above was performed on an IBM PC-AT microcomputer. Steps 2-4 were performed on the UW Cyber 180-855 mainframe computer. After completion of these steps, the array was fully classified according to the nine

classifications given previously. The soil data array file was then transferred back to the IBM AT-PC.

The data file so obtained is formatted for direct input into the program modules MODEL.FOR and SAMOPT.FOR. Note that, although the programs and equipment used have been described for documentation purposes, the monitoring design program strategy is independent of specific hardware and software.

The second important data file, WELL.DAT, contains data for 24 previously sampled wells in Whatcom County and 54 hypothetical unsampled wells. The type of data included for each sample well are:

1) An 8-character well name

2) Location of the well (X and Y coordinates referenced in feet from the northwest corner of the study area)

3) Contamination status of the well

4) Depth to static water level

5) Estimated regional groundwater flow direction at the well

6) Average pumping rate

7) Number of drinking water users

8) Distance to, and contamination status of, nearby sampled wells.

For each unsampled well, the data file contains the same information, except that the contamination status is not included (as it is of course unknown).

The file WELL.DAT was developed using the previously mentioned BASIC program WELLDAT.BAS. Data used were obtained from several sources, including the 1985 DSHS study (DSHS,1985) as well as the sources listed in Section V.2.

Two notes regarding the well data should be emphasized:

1) Although the data for the previously sampled wells are for the most part measured observations, some information had to be estimated. In particular, well locations were only known to the nearest sixteenth section, as they had to be estimated from aerial photographs and owner addresses. Also, well logs (and thus well depths and pumping rates) were not available for all wells; these data were filled in where necessary by using information from nearby wells serving similar populations.

2) The unsampled well data set is completely hypothetical. There exist a large number of actual unsampled wells in the study area (approximately 200 with well logs on file plus an unknown number drilled prior to 1973). However, few data were available for these wells, since the previous studies focused only on those wells where samples were taken. Therefore, a set of hypothetical wells was established, distributed evenly over the study area. Well depths were estimated from nearby actual wells; groundwater

flow directions were known for all locations in the study area. Pumping rates and number of users were set to the same values for all unsampled wells. Appendix C contains a listing of the well data used.

Although the above factors preclude interpretation of true contamination risk for the case study area, all the data that were hypothesized could be obtained with reasonable effort in a real study. Therefore, the data set as developed provides a useful demonstration of how such a study might be implemented. Figure 6 shows the locations of the wells sampled in the DSHS study (DSHS,1985) as well as the hypothesized locations of the unsampled wells, from which the next round of samples is to be taken.

V.6 DEMONSTRATION STUDY RESULTS

V.6.1 Contamination Risk Model Calibration

Nine runs of the program MODEL.FOR were performed, each using a different set of model parameters and weightings. Each parameter set was established by varying one parameter from the previous parameter set. For example, parameter set 3 is the same as parameter set 2 except that the relative weights of the three contamination risk factors are changed. The outputs from these nine runs (which indicate well data and parameters used) are reproduced in Appendix B.

As data from only 24 previously sampled wells were available, it should not be surprising that none of the parameter sets provided a perfect calibration. However, four of the parameter sets (numbers 1, 3, 5 and 9

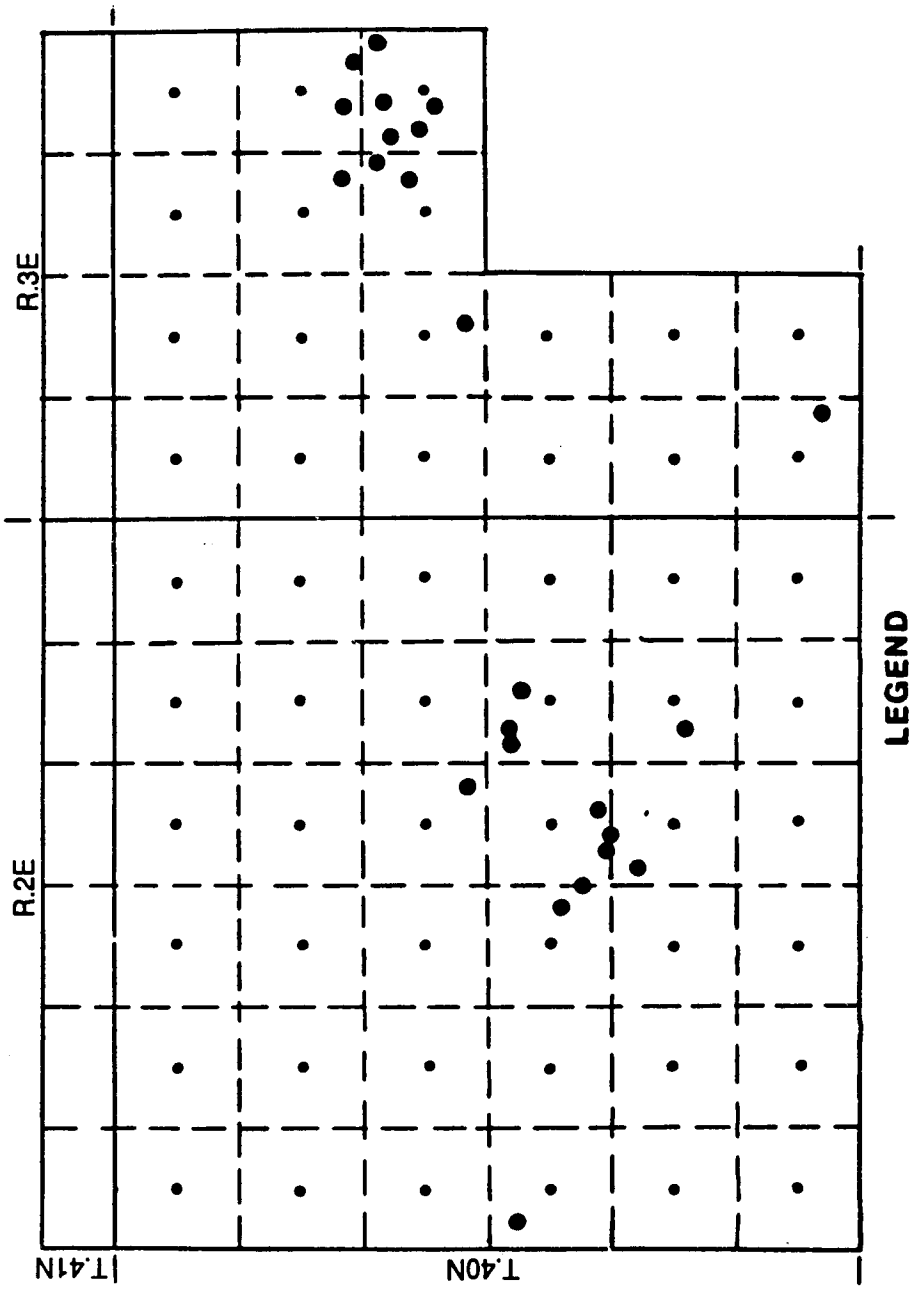
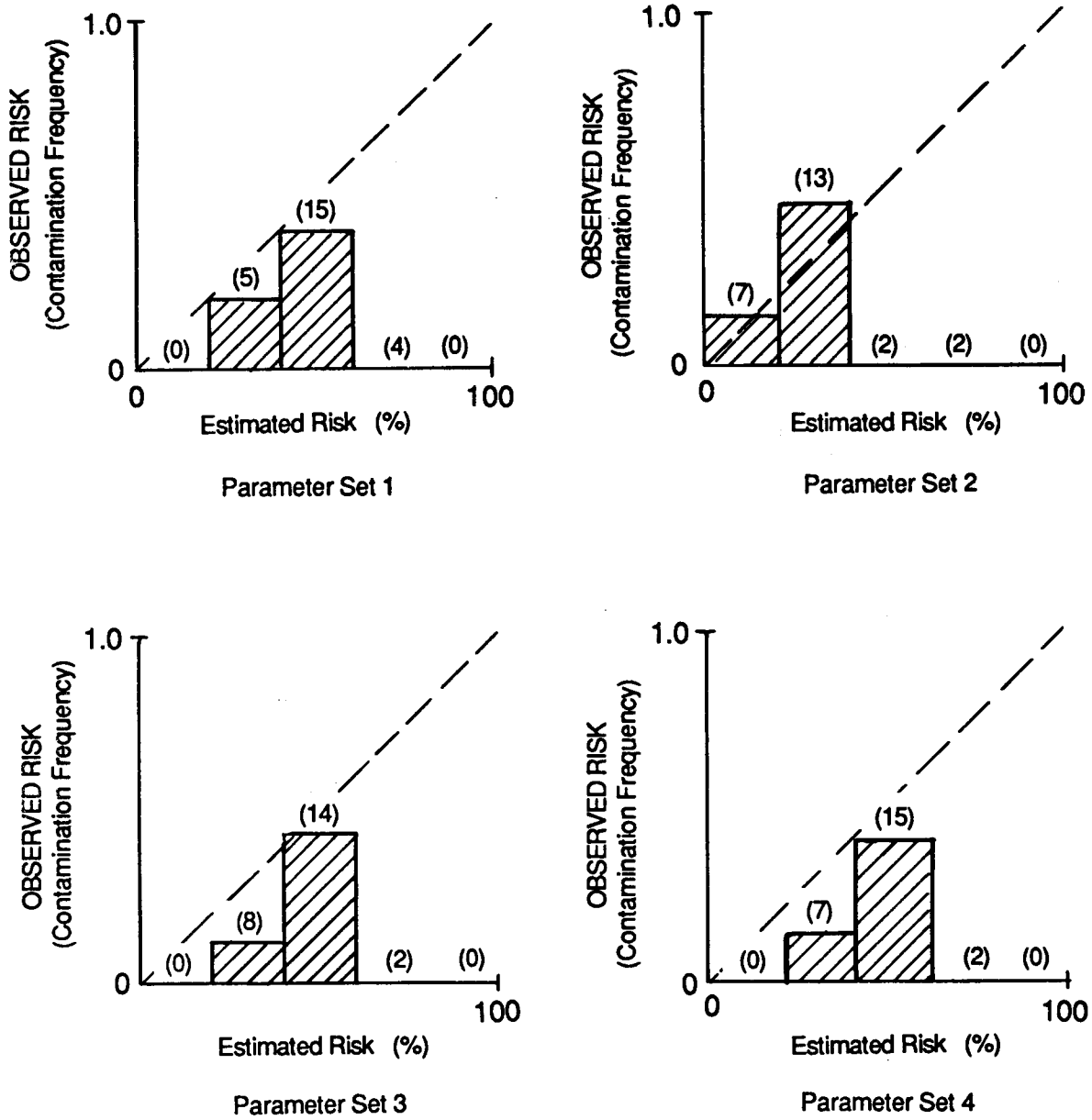


Figure 6. Map of Locations of 24 Wells Sampled for EDB and 54 (Hypothetical) Unsampled Wells in Whatcom County, Washington

in Appendix B), which provided a fairly good match between predicted and observed results, were selected. Figures 7 shows the comparison between predicted results (estimated contamination risk) and observed results (actual contamination frequency) for these four parameter sets, in histogram form. These four sets were used in the sample design phase (Level Three in the hierarchy) using the program SAMOPT.FOR to examine possible sample designs and to compare the results of the three sampling optimization approaches.

V.6.2 Sample Optimization

For each of the four model parameter sets chosen, four runs of SAMOPT.FOR were performed. In each of these four runs, a different method was used to choose a set of wells to be sampled. The first run (made once for each of the four sets of parameters) employed the optimization method described in Section IV.3.5 (no error). The second employed the binomial error characterization method described in Section IV.3.6. The last two runs both used the information content characterization method described in Section IV.3.7; however, the value of coefficients C and D (see Eq.4-8) used were C=0.1, D=0.9 for run three and C=0.5, D=0.5 for run four. The former coefficient set places high value on new information (i.e., uncertainty reduction) and little on minimization of (estimated) aggregate health risk; the latter gives equal weight to each. Note also that the method used in the first run is equivalent to the use of the information content characterization method where C=1.0, D=0.0, so that a wide range of possible coefficients have been explored.



- Numbers in parentheses represent the number of wells falling into the specified estimated risk interval
- Dashed lines represent a slope of 1.0 ("best fit")

Figure 7. Comparison of Estimated EDB Contamination Risk Versus Observed EDB Contamination Frequency in Whatcom County, Washington (See Appendix B for Parameter Values).

V.6.3 Comparison of Results

In each of the sample optimization runs made (sixteen total as described in the previous paragraph), ten unsampled wells were to be selected from the hypothetical set of 54 wells. Comparison of the wells selected in each run (and their ordering) provides insight into the effects of the choice of both sample optimization method and contamination risk estimation parameters on the sample design.

Figure 8 presents the results of the runs in bar chart form. Well number (assigned arbitrarily) is given along the vertical axis, representing the 54 wells from which the sample set is to be chosen. The length of the horizontal bar represents the number of times a particular well was chosen for sampling, and can range from zero (never chosen) to four (chosen in all four runs). The plots are separated according to the optimization method (A-D) used so that comparisons can be drawn between the results from the four methods.

For a given optimization method, the four runs represent the four different parameter sets used. Therefore, the extent to which the wells chosen vary for a given method reflects the sensitivity of that optimization method to the chosen parameters. Figure 8 shows that methods A, C, and D were relatively insensitive to the choice of model parameters (at least within the range tested), while method B (the binomial method) was quite sensitive to the choice of parameters.

Comparison between methods shows that the wells chosen by method A are those with high estimated values of contamination risk. Methods B, C,

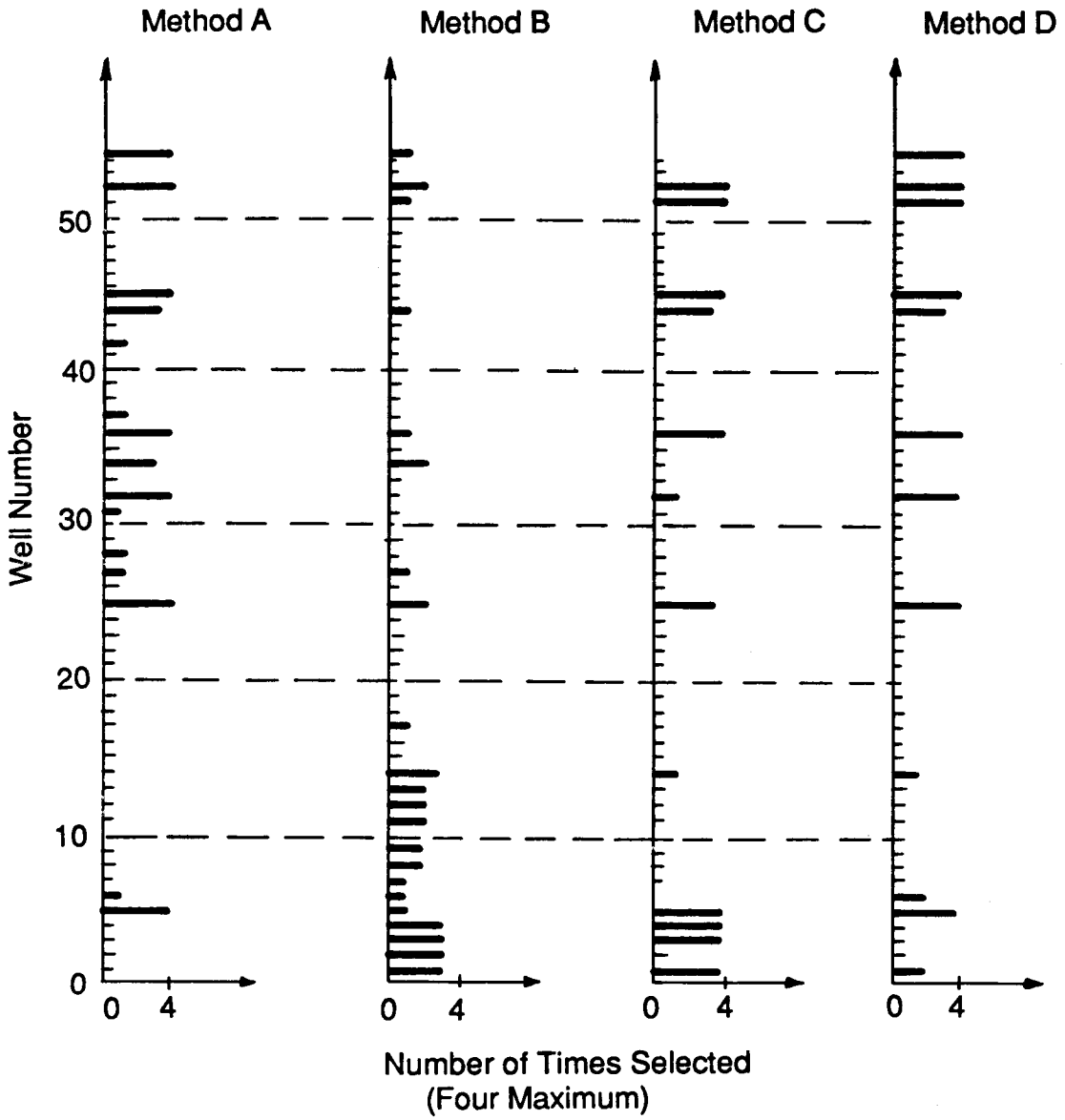


Figure 8. Comparison of Hypothetical Wells Chosen for EDB Sampling in Whatcom County, Washington Using Four Optimization Methods.

and (to a lesser extent) D, while choosing to sample some of the same high risk wells, also recommended sampling of some wells with lower estimated contamination risk values, for the purpose of contamination risk model verification. Table 5 illustrates this fact more clearly. Method A tends to select wells with the highest estimated risk, and then wells are relatively less diverse (lower standard deviation) with respect to estimated risk.

TABLE 5. Means and Standard Deviations of Estimated Contamination Risk Values of Wells Selected for Sampling using Four Sample Optimization Methods

	OPTIMIZATION METHOD			
	A	B	C	D
Mean Estimated Risk (percent)	59.6	46.9	53.1	57.3
Standard Deviation	14.0	18.0	16.9	17.8

The other methods tend to choose some low as well as high estimated contamination risk wells, leading to lower values of mean estimated contamination risk and higher standard deviations (greater diversity). As expected, method A tends to bias the sampling toward the assumed high contamination risk wells and provides less basis for verifying the contamination risk for wells which are assumed to be low risk. Another important observation which can be seen from the graph is that a few wells (in particular wells number 25 and 52) were consistently chosen in all cases regardless of optimization method and/or parameters used.

V.6.4 Rank Correlation

Rank correlation can be used as a summary index of the comparability of the sequence in which additional sampling wells are selected under

different optimization methods and assumed parameters. The rank correlation between two sequences is analogous to the Pearson product-moment correlation, except that is uses the ranks of the sequence elements rather than their numerical values. The rank correlation is defined as follows:

Let R_{1i} = the rank of well number i in a ranked sequence of length N, and

R_{2i} = the rank of well number i in a second ranked sequence, also of length N.

Then, the rank correlation is calculated as

$$p = \frac{\sum_{i=1}^{N} [R_{1i} - \mu_1] [R_{2i} - \mu_2]}{\sum_{i=1}^{N} [R_{1i} - \mu_1]^2} \qquad (5\text{-}1)$$

where $\mu_1 = \mu_2$ = the mean of the rank of the entire series = (N+1)/2.

Eq. 5-1 can be applied to calculate the correlation between the ordered ranking of two different sequences of wells (i.e., output from two different runs). In the demonstration study, 10 of 54 wells were chosen and ranked, 1 through 10. The remaining (unranked) wells, then, were assigned the average ranking (μ_i or μ_2) so as not to affect the correlation calculation.

Two notes on the rank correlation procedure follow:

1) Contrary to a normal correlation coefficient, negative correlations are not possible for the case where the number of candidate wells (10) is less than N/2. As a result, a rank

correlation of zero (the lowest possible) indicates that no wells were in the top ten of both sequences, whereas a correlation of 1.0 (the highest possible) indicates that both sequences contained the same wells in the same order.

2) The entire sequence of 54 wells could have been ranked and correlated, in which case correlations as small as -1.0 could have been obtained. However, this was not done because only the most highly ranked wells are of interest; the rank correlation (used here as a comparative indicator) should not reflect information which is irrelevant to the present decision.

Rank correlations were calculated between all 16 output sequences. The results confirmed numerically that which was observed graphically in Figure 8. Tables 6a through 6d give the correlations between results of the different optimization methods for each parameter set, and reflect the extent to which results are sensitive to the method used. Tables 7a through 7d show the correlations between results using various parameter sets for each optimization method, and reflect the extent to which the choice of parameters affects the sampling design.

Note (in Tables 7a through 7d) that the results obtained using method A are highly correlated to those obtained using method D (ranging from 0.776 to 0.836, depending on which parameter set was used). They have less correlation to the results from method C, however. This illustrates the effect of changing the coefficients C and D in Eq. 4-8. A larger value of C tends to give results more like those obtained using method A, which would generally be inappropriate in the initial stages of a

Table 6a-d. Rank Correlations Between Sequences of Wells Selected for Sampling Using Four Optimization Methods (for Alternative Parameter Sets, Values of which are given in Appendix B).

OPTIMIZATION METHOD

	A	B	C	D
A	1.0	.722	.549	.811
B	---	1.0	.409	.560
C	---	---	1.0	.773
D	---	---	---	1.0

6a. Parameter Set 1

OPTIMIZATION METHOD

	A	B	C	D
A	1.0	.397	.566	.816
B	---	1.0	.585	.574
C	---	---	1.0	.789
D	---	---	---	1.0

6b. Parameter Set 2

OPTIMIZATION METHOD

	A	B	C	D
A	1.0	.000	.547	.836
B	---	1.0	.366	.000
C	---	---	1.0	.681
D	---	---	---	1.0

6c. Parameter Set 3

OPTIMIZATION METHOD

	A	B	C	D
A	1.0	.000	.459	.776
B	---	1.0	.449	.069
C	---	---	1.0	.670
D	---	---	---	1.0

6d. Parameter Set 4

Table 7a-d. Rank Correlations Between Sequences of Wells Selected for Sampling Using Four Parameter Sets (Parameter Values are given in Appendix B)

PARAMETER SET	1	2	3	4
1	1.0	.864	.937	.867
2	---	1.0	.850	.777
3	---	---	1.0	.868
4	---	---	---	1.0

7a. Method A

PARAMETER SET	1	2	3	4
1	1.0	.378	.000	.000
2	---	1.0	.463	.463
3	---	---	1.0	1.0
4	---	---	---	1.0

7b. Method B

PARAMETER SET	1	2	3	4
1	1.0	.931	.934	.825
2	---	1.0	.999	.891
3	---	---	1.0	.887
4	---	---	---	1.0

7c. Method C

PARAMETER SET	1	2	3	4
1	1.0	.999	.894	.825
2	---	1.0	.892	.825
3	---	---	1.0	.912
4	---	---	---	1.0

7d. Method D

sampling program (for reasons discussed previously). A small value of the coefficient C, however, will give a sample design different from that of A, placing some sampling effort into wells with low estimated contamination risk, which would be desirable in early stages of a sampling program.

V.6.5 Summary

It has been shown that several factors influence the choice of which wells to sample. The most important of these are soil type, proximity to a known contaminated well, and well depth normalization of related contamination susceptibility indices and their combination according to the three objective functions investigated provide a rationale by which to make decisions as to which wells to sample.

The sensitivity analysis clearly indicated that wells number 25 and 52 should be sampled, since they tended to be highly ranked regardless of optimization method or model parameter set used. None of the parameter sets provide a clearly superior calibration. In addition, the correlation pattern between the results of the various sample optimization methods confirms that with only 24 sampled wells, the sampling program is still in the initial stage. It would therefore be prudent to assign greater priority to sampling those wells recommended using optimization methods B and C. Wells which ranked high in both methods were wells number 1, 3, and 4 (as well as the previously mentioned 25 and 52). Therefore, there is reasonable consensus across parameters and objective functions that wells number 1, 3, 4, 25, and 52 should be included in the next round of field sampling.

It should be again noted that these wells do not actually exist; the purpose of the demonstration is not to recommend specific sampling sites in Whatcom County, but rather to demonstrate a methodology which could be employed in such a sampling program. However, application to a set of actual candidate wells would be straightforward.

CHAPTER VI: CONCLUSIONS

VI.1 SUMMARY

The design of sampling programs for detection of agricultural chemicals in groundwater is a difficult task. A review of groundwater pesticide sampling programs which have been undertaken to date indicate that a lack of direction has existed in many past studies. The lack of focus generally has resulted from failure to clearly define sampling program objectives and to relate data collection priorities to those objectives. Even in California, where a very large sampling program for DBCP was undertaken (over 8,000 wells sampled), Holden (1986) reported that due to the lack of specific study objectives, the data obtained were limited in the scope of their applicability.

In this report, a methodology has been described which provides a framework for clear definition of objectives and data needs, enabling efficient design of sampling programs. The framework consists of a three level hierarchy. Once study objectives and data needs have been defined at the top level of the hierarchy, specific analytical methods are used (in the second level) to link well contamination risk to certain susceptibility factors and (in the third level) to select wells for sampling in a multi-stage sampling process.

The methodology was applied to a specific problem, the contamination of drinking water in Whatcom County, Washington by the pesticide EDB. The application study demonstrated:

1) The use of available data to estimate the probability of

contamination (contamination risk) for each well in the study area, and

2) The use of contamination risk estimates to guide future sampling as part of a multi-stage, iterative sampling program.

Advantages of implementing the methodology on a personal computer were also demonstrated. These advantages include the following:

1) Easy storage and access of data;

2) Ability to view the effect of varying parameters quickly and easily by making multiple sensitivity runs;

3) Ease of comparison of sample designs resulting from use of various sample optimization methods; and

4) Graphical presentation of data and results.

The proposed approach is generally applicable to the problem of groundwater contamination by agricultural chemicals, and not just to EDB. Many pesticides and herbicides are currently of concern because of their potential presence in drinking water. Sampling programs presently being undertaken to study these problems could clearly benefit from structuring of the monitoring design decision process as proposed and demonstrated.

VI.2 RECOMMENDATIONS FOR FUTURE STUDY

The value and feasibility of the monitoring design approach developed in this research have been clearly demonstrated. Some important directions

which future extensions of this work could pursue have been identified during the course of this study, and are outlined here:

1) A large number of agricultural chemicals pose health concerns; within a given area, many such chemicals may have concurrently been used. Consideration should be given as to how this approach could be expanded to enable simultaneous monitoring of several chemical compounds.

2) In the application of Bayes' Theorem to the binomial error characterization method of sample design (see Section IV.3.6), an assumption of no prior knowledge regarding the distribution of p was made. It might be possible to use information from the contamination risk estimation scheme to impose a prior probability distribution of p other than uniform.

3) The number of actual samples taken in the DSHS study (DSHS, 1985), on which the demonstration study was based, was small. Application of the proposed strategy to a case in which a large number of sample data were available, such as in the California study of DBCP or the Florida EDB study (see Holden, 1986), would be beneficial.

REFERENCES

Bogardi, I., A. Bardossy, and L. Duckstein (1985). "Multicriterion network design using geostatistics", Water Resources Research, Vol. 21, No. 2, Feb., 1985, pp. 199-208.

Bras, R.L. and I. Rodriguez-Iturbe (1976). "Network design for the estimation of areal mena of rainfall events", Water Resources Research, Vol. 12, No. 6, Dec., 1976, pp. 1185-1195.

Brown, Albert F, Jr. (1984). "Ethylene Dibromide . . . Its use, hazards, recent regulatory action", Journal of Environmental Health, Vol. 46, No. 5, pp. 220-225.

California Department of Food and Agriculture (1983). "Pesticide movement to ground water - Volume I: Survey of ground water basins for DBCP, EDB, SIMAZINE, and CARBOFURAN", Jan., 1983.

California Department of Food and Agriculture (1984). "Pesticide movement to ground water - Volume 2: Pesticide contamination in the soil profile at DBCP, EDB, SIMAZINE, and CARBOFURAN application sites", April, 1984.

Fanini, D., M.S. Legator, and P.M. Adams. "Effects of paternal ethylene dibromide exposure on F-1 generation in the rat", Mutation Research, Vol. 139, No. 3, March 1984, pp. 133-38.

Holden, P.W. (1986). "Pesticides and groundwater quality; issues and problems in four states", National Academy Press, Washington, D.C., 1986.

Javendal,I. and C.F. Tsang (1985). "Capture-Zone Type Curves: A Tool for Aquifer Cleanup", Lawrence Berkeley Laboratory LBL-19843, University of California, Berkeley, July, 1985.

Lettenmaier, D.P., D.E. Anderson, and R.N. Brenner (1984). "Consolidation of a stream quality monitoring network", Water Resources Bulletin, Vol. 20, No. 4, Aug., 1984, pp. 473-481.

Mackay, D.M., P.V. Roberts, and J.A. Cherry (1985). "Transport of organic contaminants in groundwater", Environmental Science and Technology, Vol. 19, No. 5, pp. 384-392.

Media Cybernetics, Inc. (1986) HALO Version 2.26A, Silver Spring, Maryland.

Moss, M.E. , and M.R. Karlinger (1974). "Surface water network design by regression analysis simulations", Water Resources Research, Vol. 10, No. 3, pp. 427-433, June, 1974.

Moss, M.E. (1979). "Some basic considerations in the design of hydrologic data networks", Water Resources Research, Vol. 15, No. 6, Dec., 1979, pp. 1673-1676.

Olson, W.A. et al. (1973). "Induction of stomach cancer in rats and mice by halogenated aliphate fumigants", Journal of the National Cancer Institute, Vol. 51 No. 6, pp. 1993-95.

Ott, M.E. (1980). "Mortality experience of 161 employees exposed to ethylene dibromide in two production units", British Journal of Industrial Medicine, No. 37 pp.163-68.

Rodriguez-Iturbe, I., and J.M. Mejia (1974). "The design of rainfall networks in time and space", Water Resources Research, Vol. 10, No. 4, Aug., 1974, pp. 713-728.

Short, R.D. et al. (1978). "Inhalation of EDB during gestation by rats and mice", Toxicology and Applied Pharmacology, Vol. 49 No. 11, pp. 173-82.

Short, R.D. (1979). "Effects of ethylene dibromide on reproduction in male and female rats", Toxicology and Applied Pharmacology, Vol. 49 No. 1, pp. 97-106.

Smith, R.F. and L. Goldman (1983). "Behavioral effects of prenatal exposure to ethylene dibromide", Neurobeh. Toxicol. and Teratology, Vol. 5, No. 5 pp.579-85.

Strecker, E.W., W.S. Chu, and D.P. Lettenmaier (1985). "Evaluation of data requirements for groundwater contaminant transport modeling", University of Washington, Water Resources Series Technical Report No. 94, Department of Civil Engineering.

United States Department of Agriculture (1953). "Soil Survey, Whatcom County, Washington", Soil Conservation Service Series 1941, No. 7.

U.S. Environmental Protection Agency (1983a). "EDB, intent to cancel registrations of pesticide products containing EDB; notice of intent to cancel", Federal Register 48:197.

U.S. Environmental Protection Agency (1983b). "Ethylene dibromide (EDB) position document 4", Office of Pesticide Programs.

U.S. Environmental Protection Agency (1984). "Scientific Support and Decision Document for Grain and Grain Milling Fumigation Uses", Office of Pesticide Programs.

U.S. Fish and Wildlife Service (1974). Systems Applications Group Information System (SAGIS), 1974. (Presently maintained by the National Park Service, Denver, Colorado).

U.S. Geological Survey (1984a). "National water summary 1984", U.S. Geological Water Supply Paper 2275, U.S. Government Printing Office, 1985.

U.S. Geological Survey (1984b). "Investigation of ethylene dibromide (EDB) in ground water in Seminole County, Georgia", by McConnell, J. B. and others, USGS Circular 933.

Ward, R.C., and D.H. Vanderholm (1973). "Cost effectiveness methodologies for data acquisition in water quality management", Water Resources Research, Vol. 9, No. 3, 1973, pp. 536-545.

Washington Administration Code (1983). Vol. 4, No. 248.

Washington State Department of Ecology (1986). "Phase I Investigation, Ethylene Dibromide Sites, Thurston and Skagit Counties", Remedial Action Division, Office of Hazardous Substances and Air Quality, February, 1986.

Washington State Department of Social and Health Services DSHS (1985). "Results and implications of the investigation of ethylene dibromide in ground water in Western Washington", Feb., 1985.

Wood, E.F. (1979). "A statistical approach to station discontinuance", Water Resources Research, Vol. 15, No. 6, Dec., 1979, pp. 1859-1866.

APPENDIX A: PROGRAM CODE LISTINGS

A.1 DATIN.BAS

```
10  '*********************************************************
20 '
30 '      INTERACTIVE DATA INPUT DRIVER FOR THE GROUNDWATER
40 '        MONITORING SAMPLE DESIGN PROGRAM "SAMPDES"
50 '
60 '*********************************************************
65 KEY OFF
70 COLOR 15,9
80 CLS
90 PRINT" ********************************************************************************"
100 PRINT" ********************************************************************************"
110 PRINT" "
120 PRINT"            GROUNDWATER PESTICIDE MONITORING PROGRAM"
130 PRINT" "
140 PRINT"                        Developed by
150 PRINT"                    "
160 PRINT"                        University of Washington"
170 PRINT"                        Department of Civil Engineering"
180 PRINT"                        Environmental Engineering and Science Program"
190 PRINT"                        June, 1987"
200 PRINT"
210 COLOR 11,9
220 PRINT"            This program has been developed as part of a master's"
230 PRINT"            thesis project at the Univ. of Washington.  The research"
240 PRINT"            was funded in part through a grant from the State of "
250 PRINT"            Washington Water Research Center and matching funds from"
260 PRINT"            the State of Washington Department of Social and Health"
270 PRINT"            Services and Department of Ecology."
280 PRINT"          "
290 PRINT"            Press ENTER to continue":PRINT" "
295 COLOR 15,9
300 PRINT" ********************************************************************************"
310 PRINT" ********************************************************************************"
320 INPUT"",DUM1
330 CLS
350 PRINT" ********************************************************************************"
360 PRINT" ********************************************************************************"
370 PRINT" "
380 PRINT" "
390 PRINT" "
400 COLOR 14,9
410 PRINT"       This program is experimental in nature.  Users should be
420 PRINT"         aware that it is";:COLOR 4,9:PRINT" not a predictive model";
430 COLOR 14,9
440 PRINT".  Actual contamination of"
450 PRINT"         a specific site can be determined only through laboratory"
460 PRINT"         testing of field samples, and the source of such contamination"
470 PRINT"         will in most cases not be known with certainty."
480 PRINT"
```

```
490 PRINT"       This program is intended simply as a tool for determining the"
500 PRINT"         most efficient sampling strategy based upon the limited data"
510 PRINT"         available."
520 PRINT"    "
530 PRINT" "
540 PRINT"             Press ENTER to continue"
550 PRINT" "
560 PRINT" "
570 PRINT" "
580 PRINT" "
590 COLOR 15,9
600 PRINT" ********************************************************************************"
610 PRINT" ********************************************************************************"
620 INPUT"",DUM1
630 CLS
640 PRINT" "
650 PRINT" "
660 COLOR 13,9:PRINT"                          DATA INPUT/MODIFICATION   "
670 COLOR 15,9
680 PRINT" ":PRINT"          Weighting coefficients, exponents, threshold values,"
690 PRINT"               and category definitions must be set for each of the "
700 PRINT"               three risk determination variables.  There are two "
710 PRINT"               methods available for input of this data.
720 PRINT" "
730 PRINT" "
740 PRINT"          Please choose one of the following:
750 PRINT" "
760 PRINT"              1) Input Data Interactively from Keyboard/Screen
770 PRINT"              2) Read Data from an Existing File and Modify Interactively"
780 PRINT"     "
790 PRINT" "
800 INPUT;"         Enter 1 or 2: ",ANS1
810 IF ANS1=1 THEN GOTO 850
820 IF ANS1=2 THEN GOSUB 12000
825 IF ANS1=2 THEN GOTO 885
830 PRINT" "
840 GOTO 800
850 '+++++++++++++++INITIALIZE VARIABLES++++++++++++++++++
855 NLC=9:TC=15
857 LW1=100:LW2=80:LW3=60:LW4=60:LW5=40:LW6=40:LW7=20:LW8=85:LW9=0
860 NDIV=5:DDIV=50:EXP3=1
865 W1=.4:W2=.25:W3=.15:W4=.12:W5=.08
870 DMAX=500:EXP1=5:XMAX=5000:EXP2=2!
875 A=.6:B=.3:C=.1
885 '+++++++++++++++INITIALIZE COLORS++++++++++++++++++++
886 RED=4:BLUE=9:BROWN=6:GREY=7:BGRN=10:PRPL=5
887 BYELL=14:WHITE=15:BBLUE=11:BPRPL=13:BRED=12
888 FRED=20:TC=WHITE
890 CLS
900 PRINT" "
910 PRINT" "
920 COLOR 14,9:PRINT"                              INTERACTIVE DATA INPUT "
930 PRINT" "
940 COLOR 15,9
```

```
950 PRINT"   EQUATION FORM 1:"
960 PRINT" ":PRINT"     Well Depth (to the water table) is one of the risk determination factors."
970 PRINT"     The following equation is used to calculate the level of risk"
980 PRINT"     due to well depth:":PRINT" "
990 PRINT"            R1 = 100 * ((DMAX-DEPTH)/DMAX)**EXP1":PRINT" "
1000 PRINT"     Where":PRINT" "
1010 PRINT"            DMAX = A threshold well depth (feet) beyond which the risk "
1020 PRINT"                   of contamination is assumed to be negligible, "
1030 PRINT"                   and above which the risk decreases as depth"
1040 PRINT"                   increases.";:COLOR 4,9:PRINT" (Default =";DMAX;")":COLOR 15,9
1050 PRINT"            EXP1 = An exponent which allows the relationship"
1060 PRINT"                   between contamination risk and depth to be "
1070 PRINT"                   non-linear to the degree specified.";:COLOR 4,9:PRINT" (Default
=";EXP1;")":COLOR 15,9
1080 PRINT" "
1090 COLOR 14,9
1100 INPUT"   Would you like to use values other than the default (Y or N)";ANS2$
1110 IF ANS2$="Y" OR ANS2$="y" THEN GOTO 1180
1120 COLOR 26,9
1130 PRINT"                      DEFAULT VALUES USED
1140 FOR I=1 TO 5000:NEXT I  ' use 5000
1150 COLOR 15,9
1160 CLS
1170 GOTO 1210
1180 PRINT"":COLOR 11,9
1190 INPUT"            EXP1";EXP1
1200 INPUT"            DMAX";DMAX
1210 FOR I=1 TO 1500:NEXT I
1220 CLS
1230 PRINT""
1240 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
1250 PRINT" "
1260 COLOR 15,9
1270 PRINT"   EQUATION FORM 2:"
1280 PRINT" ":PRINT"        The second risk determination factor is the distance":PRINT"        from a
previously sampled well.  The equation used to ":PRINT"        evaluate the risk due to this factor is:"
1290 PRINT" "
1300 PRINT"              Risk = A * ((X-XMAX)/XMAX)**EXP2"
1310 PRINT"":PRINT"         where"
1320 PRINT"":PRINT"           A = -1 if the sampled well tested negative,and"
1330 PRINT"             1 if the sampled well tested positive."
1340 PRINT"          X = distance to sampled well (feet).
1350 PRINT"          XMAX = threshold distance (feet) beyond which no correlation"
1360 PRINT"                 can be assumed.";:COLOR 4:PRINT" (Default=";XMAX;")":COLOR 15
1370 PRINT"          EXP2 = An exponent which allows the relationship"
1380 PRINT"                 between contamination risk and distance to be "
1390 PRINT"                 non-linear to the degree specified.";:COLOR 4,9:PRINT" (Default
=";EXP2;")":COLOR 15,9
1400 PRINT" "
1410 COLOR 14,9
1420 INPUT"   Would you like to use values other than the default (Y or N)";ANS2$
1430 IF ANS2$="Y" OR ANS2$="y" THEN GOTO 1490
1440 COLOR 26,9
1450 PRINT"                      DEFAULT VALUES USED
```

```
1460 FOR I=1 TO 5000:NEXT I  ' use 5000
1470 COLOR 15,9
1480 GOTO 1530
1490 PRINT"":COLOR 11,9
1500 INPUT"            EXP2";EXP2
1510 INPUT"            XMAX";XMAX
1520 FOR I=1 TO 1500:NEXT I
1530 CLS
1540 PRINT""
1550 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
1560 PRINT" "
1570 COLOR 15,9
1580 PRINT"   EQUATION FORM 3:":PRINT""
1590 PRINT"     The final factor used to estimate risk is the land use"
1600 PRINT"     factor, the use of which is more complicated than the first"
1610 PRINT"     two factors.  A 'capture zone' is derived for each well based"
1620 PRINT"     upon the estimated regional flow gradient and direction, the "
1630 PRINT"     estimated transmissivity, and the average pumping rate of the well"
1640 PRINT"     (following the method of Javendal et al., 19**)."
1650 PRINT" "
1660 PRINT"     Then, the capture zone is divided into a number of segments"
1670 PRINT"     according to distance from the well.  Risk weights are established"
1680 PRINT"     for various land uses and the percentage of each land use within"
1690 PRINT"     each segment of the capture zone calculated.  Finally, then, the"
1700 PRINT"     risk is simply the area-weighted sum of the land-use risk factors."
1710 PRINT"     This method requires input of the following information:"
1720 PRINT" ":INPUT"          (Press ENTER to see next page)",ANS1
1730 CLS
1740 PRINT" "
1750 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
1760 COLOR 15,9:PRINT""
1770 PRINT"   (EQUATION FORM 3 continued)":PRINT""
1780 PRINT"     Input required:":PRINT""
1790 PRINT"       * NLC = Number of land-use categories to be used.
1800 PRINT"       * Risk weights (between 0 and 100, where 100 is the highest"
1810 PRINT"         risk possible) for each of the NLC categories.
1820 PRINT"       * NDIV = Number of sub-areas which the capture zone is to be"
1830 PRINT"         divided into.
1840 PRINT"       * Area weights (between 0 and 1 summing to 1.0) for each of"
1850 PRINT"         the NDIV sub-areas.
1860 PRINT"       * DDIV = The travel time from the well to the first 'upstream'"
1870 PRINT"         sub-area dividing line.
1880 PRINT"       * EXP3 = An exponent used to increase the travel time between"
1890 PRINT"         sub-area dividing lines as distance from the well increases."
1900 PRINT""
2000 PRINT"     Default values for the above variables have been established; you"
2010 PRINT"     will at this time be given an opportunity to view them, and change"
2020 PRINT"     them if desired.":PRINT""
2030 INPUT"                    Press ENTER to continue",ANS1
2040 CLS:PRINT""
2050 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
2060 COLOR 15,9:PRINT""
2070 PRINT"   (EQUATION FORM 3 continued)":PRINT""
2080 COLOR 15
```

```
2090 COLOR 14:PRINT "     ";NLC;:COLOR 15:PRINT" land-use categories have been established. They
are:":PRINT"":COLOR NLC:PRINT,,,," WEIGHT":COLOR TC
2100 PRINT"        1) Known EDB application areas",:COLOR NLC:PRINT," (";LW1;")":COLOR TC
2110 PRINT"        2) High risk soil type in crop growth area",:COLOR NLC:PRINT" (";LW2;")":COLOR TC
2120 PRINT"        3) -------''-------- outside crop growth area",:COLOR NLC:PRINT" (";LW3;")":COLOR TC
2130 PRINT"        4) Medium risk soil type in crop growth area",:COLOR NLC:PRINT" (";LW4;")":COLOR TC
2140 PRINT"        5) -------''-------- outside crop growth area",:COLOR NLC:PRINT" (";LW5;")":COLOR TC
2150 PRINT"        6) Low risk soil type in crop growth area",:COLOR NLC:PRINT" (";LW6;")":COLOR TC
2160 PRINT"        7) -------''-------- outside crop growth area",:COLOR NLC:PRINT" (";LW7;")":COLOR TC
2170 PRINT"        8) Documented EDB-type crop growth field",:COLOR NLC:PRINT" (";LW8;")":COLOR TC
2180 PRINT"        9) Surface water area",:COLOR NLC:PRINT," (";LW9;")":COLOR TC
2185 PRINT""
2190 INPUT"       Would you like to change any of the weights (Y or N)";ANS$
2200 IF ANS$="y" OR ANS$="Y" THEN GOSUB 5000 ELSE GOTO 2250
2210 GOTO 2040
2250 ' continue
2260 CLS:PRINT""
2270 COLOR 14,9:PRINT"                              INTERACTIVE DATA INPUT "
2280 COLOR 15,9:PRINT""
2290 PRINT"   (EQUATION FORM 3 continued)":PRINT""
2300 PRINT"       Number of sub-areas is";NDIV
2310 PRINT"       Travel time to first sub-area division line is";DDIV;"days
2320 PRINT"       Travel time increment exponent is";EXP3
2330 PRINT""
2332 PRINT"      Sub-Area         Travel Time From Well (days)     Weighting Factor"
2333 DO=0:DN=DDIV
2334 PRINT"              ","FROM"," TO "
2335 PRINT"      ********","*****","*****","*************"
2337 PRINT"         1    ",DO,DN,"    ";W1
2338 DO=DDIV
2339 INC=DDIV
2340 FOR I=2 TO NDIV
2350 INC=INC^EXP3
2360 DN=DO+INC
2361 IF I=2 THEN WT=W2
2362 IF I=3 THEN WT=W3
2363 IF I=4 THEN WT=W4
2364 IF I=5 THEN WT=W5
2365 IF I=6 THEN WT=W6
2366 IF I=7 THEN WT=W7
2367 IF I=8 THEN WT=W8
2368 IF I=9 THEN WT=W9
2369 IF I=10 THEN WT=W10
2370 PRINT"        ";I;"   ",DO,DN,"    ";WT
2380 DO=DN
2390 NEXT I
2400 WSUM=W1+W2+W3+W4+W5+W6+W7+W8+W9+W10
2401 DIFF=ABS(WSUM-1!)
2410 IF DIFF<.001 THEN GOTO 2500
2414 PRINT,,,"                 ********"
2415 COLOR 22
2420 PRINT,,,"SHOULD BE 1.0!!  ";WSUM
2425 COLOR 15
2500 PRINT""
```

```
2510 PRINT"   You may:      1) Use these values"
2520 PRINT"                 2) Change travel time to first sub-area division
2530 PRINT"                 3) Change the exponent
2540 PRINT"                 4) Change one or more of the weights
2550 PRINT"                 5) Change the number of sub-areas
2560 INPUT"   Which would you like to do";ANS
2570 IF ANS=1 THEN GOTO 2700
2580 IF ANS=2 THEN GOSUB 6000
2590 IF ANS=3 THEN GOSUB 7000
2600 IF ANS=4 THEN GOSUB 8000
2605 IF ANS=5 THEN GOSUB 9500
2610 GOTO 2260
2700 ' continue
2710 CLS:PRINT""
2720 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
2730 COLOR 15,9:PRINT""
2740 PRINT"   OVERALL WEIGHTING FACTORS":PRINT""
2750 PRINT"     The equation used to calculate the overall estimated risk for"
2760 PRINT"     each well is as follows:":PRINT""
2770 PRINT"         Risk = (A * R1) + (B * R2) + (C * R3)":PRINT""
2780 PRINT"     where":PRINT""
2790 PRINT"         R1 = the risk associated with the well depth as calculated"
2800 PRINT"              using equation form 1"
2810 PRINT"         R2 = the risk associated with the distance from sampled wells"
2820 PRINT"              as calculated using equation form 2
2830 PRINT"         R3 = the risk associated with the land use as calculated "
2840 PRINT"              using equation form 3"
2850 PRINT"         A, B, and C = weighting factors (between 0 and 1 and summing"
2860 PRINT"                       to 1.0) which reflect the relative importance"
2870 PRINT"                       of factors 1, 2, and 3, respectively.
2880 PRINT""
2890 INPUT"         Press ENTER to see next page",ANS
2910 CLS:PRINT""
2920 COLOR 14,9:PRINT"                          INTERACTIVE DATA INPUT "
2930 COLOR 15,9:PRINT""
2940 PRINT"   OVERALL WEIGHTING FACTORS (continued)":PRINT""
2950 PRINT"     The values of A, B, and C have been set as follows:"
2960 PRINT"":COLOR BYELL
2970 PRINT"                 A =";A
2980 PRINT"                 B =";B
2990 PRINT"                 C =";C
2991 OWSUM=A+B+C
2993 DIFF=ABS(OWSUM-1!)
2994 IF DIFF<.001 THEN GOTO 3000
2995 PRINT"                 ******":COLOR FRED
2996 PRINT"                 ";OWSUM;"    SHOULD BE 1.0 !!"
3000 PRINT:COLOR WHITE:INPUT"     Would you like to change any of these (Y or N)";ANS$
3010 IF ANS$="y" OR ANS$="Y" THEN GOSUB 14000
3020 IF ANS$="n" OR ANS$="N" THEN GOTO 3050
3030 GOTO 2910
3050 'continue
3060 '  make output file
3070 CLS:PRINT:PRINT
3080 PRINT"   All necesssary parameter values have been set.  Now, they will"
```

```
3090 PRINT"   be saved in a permanent file for for future modification and use."
3100 PRINT""
3110 INPUT"   Enter the name you wish to give the output file: ",FILOT$
3120 OPEN "O" ,#2,FILOT$
3130 PRINT #2,USING "#####.## ";DMAX;EXP1
3140 PRINT #2,USING "#####.## ";XMAX;EXP2
3150 PRINT #2, NLC
3160 PRINT #2,USING "####.## ";LW1;LW2;LW3;LW4;LW5;LW6;LW7;LW8;LW9
3170 PRINT #2, NDIV
3180 PRINT #2,USING "#.#### ";W1;W2;W3;W4;W5;W6;W7;W8;W9;W10
3190 PRINT #2,USING "#####.### ";DDIV,EXP3
3200 PRINT #2,USING "#.#### ";A;B;C
3210 PRINT""
4998 CLOSE
4999 SYSTEM
5000 PRINT""
5010 INPUT"       Which one";ANS
5040 IF ANS=1 THEN INPUT"       New Weight";LW1
5050 IF ANS=2 THEN INPUT"       New Weight";LW2
5060 IF ANS=3 THEN INPUT"       New Weight";LW3
5070 IF ANS=4 THEN INPUT"       New Weight";LW4
5080 IF ANS=5 THEN INPUT"       New Weight";LW5
5090 IF ANS=6 THEN INPUT"       New Weight";LW6
5100 IF ANS=7 THEN INPUT"       New Weight";LW7
5110 IF ANS=8 THEN INPUT"       New Weight";LW8
5120 IF ANS=9 THEN INPUT"       New Weight";LW9
5130 RETURN
6000 PRINT""
6010 INPUT"   New initial travel time";DDIV
6020 RETURN
7000 PRINT""
7010 INPUT"   New exponent";EXP3
7020 RETURN
8000 PRINT""
8010 INPUT"   Which weight do you want to change (enter corresponding area number)";ANSX
8020 IF ANSX=1 THEN GOSUB 8100
8030 IF ANSX=2 THEN GOSUB 8200
8040 IF ANSX=3 THEN GOSUB 8300
8045 IF ANSX=4 THEN GOSUB 8400
8050 IF ANSX=5 THEN GOSUB 8500
8055 IF ANSX=6 THEN GOSUB 8600
8056 IF ANSX=7 THEN GOSUB 8700
8058 IF ANSX=8 THEN GOSUB 8800
8059 IF ANSX=9 THEN GOSUB 8900
8060 IF ANSX=10 THEN GOSUB 9000
8070 PRINT"":INPUT"   Would you like to make another change (Y or N)";ANS$
8075 IF ANS$="Y" OR ANS$="y" THEN GOTO 8000
8080 RETURN
8100 PRINT""
8101 INPUT"   New weight for area 1";W1
8110 RETURN
8200 PRINT""
8210 INPUT"   New weight for area 2";W2
8220 RETURN
```

```
8300 PRINT""
8310 INPUT"   New weight for area 3";W3
8320 RETURN
8400 PRINT""
8410 INPUT"   New weight for area 4";W4
8420 RETURN
8500 PRINT""
8510 INPUT"   New weight for area 5";W5
8520 RETURN
8600 PRINT""
8610 INPUT"   New weight for area 6";W6
8620 RETURN
8700 PRINT""
8710 INPUT"   New weight for area 7";W7
8720 RETURN
8800 PRINT""
8810 INPUT"   New weight for area 8";W8
8820 RETURN
8900 PRINT""
8910 INPUT"   New weight for area 9";W9
8920 RETURN
9000 PRINT""
9010 INPUT"   New weight for area 10";W10
9020 RETURN
9500 PRINT""
9510 INPUT"   Number of sub-areas";NDIV
9511 IF NDIV<=10 THEN GOTO 9520
9512 PRINT"":COLOR 14:PRINT"   Sorry, the maximum number is 10.  Please try again.":COLOR 15: GOTO 9500
9520 PRINT""
9530 COLOR 14:PRINT"   Note:  The weights have all been set to 0.0 and must be changed !! "
9540 COLOR 15
9560 INPUT"       Press ENTER to continue",ANS
9570 W1=0!:W2=0!:W3=0!:W4=0!:W5=0!:W6=0!:W7=0!:W8=0!:W9=0!:W10=0!
9580 RETURN
12000 CLS:PRINT""
12010 INPUT"  Enter name of existing parameter input file: ",FILIN$
12020 OPEN "I" ,#1,FILIN$
12030 INPUT #1, DMAX, EXP1, XMAX, EXP2, NLC, LW1,LW2,LW3,LW4,LW5,LW6,LW7,LW8,LW9, NDIV,
W1,W2,W3,W4,W5,W6,W7,W8,W9,W10, DDIV, EXP3, A, B, C
13000 RETURN
14000 PRINT""
14010 INPUT"    Which one (A, B, or C)";ANS$
14020 IF ANS$="a" OR ANS$="A" THEN INPUT"   New A";A
14030 IF ANS$="b" OR ANS$="B" THEN INPUT"   New B";B
14040 IF ANS$="c" OR ANS$="C" THEN INPUT"   New C";C
14050 RETURN
```

A.2 WELLDAT.BAS

```
10 CLS
20 COLOR 11,5
30 CLS
40 PRINT
50 PRINT
60 PRINT"                          WELL DATA INPUT PHASE"
70 PRINT
80 PRINT"     Input data for each of the water wells, both those already"
90 PRINT"       sampled and those to be considered for sampling, is required."
100 PRINT
150 PRINT"     Well data can be provided in one of three manners:"
160 PRINT"
170 PRINT"       1)  From an existing well file, without modification,
180 PRINT"       2)  From an existing well file, but with modifications, or
190 PRINT"       3)  Interactive input of new data.
200 PRINT"
210 INPUT"     Which of these do you prefer";ANS1
220 IF ANS1=1 THEN GOSUB 260
230 IF ANS1=2 THEN GOSUB 1000
240 IF ANS1=3 THEN GOSUB 2000
250 SYSTEM
260 PRINT:PRINT:
270 COLOR 4
280 PRINT"     NO MODIFICATIONS REQUESTED; CONTINUING TO NEXT PHASE"
290 PRINT:PRINT:PRINT:
300 COLOR 1
310 INPUT"     Press ENTER to continue",ANS2
320 RETURN
1000 CLS:PRINT:PRINT
1010 INPUT"   Name of existing well file";WELFIL$
1020 OPEN "I" ,#1,WELFIL$
1030 INPUT #1, NWCAL, NWSAM
1040 PRINT
1050 PRINT"   File contains data for",NWCAL,"calibration wells and"
1060 PRINT"                          ",NWSAM,"unsampled wells."
1061 PRINT:PRINT
1065 '**********ARRAY DIMENSIONS**************************
1066 NWCMX=100:'    Max. number of calibration wells
1067 NWSMX=200:'    Max. number of sample wells
1068 NWNMX=5:'     Max. number of proximate wells
1070 DIM WDESC$(NWCMX), WDEPC(NWCMX), NNEAR(NWCMX), WCONC(NWCMX,NWNMX), XC(NWCMX), YC(NWCMX),
WCONT(NWCMX), DIST(NWCMX,NWNMX), THETA(NWCMX), QC(NWCMX), U(NWCMX)
1075 DIM WDESS$(NWSMX), WDEPS(NWSMX), NNEAS(NWSMX), WCONS(NWSMX,NWNMX), XS(NWSMX), YS(NWSMX),
DISS(NWSMX,NWNMX), THETAS(NWSMX), QS(NWSMX), US(NWSMX)
1080 FOR I=1 TO NWCAL
1088 INPUT #1, WDESC$(I)
1090 INPUT #1, XC(I), YC(I), WCONT(I), WDEPC(I), THETA(I), QC(I), U(I)
1100 INPUT #1, NNEAR(I)
1120 FOR J = 1 TO NNEAR(I)
1130    INPUT #1, DIST(I,J), WCONC(I,J)
1135 NEXT J
1140 NEXT I
```

```
1150 FOR I = 1 TO NWSAM
1155 INPUT #1, WDESS$(I)
1160 INPUT #1, XS(I),YS(I),WDEPS(I),THETAS(I),QS(I),US(I)
1170 INPUT #1, NNEAS(I)
1180    FOR J = 1 TO NNEAS(I)
1190    INPUT #1, DISS(I,J), WCONS(I,J)
1200    NEXT J
1210 NEXT I
1220 PRINT"   The data has been read in, and can now be modified.":PRINT
1230 PRINT"   The following options are available:":PRINT
1240 PRINT"       1)  Add data for a new calibration well"
1250 PRINT"       2)  Add data for a new sample well"
1260 PRINT"       3)  Modify data for an existing calibration well"
1270 PRINT"       4)  Modify data for an existing sample well"
1280 PRINT"       5)  No more modifications required":PRINT
1290 INPUT"    Which option do you want (1-5)";OPT1
1300 IF OPT1=5 GOTO 2900
1310 IF OPT1=1 THEN GOSUB 4000
1320 IF OPT1=2 THEN GOSUB 5000
1330 IF OPT1=3 THEN GOSUB 6000
1340 IF OPT1=4 THEN GOSUB 8000
1350 CLS:PRINT:PRINT:GOTO 1230
1990 RETURN
2000 CLS:PRINT:PRINT
2010 PRINT"                      INTERACTIVE WELL DATA INPUT"
2011 '**********ARRAY DIMENSIONS**************************
2012 NWCMX=100:'    Max. number of calibration wells
2013 NWSMX=200:'    Max. number of sample wells
2014 NWNMX=5:'     Max. number of proximate wells
2020 DIM WDESC$(NWCMX), WDEPC(NWCMX), NNEAR(NWCMX), WCONC(NWCMX,NWNMX), XC(NWCMX), YC(NWCMX),
WCONT(NWCMX), DIST(NWCMX,NWNMX), THETA(NWCMX), QC(NWCMX), U(NWCMX)
2030 PRINT:INPUT"   Input number of calibration wells: ",NWCAL
2031 IF NWCAL<=NWCMX GOTO 2040
2032    PRINT"  Number of calibration wells exceeds maximum dimension. "
2033    PRINT"  Terminating Execution"
2034    STOP
2040 INPUT"   Input number of unsampled wells: ",NWSAM
2041 IF NWSAM<=NWSMX GOTO 2050
2042    PRINT"  Number of sample wells exceeds maximum dimension. "
2043    PRINT"  Terminating Execution"
2044    STOP
2050 FOR I = 1 TO NWCAL
2060 CLS:PRINT:PRINT
2070 PRINT"  Enter Data for the Calibration Well # ";I;" below:"
2080 PRINT
2090 INPUT"      Well name or number (1-8 characters)";WDESC$(I)
2100 PRINT"      Well coordinates (in feet):"
2120 INPUT"                      X-coordinate";XC(I)
2130 INPUT"                      Y-coordinate";YC(I)
2134 WCONT(I)=0
2135 INPUT"      Is this well contaminated (Y or N)";ANS8$
2136 IF ANS8$="Y" OR ANS8$="y" THEN WCONT(I)=1
2137 IF ANS8$="N" OR ANS8$="n" THEN WCONT(I)=2
2138 IF WCONT(I)=0 GOTO 2135
```

```
2140 INPUT"      Depth to static water table (in feet)";WDEPC(I)
2145 INPUT"      Azimuth direction of groundwater flow (degrees)";THETA(I)
2146 INPUT"      Average pumping rate (in GPM)";QC(I)
2160 INPUT"      Number of drinking water users";U(I)
2400 NEXT I
2410 CLS:PRINT:PRINT
2420 PRINT"                SAMPLE WELL SET DATA ENTRY
2430 PRINT
2440 PRINT"   The calibration well set data has been entered in full.
2450 PRINT"   Next, begin data entry for the set of wells from which the
2460 PRINT"   wells to be sampled is to be chosen (i.e., wells which
2470 PRINT"   have not yet been tested).
2480 PRINT:INPUT"   Press ENTER to continue";ANS5
2485 DIM WDESS$(NWSMX), WDEPS(NWSMX), NNEAS(NWSMX), WCONS(NWSMX,NWNMX), XS(NWSMX), YS(NWSMX),
DISS(NWSMX,NWNMX), THETAS(NWSMX), QS(NWSMX), US(NWSMX)
2489 FOR I=1 TO NWSAM
2490 CLS:PRINT:PRINT
2500 PRINT"  Enter Data for Sample Well #";I;" below:"
2510 PRINT
2520 INPUT"      Well name or number (1-8 characters)";WDESS$(I)
2530 PRINT"      Well coordinates (in feet):"
2540 INPUT"                      X-coordinate";XS(I)
2550 INPUT"                      Y-coordinate";YS(I)
2560 INPUT"      Depth to static water table (in feet)";WDEPS(I)
2565 INPUT"      Azimuth direction of groundwater flow (degrees)";THETAS(I)
2566 INPUT"      Average pumping rate (in GPM)";QS(I)
2570 INPUT"      Number of drinking water users";US(I)
2800 NEXT I
2900 CLS:PRINT:PRINT
2905 GOSUB 10000
2910 PRINT"   A permanent well file will now be created and saved on disk"
2920 PRINT"     for future use and/or modification."
2930 PRINT
2940 INPUT"   What would you like to name this file";WELOUT$
2950 OPEN "O" ,#2,WELOUT$
2960 PRINT#2, NWCAL,NWSAM
2965 FOR I=1 TO NWCAL
2970 PRINT#2, WDESC$(I)
2971 PRINT#2, XC(I),YC(I),WCONT(I),WDEPC(I),THETA(I),QC(I),U(I)
2972 PRINT#2, NNEAR(I)
2975    FOR J=1 TO NNEAR(I)
2980    PRINT#2, DIST(I,J), WCONC(I,J)
2985    NEXT J
2990 NEXT I
3000 FOR I=1 TO NWSAM
3010 PRINT#2, WDESS$(I)
3011 PRINT#2, XS(I),YS(I),WDEPS(I),THETAS(I),QS(I),US(I)
3012 PRINT#2, NNEAS(I)
3015    FOR J = 1 TO NNEAS(I)
3020    PRINT#2, DISS(I,J), WCONS(I,J)
3025    NEXT J
3030 NEXT I
3040 RETURN
4000 CLS:PRINT:PRINT
```

```
4009 IF NWCAL<NWCMX GOTO 4014
4012    PRINT:PRINT"   Exceeded calibration well array dimension; cannot add any more."
4013    RETURN
4014 NWCAL=NWCAL+1
4015 I=NWCAL
4020 PRINT"  Enter data for the new calibration well below:"
4030 PRINT
4040 INPUT"      Well name or number (1-8 characters)";WDESC$(I)
4050 PRINT"      Well coordinates (in feet):"
4060 INPUT"                      X-coordinate";XC(I)
4070 INPUT"                      Y-coordinate";YC(I)
4074 WCONT(I)=0
4075 INPUT"      Is this well contaminated (Y or N)";ANS8$
4076 IF ANS8$="Y" OR ANS8$="y" THEN WCONT(I)=1
4077 IF ANS8$="N" OR ANS8$="n" THEN WCONT(I)=2
4078 IF WCONT(I)=0 GOTO 4075
4080 INPUT"      Depth to static water table (in feet)";WDEPC(I)
4085 INPUT"      Azimuth direction of groundwater flow (degrees)";THETA(I)
4086 INPUT"      Average pumping rate (in GPM)";QC(I)
4100 INPUT"      Number of drinking water users";U(I)
4400 RETURN
5000 CLS:PRINT:PRINT
5100 IF NWSAM<NWSMX GOTO 5200
5110    PRINT:PRINT"  Sample well array dimension exceeded; cannot add another"
5120    RETURN
5200 NWSAM=NWSAM+1
5300 I=NWSAM
5500 PRINT"  Enter data for new sample well below:"
5510 PRINT
5520 INPUT"      Well name or number (1-8 characters)";WDESS$(I)
5530 PRINT"      Well coordinates (in feet):"
5540 INPUT"                      X-coordinate";XS(I)
5550 INPUT"                      Y-coordinate";YS(I)
5562 INPUT"      Depth to groundwater table";WDEPS(I)
5565 INPUT"      Azimuth direction of groundwater flow (degrees)";THETAS(I)
5566 INPUT"      Average pumping rate (in GPM)";QS(I)
5600 INPUT"      Number of drinking water users";US(I)
5800 RETURN
6000 CLS:PRINT:PRINT
6010 INPUT"  Enter the description of the calibration well to be modified: ",WD$
6020 FOR I = 1 TO NWCAL
6030    IF WDESC$(I)=WD$ THEN GOTO 6059
6040 NEXT I
6050 PRINT:PRINT"  That description does not match any existing calibration well.":PRINT"   Try again,
but make sure to use the correct case.":PRINT:GOTO 6010
6059 CLS:PRINT:PRINT
6060 PRINT"          Existing Well Data"
6061 PRINT"          ******************"
6070 PRINT"  1)  Well Description = ";WDESC$(I)
6080 PRINT"      Well Coordinates (in feet):"
6090 PRINT"  2)         X = ";XC(I)
6100 PRINT"  3)         Y = ";YC(I)
6110 IF WCONT(I)=1 THEN PRINT"  4)  This well is contaminated"
6120 IF WCONT(I)=2 THEN PRINT"  4)  This well is not contaminated"
```

```
6130 PRINT"  5)  Depth to water table = ";WDEPC(I)
6140 PRINT"  6)  Azimuth direction of groundwater flow = ";THETA(I)
6145 PRINT"  7)  Average pumping rate (GPM) = ";QC(I)
6150 PRINT"  8)  Number of drinking water users = ";U(I)
6300 PRINT:PRINT
6310 INPUT"     Which item (1-8) do you wish to change (0 for no more changes)";ITEM
6315 IF ITEM=0 THEN RETURN
6320 IF ITEM>1 GOTO 6400
6330    PRINT:INPUT"    New well description";WDESC$(I)
6340    GOTO 6059
6400 IF ITEM>2 GOTO 6500
6410    PRINT:INPUT"    New X coordinate";XC(I)
6420    GOTO 6059
6500 IF ITEM>3 GOTO 6600
6510    PRINT:INPUT"    New Y coordinate";YC(I)
6520    GOTO 6059
6600 IF ITEM>4 GOTO 6700
6610    IF WCONT(I)=1 GOTO 6650
6620       WCONT(I)=1
6630       GOTO 6059
6650    WCONT(I)=2
6660    GOTO 6059
6700 IF ITEM>5 GOTO 6800
6710    PRINT:INPUT"    New depth to water table";WDEPC(I)
6720    GOTO 6059
6800 IF ITEM>6 GOTO 6830
6810    PRINT:INPUT"    New azimuth direction of GW flow";THETA(I)
6820    GOTO 6059
6830 IF ITEM>7 GOTO 6860
6840    PRINT:INPUT"    New average pumping rate (GPM)";QC(I)
6850 GOTO 6059
6860 PRINT:INPUT"    New number of water users";U(I)
6870 GOTO 6059
7000 GOTO 6059
8000 CLS:PRINT:PRINT
8010 INPUT"  Enter the description of the sample well to be modified: ",WD$
8020 FOR I = 1 TO NWSAM
8030    IF WDESS$(I)=WD$ THEN GOTO 8059
8040 NEXT I
8050 PRINT:PRINT"  That description does not match any existing sample well.":PRINT"   Try again, but
make sure to use the correct case.":PRINT:GOTO 8010
8059 CLS:PRINT:PRINT
8060 PRINT"          Existing Well Data"
8061 PRINT"          ******************"
8070 PRINT"  1)  Well Description = ";WDESS$(I)
8080 PRINT"      Well Coordinates (in feet):"
8090 PRINT"  2)         X = ";XS(I)
8100 PRINT"  3)         Y = ";YS(I)
8130 PRINT"  4)  Depth to water table = ";WDEPS(I)
8140 PRINT"  5)  Azimuth direction of groundwater flow = ";THETAS(I)
8145 PRINT"  6)  Average pumping rate (GPM) = ";QS(I)
8150 PRINT"  7)  Number of drinking water users = ";US(I)
8300 PRINT:PRINT
8310 INPUT"     Which item (1-7) do you wish to change (0 for no more changes)";ITEM
```

```
8315 IF ITEM=0 THEN RETURN
8320 IF ITEM>1 GOTO 8400
8330    PRINT:INPUT"    New well description";WDESS$(I)
8340    GOTO 8059
8400 IF ITEM>2 GOTO 8500
8410    PRINT:INPUT"    New X coordinate";XS(I)
8420    GOTO 8059
8500 IF ITEM>3 GOTO 8600
8510    PRINT:INPUT"    New Y coordinate";YS(I)
8520    GOTO 8059
8600 IF ITEM>4 GOTO 8700
8610    PRINT:INPUT"    New depth to water table";WDEPS(I)
8620    GOTO 8059
8700 IF ITEM>5 GOTO 8730
8710    PRINT:INPUT"    New azimuth direction of GW flow";THETAS(I)
8720    GOTO 8059
8730 IF ITEM>6 GOTO 8760
8740    PRINT:INPUT"    New average pumping rate (GPM)";QS(I)
8750    GOTO 8059
8760 PRINT:INPUT"    New number of water users";US(I)
8770 GOTO 8059
8900 GOTO 8059
10000 '************SUBROUTINE TO CALCULATE PROXIMITY*****************'
10005 CLS:PRINT:PRINT
10006 INPUT"    Enter maximum distance for definition of 'nearby' wells: ",DELMAX
10007 '     CALL SUBROUTINE TO ZERO NNEAR(*), DIST(*,*), WCONC(*,*), NNEAS(*), DISS(*,*), WCONS(*,*)
10008 GOSUB 15000
10010 FOR I = 1 TO NWCAL
10015    IF I=1 THEN GOTO 10050
10020    FOR J = 1 TO I-1
10022      X1=XC(I)
10024      X2=XC(J)
10026      Y1=YC(I)
10028      Y2=YC(J)
10029      FLAG%=1
10030      GOSUB 12000
10040    NEXT J
10045    IF I=NWCAL THEN GOTO 10080
10050    FOR J = I+1 TO NWCAL
10052      X1=XC(I)
10054      X2=XC(J)
10056      Y1=YC(I)
10058      Y2=YC(J)
10059      FLAG%=1
10060      GOSUB 12000
10070    NEXT J
10080 NEXT I
10090 FOR I = 1 TO NWSAM
10100    FOR J = 1 TO NWCAL
10102      X1=XS(I)
10104      X2=XC(J)
10106      Y1=YS(I)
10108      Y2=YC(J)
10109      FLAG%=2
```

```
10110      GOSUB 12000
10120    NEXT J
10160 NEXT I
10170 RETURN
12000 DELX=ABS(X1-X2)
12010 DELY=ABS(Y1-Y2)
12020 IF DELX>DELMAX THEN RETURN
12030 IF DELY>DELMAX THEN RETURN
12040 DELTA=((DELX^2+DELY^2)^.5)
12050 IF DELTA>DELMAX THEN RETURN
12060 IF FLAG%=2 THEN GOTO 13000
12070    NNEAR(I)=NNEAR(I)+1
12080    K = NNEAR(I)
12085    IF K > NWNMX THEN GOTO 14000
12090    DIST(I,K)=DELTA
12100    WCONC(I,K)=WCONT(J)
12110    RETURN
13000 NNEAS(I)=NNEAS(I)+1
13010 K = NNEAS(I)
13015 IF K > NWNMX THEN GOTO 14500
13020 DISS(I,K)=DELTA
13030 WCONS(I,K)=WCONT(J)
13040 RETURN
14000 NNEAR(I) = NWNMX
14010 DISMX = 0!
14020 FOR L = 1 TO NWNMX
14025    IF DIST(I,L) > DISMX THEN REPL% = L
14030    IF DIST(I,L) > DISMX THEN DISMX=DIST(I,L)
14050 NEXT L
14060 IF DELTA > DISMX THEN RETURN
14070 DIST(I,REPL%) = DELTA
14080 WCONC(I,REPL%) = WCONT(J)
14090 RETURN
14500 NNEAS(I) = NWNMX
14510 DISMX = 0!
14520 FOR L = 1 TO NWNMX
14530    IF DISS(I,L) > DISMX THEN DISMX=DIST(I,L)
14540    IF DISS(I,L) > DISMX THEN REPL% = L
14550 NEXT L
14560 IF DELTA > DISMX THEN RETURN
14570 DISS(I,REPL%) = DELTA
14580 WCONS(I,REPL%) = WCONT(J)
14590 RETURN
15000 FOR I = 1 TO NWCAL
15010    FOR J = 1 TO NWNMX
15020      DIST(I,J) = 0
15030      WCONC(I,J) = 0
15040    NEXT J
15050    NNEAR(I) = 0
15060 NEXT I
15070 FOR I = 1 TO NWSAM
15080    FOR J = 1 TO NWNMX
15090      DISS(I,J) = 0
15100      WCONS(I,J) = 0
```

```
15110     NEXT J
15120     NNEAS(I) = 0
15130 NEXT I
15140 RETURN
```

A.3 MODEL.FOR

```
C***********************************************************************
C
C       PESTICIDE MONITORING DESIGN PROGRAM - FORTRAN CODE FOR
C            RISK ANALYSIS AND OPTIMIZATION OF SAMPLING DESIGN.
C
C       MODULE I: CALIBRATION WELL RISK ESTIMATION AND HISTOGRAMMING
C
C                    Developed by
C
C                         TIM SCHEIBE
C                         UNIVERSITY OF WASHINGTON
C                         DEPARTMENT OF CIVIL ENGINEERING
C                         JULY, 1987
C
C
C***********************************************************************
      PROGRAM SAMPDES
C
C     PARAMETER STATEMENTS
C
C     MAXIMUM NUMBER OF
C        CALIBRATION WELLS = NWCMX           50
C        SAMPLE WELLS = NWSMX               100
C        PROXIMATE WELLS = NPRMX              5
C        ROWS IN SOIL ARRAY = NXMX          250
C        COLUMNS IN SOIL ARRAY = NYMX       360
C        CATEGORIES OF SOIL TYPES = NCATMX    57
C        WELLS TO BE SAMPLED IN NEXT ROUND = NNWMX  =  20
C        INTERVALS IN HISTOGRAM = NINTMX =    20
C
      INTEGER NWCMX, NPRMX
      PARAMETER(NWCMX=50,NPRMX=5)
      INTEGER NINTMX
      PARAMETER(NINTMX=10)
      INTEGER NXMX, NYMX, NCATMX
      PARAMETER(NXMX=250,NYMX=360,NCATMX=57)
C
C     COMMON BLOCK DEFINITIONS
C
      COMMON / A / RISK, WCONT
         REAL RISK(NWCMX)
         INTEGER WCONT(NWCMX)
      COMMON / B / NLC, NDIV, LW, W, DDIV, EXP3
         REAL LW(9), W(10), DDIV, EXP3
         INTEGER NLC, NDIV
      COMMON / C / HISINT, BINSUM, BINC
         INTEGER HISINT, BINSUM(NINTMX), BINC(NINTMX)
      COMMON / D / DMAX, EXP1
         REAL DMAX, EXP1
      COMMON / E / XMAX, EXP2
         REAL XMAX, EXP2
      COMMON / F / DEL, SOIARR, NROWS, NCOLS
```

```
        REAL DEL
        INTEGER NROWS, NCOLS, SOIARR(NXMX,NYMX)
C
C     OTHER VARIABLE DECLARATIONS
C
      REAL X(NWCMX), Y(NWCMX), DEP(NWCMX), QC(NWCMX), U(NWCMX),
     &     PDIST(NWCMX,NPRMX), THETA(NWCMX), FREREL(NINTMX),
     &     A, B, C, R1, R2, R3, AM, BM, CM, DIFF, SUM, RISAVE(NINTMX)
      INTEGER NCAL, NPROX(NWCMX), NCONT(NWCMX,NPRMX), ANS
      CHARACTER*12 WELIN, PARIN, SOILIN, FILOT
      CHARACTER*8  WDESC(NWCMX)
C
C     FORMAT STATEMENTS
C
    1 FORMAT(1X,A,\)
    2 FORMAT(A12)
    3 FORMAT(80I1)
    4 FORMAT(A8)
    5 FORMAT(1X,'HISINT = ',I5)
    6 FORMAT(10X,'RISK LEVEL ',F5.1)
    7 FORMAT(10X,'  NUMBER CONTAMINATED = ',I5,/,10X,'  TOTAL NUMBER ',
     &       'IN BIN = ',I5,/,10X,'  RELATIVE FREQUENCY = ',F7.3)
   11 FORMAT(1X,A)
   12 FORMAT(1X,A,A)
   13 FORMAT(1X,A,F8.3)
   14 FORMAT(1X,I5)
   15 FORMAT(1X,F7.3)
   16 FORMAT(1X,A,F8.5)
   17 FORMAT(1X,A,I3,A)
   18 FORMAT(6X,A10,5X,F8.0,2X,F8.0,3X,F5.1)
   19 FORMAT(1X,A,A10)
   20 FORMAT(10X,'WELL ',A10,';  RISK = ',F8.3)
   21 FORMAT(1X,A8,2X,F6.0,2X,F6.0,2X,I1,2X,F4.0,2X,F4.0,2X,F4.0,2X,
     &       F4.0)
   22 FORMAT(1X,A8,2X,F6.0,2X,F6.0,2X,F4.0,2X,F4.0,2X,F4.0,2X,F4.0)
   23 FORMAT(1X,A,I3)
   24 FORMAT(9X,F6.0,20X,I1)
   25 FORMAT(1X,A,F5.0,A,F5.3)
   26 FORMAT(19X,I2,18X,F6.4)
   27 FORMAT(1X,A,F6.0,A)
   28 FORMAT(1X,A,F8.4)
   29 FORMAT(3X,A8,4X,F5.1)
  101 FORMAT(1X,/)
C
C     SCREEN INTRO
C
C
C     INPUT
C
      WRITE(*,1) 'Enter name of well data input file: '
      READ(*,2) WELIN
      WRITE(*,1) 'Enter name of parameter input file: '
      READ(*,2) PARIN
      WRITE(*,1) 'Enter name of soil data input file: '
```

```
      READ(*,2) SOILIN
      WRITE(*,1) 'Enter desired name of output file: '
      READ(*,2) FILOT
      OPEN(3,FILE=WELIN,STATUS='OLD')
      OPEN(4,FILE=PARIN,STATUS='OLD')
      OPEN(5,FILE=SOILIN,STATUS='OLD')
      OPEN(6,FILE=FILOT,STATUS='NEW')
      OPEN(7,FILE='TEMP.DAT',STATUS='NEW')
      READ(3,*) NCAL
C
C     READ CALIBRATION WELL DATA
C
      DO 50 I = 1, NCAL
         READ(3,4) WDESC(I)
         READ(3,*) X(I), Y(I), WCONT(I), DEP(I), THETA(I), QC(I), U(I)
         READ(3,*) NPROX(I)
         IF (NPROX(I).EQ.0) GO TO 50
         DO 45 J = 1, NPROX(I)
            READ(3,*) PDIST(I,J), NCONT(I,J)
   45    CONTINUE
   50 CONTINUE
C
C     READ PARAMETER DATA AND SOIL DATA
C
      READ(4,*) DMAX,EXP1
      READ(4,*) XMAX,EXP2
      READ(4,*) NLC
      READ(4,*) (LW(I), I=1,NLC)
      READ(4,*) NDIV
      READ(4,*) (W(I), I=1,NDIV)
      READ(4,*) DDIV, EXP3
      READ(4,*) C, B, A
      READ(5,*) NROWS, NCOLS, DEL
      IF (NROWS.GT.NXMX) THEN
         WRITE(6,12) ' NUMBER OF ROWS IN DATA ARRAY EXCEEDS',
     &               ' DIMENSION LIMITS'
         WRITE(6,11) '   TERMINATING EXECUTION'
         GO TO 999
      ENDIF
      IF (NCOLS.GT.NYMX) THEN
         WRITE(6,12) ' NUMBER OF COLS IN DATA ARRAY EXCEEDS',
     &               ' DIMENSION LIMITS'
         WRITE(6,11) '   TERMINATING EXECUTION'
         GO TO 999
      ENDIF
      READ(5,3) ((SOIARR(I,J), J=1,NCOLS), I=1,NROWS)
C
C     ECHO INPUT DATA
C
  104 CONTINUE
      WRITE(*,101)
      WRITE(*,11) 'Input data can be printed to the output file for'
      WRITE(*,11) '  verification or identification purposes.  Please'
      WRITE(*,11) '  indicate which option you prefer:'
```

```
      WRITE(*,11) '     1) Full input echo'
      WRITE(*,11) '     2) Parameter echo only (no well data)'
      WRITE(*,11) '     3) No input echo'
      WRITE(*,101)
      WRITE(*,1)  'Enter option 1, 2, or 3 here: '
      READ(*,'(I1)') ANS
      IF (ANS.EQ.2) GO TO 111
      IF (ANS.EQ.3) GO TO 140
      IF (ANS.NE.1) GO TO 104
      WRITE(6,11) ' CALIBRATION WELL DATA ECHO:'
      WRITE(6,101)
      WRITE(6,11) 'WELL        X       Y     C   DEP  THET   Q   #USERS'
      WRITE(6,11) '****      *****   *****   *   ***  ****  ****  ****'
      DO 110 I = 1, NCAL
         WRITE(6,21) WDESC(I), X(I), Y(I), WCONT(I), DEP(I), THETA(I),
     &              QC(I), U(I)
         WRITE(6,23) '   NUMBER OF PROXIMATE WELLS = ',NPROX(I)
         IF (NPROX(I).EQ.0) GO TO 110
         WRITE(6,11) '      DISTANCE(FT)      CONTAMINATED? (1=YES)'
         WRITE(6,11) '      ************      *********************'
         DO 105 J = 1, NPROX(I)
            WRITE(6,24) PDIST(I,J), NCONT(I,J)
  105    CONTINUE
  110 CONTINUE
  111 CONTINUE
      WRITE(6,101)
      WRITE(6,101)
      WRITE(6,11) ' PARAMETER DATA ECHO:'
      WRITE(6,101)
      WRITE(6,25) '  THRESHOLD DEPTH = ',DMAX,'ft.; EXPON. = ',EXP1
      WRITE(6,25) '  THRESHOLD DIST. = ',XMAX,'ft.; EXPON. = ',EXP2
      WRITE(6,101)
      WRITE(6,23) '  NUMBER OF LAND USE CATEGORIES = ',NLC
      WRITE(6,101)
      WRITE(6,11) '             CATEGORY                 WEIGHT'
      WRITE(6,11) '    ******************************   *******'
      WRITE(6,28) '    Known EDB application area      ',LW(1)
      WRITE(6,28) '    High risk soil in crop area     ',LW(2)
      WRITE(6,28) '    Med. risk soil -----"------      ',LW(4)
      WRITE(6,28) '    Low risk soil  -----"------      ',LW(6)
      WRITE(6,28) '    High risk soil; not crop area   ',LW(3)
      WRITE(6,28) '    Med. risk soil; ------"------    ',LW(5)
      WRITE(6,28) '    Low risk soil;  ------"------    ',LW(7)
      WRITE(6,28) '    Known EDB-type crop growth      ',LW(8)
      WRITE(6,28) '    Surface water area              ',LW(9)
      WRITE(6,101)
      WRITE(6,23) '  NUMBER OF CAPTURE ZONE SUB-AREAS = ',NDIV
      WRITE(6,101)
      WRITE(6,11) '    SUB-AREA (1 IS CLOSEST TO WELL)   WEIGHT'
      WRITE(6,11) '    ******************************    ******'
      DO 130 I = 1, NDIV
         WRITE(6,26) I, W(I)
  130 CONTINUE
      WRITE(6,101)
```

```
      WRITE(6,27) '    TRAVEL TIME TO AREA 1 BOUND. = ',DDIV,' DAYS'
      WRITE(6,16) '    EXPONENT = ',EXP3
      WRITE(6,101)
      WRITE(6,11) '  OVERALL FACTOR WEIGHTS USED:'
      WRITE(6,101)
      WRITE(6,16) '     Depth to water table    - ',A
      WRITE(6,16) '     Status of nearby wells  - ',B
      WRITE(6,16) '     Capture zone soil types - ',C
      WRITE(6,101)
      WRITE(6,101)
      WRITE(6,11) 'SOIL DATA INFORMATION:'
      WRITE(6,101)
      WRITE(6,23) '  NUMBER OF ROWS IN SOIL ARRAY = ',NROWS
      WRITE(6,23) '  NUMBER OF COLUMNS IN SOIL ARRAY = ',NCOLS
      WRITE(6,13) '  DIMENSION OF ARRAY ELEMENTS (ft) = ',DEL
  140 CONTINUE
      WRITE(6,101)
      WRITE(6,101)
      WRITE(6,11) 'RESULTS:'
      WRITE(6,11) '********'
      WRITE(6,101)
      WRITE(6,11) '    WELL     EST.RISK'
      WRITE(6,11) '   ******    ********'
C
C     SUBROUTINE CALLS
C
      DO 200 I = 1, NCAL
         CALL FORM1(DEP(I),R1)
         SUM = 0.0
         AM = A
         BM = B
         CM = C
         IF (NPROX(I).EQ.0) THEN
            BM = 0
            R2 = 0.0
            DIFF = 1.0 - AM - CM
            SUM = AM + CM
            AM = AM + (AM/SUM)*DIFF
            CM = CM + (CM/SUM)*DIFF
            GO TO 195
         ENDIF
         DO 190 J = 1, NPROX(I)
            CALL FORM2(R2,PDIST(I,J),NCONT(I,J))
            SUM = SUM + R2
  190    CONTINUE
         R2 = SUM/NPROX(I)
  195    CONTINUE
         CALL FORM3(R3,X(I),Y(I),THETA(I),QC(I))
         RISK(I) = AM*R1 + BM*R2 + CM*R3
         IF (RISK(I).LT.0.0) RISK(I)=0.0
         WRITE(6,29) WDESC(I), RISK(I)
  200 CONTINUE
      CALL HISTO(NCAL)
      DO 300 L = 1, HISINT
```

```
         IF (BINSUM(L).GT.0) THEN
            FREREL(L)=(FLOAT(BINC(L))/FLOAT(BINSUM(L)))*100.0
         ELSE
            FREREL(L)=0.0
         ENDIF
         RISAVE(L)=(100.0/FLOAT(HISINT))*(2.0*FLOAT(L)-1.0)/2.0
  300 CONTINUE
C
C     OUTPUT
C
      WRITE(6,101)
      WRITE(6,5) HISINT
      DO 400 I = 1, HISINT
         WRITE(6,6) RISAVE(I)
         WRITE(6,7) BINC(I), BINSUM(I), FREREL(I)
  400 CONTINUE
      WRITE(7,14) HISINT
      DO 500 I = 1, HISINT
         WRITE(7,15) FREREL(I)
  500 CONTINUE
  999 CONTINUE
      STOP
      END
C*********************************************************************
      SUBROUTINE FORM1(DEPTH,RISK)
C
C     COMMON BLOCKS
C
      COMMON / D / DMAX, EXP1
         REAL DMAX, EXP1
C
C     OTHER DECLARATIONS
C
      REAL RISK, DEPTH
C
C     EXECUTABLE STATEMENTS
C
      RISK = 100.0 * ((DMAX-DEPTH)/DMAX)**EXP1
      RETURN
      END
C*********************************************************************
      SUBROUTINE FORM2(RISK,X,ICONT)
C
C     COMMON BLOCKS
C
      COMMON / E / XMAX, EXP2
         REAL XMAX, EXP2
C
C     OTHER DECLARATIONS
C
      REAL RISK, A, X
      INTEGER ICONT
C
C     EXECUTABLE STATEMENTS
```

```
C
      IF (ICONT.EQ.1) THEN
         A = 1.0
      ELSE
         A = -1.0
      ENDIF
      RISK = A * ((X-XMAX)/XMAX)**EXP2
      RETURN
      END
C*********************************************************************
      SUBROUTINE FORM3(RISK,X,Y,THETA,Q)
C
C     PARAMETER STATEMENTS
C
      INTEGER NXMX, NYMX, NCATMX
      PARAMETER(NXMX=250,NYMX=360,NCATMX=57)
C
C     COMMON BLOCKS
C
      COMMON / B / NLC, NDIV, LW, W, DDIV, EXP3
         REAL LW(9), W(10), DDIV, EXP3
         INTEGER NLC, NDIV
      COMMON / F / DEL, SOIARR, NROWS, NCOLS
         REAL DEL
         INTEGER NROWS, NCOLS, SOIARR(NXMX,NYMX)
C
C     OTHER DECLARATIONS
C
      REAL BU, LCT, PI, Q, R, RISK, RR(10), SUBRSK(10), SUM(10),
     &     T, THETA, THETAR, X, Y, B, U, DELX, DELY, TERM,
     &     YMAX, Y1, Y2, YAVE, YCALC, DIFF, UCALC, RT,
     &     TEXP, TEST, DELT, TIME
      INTEGER ROW, COL, COUNT(10), LEFT, RIGHT, JUMP, MED, ITER,
     &        IFLAGR, IFLAGL, NJ, QUIT, COLB, XROW, YCOL, ICHK
      REAL ALPHA, BETA, L, CONVRD, CONVDR, RHS, LHS, SUMW
C
C     FORMATS
C
    3 FORMAT(1X,A,F8.3,A,F8.3)
    4 FORMAT(1X,A,F8.3,A,F10.8)
    5 FORMAT(1X,'ROW ',I3,',COL ',I3)
    6 FORMAT(1X,A)
    7 FORMAT(1X,A,F8.3)
    8 FORMAT(1X,A,F12.3)
    9 FORMAT(1X,'RR(',I2,') = ',F10.2)
   11 FORMAT(1X,A,I2,A)
C
C     EXECUTABLE STATEMENTS
C
C-------------
C     GET BU AND U
C
C     FOR NOW, PUT IN ARBITRARY VALUES FOR TEST RUN
C
```

```
C  B IS AQUIFER THICKNESS IN FEET; U IS REGIONAL FLOW VEL IN
C     FEET/DAY.
      B = 50.0
      U = 0.5
C
C  CONVERT U IN FEET/DAY TO FEET/SECOND; CONVERT Q FROM GPM TO
C     CFS;  MULTIPLY TO OBTAIN BU
C
      U = U / 86400.0
      Q = Q / 448.831
      BU = B * U
C-------------
      RISK=0.0
      PI=3.14159265
      ROW = INT(Y/DEL) + 1
      COL = INT(X/DEL) + 1
      XROW = INT(Y/DEL) + 1
      YCOL = INT(X/DEL) + 1
      COLB=COL
      MED=COL
      THETAR = (THETA*2.0*PI)/360.0
      DO 10 I = 1, NDIV
         COUNT(I)=0
         SUM(I)=0.0
   10 CONTINUE
C-------------
C     CALCULATE RR(I) FROM DDIV, EXP3, AND U (FLOW VELOCITY)
C
C        ASSUME U IS FLOW VELOCITY IN FEET/SEC; DDIV IS INITIAL
C           TRAVEL TIME IN DAYS
      YMAX = Q/(2.0*B*U)
      TEXP = 1.05
      TEST = 100.0
      DELT = 100.0
      TIME = 0.0
   14    Y1 = 0.0
         Y2 = YMAX
         ITER = 0
   12    YAVE = (Y1 + Y2) / 2.0
            ITER = ITER + 1
            YCALC = Q/(2.0*B*U) - Q/(2.0*PI*B*U)*ATAN(YAVE/TEST)
            DIFF = ABS(YCALC-YAVE)
            IF (DIFF.LE.1.0) GO TO 13
            IF (ITER.GT.100) THEN
               WRITE(*,6) 'ITERATION LIMIT FOR RR(1) CALCULATION'
               GO TO 13
            ENDIF
            IF (YCALC.GT.YAVE) THEN
               Y1 = YAVE
            ELSE
               Y2 = YAVE
            ENDIF
            GO TO 12
   13    CONTINUE
```

```
         UCALC = Q/(2.0*B*YCALC)
C        WRITE(*,4) 'YCALC = ',YCALC,';  UCALC = ',UCALC
         TIME = TIME + DELT/(UCALC*86400.0)
C        WRITE(*,3) 'TIME = ',TIME,';  DDIV = ',DDIV
         IF (TIME.LT.DDIV) THEN
            DELT = DELT**TEXP
            TEST = TEST + DELT
C           WRITE(*,3) 'DELT = ',DELT,';  TEST = ',TEST
            GO TO 14
         ENDIF
      RR(1) = TEST - (TIME-DDIV)*(UCALC*86400.0)
      RR(2) = RR(1) + RR(1)**EXP3
      DO 15 I = 3, NDIV
         RR(I) = RR(I-1) + (RR(I-1)-RR(I-2))**EXP3
   15 CONTINUE
      DO 17 I = 1, NDIV
C        WRITE(6,9) I, RR(I)
   17 CONTINUE
C-------------
      ITER=0
      PI=3.14159265
      CONVRD=360.0/(2.0*PI)
      CONVDR=1.0/CONVRD
      THETAR = THETA*CONVDR
   20 CONTINUE
C     WRITE(6,6) '20'
      IFLAGR=0
      IFLAGL=0
      ITER=ITER+1
      LEFT=0
      RIGHT=0
      JUMP=0
      IF (JUMP.EQ.0) GO TO 40
   30 CONTINUE
C     WRITE(6,6) '30'
      NJ = (JUMP/2)
      NJ = NJ * 2
      IF (NJ.EQ.JUMP) THEN
         COL=COL-JUMP
         IF (IFLAGL.EQ.1) THEN
            JUMP=JUMP+1
            GO TO 30
         ENDIF
         IF (COL.LT.1) THEN
            IFLAGL=1
            JUMP=JUMP+1
            GO TO 30
         ENDIF
         LEFT=LEFT+1
      ELSE
         COL=COL+JUMP
         IF (IFLAGR.EQ.1) THEN
            IF (IFLAGL.EQ.1) THEN
               IF (QUIT.EQ.1) THEN
```

```
                ROW = ROW - 1
                IF (ROW.LT.1) GO TO 300
             ELSE
                ROW = ROW + 1
                IF (ROW.GT.NROWS) THEN
                   QUIT=1
                   ROW = (INT(Y/DEL)+1) - 1
                   COL = MED
                   COLB = COL
                   GO TO 20
                ENDIF
C ----------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
                IF (ROW.GT.126. AND .COL.GT.283) THEN
                   QUIT=1
                   ROW = (INT(Y/DEL)+1) - 1
                   COL = MED
                   COLB = COL
                   GO TO 20
                ENDIF
C ----------------------------
             ENDIF
             COL = COLB + (RIGHT/2) - (LEFT/2)
             IF (ITER.EQ.1) MED=COL
             COLB=COL
             GO TO 20
          ENDIF
          JUMP=JUMP+1
          GO TO 30
       ENDIF
       IF (COL.GT.NCOLS) THEN
          IFLAGR=1
          JUMP=JUMP+1
          GO TO 30
       ENDIF
C ----------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
       IF (COL.GT.283. AND .ROW.GT.126) THEN
          IFLAGR=1
          JUMP=JUMP+1
          GO TO 30
       ENDIF
C ----------------------------
       RIGHT=RIGHT+1
    ENDIF
 40 CONTINUE
```

```
C     WRITE(6,6) '40'
      IF (ITER.EQ.1. AND .JUMP.EQ.0) THEN
         T = 0.0
         LCT = 1.0
         R = 0.0
         GO TO 45
      ENDIF
C
C     DETERMINE R, T
C
      DELX = FLOAT(COL-YCOL) * DEL
      DELY = FLOAT(XROW-ROW) * DEL
      IF (DELY.EQ.0.0) THEN
         ALPHA=90.0*CONVDR
      ELSE
         ALPHA=ATAN(ABS(DELX/DELY))
      ENDIF
C     WRITE(6,8) 'DELX = ',DELX
C     WRITE(6,8) 'DELY = ',DELY
      L = SQRT((DELX**2.0)+(DELY**2.0))
      ICHK=0
      IF (THETA.LT.90.0) THEN
C        WRITE(6,6) 'NEQUAD'
         IF (DELX.GE.0.0. AND .DELY.LE.0.0) THEN
            RHS=90.0*CONVDR - THETAR
            IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR + ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LE.0.0. AND .DELY.LE.0.0) THEN
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND. ALPHA.LT.THETAR) THEN
               BETA=THETAR-ALPHA
            ELSE IF (ALPHA.GE.THETAR. AND .ALPHA.LE.RHS) THEN
               BETA=ALPHA-THETAR
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LE.0.0. AND .DELY.GT.0.0) THEN
            LHS = 90.0*CONVDR - THETAR
            RHS = 90*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = 180.0*CONVDR - THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE
            ICHK=1
         ENDIF
       ELSE IF (THETA.LT.180.0) THEN
C        WRITE(6,6) 'SEQUAD'
         IF (DELX.LE.0.0. AND .DELY.LE.0.0) THEN
C           WRITE(6,6) 'BOTH<=0'
```

```
            LHS = THETAR - 90.0*CONVDR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LE.0.0. AND .DELY.GT.0.0) THEN
C           WRITE(6,6) 'Y>0'
            RHS = 90.0*CONVDR
            LHS = 180.0*CONVDR - THETAR
            IF (ALPHA.GT.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR - 180.0*CONVDR + ALPHA
            ELSE IF (ALPHA.GE.0.0. AND .ALPHA.LE.LHS) THEN
               BETA = 180.0*CONVDR - THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.GT.0.0. AND .DELY.GE.0.0) THEN
C           WRITE(6,6) 'BOTH>=0'
            RHS = THETAR - 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
               BETA = 180.0*CONVDR - THETAR + ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE
            ICHK=1
         ENDIF
      ELSE IF (THETA.LT.270.0) THEN
C        WRITE(6,6) 'SWQUAD'
         IF (DELX.LE.0.0. AND .DELY.GE.0.0) THEN
            RHS = 270.0*CONVDR - THETAR
            IF (ALPHA.GE.0.0 .AND. ALPHA.LE.RHS) THEN
               BETA = THETAR + ALPHA - 180.0*CONVDR
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.GE.0.0. AND .DELY.GE.0.0) THEN
            LHS = THETAR - 180.0*CONVDR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND .ALPHA.LT.LHS) THEN
               BETA = THETAR - 180.0*CONVDR - ALPHA
            ELSE IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = ALPHA - THETAR + 180.0*CONVDR
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.GE.0.0. AND .DELY.LT.0.0) THEN
            LHS = 270.0*CONVDR - THETAR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = 360.0*CONVDR - ALPHA - THETAR
            ELSE
```

```
            ICHK=1
          ENDIF
        ELSE
          ICHK=1
        ENDIF
      ELSE
C       WRITE(6,6) 'NWQUAD'
        IF (DELX.GE.0.0. AND .DELY.GE.0.0) THEN
          LHS = THETAR -270.0*CONVDR
          RHS = 90.0*CONVDR
          IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
            BETA = ALPHA + 270.0*CONVDR - THETAR
          ELSE
            ICHK=1
          ENDIF
        ELSE IF (DELX.GE.0.0. AND .DELY.LT.0.0) THEN
          LHS = 360.0*CONVDR - THETAR
          RHS = 90.0*CONVDR
          IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
            BETA = ALPHA + THETAR - 360.0*CONVDR
          ELSE IF (ALPHA.GE.0.0. AND .ALPHA.LT.LHS) THEN
            BETA = 360.0*CONVDR - THETAR - ALPHA
          ELSE
            ICHK=1
          ENDIF
        ELSE IF (DELX.LT.0.0. AND .DELY.LE.0.0) THEN
          RHS = THETAR - 270.0*CONVDR
          IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
            BETA = ALPHA + 360.0*CONVDR - THETAR
          ELSE
            ICHK=1
          ENDIF
        ELSE
          ICHK=1
        ENDIF
      ENDIF
      R = L*COS(BETA)
      T = L*SIN(BETA)
      T = ABS(T)
C     WRITE(6,6) 'ALMOST TO 45'
C
C
      IF (ICHK.EQ.1) THEN
        LCT = 0.0
        T = 1.0
      ENDIF
      TERM = Q/(4.0*BU)
      IF (L.LE.TERM) THEN
        LCT=1.0
        T = 0.0
        GO TO 45
      ENDIF
      IF (ICHK.EQ.1) GO TO 45
      IF (R.EQ.0.0) THEN
```

```
         LCT = Q/(2.0*BU) - (Q/(2.0*PI*BU))*90.0*CONVDR
      ELSE
         LCT = Q/(2.0*BU) - (Q/(2.0*PI*BU))*ATAN(T/R)
      ENDIF
   45 CONTINUE
C     WRITE(6,6) '45'
      IF (LCT.GE.T) THEN
         DO 50 I = 1, NDIV
            IF (R.LE.RR(I)) THEN
               COUNT(I)=COUNT(I)+1
               SUM(I)=SUM(I)+LW(SOIARR(ROW,COL))
               JUMP=JUMP+1
C              WRITE(6,5) ROW,COL
               GO TO 30
            ENDIF
   50    CONTINUE
         LCT = 0.0
         T = 1.0
         GO TO 45
      ELSE
         IF (JUMP.EQ.0) THEN
            IF (QUIT.EQ.1) GO TO 300
            QUIT=1
            ROW=(INT(Y/DEL)+1) - 1
            COL=MED
            COLB=COL
            GO TO 20
         ELSE IF (IFLAGL.EQ.1. AND .IFLAGR.EQ.1) THEN
   75       IF (QUIT.EQ.1) THEN
               ROW = ROW - 1
               IF (ROW.LT.1) GO TO 300
            ELSE
               ROW = ROW + 1
               IF (ROW.GT.NROWS) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
C ------------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
               IF (ROW.GT.126. AND .COL.GT.283) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
C ------------------------------
```

```
            ENDIF
            COL = COLB + (RIGHT/2) - (LEFT/2)
            IF (ITER.EQ.1) MED=COL
            COLB=COL
            GO TO 20
         ELSE
            IF(NJ.EQ.JUMP) THEN
               IFLAGL = 1
            ELSE
               IFLAGR = 1
            ENDIF
         ENDIF
      ENDIF
      JUMP=JUMP+1
      GO TO 30
  300 CONTINUE
      SUMW = 0.0
      RISK = 0.0
      DO 400 I = 1, NDIV
         IF (COUNT(I).EQ.0) THEN
            SUBRSK(I)=0.0
C           WRITE(6,11) '****WARNING: SUBRSK(',I,') IS ZERO'
         ELSE
            SUBRSK(I) = SUM(I)/FLOAT(COUNT(I))
            SUMW = SUMW + W(I)
            RISK = RISK + SUBRSK(I)*W(I)
         ENDIF
  400 CONTINUE
      RISK = RISK/SUMW
      RETURN
      END
C*********************************************************************
      SUBROUTINE HISTO(NCAL)
C
C     PARAMETER STATEMENTS
C
      INTEGER NWCMX, NPRMX
      PARAMETER(NWCMX=50,NPRMX=5)
      INTEGER NINTMX
      PARAMETER(NINTMX=10)
C
C     COMMON BLOCKS
C
      COMMON / A / RISK, WCONT
         REAL RISK(NWCMX)
         INTEGER WCONT(NWCMX)
      COMMON / C / HISINT, BINSUM, BINC
         INTEGER HISINT, BINSUM(NINTMX), BINC(NINTMX)
C
C     OTHER DECLARATIONS
C
      REAL DY, RNC, ARG
      INTEGER NCAL, BIN
C
```

```
C     FORMATS
C
    1 FORMAT(1X,' NCAL = ',I3)
    2 FORMAT(1X,' HISINT = ',I3)
C
C     EXECUTABLE STATEMENTS
C
C     WRITE(6,1) NCAL
      RNC = FLOAT(NCAL)
      ARG = 1.0 + 3.3*ALOG10(RNC)
      HISINT = INT(ARG)
C     WRITE(6,2) HISINT
      DY=100.0/FLOAT(HISINT)
      DO 10 L = 1, HISINT
         BINSUM(L)=0
         BINC(L)=0
   10 CONTINUE
      DO 100 N = 1, NCAL
         ARG = RISK(N)/DY + 1.0
         BIN=INT(ARG)
         BINSUM(BIN)=BINSUM(BIN)+1
         IF (WCONT(N).EQ.1) BINC(BIN)=BINC(BIN)+1
  100 CONTINUE
      RETURN
      END
```

A.4 HISTO.FOR

```
C
C     PROGRAM TO PLOT A HISTOGRAM USING HALO
C
      CHARACTER*20 DEVICE, DUMT
      REAL FREREL(10)
      INTEGER HISINT, NPIX(10), NX(10)
C
C     OPEN "TEMPORARY" INPUT DATA FILE (CREATED BY 'MODEL.FOR')
C
      OPEN(7,FILE='TEMP.DAT',STATUS='OLD')
C
C     SET DEVICE DRIVER AND INITIALIZE TO MODE 2
C
C        COLOR LIST:
C
C           1 = DARK BLUE
C           2 = BRIGHT GREEN
C           3 = SKY BLUE
C           4 = RED
C           5 = PURPLE
C           6 = BROWN
C           7 = DULL WHITE
C           8 = GREY
C           9 = BRIGHT BLUE
C           10 = VERY BRIGHT GREEN
C           11 = BRIGHT SKY BLUE
C           12 = PINK/BRIGHT RED
C           13 = BRIGHT PURPLE
C           14 = YELLOW
C           15 = BRIGHT WHITE
C
      DEVICE='/HALOIBME.DEV/'
      CALL SETDEV(DEVICE)
      CALL INITGRAPHICS(2)
C
C     READ IN DATA
C
      READ(7,*) HISINT
      DO 50 I = 1, HISINT
         READ(7,*) FREREL(I)
   50 CONTINUE
C
      CALL FILL(9)
      CALL SETTCL(1,1)
      CALL INITTCUR(1,1,9)
      CALL MOVTCA(15,160)
      CALL SETTEXT(1,1,1,0)
      CALL TEXT('/CONTAMIN. FREQ./')
      CALL SETTEXT(1,1,0,0)
      CALL MOVTCA(70,185)
      CALL TEXT('/ESTIMATED RISK (%)/')
      CALL SETTCL(11,1)
```

```
      CALL MOVTCA(16,34)
      CALL TEXT('/1.0/')
      CALL MOVTCA(24,178)
      CALL TEXT('/0.0/')
      CALL MOVTCA(268,178)
      CALL TEXT('/100/')
      CALL SETCOLOR(15)
      CALL BOX(40,170,280,30)
      DO 100 I = 1, HISINT
         NPIX(I)= 170 - 140*INT(FREREL(I))/100
         NX(I)= 40 + (240/HISINT)*I
  100 CONTINUE
      CALL BOX(40,170,NX(1),NPIX(1))
      CALL MOVABS(41,169)
      CALL FILL(12)
      DO 200 I = 2, HISINT
         J=I-1
         CALL BOX(NX(J),170,NX(I),NPIX(I))
         CALL MOVABS(NX(J)+1,169)
         CALL FILL(12)
  200 CONTINUE
      CALL MOVABS(40,170)
      CALL SETCOLOR(14)
      CALL LNABS(280,30)
C
C     WAIT FOR ENTER KEY
C
      READ(*,'(A20)') DUMT
      STOP
      END
```

A.5 SAMOPT.FOR

```
C**********************************************************************
C
C       PESTICIDE MONITORING DESIGN PROGRAM - FORTRAN CODE FOR
C            RISK ANALYSIS AND OPTIMIZATION OF SAMPLING DESIGN.
C
C       MODULE II: SAMPLE WELL RISK ESTIMATION AND SAMPLE DESIGN
C
C                    Developed by
C
C                          TIM SCHEIBE
C                          UNIVERSITY OF WASHINGTON
C                          DEPARTMENT OF CIVIL ENGINEERING
C                          AUGUST, 1987
C
C
C**********************************************************************
      PROGRAM SAMPDES
C
C     PARAMETER STATEMENTS
C
C     MAXIMUM NUMBER OF
C        CALIBRATION WELLS = NWCMX            50
C        SAMPLE WELLS = NWSMX                100
C        PROXIMATE WELLS = NPRMX               5
C        ROWS IN SOIL ARRAY = NXMX           250
C        COLUMNS IN SOIL ARRAY = NYMX        360
C        CATEGORIES OF SOIL TYPES = NCATMX    57
C        WELLS TO BE SAMPLED IN NEXT ROUND = NNWMX  =  20
C        INTERVALS IN HISTOGRAM = NINTMX =    20
C
      INTEGER NWCMX, NPRMX
      PARAMETER(NWCMX=50,NPRMX=5)
      INTEGER NXMX, NYMX, NCATMX
      PARAMETER(NXMX=250,NYMX=360,NCATMX=57)
      INTEGER NWSMX
      PARAMETER(NWSMX=100)
      INTEGER NNWMX
      PARAMETER(NNWMX=20)
      INTEGER NINTMX
      PARAMETER(NINTMX=20)
C
C     COMMON BLOCK DEFINITIONS
C
      COMMON / A / RISK
         REAL RISK(NWSMX)
      COMMON / B / NLC, NDIV, LW, W, DDIV, EXP3
         REAL LW(9), W(10), DDIV, EXP3
         INTEGER NLC, NDIV
      COMMON / D / DMAX, EXP1
         REAL DMAX, EXP1
      COMMON / E / XMAX, EXP2
         REAL XMAX, EXP2
```

```
      COMMON / F / DEL, SOIARR, NROWS, NCOLS
         REAL DEL
         INTEGER NROWS, NCOLS, SOIARR(NXMX,NYMX)
C
C     OTHER VARIABLE DECLARATIONS
C
      REAL X(NWCMX), Y(NWCMX), DEP(NWCMX), QC(NWCMX), RISKC(NWCMX),
     &     PDIST(NWCMX,NPRMX), THETA(NWCMX), U(NWCMX),
     &     A, B, C, R1, R2, R3(NWCMX), AM, BM, CM, DIFF, SUM,
     &     XS(NWSMX), YS(NWSMX), DEPS(NWSMX), THETAS(NWSMX),
     &     QS(NWSMX), US(NWSMX), PDISS(NWSMX,NPRMX) , ARG, RNC
      REAL DY, PHAT, PACT(11), PX(11), DELDEP, DELDIS, DELSOI,
     &     VAL(10), D, C2, UMAX, RISMX, AVPROX, RATMAX, IR(NWSMX),
     &     RATING(NWSMX), R3S(NWSMX), PRODI, PRODJ , FACT, BINOM
      INTEGER NCAL, NPROX(NWCMX), NCONT(NWCMX,NPRMX), WCONT(NWCMX),
     &     NSAM, NNEW, NPROXS(NWSMX), NCONTS(NWSMX,NPRMX), IMETH,
     &     WN(NNWMX), WNT(NNWMX), HISINT, BINSUM(NINTMX),
     &     BINC(NINTMX), BIN, N, K, VALMAX, NS, WELLNO,
     &     ISUM, COUNT, ANS
      CHARACTER*12 WELIN, PARIN, SOILIN, FILOT, RANKS
      CHARACTER*8  WDESC(NWCMX), WDESS(NWSMX)
C
C     FORMAT STATEMENTS
C
    1 FORMAT(1X,A,\)
    2 FORMAT(A12)
    3 FORMAT(80I1)
    4 FORMAT(A8)
   11 FORMAT(1X,A)
   12 FORMAT(1X,A,A)
   13 FORMAT(1X,A,F8.3)
   14 FORMAT(1X,I5)
   15 FORMAT(1X,F7.3)
   16 FORMAT(1X,A,F8.5)
   17 FORMAT(1X,A,I3,A)
   18 FORMAT(6X,A8,5X,F8.0,2X,F8.0,3X,F5.1)
   19 FORMAT(1X,A,A10)
   20 FORMAT(3X,A8,4X,F5.1)
   21 FORMAT(1X,A8,2X,F6.0,2X,F6.0,2X,I1,2X,F4.0,2X,F4.0,2X,F4.0,2X,
     &       F4.0)
   22 FORMAT(1X,A8,2X,F6.0,2X,F6.0,2X,F4.0,2X,F4.0,2X,F4.0,2X,F4.0)
   23 FORMAT(1X,A,I3)
   24 FORMAT(9X,F6.0,20X,I1)
   25 FORMAT(1X,A,F5.0,A,F5.3)
   26 FORMAT(19X,I2,18X,F6.4)
   27 FORMAT(1X,A,F6.0,A)
   28 FORMAT(1X,A,F8.4)
   30 FORMAT(1X,A,I3,A,I1)
  101 FORMAT(1X,/)
C
C     SCREEN INTRO
C
C
C     INPUT
```

```
C
      WRITE(*,1) 'Enter name of well data input file: '
      READ(*,2) WELIN
      WRITE(*,1) 'Enter name of parameter input file: '
      READ(*,2) PARIN
      WRITE(*,1) 'Enter name of soil data input file: '
      READ(*,2) SOILIN
      WRITE(*,1) 'Enter desired name of general output file: '
      READ(*,2) FILOT
      WRITE(*,1) 'Enter desired name of output file for RANKCOR: '
      READ(*,2) RANKS
      OPEN(3,FILE=WELIN,STATUS='OLD')
      OPEN(4,FILE=PARIN,STATUS='OLD')
      OPEN(5,FILE=SOILIN,STATUS='OLD')
      OPEN(6,FILE=FILOT,STATUS='NEW')
      OPEN(7,FILE=RANKS,STATUS='NEW')
      READ(3,*) NCAL, NSAM
C
C     READ CALIBRATION WELL DATA
C
      DO 50 I = 1, NCAL
         READ(3,4) WDESC(I)
         READ(3,*) X(I), Y(I), WCONT(I), DEP(I), THETA(I), QC(I), U(I)
         READ(3,*) NPROX(I)
         IF (NPROX(I).EQ.0) GO TO 50
         DO 45 J = 1, NPROX(I)
            READ(3,*) PDIST(I,J), NCONT(I,J)
   45    CONTINUE
   50 CONTINUE
C
C     READ SAMPLE WELL DATA
C
      DO 70 I = 1, NSAM
         READ(3,4) WDESS(I)
         READ(3,*) XS(I), YS(I), DEPS(I), THETAS(I), QS(I), US(I)
         READ(3,*) NPROXS(I)
         IF (NPROXS(I).EQ.0) GO TO 70
         DO 55 J = 1, NPROXS(I)
            READ(3,*) PDISS(I,J), NCONTS(I,J)
   55    CONTINUE
   70 CONTINUE
C
C     READ PARAMETER DATA AND SOIL DATA
C
      READ(4,*) DMAX,EXP1
      READ(4,*) XMAX,EXP2
      READ(4,*) NLC
      READ(4,*) (LW(I), I=1,NLC)
      READ(4,*) NDIV
      READ(4,*) (W(I), I=1,NDIV)
      READ(4,*) DDIV, EXP3
      READ(4,*) C, B, A
      READ(5,*) NROWS, NCOLS, DEL
      IF (NROWS.GT.NXMX) THEN
```

```
      WRITE(6,12) ' NUMBER OF ROWS IN DATA ARRAY EXCEEDS',
     &            ' DIMENSION LIMITS'
      WRITE(6,11) '   TERMINATING EXECUTION'
      GO TO 999
     ENDIF
     IF (NCOLS.GT.NYMX) THEN
      WRITE(6,12) ' NUMBER OF COLS IN DATA ARRAY EXCEEDS',
     &            ' DIMENSION LIMITS'
      WRITE(6,11) '   TERMINATING EXECUTION'
      GO TO 999
     ENDIF
     READ(5,3) ((SOIARR(I,J), J=1,NCOLS), I=1,NROWS)
C
C    ECHO INPUT DATA
C
 104 CONTINUE
     WRITE(*,101)
     WRITE(*,11) 'Input data can be printed to the output file for'
     WRITE(*,11) '  verification or identification purposes.  Please'
     WRITE(*,11) '  indicate which option you prefer:'
     WRITE(*,11) '      1)  Full input echo'
     WRITE(*,11) '      2)  Parameter echo only (no well data)'
     WRITE(*,11) '      3)  No input echo'
     WRITE(*,101)
     WRITE(*,1)  'Enter option 1, 2, or 3 here:  '
     READ(*,'(I1)') ANS
     IF (ANS.EQ.2) GO TO 121
     IF (ANS.EQ.3) GO TO 140
     IF (ANS.NE.1) GO TO 104
     WRITE(6,11) ' CALIBRATION WELL DATA ECHO:'
     WRITE(6,101)
     WRITE(6,11) 'WELL        X       Y     C   DEP  THET   Q   #USERS'
     WRITE(6,11) '****      *****   *****   *   ***  ****  ****  ****'
     DO 110 I = 1, NCAL
        WRITE(6,21) WDESC(I), X(I), Y(I), WCONT(I), DEP(I), THETA(I),
     &              QC(I), U(I)
        WRITE(6,23) '   NUMBER OF PROXIMATE WELLS = ',NPROX(I)
        IF (NPROX(I).EQ.0) GO TO 110
        WRITE(6,11) '      DISTANCE(FT)      CONTAMINATED? (1=YES)'
        WRITE(6,11) '      ************      *********************'
        DO 105 J = 1, NPROX(I)
           WRITE(6,24) PDIST(I,J), NCONT(I,J)
 105    CONTINUE
 110 CONTINUE
     WRITE(6,101)
     WRITE(6,101)
     WRITE(6,11) ' SAMPLE WELL DATA ECHO:'
     WRITE(6,101)
     WRITE(6,11) 'WELL        X       Y      DEP  THET   Q   #USERS'
     WRITE(6,11) '****      *****   *****    ***  ****  ****  ****'
     DO 120 I = 1, NSAM
        WRITE(6,22) WDESS(I), XS(I), YS(I), DEPS(I), THETAS(I),
     &              QS(I), US(I)
        WRITE(6,23) '   NUMBER OF PROXIMATE WELLS = ',NPROXS(I)
```

```
      IF (NPROXS(I).EQ.0) GO TO 120
      WRITE(6,11) '      DISTANCE(FT)      CONTAMINATED? (1=YES)'
      WRITE(6,11) '      ************      *********************'
      DO 115 J = 1, NPROXS(I)
         WRITE(6,24) PDISS(I,J), NCONTS(I,J)
115   CONTINUE
120 CONTINUE
121 CONTINUE
    WRITE(6,101)
    WRITE(6,101)
    WRITE(6,11) ' PARAMETER DATA ECHO:'
    WRITE(6,101)
    WRITE(6,25) '  THRESHOLD DEPTH = ',DMAX,'ft.; EXPON. = ',EXP1
    WRITE(6,25) '  THRESHOLD DIST. = ',XMAX,'ft.; EXPON. = ',EXP2
    WRITE(6,101)
    WRITE(6,23) '  NUMBER OF LAND USE CATEGORIES = ',NLC
    WRITE(6,101)
    WRITE(6,11) '             CATEGORY                 WEIGHT'
    WRITE(6,11) '    ******************************   *******'
    WRITE(6,28) '    Known EDB application area      ',LW(1)
    WRITE(6,28) '    High risk soil in crop area     ',LW(2)
    WRITE(6,28) '    Med. risk soil -----"------      ',LW(4)
    WRITE(6,28) '    Low risk soil  -----"------      ',LW(6)
    WRITE(6,28) '    High risk soil; not crop area   ',LW(3)
    WRITE(6,28) '    Med. risk soil; ------"------    ',LW(5)
    WRITE(6,28) '    Low risk soil;  ------"------    ',LW(7)
    WRITE(6,28) '    Known EDB-type crop growth      ',LW(8)
    WRITE(6,28) '    Surface water area              ',LW(9)
    WRITE(6,101)
    WRITE(6,23) '  NUMBER OF CAPTURE ZONE SUB-AREAS = ',NDIV
    WRITE(6,101)
    WRITE(6,11) '    SUB-AREA (1 IS CLOSEST TO WELL)   WEIGHT'
    WRITE(6,11) '    ******************************    ******'
    DO 130 I = 1, NDIV
       WRITE(6,26) I, W(I)
130 CONTINUE
    WRITE(6,101)
    WRITE(6,27) '    TRAVEL TIME TO AREA 1 BOUND. = ',DDIV,' DAYS'
    WRITE(6,16) '    EXPONENT = ',EXP3
    WRITE(6,101)
    WRITE(6,11) '  OVERALL FACTOR WEIGHTS USED:'
    WRITE(6,101)
    WRITE(6,16) '     Depth to water table    - ',A
    WRITE(6,16) '     Status of nearby wells  - ',B
    WRITE(6,16) '     Capture zone soil types - ',C
    WRITE(6,101)
    WRITE(6,101)
    WRITE(6,11) 'SOIL DATA INFORMATION:'
    WRITE(6,101)
    WRITE(6,23) '  NUMBER OF ROWS IN SOIL ARRAY = ',NROWS
    WRITE(6,23) '  NUMBER OF COLUMNS IN SOIL ARRAY = ',NCOLS
    WRITE(6,13) '  DIMENSION OF ARRAY ELEMENTS (ft) = ',DEL
140 CONTINUE
    WRITE(6,101)
```

```
      WRITE(6,101)
      WRITE(6,11) 'RESULTS:'
      WRITE(6,11) '********'
      WRITE(6,101)
      WRITE(6,11) '    WELL     EST.RISK'
      WRITE(6,11) '   ******    ********'
C
C     SUBROUTINE CALLS
C
      DO 150 I = 1, NCAL
         CALL FORM1(DEP(I),R1)
         SUM = 0.0
         AM = A
         BM = B
         CM = C
         IF (NPROX(I).EQ.0) THEN
            BM = 0
            R2 = 0.0
            DIFF = 1.0 - AM - CM
            SUM = AM + CM
            AM = AM + (AM/SUM)*DIFF
            CM = CM + (CM/SUM)*DIFF
            GO TO 145
         ENDIF
         DO 142 J = 1, NPROX(I)
            CALL FORM2(R2,PDIST(I,J),NCONT(I,J))
            SUM = SUM + R2
  142    CONTINUE
         R2 = SUM/NPROX(I)
  145    CONTINUE
         CALL FORM3(R3(I),X(I),Y(I),THETA(I),QC(I))
         RISKC(I) = AM*R1 + BM*R2 + CM*R3(I)
         IF (RISKC(I).LT.0.0) RISKC(I) = 0.0
         WRITE(6,20) WDESC(I), RISKC(I)
  150 CONTINUE
      DO 200 I = 1, NSAM
         CALL FORM1(DEPS(I),R1)
         SUM = 0.0
         AM = A
         BM = B
         CM = C
         IF (NPROXS(I).EQ.0) THEN
            BM = 0
            R2 = 0.0
            DIFF = 1.0 - AM - CM
            SUM = AM + CM
            AM = AM + (AM/SUM)*DIFF
            CM = CM + (CM/SUM)*DIFF
            GO TO 195
         ENDIF
         DO 190 J = 1, NPROXS(I)
            CALL FORM2(R2,PDISS(I,J),NCONTS(I,J))
            SUM = SUM + R2
  190    CONTINUE
```

```
        R2 = SUM/NPROXS(I)
  195   CONTINUE
        CALL FORM3(R3S(I),XS(I),YS(I),THETAS(I),QS(I))
        RISK(I) = AM*R1 + BM*R2 + CM*R3S(I)
        IF (RISK(I).LT.0.0) RISK(I) = 0.0
        WRITE(6,20) WDESS(I), RISK(I)
  200 CONTINUE
C***********************
C     VALUES OF RISK HAVE NOW BEEN ESTIMATED FOR EACH
C        OF THE SAMPLE WELLS.  THE NEXT TASK IS TO CHOOSE THE
C        NEXT SET OF WELLS TO BE SAMPLED ACCORDING TO ONE OF THE
C        THREE OPTIMIZATION APPROACHES OUTLINED.  EACH OF THE THREE
C        IS PROGRAMMED BELOW, ALLOWING USER SPECIFICATION OF WHICH
C        APPROACH TO USE AND COMPARISON OF RESULTS USING THE VARIOUS
C        APPROACHES.
C***********************
      WRITE(*,11) '*****************************************************'
      WRITE(*,11) '*                                                   *'
      WRITE(*,11) '*   BEGINNING SAMPLE OPTIMIZATION PHASE             *'
      WRITE(*,11) '*                                                   *'
      WRITE(*,11) '*                                                   *'
      WRITE(*,11) '*****************************************************'
      WRITE(*,101)
      WRITE(*,11) 'Please enter the number of wells to be sampled'
      WRITE(*,1)  '  in the next round of testing: '
      READ(*,*) NNEW
      WRITE(*,101)
      WRITE(*,101)
      WRITE(*,11) 'Three methods of sample design are available:'
      WRITE(*,11) '   1) No error characterization'
      WRITE(*,11) '   2) Binomial error characterization'
      WRITE(*,11) '   3) Information content characterization'
      WRITE(*,101)
      WRITE(*,1) 'Which of these methods do you wish to use? '
  201 CONTINUE
      READ(*,*) IMETH
C     WRITE(*,30) 'NNEW = ',NNEW,';  IMETH = ',IMETH
      IF (IMETH.EQ.1) GO TO 202
      IF (IMETH.EQ.2) GO TO 250
      IF (IMETH.EQ.3) GO TO 500
      WRITE(*,1) 'ERROR** Please re-enter (1, 2, or 3)?'
      GO TO 201
  202 CONTINUE
C**********
C
C     APPROACH ONE - NO ERROR CHARACTERIZATION
C
      WRITE(6,101)
      WRITE(6,11) 'OPTIMIZATION METHOD 1 - NO ERROR CHARACTERIZATION'
      WRITE(6,101)
      DO 210 I = 1, NNEW
         WN(I) = I
         IF (I.EQ.1) GO TO 210
         DO 207 J = 1, I-1
```

```
            PRODI=RISK(I)*US(I)
            PRODJ=RISK(WN(J))*US(WN(J))
            IF (PRODI.GT.PRODJ) THEN
               WNT(J) = I
               DO 203 K = J+1, I
                  WNT(K) = WN(K-1)
  203          CONTINUE
               DO 205 K = J, I
                  WN(K) = WNT(K)
  205          CONTINUE
               GO TO 210
            ENDIF
  207    CONTINUE
  210 CONTINUE
      DO 220 I = NNEW+1, NSAM
         DO 217 J = 1, NNEW
            PRODI=RISK(I)*US(I)
            PRODJ=RISK(WN(J))*US(WN(J))
            IF (PRODI.GT.PRODJ) THEN
               WNT(J) = I
               DO 213 K = J+1, NNEW
                  WNT(K) = WN(K-1)
  213          CONTINUE
               DO 215 K = J, I
                  WN(K) = WNT(K)
  215          CONTINUE
               GO TO 220
            ENDIF
  217    CONTINUE
  220 CONTINUE
      GO TO 800
C
C**********
C
C     APPROACH TWO - BINOMIAL ERROR CHARACTERIZATION
C
  250 CONTINUE
      WRITE(6,101)
      WRITE(6,11) 'OPTIMIZATION METHOD 2 - BINOMIAL METHOD'
      WRITE(6,101)
C
C     USE HISTOGRAMMING RULE TO SET UP Rj INTERVALS AND ESTABLISH
C         N AND K
C
      RNC = FLOAT(NCAL)
      ARG = 1.0 + 3.3*ALOG10(RNC)
      HISINT = INT(ARG)
      DY = 100.0/FLOAT(HISINT)
      DO 260 I = 1, HISINT
         BINSUM(I) = 0
         BINC(I) = 0
  260 CONTINUE
      DO 270 I = 1, NCAL
         ARG = RISKC(I)/DY + 1.0
```

```
         BIN = INT(ARG)
         BINSUM(BIN) = BINSUM(BIN) + 1
         IF (WCONT(I).EQ.1) BINC(BIN) = BINC(BIN) + 1
  270 CONTINUE
C
C     CALCULATE PHAT FROM BINOMIAL DISTRIBUTION
C
      DO 300 I = 1, NSAM
         ARG = RISK(I)/DY + 1.0
         BIN = INT(ARG)
         IF (BINSUM(BIN).EQ.0) THEN
            RISK(I) = 100.0
            GO TO 300
         ENDIF
         N = BINSUM(BIN)
         K = BINC(BIN)
         BINOM = FACT(N)/(FACT(K)*FACT(N-K))
         PHAT = 0.0
         SUM = 0.0
C        WRITE(*,30) 'N = ',N,';  K = ',K
         DO 280 J = 1, 11
            PACT(J) = (FLOAT(J)*0.1) - 0.1
            PX(J) = BINOM*(PACT(J)**K)*((1.0-PACT(J))**(N-K))
            SUM = SUM + PX(J)
C           WRITE(*,16) 'SUM = ',SUM
  280    CONTINUE
         DO 285 J = 1, 11
            PX(J) = PX(J)/SUM
            PHAT = PHAT + PX(J)*PACT(J)
  285    CONTINUE
         RISK(I) = (PHAT*100.0*0.9)+(RISK(I)*0.1)
         IF (RISK(I).GT.100.0) RISK(I)=100.0
         WRITE(6,20) WDESS(I), RISK(I)
  300 CONTINUE
      DO 310 I = 1, NNEW
         WN(I) = I
         IF (I.EQ.1) GO TO 310
         DO 307 J = 1, I-1
            PRODI=RISK(I)*US(I)
            PRODJ=RISK(WN(J))*US(WN(J))
            IF (PRODI.GT.PRODJ) THEN
               WNT(J) = I
               DO 303 K = J+1, I
                  WNT(K) = WN(K-1)
  303          CONTINUE
               DO 305 K = J, I
                  WN(K) = WNT(K)
  305          CONTINUE
               GO TO 310
            ENDIF
  307    CONTINUE
  310 CONTINUE
      DO 320 I = NNEW+1, NSAM
         DO 317 J = 1, NNEW
```

```
            PRODI=RISK(I)*US(I)
            PRODJ=RISK(WN(J))*US(WN(J))
            IF (PRODI.GT.PRODJ) THEN
               WNT(J) = I
               DO 313 K = J+1, NNEW
                  WNT(K) = WN(K-1)
  313          CONTINUE
               DO 315 K = J, I
                  WN(K) = WNT(K)
  315          CONTINUE
               GO TO 320
            ENDIF
  317    CONTINUE
  320 CONTINUE
      GO TO 800
C**********
C
C     APPROACH THREE - INFORMATION CONTENT CHARACTERIZATION
C
  500 CONTINUE
      WRITE(6,101)
      WRITE(6,11) 'OPTIMIZATION METHOD 3 - INFO. CONTENT'
      WRITE(6,101)
C
C     ESTABLISH INTERVALS AND WEIGHTING FACTORS FOR DEFINITION
C        OF INFORMATION CONTENT
C
      DELDEP = 10.0
      DELDIS = 500.0
      DELSOI = 10.0
      VALMAX = 5
      VAL(1) = 33.0
      VAL(2) = 20.0
      VAL(3) = 10.0
      VAL(4) = 5.0
      VAL(5) = 3.0
      VAL(6) = 2.0
  501 CONTINUE
      WRITE(*,101)
      WRITE(*,101)
      WRITE(*,1) 'Enter information value weight (0-1): '
      READ(*,*) D
      WRITE(*,1) 'Enter risk reduction value weight (0-1): '
      READ(*,*) C2
      SUM = C2 + D
      IF (SUM.NE.1.0) THEN
         WRITE(*,101)
         WRITE(*,16) 'ERROR**  C + D = ', SUM
         WRITE(*,11) '    C + D  must equal 1.0; please re-enter.'
         GO TO 501
      ENDIF
      WRITE(6,101)
      WRITE(6,11) 'OBJECTIVE FUNCTION COEFFICIENTS USED:'
      WRITE(6,16) '   Information Content Coefficient = ',D
```

```
      WRITE(6,16) '   Risk Reduction Coefficient = ',C2
      WRITE(6,101)
      WRITE(6,101)
      UMAX = 0.0
      DO 510 I = 1, NSAM
         IF (US(I).GT.UMAX) UMAX=US(I)
  510 CONTINUE
      NS = 0
  511 NS = NS + 1
      IF (NCAL.EQ.0) THEN
         RISMX = 0.0
         DO 512 I = 1, NSAM
            IF (RISK(I).GT.RISMX) THEN
               RISMX = RISK(I)
               WELLNO = I
            ENDIF
  512    CONTINUE
         GO TO 601
      ENDIF
      ISUM = 0
      DO 515 I = 1, NCAL
         ISUM = ISUM + NPROX(I)
  515 CONTINUE
      AVPROX = FLOAT(ISUM)/FLOAT(NCAL)
      RATMAX = 0.0
      DO 600 I = 1, NSAM
         IF (NS.EQ.1) GO TO 518
         DO 517 J = 1, NS-1
            IF (I.EQ.WN(J)) GO TO 600
  517    CONTINUE
  518    CONTINUE
         IR(I) = 0.0
         COUNT = 0
         DO 520 J = 1, NCAL
            IF (DEP(J).GE.DEPS(I)-DELDEP/2.0) THEN
               IF (DEP(J).LE.DEPS(I)+DELDEP/2.0) COUNT = COUNT + 1
            ENDIF
  520    CONTINUE
         IF (COUNT.LE.VALMAX) THEN
            IR(I) = IR(I) + VAL(COUNT+1)
         ENDIF
         COUNT = 0
         IF (NPROXS(I).EQ.0) THEN
            COUNT = 0
            GO TO 531
         ENDIF
         DO 530 J = 1, NCAL
            IF (NPROX(J).EQ.0) GO TO 530
            DO 525 K = 1, NPROXS(I)
               DO 523 L = 1, NPROX(J)
                  IF (PDIST(J,L).GE.PDISS(I,K)-DELDIS/2.0) THEN
                     IF (PDIST(J,L).LE.PDISS(I,K)+DELDIS/2.0)
     &                  COUNT = COUNT + 1
                  ENDIF
```

```
  523          CONTINUE
  525        CONTINUE
  530     CONTINUE
          COUNT = COUNT/(NPROXS(I)*AVPROX)
  531     CONTINUE
          IF (COUNT.LE.VALMAX) THEN
             IR(I) = IR(I) + VAL(COUNT+1)
          ENDIF
          COUNT = 0
          DO 540 J = 1, NCAL
             IF (R3(J).GE.R3S(I)-DELSOI/2.0) THEN
                IF (R3(J).LE.R3S(I)+DELSOI/2.0) COUNT = COUNT + 1
             ENDIF
  540     CONTINUE
          IF (COUNT.LE.VALMAX) THEN
             IR(I) = IR(I) + VAL(COUNT+1)
          ENDIF
          RATING(I) = C2*(RISK(I)*US(I)/UMAX) + D*IR(I)
          IF (RATING(I).GT.RATMAX) THEN
             RATMAX = RATING(I)
             WELLNO = I
          ENDIF
  600  CONTINUE
  601  CONTINUE
       WN(NS) = WELLNO
       NCAL = NCAL + 1
       DEP(NCAL) = DEPS(NS)
       R3(NCAL) = R3S(NS)
       NPROX(NCAL) = NPROXS(NS)
       DO 610 I = 1, NPROX(NCAL)
          PDIST(NCAL,I) = PDISS(NS,I)
  610  CONTINUE
       IF (NS.LT.NNEW) GO TO 511
C**********
C
C  OUTPUT
C
C
  800  CONTINUE
       DO 805 I = 1, 25
          WRITE(*,101)
  805  CONTINUE
       WRITE(*,11) '*****************************************************'
       WRITE(6,11) '*****************************************************'
       WRITE(*,11) '    SAMPLE DESIGN RESULTS: '
       WRITE(6,11) '    SAMPLE DESIGN RESULTS: '
       WRITE(*,101)
       WRITE(6,101)
       WRITE(*,17) '      ',NNEW,' WELLS TO SAMPLE:'
       WRITE(6,17) '      ',NNEW,' WELLS TO SAMPLE:'
       WRITE(*,101)
       WRITE(6,101)
       WRITE(*,11) '    WELL DESC.       X          Y        EST. RISK '
       WRITE(6,11) '    WELL DESC.       X          Y        EST. RISK '
```

```
      WRITE(*,11) '    *********    *********  *********   ***********'
      WRITE(6,11) '    *********    *********  *********   ***********'
      WRITE(*,101)
      WRITE(6,101)
      DO 820 I = 1, NNEW
         J = WN(I)
         WRITE(*,18) WDESS(J), XS(J), YS(J), RISK(J)
         WRITE(6,18) WDESS(J), XS(J), YS(J), RISK(J)
         WRITE(7,14) WN(I)
  820 CONTINUE
      WRITE(*,101)
      WRITE(*,11) '    THIS INFORMATION HAS ALSO BEEN WRITTEN TO THE '
      WRITE(*,19) '      FILE NAMED ',FILOT
      WRITE(*,101)
      WRITE(*,11) '    A RANKED LISTING OF WELL NUMBER (FOR USE IN THE'
      WRITE(*,11) '      CALCULATION OF RANK CORRELATIONS) HAS BEEN'
      WRITE(*,19) '      WRITTEN TO THE FILE NAMED ',RANKS
      WRITE(*,101)
C
C**********
  999 CONTINUE
      STOP
      END
C*************************************************************************
      SUBROUTINE FORM1(DEPTH,RISK)
C
C     COMMON BLOCKS
C
      COMMON / D / DMAX, EXP1
         REAL DMAX, EXP1
C
C     OTHER DECLARATIONS
C
      REAL RISK, DEPTH
C
C     EXECUTABLE STATEMENTS
C
      RISK = 100.0 * ((DMAX-DEPTH)/DMAX)**EXP1
      RETURN
      END
C*************************************************************************
      SUBROUTINE FORM2(RISK,X,ICONT)
C
C     COMMON BLOCKS
C
      COMMON / E / XMAX, EXP2
         REAL XMAX, EXP2
C
C     OTHER DECLARATIONS
C
      REAL RISK, A, X
      INTEGER ICONT
C
C     EXECUTABLE STATEMENTS
```

```
C
      IF (ICONT.EQ.1) THEN
         A = 1.0
      ELSE
         A = -1.0
      ENDIF
      RISK = A * ((X-XMAX)/XMAX)**EXP2
      RETURN
      END
C*********************************************************************
      SUBROUTINE FORM3(RISK,X,Y,THETA,Q)
C
C     PARAMETER STATEMENTS
C
      INTEGER NXMX, NYMX, NCATMX
      PARAMETER(NXMX=250,NYMX=360,NCATMX=57)
C
C     COMMON BLOCKS
C
      COMMON / B / NLC, NDIV, LW, W, DDIV, EXP3
         REAL LW(9), W(10), DDIV, EXP3
         INTEGER NLC, NDIV
      COMMON / F / DEL, SOIARR, NROWS, NCOLS
         REAL DEL
         INTEGER NROWS, NCOLS, SOIARR(NXMX,NYMX)
C
C     OTHER DECLARATIONS
C
      REAL BU, LCT, PI, Q, R, RISK, RR(10), SUBRSK(10), SUM(10),
     &     T, THETA, THETAR, X, Y, B, U, DELX, DELY, TERM,
     &     YMAX, Y1, Y2, YAVE, YCALC, DIFF, UCALC, RT,
     &     TEXP, TEST, DELT, TIME
      INTEGER ROW, COL, COUNT(10), LEFT, RIGHT, JUMP, MED, ITER,
     &        IFLAGR, IFLAGL, NJ, QUIT, COLB, XROW, YCOL, ICHK
      REAL ALPHA, BETA, L, CONVRD, CONVDR, RHS, LHS, SUMW
C
C     FORMATS
C
    3 FORMAT(1X,A,F8.3,A,F8.3)
    4 FORMAT(1X,A,F8.3,A,F10.8)
    5 FORMAT(1X,'ROW ',I3,',COL ',I3)
    6 FORMAT(1X,A)
    7 FORMAT(1X,A,F8.3)
    8 FORMAT(1X,A,F12.3)
    9 FORMAT(1X,'RR(',I2,') = ',F10.2)
   11 FORMAT(1X,A,I2,A)
C
C     EXECUTABLE STATEMENTS
C
C-------------
C     GET BU AND U
C
C     FOR NOW, PUT IN ARBITRARY VALUES FOR TEST RUN
C
```

```
C  B IS AQUIFER THICKNESS IN FEET; U IS REGIONAL FLOW VEL IN
C     FEET/DAY.
      B = 50.0
      U = 0.5
C
C  CONVERT U IN FEET/DAY TO FEET/SECOND; CONVERT Q FROM GPM TO
C     CFS;  MULTIPLY TO OBTAIN BU
C
      U = U / 86400.0
      Q = Q / 448.831
      BU = B * U
C-------------
      RISK=0.0
      PI=3.14159265
      ROW = INT(Y/DEL) + 1
      COL = INT(X/DEL) + 1
      XROW = INT(Y/DEL) + 1
      YCOL = INT(X/DEL) + 1
      COLB=COL
      MED=COL
      THETAR = (THETA*2.0*PI)/360.0
      DO 10 I = 1, NDIV
         COUNT(I)=0
         SUM(I)=0.0
   10 CONTINUE
C     WRITE(*,6) 'PAST 10'
C-------------
C     CALCULATE RR(I) FROM DDIV, EXP3, AND U (FLOW VELOCITY)
C
C        ASSUME U IS FLOW VELOCITY IN FEET/SEC; DDIV IS INITIAL
C           TRAVEL TIME IN DAYS
C
C     WRITE(*,6) 'BEGINNING RR(I) CALCULATION'
      YMAX = Q/(2.0*B*U)
      TEXP = 1.05
      TEST = 100.0
      DELT = 100.0
      TIME = 0.0
   14    Y1 = 0.0
         Y2 = YMAX
         ITER = 0
   12    YAVE = (Y1 + Y2)/2.0
            ITER = ITER + 1
            YCALC = Q/(2.0*B*U) - Q/(2.0*PI*B*U)*ATAN(YAVE/TEST)
            DIFF = ABS(YCALC-YAVE)
            IF (DIFF.LE.1.0) GO TO 13
         IF (ITER.GT.100) THEN
            WRITE(*,6) 'ITERATION LIMIT FOR RR(1) CALCULATION'
            GO TO 13
         ENDIF
         IF (YCALC.GT.YAVE) THEN
            Y1 = YAVE
         ELSE
            Y2 = YAVE
```

```
         ENDIF
         GO TO 12
   13 CONTINUE
      UCALC = Q/(2.0*B*YCALC)
      TIME = TIME + DELT/(UCALC*86400.0)
      IF (TIME.LT.DDIV) THEN
         DELT = DELT**EXP
         TEST = TEST + DELT
         GO TO 14
      ENDIF
      RR(1) = TEST - (TIME-DDIV)*(UCALC*86400.0)
      RR(2) = RR(1) + RR(1)**EXP3
      DO 15 I = 3, NDIV
         RR(I) = RR(I-1) + (RR(I-1)-RR(I-2))**EXP3
   15 CONTINUE
      DO 17 I = 1, NDIV
C        WRITE(6,9) I, RR(I)
   17 CONTINUE
C-------------
C     WRITE(*,6) 'FINISHED RR(I) CALCULATION'
      ITER=0
      PI=3.14159265
      CONVRD=360.0/(2.0*PI)
      CONVDR=1.0/CONVRD
      THETAR = THETA*CONVDR
   20 CONTINUE
C     WRITE(*,6) '20'
      IFLAGR=0
      IFLAGL=0
      ITER=ITER+1
      LEFT=0
      RIGHT=0
      JUMP=0
      IF (JUMP.EQ.0) GO TO 40
   30 CONTINUE
C     WRITE(*,6) '30'
      NJ = (JUMP/2)
      NJ = NJ * 2
      IF (NJ.EQ.JUMP) THEN
         COL=COL-JUMP
         IF (IFLAGL.EQ.1) THEN
            JUMP=JUMP+1
            GO TO 30
         ENDIF
         IF (COL.LT.1) THEN
            IFLAGL=1
            JUMP=JUMP+1
            GO TO 30
         ENDIF
         LEFT=LEFT+1
      ELSE
         COL=COL+JUMP
         IF (IFLAGR.EQ.1) THEN
            IF (IFLAGL.EQ.1) THEN
```

```
            IF (QUIT.EQ.1) THEN
               ROW = ROW - 1
               IF (ROW.LT.1) GO TO 300
            ELSE
               ROW = ROW + 1
               IF (ROW.GT.NROWS) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
C -----------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
               IF (ROW.GT.126. AND .COL.GT.283) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
C -----------------------------
            ENDIF
            COL = COLB + (RIGHT/2) - (LEFT/2)
            IF (ITER.EQ.1) MED=COL
            COLB=COL
            GO TO 20
         ENDIF
         JUMP=JUMP+1
         GO TO 30
      ENDIF
      IF (COL.GT.NCOLS) THEN
         IFLAGR=1
         JUMP=JUMP+1
         GO TO 30
      ENDIF
C -----------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
      IF (COL.GT.283. AND .ROW.GT.126) THEN
         IFLAGR=1
         JUMP=JUMP+1
         GO TO 30
      ENDIF
C -----------------------------
      RIGHT=RIGHT+1
   ENDIF
```

```
   40 CONTINUE
C     WRITE(*,6) '40'
      IF (ITER.EQ.1. AND .JUMP.EQ.0) THEN
         T = 0.0
         LCT = 1.0
         R = 0.0
         GO TO 45
      ENDIF
C
C     DETERMINE R, T
C
      DELX = FLOAT(COL-YCOL) * DEL
      DELY = FLOAT(XROW-ROW) * DEL
      IF (DELY.EQ.0.0) THEN
         ALPHA=90.0*CONVDR
      ELSE
         ALPHA=ATAN(ABS(DELX/DELY))
      ENDIF
C     WRITE(6,8) 'DELX = ',DELX
C     WRITE(6,8) 'DELY = ',DELY
      L = SQRT((DELX**2.0)+(DELY**2.0))
      ICHK=0
      IF (THETA.LT.90.0) THEN
C        WRITE(6,6) 'NEQUAD'
         IF (DELX.GE.0.0. AND .DELY.LE.0.0) THEN
            RHS=90.0*CONVDR - THETAR
            IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR + ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LE.0.0. AND .DELY.LE.0.0) THEN
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND. ALPHA.LT.THETAR) THEN
               BETA=THETAR-ALPHA
            ELSE IF (ALPHA.GE.THETAR. AND .ALPHA.LE.RHS) THEN
               BETA=ALPHA-THETAR
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LE.0.0. AND .DELY.GT.0.0) THEN
            LHS = 90.0*CONVDR - THETAR
            RHS = 90*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = 180.0*CONVDR - THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE
            ICHK=1
         ENDIF
      ELSE IF (THETA.LT.180.0) THEN
C        WRITE(6,6) 'SEQUAD'
         IF (DELX.LE.0.0. AND .DELY.LE.0.0) THEN
```

```
C           WRITE(6,6) 'BOTH<=0'
            LHS = THETAR - 90.0*CONVDR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
          ELSE IF (DELX.LE.0.0. AND .DELY.GT.0.0) THEN
C           WRITE(6,6) 'Y>0'
            RHS = 90.0*CONVDR
            LHS = 180.0*CONVDR - THETAR
            IF (ALPHA.GT.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = THETAR - 180.0*CONVDR + ALPHA
            ELSE IF (ALPHA.GE.0.0. AND .ALPHA.LE.LHS) THEN
               BETA = 180.0*CONVDR - THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
          ELSE IF (DELX.GT.0.0. AND .DELY.GE.0.0) THEN
C           WRITE(6,6) 'BOTH>=0'
            RHS = THETAR - 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
               BETA = 180.0*CONVDR - THETAR + ALPHA
            ELSE
               ICHK=1
            ENDIF
          ELSE
            ICHK=1
          ENDIF
        ELSE IF (THETA.LT.270.0) THEN
C         WRITE(6,6) 'SWQUAD'
          IF (DELX.LE.0.0. AND .DELY.GE.0.0) THEN
            RHS = 270.0*CONVDR - THETAR
            IF (ALPHA.GE.0.0 .AND. ALPHA.LE.RHS) THEN
               BETA = THETAR + ALPHA - 180.0*CONVDR
            ELSE
               ICHK=1
            ENDIF
          ELSE IF (DELX.GE.0.0. AND .DELY.GE.0.0) THEN
            LHS = THETAR - 180.0*CONVDR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.0.0. AND .ALPHA.LT.LHS) THEN
               BETA = THETAR - 180.0*CONVDR - ALPHA
            ELSE IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = ALPHA - THETAR + 180.0*CONVDR
            ELSE
               ICHK=1
            ENDIF
          ELSE IF (DELX.GE.0.0. AND .DELY.LT.0.0) THEN
            LHS = 270.0*CONVDR - THETAR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = 360.0*CONVDR - ALPHA - THETAR
```

```
            ELSE
               ICHK=1
            ENDIF
         ELSE
            ICHK=1
         ENDIF
      ELSE
C        WRITE(6,6) 'NWQUAD'
         IF (DELX.GE.0.0. AND .DELY.GE.0.0) THEN
            LHS = THETAR -270.0*CONVDR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = ALPHA + 270.0*CONVDR - THETAR
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.GE.0.0. AND .DELY.LT.0.0) THEN
            LHS = 360.0*CONVDR - THETAR
            RHS = 90.0*CONVDR
            IF (ALPHA.GE.LHS. AND .ALPHA.LE.RHS) THEN
               BETA = ALPHA + THETAR - 360.0*CONVDR
            ELSE IF (ALPHA.GE.0.0. AND .ALPHA.LT.LHS) THEN
               BETA = 360.0*CONVDR - THETAR - ALPHA
            ELSE
               ICHK=1
            ENDIF
         ELSE IF (DELX.LT.0.0. AND .DELY.LE.0.0) THEN
            RHS = THETAR - 270.0*CONVDR
            IF (ALPHA.GE.0.0. AND .ALPHA.LE.RHS) THEN
               BETA = ALPHA + 360.0*CONVDR - THETAR
            ELSE
               ICHK=1
            ENDIF
         ELSE
            ICHK=1
         ENDIF
      ENDIF
      R = L*COS(BETA)
      T = L*SIN(BETA)
      T = ABS(T)
C     WRITE(6,6) 'ALMOST TO 45'
C
C
      IF (ICHK.EQ.1) THEN
         LCT = 0.0
         T = 1.0
      ENDIF
      TERM = Q/(4.0*BU)
      IF (L.LE.TERM) THEN
         LCT=1.0
         T = 0.0
         GO TO 45
      ENDIF
      IF (ICHK.EQ.1) GO TO 45
```

```
      IF (R.EQ.0.0) THEN
         LCT = Q/(2.0*BU) - (Q/(2.0*PI*BU))*90.0*CONVDR
      ELSE
         LCT = Q/(2.0*BU) - (Q/(2.0*PI*BU))*ATAN(T/R)
      ENDIF
   45 CONTINUE
C     WRITE(6,6) '45'
      IF (LCT.GE.T) THEN
         DO 50 I = 1, NDIV
            IF (R.LE.RR(I)) THEN
               COUNT(I)=COUNT(I)+1
               SUM(I)=SUM(I)+LW(SOIARR(ROW,COL))
               JUMP=JUMP+1
C              WRITE(6,5) ROW,COL
               GO TO 30
            ENDIF
   50    CONTINUE
         LCT = 0.0
         T = 1.0
         GO TO 45
      ELSE
         IF (JUMP.EQ.0) THEN
            IF (QUIT.EQ.1) GO TO 300
            QUIT=1
            ROW=(INT(Y/DEL)+1) - 1
            COL=MED
            COLB=COL
            GO TO 20
         ELSE IF (IFLAGL.EQ.1. AND .IFLAGR.EQ.1) THEN
   75       IF (QUIT.EQ.1) THEN
               ROW = ROW - 1
               IF (ROW.LT.1) GO TO 300
            ELSE
               ROW = ROW + 1
               IF (ROW.GT.NROWS) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
C ------------------------------
C     THIS IS INCLUDED DUE TO THE SPECIFIC CASE OF MY DATA
C        WHICH IS NOT A PERFECT RECTANGLE; THIS ACCOUNTS FOR
C        THE LOWER LEFT BLANK AREA.  IN GENERAL, THIS IS NOT
C        REQUIRED.
C
               IF (ROW.GT.126. AND .COL.GT.283) THEN
                  QUIT=1
                  ROW = (INT(Y/DEL)+1) - 1
                  COL = MED
                  COLB = COL
                  GO TO 20
               ENDIF
```

```
C ----------------------------
            ENDIF
            COL = COLB + (RIGHT/2) - (LEFT/2)
            IF (ITER.EQ.1) MED=COL
            COLB=COL
            GO TO 20
         ELSE
            IF(NJ.EQ.JUMP) THEN
               IFLAGL = 1
            ELSE
               IFLAGR = 1
            ENDIF
         ENDIF
      ENDIF
      JUMP=JUMP+1
      GO TO 30
  300 CONTINUE
      SUMW = 0.0
      RISK = 0.0
      DO 400 I = 1, NDIV
         IF (COUNT(I).EQ.0) THEN
            SUBRSK(I)=0.0
C           WRITE(6,11) '****WARNING: SUBRSK(',I,') IS ZERO'
         ELSE
            SUBRSK(I) = SUM(I)/FLOAT(COUNT(I))
            SUMW = SUMW + W(I)
            RISK = RISK + SUBRSK(I)*W(I)
         ENDIF
  400 CONTINUE
      RISK = RISK/SUMW
      RETURN
      END
C*******************************************************************************
      FUNCTION FACT(N)
C
C
      REAL FACT, PROD
      INTEGER N
C
      IF (N.EQ.0) THEN
         FACT=1.0
         GO TO 20
      ENDIF
      PROD = FLOAT(N)
      DO 10 I = N-1, 1, -1
         PROD=PROD*FLOAT(I)
   10 CONTINUE
      FACT = PROD
   20 CONTINUE
      RETURN
      END
```

APPENDIX B: OUTPUT FROM CALIBRATION RUNS USING NINE DIFFERENT PARAMETER SETS

PARAMETER SET #1:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 500.ft.; EXPON. = 5.000
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
**********	*******
Known EDB application area	100.0000
High risk soil in crop area	80.0000
Med. risk soil -----"------	60.0000
Low risk soil -----"------	40.0000
High risk soil; not crop area	60.0000
Med. risk soil; ------"------	40.0000
Low risk soil; ------"------	20.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
**********	******
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 180. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .10000
Status of nearby wells - .30000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	64.9
CAL2	55.7
CAL3	51.8
CAL4	55.6
CAL5	57.6
CAL6	45.8
CAL7	46.4
CAL8	33.3
CAL9	55.8
CAL10	54.2
CAL11	54.0
CAL12	33.7
CAL13	43.7
CAL14	56.4
CAL15	69.5
CAL16	55.5
CAL17	37.1
CAL18	33.1
CAL19	49.4
CAL20	54.0
CAL21	56.4
CAL22	69.1
CAL23	32.7
CAL24	64.3

```
HISINT =     5
         RISK LEVEL  10.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     0
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  30.0
           NUMBER CONTAMINATED =     1
           TOTAL NUMBER IN BIN =     5
           RELATIVE FREQUENCY =  20.000
         RISK LEVEL  50.0
           NUMBER CONTAMINATED =     6
           TOTAL NUMBER IN BIN =    15
           RELATIVE FREQUENCY =  40.000
         RISK LEVEL  70.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     4
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  90.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     0
           RELATIVE FREQUENCY =    .000
```

PARAMETER SET #2:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 500.ft.; EXPON. = 5.000
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
******************************	*******
Known EDB application area	100.0000
High risk soil in crop area	80.0000
Med. risk soil -----"------	60.0000
Low risk soil -----"------	40.0000
High risk soil; not crop area	60.0000
Med. risk soil; ------"------	40.0000
Low risk soil; ------"------	20.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 180. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table	-	.00000
Status of nearby wells	-	.30000
Capture zone soil types	-	.70000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
CAL1	60.0
CAL2	55.9
CAL3	50.8
CAL4	55.3
CAL5	57.9
CAL6	40.0
CAL7	44.5
CAL8	29.1
CAL9	56.0
CAL10	54.6
CAL11	54.8
CAL12	30.3

CAL13	42.6
CAL14	56.1
CAL15	69.8
CAL16	56.1
CAL17	33.8
CAL18	27.8
CAL19	44.9
CAL20	56.1
CAL21	56.0
CAL22	69.8
CAL23	27.9
CAL24	60.0

HISINT = 5

RISK LEVEL 10.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

RISK LEVEL 30.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 5
RELATIVE FREQUENCY = 20.000

RISK LEVEL 50.0
NUMBER CONTAMINATED = 6
TOTAL NUMBER IN BIN = 15
RELATIVE FREQUENCY = 40.000

RISK LEVEL 70.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 4
RELATIVE FREQUENCY = .000

RISK LEVEL 90.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

PARAMETER SET #3:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 500.ft.; EXPON. = 5.000
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
******************************	*******
Known EDB application area	100.0000
High risk soil in crop area	80.0000
Med. risk soil -----"------	60.0000
Low risk soil -----"------	40.0000
High risk soil; not crop area	60.0000
Med. risk soil; ------"------	40.0000
Low risk soil; ------"------	20.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
******************************	******
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 180. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .00000
Status of nearby wells - .70000
Capture zone soil types - .30000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	60.0
CAL2	23.9
CAL3	21.5
CAL4	23.4
CAL5	24.7
CAL6	40.0
CAL7	19.0
CAL8	12.5
CAL9	24.0
CAL10	23.4
CAL11	23.4
CAL12	12.9
CAL13	18.5
CAL14	24.2
CAL15	29.6
CAL16	24.3
CAL17	14.5
CAL18	11.6
CAL19	44.9
CAL20	24.3
CAL21	24.1
CAL22	29.6
CAL23	11.7
CAL24	60.0

HISINT = 5

RISK LEVEL 10.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 7
RELATIVE FREQUENCY = 14.286

RISK LEVEL 30.0
NUMBER CONTAMINATED = 6
TOTAL NUMBER IN BIN = 13
RELATIVE FREQUENCY = 46.154

```
RISK LEVEL  50.0
  NUMBER CONTAMINATED =     0
  TOTAL NUMBER IN BIN =     2
  RELATIVE FREQUENCY =    .000
RISK LEVEL  70.0
  NUMBER CONTAMINATED =     0
  TOTAL NUMBER IN BIN =     2
  RELATIVE FREQUENCY =    .000
RISK LEVEL  90.0
  NUMBER CONTAMINATED =     0
  TOTAL NUMBER IN BIN =     0
  RELATIVE FREQUENCY =    .000
```

PARAMETER SET #4

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 500.ft.; EXPON. = 5.000
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
Known EDB application area	100.0000
High risk soil in crop area	80.0000
Med. risk soil -----"------	60.0000
Low risk soil -----"------	40.0000
High risk soil; not crop area	60.0000
Med. risk soil; ------"------	40.0000
Low risk soil; ------"------	20.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
******	******
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 180. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .00000
Status of nearby wells - .50000
Capture zone soil types - .50000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	60.0
CAL2	39.9
CAL3	36.1
CAL4	39.4
CAL5	41.3
CAL6	40.0
CAL7	31.7
CAL8	20.8
CAL9	40.0
CAL10	39.0
CAL11	39.1
CAL12	21.6

CAL13	30.5
CAL14	40.1
CAL15	49.7
CAL16	40.2
CAL17	24.1
CAL18	19.7
CAL19	44.9
CAL20	40.2
CAL21	40.1
CAL22	49.7
CAL23	19.8
CAL24	60.0

```
HISINT =     5
         RISK LEVEL  10.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     2
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  30.0
           NUMBER CONTAMINATED =     4
           TOTAL NUMBER IN BIN =    10
           RELATIVE FREQUENCY =  40.000
         RISK LEVEL  50.0
           NUMBER CONTAMINATED =     3
           TOTAL NUMBER IN BIN =    10
           RELATIVE FREQUENCY =  30.000
         RISK LEVEL  70.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     2
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  90.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     0
           RELATIVE FREQUENCY =    .000
```

PARAMETER SET #5:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 200.ft.; EXPON. = 1.400
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
******************************	*******
Known EDB application area	100.0000
High risk soil in crop area	75.0000
Med. risk soil -----"------	50.0000
Low risk soil -----"------	20.0000
High risk soil; not crop area	50.0000
Med. risk soil; ------"------	20.0000
Low risk soil; ------"------	.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
******************************	******
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 180. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .10000
Status of nearby wells - .30000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	56.5
CAL2	53.2
CAL3	48.2
CAL4	52.9
CAL5	55.5
CAL6	29.4
CAL7	40.7
CAL8	22.2
CAL9	53.3
CAL10	51.5
CAL11	51.2
CAL12	23.1
CAL13	38.2
CAL14	53.8
CAL15	69.6
CAL16	53.1
CAL17	27.3
CAL18	21.3
CAL19	35.5
CAL20	51.8
CAL21	53.8
CAL22	69.3
CAL23	21.1
CAL24	56.2

HISINT = 5

RISK LEVEL 10.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

RISK LEVEL 30.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 8
RELATIVE FREQUENCY = 12.500

RISK LEVEL 50.0
NUMBER CONTAMINATED = 6
TOTAL NUMBER IN BIN = 14
RELATIVE FREQUENCY = 42.857

RISK LEVEL 70.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 2
RELATIVE FREQUENCY = .000
RISK LEVEL 90.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

PARAMETER SET #6:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 200.ft.; EXPON. = 1.400
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
******	*******
Known EDB application area	100.0000
High risk soil in crop area	75.0000
Med. risk soil -----"------	50.0000
Low risk soil -----"------	20.0000
High risk soil; not crop area	50.0000
Med. risk soil; ------"------	20.0000
Low risk soil; ------"------	.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
******	******
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 360. DAYS
EXPONENT = 1.05000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .10000
Status of nearby wells - .30000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	56.5
CAL2	53.3
CAL3	46.5
CAL4	52.9
CAL5	56.4
CAL6	29.4
CAL7	43.3
CAL8	22.6
CAL9	53.3
CAL10	51.0
CAL11	51.0
CAL12	24.4
CAL13	38.3
CAL14	53.8
CAL15	69.6
CAL16	53.1

```
CAL17        32.3
CAL18        21.3
CAL19        39.6
CAL20        51.8
CAL21        53.8
CAL22        69.3
CAL23        21.1
CAL24        56.2


HISINT =     5
         RISK LEVEL  10.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     0
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  30.0
           NUMBER CONTAMINATED =     1
           TOTAL NUMBER IN BIN =     8
           RELATIVE FREQUENCY =  12.500
         RISK LEVEL  50.0
           NUMBER CONTAMINATED =     6
           TOTAL NUMBER IN BIN =    14
           RELATIVE FREQUENCY =  42.857
         RISK LEVEL  70.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     2
           RELATIVE FREQUENCY =    .000
         RISK LEVEL  90.0
           NUMBER CONTAMINATED =     0
           TOTAL NUMBER IN BIN =     0
           RELATIVE FREQUENCY =    .000
```

PARAMETER SET #7:

PARAMETER DATA ECHO:

```
THRESHOLD DEPTH =  200.ft.; EXPON. = 1.400
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000
```

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
Known EDB application area	100.0000
High risk soil in crop area	75.0000
Med. risk soil -----"------	50.0000
Low risk soil -----"------	20.0000
High risk soil; not crop area	50.0000
Med. risk soil; ------"------	20.0000
Low risk soil; ------"------	.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 360. DAYS
EXPONENT = 1.05000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .00000
Status of nearby wells - .40000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	50.0
CAL2	45.0
CAL3	37.6
CAL4	44.2
CAL5	47.9
CAL6	20.0
CAL7	34.6
CAL8	13.8
CAL9	45.0
CAL10	43.0
CAL11	43.3
CAL12	16.1
CAL13	30.6
CAL14	45.1
CAL15	59.8
CAL16	45.2
CAL17	23.7
CAL18	11.8
CAL19	32.5
CAL20	45.2
CAL21	45.1
CAL22	59.8
CAL23	11.8
CAL24	50.0

HISINT = 5

RISK LEVEL 10.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 4
RELATIVE FREQUENCY = 25.000

RISK LEVEL 30.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 6
RELATIVE FREQUENCY = 16.667

RISK LEVEL 50.0
NUMBER CONTAMINATED = 5
TOTAL NUMBER IN BIN = 14
RELATIVE FREQUENCY = 35.714

```
RISK LEVEL  70.0
  NUMBER CONTAMINATED =     0
  TOTAL NUMBER IN BIN =     0
  RELATIVE FREQUENCY =    .000
RISK LEVEL  90.0
  NUMBER CONTAMINATED =     0
  TOTAL NUMBER IN BIN =     0
  RELATIVE FREQUENCY =    .000
```

PARAMETER SET #8:

PARAMETER DATA ECHO:

THRESHOLD DEPTH = 200.ft.; EXPON. = 1.400
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
Known EDB application area	100.0000
High risk soil in crop area	75.0000
Med. risk soil -----"------	50.0000
Low risk soil -----"------	20.0000
High risk soil; not crop area	50.0000
Med. risk soil; ------"------	20.0000
Low risk soil; ------"------	.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
1	.4000
2	.2500
3	.1500
4	.1200
5	.0800

TRAVEL TIME TO AREA 1 BOUND. = 360. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .10000
Status of nearby wells - .30000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	56.5
CAL2	49.8
CAL3	45.6
CAL4	51.0
CAL5	54.3
CAL6	29.4
CAL7	43.1
CAL8	24.2
CAL9	53.3
CAL10	49.3
CAL11	47.0
CAL12	27.0
CAL13	38.8
CAL14	53.8

```
CAL15        69.6
CAL16        53.0
CAL17        30.3
CAL18        21.3
CAL19        40.0
CAL20        51.8
CAL21        53.0
CAL22        69.3
CAL23        21.1
CAL24        56.2


HISINT =     5
          RISK LEVEL  10.0
            NUMBER CONTAMINATED =     0
            TOTAL NUMBER IN BIN =     0
            RELATIVE FREQUENCY =    .000
          RISK LEVEL  30.0
            NUMBER CONTAMINATED =     1
            TOTAL NUMBER IN BIN =     7
            RELATIVE FREQUENCY =  14.286
          RISK LEVEL  50.0
            NUMBER CONTAMINATED =     6
            TOTAL NUMBER IN BIN =    15
            RELATIVE FREQUENCY =  40.000
          RISK LEVEL  70.0
            NUMBER CONTAMINATED =     0
            TOTAL NUMBER IN BIN =     2
            RELATIVE FREQUENCY =    .000
          RISK LEVEL  90.0
            NUMBER CONTAMINATED =     0
            TOTAL NUMBER IN BIN =     0
            RELATIVE FREQUENCY =    .000
```

PARAMETER SET #9:

PARAMETER DATA ECHO:

```
THRESHOLD DEPTH =  200.ft.; EXPON. = 1.400
THRESHOLD DIST. = 5000.ft.; EXPON. = 2.000
```

NUMBER OF LAND USE CATEGORIES = 9

CATEGORY	WEIGHT
Known EDB application area	100.0000
High risk soil in crop area	75.0000
Med. risk soil -----"------	50.0000
Low risk soil -----"------	20.0000
High risk soil; not crop area	50.0000
Med. risk soil; ------"------	20.0000
Low risk soil; ------"------	.0000
Known EDB-type crop growth	85.0000
Surface water area	.0000

NUMBER OF CAPTURE ZONE SUB-AREAS = 5

SUB-AREA (1 IS CLOSEST TO WELL)	WEIGHT
1	.2000
2	.2000
3	.2000
4	.2000
5	.2000

TRAVEL TIME TO AREA 1 BOUND. = 360. DAYS
EXPONENT = 1.10000

OVERALL FACTOR WEIGHTS USED:

Depth to water table - .10000
Status of nearby wells - .30000
Capture zone soil types - .60000

SOIL DATA INFORMATION:

NUMBER OF ROWS IN SOIL ARRAY = 236
NUMBER OF COLUMNS IN SOIL ARRAY = 355
DIMENSION OF ARRAY ELEMENTS (ft) = 147.120

RESULTS:
****

WELL	EST.RISK
******	********
CAL1	56.5
CAL2	45.6
CAL3	47.2
CAL4	48.3
CAL5	52.1
CAL6	29.4
CAL7	47.5
CAL8	26.3
CAL9	53.3
CAL10	45.9
CAL11	40.7
CAL12	33.0
CAL13	39.3
CAL14	53.8
CAL15	69.6
CAL16	52.8
CAL17	36.8
CAL18	21.3
CAL19	44.6
CAL20	51.8
CAL21	51.8
CAL22	69.3
CAL23	21.1
CAL24	56.2

HISINT = 5

RISK LEVEL 10.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

RISK LEVEL 30.0
NUMBER CONTAMINATED = 1
TOTAL NUMBER IN BIN = 7
RELATIVE FREQUENCY = 14.286

RISK LEVEL 50.0
NUMBER CONTAMINATED = 6
TOTAL NUMBER IN BIN = 15
RELATIVE FREQUENCY = 40.000

RISK LEVEL 70.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 2
RELATIVE FREQUENCY = .000
RISK LEVEL 90.0
NUMBER CONTAMINATED = 0
TOTAL NUMBER IN BIN = 0
RELATIVE FREQUENCY = .000

APPENDIX C: WELL DATA USED IN DEMONSTRATION STUDY

C.1 Previously Sampled Well Data:

WELL	X	Y	C	DEP	THET	Q	#USERS
****	*****	*****	*	***	****	****	****
CAL1	443.	19765.	2	6.	200.	10.	4.

NUMBER OF PROXIMATE WELLS = 0

WELL	X	Y	C	DEP	THET	Q	#USERS
CAL2	15045.	23010.	1	24.	198.	50.	10.

NUMBER OF PROXIMATE WELLS = 4

DISTANCE(FT)	CONTAMINATED? (1=YES)
1979.	2
2660.	1
1073.	2
1979.	1

WELL	X	Y	C	DEP	THET	Q	#USERS
CAL3	47495.	14308.	1	18.	177.	50.	10.

NUMBER OF PROXIMATE WELLS = 5

DISTANCE(FT)	CONTAMINATED? (1=YES)
933.	2
1922.	2
1682.	2
1482.	2
2178.	2

WELL	X	Y	C	DEP	THET	Q	#USERS
CAL4	50593.	13128.	1	20.	170.	50.	10.

NUMBER OF PROXIMATE WELLS = 3

DISTANCE(FT)	CONTAMINATED? (1=YES)
1629.	2
1649.	2
1064.	2

WELL	X	Y	C	DEP	THET	Q	#USERS
CAL5	47200.	13423.	2	22.	188.	70.	30.

NUMBER OF PROXIMATE WELLS = 5

DISTANCE(FT)	CONTAMINATED? (1=YES)
933.	1
2331.	2
1968.	2
2401.	2
1269.	2

WELL	X	Y	C	DEP	THET	Q	#USERS
CAL6	36433.	32303.	2	21.	333.	10.	4.

NUMBER OF PROXIMATE WELLS = 0

```
CAL7      45873.  15340.  2   18.  180.   70.   30.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1922.                    1
         2331.                    2
         1825.                    2
CAL8      52215.  13275.  2   17.  170.   70.   30.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1629.                    1
         2613.                    2
CAL9      49118.  13865.  2   25.  175.   10.    4.
   NUMBER OF PROXIMATE WELLS =   5
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1682.                    1
         1649.                    1
         1968.                    2
         1452.                    2
         2233.                    1
CAL10     49708.  12538.  2   30.  173.   70.   30.
   NUMBER OF PROXIMATE WELLS =   5
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2834.                    1
         1064.                    1
         2660.                    2
         2613.                    2
         1452.                    2
CAL11     46463.  12390.  2   34.  189.  200.   90.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2178.                    1
         1269.                    2
CAL12     48823.  16078.  1   25.  174.  150.   65.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2213.                    1
         2233.                    2
         1216.                    2
CAL13     15930.  24780.  2   32.  189.   70.   30.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1979.                    1
         1849.                    1
         1252.                    1
CAL14     17553.  23895.  1   18.  175.   10.    4.
   NUMBER OF PROXIMATE WELLS =   4
      DISTANCE(FT)      CONTAMINATED? (1=YES)
```

```
      ************       **********************
         2660.                      1
         1849.                      2
         1540.                      1
          738.                      1
CAL15     22420.  19175.  2    3.  201.   10.    4.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       **********************
         1327.                      2
         1475.                      2
CAL16     19028.  23453.  1   30.  170.   50.   10.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       **********************
         1540.                      1
         2257.                      1
CAL17     47643.  15783.  2   20.  179.   10.    4.
   NUMBER OF PROXIMATE WELLS =   5
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       **********************
         1482.                      1
         2401.                      2
         1825.                      2
         2420.                      2
         1216.                      1
CAL18     21093.  19175.  2    7.  200.   10.    4.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       **********************
         1327.                      2
          148.                      2
         1923.                      2
CAL19     21535.  26845.  2   26.  158.   70.   30.
   NUMBER OF PROXIMATE WELLS =   0
CAL20     14750.  21978.  2   50.  185.   10.    4.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       **********************
         1073.                      1
         2818.                      1
```

```
CAL21     16815.  23895.  1   18.  180.   10.    4.
   NUMBER OF PROXIMATE WELLS =   5
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1979.                    1
         1252.                    2
          738.                    1
         2257.                    1
         2818.                    2
CAL22     20945.  19175.  2    7.  200.   10.    4.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1475.                    2
          148.                    2
         1800.                    2
CAL23     19470.  18143.  2   12.  194.   10.    4.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         1923.                    2
         1800.                    2
CAL24     39825.  17553.  2   10.  175.   10.    4.
   NUMBER OF PROXIMATE WELLS =   0
```

C.2 Unsampled Well Data:

```
WELL        X       Y      DEP  THET   Q   #USERS
****      *****   *****    ***  ****  ****  ****
SAM1       2644.   5500.   70.  225.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM2       7932.   5500.    5.  225.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM3      13220.   5500.   50.  170.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM4      18508.   5500.  100.  170.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM5      23796.   5500.   50.  135.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM6      29084.   5500.    5.  210.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM7      34372.   5500.    5.  195.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM8      39660.   5500.    8.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM9      44948.   5500.    6.  195.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM10     50236.   5500.   10.  225.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM11      2644.  10730.   11.  220.   20.    5.
```

```
   NUMBER OF PROXIMATE WELLS =   0
SAM12      7932.  10730.    9.  215.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM13     13220.  10730.   20.  170.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM14     18508.  10730.    5.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM15     23796.  10730.   10.  165.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM16     29084.  10730.   15.  220.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM17     34372.  10730.    5.  195.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM18     39660.  10730.    5.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM19     44948.  10730.   10.  180.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      *********************
         2247.                    2
SAM20     50236.  10730.   18.  185.   20.    5.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      *********************
         2424.                    1
         1884.                    2
SAM21      2644.  16230.    6.  200.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM22      7932.  16230.    5.  285.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM23     13220.  16230.    5.  185.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM24     18508.  16230.   12.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      *********************
         2141.                    2
SAM25     23796.  16230.   20.  195.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM26     29084.  16230.    6.  200.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM27     34372.  16230.    6.  190.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM28     39660.  16230.   10.  165.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      *********************
         1333.                    2
SAM29     44948.  16230.   14.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      *********************
         1284.                    2
         2732.                    2
```

```
SAM30     50236.  16230.   25.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   3
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       *********************
         2616.                      2
         1421.                      1
         2631.                      2
SAM31      2644.  21360.    7.  200.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       *********************
         2718.                      2
SAM32      7932.  21360.    5.  285.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM33     13220.  21360.    7.  185.   20.    5.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       *********************
         2460.                      1
         1650.                      2
SAM34     18508.  21360.   18.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   2
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       *********************
         2709.                      1
         2157.                      1
SAM35     23796.  21360.    7.  195.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)       CONTAMINATED? (1=YES)
      ************       *********************
         2582.                      2
SAM36     29084.  21360.    8.  200.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM37     34372.  21360.   10.  190.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM38     39660.  21360.   10.  165.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM39      2644.  26700.    7.  190.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM40      7932.  26700.   18.  225.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM41     13220.  26700.    5.  225.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
```

```
SAM42     18508.  26700.   11.  155.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2963.                    1
SAM43     23796.  26700.   14.  150.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2266.                    2
SAM44     29084.  26700.   10.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM45     34372.  26700.   10.  175.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM46     39660.  26700.    8.  330.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM47      2644.  31940.    8.   15.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM48      7932.  31940.   19.   20.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM49     13220.  31940.   15.   45.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM50     18508.  31940.   10.  150.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM51     23796.  31940.   10.  180.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM52     29084.  31940.   10.  330.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
SAM53     34372.  31940.   18.  315.   20.    5.
   NUMBER OF PROXIMATE WELLS =   1
      DISTANCE(FT)      CONTAMINATED? (1=YES)
      ************      **********************
         2093.                    2
SAM54     39660.  31940.   30.  345.   20.    5.
   NUMBER OF PROXIMATE WELLS =   0
```

APPENDIX D: SOIL CATEGORY LISTING

All soil types occurring in the demonstration study area were assigned either high, medium, or low probability of EDB application, according to the typical agricultural uses of the various soils. The soil type designations given below are those used in the U.S. Soil Conservation Service soil survey of Whatcom County, Washington (U.S Department of Agriculture, 1957).

Soil types classified as having the highest risk of EDB application are the following (in alphabetical order): GA, GD, LL, NC, PE, and SA.

Soil types classified as having moderate risk of EDB application are the following (in alphabetical order): CD, CE, GC, GG, KD, LD, LK, MB, NB, NG, PG, SX, TD, and WG.

Soil types classified as having the lowest risk of EDB application are the following (in alphabetical order): BO, BP, BR, CF, CG, CO, EA, EB, EC, IA, KB, LA, LF, LG, MC, PC, PD, PF, RA, RB, RC, RD, SG, SH, SN, SZ, TB, TC, TE, WA, WB, WC, and WE.