

Montana Bureau of Mines and Geology
Open-File Report
MBMG-326

Montana Ground-Water Information Center:
Deep-Aquifer Data Base

By

Thomas W. Patton
Montana Bureau of Mines and Geology
Butte, Montana

August 1994

Table of Contents

Introduction	1
Project History	2
Present Level of Service:	3
Project Scope	4
Ground-Water Information Center	5
Sites (SITES) File:	6
Wells (WELLS) File:	6
Water Quality (WATER QUALITY) File:	7
Lithology (LITHOLOGY) File:	7
Deep-Aquifer (DEEPAQU) File:	7
Static Water Level (SWL) File:	8
Deep-Aquifer Data	8
Water Quality:	9
Formation Tops:	10
Other Tasks	12
Budgets	14
References	15

Illustrations

Figure 1:File relationships in the Ground-Water Information Center, August 1994.	5
---	---

Tables

Table I:Formations and number of analyses added to the water-quality data base, Ground-Water Information Center, August, 1994.	9
Table II:Formations represented in the Deep-Aquifer data base, Ground-Water Information Center, August 1994.	11
Table III:Expenditure summary, Deep-Aquifer data base project.	14

Introduction

The Deep-Aquifer project addressed a problem of ground-water data accessibility. Previously, locating and using formation-top data for ground-water evaluations required: finding where the appropriate drill hole records were, obtaining the geophysical and other logs for the wells of interest, and interpreting the drilling data to produce the desired formation-top information. The Deep-Aquifer project was to make previously interpreted formation-top data accessible by storing the information in machine readable, easily retrievable formats. An earlier effort to increase the accessibility of formation-top interpretations for aquifers and non-aquifers in eastern Montana was made by Feltus, etal (1984). in U.S. Geological Survey Open-File Report 81-415. Unfortunately, the formation-top data interpreted by Feltus were not available in magnetic media when the Deep-Aquifer project began (personal communication, Gary Rogers U.S. Geological Survey, November 1990) and the Montana Bureau of Mines and Geology determined that placing the data contained in U.S. Geological Survey Open-File Report 81-415 into the data bases would be the most beneficial use of the project funds.

The Deep-Aquifer (formation-top) data base is the first "interpretative" file at the Ground Water Information Center. All other Information Center data bases (SITES, WELLS, WATER QUALITY, LITHOLOGY, and STATIC WATER LEVEL) contain basic data transcribed from either driller's logs or obtained from direct measurements. Conversely, interpretation of geophysical and lithologic logs is required to derive the altitudes and thicknesses of formations necessary to calculate formation-top values for the data base.

Another goal of the Deep-Aquifer project was to increase the accessibility of selected water-quality data for deep aquifers in eastern Montana. Considerable water-quality information for deep aquifers in eastern Montana exists in the form of paper records scattered throughout thousands of files at the Montana Board of Oil and Gas Conservation; in a few publications (Crawford, 1942; Hopkins, 1976); and in paper files at the Montana Bureau of Mines and Geology. Most deep-aquifer water-quality information was originally collected as a result of and for the purpose of oil and gas exploration, but is also useful in describing water quality in deep aquifers in eastern Montana.

Project History

The need for a Ground-Water Information Center was first proposed in April 1983 at a ground-water issues conference held in Great Falls, Montana. Because the Montana Bureau of Mines and Geology had been fulfilling some of the functions of the proposed Ground-Water Information Center, the Governor's Advisory Council on ground water suggested in the fall of 1984 that the Bureau of Mines and Geology apply for Water Development Grant funding to support and develop the Ground-Water Information Center. That grant application requested funds to purchase computer hardware and software. In addition to the Water Development grant, a Resource Indemnity Trust grant was requested by the Bureau to support some of the personnel needs of the Information Center. The 49'th Montana Legislature approved both grant applications, and contract number WDG-86-5046 to establish the Information Center was subsequently written between the Department of Natural Resources and Conservation and the Bureau of Mines and Geology. This contract was completed on June 30, 1989 and the final report released as Montana Bureau of Mines and Geology Open-File Report MBMG 231 in June 1990.

At the end of the contract WDG-86-5046, the data bases at the Ground Water Information Center had been converted to the present structure, data entry and editing were ongoing, the backlog of unprocessed water-well log data had been eliminated, and telephone access to the data system had been established.

In 1986 the Montana Bureau of Mines and Geology proposed the Deep-Aquifer project in part to continue the development of the Ground-Water Information Center. The Deep-Aquifer project would add formation-top and water-quality information to the data bases while supporting routine Information Center operations such as: adding new water-well log data, verifying existing records in the data bases, and improving file structures and reports. The Deep-Aquifer project at the Montana Bureau of Mines and Geology was authorized in 1987 by the 50'th legislature and \$175,000 was authorized to accomplish tasks outlined in the proposal. Because funds in the total amount were not available when the contract between the Montana Bureau of Mines and Geology and the Montana Department of

Natural Resources and Conservation was written, \$155,950 was the total funding obligated in grant agreement RIT-89-8543. The grant agreement was signed by the Department of Natural Resources and the Bureau of Mines and Geology on June 21, 1989 and the completion date was extended until September 30, 1994 by written agreement between the two agencies.

Present Level of Service:

The Ground-Water Information Center data bases are used daily by staff at the Montana Bureau of Mines and Geology and by other users in State and Federal Government using telephone or network access. The Bureau of Mines and Geology uses the data bases to provide ground-water data to the public, state agencies, federal agencies, private industry, water well drillers, students, and various Bureau projects. The Soil Conservation Service, Bureau of Land Management, Montana Department of Agriculture, Montana Department of Health and Environmental Sciences, Montana Department of Natural Resources and Conservation, and the Natural Resources Information System (State Library) all have remote access to the data bases. Workers at these agencies routinely access ground-water information, including Deep-Aquifer data, from the Information Center.

In addition to remote telephone access to the data bases, water-well log data are distributed on diskette to some of the Regional Water Resources Offices of the Montana Department of Natural Resources and Conservation. The Water Resources Offices use the information contained on the diskettes to answer requests for ground-water information and in some cases as a data source for small scale ground-water investigations. The effort is cooperative between the Bureau of Mines and Geology, and the Natural Resources Information System at the State Library. The Bureau of Mines and Geology provides and maintains the data through the Ground-Water Information Center, and the State Library provides the personal computer software to access the data. Water-well data has been distributed using this mechanism to the Kalispell, Missoula, Bozeman, Billings, and Helena Water Resources Offices. Other agencies and groups have also received the data/software package. The Department of State Lands uses the information to evaluate potential impacts of abandoned mines and in permitting gravel

pits. The data/software package is available to the public, and several water-well drillers have also taken advantage of the service.

Project Scope

The following tasks were to be accomplished during the Deep-Aquifer project.

1. Between 500 and 800 water-quality analyses would be added to the Ground Water Information Center water-quality data base.
2. Formation-top data would be entered into the Ground-Water Information Center data bases for Deep Aquifers in eastern Montana.
3. Dissolved solids maps for the Kootenai Formation (and related rocks) and the Judith River Formation (and related rocks) would be generated by the Bureau of Mines and Geology and placed on Open File to demonstrate the accessibility and utility of the deep aquifer water-quality information.
4. Altitude of Formation maps for two aquifers would be generated and placed on Open File by the Bureau of Mines and Geology to demonstrate the accessibility and utility of the formation-top information. The aquifers selected for mapping were the Judith River and the Kootenai.
5. Daily activities (data entry, data verification, service requests, etc.) of the Information Center would be maintained.

All of the tasks included in the Deep-Aquifer project have been completed. A total of 695 historic water-quality analyses obtained both from paper files at the Bureau and from previously published data were added to the WATER QUALITY data base. Formation-top information for 2,036 locations in eastern and central Montana were entered into the DEEP AQUIFER data base structure and made available to the public through the Information Center. Four maps demonstrating the new water-quality and formation-top data were placed on Open File by the Bureau. Dissolved solids data for the Kootenai Formation and equivalent rocks and the Judith River Formation and equivalent rocks are Open-File Reports MBMG 269 and MBMG 270. Formation top information for the Kootenai and Judith River formations and their equivalents are Open File Reports MBMG 274 and MBMG 322. Daily operation of the Information Center was supported by the Deep-Aquifer project during the time funds were being expended from the project account.

Ground-Water Information Center

The Ground Water Information Center consists of six main files linked together by use of a unique identifier (Figure 1) called the site number. The identifier links all records in each of the files back to a parent record in the SITES File. In the WELLS, DEEPAQU, SWL, and LITHOLOGY files, the identifier

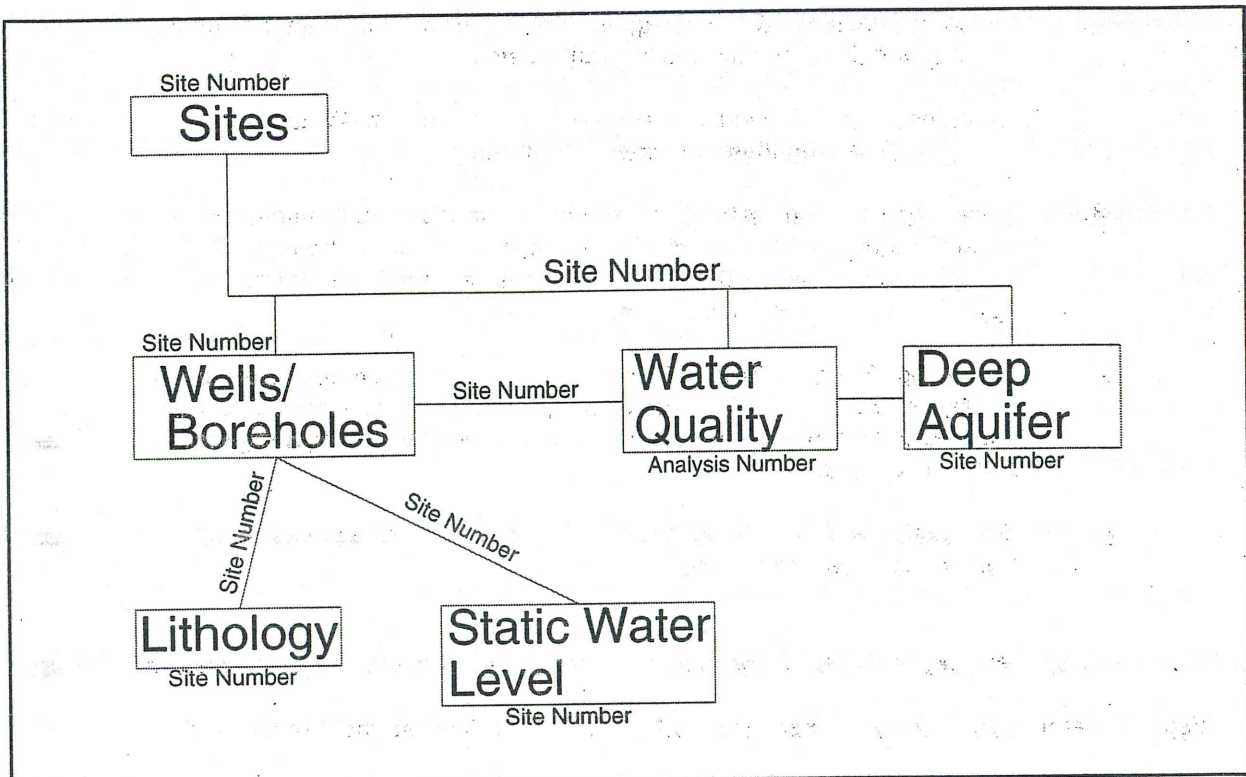


Figure 1: File relationships in the Ground-Water Information Center, August 1994.

is also the record locator key for the data base. The record locator keys for each file are shown near each box in Figure 1. The WATER QUALITY file uses a separate record locator key but is cross referenced to the SITES and WELLS files by a data field containing the record key to those files. The use of a separate record locator key allows a 'many to one' relationship between the WATER QUALITY and the SITES files. The six main files are indexed by County, Township and Range, Project, Year and several other criteria depending on the file involved. In addition to the six main files, an additional 18 support files are maintained in the data base.

Sites (SITES) File:

The SITES file contains location, ownership, and other information common to an individual site in the data base. Every record in each of the other data bases must have a matching record in the SITES file. In August 1994, there were 157,055 records in the SITES file of which 127,937 were related to water wells. Records in the SITES file not related to water wells are for streams, mines, petroleum exploration holes, and other points. Location, latitude, longitude, land surface altitude, owner name, and topographic map are examples of fields stored in the SITES file. Although the SITES file can be accessed directly using methods identical to the other data bases, it is most often used as a reference for fields included in the other files. For example, a user needing location data for water wells asks for the LOCAT field in the WELLS file. However, the information produced by the LOCAT field is stored in and retrieved from the SITES file using the record locator key (unique identifier) for both files.

Wells (WELLS) File:

The WELLS file contains 127,937 records in a 'one-to-one' relationship to records in the SITES file. Water well, monitoring well, and other borehole information are all stored in the WELLS file. Records in the WELLS file are also linked in a 'one-to-one' relationship with records in the SWL (Static Water Level) and LITHOLOGY files. Records in the WELLS file may also be linked in a 'one-to-many' relationship with records in the WATER QUALITY file. Total depth, driller's static water level, casing information, perforation information, and annular seal information are examples of some fields in the WELLS file. In addition to driller's well-construction data, a special group of fields contains WELL-INVENTORY information. Field measured water-level, specific conductance, pH, measuring point altitude, agency name, and the name of the person visiting the well are stored in the WELL INVENTORY part of the WELLS file. Entry of data in the WELL INVENTORY fields also indicates that the location recorded in the SITES file has been field verified. Because the location in the SITES file for the well record is more likely to be correct, other information in the WELLS file record becomes more valuable.

Water Quality (WATER QUALITY) File:

Water-quality records are in a 'many-to-one' relationship with the WELLS and SITES files. Any well or site in the data base may have more than one water quality analyses. In August, 1994, there were 14,677 analyses representing 9,087 sites in the WATER QUALITY data base. Of these, there were 11,176 analyses for 7,776 wells, springs, test holes etc. The WATER QUALITY file contains inorganic chemical data including common ions and trace metals. The Deep-Aquifer project added 695 analyses to this file.

Lithology (LITHOLOGY) File:

Descriptions of formation materials penetrated during drilling of wells and boreholes are placed in the LITHOLOGY data base. In August 1994 there were 43,719 records in the data base in a 'one-to-one' relationship with the WELLS file. All lithologic records for Bighorn, Dawson, Fallon, Flathead, Lake, Prairie, Richland, and Wibaux counties have been placed in the data base. State wide, all lithologic records for water well and other boreholes received by the Information Center since January 1, 1990 are in the data base. Lithologic information for older wells is being added as time permits in operation of the Information Center, and as the Montana Ground-Water Characterization Program begins study in different counties.

Deep-Aquifer (DEEPAQU) File:

The DEEPAQU file contains 26,495 records in a 'one-to-one' relationship with the SITES file. Formation-top information for 2,036 records in the DEEPAQU file was almost entirely obtained from U.S. Geological Survey Open-File Report 81-415 (Feltis et al, 1984). In addition to the formation-top information, the report contained interpretations of sand thickness that were also added to the data base. Records in the DEEPAQU file that do not presently contain formation-top information are useful for determining locations of wells where formation-top data are potentially available. In addition to the formation-tops, the data base contains well name, total depth, year drilled, and other information.

Currently, formation-top information for approximately 600 additional wells is being generated by the Ground-Water Characterization Program in the Lower Yellowstone River study area. When these data are available, they will be added to the data base created by the Deep-Aquifer project. One primary purpose of developing the Deep-Aquifer data base was to create a place to store formation-top information developed from future projects, and that purpose will soon be fulfilled. More detail on the formation-top information added to the data bases during the Deep-Aquifer project is contained in the Deep-Aquifer Data section below.

Static Water Level (SWL) File:

The SWL (Static Water Level) file contains 951 records (August, 1994) and 36,272 water-level values for wells in western, central, and eastern Montana. The SWL file is the newest data base in the Information Center and currently is growing rapidly as a part of the Montana Ground Water Assessment Act's Monitoring Program. The Monitoring Program has provided data for 504 of the 951 wells. Growth in the data base is expected to include quarterly or more frequent water-level data for 700 to 1,000 wells statewide, as well as water-level measurements made by other programs. Water-level data are available through a report selected from the Information Center's report menu.

Deep-Aquifer Data

Deep-aquifer water-quality and formation-top data handled during the Deep-Aquifer project are described more completely in the following sections. The selection, keystroking, and verification required for entry of the formation-top information was time intensive. Numerous students were assigned tasks to enter the information and proof-read the resulting data entries. The data entry process required hand calculated latitudes and longitudes for all of the points added to the formation-top and water-quality files so that the data could be retrieved and plotted on the Open-File maps. One time consumptive part of the process was the necessity of verifying the hand calculated latitudes and longitudes by an independent process. Approximately 25 percent of the points added to the data base

during the Deep-Aquifer project were corrected by calculating latitudes and longitudes from the reported Township and Range locations with the computer and then comparing those to the hand-calculated values. The correction process showed that the machine calculated latitude longitudes from the location of the site were the more accurate.

Water Quality:

The Montana Bureau of Mines and Geology holds in its paper files about 1,500 water-quality analyses from deep formations in eastern Montana. The majority were purchased by the U.S. Geological Survey from various laboratories, used by the Survey for its own project needs, and eventually forwarded to the Bureau. Dates on these analyses range from the late 1940's to the early 1970's. Some analyses were given to the Bureau by the Environmental Protection Agency. These analyses were completed by J.G. Crawford and others at the former Casper, Wyoming, laboratory of the U.S. Geological Survey in the late 1930's and the early 1940's. A few analyses have also been forwarded to the Bureau by the Environmental Protection Agency as a result of the permitting process for underground injection wells. From the 1,500 analyses in the paper files, 428 were selected for entry into the WATER QUALITY data base.

In addition to the analyses selected from the Bureau's paper files, 213 analyses published by the U.S. Geological Survey in Open-File Report 76-40 were also entered in the WATER QUALITY data base. The analyses represent aquifers ranging from the Fox Hills/Hell Creek Aquifer to the Madison Formation throughout eastern Montana.

U.S. Geological Survey Water Supply Paper 1487 provided 54 water-quality analyses for the data base. Although most of those data are for shallow alluvial aquifers, their inclusion helped fill a void in the water-quality data base for the Little Bighorn River Valley.

The water-quality data were placed in a temporary file structure for data entry purposes, and later transferred to the file structure used for all other water-quality data in the Information Center. The analyses are currently available along with 14,677 others in the water-quality data base. Table I contains the number of analyses added to the water-quality data base for each aquifer during the Deep-Aquifer project. The total number of aquifers listed in Table 1 is 704 rather than 695 (the actual number of analyses added) because a few analyses represent water samples from more than one formation.

Table I: Formations and number of analyses added to the water-quality data base, Ground-Water Information Center, August, 1994.

Code	Description	Number of Analyses
MISC	Miscellaneous Formations	89
110ALVM	Recent Alluvium	52
211DKTA	Dakota (Basal Colorado Group) Formation	25
211EGLE	Eagle Formation	110
211JDRV	Judith River Formation	54
217KOTN	Kootenai Formation	258
320AMSD	Amsden Formation	26
330MDSN	Madison Group Rocks	90

No quality-control or quality-assurance data are available for the water-quality samples included in the Deep-Aquifer project. Consequently, use of the data is limited to the historic evaluation and generalized description of dissolved solids in various aquifers in eastern Montana. Water quality at any specific site may need to be verified by modern analytical work supported by appropriate quality assurance and control, depending on the current need for the data.

Formation Tops:

Formation-top data for the Deep-Aquifer Data Base were obtained from U.S. Geological Survey Open File Report 81-415. Altitude of the formation-top, thickness of the formation, and cumulative

Table II: Formations represented in the Deep-Aquifer data base, Ground-Water Information Center, August 1994.

<u>Code</u>	<u>Formation Description</u>	<u>Tops</u>
125LEBO	Lebo Shale (Fort Union Formation)	137
125TGRV	Tongue River (Fort Union Formation)	128
125TLCK	Tullock Member (Fort Union Form.)	206
211BLFC	Belle Fourche Shale	1,228
211CLLG	Claggett Shale	1,045
211EGLE	Eagle Formation	1,129
211FHHC	FoxHills/HellCreek Aquifer	458
211GRNR	Green River Formation	1,263
211HLCK	Hell Creek Formation	272
211JDRV	Judith River Formation	956
211NBRR	Niobrara Shale (Colorado Group)	1,131
211PIRR	Pierre (Bearpaw) Shale	617
217FLRV	Fall River Formation	1,631
217FUSN	Fuson Formation	1,568
217LKOT	Lakota (basal Kootenai Formation)	1,491
217MDDY	Muddy Formation	1,403
217MWRY	Mowry Formation	1,234
217SKCK	Skull Creek Formation	1,604
221MRSN	Morrison Formation	1,003
221RRDN	Rierdon Formation	889
221SWFT	Swift Sandstone	1,039
224PIPR	Piper Formation	1
320AMSD	Amsden Formation	1
320TYLR	Tyler Formation	1

thickness-of-sand data were read from the report and entered into the Deep-Aquifer data structure for 2,036 wells. The 2,036 wells include data from 24 formations and 20,435 individual formation tops. Table II contains the formations and the number of formation tops included in the data base. Using formation-top and land-surface-altitude data, the data base calculates depths to individual formation tops from land surface. Some of the formations represented in the data base (e.g. Pierre Shale, Claggett Shale) are not-aquifers but are included because the tops and bottoms of these formations define aquifers such as the Eagle and Judith River Formations.

Also included in the SITES records for the DEEP AQUIFER data base are computer-calculated latitude and longitude values which allow the formation-top data to be plotted with Geographic Information System software. The Open-File Reports showing formation-top altitudes for the Judith River and Kootenai formations were constructed by transporting data from the SITES and DEEP AQUIFER files to ARC/INFO software operating on a SUN Workstation. Maps were created using existing geology coverages, were plotted, and were forwarded to the Department of Natural Resources and Conservation. The maps are also available directly from the Montana Bureau of Mines and Geology. The formation-top data have also been used by the Ground-Water Characterization Program in its Lower Yellowstone Study Area. Records in the Deep-Aquifer data base became the core to which additional data are being added to evaluate deep aquifers in that study area. Eventually the formation-tops derived during the Characterization Study will be added to the Deep-Aquifer data base.

Other Tasks

Along with work on the deep water-quality and formation-top data, Bureau staff added about 16,000 new water well logs to the data bases. The data entry process includes: initial certification that the log is a new record by searching for it in the data base; adding a drainage basin code to the document; and typing the information contained on the log into the SITES, WELLS, and LITHOLOGY files. After the information has been entered, the data are verified by having a different person compare the log to the computer record. The final step of processing is the filing of the log in the paper files. During the term of the Deep-Aquifer project, staff at the Information Center answered approximately 5,000 service requests. They came from all parts of the state and ranged from queries for specific well-log records, to requests for listings of wells from the computer. In many cases information from the data base was transferred to a personal computer, converted to other file formats, and sent to customers. A good example of this process was the downloading of water-well information to the Department of Natural Resources and Conservation Water Resources Offices in Kalispell, Missoula, Helena, and Bozeman.

In addition to processing new well-log information, there is an ongoing effort to verify and complete older information in the data base. 'Verifying' data matches the computer record with the paper document, eliminates duplicate records, and ensures that all paper documents are represented in the data base. 'Completing' data makes sure that all information on the well log has been transferred to the data base. At the end of the Deep-Aquifer project, 39 counties had been 'verified' and 8 had been 'completed'. Additionally, all water-well logs received since January 1, 1990 have been fully 'verified' and 'completed'.

Refinements to the Ground Water Information Center data bases during the Deep-Aquifer project extended beyond the addition of the Deep-Aquifer formation-top and water-quality information. Three additional reports (LITHOLOGY, SWL, FULL WELLS) were added to the report menu and other reports were modified to present data in a more organized manner. The reports were optimized for direct downloading to personal computers and were structured to ease import into word processors and spreadsheets. Additionally, programming bugs in the report generation software were fixed.

An additional task that developed and was met during the course of the Deep-Aquifer project was the processing of monitoring well logs. In 1990 the Department of Natural Resources and Conservation began forwarding copies of monitoring well logs to the Information Center. During the Deep-Aquifer project, 2,700 monitoring well records were added to the Information Center data bases.

For many years the Montana Department of Highways (now Department of Transportation) has been forwarding logs of geotechnical holes to the Bureau of Mines and Geology. These records include valuable information about depth to water and formations in various parts of the state. During the Deep-Aquifer project, work began on integrating these logs into the Information Center data bases.

Budgets

Table III: Expenditure summary, Deep-Aquifer data base project.

<u>Cost Category</u>	<u>RDGP Budget</u>	<u>RDGP Expenditures</u>	<u>Applicant Contribution</u>	<u>Outside Sources</u>	<u>Total</u>
Salaries and Wages	110,886	118,033	0	0	118,033
Employee Benefits	35,272	31,178	0	0	31,178
Contracted Services	3,000	52	0	0	52
Communications	0	45	0	0	45
Travel	0	497	0	0	497
Supplies and Materials	2,000	904	0	0	904
Equipment	4,792	4,406	0	0	4,406
Miscellaneous	0	973	0	0	973
Total	155,950	156,088	0	0	156,088

Finances for the Deep-Aquifer project were tracked through the SBAS system used by the Montana Department of Administration. According to the final financial report for the Deep-Aquifer project dated October 1992, the total amount of funds expended during the project was \$156,088. The overage of \$138 was absorbed by the Montana Bureau of Mines and Geology. Of the total expenditures, \$149,211 was spent on salaries and benefits, \$2,949 on purchase of computer hardware and software, and \$3,929 on general operations. Expenditures for the project are illustrated in Table III. Salaries were overspent during the project but significant underspending in other categories allowed the total expenditures for the project to be near to those budgeted.

References

- Crawford, J.G., 1942: Oil field waters of the Montana Plains. Bulletin of the American Association of Petroleum Geologists, Volume 26 Number 8. Pages 1317-1374
- Feltus, R.B., et al, 1971: Selected geologic data from the northern Great Plains area of Montana. U.S. Geological Survey Water-Resources Investigations Open-File Report 81-415. 63 pages.
- Hopkins, R. B., 1976: Water-resources data for deep aquifers of eastern Montana. U.S. Geological Survey Water-Resources Investigation Open-File Report 76-40. 37 pages.
- Moulder, E.A., Klug, M.F., Morris, D.A., and Swenson, F.A., 1960: Geology and ground-water resources of the Lower Little Bighorn River Valley Big Horn County, Montana; with a section on chemical quality of the water by R.A. Krieger, U.S. Geological Survey Water Supply Paper 1487. 223 pages.
- Patton T.W., 1990: Montana Ground-Water Information Center: Status report. Including basic data for Cascade, Missoula, and Yellowstone Counties. Montana Bureau of Mines and Geology Open-File Report MBMG 231. 393 pages.
- Patton, T.W., compiler, 1993: Dissolved solids in the Kootenai Formation and equivalent rocks east of the disturbed belt, Montana. Montana Bureau of Mines and Geology Open-File Report MBMG 269. Map. Scale 1:1,000,000.
- Patton, T.W., compiler, 1993: Dissolved solids in the Judith River Formation and equivalent rocks east of the disturbed belt, Montana. Montana Bureau of Mines and Geology Open-File Report MBMG 270. Map. Scale 1:1,000,000.
- Patton, T.W., compiler, 1994: Altitude of the top of the Kootenai Formation and equivalent rocks east of the disturbed belt. Montana Bureau of Mines and Geology Open-File Report MBMG 274. Map. Scale 1:1,000,000.
- Patton, T.W., compiler, 1994: Altitude of the top of the Judith River Formation and equivalent rocks east of the disturbed belt. Montana Bureau of Mines and Geology Open-File Report MBMG 322. Map. Scale 1:1,000,000.