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UWC Geothermal Resource Exploration

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ABSTRACT

A consortium was formed with Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), and New Mexico State University (NMSU). Funding support was received from the U.S. Department of Energy (U.S. DOE) and the State of New Mexico. A program was developed to explore the strength of the geothermal and hot dry rock (HDR) resource at the Montezuma Hot Springs at the United World College (UWC). The purpose of the UWC #1 well is to obtain hydrologic, geologic, and temperature information for ongoing geothermal evaluation of the Montezuma Hot Springs area. If sufficient fluids are encountered, the hole will be cased with a 4 1/2 inch production casing and re-permitted as a geothermal low-temperature well. If no fluid is encountered, the well will be abandoned per Oil Conservation Division regulation. The objectives of the exploration are to evaluate the resource potential to provide space heating for the entire campus of the United World College, determine the effect of a well on the Hot Springs outflow, accurately measure the UWC heating loads versus time, evaluate the potential to support local thermal industry development, assess the feasibility of HDR development, and create an educational program from the collection of data derived from the research effort.

PROJECT OVERVIEW

This report is being presented in January 1996, to correspond to the requirements of subcontract #6849V0015-3G. As of this date, drilling of the exploratory well is scheduled for the end of February 1996, which is in about four weeks. The accomplishments to date consist of instrumentation installed to accurately measure UWC heating loads. These measurements included heating loop supply and return water temperature, heating loop flow rate, input and output main water circulation pump pressure, power consumption of the main and re-circulation pumps, ambient air temperature inside and outside the heating plant, and outdoor wind speed and direction. See report entitled, "UWC Geothermal Resource Exploration," submitted as Attachment A. Additional instrumentation was installed in the Hot Springs to measure spring flow rate, spring water temperature, and to collect data over a longer period of time, submitted as Attachment B.

Location and survey of UWC Well #1 have been completed by project geologists from NMSU and LANL. Several surveys were conducted and errors were corrected on local maps.

The project team has met with local drilling contractors to discuss type of equipment needed for the project. The safety aspect of the equipment is of primary concern due to the many unknowns of the project. For example, Blow Off Protection Equipment (BOPE) is required for protection from high pressure pockets. Decisions have been made to bring instrumentation to the drilling site in the form of well logging tools and instrumentation trailers from Sandia. Measurements will be made for temperature, flow rate, gamma radiation and chemical composition.

Considerations are being given to harness the natural power beneath the springs to replace the existing coal-burning heating plant, depending upon the geothermal strength.

Upon completion of the exploratory well and analysis of the data, decisions will be made to select the most viable option. See report entitled, "United World College Geothermal Space Heating Project Overview," submitted as Attachment C.

Collaborative efforts are continuing with LANL to establish an educational resource center at the hot springs on geothermal energy. The development of educational materials and programs would be based on the information gathered during the course of evaluating the geothermal potential of the springs.

Information collected by researchers at the UWC about the hot springs is provided as Attachment D, an extension of an earlier report submitted a year ago. This information provides a rich mine of material, which can be used for science lessons and laboratory projects at the senior high school or university level. Materials already written for both students and teachers are included as Attachments E and F.

At the Armand Hammer United World College, students study for the diploma of the International Baccalaureate, a two-year curriculum in which every candidate must take at least one course in science. Changes in the structure of the science curriculum to be implemented from August 1996, require that each student participates in a project with students from other science courses. Faculty members of the science department at UWC have decided that these science group projects should use the hot springs as the focus of study and investigation. These efforts will involve over one hundred students and six members of the faculty each year and will provide a great deal of impetus and effort towards developing new educational ideas and materials.

ATTACHMENT A

The Hot Springs

at

Montezuma, New Mexico

**UWC Geothermal Resource Exploration
Sandia National Laboratories Report**

Section 1

UWC Geothermal Resource Exploration

Gale Martinez and Bill Sullivan

Sandia National Laboratories

January 1995

Project History

Sandia
National
Laboratories

-
1992	UWC President, Ted Lockwood, asks LANL to examine using geothermal hot springs to replace coal-fired boiler.
1993-1994	Mark Nickerson (LANL) drafted report on geological characteristics of area and possibility of using the geothermal resource for heating. SNL participated by supplying data on heat pumps for augmenting geothermal sources.
March 1994	LANL/SNL met with new UWC President, Phil Geier, to discuss heating options for facilities. All options required further knowledge of the resource which can only be determined by exploratory drilling.
Summer 1994	NMSU (SWTDI) asked to participate because of their knowledge of New Mexico resources and experience in direct geothermal heating systems. Joint proposal written by SNL, UWC, LANL, and NMSU to request funding of \$200K for exploratory drilling.
Fall 1994	Submitted Proposal for "State Match for Technology-Based Proposals" Program. Requested \$45K of state funds and \$55K of DOE funds to develop a shallow, low cost, exploratory well and explore broader economic development options for the region.
Winter
1994-1995	DOE/GD and State match funds awarded.
Present	Monitoring UWC heating load and weather data. Beginning geological survey to determine best site for exploratory well.

Why Support this Project?

- UWC is a Valuable Cultural, Educational, and Economic Resource for the State of New Mexico and the Economically Depressed Las Vegas Region which may Benefit from Laboratory-Sponsored Technology Transfer.
- Great Opportunity to Support Displacement of a Coal-Fired System with DOE-Sponsored Renewable Energy Technology.
- Can be a Highly Visible and Effective Demonstration of Federal/State/Public/Private Partnerships.

Initial Project Goals

- Utilize the Montezuma Hot Springs to:
 - Heat the College Facilities
 - Promote Environmental Awareness
 - Educate the Students and Local Community
- Initial Funding by DOE(\$55K) and the State of NM (\$45K) will Provide Shallow Exploratory Well(s) for Resource Evaluation and Detailed Measurements of UWC Heating Loads.

Future Goals

Sandia
National
Laboratories

If the Resource is Substantial, Additional Goals are Possible:

- Broaden UWC's Environmental Studies Program
- Develop a Renewable Energy Educational Center in Northern NM
- 'Adaptive Reuse' of the Montezuma Castle
- Generate electricity using HDR Technology
- Local Economic Development Opportunities:
 - Well Drilling Industry
 - Greenhouse Horticulture
 - Aquaculture
 - Apple Dehydration
 - Tourism

Funding Sources for these Broader Goals is TBD!

UWC Heating System

Sandia
National
Laboratories

- **Boiler Heating System for Space Heating & Hot Water Heating**
 - 121,000 ft² of facilities
 - Coal Boiler Consumes 600 Tons per Year
 - * Annual Coal Costs: \$35,000, \$6500 for Maintenance
 - * Annual Electricity Costs: \$126,000, \$10,000 for Maintenance
 - Future Expansion of Heating System Proposed
 - * 25,800 ft² of Additional Residences Currently Heated by Propane or Electricity
 - * Montezuma Castle
- **Heated Water Circulated through Radiators and Fan Coil Units in Individual Rooms of Buildings**
 - $T_{\text{supply}} = 178^{\circ}\text{F}$, $T_{\text{return}} = 175^{\circ}\text{F}$
 - Flow Rate = 1150 GPM During the Heating Load, 700 GPM in Summer.

UWC Heating System Schematic

- High Temperature (180°F) Water Loop

Geothermal Space Heating Options

Choice of Heating Options Depends on Resource Strength

Option 1: Direct Geothermal Heating

Lowest Cost Option if the Resource Temperature $> 150^{\circ}\text{F}$, High Flow Rate.

Option 2: Geothermal Heating Augmented with Heat Pumps

Necessary if Resource Temperature $< 150^{\circ}\text{F}$, Flow Rate < 200 GPM.

Option 3: Geothermal Heating Augmented with HDR

HDR Used to Boost Flow if Resource Flow Rate Weak.

Option 4: Geothermal Heating Using HDR

Development of HDR Geothermal Energy System if High Temperature Gradient Exists.

Geothermal Exploration Project

Sandia
National
Laboratories

Phase I Objectives

- Explore the Strength of the Geothermal Resource at UWC.
- Evaluate the Resource Potential to Provide Space Heating for UWC.
- Determine the Effect of a Well on the Hot Spring Outflow.
- Accurately measure the UWC Heating Loads.
- Evaluate the Potential to Support Local Thermal Industry Development.
- Assess the Feasibility of HDR Development.

Geothermal Exploration Project Plan

PHASE I TASKS

- Complete Geological Survey of the Hot Springs Area.
- Determine Best Exploratory Drilling Site(s).
- Drill Test Well(s).
- Acquire Well Logging Data.
- Measure Heating Demand of UWC Facility.
- Analyze Test Data.
- Recommend Best Heating Option and Propose Future Studies for Phase II.

Roles of Partners in Exploration Project

Sandia
National
Laboratories

Partner/ Tasks	Geological Survey	Pick Drill Site	Contract Drilling	Well Logging	Measure Heating Demand	Data Analysis	Funding
UWC	X	X	X			X	\$25K (in-kind)
NMSU	X	X	X			X	\$45K
LANL	X	X				X	\$15K
SNL		X		X	X	X	\$40K

UWC Heating Load Measurements

- Instrumentation Installed in October 1994.
- Measurements Include:
 - Heating Loop Supply and Return Water Temperature
 - Heating Loop Flow Rate
 - Input and Output Main Water Circulation Pump Pressure
 - Power Consumption of the Main and Recirculation Pumps
 - Ambient Air Temperature Inside and Outside the Heating Plant
 - Outdoor Wind Speed and Direction
- Measurement System Samples Data every 20 Seconds.
- Data is Stored every 15 Minutes.
 - 15 Minute, Hourly, and Daily Averages
 - Maximums, Minimums, and Totals

UWC Heating Loop & Air Temperature Histories

UWC Heating Loop Flow Rate

UWC Heating Load

UWC Heating Load vs. Outdoor Air Temperature

Objectives

Sandia
National
Laboratories

- Support of Environmental Clean-Up by Replacing a Fossil Fuel Heating System with a Geothermal Energy System.
- Enhance Local Economic Development Opportunities to this Economically Depressed Region.
- Build Important Government and Private Industry Partnerships.
- Develop a Renewable Energy Educational Center.
- Demonstrate New HDR Technology.

ATTACHMENT B

The Hot Springs

at

Montezuma, New Mexico

Data Collection Charts

Section 2

Bath House Spring Flow Rate

9/18/95

Day of the Year

Bath House Spring Temperature History

UWC Heating Load using Average Flow Data

UWC Outside Air Temperature

UWC Average Heating Load vs. Outdoor Air Temperature

6/13/95

Outdoor Daily Average Air Temperature (°F)

UWC Maximum Heating Load vs. Outdoor Air Temperature

ATTACHMENT C

The Hot Springs

at

Montezuma, New Mexico

**United World College Geothermal Resource
Exploration Project Overview**

Section 3

United World College Geothermal Resource Exploration Project Overview

Introduction

The Armand Hammer United World College of the American West located in Montezuma, New Mexico, is situated on property where there are numerous natural hot springs known as the Montezuma Hot Springs. Consistent with its mission, United World College (UWC) would like to utilize these natural springs for a variety of purposes not only to supplement its international educational goals, but also to promote environmental awareness and community service ideals to its intercultural student body representing 70 countries as well as the United States.

The first objective is to harness the natural power beneath the springs to replace the existing coal-burning heating plant. The college currently heats the majority of their buildings and facilities with hot water produced by this plant. They are anxious to replace the coal boiler with an alternative environmentally friendly technology to both lower their space and hot water heating costs and reduce the pollutants produced by the coal-burning plant.

Larger objectives exist which will benefit not only UWC, but the local community. With geothermal power in use, the college could broaden its existing environmental studies program to include first-hand experience with geothermal/natural power issues. The working geothermal system could serve as a demonstration program not only for the college's multi-cultural student body but also extend UWC's present community service program to develop a renewable energy educational center in northern New Mexico. This would benefit the local elementary, high school, college, and community educational opportunities in this region. Depending on the actual strength of the geothermal resource, it may be possible to use geothermal power for additional purposes beyond replacing the existing coal furnace at UWC. Examples include: 1.) generating electricity for the campus and surrounding community using state-of-the-art hot dry rock technology, 2.) developing the local well drilling industry for geothermal resource exploration, 3.) expanding greenhouse horticulture and aquaculture industries to northern New Mexico, and 4.) strengthening the state tourism industry by enhancing the natural hot springs for public use and eventually developing this area into a state park.

All of these objectives fall within the current U.S. administration's goals to promote the U.S. as a worldwide leader in the development, application, and export of environmentally clean and economically competitive renewable energy systems. Working toward these objectives will build and strengthen government and private industry partnerships as well.

None of these desired objectives are within the realm of possibility without further explorations of the geothermal potential. Drilling test wells will indicate the critical elements of heat and pressure available and is necessary to assess the feasibility of these project objectives.

Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), and the Southwest Technology Development Institute (SWTDI) at New Mexico State University (NMSU) are interested in helping UWC utilize this geothermal resource. This project is relevant to several of SNL's and LANL's research and development activities including geothermal heat pumps, slimhole drilling, downhole instrumentation and hot dry rock technologies. SWTDI has considerable experience with utilizing

geothermal energy to provide space heating and developing greenhouse horticulture and aquaculture in New Mexico. Thus, exploration of the natural resource potential of the Montezuma Hot Springs is of significant value to the programs of UWC, the national laboratories, NMSU, the geothermal and renewable energy resource industries, the state economy, and the surrounding New Mexican community.

This overview is intended to outline the project objectives, discuss possible geothermal heating options to replace the coal-burning plant, and outline the proposed tasks needed to initiate this project. In addition, possible funding sources as well as the benefits of this project to United World College, the local community, the environment, and renewable energy technologies are discussed.

Facility Description

The Armand Hammer United World College of the American West was founded in 1982 by noted humanitarian and philanthropist Dr. Armand Hammer. It is a non-profit two-year international residential school for students 16 to 19 years of age and the only United World College in the United States. It serves as the equivalent of the 12th and 13 grades and is a "bridging" school between secondary and university education. UWC enrolls 200 students from 70 countries and from throughout the United States who are hand selected solely on the basis of their academic merit and leadership qualities. The mission of UWC is to enable young people to become responsible citizens, politically and environmentally aware, committed to the ideals of peace, justice, understanding, and cooperation, and to the implementation of these ideals through international education, shared experience and community service.

The Armand Hammer United World College is located on property consisting of approximately 110 acres, of which about 30 acres are developed. The Gallinas River runs through the property in the southern section. The Montezuma Hot Springs are near the current coal boiler plant and are used mostly by the surrounding residents for bathing.

The college uses a boiler heating system for space heating and hot water heating for approximately 121,000 ft² of facilities. The facilities consist of the cafeteria, administration building, campus center, fine arts center, maintenance building, other academic buildings, four dormitories, and residences for the college president and faculty. Additional residential facilities ($\approx 25,800$ ft²) are not heated by the hot water loop but rather use electricity and propane for space heating. In the future, the heating system may need to be expanded to include these residences along with the Montezuma Castle (a large structure on the property presently not used). The boiler house contains the central heating plant where the hot water for heating is produced and pumped through a large underground loop constructed of insulated steel pipe and delivered to the buildings. The hot water is then circulated through standard radiators and fan coil units in the individual rooms for space heating.

The boiler heating system has been in use since 1982 and operates on bituminous coal which is purchased from King Coal Company in Durango, Colorado. It is trucked in year round and approximately 600 tons of coal are used annually. December is usually when the peak heating load occurs and as much as 100 tons are used to meet the heating demand. The hot water leaves the heating facility at approximately 182°F and returns at 178°F and is pumped at approximately 1445 gpm (the rated capacity of the constant speed pump). In the summer, when the demand is quite low, the water continues to circulate through the loop although a smaller pump (with a rated capacity of about 700 gpm) is used. Using these figures, the peak heating load is estimated at 3 million Btu/hr [1]. The average heating load assuming a 200 day heating season and 50% boiler efficiency is estimated at 1.5 million Btu/hr [2].

The coal budget for 1993 was \$35,000 and the electricity costs were \$126,000. In addition, the annual maintenance cost is \$6500 for coal and \$10,000 for electricity. Presently, natural gas service to the college is not available. However, it will be available beginning this summer and the college has considered options to convert the boiler to natural gas at a capital cost on the order of \$40,000 to \$50,000 and an expected rise in annual fuel costs to approximately \$51,000 per year (assuming a gas boiler efficiency of 80% and a fuel cost of \$0.57 per therm).

The Montezuma Hot Springs on the property are owned by UWC, although the local community and tourists are the major users. Though the liability insurance on the springs is a hindrance to the college, the college does not want to create poor public relations with the community by closing the springs and denying the public access to a natural resource. However, UWC would like to see this natural geothermal resource utilized to its maximum potential.

Reference 1 began to characterize the Montezuma Hot Springs area from a geothermal resource viewpoint. The area contains a number of small faults. The highest water temperature found near the hot springs in a shallow well at a depth of 20 feet was 133 °F. It is likely that the temperature will be much higher in deeper wells. To determine the actual geothermal potential, a thorough geological survey of the region needs to be conducted, followed by drilling of test wells.

Project Objectives

The major objectives of this proposed project include:

1. **Reduce consumption of fossil fuel for space heating and water heating at UWC and in the local community.** Utilization of the geothermal resource to replace the coal boiler at UWC will reduce pollution. If successful, this technology can be expanded to replace the space heating systems of other local fossil fuel users in the community such as Highlands University and the state mental hospital, in direct support of the U.S. global climate change initiative.
2. **Develop and demonstrate a new world-class, economical, environmentally attractive, renewable energy system at UWC, possibly extending it into the surrounding community, in collaboration with the state and the national laboratories.** While utilizing direct geothermal energy for space heating is useful, it is not a new technology. However, development of a hot dry rock (HDR) geothermal energy system to initially provide space heating with the potential to later produce electricity for UWC and the local community would be a unique, state-of-the-art, application of clean geothermal energy technology.
3. **Develop a renewable energy educational center in northern New Mexico.** The educational benefits of such a project will be numerous. It will enrich UWC's environmental studies program by including first hand experience with geothermal energy utilization. It will also enhance the educational programs of local schools including elementary, high school, local colleges, and state universities. It will serve to introduce and promote this technology around the world as the UWC international student body is exposed to its benefits. In addition, if a HDR facility were built, this area would receive intense interest by energy researchers around the world as well as by the general public.
4. **Promote local economic development opportunities in the drilling, aquaculture, agricultural, and tourism industries.** The Las Vegas, New Mexico region is economically depressed and would benefit immensely by such a project. This project would educate local water well drillers to expand their business into the exploratory geothermal resource business with the goal of reducing costs of such explorations, thereby promoting the use of geothermal resources in New Mexico. Local growers could expand their markets by building geothermally-heated greenhouses and aquaculture projects. State tourism could be boosted from the development of a state park around the hot springs as well as the development of a renewable energy educational center.
5. **Build government and private industry partnerships.** This program would successfully demonstrate a collaborative project working toward the U.S. administration's goal of promoting renewable energy systems, the national laboratories' goals of technology development and transfer, private industries' goal of economic development, and the state goal of enhancing the educational opportunities of our youth.

Geothermal Space Heating Options

Various options have been proposed to address the first project objective of utilizing the geothermal resource at UWC to replace the current coal boiler heating system. (See Reference 2 which is also attached as an addendum.) Each of these are briefly described below. The choice of options is very dependent on the strength of the geothermal resource and must be determined by drilling one or more test wells in the vicinity of the natural hot springs at UWC.

Option 1: Direct Geothermal Heating

If the geothermal resource is hot enough ($>150^{\circ}\text{F}$) and produces a large enough flow¹ to support the UWC heating loads, the water could be pumped from a geothermal well and used to heat the water in the existing hot water loop through a heat exchanger or be directly injected into the hot water loop depending on the well water quality. The geothermal well would serve to replace the boiler. The boiler, however, would be retained for backup heating. The discharge from the heat exchanger, if used, could be piped back into an injection well or the river. This option proposes lowering the existing loop circulation temperature to approximately 140°F from the temperature now used (180°F). The feasibility of this circulation temperature using the fan coil units, baseboard heating units and hot water needs must be investigated.

If the geothermal resource is sufficient to meet the peak UWC heating loads, the annual fuel costs would be minimal compared to the cost of coal currently used in the boiler (approximately \$35,000 annually in 1993). The operating costs will decrease to only the electricity charges to power the pumps. The major capital expense to implement this option is the cost of the geothermal well and heat exchanger. This is the preferred option if the geothermal resource is available.

Option 2: Geothermal Heating Augmented with Heat Pumps at the Loads

If the geothermal resource is not sufficient to meet the heating loads at UWC alone (well temperature below 150°F and a flow rate below 200 GPM), commercial water loop heat pump units could be installed in the buildings replacing the fan coil units and baseboard radiators. This would eliminate the coal boiler except for backup heating. As in Option 1, the well water could be used to heat the existing circulating loop water to a much lower temperature using direct injection or a heat exchanger as described above. The heat pump units on each building then can operate at a loop temperature of approximately 70°F to supply the heating requirements.

This option will work with much less geothermal energy² but will require electrical energy to run the heat pumps. It is estimated that the annual electricity costs to power the heat pumps would be approximately \$60,000³ to meet the average annual heating load at UWC. As noted above, costs to operate the pumps would be additional. However, these costs are incurred with all options as well as the current coal boiler operated system. Capital costs for this option are also much higher than Option 1. Besides the cost of the geothermal well and heat exchanger, heat pump units must be purchased but are commercially available at a

¹ Estimates of the minimum flow rate required from the well as a function of well water temperature were made for the projected peak loads at UWC. For example, if the well temperature is 150°F , a flow of 600 GPM would be required to meet the peak load. If the well temperature is 200°F , a flow of 120 GPM would be required. (See Reference 2 for a complete table.)

² For example, if the geothermal well temperature was not hotter than 120°F , a minimum flow rate of 100 GPM would be sufficient assuming the heat pump operates at a COP of 3.5 [2].

³ Assumes the heat pumps operate at a COP of 3.5 and the cost of electricity is \$0.10/kWh [2].

reasonable cost. (See Reference 2 for a rough cost estimate.) In addition, modifications to the current building HVAC systems would be required to install the heat pumps.

Option 3: Geothermal Heating Augmented by Heat Pumps at the Source

The third option is proposed in the event that the geothermal resource is even less substantial than that needed for Option 2. For example, if the well temperature is below 150 °F and the flow rate less than 70 GPM, a large multi-stage heat pump could be installed at the geothermal resource to heat the well water so that it can be used to raise the existing circulating loop water temperature to approximately 140 °F through a heat exchanger as in Option 1.

This option results in approximately the same annual electricity costs as Option 2. This option may also be a preferred choice over Option 2 since a simpler retrofit is required; the existing fan coil units and baseboard radiators in the buildings could be utilized as in Option 1. However, a "multi-stage heat pump" will probably consist of large industrial units which may or may not be readily available.

Option 4: Geothermal Heating Using Water Injection to Augment Hot Water Production

This option involves the application of HDR technology to inject additional water deep into the underground strata in order to boost the flow of the hot springs. The source of the additional water could be the waste-water plant at the college, the primary college water supply, or the Gallinas River. Recirculation could be employed to minimize the total net water consumption. The added water would be pumped down an injection well and heated underground to augment the flow of the springs. A second well, probably shallow, would be needed to capture the added flow. With the higher flow, the water could be used to heat the UWC facility as described under Option 1 and then the partially cooled (but still warm) water returned to the springs or, alternatively, the water use could be partitioned with some going to maintain the natural hot springs and the remainder being used to heat the college. This application of HDR and natural hot water geothermal technology would be unusual (perhaps even unique) and could be promoted as a novel application of geothermal technology.

Option 5: Geothermal Heating Using Pure Hot Dry Rock Technology

If the hot water resources at UWC are insufficient to meet the school's heating requirements but a moderately high temperature gradient (22° F/1000 ft (40°C/km) or higher) is observed during test drilling, the development of a HDR geothermal energy system could be feasible. HDR is a demonstrated but not yet commercialized geothermal technology with the potential to revolutionize energy use around the world. A practical HDR facility at UWC would make the UWC a world-leader in the application of clean energy technology and would lead to intense interest by energy professionals around the world as well as by the general public. The operating costs of an HDR facility would be lower than the current costs of running the coal plant, but the capital investment would be high. The project would be justified for funding primarily because of its pioneering nature. HDR requires a small but continual supply of water. At UWC, this could probably be supplied by the effluent from their waste-water treatment facility. An HDR facility would also be compatible with the utilization of the hot springs for recreational purposes.

All of the above options will effectively reduce the emissions at UWC to zero compared to the coal boiler system now in use. However, the choice of options is very dependent on the strength of the geothermal resource that is available.

Possible Site Locations of Exploratory Wells

In order to assess the feasibility of any of the Geothermal Space Heating Options discussed above, the strength of the geothermal resource at UWC must be determined. In discussions with LANL scientists

familiar with the local topography and geology at UWC and initial site tours by SNL, LANL, and SWTDI representatives, four potential sites for geothermal exploratory well drilling were suggested. These are as follows:

1. Across the road south of the springs. One older shallow well has been found in this area and has standing, hot water in it.
2. In the parking lot next to the coal-fired power plant: This location is readily accessible and would have a minimal visual and psychological impact. It is likely hot water will be accessed from this site, although the maximum possible flow may not be obtainable.
3. On school property 50 to 100 yards west of the springs: This would also be a technically excellent site since the fault from which the springs emerge appears to dip to the west.
4. Up to a mile to the north of the spring: This site could be on the property of UWC and is located some distance from the spring but in a direction expected to produce the largest water and/or heat flow. This location would provide the most information about the real potential of this geothermal resource. It is possible and even likely that water would not be hit, but if it were, a significant geothermal resource would be indicated. The geological information obtained from the well could be very important for evaluating the geology and the HDR potential of the site as well as the hydrothermal resource.

Since seepages appear at the surface within the area of the springs near the bathhouse, it is virtually certain that hot water will be obtained and appears to be a good drill site location. However, the risk of tapping into very high pressure water must be assessed to insure a safe drilling operation and preserve the natural springs. In geothermal explorations, a surface casing must be anchored into the ground to secure blow-out protection equipment. This region is very swampy and does not appear to be a good choice from a safety standpoint.

The above site considerations are simply preliminary discussions of the important aspects of drilling at the four general locations mentioned. A detailed, on-site evaluation by an expert geologist will be necessary to finalize the specific site of drilling within any one of these areas.

Proposed Work

As indicated above, to assess the feasibility of any of these proposed project objectives, a determination of the strength of the resource is required. Therefore, the initial step (Phase I) involves a thorough geological survey of the hot springs area. An experienced geologist will review the existing data regarding the geology and faults of the region as summarized in Reference 1 and take appropriate field measurements to estimate the potential flow and temperature of the resource. From this geological survey and data analysis, the best locations to drill one or two exploratory test wells will be determined and may or may not be in the locations discussed in the previous section. These sites must meet safety criteria and preserve the natural hot springs area.

In Phase II of the project, one or two exploratory wells will be drilled at sites determined from the Phase I study. It is estimated that a depth of 1000 to 2000 feet will be necessary to not only determine the maximum well fluid temperature and flow potential for direct geothermal space heating applications, but also measure the thermal gradient necessary to assess the feasibility of an HDR project. A local well driller is preferred assisted by a consultant such as an industrial partner experienced in geothermal well drilling to insure well drilling safety and integrity.

The use of slim holes for the geothermal assessment should be considered. SNL is currently working with the geothermal industry to evaluate slimhole drilling for geothermal exploration and reservoir characterization. State of the art measurement techniques such as borehole instrumentation available at the national laboratories will be utilized for this project. LANL will examine the possibility of developing HDR technology from this resource based on their analysis of the data.

Concurrently, the heating load at UWC must be determined more accurately with a small measurement program. The circulating water loop temperatures leaving and returning to the heating plant and loop flow rates will be monitored during the 1994 heating season. The electrical energy used by the circulating pumps will be monitored as well as the coal usage. Weather data will also be measured.

Based on the outcome of the geothermal assessment and the measurement of the heating loads, the future project tasks will be defined. The geothermal heating options described above and any other proposed options that appear feasible will be evaluated. This will include extending this project to provide geothermal heating to the surrounding community and production of electricity utilizing HDR technology. Note that combinations or hybrids of the options described above should also be considered. For example, if the geothermal resource is not capable of supplying the heating loads, it may be utilized in conjunction with the present coal boiler system or a retrofitted gas boiler system if these scenarios were economically feasible compared to either Options 2 or 3. Options that are feasible will be assessed in detail in a two phase study as outlined below.

In addition to the replacement of the coal boiler system, UWC would like to preserve and enhance the natural springs area and possibly develop a state recreation area. Along with the geothermal well development plans, therefore, a design of a state recreation area will be performed to estimate the costs, time, and schedule required.

Phase II of this study will conclude by recommending the best option for further study based on the exploratory well measurements. It will include an estimate of the capital costs of each option including the costs of dismantling existing HVAC hardware, possible thermal upgrades to the buildings, geothermal equipment (i.e., geothermal well development, pumps, piping, heat exchangers, etc.) and HVAC hardware upgrades or retrofits if necessary (i.e., heat pumps, duct work, electrical wiring, etc.). The annual operating costs for each option will also be estimated based on the heating load projected to a credible bin-type weather year in the Montezuma area. These costs will include the estimated maintenance costs as well. The total annualized cost of the options will also be calculated. Estimates of energy usage for all the options will be made and compared to the present energy usage at the college.

Once the costs and energy consumption data requested above is obtained, recommendations for the best option will be made. The criteria for this recommendation will be outlined in detail and address the project objectives discussed above.

Phase III of this study will follow with a complete and detailed engineering design study of the recommended option resulting from Phase II. The geothermal well development and distribution system, if applicable, will be designed. All HVAC equipment as well as any additional thermal upgrades to the existing campus facilities will be specified.

The first cost, annual operating costs, maintenance requirements and costs, the total annualized cost, and energy consumption estimates will be determined and compared with the present HVAC system as described under Phase II. The schedule for the conversion project will be estimated and the impact on the college's academic or summer operations will be detailed.

We estimate the cost of Phases I and II (including the geological survey, drilling and monitoring the test wells, analysis of the data, documenting results, and recommending the Phase III option) at approximately \$280,000. This is in addition to the contribution valued at approximately \$100,000 from UWC which includes their donation of the exploratory drilling site, faculty, staff, and facility maintenance support, and expansion of their community service projects. We believe a Phase III engineering design based on the exploratory well data could be completed for \$100,000.

Building Partnerships

This project lends itself well for building government and private industry partnerships to increase the economic development of the northern New Mexico region. Both the state and federal government can contribute to promote the U.S. administration's goals of development of clean, environmentally friendly renewable energy technologies. The national laboratories can contribute their technical expertise for the

development of renewable energy technologies and transfer these technologies to private industries. Their support will promote and establish economic development for the local drilling industries, independent power producers, agriculture, aquaculture, and tourism industries in the state of New Mexico. Through UWC's interest and participation, educational programs within the community and worldwide will be enhanced. This collaborative effort will serve as a model for public and private sector cooperation.

Funding Sources

Possible government funding sources for the initial geothermal resource assessment and heating load measurement program include the Department of Energy (DOE) under the global climate change and drilling program funds, the National Science Foundation (NSF), and the State of New Mexico through petroleum escrow funds or through the Environment Department and the Energy & Minerals Department. UWC has committed to contributing the exploratory drilling site, faculty, staff, and maintenance support, and expansion of their community service projects. The value of their contributions is estimated at approximately \$100,000. Possible private industry collaborators such as drilling companies (Pro Drill, Occidental Petroleum, local drillers), utilities (Public Service Company of New Mexico, and independent power producers), and local agricultural business interested in expanding their markets with greenhouse horticulture and aquaculture may fund portions of the design and feasibility studies once the resource has been characterized.

Benefits of Project

The benefits of this project are numerous and target not only UWC but also the local community through enhanced educational opportunities, environmental clean-up, the advancement of renewable energy technologies, and increased economic development. Replacing fossil fuels with clean geothermal energy resources will certainly contribute to reduced emissions and support the global climate change initiative. If the geothermal resource is substantial, UWC may become the site of a demonstration project of the most advanced, world-class, 21st Century application of clean renewable energy technology in the world which may not only supply heating but also electric power generation to the local community. This demonstration project will also provide an enormous educational opportunities to the international student body at UWC, the local elementary and high schools, the nearby colleges, the state universities, and the general public. A renewable energy educational center will be started at UWC to promote the educational benefits worldwide. Economic development within the local drilling, agricultural, and tourism industries will be promoted. And this project will foster important government and private industry partnerships aimed at the U.S. administration's goal of promoting the U.S. as a world leader in the development, application, and export of environmentally clean and economically competitive renewable energy systems.

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ATTACHMENT D

The Hot Springs

at

Montezuma, New Mexico

**Hydrogeochemistry and Biota of the
Montezuma Hot Springs, New Mexico**

Section 4

ATTACHMENT D

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HYDROGEOCHEMISTRY AND BIOTA OF THE MONTEZUMA HOT SPRINGS, NEW MEXICO

Introduction

Before recorded history, the Montezuma hot springs were used by Indians. The legend of their use by the Aztec chief Montezuma, and hence their current name, was propagated by Indians. The legend may be true, or it might have been used to appease or confuse the white man. During the Civil War the Union army used the springs for convalescence of wounded soldiers. Local women made extensive use of the springs for washing clothes. In the latter half of the 19th century the property changed hands numerous times, for increasing sums of money. Small hotels, then larger, were built by various entrepreneurs to capitalize on the presence of the springs. Several bathhouses were built. The last major one was destroyed in a flood in 1904. Several years before that the third large Montezuma Hotel had become unprofitable, and the tourist industry ended in Montezuma. The hotel and property had several reincarnations as a Baptist college and Mexican Catholic Jesuit seminary. It is presently owned by The Armand Hammer United World College of the American West. The castle is no longer in use; the college occupies buildings which include an old stone hotel built in 1880. Most of the others were built during the time of the seminary [1]. The present heating system for the college utilizes hot water produced by a coal-fired boiler. To reduce pollution and heating costs, the college has initiated an investigation of the geothermal potential of the hot springs, in collaboration with Los Alamos National Laboratory (LANL), Sandia National Laboratories, and the Southwest Technology Development Institute at New Mexico State University. The work reported here is directed towards gaining information about the source, age, quantity, and properties of the water of the hot springs to help in the evaluation of their geothermal potential and to establish baseline data from which the influence of extraction of hot water from the geothermal system can be determined.

Historical

Information on the Montezuma Hot Springs and the nearby Gallinas River has been available since 1869, not long after the first permanent settlement in the area in 1885. The last major allocation of water to users along the Gallinas River was made by the U.S. District Court for the District of New Mexico in 1933 [2]. The "Hope Decree" allocated 200 000 gallons per day to the "college" through the "Montezuma College Pipe Line" and also allowed the use of water of the hot springs for domestic use and for heating and bathing purposes. In addition, 1.5 acre feet per year were allowed for irrigation for each of 21.9 acres. From the "Vigil Ditch" the college was allowed 1.5 acre feet for each of 10.8 acres. In a 1991 hydrographic survey report the Archdiocese of Santa Fe is listed as the owner of 21.9 of these acres [3]. Because the college no longer uses its earlier water rights, they are no longer assigned to it.

The number of springs recorded has varied with time.

1869	20 - 30 springs (Ref. [4])
1881	22 springs (Ref. [5])
1885	40 springs (25 excavated and walled) (30 produced water at 120 - 140 ⁰ F) (20 connected to the main bathhouse) (Ref. [6])
1899	40 springs (This may rely on information from 1885) (Ref. [7])
1966	12 wells, 3 pipes, 13 points in the Gallinas River releasing water at above ambient temperature, unspecified number of seeps (Ref. [8])
1994	4 groups of wells or baths; 3 are used for bathing

Estimates of flow from various springs have been made over many years, with greatly varying results. Comparisons are made difficult by the fact that in earlier years the spring tested may not be specified, or may be numbered according to a plan which is no longer available. Springs have been rerouted over the years, and roadwork above the springs may have had an effect on flow. Figure 1 [9] shows the location of springs as of 1966, with numbers to distinguish them. These locations are essentially unchanged in 1994. All references to spring numbers below are keyed to Figure 1.

- 1885 One spring produced 30 000 gal. per day (21 gal. per minute or $80 \text{ dm}^3 \text{ min}^{-1}$) (Ref. [6])
- 1952 Two springs produced 5 and 1 gpm (19 and $4 \text{ dm}^3 \text{ min}^{-1}$; perhaps spring #6) (Ref. [10])
- 1966 6 wells and several pipes produced a total of 23.3 gpm ($88.5 \text{ dm}^3 \text{ min}^{-1}$); the largest flow was at #1 with 5.8 gpm ($22 \text{ dm}^3 \text{ min}^{-1}$); 5.2 gpm ($20 \text{ dm}^3 \text{ min}^{-1}$) flowed from springs #5 and #6 to the seminary (Ref. [8])
- 1993 15 gpm ($57 \text{ dm}^3 \text{ min}^{-1}$) from #1; 4 gpm ($15 \text{ dm}^3 \text{ min}^{-1}$) and 1.5 gpm ($5.7 \text{ dm}^3 \text{ min}^{-1}$) from #5 and #6; 5 gpm ($19 \text{ dm}^3 \text{ min}^{-1}$) from #13 (Ref. [11])

Total flow from the springs was measured in 1966 by the U.S. Geological Survey by taking the difference between river flow measurements above and below the springs (location 24, Figure 1; gauging station downstream). The value obtained was 325 gallons per minute ($1.23 \text{ m}^3 \text{ min}^{-1}$) [12]. In 1993 an estimate was made by adding to the measured flow of 26 gpm from four springs a guess of 5 gpm for the seeps, giving a total flow of 31 gallons per minute ($1.2 \times 10^2 \text{ dm}^3 \text{ min}^{-1}$) [11].

Maximum temperatures also show appreciable differences with time, although the pattern is that of high temperatures in early years, and lower at present. The temperatures given below are those reported for the hottest spring(s). They are given in both degrees Fahrenheit and Celsius. No records of continuous monitoring of temperatures have been found, although it is known that individuals have done this without leaving records of their results.

1869	140°F	60°C	(Ref. [4])
1885	140°F	60°C	(Ref. [6])
1899	140°F	60°C	(Ref. [7])
1940	>130°F	>54°C	(Probably spring #1, Figure 1) (Ref. [10])
1966	130.1°F	54.5°C	(Spring #1, Figure 1, at surface; 55.2°C at bottom) (Ref. [13])
1993	131.2°F	55.1°C	(Ref. [11])

Many analyses of the chemistry of the waters have been made, and these show much greater consistency than the other data. In Table 1 below are

given representative data for chloride, fluoride, silica, and sodium. Values are given as ppm, and calculated where necessary from other units. Where analyses were made of different springs, the number (N) of analyses are given, the range of values, and the average and standard deviation.

Table 1: Selected Values from Previous Chemical Analyses of the Montezuma Hot Springs, New Mexico

<u>Year</u>	<u>[Cl⁻]/ppm</u>	<u>[F⁻]/ppm</u>	<u>[SiO₂]/ppm</u>	<u>[Na⁺]/ppm</u>	<u>Reference</u>
1869	N=3 148-166 160±10		N=2 (traces in 1) 10.4-25.1 ("silicic acid")		[4]
1882	N=21 142-175 166±7		N=17 44.1-99.7 66±13		[6]
1899	N=17 152		N=17 59.9		[7]
1910	N=17 24			N=17 9.5	[14]
1939-52	N=6 154-160 157±3	N=2 20, 20 20	N=2 59, 68 64		[15]
1966	N=1 160	N=1 3.4	N=1 80	N=9 115-200 173±24	[16]
1993	N=3 175-182 179±3	N=3 21.3-22.6 22.1±0.7	N=3 65-73 68±5	N=3 170-177 174±4	[11]

Nature of the Study

The current investigations have been undertaken to obtain more information about the nature and source of the hot springs, and to develop educational materials which will be useful for students in educational institutions.

Tasks undertaken include measuring total discharge of water from the springs into the river; comparing the chemistry of different springs to determine if they have a common source, and the nature of that source; and monitoring the rate of flow and temperature of different springs over a period of one year to see if variations exist and if so, whether they are related to local precipitation, river flow, and other weather conditions. In addition, measurements of dissolved oxygen, biological oxygen demand, and identification of organisms, mainly cyanobacteria, were also carried out.

Several approaches could be taken to measurement of total spring discharge. Measuring the flow of each spring is not possible because many exist as seeps without a clearly defined source, and others emerge within the river. The most direct method possible is to measure the rate of flow of the river above and below the area of the springs, with the difference being attributable to the discharge of the springs. Several problems were encountered with this approach. Most of the time, the flow of the river is so much greater than the discharge of the springs that the contribution of the latter to the overall flow cannot be measured with any reliability. Reliable measurements can be made only when the flow of the river is very low, and during the time of this study this condition was met for only a relatively small number of days in late July. Even during this period, the level of the river changed constantly, as a result of diversions upstream by the city of Las Vegas for its municipal water supply, and by individuals for irrigation and stock ponds. This change of the river during flow measurements amplified the uncertainties inherent in the method. A third problem was encountered in locating places suitable for flow measurements. A suitable place was found downstream, but two different sites had to be found upstream -- one for low flow and another for relatively high flow, as neither of these places, nor any other close to the upper level of the hot springs, were suitable for all conditions. The main problem was extreme unevenness of the stream bed caused by scattered rocks and boulders. At the high flow site velocity was too slow to measure at low flow; at the low flow site, the width and path of the flow changed greatly except at low flow. These problems have an impact on all methods of measuring discharge, since all methods require measurements of stream flow above the hot springs. Since measurement of stream flow is a time-consuming task, an attempt was made to relate measurements of rate of flow with depth, or stage of the river, above and below the hot springs. This eventually should allow a rapid measurement of stage to be immediately translated into rate of flow.

Alternative methods of measuring stream flow are indirect and involve treating the system as a dilution problem.[17] The concentration of some substance must be measured in the springs and in the river above and below the springs. If the flow of the river above the springs is known, the discharge of the springs can be calculated according to the following formula:

$$V_s = V_i(C_f - C_i)/(C_s - C_f) \quad (\text{equation 1})$$

where V_s = discharge of the springs

V_i = discharge of river above springs

C_f = concentration of substance in river below springs

C_i = concentration of substance in river above springs

C_s = concentration of substance in springs

The concentrations can be measured by conductivity or in terms of a specific chemical substance. Such a substance should be present in relatively high concentration in the springs and relatively low concentration in the river. Chloride and sodium ions best meet these criteria, but where possible more ions should be used and the calculated results averaged. Chloride and sodium ions have the additional advantage that they are relatively easy to determine by methods accessible to students.

Another analysis worth exploring for educational purposes is the determination of silica (SiO_2). This can be measured colorimetrically and is useful as a geothermometer to estimate the temperature at which the underground water is in equilibrium with the rock.

Procedures

Locations for Measurements and Sampling

Springs sampled are located in Figure 1 by numbers. The following names or descriptions have been used within this report in place of the numbers:

1. Bathhouse spring
6. Central spring, also spring under slab, or concrete slab
9. Seep near road
13. St. Michael's spring

River flow measurement locations are numbered F1-F4 below, and can be described as follows:

F1. about 500 meters up river from the springs; located about 35 meters above the remains of a dam; used for low flow measurements

F2. about 25 meters upriver (west) of the north-south fence line on the left side of figure 1, approaching site 27; noted as F2 in Figure 1; used for high flow measurements

F3. at power house, around bend in river downstream from springs; about 50 meters downstream from site 40 in Figure 1

F4. about 15 meters above the bridge from the United World College to the Montezuma Post Office; about 500 meters downstream from site 40 in Fig. 1

River samples were taken at location F3 (referred to as "river below power house" in analytic data and at "river above spring", which is located about 150 meters above the north-south fence on the left side of Figure 1.

Measurement of Stage

Stage refers to the height of a water surface above a fixed point [18]. It was decided that no permanent measuring device should be installed because of the risk of its being changed by users of the nearby springs. Stage was measured at two points above the springs. At the first point (location F2, above) an aluminum tent stake was driven into the bed of the river. Measurements were taken by hooking the loop of a fiberglass tape over the top of the stake and reading the scale in cm at the surface of the water. At low stage the surface was below the lowest mark on the tape. The point reached by the surface was marked, measured from the zero point, and recorded as a negative value. Attempts to drive a larger and more permanent stake into the river proved fruitless. The small stake served well when the river was low and clear, but was impossible to locate when the river was deeper and muddy, and would be difficult to use in cold weather when entering the river would be necessary.

A second site was located about 50 meters further upriver where the river runs along a concrete wall with gabions above the wall. Measurements

can be taken while standing on the wall, above the river. A two-inch PVC pipe about one meter in length was held vertical at a specified location where the bottom of the river is solid rock. A small amount of powdered cork was poured into the tube, and a meter ruler was lowered until it touched the rock bottom. When the ruler was withdrawn the depth could be read from where the cork adhered to the ruler. These measurements are referred to as gauge readings.

River Flow Measurements

Stream flow was measured with a Swoffer Instruments Model 2100 current velocity meter with a digital readout. Readings were averaged internally at 20-second intervals, and five readings were taken at each location. The meter gave depth measurements which were estimated to 0.01 ft., and velocities were measured at 0.6 of total depth. Distances were measured by stretching a fiberglass measuring tape across the stream and anchoring it at both sides. Distances between half-way points between each measurement, multiplied by depth, gave a cross-sectional area for each measurement. These values, multiplied by the velocities, and summed, gave the discharge in $\text{ft}^3 \text{s}^{-1}$ [19, 20]. Preliminary experiments showed that five readings gave different results from three readings, so the former number was chosen for greater accuracy. Standard procedures for velocity readings recommend that no individual section should contain more than 10% of the total flow, and that 20-30 separate readings be taken [19, 20]. These recommendations were followed for early determinations, but were later modified when it was found that the stage of the river often changed appreciably during the course of one series of measurements, which usually took about one hour. The effect of this change in stage could be reduced by completing the measurements in a shorter time. Data for 8 complete determinations were reanalyzed, using alternate depth and flow measurements. All abbreviated results were within 13% of the original values, and 7 were within 4% of the values (see Table 2, where discharge values are reported as $\text{m}^3 \text{min}^{-1}$). Since these differences were less than the error caused by changes in discharge which usually occurred during the course of a series of measurements, later readings (after July 18) usually involved 8-10 sets of measurements and were usually completed within 30 minutes.

Table 2: Comparison of flow measurements of the Gallinas River using all readings and alternate readings

<u>Date</u>	<u>Location*</u>	<u>Number of readings</u>	<u>Discharge/m³ min⁻¹</u>		<u>Difference/%</u>
			<u>All values</u>	<u>Alternate values</u>	
6/22	F2	18	32.0	28.0	-13
6/23	F2	17	22.1	22.0	- 0.5
6/24	F2	17	19.9	19.9	0
7/8	F1	24	0.408	0.414	1
7/12	F1	17	0.266	0.257	- 3
7/12	F4	20	1.25	1.24	- 0.8
7/18	F2	16	4.94	5.08	3
7/18	F3	14	2.67	2.78	4

* See text for identification of locations

Spring Flow Measurements

Flows from individual springs were measured with a "14 quart" plastic bucket which was calibrated by adding one- or two-dm³ increments of water to the bucket and noting the reading on a scale on the inside of the bucket. The outflow from a spring was collected in the bucket for a specific period of time as measured by a stopwatch. The bucket was placed on a level spot where the volume was read. The bucket was then gently rotated through 180° to get a second reading which was combined with the first to obtain an average. This procedure was used to compensate for the surface being out-of-level. Three readings were usually taken on each occasion. Flow from the "bathhouse spring" emerged from a two-inch iron pipe that protruded several cm above ground level. This spring used to feed the bath house, but the connection was severed several years ago when the building was locked up because of abuse. A flexible connector was used to attach the iron pipe to a short length of PVC pipe which was in turn connected to a right-angled elbow and pipe. This allowed the flow to be collected in the bucket, but in the process the level of water in the reservoir was raised about 20 cm. At "St. Michael's spring" the overflow from the top pool passed through a pipe which allowed easy collection in the bucket. The flow of the "central spring" was occasionally measured in a similar way by collecting the overflow from the lowest bath.

Earliest temperature readings were obtained with a Taylor maximum registering pocket mercury thermometer, with 1°C divisions. Later readings employed a Fluke Model 51 K/J thermometer with K-type bead thermocouple, giving a digital readout to 0.1°C. Readings at two different temperatures were taken with the Fluke thermometer and a calibrated thermocouple thermometer provided by Los Alamos National Laboratory (see Fig. 2). This allowed earlier temperature readings to be corrected. The Fluke thermometer was then adjusted using an offset control to give the same reading as the calibrated thermometer at 48°C. Measurements at different depths in the springs were made with the maximum reading thermometer.

Figure 2: Comparison of temperature readings of Fluke thermometer against calibrated thermometer

pH Measurements

Measurements of pH were made in the field with a Hanna Instruments Checker 1, reading to 0.01 with 0.2 units accuracy. It was standardized against buffers of pH 7 and 10 before its first use, but not at each subsequent use. A later restandardization showed the meter to be reading high, so measurements of pH recorded in the field are unreliable.

Conductivity Measurements

Conductivity was measured in the field by a Fisher portable conductivity meter Model 152, using internal standardization and temperature compensation. Comparison with laboratory values obtained at LANL showed large discrepancies. The instrument was standardized with 0.00500 M KCl prepared by dissolving 0.373 g of KCl in distilled water (specific conductivity = 2 micromho cm^{-1}) and diluting to 1 dm^3 in a volumetric flask. The instrument was standardized to a value of 717 micromho cm^{-1} at a temperature of 24.9°C. (Equivalent conductivity of 0.00500 M KCl = $143.48 \times 10^{-4} \text{ m}^2 \text{ S mol}^{-1} = 717 \text{ micromhos cm}^{-1}$ at 25°C [22].) Appreciable discrepancies were found between raw and unfiltered samples of both river and spring water and between samples at different temperatures as shown in Table 3.

Table 3: Conductivities of several filtered and unfiltered samples measured at different temperatures

<u>Sample location</u>	<u>Conductivity/micromhos cm^{-1}</u>		<u>Temperature/°C</u>
	<u>Unfiltered</u>	<u>Filtered</u>	
River above springs	310	315	24.8
River below powerhouse	570	585	30.2
Bathhouse spring	1000	955	54.4/41.2
Bathhouse spring	855	865	27.6/27.4

These results indicate that internal temperature compensation is unreliable and that samples must be cooled to approximately 25°C before being

measured. The conductivity changes about 2% per degree at 25°C [23]. The source of the difference between filtered and unfiltered water is not obvious, especially in the case of the spring water which is so clear that no visible residue is left on the filter even after more than 500 cm³ of water have been processed. Since filtration is a standard procedure, it is preferable to use that method where feasible.

Laboratory Measurements

Water samples were collected in plastic bottles after filtration through a Gelman Supor-450 membrane filter supported on a Gelman magnetic filter funnel. Reduced pressure was obtained with a Nalgene hand-operated vacuum pump. Two 125 cm³ samples were provided for analysis at Los Alamos National Laboratory (LANL); one of the samples was acidified with 10 drops of 70% nitric acid. For analysis in the United World College (UWC) laboratories, 500 cm³ samples were collected in glass bottles. Two 500 cm³ samples of raw water were collected for tritium analysis.

Analyses performed at LANL on samples taken from the hot springs and river are those described by Trujillo et al. [24]. Analyses undertaken so far in the UWC laboratories have been for chloride and dissolved oxygen. Most chloride analyses used a Hach digital titrator with a 2.256 N Hg(NO₃)₂ cartridge and diphenylcarbazone as indicator. Samples of 100 cm³ were titrated according to instructions provided with the kit [25].

Argentometric titrations were also carried out using procedures recommended in *Standard Methods* [26]. Silver nitrate solution (0.0250 mol dm⁻³) was prepared by dissolving and diluting 0.425 g Fisher ACS certified AgNO₃ with distilled water to 1000 cm³ in a volumetric flask. The solution was stored in a brown bottle. Potassium chromate indicator solution was prepared by dissolving 50 g of K₂CrO₄ (Flinn Scientific, 99.0% minimum) in distilled water, adding AgNO₃ solution until a visible red precipitate was formed, allowing the mixture to stand for 12 hours, filtering, and diluting to 1000 cm³ with distilled water. The titrations were carried out on 50 cm³ samples (or smaller portions diluted to 50 cm³) to which 1 cm³ of indicator solution was added. Instructions recommend that solutions be adjusted to pH = 7-10 before titration. This was not necessary for spring samples, which already were within this range. A visual comparison was made by

adding 1 cm^3 of indicator solution to 50 cm^3 of distilled water. As titrant was added, the solution became cloudy with an almost fluorescent yellow color. The end point was taken when the color became a slightly dull orange. For a blank titration, a microspatula of powdered CaCO_3 was added to the solution, as recommended by Vogel [27], to approximate the appearance of the silver chloride precipitate.

Field Biology

The following information, though not directly tied to flow rates of the springs, does add information concerning the quality of the life in the springs and the river. This quality needs to be maintained if the water is used for any additional purpose.

Determination of dissolved oxygen and biological oxygen demand

Dissolved oxygen (DO) is essential for all aquatic life with the exception of some anaerobes (bacteria) and algae. It is considered a positive indicator for the quality of the water. Much of the DO comes from the atmosphere and through the tumbling/mixing of the water with the atmosphere. There is, however, a daily fluctuation in the amount of DO observed in most fresh water ecosystems due to the additional oxygen released by any photosynthetic organisms during the day. This normally causes the amount of DO to increase from its low point in the early morning hours (5:00 or 6:00 a.m.) to its highest point in the late afternoon (about 12 hours later). The temperature of the water is an additional consideration because cold water can hold more oxygen than warm water. An amount of 4 mg dm^{-3} is considered to be the minimum for most fish and low levels cannot be tolerated by Mayfly nymphs, Stonefly nymphs, Caddisfly larvae or beetle larvae. The first two species are considered indicator species of good quality water and all of these are commonly found in the river at this location. At low levels of DO these species are replaced by other fly larvae, worms, nuisance algae and anaerobic bacteria. Organic waste and other forms of pollution are common depleters of DO since large amounts are used by bacteria during decomposition of these substances.

The amount of DO in the river has been regularly tested in the spring and fall by the Environmental Systems class of the UWC, but not during the summer. With the exception of 1992, when a dam above the hot springs was

breached and the outflow of silt smothered virtually all the organisms in this stretch of the river, the DO in the river has been far above any danger point (8 to 9 mg dm⁻³). The hot springs have not been routinely tested. The presence of DO in the hot springs is of concern, not because of any large organisms living there, but because anaerobic conditions and the algae and bacteria that would live in them would give the water and the area an unpleasant odor and appearance.

A preliminary check of the DO in the river above and below the hot springs and in one of the baths (immediately east of #3, Figure 1) was carried out on July 19, 1994. This was done between 8:00 and 9:30 a.m. and again between 4:00 and 5:30 p.m. using a small LaMotte test kit. Two samples were tested at each of two river sites (F2 and F3); one from the flowing portion of the river and one from a relatively slow moving area. Later determinations were performed with an oxygen electrode (Orion Model 97-08) connected to a digital pH meter (Orion Model 221). At this time an additional sample was taken from the river about halfway through the hot springs discharge area (below #19, Figure 1).

Water samples collected on July 19 from the same sites as used for DO were tested for total Coliform and *E. coli*. Samples of 100 cm³ from each site were filtered and incubated on the appropriate media (MFC and Endo) for 24 hours.

Plant and algae species

On July 20 and during the following month collections of algae and plants were made to determine the common species found in the river and in the hot springs.

RESULTS

Stage Measurements

In Table 4 are shown all data concerning river stage measurements at two points above the springs: location F2 and the gauge. Figure 3 shows points where measurements were taken at both locations; this allows measurements at location F2, which can be taken quickly, to be converted to measurements at the gauge, which can be used for long-term measurements.

Measurements at the two points could not be taken simultaneously, but were separated by two to ten minutes. On July 21 a number of flow and stage measurements were made, including times when the stage changed as much as 0.1 cm per minute. A plot of these measurements at location F2 is given in Figure 4. From this graph are taken values for readings at location F2 corresponding to the times when readings were taken at the gauge. These interpolated values are included in column 6 of Table 4 as corrected readings and used as points in Figure 3.

Table 4: Stage measurements of Gallinas River at location F2 and the gauge.

Date	Location F2			Gauge	
	Time/hr:min	Reading/cm	Corrected ¹ /cm	Time/hr:min	Reading/cm
6/24/94	12:00	9.9			
	13:30	10.0			
6/27/94	15:00	11.4			
	16:30	6.2			
6/28/94	11:40	-2.8			
7/1/94	11:15	-4.9	-4.9	11:15	19.7
	15:00	-4.9	-4.9	15:10	19.5
7/9/94	10:00	-5.7	-5.7	10:10	18.7
	12:20	-6.0	-6.0	12:15	18.3
7/11/94		-5.2			
7/12/94	09:15	-6.7	-6.7	09:30	17.8
				11:20	17.6
	16:40	-7.3			
7/13/94	16:45	-4.2			
7/18/94	13:10	3.8			
	14:15	-0.4			
7/19/94	09:55	-4.8			
	14:50	-5.6			
	16:00	-5.6			
	17:15	-5.6			
	18:15	-5.6			
	19:05	-5.7			
7/21/94	09:25	9.0	9.3	09:16	37.4
	10:01	7.8			
	10:32	6.8			
	10:39	6.7			
	11:12	6.2			
	12:50	5.2	5.0	12:55	31.5
	13:00	4.8			
	13:40	4.4			

Table 4. Stage measurements of Gallinas River at location F2 and the gauge.

Date	Location F2			Gauge	
	Time/hr:min	Reading/cm	Corrected ¹ /cm	Time/hr:min	Reading/cm
6/24/94	12:00	9.9			
	13:30	10.0			
6/27/94	15:00	11.4			
	16:30	6.2			
6/28/94	11:40	-2.8			
7/1/94	11:15	-4.9	-4.9	11:15	19.7
	15:00	-4.9	-4.9	15:10	19.5
7/9/94	10:00	-5.7	-5.7	10:10	18.7
	12:20	-6.0	-6.0	12:15	18.3
7/11/94		-5.2			
7/12/94	09:15	-6.7	-6.7	09:30	17.8
				11:20	17.6
	16:40	-7.3			
7/13/94	16:45	-4.2			
7/18/94	13:10	3.8			
	14:15	-0.4			
7/19/94	09:55	-4.8			
	14:50	-5.6			
	16:00	-5.6			
	17:15	-5.6			
	18:15	-5.6			
	19:05	-5.7			
7/21/94	09:25	9.0	9.3	09:16	37.4
	10:01	7.8			
	10:32	6.8			
	10:39	6.7			
	11:12	6.2			
	12:50	5.2	5.0	12:55	31.5
	13:00	4.8			
	13:40	4.4			

Table 4, continued

<u>Date</u>	<u>Location F2</u>			<u>Gauge</u>	
	<u>Time/hr:min</u>	<u>Reading/cm</u>	<u>Corrected¹/cm</u>	<u>Time/hr:min</u>	<u>Reading/cm</u>
7/21/94	13:50	2.8	2.9	13:48	28.9
	15:00	-2.4	-2.9	15:05	22.3
7/25/94	13:55	-5.0	-5.0	14:00	18.9
7/26/94	09:30	8.3			
	10:04	8.1	8.1	09:58	35.7
	10:41	7.8	7.8	10:49	35.2
	10:52	7.8			
7/31/94	08:25	15.0			
	11:25	4.8			
	11:54	4.7			
	12:01	4.6	4.6	11:59	30.8
	12:40	4.3	4.3	12:46	30.5
	13:58	4.2	4.2	13:53	30.4
8/1/94	09:05	6.0			
	12:02	4.2			
	16:25	3.2			
8/5/94	14:30	13.7			
	14:45	13.0			
8/8/94	15:13	8.7			
8/9/94	09:15	8.2			
	14:45	7.8			
8/11/94	09:37	7.3			
	14:15	6.6	6.6	14:10	33.8

(¹) For each reading at the gauge, a "corrected" value at location F2 is given. This corrected value is either a reading taken at approximately the same time at location F2, or a value interpolated from Figure 4 to correspond to the same time as the gauge reading.

Figure 3: Plot of corrected stage readings at location F2 against gauge readings

Figure 4: Plot of stage readings at location F2 on July 21, 1994

River Flow Measurements

Data for all flow measurements are given in Table 5, grouped according to the location where the measurements were made, and arranged in chronological order within each group. The stage is that measured at the gauge, and the discharge, calculated according to equation 1, is reported as $\text{m}^3 \text{min}^{-1}$. The cross-sectional areas are summed for each set of measurements and reported as Area. The product of Area and Average velocity (column 7) provides another measure of discharge, which is given in column 8. To avoid distortion of the average velocity values, data for sections contributing less than 1% to the total flow are omitted from the calculations in column 6. In column 9, column 7 is divided by column 4 to compare these two measures of discharge. Graphs of discharge (column 4) vs. stage are given for each of the three main measurement locations in

Figures 5-7. The data show good fit to second-order, or parabolic, relationships. Results for the two sites above the springs (locations F1 and F2) in Table 5 might have been combined, but there is insufficient overlap in the data to give confidence that they belong to a single set. As a test of possible errors in the discharge data, cross-sectional areas and average velocities are plotted against stage at each location (Figures 8 -13), and like discharge measures, should fall on smooth second-order curves.

Several data were collected at sites F1 and F3 in 1995 in hopes of obtaining more reliable curves. The second measurement at F1 in 1995 was taken about eight meters upstream from the location where other measurements were taken, to check for consistency. Combining data from different years involves the risk that the stream bed may have changed, giving a different relationship between stage and discharge. The new data from F1 were included in the graphs because a reasonable curve falls close to all points. Data for F3 from 1995 were excluded because their internal consistency (column 7 divided by column 4) is relatively low.

Table 5 River stage and discharge measurements at three locations on the Gallinas River

Location	Date	Stage/cm	Discharge		Area(A)/m ²	Ave(V)/m min ⁻¹	A x V/m ³ min ⁻¹	Col 7/Col 4
			m ³ min ⁻¹					
F1	7/9/94	18.5	0.408	0.151	2.7	0.41	1.00	
F1	7/12/94	17.7	0.266	0.105	2.6	0.27	1.02	
F1	7/19/94	18.8	0.443	0.130	3.5	0.45	1.02	
F1	7/31/94	30.5	8.53	0.625	15	9.4	1.10	
F1	7/23/95	22.7	2.27	0.296	7.7	2.28	1.03	
F1	7/23/95	22.8	2.16	0.494	4.2	2.08	0.96	
F2	6/22/94		32.0	1.81	17	31	0.97	
F2	6/23/94		22.1	1.57	14	22	1.00	
F2	6/24/94	38.4	19.85	1.557	13	20	1.01	
F2	7/18/94	27.3	4.94	0.9544	4.9	4.7	0.95	
F2	7/21/94	36.1	15.7	1.38	11	15	0.96	
F2	7/21/94	33.5	10.9	1.32	7.9	10.4	0.95	
F2	7/21/94	30.2	7.34	1.31	4.9	6.4	0.87	
F2	7/26/94	35.45	13.2	1.333	9.5	13	0.98	
F2	7/31/94	30.65	6.78	1.190	5.5	6.5	0.96	
F3	7/18/94	8.0	2.67	0.372	7.1	2.6	0.97	
F3	7/19/94	4.0	0.763	0.172	4.2	0.72	0.94	
F3	7/21/94	11.3	4.20	0.447	8.6	3.8	0.90	
F3	7/26/94	17.8	12.2	1.193	9.7	11.6	0.95	
F3	8/1/94	14.6	7.35	0.814	8.4	6.8	0.93	
F3	7/28/95	7.6	2.97	0.310	7.4	2.3	0.76	
F3	7/28/95	6.8	2.16	0.290	6.6	1.91	0.88	

Note: Stage readings related to flow measurements at location F3 were taken at that location; all other stage readings refer to gauge measurements.

Figure 5: Plot of river discharge vs stage at location F1, above springs (low flow)

Figure 6: Plot of river discharge vs stage at location F2, above springs (high flow)

Figure 7: Plot of river discharge vs stage at location F3 (powerhouse, below springs)

Figure 8: Plot of cross-sectional area of river vs stage at location F1, above springs (low flow)

Figure 9: Plot of average velocity of river flow vs stage at location F1, above springs (low flow)

Figure 10: Plot of cross-sectional area of river vs stage at location F2, above springs (high flow)

Figure 11: Plot of average velocity of river flow vs stage at location F2, above springs (high flow)

Figure 12: Plot of cross-sectional area of river vs stage at location F3 (below springs)

Figure 13: Plot of average velocity of river flow vs stage at location F3 (below springs)

Spring Flow Measurements

Measurements of flow and temperature were taken for the bathhouse spring (#1 in Figure 1) and for St. Michael's spring (#13 in Figure 1) from 7/1/94 to 6/2/95. Air temperatures and atmospheric pressures were measured from 10/94. These data are recorded in Table 6. Flow and temperature readings were taken also for the central spring (#6 in Figure 1) on several occasions. The flow ranged from 14.2 to $16.3 \text{ dm}^3 \text{ min}^{-1}$ and the temperature from 53.7 to 55.5°C . Discharges and temperatures for the bathhouse and St. Michael's spring are plotted against time in Figures 14 and 15. Figure 16 compares the flow of the bathhouse spring with atmospheric pressure and Figure 17 compares the temperature of the spring with the temperature of the air.

Table 6: Discharge and temperature readings for various springs

Date	Time/hr	Bath House Spring		St. Michael's Spring		Air Temp/°C	Press./mm Hg
		Flow/dm ³ min ⁻¹	Temp/°C	Flow/dm ³ min ⁻¹	Temp/°C		
7/1/94	19	40.2					
7/5/94	10			14.0			
	12	39.1		14.0			
7/9/94	10			14.0			
	14	41.8	54.4	14.4			
7/12/94	13	40.6	54.5	14.0			
7/13/94	16		54.0				
7/19/94	14	39.9		11.8			
	20		54.3				
7/25/94	13			13.7			
	17	41.4					
7/29/94	12			15.2			
	18	43.3					
7/30/94	11	43.7	54.0	14.8	47.6		
7/31/94	18			14.4	47.7		
	21	43.7	54.3				
8/1/94	12	43.3	54.0	14.8	47.6		
8/3/94	12			15.2	48.0		
	14	44.8	54.3				
8/4/94	14	44.8	54.3				
8/5/94	10			14.8	47.5		
	11	39.5	54.1				
	16	44.8	54.3				
8/6/94	11	44.8	54.0				
8/9/94	09	44.0	54.4				
8/11/94	10			14.4	47.9		
8/12/94	11	47.5	54.3	14.8	47.7		
	17	44.0	54.1	15.2	48.7		
8/13/94	17	43.7	54.6				
8/14/94	09	43.7	54.5				
	16	44.0	54.9	11.8	48.4		
8/15/94	08	44.0	54.7				
	16	44.4	54.6				
8/16/94	08	44.0	54.6	13.3	47.4		
	18	44.0	54.6	13.7	48.6		
8/17/94	16	44.0	54.4	13.3	48.4		
8/18/94	17	43.7	54.3		48.1		
8/19/94	08	43.7	54.5	13.7	47.2		
8/20/94	20	43.7	54.7	14.4	48.0		
8/21/94	09	43.7	54.7	14.8	47.7		
8/22/94	20	47.8	54.7	14.4	47.9		
8/25/94	18	43.7	54.7		47.9		
8/26/94	08			14.8	47.3		
9/1/94	18	44.8	54.5	15.6	48.1		
9/4/94	10	45.2	54.6	15.6	47.9		
9/7/94	10		54.1	15.7	47.6		
9/11/94	04	45.2	54.1	13.5	48.3		

Table 6: Continued

Date	Time/hr	Bath House Spring		St. Michael's Spring		Air Temp/ $^{\circ}\text{C}$	Press./mm Hg
		Flow/ $\text{dm}^3 \text{ min}^{-1}$	Temp/ $^{\circ}\text{C}$	Flow/ $\text{dm}^3 \text{ min}^{-1}$	Temp/ $^{\circ}\text{C}$		
9/14/94	09	45.5	54.7	14.5	47.8		
	18				47.6		
9/18/94	14	43.9	54.4	14.6	47.8		
9/21/94	19	64.0	54.7	14.7	48.1	15.5	
9/22/94	18	46.4	55.0			12.0	
9/24/94	10	45.6	54.1	14.7	47.3	20.5	
9/29/94	18	45.3	54.5	14.8	47.9	24.5	
10/3/94	09	44.6	54.4	14.7		12.9	
10/8/94	09	45.6	54.4	14.9	47.4	08.5	
10/12/94	10	45.0	54.0	13.9	46.9	16.7	
10/22/94	12	46.0	53.4	14.9	46.7	17.7	
10/23/94	18	46.0	54.4	15.0	47.2	16.5	571
10/29/94	10	45.6	53.9	14.9	45.9	10.0	
	17	45.2	54.5	08.1	47.3	09.3	570
10/30/94	08	44.8	54.2	09.4	47.2	08.6	570
	14			10.0	47.2	18.8	567
	17	44.8	54.3	10.0	46.9	14.9	567
10/31/94	09			10.6	46.2	09.2	572
	17	45.2	54.6	11.4	47.3	11.1	570
11/1/94	09			11.5	46.0	19.5	569
	16			11.8	47.1	20.1	
11/2/94	09	44.6	54.0	12.1	46.5	19.1	564
	17			12.9	46.9	13.2	564
11/3/94	08			13.5	47.2	11.1	565
	17	45.0	54.7	13.6	47.1	08.7	563
11/4/94	14			13.5	47.1	14.9	564
11/5/94	08	45.6	54.1	13.9	46.4	04.3	567
11/10/94	16	46.2	54.4	10.7	47.0	13.3	569
11/12/94	13	47.4	54.4	13.8	47.3	11.6	565
11/13/94	09	46.8	54.2			08.5	566
11/14/94	09	46.2	54.1			04.0	572
	15			14.6	46.7	07.0	
11/16/94	09	46.0	54.1			11.1	569
11/23/94	10	45.6	54.2			08.7	577
11/24/94	13	45.8	54.2			18.2	570
11/26/94	15	44.0	54.3	14.7	46.3	11.7	560
11/30/94	13	45.6	53.9			17.7	572
12/3/94	11			14.4	45.6	13.1	569
	12	44.6	54.2			17.3	568
12/9/94	15	44.8	54.4			03.2	568
12/16/94	12	44.2	54.2			14.1	571
12/19/94	13	44.6	54.2			16.0	567
12/27/94	16	44.8	54.3			04.4	569
1/2/95	16	44.4	54.4	14.9	45.5	06.4	567
1/11/95	09	44.6	54.3			11.3	567
1/15/95	10	44.6	54.1			15.1	567
1/29/95	14	43.6	54.2			13.0	570

Table 6: Continued

Date	Time/hr	Bath House Spring		St. Michael's Spring		Air Temp/°C	Press./mm Hg
		Flow/dm ³ min ⁻¹	Temp/°C	Flow/dm ³ min ⁻¹	Temp/°C		
2/5/95	15	44.2	54.2			15.3	572
2/12/95	17	43.8	54.3	14.6	45.9	06.0	562
2/22/95	10	44.8	54.1			20.0	570
3/5/95	18	42.6	54.4			12.0	563
3/16/95	13	45.2	54.4			21.2	573
3/24/95	15	44.6	54.6			18.1	562
3/29/95	09	45.2	54.5	14.7	45.8	03.5	569
4/16/95	15	44.8	53.8			21.4	566
4/29/95	20	45.6	54.4			13.5	568
5/3/95	09	45.4	54.0			22.1	565
5/14/95	19	43.0	55.0			20.8	563
5/21/95	19	43.0	54.9			23.0	569
6/2/95	16	42.2	54.2			26.7	567

Figure 14 Plot of flow from two springs from 7/1/94 to 6/2/95

Figure 15: Plot of temperatures of two springs from 7/9/94 to 6/2/95

Figure 16: Plot of bathhouse spring flow vs atmospheric pressure

Figure 17: Plot of bathhouse temperature vs air temperature

In June, 1995, sensors to measure temperature and flow were installed at the outlet of the bathhouse spring by Sandia National Laboratories. These were intended to provide a continuous record of data that previously had been collected only intermittently. A record of these data, as provided by Sandia Laboratories, is given in Figures 18 and 19.

Figure 18: Plot of bathhouse spring flow rate (UWC and Sandia data)

Figure 19: Plot of bathhouse spring temperature (UWC and Sandia data)

Chemical and Physical Analyses

A number of samples from springs, seeps, and different river locations were collected and analyzed at Los Alamos National Laboratory. The results of these analyses are given in Table 7. Three samples from springs were collected in the summer of 1993. These analyses are given in Table 8 [11]. Measurements of pH were recorded in the field and in the laboratory (indicated as F and L in the tables). The field measurements are not reliable in many cases because the pH meter used was not calibrated before each use, and was found to be in serious error on one occasion. Two samples were taken at the bath house spring to compare the effect of filtering or not filtering on analyses that might be done in school laboratories, especially determination of Na^+ , Cl^- , F^- , SiO_2 , CO_3^{2-} , HCO_3^- , conductivity, and pH (samples UWC94-34 (filtered) and UWC94 34R (unfiltered)). Samples UWC94-35 and UWC94-36 were prepared as standards for analysis of chloride and fluoride, respectively, with concentrations being checked by analysis at LANL. In Tables 7 and 8 are calculated ratios of several pairs of elements. These are considered better indications of a common source than are values for individual ions [29]. The last columns are calculated temperatures for several geothermometers. The list below identifies the geothermometers according to the notation used in Tables 7 and 8.

tQC	Quartz, conductive (no steam loss)
tQA	Quartz, adiabatic (maximum steam loss)
tNK(F)	Sodium-potassium (Fournier)
tNK(T)	Sodium-potassium (Truesdell)
tNKC13	Sodium-potassium-calcium; $t > 100^\circ\text{C}$
tNKC43	Sodium-potassium-calcium; $t < 100^\circ\text{C}$
tAM	Amorphous silica
tCH	Chalcedony
tNL(d)	Sodium-lithium; $[\text{Cl}] < 10\,000\text{ ppm}$
tNL(c)	Sodium-lithium; $[\text{Cl}] > 10\,000\text{ ppm}$
tL(d)	Lithium; $[\text{Cl}] < 10\,000\text{ ppm}$
tL(c)	Lithium; $[\text{Cl}] > 10\,000\text{ ppm}$
tML	Magnesium-lithium
tKM	Potassium-magnesium
lcn	a term appearing in the sodium-potassium-calcium geothermometer equation

Table 7: Chemical analyses of spring and river samples, 1994
NORTHERN NEW MEXICO THERMAL WATERS

SAMPLE #	DESCRIPTION	DATE	TEMP	Ag	Al Std.D.	As	B Std.D.	Ba Std.D.	
		MM/DD/YY	-C	ppm	ppm +/-	ppm	ppm +/-	ppm +/-	
UNC94-1	Main Bath House	06/22/94	54.5	0.0011	0.24 0.02	0.0023	0.51 0.01	0.01 0.01	
UNC94-2	Concrete Slab	06/22/94	54.0	0.0005	0.22 0.01	0.0025	0.51 0.01	0.01	
UNC94-3	Seep below Hwy. by survey marker	06/22/94	42.0	0.0005	0.18 0.01	0.0031	0.51 0.01	0.02 0.01	
UNC94-4	River above Spring	06/22/94	21	0.0005	0.14 0.02	0.0002	0.01	0.04 0.01	
UNC94-5	River below Power House	06/22/94	22	0.0005	0.14 0.02	0.0003	0.02 0.01	0.03 0.01	
UNC94-14	River below Power House	07/01/94	27	0.0005	0.14 0.01	0.0012	0.18 0.01	0.04 0.01	
UNC94-15	River above Spring	07/01/94	22	0.0005	0.17 0.02	0.0008	0.02 0.01	0.05 0.01	
UNC94-16	Bath House Spring	07/01/94	54	0.0005	0.05 0.01	0.0025	0.50 0.01	0.01 0.01	
UNC94-17	Spring under slab	07/01/94	54	0.0005	0.03 0.01	0.0026	0.53 0.01	0.01 0.01	
UNC94-18	Seep near Road	07/01/94	42	0.0005	0.02	0.0034	0.53 0.01	0.02 0.01	
UNC94-25	Bath House Spring	07/13/94	53	0.0005	0.02	0.0027	0.51 0.01	0.01 0.01	
UNC94-26	Seep near Road	07/13/94	41.2	0.0005	0.02	0.0031	0.53 0.01	0.02 0.01	
UNC94-27	Spring under slab	07/13/94	52.7	0.0005	0.02	0.0028	0.53 0.01	0.01 0.01	
UNC94-28	River above Spring	07/13/94	22.2	0.0005	0.18 0.01	0.0003	0.02 0.01	0.04 0.01	
UNC94-29	River below Power House	07/13/94	25.4	0.0005	0.12 0.03	0.0008	0.11 0.01	0.03 0.01	
UNC94-30	River above causeway	07/13/94	23.5	0.0005	0.15 0.02	0.0009	0.10 0.01	0.04 0.01	
UNC94-31	River Above Springs	07/19/94	23.6	---	0.14 0.03	0.0008	0.02 0.01	0.05 0.01	
UNC94-32	River Below Power House	07/19/94	29.0	---	0.08 0.02	0.0012	0.21 0.01	0.04 0.01	
UNC94-33	Bath House Spring	07/19/94	53.2	---	0.03 0.01	0.0029	0.49 0.01	0.02 0.01	
UNC94-34	Bath House Spring, FU	08/05/94	53.2	---	0.02	---	---	0.01 0.01	
UNC94-34R	Bath House Spring, Raw	08/05/94	53.2	---	0.03 0.01	---	---	0.01 0.01	
UNC94-35	Na and Cl only	08/08/94	---	---	---	---	---	---	
UNC94-36	Na and F only	08/08/94	---	---	---	---	---	---	

SAMPLE #	Br	Ca Std.D.	Cd	Cl	Co	CO3 Cond. (L)	Cr Std.D.	Cs Std.D.	Cu Std.D.	F
	ppm	ppm +/-	ppm	ppm	ppm	ppm umho/cm	ppm +/-	ppm +/-	ppm +/-	ppm
UNC94-1	0.79	2.05 0.12	0.0005	157	0.002	40.6 878	0.002	0.067 0.002	0.005 0.002	21.5
UNC94-2	0.74	1.96 0.10	0.0005	154	0.002	20.6 870	0.07 0.01	0.066 0.002	0.005 0.002	21.8
UNC94-3	0.73	2.53 0.13	0.0005	152	0.002	18.4 869	0.002	0.060 0.002	0.002	21.3
UNC94-4	0.02	38.6 0.9	0.0005	1.55	0.002	7.7 212	0.002	0.004 0.002	0.002	0.22
UNC94-5	0.06	36.9 0.9	0.0005	3.82	0.002	8.3 221	0.002	0.002	0.002	0.48
UNC94-14	0.30	39.7 0.4	0.0005	52.4	0.002	11.4 492	0.002	0.012 0.002	0.002	6.28
UNC94-15	0.04	54.1 1.1	0.0005	7.32	0.002	10.1 312	0.002	0.002	0.002	0.47
UNC94-16	0.75	4.02 0.08	0.0005	150	0.002	17.6 862	0.002	0.068 0.002	0.002	20.2
UNC94-17	0.70	3.53 0.04	0.0005	150	0.002	19.1 860	0.002	0.068 0.002	0.002	20.5
UNC94-18	0.74	4.55 0.08	0.0005	150	0.002	16.6 865	0.002 0.002	0.077 0.002	0.002	20.5
UNC94-25	0.78	4.26 0.02	0.0005	150	0.002	17.9 860	0.002	0.068 0.002	0.002	20.3
UNC94-26	0.67	4.63 0.09	0.0005	147	0.002	17.2 862	0.002	0.071 0.002	0.002 0.002	20.0
UNC94-27	0.78	3.78 0.05	0.0005	150	0.002	18.4 831	0.002	0.068 0.002	0.002	20.2
UNC94-28	0.02	54.6 0.6	0.0005	4.91	0.002	11.5 307	0.002	0.002	0.002 0.002	0.37
UNC94-29	0.17	44.4 0.7	0.0005	35.8	0.002	12.5 420	0.002	0.013 0.002	0.002	4.22
UNC94-30	0.17	52.6 0.1	0.0005	32.5	0.002	12.6 437	0.002	0.012 0.002	0.002	3.68
UNC94-31	0.02	39.7 0.4	---	9.46	---	9.8 312	---	---	---	0.63
UNC94-32	0.32	28.1 0.9	---	65.7	---	9.3 555	---	---	---	8.60
UNC94-33	0.76	3.29 0.05	---	155	---	17.0 873	---	---	---	21.3
UNC94-34	0.78	3.25 0.03	---	156	---	18.6 875	---	---	---	21.5
UNC94-34R	0.78	3.45 0.10	---	157	---	19.3 873	---	---	---	21.1
UNC94-35	---	---	---	34.9	---	---	---	---	---	---
UNC94-36	---	---	---	---	---	---	---	---	---	---

Table 7, continued

SAMPLE #	Fe Std.D.		HCO ₃	Hg	I	K Std.D.		Li Std.D.		Mg Std.D.		Mn Std.D.		Mo Std.D.	
	ppm	+/-		ppm	ppm	ppm	+/-	ppm	+/-	ppm	+/-	ppm	+/-	ppm	+/-
UMC94-1	0.01		37.0	0.0002	0.01	5.60	0.02	0.26	0.01	0.07	0.01	0.01		0.005	0.002
UMC94-2	0.10	0.01	57.1	0.0002	0.01	5.52	0.01	0.25	0.01	0.03	0.01	0.02	0.01	0.004	0.002
UMC94-3	0.01		66.0	0.0002	0.01	5.55	0.04	0.27	0.01	0.09	0.01	0.01		0.005	0.002
UMC94-4	0.02	0.01	111	0.0002	0.01	0.69	0.01	0.01		2.75	0.04	0.02	0.01	0.002	0.002
UMC94-5	0.02	0.01	101	0.0002	0.01	0.79	0.02	0.01	0.01	2.62	0.04	0.02	0.01	0.002	
UMC94-14	0.02	0.01	127	0.0002	0.01	2.67	0.01	0.12	0.01	2.63	0.06	0.02	0.01	0.006	0.002
UMC94-15	0.01		146	0.0002	0.01	1.08	0.01	0.01	0.01	3.63	0.07	0.05	0.01	0.002	0.002
UMC94-16	0.01		61.3	0.0002	0.01	6.03	0.02	0.37	0.01	0.05	0.01	0.01		0.007	0.002
UMC94-17	0.02	0.01	59.6	0.0002	0.01	6.15	0.02	0.36	0.01	0.07	0.01	0.01		0.007	0.002
UMC94-18	0.01	0.01	69.4	0.0002	0.01	6.22	0.03	0.33	0.02	0.12	0.01	0.01	0.01	0.007	0.002
UMC94-25	0.01		61.1	0.0002	0.01	6.09	0.03	0.35	0.02	0.06	0.01	0.01		0.007	0.002
UMC94-26	0.01		68.9	0.0002	0.01	6.23	0.02	0.34	0.01	0.10	0.01	0.01		0.007	0.002
UMC94-27	0.02	0.01	60.3	0.0002	0.01	6.09	0.04	0.35	0.02	0.03	0.01	0.01		0.007	0.002
UMC94-28	0.01	0.01	149	0.0002	0.01	1.13	0.01	0.01	0.01	4.06	0.02	0.03	0.01	0.002	0.002
UMC94-29	0.01	0.01	134	0.0002	0.01	2.12	0.01	0.07	0.02	3.30	0.03	0.02	0.01	0.004	0.002
UMC94-30	0.01	0.01	145	0.0002	0.01	2.09	0.01	0.07	0.01	3.81	0.12	0.01	0.01	0.004	0.002
UMC94-31	0.01		136	0.0002	---	1.31	0.01	0.02	0.01	3.41	0.03	0.01	0.01	---	---
UMC94-32	0.01	0.01	127	0.0002	---	3.31	0.01	0.21	0.01	2.27	0.02	0.01	0.01	---	---
UMC94-33	0.01		62.0	0.0002	---	6.11	0.02	0.46	0.01	0.05	0.01	0.01		---	---
UMC94-34	0.01	---	59.3	---	---	6.08	0.04	0.42	0.01	0.05	0.01	0.01	---	---	---
UMC94-34R	0.01	---	57.9	---	---	---	---	0.39	0.01	0.04	0.01	0.01	---	---	---
UMC94-35	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
UMC94-36	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

SAMPLE #	Na Std.D.		NH ₄	Ni Std.D.		NO ₂	NO ₃	Pb Std.D.		pH (F)	pH (L)	PO ₄	Rb Std.D.		Sb
	ppm	+/-		ppm	+/-		ppm	ppm	+/-				ppm	+/-	
UMC94-1	187	7	0.07	0.002		0.02	0.02	0.002	0.002	8.96	9.27	0.05	0.081	0.002	0.0002
UMC94-2	174	3	0.04	0.045	0.002	0.02	0.02	0.002		9.07	9.03	0.05	0.078	0.002	0.0002
UMC94-3	177	3	0.07	0.045	0.002	0.02	0.02	0.002		9.09	8.97	0.05	0.084	0.002	0.0002
UMC94-4	2.93	0.03	0.10	0.002		0.02	0.02	0.002		8.82	8.06	0.05	0.002		0.0002
UMC94-5	5.81	0.02	0.07	0.002		0.02	0.02	0.002		8.80	8.15	0.05	0.002	0.002	0.0002
UMC94-14	57.9	0.2	0.09	0.002		0.02	0.02	0.002		9.45	8.55	0.05	0.026	0.002	0.0002
UMC94-15	8.30	0.08	0.08	0.002		0.02	0.02	0.002		9.35	8.28	0.05	0.002		0.0002
UMC94-16	167	2	0.07	0.002		0.02	0.02	0.011	0.002	9.51	8.96	0.05	0.081	0.002	0.0002
UMC94-17	166	2	0.05	0.002		0.02	0.03	0.002		9.61	8.99	0.05	0.081	0.002	0.0002
UMC94-18	168	1	0.06	0.002		0.02	0.08	0.002		9.55	8.90	0.05	0.082	0.002	0.0002
UMC94-25	168	3	0.05	0.002		0.02	0.02	0.002		9.66	8.95	0.05	0.082	0.002	0.0002
UMC94-26	166	1	0.06	0.002		0.02	0.05	0.014	0.002	9.70	8.93	0.05	0.080	0.002	0.0002
UMC94-27	174	1	0.05	0.002		0.02	0.02	0.002	0.002	9.70	8.98	0.05	0.082	0.002	0.0002
UMC94-28	6.71	0.04	0.05	0.002		0.02	0.02	0.002		9.26	8.52	0.05	0.002	0.002	0.0002
UMC94-29	38.7	0.5	0.05	0.002		0.02	0.02	0.002		9.42	8.63	0.05	0.019	0.002	0.0002
UMC94-30	36.8	0.7	0.27	0.002		0.02	0.07	0.002		9.41	8.62	0.05	0.017	0.002	0.0002
UMC94-31	10.1	0.1	---	---	---	0.02	0.02	---	---	8.69	8.41	0.05	---	---	0.0002
UMC94-32	88.6	0.5	---	---	---	0.02	0.02	---	---	8.86	8.41	0.05	---	---	0.0002
UMC94-33	185	4	---	---	---	0.02	0.02	---	---	9.11	8.90	0.05	---	---	0.0002
UMC94-34	177	3	---	---	---	0.02	0.02	---	---	---	8.96	0.05	---	---	---
UMC94-34R	166	8	---	---	---	0.02	0.24	---	---	---	9.02	0.05	---	---	---
UMC94-35	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
UMC94-36	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 7, continued

SAMPLE #	Se ppm	Si ppm	Std.D. +/-	SiO2 Calc	SO4 ppm	S2O3 ppm	Sr ppm	Std.D. +/-	Zn ppm	Std.D. +/-	TDS ppm	Cation Sum	Anion Sum	Balance
UMC94-1	(0.0002	32.2	0.4	68.9	41.2	(0.01	0.13	0.01	0.01	0.01	563.1	8.454	9.403	0.0061
UMC94-2	(0.0002	31.2	0.3	66.8	40.5	(0.01	0.11	0.01	(0.01		544.5	7.879	7.983	-0.0131
UMC94-3	(0.0002	30.8	0.2	65.9	40.1	(0.01	0.10	0.01	(0.01		551.0	8.038	7.964	0.0091
UMC94-4	(0.0002	4.73	0.05	10.1	9.98	(0.01	0.13	0.01	0.01	0.01	186.0	2.324	2.339	-0.0066
UMC94-5	(0.0002	4.95	0.09	10.6	10.7	(0.01	0.13	0.01	(0.01		181.5	2.356	2.290	0.0284
UMC94-14	(0.0002	13.2	0.1	28.2	26.7	(0.01	0.16	0.01	(0.01		356.0	4.827	4.836	-0.0019
UMC94-15	(0.0002	5.63	0.01	12.0	15.4	(0.01	0.18	0.01	(0.01		259.1	3.418	3.283	0.0402
UMC94-16	(0.0002	33.1	0.1	70.8	39.1	(0.01	0.12	0.01	(0.01		538.2	7.687	7.726	-0.0051
UMC94-17	(0.0002	32.5	0.7	69.6	39.2	(0.01	0.11	0.01	(0.01		535.7	7.619	7.767	-0.0192
UMC94-18	(0.0002	30.8	0.9	65.9	38.5	(0.01	0.10	0.01	0.01	0.01	541.9	7.756	7.831	-0.0096
UMC94-25	(0.0002	32.6	1.5	69.8	38.8	(0.01	0.12	0.01	0.01	0.01	538.3	7.735	7.732	0.0004
UMC94-26	(0.0002	31.0	0.9	66.3	36.9	(0.01	0.10	0.01	(0.01		535.3	7.672	7.697	-0.0033
UMC94-27	(0.0002	32.6	0.7	69.8	38.5	(0.01	0.11	0.01	(0.01		543.1	7.970	7.725	0.0312
UMC94-28	(0.0002	5.30	0.01	11.3	13.6	(0.01	0.17	0.01	(0.01		257.7	3.409	3.267	0.0424
UMC94-29	(0.0002	10.1	0.1	21.6	20.7	(0.01	0.16	0.01	(0.01		318.2	4.255	4.282	-0.0063
UMC94-30	(0.0002	9.24	0.03	19.8	27.6	(0.01	0.20	0.01	0.02	0.01	337.6	4.640	4.488	0.0332
UMC94-31	(0.0002	4.30	0.04	9.2	18.9	---	0.15	0.01	(0.01		238.9	2.757	3.250	-0.1642
UMC94-32	(0.0002	14.9	0.1	31.9	28.9	---	0.15	0.01	(0.01		394.7	5.570	5.310	0.0477
UMC94-33	(0.0002	32.6	0.7	69.8	40.5	---	0.14	0.01	(0.01		561.9	8.441	7.944	0.0606
UMC94-34	---	33.8	0.4	72.3	41.2	---	0.13	0.01	(0.01		556.7	8.081	7.984	0.0120
UMC94-34R	---	32.4	0.2	69.3	40.7	---	0.13	0.01	(0.01		---	---	---	---
UMC94-35	---	---	---	---	---	---	---	---	---	---	---	---	---	---
UMC94-36	---	---	---	---	51.0	---	---	---	---	---	---	---	---	---

SAMPLE #	B/CL by wt	LI/CL by wt	F/CL by wt	NA/CL by wt	K/CL by wt	SO4/CL by wt	HCO3/CL by wt	CS/CL by wt	BR/CL by wt	t0C	t0H	tNK(F)
UMC94-1	0.0032	0.0017	0.1369	1.1911	0.0357	0.2624	0.2357	0.0004	0.0050	117	116	132
UMC94-2	0.0033	0.0016	0.1416	1.1299	0.0358	0.2630	0.3708	0.0004	0.0048	116	115	135
UMC94-3	0.0034	0.0018	0.1401	1.1645	0.0365	0.2638	0.4342	0.0004	0.0048	115	114	134
UMC94-4	0.0000	0.0000	0.1419	1.8903	0.4452	6.4387	71.6129	0.0026	0.0000	40	48	303
UMC94-5	0.0052	0.0025	0.1257	1.5209	0.2068	2.8010	25.4398	0.0000	0.0157	41	49	245
UMC94-14	0.0034	0.0023	0.1198	1.1050	0.0510	0.5095	2.4237	0.0002	0.0057	77	81	159
UMC94-15	0.0027	0.0014	0.0642	1.1339	0.1475	2.1038	19.9454	0.0000	0.0055	45	53	241
UMC94-16	0.0033	0.0025	0.1347	1.1133	0.0402	0.2607	0.4087	0.0005	0.0050	119	117	143
UMC94-17	0.0035	0.0024	0.1367	1.1067	0.0410	0.2613	0.3973	0.0005	0.0047	118	116	144
UMC94-18	0.0035	0.0022	0.1367	1.1200	0.0415	0.2567	0.4627	0.0005	0.0049	115	114	144
UMC94-25	0.0034	0.0023	0.1353	1.1200	0.0406	0.2587	0.4073	0.0005	0.0052	118	116	143
UMC94-26	0.0036	0.0023	0.1361	1.1293	0.0424	0.2510	0.4687	0.0005	0.0046	115	114	145
UMC94-27	0.0035	0.0023	0.1347	1.1600	0.0406	0.2567	0.4020	0.0005	0.0052	118	116	141
UMC94-28	0.0041	0.0020	0.0754	1.3666	0.2301	2.7699	30.3462	0.0000	0.0000	43	51	266
UMC94-29	0.0031	0.0020	0.1179	1.0810	0.0592	0.5782	3.7430	0.0004	0.0047	66	72	170
UMC94-30	0.0031	0.0022	0.1132	1.1323	0.0643	0.8492	4.4615	0.0004	0.0052	63	69	173
UMC94-31	0.0021	0.0021	0.0666	1.0677	0.1385	1.9979	14.3763	0.0000	0.0000	37	45	240
UMC94-32	0.0032	0.0032	0.1309	1.3486	0.0504	0.4399	1.9330	0.0000	0.0049	82	85	145
UMC94-33	0.0032	0.0030	0.1374	1.1935	0.0394	0.2613	0.4000	0.0000	0.0049	118	116	137
UMC94-34	0.0000	0.0027	0.1378	1.1346	0.0390	0.2641	0.3801	0.0000	0.0050	120	118	140
UMC94-34R	---	---	---	---	---	---	---	---	---	---	---	---
UMC94-35	---	---	---	---	---	---	---	---	---	---	---	---
UMC94-36	---	---	---	---	---	---	---	---	---	---	---	---

Table 7, continued

SAMPLE #	ENK17 °C	ENK13 °C
UMC94-1	86	141
UMC94-2	90	143
UMC94-3	89	141
UMC94-4	303	150
UMC94-5	223	136
UMC94-14	117	122
UMC94-15	218	136
UMC94-16	99	143
UMC94-17	101	145
UMC94-18	101	143
UMC94-25	99	143
UMC94-26	102	143
UMC94-27	97	143
UMC94-28	251	144
UMC94-29	131	122
UMC94-30	134	122
UMC94-31	217	141
UMC94-32	101	121
UMC94-33	93	142
UMC94-34	95	143
UMC94-34R		
UMC94-35		
UMC94-36		

Table 8: Chemical analyses of spring samples, 1993

NORTHERN NEW MEXICO THERMAL WATERS

SAMPLE #	DESCRIPTION	DATE MM/DD/YY	TEMP °C	Ag ppm	Al ppm	As ppm	B ppm	Std.D. +/-	Ba ppm	Std.D. +/-
NNM93-1	Main Bath House Spring, Montazuma Hot Sprs	--/--/93	55.1	(0.001	(0.05	(0.05	0.55	0.02	0.01	0.01
NNM93-2	St. Michael's, Montazuma Hot Sprs	--/--/93	46.7	(0.001	(0.05	(0.05	0.53	0.01	(0.01	
NNM93-3	Central Spg, Montazuma Hot Sprs	--/--/93	53.9	(0.001	(0.05	(0.05	0.53	0.02	(0.01	

SAMPLE #	Br ppm	Ca ppm	Std.D. +/-	Cd ppm	Cl ppm	Co ppm	CO3 Cond. (L) ppm umho/cm	Cr ppm	Std.D. +/-	Cs ppm	Std.D. +/-	Cu ppm	Std.D. +/-	F ppm
NNM93-1	0.31	3.94	0.03	(0.001	175	(0.002	12.2	969	0.003	0.001	0.065	0.002	0.002	21.7
NNM93-2	0.36	3.45	0.06	(0.001	179	(0.002	17.5	875	(0.002	0.061	0.002	(0.002		22.8
NNM93-3	0.38	3.44	0.04	(0.001	182	(0.002	17.3	982	(0.002	0.061	0.002	0.003	0.002	22.4

SAMPLE #	Fe ppm	Std.D. +/-	HCO3 ppm	I ppm	K ppm	Std.D. +/-	Li ppm	Std.D. +/-	Mg ppm	Std.D. +/-	Mn ppm	Std.D. +/-	Mo ppm	Std.D. +/-	Na ppm	Std.D. +/-
NNM93-1	0.05	0.01	59.8	(0.01	5.58	0.03	0.36	0.01	0.09	0.01	0.01	0.01	0.009	0.001	177	4
NNM93-2	0.07	0.01	63.4	(0.01	5.70	0.04	0.33	0.01	0.04	0.01	(0.01		0.008	0.001	170	2
NNM93-3	0.05	0.01	62.8	(0.01	5.78	0.01	0.32	0.01	0.06	0.01	(0.01		0.008	0.001	176	1

SAMPLE #	NH4 ppm	Ni ppm	Std.D. +/-	NO3 ppm	Pb ppm	Std.D. +/-	pH (F)	pH (L)	PO4 ppm	Rb ppm	Std.D. +/-	Sb ppm	Si ppm	Std.D. +/-	SiO2 Calc ppm
NNM93-1	0.16	0.004	0.001	0.01	0.002	0.002	8.0	9.03	(0.02	0.081	0.002	(0.1	33.9	0.5	73
NNM93-2	0.14	(0.002		0.03	0.003	0.002	8.0	9.99	(0.02	0.082	0.002	(0.1	30.5	0.6	65
NNM93-3	0.05	0.002	0.001	0.06	0.002	0.002	7.5	8.97	(0.02	0.081	0.002	(0.1	30.4	0.9	65

SAMPLE #	SO4 ppm	SO2O3 ppm	Sr ppm	Std.D. +/-	Zn ppm	Std.D. +/-	TDS ppm	Cation Sum	Anion Sum	Balance	tAM	tCH	tGC °C
NNM93-1	42.8	0.23	0.19	0.01	0.03	0.01	578.8	8.112	8.567	-0.0545	2	91	120
NNM93-2	44.7	0.02	0.13	0.01	0.01	0.01	574.1	7.776	8.824	-0.1264	-3	85	115
NNM93-3	45.9	0.13	0.16	0.01	0.02	0.01	583.2	8.033	8.906	-0.1031	-3	85	115

SAMPLE #	tGA	tNK(F) °C	tNK(T) °C	tNL(d) °C	tNL(c) °C	tL(d) °C	tL(c) °C	tML °C	tKM °C	tNKC13 °C	tNKC43 °C
NNM93-1	118	135	90	119	312	121	20	141	113	138	127
NNM93-2	114	138	94	116	306	119	18	154	126	141	131
NNM93-3	113	137	92	111	299	118	17	144	120	141	132

Analyses for chloride were also performed in the UWC laboratory. These analyses are reported in Table 9, along with LANL analyses performed on samples collected at the same time. Conductivity and pH measurements conducted in the field were found to be erroneous, as indicated above, and are therefore not reported.

Table 9: Chloride analyses performed at laboratories of LANL and UWC

Date	Sample	Location	Analysis for $[Cl^-]$ /ppm		pH
			UWC	LANL	
6/27/94	6	Bath house	137		9.33
	7	River above springs	15		8.82
	8	River at power house	14		8.90
	9	River above springs	2 $\pm$ 1		8.85
	10	River at power house	8 $\pm$ 3		8.90
7/1/94	11=15	River above springs	6 $\pm$ 1	7.32	
	12=14	River at power house	50 $\pm$ 2	52.4	
	13=16	Bath House spring	141 $\pm$ 1	150	
7/8/94	19	River above springs	5 $\pm$ 1		9.21
	20	River at power house	56 $\pm$ 1		9.22
	21	Bath house spring	141 $\pm$ 1		9.46
7/12/94	22	River at power house	64 $\pm$ 3		9.47
	23	River above springs	7 $\pm$ 1		9.31
	24	Bath house spring	141 $\pm$ 1		9.59
7/19/94	31	River above springs	10 $\pm$ 2	9.46	8.69
	32	River at power house	69*	65	8.86
	33	Bath house spring	129 $\pm$ 1**	155	9.11

* Analysis done eight days later using new titrant cartridge

** Last analysis with old titrant cartridge

Argentometric titrations were performed on sample UWC94-33 (unfiltered). Different volumes were diluted to 50 cm³ and titrated with 0.01410 M AgNO₃. Results are given in Table 10. Analysis of this sample by LANL showed a chloride concentration of 155 ppm. Analyses of samples UWC94-34 and UWC94-34R showed no significant difference between raw and filtered samples. The entries for chloride concentrations in 50 cm³ refer to the concentrations after dilution of the original sample, using the

concentration provided by LANL. The concentration in UWC94-33 is that determined by titration.

Table 10: Argentometric titration results

Volume of sample/cm ³	25	25	10	10	5	5	2	2
Titer/cm ³	8.47	8.41	3.47	3.42	1.87	1.87	1.00	1.00
Blank/cm ³	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
[Cl ⁻] in 50 cm ³ /ppm	78	78	31	31	16	16	6	6
[Cl ⁻] in UWC94-33/ppm	164	163	161	158	162	162	187	180

Tritium Analyses

Analysis for tritium in samples UWC94-31 ("river above spring") and UWC94-33 (bathhouse spring) had concentrations of 1.8 +/-0.4 T.U. and 0.34 +/-0.09 T.U., respectively. The former value is within the range expected for New Mexico surface waters. The latter value, together with input concentration estimated from tritium concentrations in precipitation over time, was used to calculate the average residence time of water in the reservoir. Lower and upper limits are calculated assuming two types of fluid flow: piston-flow (no mixing of fluids of different ages) and well-mixed (complete mixing of fluids of different ages), respectively [30]. These calculations indicate the average residence time of the water to be between 75 and 3000 years.

Total Spring Flow

Total discharge of the hot springs into the Gallinas river can be measured by each of the following methods:

- (a) difference in river discharge above and below the springs
- (b) change in concentration of an ion in the river
- (c) change in conductivity of the river

On four occasions, river flow was measured both above and below the springs within a relatively short period of time. In Table 10 are shown for each occasion the time interval during which both flow measurements were completed, the change in gauge reading during that period, the approximate change in discharge during that interval, the flow rates above and below the

springs, and the difference between them, which should be the total discharge of the hot springs.

Table 11: Total hot springs discharge estimated by difference in river discharges above and below the springs (locations F2 and F3)

Date	Locations	Time/hr.min	Gauge readings/cm	Discharge/m ³ min ⁻¹			
				Change	River (loc. F3)	River (loc. F2)	Difference
7/18	F3,F2	13:20-15:30	30.0 - 19.8	6.07	2.67	4.94	-2.27
7/19	F3,F1	15:20-17:00	18.8 - 18.8	0	0.76	0.44	0.32
7/21	F3,F2	13:10-14:40	36.7 - 31.5	8.35	4.18	7.33	-3.15
7/26	F3,F2	10:10-11:46	35.7 - 34.8	1.52	12.15	13.21	-1.06

For 7/21, the gauge readings were obtained from Figure 4. For 7/18 and 7/26 the readings were obtained by linear extrapolation of pairs of readings for a shorter portion of the time interval. The fifth column gives the change in river discharge corresponding to the change in gauge readings during the time interval, read from Figures 5 and 6. The measured discharges appear in columns 6 and 7 and their difference in column 7. The value is positive only on 7/19, when there was no change in the gauge readings during the measurement interval.

On seven different days samples from appropriate locations were taken for analysis by LANL and/or UWC laboratories, and rate of flow or gauge readings above the springs were determined. Using only chloride concentration, the rate of flow of the springs can be calculated according to equation 1. In Table 12 are shown the relevant data. Column 2 is calculated from data in Tables 6 and 8. Column 3 gives the discharge in the river above the springs (V_1). The figures in parentheses were not measured directly but were calculated from gauge readings using Figures 5 and 6. Discharge from the springs is calculated by multiplying column 3 by column 2. Only on 7/19 was the gauge reading fairly constant. It did not change during the flow measurements, and increased by 0.2 cm at the power house between the end of the flow measurements and completion of sample collection. No information is available concerning gauge readings on 6/22. Only a single gauge reading was taken on 7/13, approximately half-way through the two-hour collection procedure. On all other days, gauge readings for a time approximately halfway through the sample collection period were made by extrapolating readings obtained earlier, assuming that the rate of change of flow of the river remained constant during the time interval in question.

UWC data are not included for 7/19, as switching from one titrant cartridge to another gave different results.

Table 12: Total hot springs discharge estimated by dilution of chloride ion entering the river

<u>Date</u>	<u>Conc. factor*</u>	<u>Analysis</u>	<u>Discharge(V_i)/m³ min⁻¹</u>	<u>Springs discharge(V_s)/m³ min⁻¹</u>
6/22/94	0.148	LANL	32.0	4.75
6/27/94	0.3	UWC	12	3.8
7/1/94	0.46	LANL	(0.57)	0.26
7/1/94	0.48	UWC	(0.57)	0.27
7/8/94	0.60	UWC	(0.30)	0.18
7/12/94	0.74	UWC	(0.23)	0.17
7/13/94	0.270	LANL	(1.14)	0.31
7/19/94	0.630	LANL	0.44	0.28

* = $(C_f - C_i)/(C_s - C_f)$ from equation 1

Considering the uncertainty in flow changes, the data for 7/19 seem the most promising, since it is known that the discharge changed very little during the time of flow measurement and sample collection. Calculations of total spring discharge can be performed using other ions which are present in the springs in substantial concentration. The results for the most common substances are given in Table 13. Carbonate and hydrogencarbonate ions were not used because their concentrations in different samples from the springs show more variation than those of the other ions. Analyses were conducted at LANL.

Table 13: Total hot springs discharge on 7/19/94 estimated by dilution of various substances entering the river

<u>Chemical Species</u>	<u>Concentration in springs/ppm</u>	<u>Discharge/m³ min⁻¹</u>
chloride ion	155	0.28
fluoride ion	21.3	0.28
sulfate ion	40.5	0.38
sodium ion	185	0.36
silicon	32.6	0.27

Conductivity measurements, performed in the field and at LANL, can be used to calculate total spring discharge, as has been shown above for specific ions. These data appear in Table 14. UWC analyses performed before 7/19 are not included because internal temperature compensation of the meter was found to be unreliable

Table 14: Total hot springs discharge estimated by changes in conductivity

<u>Conductivity/micromhos cm⁻²</u>						
<u>Date</u>	<u>Above</u>	<u>Below</u>	<u>Spring</u>	<u>Anal.</u>	<u>Discharge(V_i)/m³ min⁻¹</u>	<u>Springs discharge(V_s)/m³ min⁻¹</u>
6/22	212	221	878	LANL	32.0	3.80
7/1	312	492	862	LANL	(0.57)	0.28
7/13	307	420	860	LANL	(0.95)	0.24
7/19	315	585	865	UWC	0.44	0.43
7/19	312	555	873	LANL	0.44	0.34

Dissolved Oxygen, Biological Oxygen Demand, and Bacteria

The results of tests for dissolved oxygen at different locations and times are shown in Figure 20.

Figure 20: Dissolved oxygen, sampled at 8:00-9:00 a.m. and 4:00-5:00 p.m. at different locations

The amount of DO found in the hot bath at both times was below that considered necessary for most organisms, but it increased three-fold during the day (1.2 to 3.6 mg dm⁻³). This was most likely due to the algae growing on the sides of the enclosure; species found are discussed below. This value for DO is not extremely low considering the temperature of the water. At 40°C and one atm pressure the solubility of oxygen in water is 6.6 mg dm⁻³. At the normal local atmospheric pressure of about 560 mm Hg, the solubility would be 5.0 mg dm⁻³. The samples taken at location F2 in the flowing part of the river increased from 6.8 to 7.2 mg dm⁻³ during the day

(67 to 82% saturation, corrected for elevation) and those from the slower part went from 5.0 to 17.6 mg dm⁻³ (47 to over 100% saturation.). This increase was due to the fact that these samples were taken near a small patch of algae and show the importance of photosynthetic species to the overall health of the river. For the samples from location F3, below the springs, the samples from the flowing part of the river went from 6.5 to 6.6 mg dm⁻³ (83 to 89% saturation due to the temperature change) and in the slow area (quite stagnant) from 6.6 to 6.4 mg dm⁻³ (75 to 78% saturation.). There was a temperature difference at these two sites of 10⁰C in the morning and only 4.5⁰C in the afternoon.

The oxygen electrode was available after the above tests had been run. It was compared to the test kit using a common sample, and gave a reading of 8.65 mg dm⁻³. The test kit measured 7.2 mg dm⁻³, suggesting that results of earlier determinations are about 1.4 mg m dm⁻³ low. On August 12, 1994, samples were taken from 10:00 to 11:00 a.m. for DO and BOD determinations, with the results indicated below:

	<u>Date</u>	<u>Bath</u>	<u>F2</u>	<u>F3</u>	<u>Mid-river</u>
DO/mg dm ⁻³	8/12/94	1.5	8.65	8.75	8.7
	8/17/94	0.27	6.00	5.56	5.56
BOD/mg dm ⁻³	8/12/94	1.23	2.65	2.65	3.14
% available oxygen utilized by bacteria		82	31	31	37

Biological oxygen demand (BOD) is a measure of the activity of bacteria, mainly decomposers. Of greater interest than the actual numbers is the relative proportion of available oxygen used by the bacteria over the five days. The results shown above indicate significant activity in the hot springs water. The water samples were incubated at 20⁰C for the five days, so temperature is not considered a factor.

Bacteria cultures run with water collected from these locations on July 19 also indicated the presence of bacteria in the hot springs. The cultures from the hot bath had three colonies of Coliform and one small colony of *E. coli*. None of the other cultures contained any Coliform bacteria. Coliform bacteria are indicators of fecal material from warm-blooded organisms. *E.*

coli is specific for human waste since this is the species found normally in the large intestine. A second test from the hot springs done on July 21 did not show any *E. coli*, but did have two colonies of unidentified Coliform bacteria.

Plant and Algae Species

Species found in the river included *Spirogyra* sps. (two or three species of different sizes) which is a common green algae in fresh water. This was the species in the patch of algae near which the DO water sample was taken on July 19. This patch was gone on August 12, probably due to high water and silt deposits. Most of the algae had also disappeared from the rocks in this area. There was one small patch of *Elodea* (a common macrophyte) about 1.5 m further down stream. Other species found were *Potamogeton pectinatus* and numerous *diatom* sps. Diatoms are commonly classified as Golden Algae and require silica for their outer testa (shells). Common species found along the banks include emergents: *Eleocharis*, *Scirpus Americanus*, other reeds and rushes, *Equisetum* and numerous grasses. Russian olive, an exotic species, is beginning to crowd out some of the native species, especially the willows. None of the species found in the river or on the banks (except the Russian olive) are considered nuisance or unwanted species.

The dominant species found in the springs themselves is the blue-green (cyanobacteria) *Oscillatoria* sps. along with numerous rotifers (Protista). No species that have been classified as thermophiles (hot water species) were identified, probably because they dominate areas at temperatures closer to 60°C, while these springs have temperatures of 40 to 54°C. A more extensive study of the species from all the springs might reveal some of these thermophiles.

The species that are now called Cyanobacteria were classified as Blue-green Algae for many years until it was determined that, because of their internal cellular structure, they were prokaryotes and, therefore, Monera along with the rest of the bacteria. This has led to a great deal of confusion and conflict over names and descriptions used by bacteriologists vs botanists and others interested in aquatic species and water quality indicators.

The botanical, *Oscillatoria* sps. is used in this report. These species can survive with oxygen or at low oxygen levels. Cyanobacteria (blue-greens) are found in virtually every ecosystem, because many of them are capable of

fixing nitrogen and so can live in waters that are very low in nitrogen. Some, but not all, can become nuisance species giving water sources a bad taste and noxious odor. Since they are photosynthetic they add to the DO of the water unless they become overly abundant and die off; then their decomposition can lead to anoxic conditions. Those found in the hot springs are not so abundant and add to the DO content of the springs.

DISCUSSION

Sampling and Measuring Locations

The bathhouse spring (#1) is the best of the hot springs for sampling and measurements. It forms a "well" about 5.2 meters deep with a narrow circular opening about 40 cm above ground level and above water level. Samples were taken from an overflow pipe, and the flow is the greatest of any of the springs. Since this spring is not used for bathing and is out of sight from those used by the public, the possibility of human use affecting the spring is minimal.

Sampling at the central spring (#6) was made at the rear of a concrete trough partially covered by a concrete slab. The hot water seems to emerge in this area. The trough feeds two baths which receive considerable use from the public, members of which occasionally throw trash into the trough. Flow was measured occasionally at the overflow from the last bath.

The seep emerges directly from the ground with sufficient flow that samples can be obtained with relative ease.

St. Michael's spring (#13) has the second greatest rate of flow and is the most popular of the springs. The water enters the bottom of a concrete-lined cylinder which is about 1.5 meters deep and 1.5 meters in diameter. An overflow pipe from this top bath was used to measure flow. This spring was not sampled for chemical analysis because the top reservoir is used frequently for bathing.

Selection of locations for stage measurements proved difficult. A favorable site would be one with an even, regular stream bottom, clearly

defined edges, and an even flow of water parallel to the sides. The Gallinas River meanders, changes in width from 30 cm to 6 meters in short stretches, and is liberally strewn with rocks and boulders. Location F2 proved very convenient for measurements at relatively high rates of flow, but was sufficiently wide and deep that flow could not be measured at lower stages. The nearest location for low flow was undesirably far upstream, raising the possibility that water may enter the river between these two locations. It has not been possible to gather enough data to evaluate this situation. Location F3 proved reasonably satisfactory under conditions of low and moderate discharge. Location F4 was tested once, as appearing more favorable for very low flow than location F3. Temperature and conductivity measurements at the two locations indicated a substantial inflow of cold water with low ion concentrations between the two locations. Efforts to use conductivity measurements to locate the source of the water were interrupted by bad weather and could not be resumed when river discharge increased. Later exploration of this section of river revealed two cold-water inlets.

River Flow

Due to rapidly changing river stage throughout the period of measurements, it was never possible to repeat a discharge measurement at the same stage value in order to determine the reproducibility of the procedure under prevailing conditions. The fact that using half a set of measurements gave results very close to those obtained from the complete set of measurements (Table 2) suggests good reproducibility, as do good fits to second-order equations for plots of river discharge against stage (Figures 5-7). These apparently good fits may be more coincidental than real, for three reasons. Relatively few data points could be obtained, especially for locations F1 and F3. A second problem is that plots of cross-sectional area and average velocity against stage do not show as good a fit to second-order equations (Figures 8-13). Especially for location F2, where seven data points exist, the correlations for stage against cross-sectional area ($R^2 = 0.841$) and average velocity ($R^2 = 0.983$) are appreciably inferior to that against total discharge ($R^2 = 0.992$). It appears that errors in area and velocity might cancel each other out when used to calculate discharge. Finally, the appropriate equation for the rating curve might not be

second-order. The equation is usually considered to take the form

$$q = k(g - a)^b, \text{ where}$$

q = discharge

g = gauge height

k, a, b , are station constants [31]

These uncertainties can be resolved only with more data to clearly establish the rating curve for each location. It would be of particular interest to ascertain whether discharge values at stage heights between about 26 and 32 cm fall on both of the rating curves for locations F1 and F2. Reliable rating curves are essential to being able to determine discharge values quickly. These in turn are needed to determine total flow of the springs, both for continued monitoring of the springs if water is withdrawn for geothermal energy, and as a central part of the educational program to be developed.

Spring Flow

Flows from individual springs do not follow any obvious pattern, nor do they seem to bear any relationship to each other (Figure 14), to rainfall, to season, to river stage, or to atmospheric pressure (Figure 16). At the bathhouse spring, measurements from July 1 to July 25 varied between 36 and 42 $\text{dm}^3 \text{min}^{-1}$, then rose to values between 42 and 46 $\text{dm}^3 \text{min}^{-1}$ until May, 1995, when several lower readings were obtained before installation of the sensors prevented manual gathering of data. Data recorded from the flow meter (Figure 18) gave values mainly in the range 36.5 to 37.5 $\text{dm}^3 \text{min}^{-1}$ from early June to mid-July, values lower than any found during the previous year. After about one week of extreme fluctuations, values fell mainly in the range 37 to 40 $\text{dm}^3 \text{min}^{-1}$ for several months. Extreme fluctuations occurred again from mid-October to mid-December, when the sensor was replaced. Values about 38 $\text{dm}^3 \text{min}^{-1}$ were recorded for the rest of December, and increased to about 43 $\text{dm}^3 \text{min}^{-1}$ for the first two weeks of 1996. On the occasions where sharp increases or decreases in flow rate occurred, these changes were of brief duration and did not have any obvious cause. Comparison of the river stage readings at location F2 shows that the

stage was low from the end of June until July 19. On July 21 it increased greatly, then dropped a great deal during the day. From July 26 onwards the stage was appreciably higher due to frequent rains. This was about the same time that the bathhouse spring flow increased. Short-term fluctuations in stage due to individual storms did not seem to affect the flow of the spring.

At St. Michael's spring the discharges fall into the narrow range of 14 to 16 $\text{dm}^3 \text{min}^{-1}$ except for decreases when members of the local community empty and clean the top reservoir. Recovery to the previous flow rate takes about one week. There seems to be no relationship between changes in flow of the two springs (Figure 14).

Previous records of spring discharge are not consistent. Road construction and repair and re-routing of springs could cause substantial changes over time. From a high value of 21 gpm ($80 \text{ dm}^3 \text{min}^{-1}$) in 1885, maximum individual spring flows decreased to 5 and 5.8 gpm (19 and $22 \text{ dm}^3 \text{min}^{-1}$) in 1952 and 1966, respectively. Values obtained in the summer of 1993 for the bathhouse and St. Michael's springs are both nearly 30% higher than the measures in the current study. The measurement method used in 1993 was not specified [11].

Temperature

Almost all temperature measurements at the bathhouse spring are within the range of $54 - 55^\circ\text{C}$ (Figure 15), and show no pattern of fluctuation over one year. This agrees with other readings taken since 1940. Measurements taken in the last century were 10°C higher, but Summers [32], in a survey of thermal waters in New Mexico, notes that available temperature, flow, and chemical data are often inaccurate and incomplete. Data recorded with a thermocouple from May, 1995, show many extreme peaks exceeding 66°C , and can not be considered reliable (Figure 19). The temperature of St. Michael's spring was monitored from a later time and varied over a slightly wider, but lower, range of $47-49^\circ\text{C}$ until mid-October, when temperatures gradually decreased to about 45.5°C during the winter months. A daily pattern was also seen; during the summer temperatures were generally

below 57.9°C in the morning and above that value in the afternoon. The change can be about 1°C during the day (see data for 8/12 and 8/16 in Table 5.). This seemed unaffected by emptying the top reservoir on 8/14. On several occasions, when the top reservoir seemed not to have been used for a period of time, measurements were made at the top (about 15 cm below the surface) and bottom of the reservoir with the maximum reading thermometer. Differences were usually undetectable and never exceeded 0.3°C. Bubbles of gas continually rising through the water would cause mixing as would convection currents arising from cooling of the surface.

pH and Conductivity

Values of pH range from 8.9 to 9.3, and are similar to values of 8.4-9.0 reported by Summers [33] from USGS analyses from 1952 and 1966. These numbers are slightly below typical values for dilute chloride-bicarbonate waters, which usually fall in the range pH = 6-8 [34]. Conductance values of various springs tested from 1939-1966 give values ranging from 810 to 878 micromhos cm^{-1} , similar to the range of values of 831-882 micromhos cm^{-1} found in 1993 and 1994. No spring was consistently different from the others with respect to either pH or conductivity.

Chemical Analyses

Complete chemical analyses were done in 1993 and 1994 by LANL. The 1993 data are for three different springs sampled on one occasion. The 1994 tests were done on two of the springs sampled in 1993 plus one new source. These three sources were sampled on three different occasions, and the bathhouse spring on two additional occasions, making a total of 11 different spring samples. Comparison of these results with historical values shows remarkable consistency, especially for chloride concentrations. Of seven sets of values from 1869 to 1994, six fall in the range 152-166 ppm. In 1993 the average value was 179 ± 3 ppm. Sodium ion concentrations are virtually identical in 1966, 1993, and 1994. Fluoride ion has shown no significant change since 1952, except for an anomalous result in 1966. The SiO_2 concentration in 1994 was 66.7 ± 2.2 ppm, similar to results dating back to 1882. In Table 15 are given results for analyses of

various ions and their ratios in the springs in 1993 and 1994 and for the river above the springs in 1994. These data may be used to answer questions about a common origin for the springs and for the relation of the river to the springs.

Table 15: Ion concentrations and ion concentration ratios in the hot springs in 1993 and 1994 and the river above the springs in 1994. For each set of analyses are given the number of samples (n), the average value, and the standard deviation.

	<u>B</u>	<u>Br</u>	<u>Cl</u>	<u>Cs</u>	<u>F</u>	<u>K</u>	<u>Li</u>	<u>Na</u>	<u>SO4</u>
1993 Springs	n=3 0.54 ±0.01	n=3 0.92 ±0.04	n=3 179 ±4	n=3 0.062 ±0.002	n=3 22.1 ±0.7	n=3 5.69 ±0.10	n=3 0.34 ±0.02	n=3 174 ±4	n=3 44.5 ±1.6
1994 Springs	n=10 0.52 ±0.01	n=11 0.75 ±0.04	n=11 152 ±3	n=9 0.068 ±0.004	n=11 20.8 ±0.7	n=11 5.97 ±0.27	n=11 0.34 ±0.06	n=11 174 ±7	n=11 39.5 ±1.3
1994 River	n=3 0.02 0.00	n=3 <0.03	n=3 7.2 ±2.3		n=3 0.49 ±0.13	n=3 1.17 ±0.13	n=3 0.01 ±0.01	n=3 8.4 ±1.7	n=3 16.0 ±2.7
	B/Cl	Br/Cl	Cs/Cl	F/Cl	K/Cl	Li/Cl	Na/Cl	SO4/Cl	
1993 Springs	n=3 0.0030 0.0001	n=3 0.0051 0.0004	n=3 0.00035 0.00002	n=3 0.124 0.002	n=3 0.03183 0.0006	n=3 0.0019 0.0002	n=3 0.98 0.03	n=3 0.249 0.004	
1994 Springs	n=10 0.0034 0.0001	n=11 0.0049 0.0002	n=9 0.0004 0.0001	n=11 0.137 0.002	n=11 0.0393 0.0023	n=11 0.0023 0.0004	n=11 1.14 0.03	n=11 0.260 0.004	
1994 River	n=3 0.0034 0.0010	n=1 0.0055	n=1 0.0005	n=3 0.069 0.006	n=3 0.172 0.050	n=3 0.0018 0.0004	n=3 1.19 0.16	n=3 2.29 0.42	

The chemistry of the different springs is essentially identical, indicating a common origin. These similarities can be seen in the data of Tables 7 and 8 and in the low standard deviations of most sets of data for the springs in Table 15. This interpretation is reinforced by the consistencies of the ion ratios. The ratios B/Cl, Br/Cl and Cs/Cl are considered especially useful as indicators of a common reservoir source [35]. Of the eight ratios calculated, in five the standard deviation does not exceed 3% of the average value. For the individual ions, in five of nine analyses the standard deviation did not exceed 4% of the average value. Most of the values for 1993 and 1994 were within experimental uncertainty (the standard deviation of each value) of each other if the chloride value of 1994 was used in place of that for 1993. The only ratios not reconcilable in this manner are F/Cl and SO₄/Cl, but they do lie within the experimental uncertainty of the method. All three of these ions are determined by ion exchange chromatography, which has an uncertainty of $\pm 5\%$ for each ion [35]. A ratio of two ions thus has an experimental uncertainty of $\pm 10\%$. The F/Cl and SO₄/Cl values are well within that range.

Another interesting comparison is that of ion concentration and ion ratios in the springs and in the river above the springs. River concentrations are always lower than those in the springs, but many ion ratios are similar, specifically B/Cl, Br/Cl, Cs/Cl, Li/Cl and Na/Cl. Three ratios are very different in the two situations -- F/Cl, K/Cl, and SO₄/Cl.

Since these analyses are useful for characterizing the waters of the springs, as well as for calculating total discharge of the springs, preliminary analyses have been attempted in the UWC laboratories and compared to those done by LANL. It appears that chloride analyses using the digital titrator from the Hach kit give satisfactory results (see Table 9). The concentration value of the new cartridge is suspect, but if the analysis is used to calculate total discharge, using equation 1, a systematic error in the titration value will not affect the result. Argentometric titrations with a burette gave satisfactory agreement for solutions containing 16 ppm chloride or higher, but not for solutions containing 6 ppm. Even for the lowest flow measured, on July 19, the concentration of chloride in the river above the springs was 9 ppm. This method will find only limited use unless it can be improved to be reliable for lower concentrations.

Geothermometers

Calculations have been made in Tables 7 and 8 for several geothermometers. Values pertaining to spring samples only are summarized in Table 16.

Table 16: Temperatures calculated for several geothermometers for spring samples collected in 1993 and 1994.

Year	Sample	Location	tQC	tQA	tNK(F)	tNK(T)	tNKC13
1993	UWC93-1	Bathhouse	120	118	135	90	138
	UWC93-2	St. Michael's	115	114	138	94	141
	UWC93-3	Central	115	113	137	92	141
1994	UWC94-1	Bathhouse	117	116	132	86	141
	UWC94-2	Central	112	114	135	90	143
	UWC94-3	Seep	115	114	134	89	141
	UWC94-16	Bathhouse	119	117	143	99	143
	UWC94-17	Central	118	116	144	101	145
	UWC94-18	Seep	115	114	144	101	143
	UWC94-25	Bathhouse	118	116	143	99	143
	UWC94-26	Seep	115	114	145	102	143
	UWC94-27	Central	118	116	141	97	143
	UWC94-33	Bathhouse	118	116	137	93	142
	UWC94-34	Bathhouse	120	118	140	95	143

Silica geothermometers rely on absolute concentrations rather than on ratios, and these can be changed by physical processes such as boiling and dilution [37]. The Montezuma Hot Springs do not produce steam, and if dilution occurred, it would produce a low value for the temperature. A high value could be caused by mixing with acidic waters near the surface. This event is unlikely to be important since both spring and surface waters are slightly basic. Other geothermometers may be even less reliable. The Na-K geothermometer relations tend to break down below 120°C and/or where lateral flow allows reactions near the surface [38]. The calcium concentration is too low for use of the Na-K-Ca geothermometer [39]. Two general indicators suggest that solute geothermometers may not be appropriate for these hot springs. Conductive cooling is indicated by low

flow rate ($<30 \text{ dm}^3 \text{ min}^{-1}$) and groups of springs with similar chloride concentrations but different temperatures [40]. A high Na/K value ($>15/1$) indicates lateral flow, conductive cooling, and near-surface reactions [41]. Both of these conditions apply to the Montezuma springs, rendering them unsuitable for solute geothermometry because of the possibility of rock-water interactions as the water nears the surface, thus changing the original composition. The most that can be concluded from geothermometer data is that the temperature of the reservoir is greater than 115°C .

Total Springs Discharge

When discharges are measured both above and below the springs, the difference should be the discharge of the springs. On the four occasions when these data are available, three sets of data give substantial negative values (Table 11). In all three of these cases the river stage fell substantially during the time of measurement. On 7/21, when a continuous record of stage vs time was available, converting stake readings to gauge readings (Figure 4) and determining discharge measurements from Figures 6 and 7 gave the following results, compared to the measured discharge values:

	<u>Location F3/$\text{m}^3 \text{ min}^{-1}$</u>	<u>Location F2/$\text{dm}^3 \text{ min}^{-1}$</u>	<u>Difference/$\text{dm}^3 \text{ min}^{-1}$</u>
Measured	4.18	7.33	-3.15
Calculated	4.56	4.86	-0.30

Only on 7/19 was a positive difference obtained, as a result of two favorable conditions. The stage remained constant during both flow measurements, and it was the lowest value measured during the summer. This low stage insured that discharge of the springs made a significant contribution to the river. If the spring discharge were $0.32 \text{ m}^3 \text{ min}^{-1}$ (the value obtained on 7/19) and the river discharge were over $3.2 \text{ m}^3 \text{ min}^{-1}$, the spring discharge would be less than 10% of the total river discharge. If the uncertainty of discharge measurements at two locations were each $\pm 5\%$, the difference due to the springs could be more than 50% greater than the actual value, or less than half of it. Only on 7/19 were river discharge values below $3.2 \text{ m}^3 \text{ min}^{-1}$ at location F1 or F2 and discharge values determined also at location F3. This method also requires a constant value of the gage

reading for any conclusions to be reliable. If the average velocity of the stream is 3.5 m min^{-1} at F1 (see Table 5 for 7/19/94), with an approximate distance of 900 m from F1 to F3, water at the upper site would take over three hours to reach the lower site. This estimate assumes that the average velocity at F1 approximates the average value for the entire stream between F1 and F3. The average velocity for the entire stream is probably less than that at F1, because the site was chosen to give a measurable velocity at low flow. Comparing average velocities at F1 and F2 on 7/31, when the stage readings were similar (see Table 5), the average velocity was much greater at F1 than at F2.

This combination of low flow and constant gage readings is rarely achieved during the summer. Thus it has limited application. This method was used by the U. S. Geological Survey in 1966 [42], and gave a total spring discharge value of 325 gpm ($1.23 \text{ m}^3 \text{ min}^{-1}$), but the downstream reading was taken beyond location F4, so is rendered invalid by the fact that cold water enters the stream between locations F3 and F4.

Estimation of total spring discharge based on ion dilution shows considerable variation. Most analyses were based on chloride ion. Table 12 shows that calculated discharges on seven different occasions ranged from $0.17 \text{ m}^3 \text{ min}^{-1}$ to $4.75 \text{ m}^3 \text{ min}^{-1}$. Two values of 3.8 or more $\text{m}^3 \text{ min}^{-1}$ were at least ten times higher than any of the other values, and were obtained at relatively high river discharge values. Of the six other values, ranging from 0.17 to $0.31 \text{ m}^3 \text{ min}^{-1}$, only one was obtained with a measured rather than with an estimated river discharge value. This value of $0.28 \text{ m}^3 \text{ min}^{-1}$ was obtained on July 19 when the stage did not change, and a discharge value of $0.32 \text{ m}^3 \text{ min}^{-1}$ was found as the difference between rates of river flow above and below the springs. The dilution of other ions on that same day were also used to estimate the total discharge (Table 13). These values range from 0.27 to $0.38 \text{ m}^3 \text{ min}^{-1}$.

Table 14 gives conductivity measurements which can also be used to estimate total spring discharge. The three sets of measurements by LANL at low flow rates should be the most reliable; the results range from 0.24 to $0.34 \text{ m}^3 \text{ min}^{-1}$. The highest value of these was obtained on July 19.

Consideration of the data for total discharge suggest that the actual

value probably lies in the range 0.27 to $0.34 \text{ m}^3 \text{ min}^{-1}$ (70-90 gpm). This conclusion relies entirely on results from the one day when conditions were favorable for obtaining reliable data, but is supported by evidence from seven different sets of measurements. It is essential to obtain reliable rating curves so that estimates of flow rate can be made from stage measurements within a few minutes, and samples for ion analysis can be drawn at the same time, on those occasions when the level of the river remains constant for a few hours.

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ATTACHMENT E

The Hot Springs

at

Montezuma, New Mexico

Science Education Materials for Students

Section 5

Introduction

Before recorded history, the Montezuma hot springs were used by Indians for therapeutic purposes. The legend of their use by the Aztec chief Montezuma, and hence their current name, was propagated by Indians. The legend may be true, or it might have been used to appease or confuse the white man. During the Civil War the Union army used the springs for convalescence of wounded soldiers. Local women made extensive use of the springs for washing clothes. In the latter half of the 19th century the property changed hands numerous times, for increasing sums of money. Small hotels, then larger, were built by various entrepreneurs to capitalize on the presence of the springs. Several bathhouses were built. The last major one was destroyed in a flood in 1904. About the same time the third large Montezuma Hotel, having become unprofitable, was closed and the tourist era ended in Montezuma. The hotel and property had several reincarnations as a Baptist college and Mexican Catholic Jesuit seminary. It is presently part of The Armand Hammer United World College of the American West. The old tourist hotel is currently not in use due to structural damage although the college has plans to historically preserve and reuse the facility. The buildings occupied by the college include an older stone hotel built in 1880 and others built during the time of the seminary.

The present heating system for the college utilizes hot water produced by a coal-fired boiler. To reduce pollution and heating costs from the burning of coal, the college has started to investigate the possibility of using the energy of the hot water coming up into the springs as a source of heat for the college. Energy of this sort is called "geothermal energy". The research has been undertaken in collaboration with Los Alamos National Laboratory (LANL), Sandia National Laboratories, and the Southwest Technology Development Institute at New Mexico State University.

All of the work discussed here has the purpose of gaining information about the source, age, quantity, and properties of the water of the hot springs. This information is necessary for two main purposes. First is to help in the evaluation of its geothermal potential, for which it is necessary to know how much water is available and how hot it is. The second purpose is to have information about the quantity and properties of water coming from the springs before water is removed for other purposes, so that the process can be stopped if it has an adverse effect on the hot springs.

MAPS

Maps 1-5 show the Montezuma hot springs and surrounding area in increasing detail. Maps 4 and 5 will be referred to in many other sections. Following are some important points to note about each of the maps:

MAP 1: The Gallinas River (or Gallinas Creek) originates about 30 km west of Montezuma at an elevation of about 3300 meters. After passing Montezuma it flows through Las Vegas and continues south to join the Pecos River. The latter continues into Texas, where it meets the Rio Grande, which in turn empties into the Gulf of Mexico. The Gallinas basin covers about 200 square km west of Montezuma. This is the area which drains into the Gallinas, and includes other smaller streams which join the Gallinas. The river serves as the water supply for Las Vegas and the surrounding communities. Water is removed from the river above Montezuma and is stored in the Peterson Reservoir, which is shown just south of Montezuma on the map. The scale of this map is 1 in = 2.9 miles.

MAP 2: Map 2 is produced by the United States Geological Survey. It is called a topographical map because it shows hills and valleys by the use of contour lines. Two gaging stations are shown on the river. A gaging station measures the height of the surface of the river. This was done at the lower gaging station by fastening a wooden board marked in intervals of 0.1 foot to a bridge support that was in the river. Thus an observer could read the level of the river on the gage. It is not necessary that the bottom of the gage be at the bottom of the river. By measuring the flow of the river at different gage readings, a table of gage readings against river flow can be established. This is called a rating table. A graph can be drawn from the rating table. For any future gage readings, the corresponding flow of the river could be read from the graph. The lower gaging station required periodic visual readings and was used last on Dec. 31, 1966, and removed after that date. The upper station operates automatically; readings of gage measurements are recorded continuously with an instrument.

See Sections X and Y for further information and examples of rating tables and graphs.)

The gaging stations have been used to estimate the flow of water in the river at frequent intervals, and thus the total amount of water produced by the river on a daily and yearly basis. This information is important in calculating the amount of water available for different purposes, particularly to meet the needs of the city and for irrigation of farms and feeding livestock. In New Mexico, where water is in short supply, different individuals and institutions have traditional and legal rights to specific amounts of water. If more than the allocated amount is removed from the river, those living downstream may be deprived of water that is essential for them. Thus many people depend on reliable information about river flow and the proper use of water rights by those taking water from the river. This is especially important since the removal of water, both legally and illegally, is not monitored by any authority.

Map 2 is drawn to a scale of 1:24 000, meaning that a 1 cm measurement on the map corresponds to a distance 24 000 times as great, or 24 000 cm.

MAP 3: This map was drawn by students and teachers at the United World College for use in orienteering, using map 2 as a basis, but including much more detail.

MAP 4: This map has been prepared by enlarging map 3 twice, by 141% each time. Sampling locations in the river and hot springs are shown; these will be referred to in other sections. The hot springs are located between points F2 and F3, mainly on the south bank of the river, between the river and the road.

MAP 5: Much more detail of the springs area is provided on this map. Point 27 on map 5 is slightly upriver from F2 on map 4; point 40 is upstream about 50 meters from F3. **Table 1** gives information on each of the points shown on map 5.

Questions

1. Convert the scale of map 1 to cm and km. What is the scale in terms of 1:X?
2. On map 2, what distance (in meters) corresponds to 1 cm?
3. By what ratio is the scale of map 2 larger than that of map 1?
4. On map 3, what distance (in meters) corresponds to 1 cm?
5. On map 3, what measurement corresponds to 1 km
6. Map 4 is the same as map 3, except expanded twice by 141% each time. What scale should be shown for map 4? What distance corresponds to 1 cm? What measurement corresponds to 100 m?
7. Express the scale of map 5 as 1:X and as 1 cm = Y m.
8. How much larger is the scale of map 5 than that of map 1?
9. Determine the distance (in feet and meters) along the river from point 27 to point 40 on map 5.
10. Determine the distance (in meters) from F3 to F4 on map 4.
11. On map 5, approximately how many different springs on land have been identified (see also Table 1)? What problems make this counting difficult?
12. Points 28 to 40 may correspond to individual springs in the river. What are the arguments for and against this position? How could you test the hypothesis that 13 springs do arise in the river?

MAP 1

Las Vegas and Montezuma, NM

Scale : 1 in = 2.9 miles

Magnetic North ↑

U.S. Geological Survey (1961)

Magnetic North ↑

TOJITOS FRIOS 1172
4955 111 SE
SCALE 1:24 000

MAP 3: Montezuma, NM

Orienteering Map (1988)

MAP 4: Montezuma, NM

Enlarged Orienteering Map (1988)

MAP 5

Base from Plane Table Survey
January 2-3, 1966

MAP OF THE PREMISES OF MONTEZUMA HOT SPRINGS, SAN MIGUEL COUNTY, SHOWING THE LOCATIONS AT WHICH SAMPLES WERE COLLECTED AND FIELD MEASUREMENTS WERE MADE IN JANUARY AND FEBRUARY 1966.

TABLE 1

Field data for Montezuma Hot Springs, February 4, 1966

Location Fig. 56	Depth to water below land surface (feet)	Depth (ft)	Discharge (gpm)	Temperature (°F)	pH	Description
1*	3	3	---	130.1	8.8	A circular stone and brick well which extends 1-1/2 feet above the general land surface and has an internal diameter of 2-1/2 feet
	---	10	5.8	131.2		
	---	20	---	131.2		
	---	21	---	131.3		
2*	---	---	4.5	100.5	8.2	End of a 1-1/4 inch discharge pipe which probably delivers water from location 3 and a concrete covered well to which there is no access
3	3	3	---	129.5	---	A circular stone and meter lined well whose top is at the average land surface
	---	10	---	130.5		
3a	---	---	.5	---	8.6	Concrete covered well, no access
4	0	0	.5	77-78	---	Concrete through, averages 2 feet deep
	0	2	---	---		
4a	---	---	---	---	8.5	Concrete covered well to which there is no access, pH is of seepage
5	---	7	---	55	---	A circular stone and mortar lined well, partially filled with debris
6*	0	---	---	---	---	A concrete reservoir which ranges from 0 to 6 feet above the land surface and is dug into a steep slope. Its depth is about 11 feet
7*	0	1	4.5	71.3	8.2	A rock lined cavity covered with a rectangular stone slab with limited access
8	1	1	---	80.5	8.3	A partly destroyed stone well, whose top is at the land surface
	---	2	---	83.6	---	
9	---	---	3.2	43	8.2	End of 8 inch pipe which brings water from under the road
10	0	3	0	48.0	---	A square concrete and stone well
11	---	---	.1	39.2	---	End of 6 inch pipe which trickles water from under road
12*	---	---	.1	42.0	---	End of 2-1/2 inch pipe which trickles water from under road
13*	1/2	1/2	---	124.1	---	A concrete lined well which extends 3 feet above the general land surface
	---	6	---	124.0	---	
14	0	---	---	84	---	A concrete and stone well which receives discharge from loc. 15 and also discharges water itself into the seepage zone below
15*	2	2	---	51.5	8.4	A concrete and stone well which is full of rubble, depth indeterminable. Temperature of the discharging water 103.1°F
16*	0	0	3.2	108.7	8.9	A break in a wooden pipeline carrying water from map location 13
17	3	4	---	50	---	Well inside an old foundation, about 10 feet above Gallinas River

Field data for Montezuma Hot Springs, February 4, 1966 (cont.)

Location Fig. 56	Depth to water below land surface (feet)	Depth (ft)	Discharge (gpm)	Temperature (°F)	pH	Description
18*	0	0	2.0	125.0	7.9	Undeveloped spring
19*	---	---	5.2	117.3	8.3	Discharge pipe from concrete block reservoir. This reservoir supplies the seminary with water
20*	1	1	---	119.5	7.5	A small well
	---	6	---	120.5	---	
25	3.5	3.5	---	113.0	---	
	---	10	---	114.0		
	---	20	---	117.1		
	---	30	---	119.4		
	---	40	---	120.6		
	---	50	---	122.7		12 inch diameter well
	---	60	---	126.5		
	---	70	---	128.1		
	---	80	---	129.5		
	---	90	---	133.2		
	---	100	---	136.9		
	---	115	---	137.1		
26	4	5	---	42	---	6 inch diameter casing
27	---	---	---	---	---	Ice common on Gallinas River above this point
28	---	---	---	34.2	---	Gallinas River
29	---	---	---	33.8	---	Gallinas River
30	---	---	---	33.5	---	Gallinas River
31	---	---	---	39.0	---	Gallinas River
32	---	---	---	48.5	---	Gallinas River
33	---	---	---	48.8	---	Gallinas River
34	---	---	---	49.3	---	Gallinas River
35	---	---	---	49.6	---	Gallinas River
36	---	---	---	52.0	---	Gallinas River
37	---	---	---	55.0	---	Gallinas River
38	---	---	---	55.0	---	Gallinas River
39	---	---	---	56.0	---	Gallinas River
40	---	---	---	61.0	---	Gallinas River
41	---	---	---	106.0	---	
42	---	---	---	81.8	8.4	
43	---	---	---	67.5	7.9	
44	---	---	---	60.0	---	
45	---	---	---	94.0	---	
46	---	---	---	78.0	---	

TOTAL OUTPUT OF THE HOT SPRINGS

(Estimates prior to 1994)

Two previous estimates have been recorded for the total outflow of the hot springs. The first was made in 1966 and reported in the Catalog of Thermal Waters in New Mexico.

"Results of stream flow measurements made by the U.S. Geological Survey during February 1966 at map location 24, fig. 46 (see map 5) and at the gaging station downstream showed the following:

Site	Discharge (cfs)	Air Temp. (°F)	Water Temp. (°F)
24	0.42	28	33
gaging station	1.10	29	41

Assuming the difference to be due entirely to inflow at the springs, the spring flow was 325 gpm."

The data consist of stream flow values (discharge in cubic feet per second) above and below the springs. The difference was assumed to be the contribution from the hot springs. One value was determined by actually measuring the flow of the stream at site 24 (map 5), just above the hot springs. (See also F2 on map 4.) The other value was obtained by measuring the depth of the river at the gaging station about 500 meters downstream from site 40 on map 5. (See also F4 on map 2.) By comparing the reading on the gage to known values of stream flow and gage readings, the flow could be determined.

See Section on Rating Tables for further information and examples.

In 1993 a different method was used to estimate the total flow of the springs. The relevant section from the report by Nickerson is given below.

"The estimation of the total output of the springs is extremely difficult due to the nature of the seepage, and the fact that the primary springs have been routed and rerouted numerous times. The main spring near the bathhouse, discharges approximately 15 gpm into the bathhouse as measured at the bathhouse. ...The St. Michael Spring discharges approximately 5 gpm ... The two middle springs discharge approximately 4 gpm, and 1.5 gpm, ... This gives about 26 gpm from the largest springs, plus an estimate of approximately 5 gpm more from uncontained seeps, for a total discharge of approximately 31 gpm."

Nickerson did not identify the springs tested according to Map 1, but the first two are certainly springs 1 and 13, respectively. One of the "middle springs" is likely number 19; the other is uncertain, and may not be on the map because of changes mentioned by Nickerson.

Questions

1. Use the U.S.G.S. data to calculate the discharge in gallons per minute (gpm) and in $\text{m}^3 \text{min}^{-1}$. Comment on the results.
2. The two methods give very different results for total discharge from the hot springs. Comment on possible sources of error for each method. At this stage do you feel confident in choosing one result as more reliable than the other? Discuss your reasoning.

Further information about the discrepancy between these two estimates of flow may be obtained from additional data gathered at different times and locations. These measurements are described in Section XX.

MEASUREMENTS OF SEVERAL QUANTITIES TO EVALUATE TOTAL FLOW

The following measurements were taken at different locations, and may be useful in evaluating the flow measurements in Section XX.

conductivity, Δ_{25} : an indication of the total concentrations of all ions; higher values mean a higher concentration of ions. Measurements were taken with a portable instrument in the field and with a different instrument in the lab. The latter should be regarded as more reliable, especially at higher temperatures.

pH: a measure of the acidity of the water; a higher value indicates a less acidic solution. Measurements were made with a portable instrument in the field, and with a more reliable instrument in the laboratory.

temperature: measured in the field with an electronic instrument

chloride ion concentration, $[Cl^-]$: measured in the laboratory by titration with silver ion, and expressed as parts per million (ppm)

The above measurements were made at locations F2, F3, and F4 (see Map 4) and at the bathhouse spring (S1), site 2 on Map 5. Measurements made at approximately the same time at more than one river location are collected in Table 2.

TABLE 2**Measurements in River above and below Hot Springs**

Sampling location $\Rightarrow$		F2	F3	F4	S1
Date	Measurement $\Downarrow$				
7/12/94	$\Delta_{25}/\mu\text{mhos cm}^{-1}$ (field)	315	680	590	1200
	pH (field)	9.31	9.47		9.59
	Temperature/ $^{\circ}\text{C}$		28.9		54.4
	$[\text{Cl}^{-}]/\text{ppm}$	7	64		141
7/13/94	$\Delta_{25}/\mu\text{mhos cm}^{-1}$ (lab)	307	420	437	860
	pH (field)	9.26	9.42	9.41	9.66
	pH (laboratory)	8.52	8.63	8.62	8.95
	Temperature/ $^{\circ}\text{C}$	22.2	25.4	23.5	54.0
	$[\text{Cl}^{-}]/\text{ppm}$	4.9	35.8	32.5	150
7/29/95	$\Delta_{25}/\mu\text{mhos cm}^{-1}$ (field)		410	422	
	Temperature/ $^{\circ}\text{C}$		29.7	26.9	
7/31/95	$\Delta_{25}/\mu\text{mhos cm}^{-1}$ (field)	235	370	400	
	pH (field)	8.99	9.18	9.23	
	Temperature/ $^{\circ}\text{C}$	24.5	29.2	27.0	

Notice that river measurements were taken at F2, immediately above the springs, and at F3, immediately below the springs. Differences between measurements at these two locations should be due to the water entering the stream from the hot springs. Measurements on the water from the bathhouse spring are given for comparison. Measurements are also given for F4, further below the springs, at approximately the site of the U.S.G.S. lower gaging station. Examine the data carefully, recalling the large discrepancies in total spring flow estimates.

Questions

1. Which of the above measurements are most likely to differ from one day to another? Why?
2. Can you account for all changes between F2 and F3? Explain your reasoning.
3. Would you expect measurements taken at F3 and F4 to differ from each other? Explain.
4. Which measurement(s) show clear and consistent differences between F3 and F4?
5. How could this(these) difference(s) be accounted for? (Note that the measurements are usually taken a few minutes apart from each other, so conditions are not likely to change during such a short interval of time.)
6. Why do other measurements not show a clear and consistent difference between the two locations?
7. Suggest ways of testing your hypothesis(es) in your answer to question 5.

MEASUREMENTS AT INTERVALS DOWNSTREAM FROM F3

In order to investigate the possibility that water enters the river between locations F3 and F4, the data in Table 3 were collected by taking measurements of conductivity and temperature at roughly 20-meter intervals downstream from F3. Measurements were not taken past 220 meters downstream because the stream passed through private property, and the data already collected seemed adequate to evaluate the hypothesis.

TABLE 3**Measurements at Intervals Downstream from F3**

Distance from F3/meters	Time/hr:min	$\Delta_{25}/\mu\text{mhos cm}^{-1}$	Temp./°C	Comment
0 (F3)	15:00	410	28.6	
20	15:15	400	28.6	slow, sunny
40	15:25	400	29.3	slow, sunny
60	15:35	404	29.5	shady, rapids
77	15:45	406	29.4	shady, rapids, pool above small dam
82	15:50	400	29.1	below dam
100	16:05	400	28.6	
120	16:30	393	28.2	moderate speed
140	16:40	390	28.4	variable speed
160	16:50	393	28.2	variable speed
180	16:55	400	27.8	slow
200	17:05	403	28.3	very slow, shaded
220	17:25	410	28.4	very slow
0 (F3)	17:35	410	29.7	
F4	17:50	422	26.9	

The data may be easiest to interpret if they are plotted on an appropriate graph.

Questions

1. To what extent are the data above consistent with other data already presented?
2. Do the measurements change steadily with distance away from F3? If not, where do discrepancies occur?
3. How could any discrepancies be accounted for?
4. If water enters the river between F3 and F4, does the evidence indicate it to be "fresh" water (like that in the stream above the springs), or hot springs water?
5. Where do the data suggest that water enters the river? Is there more than one inlet?
6. Which is a better indication of water entering the stream, conductivity or temperature? Explain your reasoning.
7. Account for the change in temperature at F3 over two and one-half hours, even though the conductivity did not change.

ATTACHMENT F

The Hot Springs

at

Montezuma, New Mexico

Science Education Materials for Teachers

Section 6

MAPS

Map 1 is from The Roads of New Mexico, Shearer Publishing, 1990. This was compiled from county maps issued by the New Mexico State Highway and Transportation Department.

Map 2 is one of a set of U. S. Geological Survey maps which are produced for all areas of the United States. These are available from selected U.S.G.S. offices and from many shops specializing in equipment for hiking and camping.

The Gallinas is a very small river, only about 5 - 10 meters in width in the vicinity of the hot springs, and less than 0.5 m in depth in most places during low flow.

Many different gaging methods are used for determining river flow. A visit to a local gaging station would be of interest to students.

Water rights will be discussed in more detail in Section Z.

Map 5 and Table 1 are taken from W.K. Summers, A Catalog of Thermal Waters in New Mexico, Hydrologic Report 4, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, 1976.

Questions

Aims: interpret different scales on maps
convert units from one system to another
interpret and estimate distances on maps
interpret data and develop hypotheses for their explanation
propose tests of hypotheses

Answers

$$1. \frac{1 \text{ cm}}{2.9 \text{ mile}} \times \frac{2.54 \text{ cm}}{1 \text{ in}} \times \frac{1 \text{ mile}}{1.6 \text{ km}} = \frac{0.55 \text{ cm}}{1 \text{ km}} \Rightarrow \frac{1 \text{ cm}}{1.8 \text{ km}}$$

Ans: 1 cm = 1.8 km

$$\frac{1 \text{ cm}}{1.8 \text{ km}} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1 \text{ km}}{1000 \text{ m}} = \frac{1}{1.8 \times 10^6}$$

Ans: 1 : 180 000

Note: Proper use of significant figures has been used in the above calculations. The number 1 should be regarded as exact, but its equivalents in miles and km are reliable to only two significant figures. The final expression of 1 : 180 000 is conventional rather than accurate and should not be regarded as containing more than two significant figures. All subsequent calculations in this section contain only two significant figures, and the answers may be expressed in scientific notation to avoid ambiguity.

$$2. \quad 24\,000 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} = 240 \text{ m}$$

Ans: $2.4 \times 10^2 \text{ m}$

$$3. \quad \frac{180\,000}{24\,000} = 7.5$$

Ans: 7.5 times as large

Note: The smaller the second number in the scale ratio, the larger the scale of the map (the smaller the distance corresponding to the same unit of measurement).

$$4. \quad \text{since } 1 \text{ cm} \Rightarrow 15\,000 \text{ cm}, \quad 15\,000 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} = 150 \text{ m}$$

Ans: $1.5 \times 10^2 \text{ m}$

$$5. \quad 1 \text{ km} \times \frac{1 \text{ cm}}{150 \text{ m}} \times \frac{1000 \text{ m}}{1 \text{ km}} = 6.7 \text{ cm}$$

Ans: 6.7 cm

$$6. \quad 1.41 \times 1.41 = 1.99 \quad \text{This is an expansion by a factor of 2.0}$$

$$1 : 15\,000 \Rightarrow 75 \text{ m}$$

$$100 \text{ m} \times \frac{1 \text{ cm}}{75 \text{ m}} = 1.3 \text{ cm}$$

Ans: 1.3 cm

7. The scale shows $1 \frac{13}{16} \text{ in} \Rightarrow 200 \text{ ft}$; $1.8 \text{ in} \Rightarrow 2400 \text{ in}$

$$\frac{2400 \text{ in}}{1.8 \text{ in}} = 1.3 \times 10^3$$

Ans: Scale = 1 : 1300

OR $4.6 \text{ cm} \Rightarrow 200 \text{ ft}$; $200 \text{ ft} \times \frac{30.5 \text{ cm}}{1 \text{ ft}} = 6100 \text{ cm}$; $\frac{6100 \text{ cm}}{4.6 \text{ cm}} = 1.3 \times 10^3$

Ans: Scale = 1 : 1300

8. $\frac{180000}{1300} = 1.4 \times 10^2$

Ans: 1.4×10^2 times as large

9. The simplest method is to take a piece of string or wire, hold the end at one point, make it follow the bends of the river on the map, mark the other point, and measure the length of the string corresponding to the distance between the two points on the map. This gives a value of 12 in or 30.5 cm.

$$12 \text{ in} \times 1300 \text{ (scale factor)} \times \frac{1 \text{ ft}}{12 \text{ in}} = 1300 \text{ ft}$$

$$30.5 \text{ cm} \times 1300 \times \frac{1 \text{ m}}{100 \text{ cm}} = 400 \text{ m}$$

Ans: $1.3 \times 10^3 \text{ ft}$ or $4.0 \times 10^2 \text{ m}$

10. The distance is 6.1 cm; the scale is 1 cm = 75 m

$$6.1 \text{ cm} \times \frac{75 \text{ m}}{1 \text{ cm}} = 460 \text{ m}$$

Ans: $4.9 \times 10^2 \text{ m}$

11. Two locations on map 5 are not unique outlets of water but are a broken pipe (16) and an outlet from a spring already noted (19). Point 27 is a reference point rather than a spring. Other points, such as 41-46 are in two areas where water seeps from the ground, without a specific source. These could correspond to two different sources, or a larger number. Other areas of seeps do not have any numbers assigned to them. If locations within seeps are counted as one source, and if unnumbered seeps are

included, the number of springs on the land number approximately 32. The actual number may be greater than this, if there is more than one spring causing an area of seep. Old records show the following numbers:

1869 20-30 springs

1881 22 springs

1885 40 springs

(25 excavated and walled; 30 produced water at 120° - 140°F)

12. **For:** The temperature at the points indicated is far higher than one would expect in February from a general flow of hot spring water into the river. (See river temperatures, section M.) These high temperatures indicate point sources.

Against: Points close together may correspond to one spring producing a large amount of hot water. No indication is given of temperatures at other locations. No evidence is available to rule out one or more small springs between points 36 and 37, for example.

Test: To find the actual number of springs, a detailed grid system could be set up for the river, and temperature measurements could be taken at many regularly spaced locations over a short period of time. This would give a much more detailed pattern of temperatures, from which sources of hot water could be inferred.

TOTAL OUTPUT OF THE HOT SPRINGS

Questions

- Aims:** convert units from one system to another
 recognize that published information may contain error
 analyze sources of error in procedures
 evaluate results obtained by different methods

In this and the following sections, students (and teachers) will have to deal with ambiguous data. In some cases data can be interpreted with confidence; in others no definite conclusion is possible. An important skill is the ability to distinguish the degree of certainty with which conclusions can be extracted from a set of data. In real situations, a first set of data often leaves more than one possible solution. The scientist's task then is to design further tests to reduce the number of possible conclusions.

Answers

1. The difference in flow is $1.10 - 0.42 = 0.68 \text{ ft}^3 \text{ s}^{-1}$.

$$\frac{0.68 \text{ ft}^3}{\text{s}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{60 \text{ s}}{\text{min}} = 3.1 \times 10^2 \text{ gal min}^{-1}$$

Ans: $3.1 \times 10^2 \text{ gal min}^{-1}$

The value given in the article is not consistent with the data provided. Either there is a misprint in the original data, or the calculation is wrong. We tend to think that published scientific information is authoritative, but such errors are not uncommon.

$$\frac{0.68 \text{ ft}^3}{\text{s}} \times \left(\frac{0.305 \text{ m}}{\text{ft}} \right)^3 \times \frac{60 \text{ s}}{1 \text{ min}} = 1.16 \text{ m}^3 \text{ min}^{-1}$$

or

$$\frac{0.68 \text{ ft}^3}{\text{s}} \times \left(\frac{12 \text{ in}}{1 \text{ ft}} \right)^3 \times \left(\frac{2.54 \text{ cm}}{1 \text{ in}} \right)^3 \times \left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^3 \times \frac{60 \text{ s}}{1 \text{ min}} = 1.16 \text{ m}^3 \text{ min}^{-1}$$

Ans: $1.16 \text{ m}^3 \text{ min}^{-1}$

2. Problems with flow differences

(a) The lower gaging station is nearly 500 m downstream from the end of the springs. Other sources of water might exist between F3 and the gaging station, , which would increase the differences between the quantities measured at the two locations. Students might not come up with this suggestion at this point; it could be left open until the next section.

(b) It is difficult to take measurements within only a short time interval. If the flow of the river changes significantly during the course of an hour, measurements taken over that interval are not comparable. These changes do in fact occur at some times (see Section YY), but students probably are not aware of that fact at this time , so are unlikely to come up with this suggestion.

Problems with estimates of flows of individual springs

(a) Outflows from seeps are difficult or impossible to measure.

(b) Not all sources were measured (compare description of measurements with Table 1), although the totals are similar.

(c) Some springs may be in the river.

Students should be able to come up with at least two of these possibilities.

The discrepancy between the two estimates is very large, but there is nothing so far to indicate that one is clearly more reliable than the other.

MEASUREMENTS OF SEVERAL QUANTITIES TO EVALUATE TOTAL FLOW

Questions

Aims make reasoned predictions of possible experimental results
 account for experimental results in terms of simple models
 evaluate experimental data to find patterns
 interpret data and develop hypotheses for their explanation
 propose tests of hypotheses

Answers:

1. Temperature varies according to the weather. Change with season should be much greater than variation from one day to the next. Ion concentrations depend on the amount of water, since heavy rainfall dilutes the water in the river. pH may also change for the same reason, but not to such a great extent because the river water is buffered to a significant extent.

Only relatively advanced students will find this last argument meaningful. The main point to this question is to encourage students to consider and evaluate their ideas, rather than to come up with a specific set of answers. Closer examination of the data should be used to evaluate the predictions.

2. From F2 to F3,

Ans increases because of inflow of springs with higher ion concentrations
pH increases slightly because of inflow of springs with higher pH
temperature increases because of inflow of springs with higher temperatures
[Cl⁻] increases considerably because of inflow of springs with much higher chloride ion concentrations

3. No change between F3 and F4 would be expected unless another source of water enters the stream between these two points.

4. Only temperature shows a substantial and consistent change (decrease) from F3 to F4. Conductivity shows one large decrease and three small increases. pH shows very small changes which are not consistent in direction. Chloride ion concentration was measured only once at both locations, and shows a decrease.

5. The most likely explanation for a decrease in temperature is the possibility that cooler water enters the river between F3 and F4. Since the measurements were made in July, it is unlikely that contact with the air would cause significant cooling. (This point would be more convincing if air temperature data were available.) If water with relatively low ion concentrations enters the river between F3 and F4, that possibility could account for the decrease in chloride ion concentration (measured on 7/13/94 only) and conductivity (measured on 7/12/94).

6. pH shows changes which are small and inconsistent because the pH of the springs is not very different from that of the river. The increases shown in conductivity measurements are small and inconsistent with the relatively large decrease shown on 7/12/94. There is no obvious explanation for the increases, which are inconsistent with expectations.

7. (a) Take temperature measurements in the river at regular distance intervals between F3 and F4;

(b) Conductivity measurements could also be taken, but may not prove as useful as temperature measurements;

(c) Inspect for fresh water inflow along the river between F3 and F4.

TEMPERATURE AND CONDUCTIVITY MEASUREMENTS BETWEEN F3 AND F4

Data for temperature and conductivity should be plotted as a function of distance. If both variables are plotted on one graph (see Graph T1 as an example), any common pattern is more likely to be seen. This graph was plotted using the Cricket Graph program. In order to plot both variables on a common vertical axis, the temperature was multiplied by a factor of 15.

Questions

- Aims**
- evaluate the consistency of different sets of data
 - find patterns in data
 - account for experimental results in terms of simple models
 - interpret data and develop hypotheses for their explanation

Answers

1. Both temperature and conductivity show very similar values at F3 (distance = 0) and 220 meters downstream. At F4, conductivity is slightly higher and temperature slightly lower than at F3. These data were obtained on 7/29/95, and appear in Table 2.
2. Neither measurement changes consistently with distance, nor are discontinuities consistent with each other. For example, between 120 and 140 m, temperature rises and conductivity falls. The opposite happens from 140 to 180 m. Beyond 180m, both rise. No model can account for this inconsistent pattern of changes. Consistent discontinuities occur at about 80 m and between 100 and 1230 m when both values decrease.
3. The above changes (about 80 and 100-120 m) are consistent with additional water entering the stream.
4. If additional water enters the stream, it must be fresh, with lower temperature and ion concentration, to account for the decreases in temperature and conductivity.
5. Data are consistent with two inflows at about 80 m and between 100 and 120 m. Other temperature decreases are contradicted by conductivity increases, except between 80 and 100 m. Inspection of the stream reveals inlets of fresh water at 92 and 106 m. The following measurements were made on the incoming water:

<u>Distance/m</u>	<u>Temperature/°C</u>	<u>Δ_{25} / $\mu\text{mhos cm}^{-1}$</u>
92	15.6	370
106	16.1	320

These values suggest why temperature changes between 80 and 100 m while conductivity does not. The incoming water has a conductivity only slightly less than that of the stream, while the temperature shows a much greater difference. The misleading decrease at about 80 m must be due to the obstruction in the river at that point.

6. Neither measurement by itself seems adequate, since both show decreases where the other measure increases.

7. The temperature at F3 rose by 1.1°C in the late afternoon. This could be due to warming by the sun, which should not affect conductivity.