THESIS

DATA ANALYSIS AND REPORTING PROTOCOLS FOR GROUND WATER QUALITY MONITORING IN THE SAN LUIS VALLEY, COLORADO

Submitted by
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In partial fulfillment of the requirements
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY LACEY R. GOETZ ENTITLED DATA ANALYSIS AND REPORTING PROTOCOLS FOR GROUND WATER QUALITY MONITORING IN THE SAN LUIS VALLEY, COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASER OF SCIENCE.

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ABSTRACT

DATA ANALYSIS AND REPORTING PROTOCOLS FOR GROUND WATER QUALITY MONITORING IN THE SAN LUIS VALLEY, COLORADO

This thesis investigates the concept of designing a regional, long term, ground water quality information system that complies with all of the laws and regulations applicable and provides information needed by water resource managers, water users, and the general public for the upper, unconfined aquifer in the San Luis Valley, Colorado. A set of "Integrated Information Goals" was developed by Bagenstos (1994) and provides the foundation for this thesis.

The laws forming the bases of the information goals are examined further to provide a rationale for translating the information goals into quantifiable statements. These statements are subsequently examined to determine if statistical analysis is required and to develop statistical goals where needed. Statistical methods for handling the data to meet the statistical goals are suggested. Via this exercise, monitoring activities and subsequent data analyses are directly linked to the information goals by the data analysis protocols developed.

Reports currently generated that include information about the quality of the water in the upper aquifer of the San Luis Valley are reviewed, along with EPA's requirements for reporting ground water quality and recommendations for preparing reports presented by the Intergovernmental Task Force on Monitoring. A report format is suggested and samples of graphics for quick and easy conveyance of water quality information sought are provided. This exercise provides the people of the San Luis Valley with a method for ensuring the monitoring system is productive because the final product is defined prior to implementation of the monitoring system.

The purpose of this thesis is to demonstrate how to link monitoring activities to legislation, ensuring the accountability of monitoring systems, and providing scientifically defensible information that meets the needs of resource managers and water users.

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CHAPTER I

INTRODUCTION

A. THE NEED FOR DATA ANALYSIS AND REPORTING PROTOCOLS

Typically, gathering of information about the environment for protection and management has been dictated by Congress and implemented by the Environmental Protection Agency or the U.S. Geological Survey or other Federal, state, or local agencies required to implement environmental laws. Ground water quality is a specific case in point. Many of the laws passed by Congress and the State of Colorado call for monitoring of aquifers for various purposes, yet specifics about what information is required, how the information is to be obtained, how the information is to be presented, and even whether the information can actually be produced or not, are lacking. Indeed, Ward *et al.* (1990) state: "It is left to the professionals hired by the government to implement the law to decide how the results of monitoring are to be used in management decision making." And Ward (1994) lists 13 reports and papers that point out the problem of monitoring systems collecting substantial data but not producing the desired information regarding the quality of the water.

Discussions about how to design ground water quality monitoring systems necessarily begin with trying to identify what information is legally and managerially required. Just stating the information goals, however, is insufficient as Ward *et al.* (1990) note; if the acquisition of data is not clearly connected with the production and use of the information from the data, the data are often simply collected and not used. Identifying the information goals

and outlining how the data will be collected, analyzed, and reported **before** implementing the monitoring system is critical to ensuring the success of the system. Outlining how the data will be collected and analyzed is important as these steps quantify what information the system is capable of producing. Ward *et al.* (1990) point out that information expectations that far exceed the ability of the system to produce information may be one of the major failings of past monitoring systems.

B. WHY THE SAN LUIS VALLEY?

The San Luis Valley is a good location to begin discussions of implementing a long-term ambient ground water quality monitoring network for several reasons. Much work on ground water quality has already been conducted in the Valley, and the unconfined aquifer has been found to be highly vulnerable to ground water contamination (Durnford *et al.,* 1990). This discovery underscores the need to monitor ground water quality. Indeed, Durnford *et al.* (1990) recommend a long-term ground water quality monitoring system be implemented in the San Luis Valley. Ground water is the main source of water in the Valley, not only for drinking water but also for agriculture, the major industry in the area. The importance of ground water is well known to the residents of the Valley due to a recent effort by American Water Developers, Inc. (AWDI) to export large quantities of water for use elsewhere. This attempt by AWDI resulted in a lawsuit regarding inter-basin transfers of water and heightened the awareness of Valley residents about the importance of ground water in their communities. Finally, regulatory information goals have been identified by reviewing all the applicable laws regarding ground water quality in the San Luis Valley (Bagenstos, 1994).

C. THE PROBLEM

There have been a large number of ground water quality studies conducted in the San Luis Valley over the past ten years. These include studies conducted by the U.S. Geological Survey (USGS) in 1972, 1973, 1984, 1989, and 1995; a study done by Colorado Department of Public Health and Environment (CDPHE) in 1993; studies done by Colorado State University (CSU) in 1990 and 1993; and ongoing studies by the Bureau of Reclamation (BOR) in conjunction with the Closed Basin Division Project (CBD), by the San Luis Valley Water Quality Demonstration Project, the Soil Conservation Service, and by independent agricultural engineers operating in the Valley. Each of these studies was conducted to answer a particular question or several questions about the quality of ground water in the San Luis Valley. Due to the disparity of motives, techniques employed, wells sampled, and agencies involved, much of the data gathered during these investigations cannot be compared.

Additionally, it is sometimes very difficult to obtain current data from studies due to a variety of reasons such as: extremely long review times, insufficient agency personnel to complete reports in a timely fashion, fear of misinterpretation of the data, difficulty in assimilating the data because it is not in a computerized format, and because of "proprietary" concerns. These "proprietary" concerns are understandable as sometimes data are taken out of context, misinterpreted, or exaggerated. This can result in media sensationalism, unfounded health scares, or overreaction in the political arena resulting in unduly restrictive regulations.

While past investigations provide information on many aspects of the geo-hydrological dynamics at work in the Valley, questions concerning water quality trends, and baseline conditions remain. Indeed, the USGS (Anderholm *et al.,* 1995), Thompson (1993) and CDPHE Water Quality Control Division (WQCD)

(1992) site the lack of a sufficient number of multiple analyses at an individual well as a reason for the inability to quantify long-term trends in ground water quality. While there is a current contract to monitor nitrate concentrations in ground water over the years 1994 and 1995 (Cain 1994), none of the agencies is actively involved in detecting long-term trends in the quality of the ground water in the San Luis Valley as called for by Durnford *et al.* (1990). No agency (Federal, state, or local) has taken the responsibility to inform the public or the agencies collectively what the ground water quality is over time and space on a regular basis. In other words, the overall accountability for reporting ground water conditions in the San Luis Valley is missing.

D. PURPOSE

The purpose of this thesis is to examine how legally required information and information desired by interested parties can be coupled with available data analysis and reporting methods to define how the results of a long-term ground water quality monitoring system can meet information goals regarding the quality of ground water in the upper aquifer of the San Luis Valley and hence, provide accountability for the management of ground water resources in the Valley.

More specifically, this study will:

1. Articulate information goals of a long-term ground water quality monitoring effort in the San Luis Valley.
2. Identify the role of statistics in providing the information goals articulated.
3. Recommend data analysis methods for a long-term ground water quality monitoring system in the San Luis Valley.
4. Investigate reporting requirements for legal and public accountability regarding ground water quality conditions.
5. Suggest reporting formats for presenting ground water quality information in the San Luis Valley.

E. WATER QUALITY MONITORING SYSTEMS

Based on the flow of information, Ward *et al.* (1990) define a complete water quality monitoring system as shown in Figure 1.

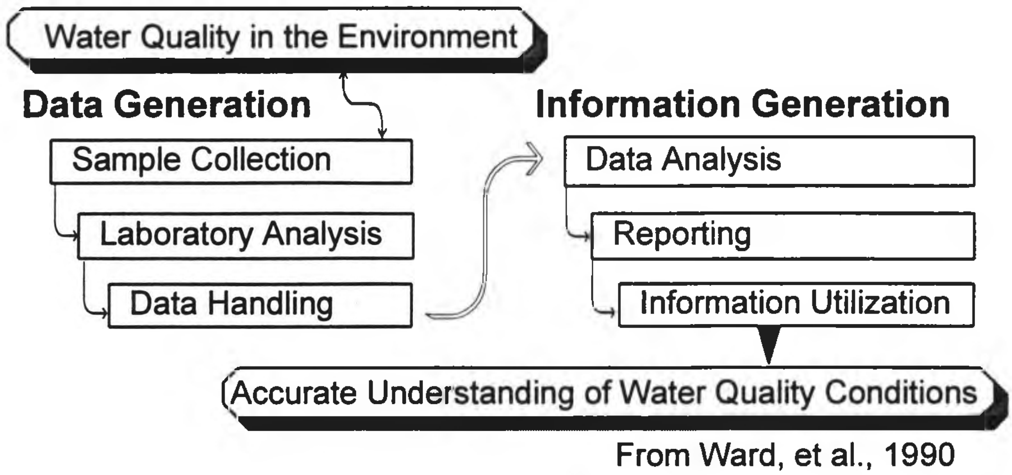

Figure 1. Water quality monitoring system.

As labeled in Figure 1, the first three components are the data generation portion and the last three components are the information generation portion. Past monitoring systems have tended to focus on the first three components, that is, the data generation portion, and ignored or only gave cursory attention to the last three components thus contributing to the "data rich, but information poor" syndrome. To guard against this shortcoming of past monitoring systems, this thesis focuses on the information generation portion of a long-term ground water quality monitoring system for the San Luis Valley, Colorado.

In a comprehensive monitoring system, long-term trend detection represents only a portion of the overall system. To ensure maximum utilization of information, relationships of the different parts of the monitoring system must be pre-defined. Payne and Ford (1988) and Pollack and Ford (1989) present a wheel and axle model that provides an excellent method for visualizing the relationships between the various parts of a monitoring system. The wheel and axle model has been adapted to the San Luis Valley, Colorado, as shown in Figure 2.

The "wheels" represent special studies, and the "axle" represents the fixed-station, long-term trend monitoring portion of the system. Prior to the implementation of a comprehensive, documented system, the axle is shown as dashed and the wheels are not connected to the axle as past studies usually have not been "connected" to fixed-station, trend monitoring studies if such studies were even underway. After the entire system has been designed and implemented, the axle appears as a solid line with the "wheels" attached.

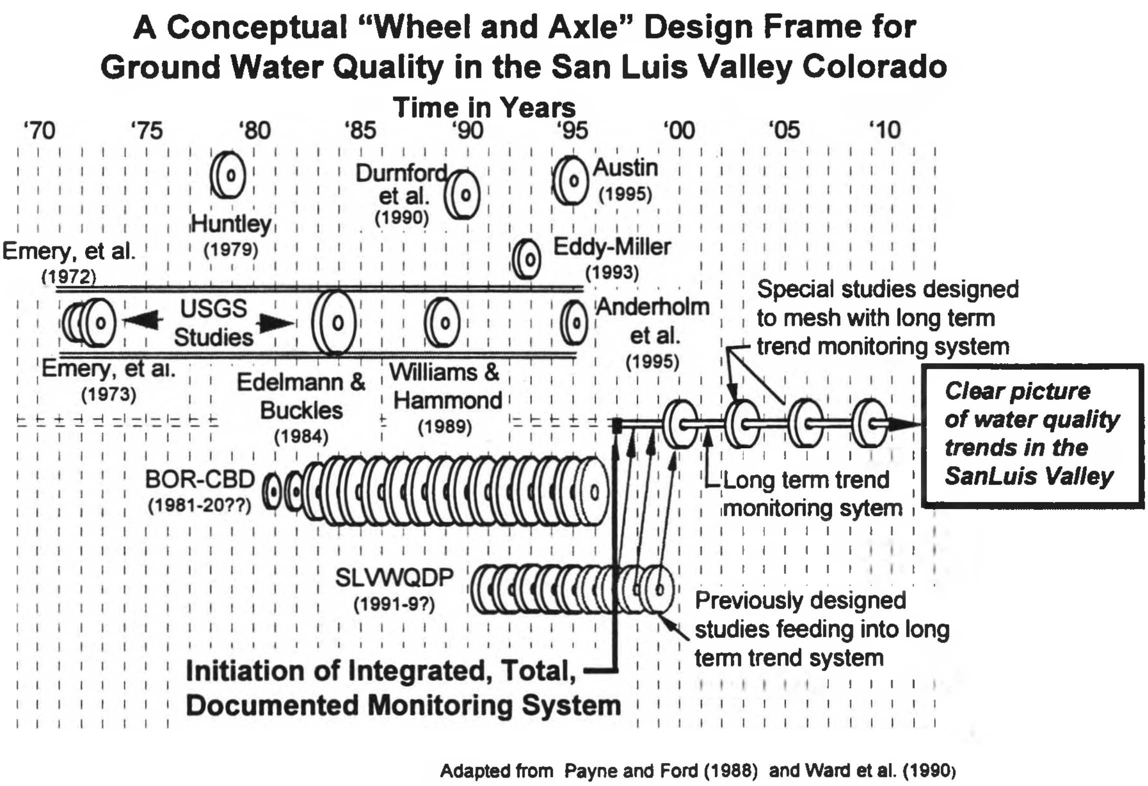

Figure 2. A conceptual wheel and axle design frame for the San Luis Valley, Colorado.

Figure 2 illustrates how past investigations in the San Luis Valley were not connected and, therefore, do not provide information on long-term water quality trends in the Valley as noted by USGS (Anderholm *et al.,* 1995) and Thompson (1993). Ensuring the different parts of the monitoring system are connected and consistent requires the data generation components identified above (sample collection, laboratory analysis, data handling) be the same, or correlated for each study. Ensuring the data generation components are related requires delineation and use of data generating protocols, which can be defined as the standard operating procedures to collect samples, analyze samples, and handle data. As noted previously, data generating has tended to be the focus of past monitoring systems and, hence, sufficient standard operating procedures, i.e., data collection protocols for ensuring consistency and comparability between data from different studies already exist. Therefore, within the wheel and axle model, this thesis addresses the "axle," i.e., the long-term trend detection portion of the monitoring system.

F. SCOPE

Ward *et al.* (1990) present a five-step framework for the design of monitoring systems as follows:

Step 1. Define information needs of management,
Step 2. Define information that can be produced by monitoring,
Step 3. Design the monitoring network,
Step 4. Document data collection procedures, and
Step 5. Document information generation and reporting procedures.

Within the five-step framework, this thesis addresses steps 1, 2, and 5. Step 1, defining information goals, is a three-stage process (Adkins, 1993). The first stage is identifying regulatory information goals by reviewing applicable laws and regulations. This stage has been done for the San Luis Valley by Bagenstos (1994). The second stage is included in Chapter III and consists of further refinement of the regulatory information goals into more specific and quantifiable monitoring information goals. The final stage involves developing specific statistical methods for meeting the monitoring information goals. In this context, statistical methods are data analysis protocols which subsequently define the information that can be produced by the monitoring system. Thus, developing specific statistical methods completes Step 2 of the framework for design and is the subject of Chapter IV.

Step 5, documenting information generation and reporting procedures, is addressed in Chapter V. In an attempt to determine the best methods for presenting the results of the monitoring system, the first half of Chapter V is a review of current reports generated including identification of: report recipients, law or regulation requiring the report, and current formats. The second portion of Chapter V discusses requirements for the preparation of 305 (b) reports for EPA, reviews the recommendations of the Intergovernmental Task Force on Water Quality Monitoring (ITFM) regarding audience categories and presentation techniques, and explores a method for ensuring integrity of graphical presentations of quantitative information. Finally, recommendations of reporting formats for presenting long-term ground water quality information are introduced at the end of Chapter V.

This study is directed to those individuals who will ultimately be responsible for the design and implementation of a long-term ground water quality monitoring system for the upper, unconfined aquifer of the San Luis Valley. Unfortunately, the most up-to-date and comprehensive data record analyses and/or reports were not available for evaluation in this thesis. These include the recent Rio Grande National Water Quality Assessment (NAWQA) study conducted by the USGS, which is not yet ready for publication[1], the well water survey done by the Colorado Department of Public Heath and the Environment,

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[1] Personal comm. with Steve Richey of the USGS.

Water Quality Control Division, Ag. Chemicals Program, which is not yet complete[2], the information gathered and analyzed for the American Water Developers, Inc. lawsuit which is not being released because "the investigators or their clients are reluctant to release the data"[3], and the information the Bureau of Reclamation collects during the daily operation of the Closed Basin Division which is not being released due to concerns of misinterpretation[4]. Also, the data collected by the BOR is not in an electronic format and would require substantial effort to analyze statistically.

No new data will be gathered for this report as substantial information is soon to be released in the reports listed above. This study is limited to examining water quality information generation, reporting, and accountability and is oriented toward ensuring the information resulting from a long-term ground water quality monitoring system is presented, in a useable format, to those who need it for resource management and policy making.

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[2] Personal comm. with Brad Austin of CDPHE.
[3] Written comm. from John Allen Davey of Davis Service Engineering, Inc., Sept. 22, 1994.
[4] Personal comm. with Charlie Johnson of the BOR Closed Basin Division.

CHAPTER II

BACKGROUND

While examining data analysis and reporting protocols for a regional, long-term, ground water quality monitoring system is a relatively new process, several references discuss data analysis methods and reporting formats in general. These references are discussed in the section in which the protocols are developed. This organization aids in linking the development of the suggested methods to the background work done in these areas. The remainder of this chapter is devoted to describing the San Luis Valley as the case study and listing investigations already conducted in the Valley to provide a quick reference and to lay the foundation for future work.

A. THE SAN LUIS VALLEY

The San Luis Valley is a high, inter-mountain, desert Valley with the Sangre de Cristo Mountains on the east and the San Juan Mountains on the west, the junction of these two mountain ranges on the north and the border, with New Mexico on the south. It comprises approximately 3200 square miles, has an average elevation of 7700 feet (Edelmann and Buckles, 1984) with an average slope of 6 feet per mile (Durnford *et al.,* 1990) and receives approximately 7.5 inches of rain annually (Edelmann and Buckles, 1984). Figure 3, shows the Valley, the outline of the upper, unconfined aquifer, and the boundary of the Bureau of Reclamation's Closed Basin Division project.

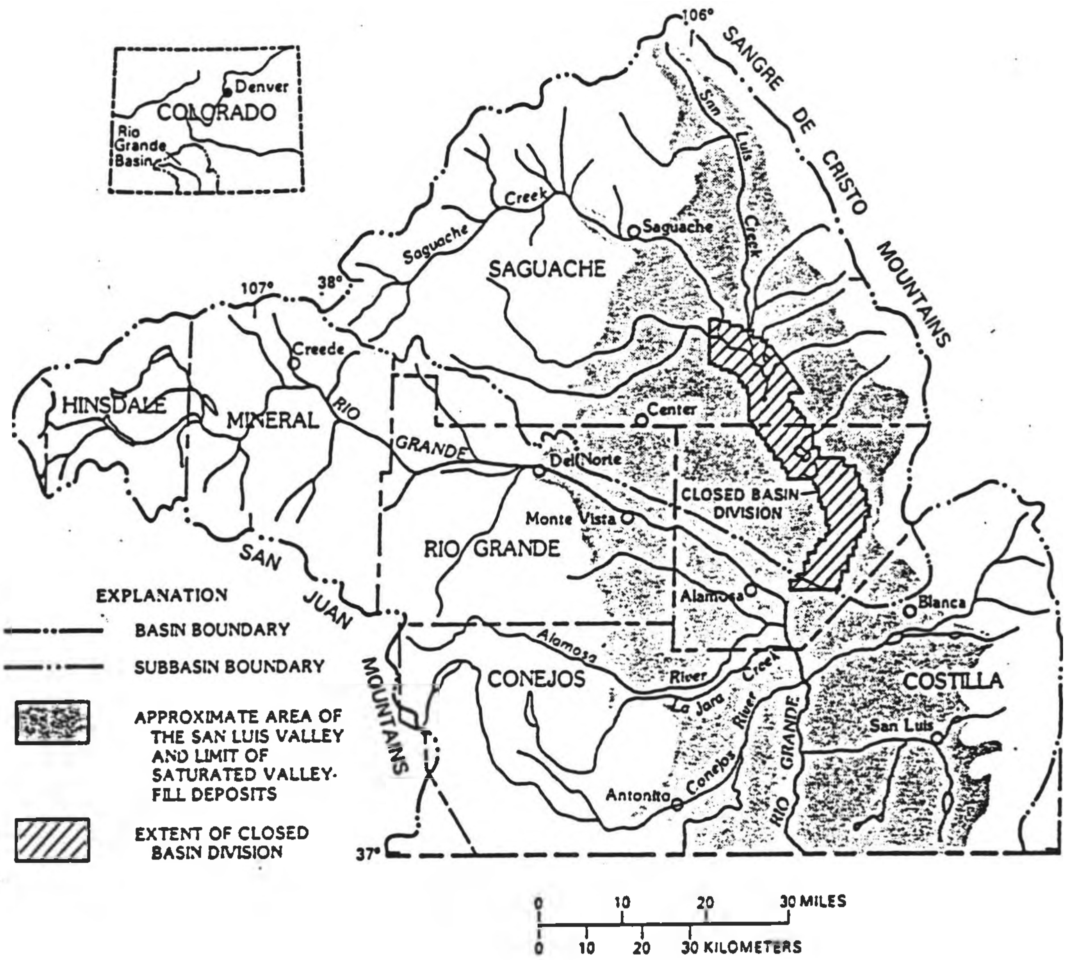

Figure 3. Map of the San Luis Valley.

The ground water system in the Valley consists of an unconfined upper aquifer and a confined lower aquifer. The main industry in the Valley is agriculture irrigated mostly by ground water. Eighty percent of the large capacity irrigation wells are completed in the unconfined aquifer (Emery *et al.*, 1973). The unconfined aquifer is vulnerable to pesticide contamination (Durnford *et al.*, 1990) and some water quality problems such as local areas of high nitrates and local areas of high salinity hazard have been identified (Edelmann and Buckles, 1984).

B. INVESTIGATIONS IN THE SAN LUIS VALLEY

1. ORGANIZATION

This section is divided into two parts: Conceptual Ground Water Flow and Previous Ground Water Quality Investigations. Each part is further categorized by the agency that performed the investigation followed by the author, the year the study was published, the title of the investigation, purpose, and conclusions. This section is intended to provide quick reference to the available information on ground water quality in the Valley. If additional or more in depth information is desired, the reader is directed to the reference cited. It also should be noted that, although every attempt was made to be thorough and complete, this may not include every ground water investigation conducted in the Valley. However, it does provide sufficient background information on the most prominent studies done.

2. CONCEPTUAL GROUND WATER FLOW

a. UNITED STATES GEOLOGICAL SURVEY

Hearne, G.A. and J.D. Dewey, 1988:

> *Hydrologic Analysis of the Rio Grande Basin North of Embudo, New Mexico, Colorado and New Mexico.*
>
> "The purposes of this study are to: (1) Provide estimates of water exchange rates between components of the flow system; and (2) improve the ability to estimate the hydrologic changes in the ground-water flow system in response to management alternatives."

"Ground water occurs in a variety of conditions (figure 3) within the study area. Perched or semiperched conditions occur in aquifers of the Toas Plateau (not included in the Valley) (Winograd, 1959, p. 34), the Costilla Plains (Winograd, 1959, p. 25) and around the perimeter of the Alamosa Basin and indicate that water is flowing from shallow to deeper aquifers of the system."

Leonard, G.J. and K. R. Watts, 1988:

Hydrogeology and Simulated Effects of Ground-Water Development on an Unconfined Aquifer in the Closed Basin Division, San Luis Valley, Colorado. In cooperation with the U.S. Bureau of Reclamation.

"This report describes the hydrogeology of the San Luis Valley and emphasizes the closed basin in the northern part of the Valley."

b. OTHERS

Huntley, D. L. , 1979:

Ground Water Recharge to the Aquifers of the Northern San Luis Valley, Colorado. Department of Geological Sciences, San Diego State University, San Diego, California.

Purpose:

"... to focus specifically on the ground water recharge system of the northern San Luis Basin (p. 1198)."

Conclusions:

"... the basin can be divided into three distinct, but hydrologically interconnected regions (p. 1251)." These are the Sangre de Cristo Mountain Range, the San Juan Mountain Range, and the San Luis Valley. "Ground-water recharge to the western San Luis Valley is primarily from ground-water flow in the volcanic rock of the San Juan Mountains. Ground-water recharge to the eastern Valley is primarily from seepage of surface water into the upper parts of the alluvial fans bordering the eastern edge of the Valley (p. 1252)."

"Ground-water flow in the confining clays is vertically upward through all of the western half of the basin and most of the eastern half, recharging the unconfined aquifer with water from the confined aquifer (p. 1249)."

"... ground water in both aquifers does flow from the Valley margins to the center of the basin (p. 1227)."

"... ground-water divides at the extremities of the basin are coincident with surface-water divides (p. 1243)."

"Ground-water flow in the unconfined aquifer is near-horizontal everywhere in the San Luis Valley except near the central drainages, where a vertical upward component of motion becomes important, and near the Sangre de Cristo fault, where a vertical downward component of motion becomes important (p. 1250)."

3. Previous Ground Water Quality Investigations

a. United States Geological Survey

Emery, P.A., R.J. Snipes, and J.M. Dumeyer,

Hydrologic Data for the San Luis Valley, Colorado. In cooperation with the Colorado Water Conservation Board and Colorado Division of Water Resources (Basic Data Release No. 22).

Purpose:

"The purpose of the study is to provide the hydrologic information needed by state and local agencies for recommending sound water-development and water-management practices." Data was collected from July 1966 to July 1970.

Conclusions:

This is a basic data release and as such does not present conclusions.

Emery, P.A., R.J. Snipes, J.M. Dumeyer, and J.M. Klein, 1972:

Water in the San Luis Valley, South-Central Colorado. In cooperation with the Colorado Water Conservation Board and Colorado Division of Water Resources (Circular 18).

Purpose:

"The purpose of this report is to summarize recent data regarding the occurrence, availability, use, quantity, and quality of the ground- and surface-water resources of the Valley (p. 2)."

Conclusions:

"Upward leakage from the confined aquifer to the unconfined aquifer occurs through and around the clay layers. An estimated 0.6- to 0.8-foot of water per unit area leaks upward each year. Although this is a tenuous estimate, the fact that leakage occurs is certain, and that it involves considerable amounts of water is important (p. 12)."

"No long-term fluctuation in the water table has been detected (p. 14)."

"The chemical quality of water in the unconfined aquifer is excellent around the rim of the Valley. ... As the ground water flows toward the center of the Valley, a deterioration in water quality occurs (p. 15)."

"The chemical composition of the water in the unconfined aquifer changes with increasing concentration of dissolved solids as the water moves laterally toward the center of the Valley (p. 18)."

"The dissolved-solids concentration is the most important single criterion for irrigation-water quality (p. 15)."

"Nitrate was detected in excessive concentrations in the unconfined ground water of the Rio Grande fan (p. I. 5). The high concentration of nitrate is probably the result of heavy applications of chemical fertilizer during the last decade (p. 19)."

"[Nitrate] Concentration is primarily a function of depth–a well 45 feet deep will have a higher nitrate concentration than a well 90 feet deep."

Edlemann, Patrick and D.R. Buckles, 1973:

Quality of Ground Water in Agricultural Areas of the San Luis Valley, South-Central Colorado. In cooperation with the Rio Grande Water Conservation District.

Purpose:

"The purposes of this investigation were to describe the chemical quality of the ground water in the principal agricultural areas of the San Luis Valley and to assess temporal trends in the quality of ground water (p. 3)."

Conclusions:

"In most areas, the nitrite plus nitrate as nitrogen concentrations generally are less than 1 milligram per liter. However, the quality of water from wells completed in the unconfined aquifer in certain parts of the study area may pose potential health and agricultural hazards due to high concentrations of nitrate as nitrogen and high concentrations of dissolved solids resulting from recharge from irrigated fields (p. 24)."

"Nitrite plus nitrate concentrations exceeded the drinking-water standard in water sampled from wells completed in the unconfined aquifer near Center ...The highest nitrite plus nitrate concentration, expressed as nitrogen, measured in this area was 33 milligrams per liter (p. 12)."

"The most significant fact is that a well drilled and completed in the upper part of the unconfined aquifer is likely to yield water having greater concentrations of nitrogen than a well completed at the base of the aquifer (p. 14)."

"Some of the water from wells completed in the unconfined aquifers in the study area contain high concentrations of dissolved solids. This water has a high to very high salinity hazard... The high salinity hazard in ground water seems to occur in these areas where evapotranspiration from a shallow water table and leaching of salts by recirculation of applied water may be concurrently concentrating the dissolved solids in the ground water. In certain parts of the area, the ground water having high dissolved-solids concentrations also contains a high percent of sodium resulting from ion exchange. The combination of a high percent of sodium in combination with relatively low concentrations of calcium and magnesium results in a high sodium (alkali) hazard (p. 24)."

"Areas of very high and high salinity hazard extend over large portions of the unconfined aquifer in the study area..."

"A few small areas of very high and high sodium (alkali) hazard were found..."

Williams, R.S., Jr. and S.E. Hammond, 1989:

Selected Water-Quality Characteristics and Flow of Ground Water in the San Luis Basin, Including the Conejos River Sub-basin, Colorado and New Mexico.

Purpose:

"1. Describe the screening procedure used to evaluate water-quality data in the WATSTORE files and to tabulate data for selected water-quality characteristics...

"2. Describe the water types, based on percent composition of major ions present in the shallow aquifer system (less than 100 ft deep and the deep aquifer system (more than 100 ft deep). Additional water-quality characteristics, including dissolved-solids concentration, water temperature, and concentrations of fluoride and tritium, also are described.

"3. Describe the change in ground-water quality as ground water flows from areas of recharge to area of discharge."

Anderholm, S.K., M.J. Radell, and S.F. Richey, 1995 (Provisional):

Water-Quality Assessment of the Rio Grande Valley Study Unit, Colorado, New Mexico, and Texas–Analysis of Selected Nutrient, Suspended-Sediment, and Pesticide Data.

This report is not yet complete, however, preliminary data and a draft report have been graciously provided for information purposes only. All information is subject to change until the final review is completed.

Purpose:

"The purposes of this report are to (1) describe the spatial and temporal availability of nutrients, suspended-sediment (or suspended-solids), and pesticides data in the Rio Grande Valley study unit, and (2) present and evaluate the spatial and temporal patterns of concentrations and loads within the study unit. ... Information presented includes the sources and types of water-quality data available, the utility of water-quality data for statistical analysis, and a description of recent water-quality conditions and trends and their relation to natural and human factors (p. 3)." Only 16% of this study is in Colorado (the San Luis Valley), less than 1% in Texas and the remainder in New Mexico. This study includes surface water as well as ground water.

Conclusions:

"The number of multiple analysis at a particular well were generally insufficient to study temporal trends (p. 26).

"For the ground-water analysis, the summary statistics were calculated using an adjusted log normal maximum likelihood estimator (Helsel and Hirsch, 1992). Tukey's test was done on the ranks of the data to determine if there were differences in the median nutrient concentrations at the 0.05 probability level between groups of data (Helsel and Hirsch, 1992)" (p. 28).

"In the Southern Rocky Mountains-alluvial basins hydrogeologic setting, 318 wells were sampled for nitrate concentration, the largest number from the rangeland and agricultural land-use settings. The median nitrate concentration was largest in water from wells located in the urban land-use setting (0.66 mg/L) and smallest in the rangeland land-use setting (0.16 ,g/L) (Fig. 81). There was a significant difference in median nitrate concentrations in water from wells located in the agricultural and rangeland land-use settings (Table 22). No significant difference was found in the median nitrate concentrations in water from wells sampled in the other land-use setting in this hydrogeologic settings" (p. 58).

"Nitrate concentrations tend to be larger in the samples from the shallower wells for all land-use settings.

"None of the 15 samples collected from wells in the Southern Rocky Mountains-alluvial basins-agricultural data stratum had ammonia concentrations grater than 0.01 mg/L.

"In the Southern Rocky Mountains-alluvial basins setting 93 wells were sampled for orthophosphate concentration, the largest number from the rangeland land-use setting. The largest median orthophosphate concentration was in water from wells in the rangeland land-use setting 90.12 mg/L) ..."

b. COLORADO DEPARTMENT OF HEALTH

Austin, Bradford, 1995 (preliminary):

> *Ground Water Monitoring Activities, San Luis Valley Alluvial Aquifer, Report to the Commissioner of Agriculture.* Colorado Department of Agriculture, Agricultural Chemicals Program Water Quality Control Division.

Although this report is not yet complete, some preliminary information is available by courtesy of the Agricultural Chemicals Program Manager. The study sampled 93 domestic wells throughout the Valley. Each well was sampled once between May and August 1993.

> "Analysis of the laboratory reports, particularly for the nitrate and pesticide data, indicates that ground water in several areas of the study has been impacted by various agricultural chemicals... Fourteen percent (14%) of the domestic wells sampled showed nitrate levels in excess of the EPA standard for drinking water (10 mg/L)... Three different pesticides were detected, but only one well contained a pesticide at a level higher than the EPA Drinking water standard. This pesticide, lindane, was detected at a level o f 0.29 µg/L; the MCL for lindane is 0.20 µg/L."

c. COLORADO STATE UNIVERSITY

Durnford, D.S., K.R. Thompson, D.A. Ellerbroek, J.C. Loftis, G.S. Davies, and K.W. Knutson, 1990:

> *Screening Methods for Ground Water Pollution Potential from Pesticide Use in Colorado Agriculture.* In conjunction with the Colorado Water Resources Research Institute (Completion Report No. 157) and Colorado Department of Health.

Purpose:

> "The goals of this project were to:
>
> "1) Evaluate pesticide contamination of the groundwater in the San Luis Valley through direct sampling.

"2) Evaluate screening models for their ability to predict which pesticides would contaminate the groundwater, predict which areas would have the highest risk of contamination, and predict what levels of contamination would occur.

"3) Determine the relative importance of different factors with respect to groundwater contamination by pesticides. The relative importance of hydrogeologic factors, agricultural management factors, and the characteristics of the individual pesticides were assessed."

Conclusions:

"... groundwater has nitrate levels above drinking water standards in some areas and may contain low levels of pesticides. ... The results from the sampling program are, however, inconclusive (p. 47).

"... the San Luis Valley aquifer is highly vulnerable to contamination when compared to other areas of Colorado. However, the variability in the Pollution Potential Index is small because of the homogeneity of the Valley and, as a result, the model cannot adequately differentiate between discrete locations in the Valley (p. 47).

"... CMLS determined that Sencor, Eptam, Dual, and 2,4-D were potential leachers. The other four pesticides that CMLS indicated have potential for ground water contamination were Temik, Rhomene, Buctril, and Manzate (p. 47).

"... Because of the uniformity of the Valley's hydrogeology, management practices and pesticides properties are considered to be more important in determining pollution potential. ... Pesticide properties can be used to rank each agricultural chemical by its potential ability to contaminate the groundwater. Regardless of rank, however, the pesticides most heavily used in the area should be evaluated as potential candidates which will likely be found in the groundwater (p. 49)."

Thompson, K.L., 1993:

Nitrate Contamination in the Unconfined Aquifer of the San Luis Valley. Department of Agricultural and Chemical Engineering, Senior Honors Thesis.

Purpose:

> "The purpose of this study was to evaluate nitrate contamination of the groundwater in the unconfined aquifer of the San Luis Valley. Existing data were used to quantify both the spatial and the temporal distributions of nitrate concentrations (p. viii)."

Conclusions:

> "First, plots ... indicated that high nitrate concentration areas were more widespread and in more southern location than the areas of high nitrate concentrations that were identified in the 1984 United States Geological Survey report. These high nitrate concentration areas were more centered near the Sargent District rather than near the town of Center (p. viii-ix)."
>
> "Little statistical certainty could be place in the results of these [temporal trend] analyses, and the degree to which these trends were increasing could not be accurately quantified. However, all three trend analysis methods indicated a net positive increase in nitrate concentrations... and high statistical certainty was placed in the existence of an overall regional trend of increasing nitrate concentrations (p. ix)."

d. OTHERS

Agro Engineering, Inc.

1984 to Present - Agro-Engineering is a private consulting firm in the San Luis Valley that has collected water samples from agricultural wells as part of their fertility management service for potato farmers. The data collected by Agro-Engineering was graciously provided to K. L. Thompson in an uncompiled and unstudied form. This data and Mr. Thompson's findings are in "Nitrate Contamination in the Unconfined Aquifer of the San Luis Valley" under CSU noted above.

CHAPTER III

INFORMATION GOALS

A. REGULATORY INFORMATION GOALS

Regulatory information goals are essentially the information required by regulators in compliance with various laws. Substantial investigation into the laws, regulations, and interests of private parties in the San Luis Valley, Colorado, was done by Bagenstos (1994) with the following information goals as the result:

1. Determine baseline ground water quality for the unconfined aquifer,
2. Determine baseline ground water quality for the confined aquifer,
3. Source impacts,
4. Water table and piezometric head levels,
5. Trend detection, and
6. Best management plan analysis.

As noted previously in the section titled Scope (Chapter I), two of the six information goals will be addressed in this report. These are:

1. Baseline conditions of the unconfined aquifer, and
2. Trend detection.

In order to provide accountability and to understand more clearly what information is desired, the bases for each of the two regulatory information goals are examined in more detail below.

1. Regulatory Information Goal #1: Baseline Conditions:

"Determine baseline ground water quality for the unconfined aquifer... monitoring for those contaminants listed in the tables in 5CCR 1002-8 3.11 and 3.12 that are suspected of existing within the aquifer based on land uses and chemical uses" (Bagenstos, 1994).

Bases for Goal

A. Federal Water Pollution Control Act (PL 92-500) § 208:

> "(a)(2) The Governor of each State, ...shall identify each area within the State which, as a result of urban-industrial concentrations or other factors, has substantial water quality control problems. ... the Governor shall designate (A) the boundaries of each such area, and (B) a single representative organization, ... capable of developing effective area wide waste treatment management plans for such areas.
>
> "(b)(2)(F) a process to (I) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, including return flows from irrigated agriculture, and their cumulative effects, ... and from land used for ... crop production.

Comment: To identify each area that has substantial water quality control problems, it is first necessary to determine what the quality of the water would be if there were no quality control problems. More often than not, this is impossible. Therefore, a baseline quality is proposed from which future water quality changes can be measured.

B. Clean Water Act (PL 92-500) § 319:

> (b)(2)(A)[each report shall include] An identification of the best management practices and measures which will be undertaken to reduce pollutant loadings resulting from each category, subcategory, or particular nonpoint source designated under paragraph (1)(8), taking into account the impact of the practice on ground water quality.

Comment: To measure the effectiveness of BMPs, a baseline point of reference must first be established.

C. Colorado Code of Regulations 5CCR 1002-8 § 3.12.5(2):

(a) "... ground water quality shall be maintained for each parameter at which ever of the following levels is less restrictive:

(i) Existing ambient quality as of January 31, 1994, or
(ii) that quality which meets the most stringent criteria set forth in Tables 1 through 4 of 'The Basic Standards for Ground Water'."

(c) Implementing agencies "...will exercise their best professional judgment as to what constitutes adequate information to determine or estimate existing ambient quality, ... Data generated subsequent to January 31, 1994, shall be presumed to be representative of exiting quality as of January 31, 1994, if the available information indicates that there have been no new or increased sources of ground water contamination initiate in the area in question subsequent to that date. ..."

Comment: These sections essentially define the baseline conditions and identify how baseline conditions are to be determined, i.e., "best professional judgment." It is the intent of this work to assist the implementing agencies determine what constitutes adequate information to estimate the baseline conditions in the San Luis Valley.

D. Senate Bill 90-126 (Colorado Water Quality Control Act):

SECTION 4. Part 2 of article 8 of title 25, Colorado Revised Statutes, 1989 Repl. Vol., 25-8-205.5 (1)"...the public policy of this state is to protect groundwater and the environment from impairment or degradation due to the improper use of agricultural chemicals while allowing for their proper and correct use, in particular, to provide for the management of agricultural chemicals to prevent, minimize, and mitigate their presence in groundwater..."

Comment: This is an anti-degradation clause and requires knowledge of existing (baseline) water quality for enforcement.

E. Senate Bill 90-126 (Colorado Water Quality Control Act):

> Section 4. Part 2 of article 8 of title 25, Colorado Revised Statutes, 1989 Repl. Vol., is amended BY THE ADDITION OF A NEW SECTION to read:
>
> "(5) Monitoring. Pursuant to its duties, ... the division shall assist the commissioner in the identification of agricultural management areas... and shall conduct monitoring programs to determine:
>
> (a) The presence of any agricultural chemical in groundwater at a level which meets or exceeds any water quality standard applicable under this article or which has a reasonable likelihood of meeting or exceeding any such standard; or ..."

Comment: Monitoring agricultural chemicals is identified as the method of obtaining information about ground water quality. Also, this section requires the identification of agricultural management areas (AMA's).

F. Senate Bill 90-126 (Colorado Water Quality Control Act):

> SECTION 2. 25-8-103, Colorado Revised Statutes, 1989 Repl . Vol ., is amended BY THE ADDITION OF THE FOLLOWING NEW SUBSECTIONS to read:
>
> 25-8-103. Definitions. (1.1) "Agricultural management area" means a designated geographic area defined by the commissioner of agriculture that includes natural or manmade features where there is a significant risk of contamination or pollution of groundwater from agricultural activities conducted at or near the land surface.

Comment: This section defines agricultural management areas.

G. Senate Bill 90-126 (Colorado Water Quality Control Act):

> Section 4. Part 2 of article 8 of title 25, Colorado Revised Statutes, 1989 Repl. Vol., is amended BY THE ADDITION OF A NEW SECTION to read:
>
> "(6) Reporting of monitoring results - regulation. ...(c) If continued monitoring reveals that rules and regulations adopted by the commissioner pursuant to this section are not preventing or mitigating the presence of the subject agricultural chemical to the extent necessary...."

Comment: In order for continued monitoring to reveal the lack of prevention or mitigation of ground water contamination, a baseline condition must be established for comparison.

2. Regulatory Information Goal #2: Trend Detection:

"Considering hydrogeologic and land use factors, use representative sites from goal #1 to determine regional trends in water quality and water levels" (Bagenstos, 1994).

BASES FOR GOAL

D. Senate Bill 90-126 (Colorado Water Quality Control Act):

> SECTION 4. Part 2 of article 8 of title 25, Colorado Revised Statutes, 1989 Repl. Vol., 25-8-205.5 (1)"...the public policy of this state is to protect groundwater and the environment from impairment or degradation due to the improper use of agricultural chemicals while allowing for their proper and correct use, in particular, to provide for the management of agricultural chemicals to prevent, minimize, and mitigate their presence in groundwater..."

Comment: This is an anti-degradation clause and requires detection of increasing concentrations of pollutants, or lack thereof, to ensure anti-degradation.

E. Senate Bill 90-126 (Colorado Water Quality Control Act):

> Section 4. Part 2 of article 8 of title 25, Colorado Revised Statutes, 1989 Repl. Vol., is amended BY THE ADDITION OF A NEW SECTION to read:
>
> "(5) Monitoring. Pursuant to its duties, ... the division shall assist the commissioner in the identification of agricultural management areas... and shall conduct monitoring programs to determine:
>
> (a) The presence of any agricultural chemical in groundwater at a level which meets or exceeds any water quality standard applicable under this article or which has a reasonable likelihood of meeting or exceeding any such standard; or ..."

Comment: It is *inferred* from this section that identification of AMA's and detection of agricultural chemicals are to be ongoing programs conducted over time.

H. Federal Insecticide, Fungicide, and Rodenticide Act - U.S. Code Title 7 §136r (c) Monitoring

> "The Administrator shall undertake such monitoring activities, including, but not limited to monitoring in air, water, soil, man, plants, and animals, as may be necessary for the implementation of this subchapter and of the national pesticide monitoring plan. The Administrator shall establish procedures for the monitoring of man and animals and their environment for incidential pesticide exposure, including, but not limited to, the quantification of incidental human and environmental pesticide pollution and the **secular trends** thereof, and identification of the sources of contamination and their relationship to human and environmental effects." [sic] [emphasis added]

Comment: The "Administrator" referred to in this section is the Administrator of the Environmental Protection Agency. This section clearly calls for the quantification of long-term (secular) trends in water quality, and although not explicitly stated, one could easily interpret this section as including ground water.

General Comment: RCRA, and CERCLA water quality monitoring mandates do not apply to the Valley as a region. These laws are concerned with Superfund (i.e., specific) sites only and not *regional* water quality.

Table 1. Summary of legal references for regulatory information goals.

INFORMATION GOAL	LEGAL REQUIREMENT REFERENCE	
Baseline conditions	Federal Water Pollution Control Act (PL 92-500) § 208	A
	Clean Water Act (PL 92-500) § 319.	B
	Colorado Code of Regulations 5CCR 1002-8 § 3.12.5(2)(a) and §3.12.5(2)(c).	C
	Senate Bill 90-126 (Colorado Water Quality Control Act): SECTION 4. Part 2 of article 8 of title 25, CRS, 1989 Repl. Vol., 25-8-205.5 (1)	D
	Senate Bill 90-126 (Colorado Water Quality Control Act): Section 4. Part 2 of article 8 of title 25, CRS, 1989 Repl. Vol., SECTION (5) and (5) (a)	E
	Senate Bill 90-126 (Colorado Water Quality Control Act): SECTION 2. 25-8-103, Colorado Revised Statutes, 1989 Repl . Vol ., SUBSECTION: 25-8-103. Definitions. (1.1)	F
	Senate Bill 90-126 (Colorado Water Quality Control Act): Section 4. Part 2 of article 8 of title 25, CRS, 1989 Repl. Vol., SECTION: (6) (c).	G
Trend detection	Senate Bill 90-126 (Colorado Water Quality Control Act): SECTION 4. Part 2 of article 8 of title 25, CRS, 1989 Repl. Vol., 25-8-205.5 (1)	D
	Senate Bill 90-126 (Colorado Water Quality Control Act): Section 4. Part 2 of article 8 of title 25, CRS, 1989 Repl. Vol., SECTION (5) and (5) (a)	E
	Federal Insecticide, Fungicide, and Rodenticide Act - U.S. Code Title 7 §136r (c)	H

Table 1 provides a summary of the legal references for the regulatory information goals.

B. MONITORING INFORMATION GOALS

According to Adkins (1993), "Monitoring information goals are qualitative statements which describe specific information expectations of the monitoring program" and do not necessarily have to correspond one-to-one with the regulatory information goals. The following monitoring goals for the San Luis Valley unconfined aquifer are offered:

1. Establish baseline concentrations of contaminants. Develop a list of Routinely Monitored Indicators.
2. Detect increasing, decreasing, or the lack of trends in concentrations of Routinely Monitored Indicators over time.
3. Estimate the magnitude of the trends detected.
4. Detect areal (spatial) patterns in concentrations of Routinely Monitored Indicators.
5. Screen for new contaminants. A new contaminant is defined as a contaminant not included in the list of Routinely Monitored Indicators.
6. Identify contaminants with concentrations at or above the standards for that contaminant.

Monitoring Information Goal 1 is derived directly from Regulatory Information Goal 1. Monitoring Information Goals 2, 3, 4, and 5 are derived from Regulatory Goal 2–trend detection. Trend detection is divided into four components: temporal trend detection, temporal trend magnitude, identification of spatial patterns, and detection of new contaminants. While monitoring goal 6 is not directly tied to a regulatory goal, it does satisfy the legal requirement of Senate Bill 90-126 (legal reference E above). These relationships are more clearly shown in Table 2.

Table 2. Regulatory goals, monitoring goals, and legal references.

REGULATORY GOAL		MONITORING GOAL		LEGAL REF.*
#1	Baseline Conditions	#1	Establish baseline concentrations and develop a list of indicators to be monitored routinely.	A, B, C, D, E, F, G
#2	Trend detection	#2	Detect trends in concentrations of Routinely Monitored Indicators over time.	D, H
		#3	Estimate the magnitude of trends detected.	H
		#4	Detect spatial patterns in concentrations of Routinely Monitored Indicators.	A, D, E, H
		#5	Screen for new contaminants.	D, H
		#6	Identify contaminants with high concentrations.	E

* See Table 1, Summary of legal references for regulatory information goals.

CHAPTER IV

DATA ANALYSIS

A. INTRODUCTION

Data analysis protocols are specified methods of handling the data produced by a monitoring system. It is important to have the data analysis protocols well defined prior to the implementation of a long-term monitoring system. This is important for three reasons: 1) to design the monitoring system to meet rigorous statistical requirements, 2) to identify what information can be produced by the system, and 3) if these protocols are not clearly defined, the data and all subsequent interpretations of the data become ad hoc and, hence, suspect. With data analysis protocols clearly defined prior to gathering data, the likelihood of biased data or skewed analysis is substantially reduced and all interested parties can have input on how the results are to be interpreted before the results are known. For additional advantages of using water quality data analysis protocols, the reader is directed to Adkins, 1993.

"Statistical information goals are complete, detailed statements which describe statistical intent" (Adkins, 1993). The key here is determining the "statistical intent" of the monitoring goals, i.e., what statistical information is desired and what methods (analysis protocols) will be employed to provide the information. This is not a trivial problem as the basic assumptions required for most statistical methods are often violated by water quality data records, and consequently, standard statistical methods can be misleading or erroneous.

The best method for ensuring the statistical methods chosen are appropriate is by analyzing all existing data for attributes specific to the region of interest. As previously mentioned, the most comprehensive and recent ground water quality data in the San Luis Valley were not available for this study. However, general attributes of water quality data records that complicate statistical analysis are identified in Adkins (1993), Harcum (1990), and Ward *et al.* (1990). No guidance in the laws and regulations is provided on how to handle these limitations in water quality data attributes. Table 3 is a summary of these limitations and recommendations for handling them as identified by Adkins (1993).

Table 3. Water quality data record attributes and recommendations.

ATTRIBUTE	RECOMMENDATION
Multiple observations	Average multiple values.
Outliers	If there is evidence to indicate the outlier is an erroneous observation, it should be discarded. Otherwise, it should be retained.
Changing sampling frequencies	This should be prevented.
Missing values	Prevent missing values and/or use robust analysis methods.
Non-normality	Use nonparametric analysis methods.
Seasonality	Use analysis methods that can accommodate seasonality.
Censoring	Request non-censored data.
Serial correlation	There are no methods for dealing with serial correlation.

Additionally, properly choosing well locations is critical to the statistical integrity of the monitoring system. Table 4 shows how improperly choosing well locations can be the source of bias when applying statistics to data collected from the monitoring system.

Table 4. Errors in estimating statistical properties of regional ground water quality.

Type of error	Sources of error	Methods used to reduce errors
Random errors		
Random sampling errors	Inherent variability in ground-water quality	Increase number of wells sampled and frequency of sampling
Random measurement error	Variability in measurement techniques and well designs	Use consistent techniques for water-quality sampling and well construction
Bias		
Selection bias	Wells selected for sampling do not represent target population	Randomized well selection
Measurement Bias	Alteration of the chemistry of the water by well installations and by the equipment and methods used to obtain the water-quality sample	Careful adherence to established sample collection, handling, and analysis techniques Existing wells–exclude wells that do not meet specified criteria for obtaining a representative sample Newly constructed wells–follow well-construction guidelines appropriate for problem under study

(From Alley, 1993)

To avoid selection bias, Alley (1993) recommends randomized well selection; however, "representative" sites may be chosen when bias can be accounted for when interpreting the data. Alley (1993) addresses how to chose well locations to ensure randomness and using information from previous studies to increase precision by dividing the region of interest into strata. To improve precision, strata should be chosen with maximum homogeneity within strata and maximum heterogeneity between strata (Alley, 1993). With the number of water quality studies conducted in the San Luis Valley and the information provided by these studies, it should be possible to divide the Valley into strata according to these criteria. Indeed, Figures 3, 5 and 6 of Edelmann and Buckles (1984) are maps of the areal distribution of nitrate plus nitrate as nitrogen, salinity hazard, and sodium (alkali) hazard, respectively, for the unconfined aquifer. These maps might be used as the basis for delineating strata. Because it is recommended to divide the region into strata, monitoring goals will be developed for the strata and as well as for the region.

B. MONITORING INFORMATION GOAL 1: BASELINE CONDITIONS

1. Discussion

The intent of this goal is two-fold in that the Colorado Code of Regulations (5CCR 1002-8 §3.12.5(2)(a)) states that the water quality shall be maintained at whichever is the least restrictive between existing ambient conditions and the Basic Standards, while Senate Bill 90-126 (CRS, 1989 Repl. Vol., 25–8-205.5 (1)) requires protection from impairment or degradation from existing ambient conditions. Therefore, two baseline conditions will be specified: one titled *Legal Baseline Condition* in compliance with the CCR with respect to the Basic Standards and one titled *Comparative Baseline Condition* to provide a baseline against which future measurements will be compared to detect impairment or degradation.

It is inferred from above that all future ground water quality measurements will be compared to the baseline to determine if trends are present. Trends will be computed for each stratum and for the region as whole. Therefore, a baseline will be provided for both these scales.

The mean is the average concentration of the sample, and as such, it provides a indication of the central tendency. Caution is warranted when using the mean as an indicator of central tendency when dealing with water quality: it is extremely sensitive to the presence of outliers and censored data (Gilbert, 1987). However, the mean also provides information about the total quantity of the contaminant present and, therefore, is included. The median value is the value above which and below which half of the sample population lies. It is not affected by outliers or by censored data (Gilbert, 1987). Consequently, the median is a reasonably good indicator of central tendency. The extreme is included as a reference and is to be compared with the standard for determination of the *Legal Baseline*.

The Colorado Code of Regulations 5CCR 1002-8 §3.12.5(2)(c) states:

> "Data generated subsequent to January 31, 1994, shall be presumed to be representative of exiting quality as of January 31, 1994, if the available information indicates that there have been no new or increased sources of ground water contamination initiate in the area in question subsequent to that date. ..."

As no new or increased sources of ground water contamination are known to exist in the San Luis Valley, gathering data in the future for baseline conditions meets this criteria. A more detailed investigation of this assumption is recommended prior to implementation of the monitoring system.

Ward *et al.* (1990) state "Seasonality ... is the general rule, rather than the exception, in water quality–especially ... shallow alluvial ground water" as is the case in the San Luis Valley. Harcum (1990) states "Quarterly or less frequent ground water quality observations ... are typically assumed to be independent." Harcum (1990) also notes that this is a general rule of thumb, not a fact, and cites a survey of quarterly ground water observations that found 20 percent of the data records to be serially correlated. Barcelona *et al.* (1989) state that "quarterly sampling frequency is a good initial starting point for ground water quality monitoring network design." Based on these sources, it is recommended to take quarterly samples, corresponding to the seasons, over the course of a year, to establish baseline conditions.

A question then arises as to which year to use for establishing baseline conditions. Optimally, a "representative" year would be used. A representative year is one that is not experiencing, or has not experienced, the affects of drought, flood, or any other unusual phenomena that could alter the quality of the ground water in a way that is not representative of the time frame of interest. It would be ideal to evaluate past years and chose one that is representative. However, this probably cannot be done as past years' monitoring programs will probably not have information from the same wells included in the long term monitoring program, or if they do, the information may not be continuous to the present, or they may not be quarterly. Therefore, the baseline year may have to be the first year the system is in place. After the first year has passed, evaluation of weather patterns, other natural and unnatural phenomena can be examined to verify that the first year was indeed a "representative" year. Choosing a year sometime in the future as a baseline meets the legal requirements as stated in the Colorado Code of Regulations. Thus, assuming the first year a long-term ground water monitoring system is on line in 1996, the 12-month period from January 1996 to January 1997 is specified as the baseline year.

2. STATISTICAL GOAL - BASELINE CONDITIONS:

For the period of January 1996 to January 1997, take quarterly data corresponding to the seasons and determine the following:

Strata Scale: For each stratum and each indicator detected, provide the annual mean and the annual median. These values will be the Comparison Baseline and the Legal Baseline.

Regional Scale: Calculate the weighted annual mean of each indicator detected in the region. This value will serve as the Comparison Baseline and the Legal Baseline for the region.

C. MONITORING INFORMATION GOALS 2 AND 3: TEMPORAL TREND DETECTION AND ESTIMATION OF TREND MAGNITUDE

1. Discussion

Defining the scale of interest is crucial in detecting trends. For instance, if one is interested in long-term trends, sampling over a three-month period will probably not provide sufficient information to determine if long-term trends are present or not. The only mention of a time frame for this goal is in the codification of FIFRA which calls for the quantification of "secular trends." According to Chambers 20th Century Dictionary (1983) secular is defined as "pertaining to or ... observed once in a lifetime, generation, century, age." Alley (1993) states "... trends in ground-water quality can take many years to be detected with any degree of confidence." Harcum (1990) defines a "short" data record as five years of record. Therefore, it is recommended that the monitoring system be implemented for no less than five years if accurate tests and estimates of trend are desired with reasonably quantifiable levels of uncertainty.

Ward *et al.* (1990) recommend using the Seasonal Kendall test to detect trends and the Seasonal Kendall slope estimator for estimating the magnitude of trends. Gilbert (1987) points out that if the trend is upward in one season and downward in another, the Seasonal Kendall test and slope estimator will be misleading. Gilbert (1987) recommends testing for homogeneity of trends in different seasons to determine the appropriateness of using the Seasonal Kendall test and slope estimator. If the trends are not homogeneous over seasons, Gilbert recommends using the Mann-Kendall test and Sen's slope estimator for each season.

Additionally, if there are less than three years of monthly data used for the Seasonal Kendall test and slope estimator, the use of the standard normal tables to test for significance is only approximate with no calibration of accuracy available in the literature (Gilbert, 1987). If the number of samples used for the Mann-Kendall test is less than 40, an alternate method for testing significance is available (Gilbert, 1987) and Harcum (1990) notes that the Mann-Kendall is expected to have a conservative significance level for a sample size of five and a 95 percent confidence level.

Because of the limitations on the Seasonal Kendall test and slope estimator when seasonality is present, the Mann-Kendall test and Sen's slope estimator computed for each individual season appear to be the best statistics for application in a long-term ground water quality monitoring system for the San Luis Valley. Applying the Mann-Kendall test and Sen's slope estimator for each individual season means that results will not be available for several years. If approximate results are desired, the Mann-Kendall test and Sen's slope estimator can be applied to de-seasonalized quarterly data thus producing non-exact results in much less time. However, a test for correlation should be performed in either case as serial correlation levels greater than 0.2 can significantly affect the actual significance levels of uncorrected tests (Harcum 1990).

For each stratum, the recommended test and slope estimator is applied to the mean and median for all wells within the stratum. For the region as a whole, the recommended test and slope estimator is applied to the weighted mean. Again, approximate results can be produced by applying the test and slope estimators to the de-seasonalized quarterly data.

When using statistical tests, it is important to clearly identify the hypotheses being tested. It is common to call no increasing trend the null hypothesis (H_o), and control the risk of concluding that H_o is false when, in fact, it is true (α risk). A standard value for the significance level is $\alpha = .05$, which corresponds to a 95 percent confidence level. The significance level controls the risk of a Type I error known as a “false alarm,” i.e., indicating a trend is present when, in fact, no trend exists. The power controls the risk of a Type II error characterized as “slipping through the net,” i.e., indicating there is no trend when, in fact, there is. It is common to place more stringent control on the risk of a Type I error, however, the power level also should be given careful evaluation as it may be more critical to “miss” a trend and allow the aquifer to become contaminated. A large sample size is needed or only large differences can be detected if both risks are kept small (Ward *et al.*, 1990).

With application to the San Luis Valley, it must be decided which type of error is worse: concluding there is a trend when, in fact, there is not; or concluding there is not a trend when, in fact, there is. The following table provides some assistance in determining the more critical error.

Table 5. Possible consequences of Type I and Type II errors.

POSSIBLE CONSEQUENCES OF CONCLUDING THERE IS A TREND WHEN, IN FACT, NO TREND EXISTS (TYPE I ERROR):	POSSIBLE CONSEQUENCES OF CONCLUDING THERE IS NOT A TREND WHEN, IN FACT, A TREND EXISTS (TYPE II ERROR):
Farmers may needlessly alter farming practices.	Degradation of the aquifer may occur due to implementing BMP's too late.
Monitoring efforts may be increased needlessly.	Undetected health hazards may exist for humans and livestock.
Agricultural commission may designate AMA's.	Farming yields may become adversely affected.
Mandatory BMP's may be required.	Use category may be lowered if degradation of aquifer occurs.
Agricultural Commissioner may notify the pesticide registrant of the detection of the pesticide.	Remediation efforts may ultimately be required.
Agricultural Commissioner may implement control regulations on the pesticide detected.	

Based on Table 5, the possible consequences of a Type II error seem to be more catastrophic, and hence, it seems more appropriate to control the risk of a

Type II error (i.e., to control the β-risk, also called the power). It should be noted that for a given sample size, one can only lower the β-risk at the expense of increasing the α-risk (also called the significance level).

A confidence level of 90 percent and a confidence interval of 90 percent were chosen based on the standards typically used and not on an evaluation of existing data due the unavailability of current studies as noted previously. The following statements are offered as statistical goals for temporal trend detection and estimation of magnitude for long-term ground water quality monitoring of the upper aquifer in the San Luis Valley:

2. STATISTICAL GOAL - TEMPORAL TREND DETECTION:

Strata Scale: Detect monotonic, gradual trends in median and mean concentrations of the de-seasonalized data at the 90 percent confidence level for quarterly sampling over a five-year period for each strata.

Regional Scale: Detect monotonic, gradual trends in weighted mean concentrations of the de-seasonalized data at the 90 percent confidence level for quarterly sampling over a five-year period for the region.

3. STATISTICAL GOAL - TREND MAGNITUDE:

Strata Scale: Estimate the magnitude of the slope of the trend using de-seasonalized data and indicate the 90 percent confidence interval on the estimate.

Regional Scale: Estimate the magnitude of the slope of the trend using de-seasonalized data and indicate the 90 percent confidence interval on the estimate.

D. MONITORING INFORMATION GOAL 4: SPATIAL PATTERNS

1. Discussion

Identifying patterns requires mapping contaminant concentrations and visually inspecting for patterns as opposed to rigorous statistical analysis. This can be accomplished by plotting well locations on a map of the region in colors corresponding to annual mean and annual median concentrations in the following categories: non-detect, concentrations detected but below 50 percent of the standard, concentrations between 50 and 100 percent of the standard, and concentrations above the standard. These maps can be compared from year to year to analyze for spatial variation over time.

A question arises as to how many wells are needed to produce a map of "sufficient" resolution. While defining "sufficient" resolution and determining the number of wells required to produce the desired resolution are beyond the scope of this investigation, it is important to note that a large number of wells may be required. For example, Edleman and Buckles (1984) used 57 wells in the unconfined aquifer to evaluate existing water quality for an area of approximately 1400 square miles. This calculates to one well for approximately every 25 square miles. If this is extrapolated to the entire Valley which comprises approximately 3200 square miles, 130 wells would be required to maintain the same well to area ratio.

If it is desired to quantify the areal spread of a contaminant other than visually, a method whereby the number of wells in which the contaminant was detected could be calculated and compared from year to year for each stratum or other defined regions of interest. Additional information on spatial trends could come from special, connected studies (i.e., "wheels" on the axle). If the number of wells sampled from year to year changes, it will be necessary to use the percentage of wells in which the contaminant was detected as opposed to the total number of wells.

2. **STATISTICAL GOAL - SPATIAL PATTERNS:** none.

E. DATA ANALYSIS FOR MONITORING INFORMATION GOAL 5: SCREENING FOR NEW CONTAMINANTS

1. DISCUSSION

Screening for new contaminants is simply a matter of periodically sampling every well for every contaminant that could possibly be present in the ground water. While this is a labor intensive and expensive task, it does not require statistical analysis except for laboratory analyses where detection limits must be established. There is substantial information in the literature about establishing detection limits which is beyond the scope of this thesis. Screening for new contaminants can be done on the order of 3-5 years as ground water moves slowly. Adkins (1993) recommended three-year intervals, the USGS is using five-year intervals in their NAWQA study. However, determining when, i.e., during which season, to screen is a much more difficult task. If protection of ground water for drinking purposes is desired, perhaps sampling shortly after application of pesticides and/or fertilizer would be appropriate. If long-term affects on the aquifer are desired, it may be better to sample during the off-season.

Other difficulties include deciding when to add an indicator that has been detected to, and when to remove an indicator that has not been detected for some time period from, the list of routinely monitored indicators. Adkins (1993) recommends that if a compound is detected at or above the method detection limit (MDL), the well should be resampled. If the concentration is still at or above the MDL, the presence of the compound is confirmed, and a decision should be made as to whether or not to add it to the list. Additional factors entering into the decision to add or remove a compound to or from the list of routinely monitored indicators might be: the difficulty and cost of analyzing for the compound; the location of the well in which it was detected; the probable source, toxicity, and persistence of the compound; and time elapsed since the last confirmed detection of the compound. To prevent confusion and possible conflict in the future, it may be prudent to provide guidelines regarding the addition and deletion of indicators to and from the list of routinely monitored indicators prior to implementing a long-term ground water quality monitoring system.

2. STATISTICAL GOAL - SCREENING: none.

F. MONITORING INFORMATION GOAL 6: IDENTIFY CONTAMINANTS WITH HIGH CONCENTRATIONS

1. DISCUSSION

Identifying contaminants with high concentrations can be achieved by comparing the sample value to the corresponding standard for that contaminant. No statistical methods are required. In Colorado, the standard value is based on water use or intended use; therefore, if the use or intended use of the water is changed, the change must be incorporated into the monitoring system data analysis methods.

2. STATISTICAL GOAL - HIGH CONCENTRATIONS: none.

G. SUMMARY

Statistical goals have been identified for monitoring goals 1, 2, and 3. Monitoring goals 4, 5, and 6 do not require statistical analysis to provide the information required. It should be noted that uncertainty is inherent in all attempts to gather information from our environment, and the application of statistical methods does not eliminate this uncertainty. Statistics only help us to quantify and, hopefully, contain the uncertainty. Barcelona *et al.* (1989) stated that "natural variability over time can exceed the variability introduced into the data from sampling and analysis procedures" and "if careful sampling and analytical protocols are used, the analytical and sampling errors can be held to less than about 20 percent." However, Barcelona *et al.* (1989) also noted "The analytical and sampling variances for trace organic contaminants would be expected to be higher, ..."

CHAPTER V

REPORTING REQUIREMENTS AND FORMATS

A. INTRODUCTION

If the information produced by the monitoring system is not forwarded to, or not in a format easily understood by the recipient, then all the work done gathering and analyzing the data is lost. Indeed, Gates states (1983) "Unless facts are presented in a clear and interesting manner, they are about as effective as a television without a picture tube." This chapter begins by identifying reports regarding ground water quality in the San Luis Valley that are currently being prepared; reviews EPA 305(b) report requirements and ITFM's format recommendations; discusses the importance of and provides some guidelines for preparing graphics; and finally, provides suggestions on how the information legally required, necessary for management, and desired by interested parties, might be presented in the final product.

B. CURRENT REPORTS

1. Colorado Department of Public Health and the Environment (CDPHE)

The Water Quality Control Division (WQCD or Division) of the Colorado Department of Public Health and the Environment (CDPHE) has the responsibility of preparing reports: a) as required by EPA under the Clean Water Act section 305(b); b) for the state Department of Agriculture and the State Legislature; c) for the Colorado Water Quality Control Commission; and d) for the general public (WQCD, 1994).

a. REPORTS:

The 305(b) reports required by EPA are prepared bi-annually, and the EPA considers them a pivotal part of each state's water quality management program. EPA's guidelines for preparation of the 305(b) reports state "... It [305(b) report] is the principle means by which the EPA, Congress, and the public evaluate water quality... The 305(b) process is an integral part of the State water quality management program requirements set forth in 40 CFR 130."

In 1992, Colorado's 305(b) report consisted of 103 pages divided into two parts plus appendices. Part 2 was devoted to ground water quality in Colorado and consisted of the following sections:

1. An introduction with an overview of the complexity of ground water in Colorado, a description of ground water usage; a list of communities utilizing ground water as part of or as their complete water supply; a table profiling Colorado's ground water systems; a description of the State's major aquifers; a listing of irrigated acreage by county; an outline of issues of concern; and progress in developing ground water protection programs including a table of major point source pollution/cleanup sites being studied and a table of ground water sampling programs.
2. A ground water quality section with a general description of ground water quality problems in the state; a list of substances contaminating ground water; a list of major sources of contamination; discussions of the occurrence of specific contaminants; a table of land acreage receiving pesticide applications; and a brief discussion of trends in contaminant concentration.
3. A ground water protection program section discussing point source programs and non-point source programs.
4. A cost to benefit assessment section that discusses the economic consequences of aquifer contamination.
5. A future ground water program needs section that identifies items needed to protect ground water quality in Colorado.

Additional features were maps of the major river basins. Although not explicitly stated, it is assumed that the surface water drainage basin divisions correspond to the ground water basin divisions. This glimpse into Colorado's 305(b) report provides insight on items to include in a regional report that will feed directly into the state report.

b. REPORTS FOR THE STATE DEPARTMENT OF AGRICULTURE AND THE STATE LEGISLATURE

"The Division has the responsibility under the Agricultural Chemicals and Ground Water Protection Program (SB 90-126 [Article 8 of Title 25 §(3)(g) and §(5)]) to conduct monitoring for the presence of commercial fertilizers and pesticides in ground water" (Austin, 1993) and to submit ground water quality reports to the Department of Agriculture in conformance with Section 6 of SB 90-126 as follows:

> (6) Reporting of monitoring results - regulation. (a) If the division determines that any agricultural chemical exists at a level which meets or exceeds any water quality standard or which has a reasonable likelihood of meeting or exceeding any such standard, it shall so notify the Commissioner of Agriculture and shall provide him with any written reports it deems necessary or desirable to define the extent of such occurrence.

The Agricultural Chemicals Program (ACP) provides a single report annually to the Colorado Department of Agriculture (CDA) focusing on one of Colorado's basins in each report. The CDA subsequently includes the Division's ground water quality information in reports to the State Legislature and to the Water Quality Control Commission. In 1993 the Agricultural Chemicals Program focused on the South Platte alluvial aquifer and produced a report 157 pages in length of which over half was appendices. This report consisted of seven main sections, two appendices, three tables, and nine figures.

The main sections included the following:

1. An introduction describing the objectives and why the lower South Platte River Basin was chosen,

2. A description of the monitoring program,
3. Results of the monitoring program,
4. Follow-up sampling plans,
5. Sampling area description and characteristics,
6. Field operations, and
7. Quality assurance/quality control procedures.

The tables included a list of analytes, a summary of pesticide detections and drinking water exposure; and a list of laboratories, methods, and detection levels. The figures included:

1. Two maps of the study area, one showing sampling locations and one showing locations of pesticide detections;
2. Three multi-color maps, one of atrazine concentrations, one of nitrate concentrations in 1992, and one of nitrate concentrations in 1993;
3. Two pie charts, one with nitrate levels in domestic wells and one with atrazine levels in domestic wells; and
4. Two bar charts, one showing the spatial trend of nitrate along the river and one comparing nitrate levels in the years 1992 and 1993.

Appendix A of the report provides a table of results from all the laboratory tests conducted and Appendix B contains copies of miscellaneous information provided to well owners.

c. Reports for the Water Quality Control Commission

The (WQCC or Commission) does not require regular reports specifically including ground water quality information; however, the WQCD of CDPHE does prepare general activity reports for the Commission, and the Commission receives copies of the Agricultural Chemicals Program report described above. If the Commission requests specific information about ground water quality, the Division prepares a report addressing the specific request.

d. Reports for the Public

The Division does not prepare reports specifically for the general public. If a member of the general public requests information about ground water quality, a copy of the 305(b) report is provided.

2. San Luis Valley Water Quality Demonstration Project

The San Luis Valley Water Quality Demonstration Project (SLVWQDP) is a five-year project begun in 1991 with the main goal of reducing pollution of ground water by agricultural chemicals through the adoption of recommended best management practices (BMP's) by Valley farmers (Cooperative Extension, 1990). Evaluation of the project is provided through annual progress reports and a final report consisting of surveys of farmer's attitudes toward the BMP's, and economic and agronomic analysis of the BMP's. The annual reports also will contain summary data of the water quality data on ground water and irrigation water applied as well as the type and amount of agricultural chemicals applied to fields along with other data collected (Cooperative Extension, 1990). These annual reports are directed to the U.S. Department of Agriculture and subsequently to the U.S. Congress. By the time the long-term trend monitoring system advocated in this report is implemented, the SLVWQDP will no longer be in commission. Therefore, no reports will be received from or forwarded to the SLVWQDP.

3. Rio Grand Water Conservation District

The Rio Grand Water Conservation District (RGWCD) currently prepares monthly activity reports which include a summary of recent activities in the district as well as articles and publications that may be of interest to the Board of Directors of the District. Quarterly reports are submitted to the Board of Directors that provide information on the Norton Drain, maintenance of the Closed Basin Division, the network of observation wells used to monitor water table elevations, and financial data. None of these reports address water quality as a regular feature; however, if the District receives information about water quality it believes will interest the Board, this information may be summarized and included in a report or simply referenced.

4. United States Geological Survey

As part of its National Water Quality Assessment Program (NAWQA), the USGS is preparing a report titled "Water Quality Assessment of the Rio Grande Valley Study Unit, Colorado New Mexico and Texas–Analysis of Selected Nutrient, Suspended-Sediment, and Pesticide Data" (Anderholm *et al.,* 1995), of which the San Luis Valley comprises 16 percent. This report is a one time report and is directed to congress. Additionally, and as part of NAWQA, the USGS will re-sample wells included in the original study every five years and prepare a report for Congress.

5. Summary

Table 6 provides a quick overview of the reports generated that include water quality information in the San Luis Valley. The table includes the agency that prepares the report, the report name, report frequency, intended recipients, and legal reference requiring the report.

The majority of the reports prepared are directed toward resource managers and policy makers with only the 305(b) reports directed to the public. It is interesting to note that the U.S. Congress is receiving reports on water quality from three different, unconnected sources: USGS, EPA, and SLVWQDP. While the USGS and the SLVWQDP are conducting independent studies, the bulk of water quality investigation and reporting requirements fall on the CDPHE and result in two reports: the 305(b) and the Agricultural Chemicals Program report.

Table 6. Summary of water quality reports.

AGENCY	REPORT NAME	FREQUENCY	RECIPIENTS	LEGAL REFERENCE
U.S. EPA	305(b) (National focus)	Bi-annually	♦ EPA ♦ Congress ♦ Public	CWA §305(b)
USGS	NAWQA	Once every five years	♦ Congress	1989 - Congress appropriated funds
CDPHE	305(b) (State focus)	Bi-annually	♦ EPA ♦ Public	CWA §305(b)
	Agricultural Chemicals Program	Annually	♦ Colo. Dept. of Ag. ♦ WQCC (via CDA) ♦ State Legislature (via CDA)	S.B. 90-126
RGWCD	Activity Reports	Monthly	♦ RGWCD Board	
	Quarterly Reports	Four times per year	♦ RGWCD Board	
SLVWQDP	Progress Report	Annually	♦ US Dept. of Ag. ♦ Congress (via USDA)	USDA WQDP
CDA (from CDPHE)	Program Update	Annually	♦ WQCC ♦ State Legislature	S.B. 90-126

C. REVIEW OF REQUIRED CONTENT AND FORMAT RECOMMENDATIONS FOR REPORTS

1. CONTENT - EPA 305(B) REPORT PREPARATION GUIDELINES

EPA provides comprehensive guidelines (EPA, 1994) on how to prepare the ground water assessment portion of the 305(b) reports. These guidelines are directed toward states; however, it is logical that if regions within the state provided reports to a central agency in the same format, then the central agency's task is made much easier, and the region preparing the report has more information available to it. With respect to ground water quality, EPA's 305(b) preparation guidelines are oriented exclusively toward public water supply systems. The ground water quality monitoring system discussed in this report is regional in concept and does not focus on public water supply systems. EPA's 305(b) preparation guidelines are included here only as an example of the focus and information required by a regulatory agency. Even though a regional monitoring system is different in focus than the 305(b) reports, it is logical to include information for the 305(b) reports in a *comprehensive* report on the quality of the region's ground water quality. A brief outline of these guidelines, adapted to a region as opposed to a state, is included in Appendix I.

The 305(b) guidelines (1994) also note that "as these indicators are collected over time, the data will be used to help determine trends in the progress that States and the Nation are making in improving and protecting the resource" and "changes over time in the number of detections in this range of 50 to 100 percent of Maximum Contaminant Levels (MCL) may suggest that future MCL exceedances will occur." However, no information as to what statistical tests will be used, what level of confidence is desired, or how the information will help determine if trends are present, is included in the guidelines. In using the number of MCL exceedances as indicators of trends, EPA has overlooked the fact that MCLs frequently change. Changes in the MCLs invalidate using the number of MCL exceedances as an indicator of trends and can be likened to comparing apples to oranges. EPA does note that the information requested is the minimum acceptable and encourages states to use more detailed information if it is available.

2. FORMAT - ITFM RECOMMENDATIONS

The Intergovernmental Task Force on Monitoring (ITFM) created an Assessment and Reporting Task Group (ARTG) to "identify features and ... presentation techniques that ... produce understandable interpretations of water-quality conditions" (ITFM, 1994). Technical Appendix K of the Draft of the Final Report of the ITFM discusses target audiences, monitoring objectives, and format considerations for reporting water quality information. The Task Group defines five different audience categories for recipients and states that the monitoring objectives for the different audience categories are different.

This assessment is applicable on a national scale with much information compressed into a single report. Thus, the target audience's information objectives are the driving force by which an overwhelming amount of information is pared down into a report of manageable size. However, on a regional scale such as the San Luis Valley, preparing several different reports for the various audience categories outlined by the ITFM (1994) does not seem a prudent use of resources. Additionally, the work done by Bagenstos (1994) coalesced the different monitoring goals of all interested parties into a single set of "Integrated Information Goals" or regulatory goals as discussed previously. Therefore, the ITFM recommendation regarding audience categories was not applied to the reports that will be generated from a long-term, ground water quality monitoring system in the San Luis Valley.

ITFM's Assessment and Reporting Task Group identified the following format criteria (ITFM, 1994):

Table 7. ITFM's format criteria.

FORMAT CRITERIA
Reading Level
Level of Detail
Lay-out
Graphics
Audio Presentation
Video Presentation
Electronic Presentations

Evaluating audio, video, and electronic presentations is beyond the scope of this report. Instead, this report focuses on presentation of the information in written form. The ITFM (1994) also identified special considerations on how information should be presented. These special considerations are in Table 7. ITFM's format criteria.

Table 8. ITFM's special considerations for presenting information.

SPECIAL CONSIDERATIONS FOR HOW INFORMATION IS PRESENTED
♦ For most audiences, reports should be short: documents that consist of an executive summary and supporting appendices should accomplish this.
♦ In large reports, information should be presented in a consistent manner among varying sites.
♦ Size of font must be large enough to be read comfortably, and font should by a modern, readable, attractive (seraph) font as opposed to typewriter-style font.
♦ Margins should be large enough to prevent a page of information from appearing overwhelming.
♦ Headers and footer that include information (chapter number, chapter name, document name, and page numbers) can be helpful.
♦ Summary information can be included at the beginning of sections or in side bars.
♦ Section heading should be in large, bold, and/or italicized style to distinguish them from regular text, and provide organization for the reader.
♦ Section heading can be in the form of questions that might potentially be

SPECIAL CONSIDERATIONS FOR HOW INFORMATION IS PRESENTED
asked by the reader. ♦ Two-column format usually is easier to read. ♦ Monotony of text can be broken up with graphics or summary information. ♦ Graphics can be displayed in boxes to attract attention. ♦ Some gloss is good, although it can be overdone.

(From ITFM, 1994)

3. FORMAT - GRAPHICAL PRESENTATIONS

Graphical representation of the data is one of the most powerful tools available for conveying information. Shortland and Gregory (1991) state: "Most people find very large and very small numbers difficult to grasp" and Tufte (1983) states "...of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful." However, Tufte goes on to state that "tables usually outperform graphics in reporting on small data sets of 20 numbers or less" (Tufte, 1983). While the report recommended in this work comes from a technical view point, effective use of graphics can aid non-technically oriented readers to understand the basic message because "graphics are understood more quickly than words and are more easily related to the real world" (Horton, 1991).

With this in mind, it is important that graphics used to convey the results do so in an objective and truthful manner. Tufte (1983) identifies six principles that help to maintain graphical integrity:

1. "The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.
2. "Clear, detailed, and thorough labeling should be used to defeat graphical distortion and ambiguity. Write out explanations of the data on the graphic itself. Label important events in the data.
3. "Show data variation, not design variation.

4. “In time-series displays of money, deflated and standardized units of monetary measurement are nearly always better than nominal units.
5. “The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.
6. “Graphics must not quote data out of context.”

With respect to misrepresentation, Tufte (1983) defines the “Lie Factor” as the “size of effect shown in graphic” divided by “the size of the effect in data” and notes that to be reasonably accurate the Lie Factor should be between 0.95 and 1.05. Tufte (1983) offers following five additional principles to optimize the effectiveness of graphics:

1. “Above all else show the data.
2. “Maximize the data-ink ratio.
3. “Erase non-data-ink.
4. “Erase redundant data-ink.
5. “Revise and edit.”

Data-ink is defined as the non-erasable core of a graphic. The data-ink ratio is defined as the “proportion of a graphic’s ink devoted to the non-redundant display of data-information” (Tufte, 1983). Horton (1991) provides the following table (Table 9) as a guide to choosing which graphic to use when displaying numerical values.

Table 9. Graphical display of numerical data.

FOR THIS TYPE OF INFORMATION:		USE THIS TYPE OF GRAPHIC
Exact values	Few	Chart annotated with values
	Many	Table
Relative values	Absolute	Bar or column chart
	Proportion	Pie chart
Correlation		Scatter chart with a correlation line
Trend		Line chart

Adkins (1993) briefly describes several graphical methods available for displaying water quality data as do Helsel and Hirsch (1992), and Schmid (1983).

D. RECOMMENDATIONS

1. GENERAL

After reviewing reports currently prepared and requirements and recommendations for the preparation of water quality monitoring reports, a report summarizing the data collected from a long-term ground water quality monitoring system for the San Luis Valley may include the following sections.

1. Introduction. This section might include a description of the purpose of the report and a brief description of the San Luis Valley.
2. Monitoring Program. This section might include a brief description of the axle portion of the monitoring system with a map showing the location of the monitoring wells and strata divisions. Additional information on special studies including purpose for the study, scope, number of wells and indicators tested, and a map showing the location of the wells included in the special studies also could be included in this section or simply overlaid on the map in the previous section.
3. Monitoring results. This is the most important section and should consist of summaries of the data. Graphs, maps, bar charts, pie charts, and tables may be the most prominent aspects of this section. Major findings should be highlighted and placed in noticeable locations such as shaded boxes or sidebars.
4. Compliance with 305(b). This section would provide the information requested in the guidelines for preparing 305(b) reports as adapted to a region (see Appendix 1).
5. Conclusions. Major findings might be repeated followed by any necessary qualifiers.

Appendix A. May include results of all laboratory tests conducted.

Appendix B. May include sample calculations on how summary information provided in the Monitoring Results section were calculated.

Appendix C. May include additional summary data, such as probability distribution functions for individual wells, trend analysis for individual wells, or other data not deemed worthy to include in the main body of the report.

Appendix D. May include information on quality assurance and quality control procedures used.

Appendix E. May contain budget information such as the expense and number of work hours required to gather samples; laboratory analysis costs; and the number of work hours required for data analysis and report generation.

Although this seems long with five main sections and five appendices, the reports should be kept short. It is anticipated that an annual report summarizing the data from a long-term ground water quality monitoring system in the San Luis Valley would be less than 25 pages. This can be accomplished if graphical means for displaying the information are used and long written descriptions are avoided. It should be noted that the report described in this thesis is coming from a technical viewpoint. Resource managers may wish to investigate other means of conveying the information to the general public such as news releases or videos.

2. Displaying Monitoring Results–Section 3 of the Recommended Format

The following paragraphs provide examples of graphical displays of monitoring results designed to meet the monitoring goals as stated earlier. All graphics are based on contrived data sets analyzed using the statistical methods recommended in Chapter IV.

Figure 4 demonstrates one method of meeting monitoring information goal number one: Baseline Conditions. The boxplot format was chosen as it provides easy comparison of median and average values to the standard and shows the distributional characteristics of the water quality indicator between strata and the region. Additionally, the extreme values and the inter-quartile ranges are indicated. This graphic is a quick visual “snapshot” of the quality of water in the Valley and is more easily assimilated by the reader than text describing this information.

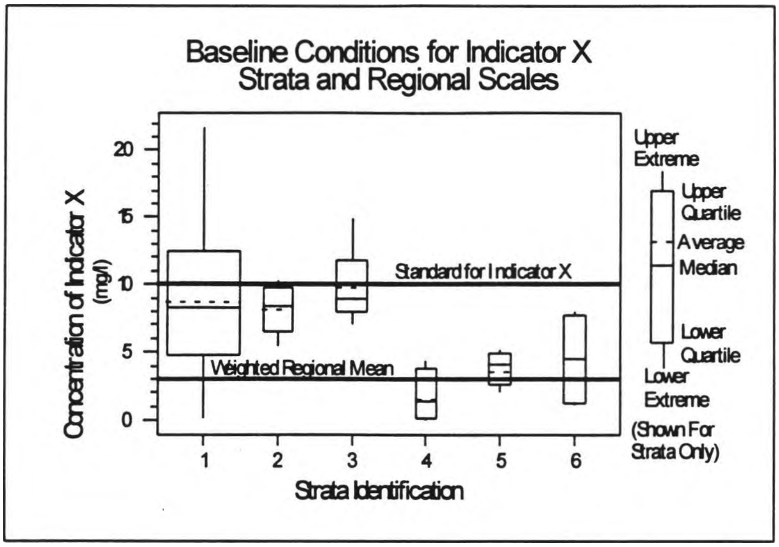

Figure 4. Graphic for displaying baseline conditions for strata and region.

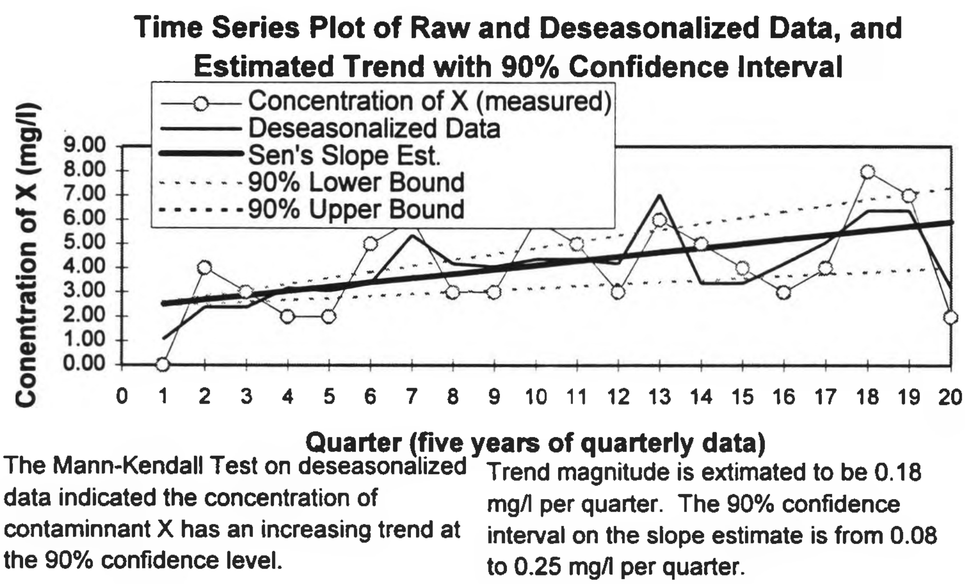

Figure 5. Graphic for displaying results of test for trend and estimation of trend magnitude for strata and region.

Figure 5 meets monitoring information goals two and three: Trend Detection and Estimation of Trend Magnitude. The time series plot format was chosen as a first step toward gaining an understanding of the behavior of the water quality indicator over time (Ward *et al.*, 1990 and Helsel and Hirsch, 1992) and it is "particularly useful for analyzing limited data records" (Adkins, 1993) as is the case for the long-term, ground water quality monitoring system advocated for the San Luis Valley. The graphic shows the actual measured values, the de-seasonalized data, the slope (magnitude) of the trend detected, and the 90 percent confidence limits on the estimation of the slope for a contrived data set. The confidence limits are shown as a sideways V anchored at the Y intercept of Sen's slope. Sen's slope was anchored at the median of the time and concentration ranges. The confidence limits could have been anchored at the median of the time and concentration ranges and shown as an X. However, it was determined by the author to be less confusing to show the confidence limits as a sideways V. This also is the method used in WQSTAT II (Phillips 1988).

Monitoring information goal number four, Detect Spatial Patterns in Concentrations of Contaminants, can be displayed as noted previously (plotting well locations on a map of the region in colors corresponding to concentrations in the following categories: non-detect, concentrations detected but below 50 percent of the standard, concentrations between 50 and 100 percent of the standard, and concentrations above the standard). Additionally, these concentration categories can be plotted on a bar chart for a specific area of interest as shown in Figure 6. The bar chart also displays monitoring goal number six.

Table 10 demonstrates how all contaminants detected and their maximum concentration can be reported in tabular format. This table addresses monitoring goal number five, Screen for New Contaminants and number six, Identify Contaminants with High Concentrations. The tabular format was chosen as it provides a quick way of comparing the measured data value to the standard and because a tabular format conveys data sets of 20 items or less better than graphs (Tufte, 1983). Standards are based on the most stringent ground water use standard applicable.

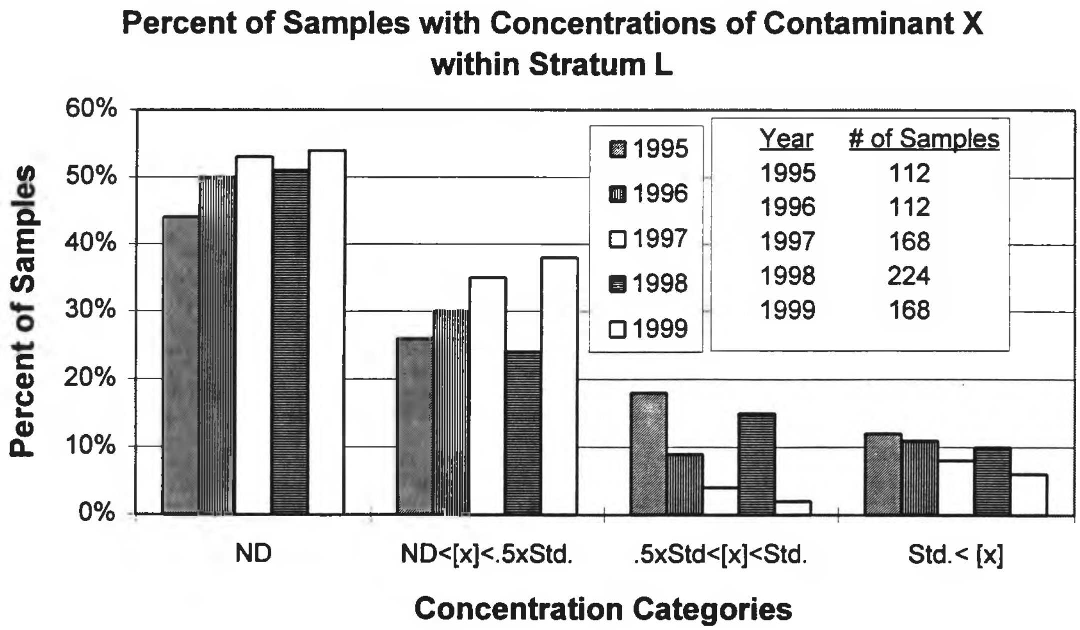

Figure 6. Graphic for displaying concentration changes within a stratum.

Table 10. Graphic for displaying results of screening for new contaminants and identifying contaminants with high concentrations .

CONTAMINANT	MAX. CONC. SAMPLED	MAX. CONC. BY STANDARD	IS STANDARD EXCEEDED?	IS CONT. ROUTINELY MONITORED? IF NOT, ADD?
Nitrate (mg/l)	32	10	Yes	Yes
Atrazine (µg/l)	1.5	3	No	No/Yes
Etc.				

Table 11 summarizes the monitoring goals and examples provided for graphically conveying the information desired. This demonstration is only a sample of graphical methods available for displaying information. The point is that graphically displaying the results of a long-term, ground water quality monitoring system is a powerful tool for communication and should not be overlooked. Rather, the means for graphically displaying information, indeed, for conveying all information to be derived from a monitoring system, should be specified during the design phase and agreed upon by all parties to receive the information, prior to implementing the monitoring system.

Table 11. Methods of graphically displaying monitoring results.

#	MONITORING GOAL	POSSIBLE DISPLAY METHOD
1	Establish baseline concentrations and develop a list of indicators to be monitored routinely.	Boxplot
2	Detect trends in concentrations of Routinely Monitored Indicators over time.	Time Series Plot
3	Estimate the magnitude of trends detected.	Time Series Plot with Trend Line
4	Detect spatial patterns in concentrations of Routinely Monitored Indicators.	Color Coded Map, Bar Chart of Concentrations within a Stratum
5	Screen for new contaminants.	Table
6	Identify contaminants with high concentrations.	Table, Bar Chart

CHAPTER VI

DISCUSSION AND CONCLUSIONS

A. DISCUSSION

While investigating the concept of a regional long-term ground water quality monitoring system for the San Luis Valley, a few issues kept arising that warrant attention. Before presenting the summary and conclusions, two of these issues are discussed.

1. Continuity

Nothing is more frustrating than spending several years and substantial sums of money for worthless data. Any lapse in continuity over the years can jeopardize the quality of data and subsequently the quality of the information produced. If a change in the operation of the system is needed, an overlap period where the system is operated in both the pre- and post-change modes will provide information on how existing data can be manipulated to continue to provide meaningful information after the change is implemented. Additionally, documentation clearly linking the monitoring system activities to the information goals is necessary as Ward *et al.* (1990) point out that: "Without a clear and documented reason for existing, water quality monitoring was an easy target for cuts in budget and personnel."

2. Coordination and Cooperation

> "A great deal of ground water quality data exist for the state but the data is scattered among many sources very little coordination exist between agencies collecting and using ground

> water quality data. Responsibility for ground water quality protection is divided among a number of state and local agencies. Agencies and responsibilities need to be identified and a comprehensive state-wide ground water protection plan developed to coordinate their activities as part of a state strategy" (WQCD 1992 p. 73). [sic]

Although the above quote refers to ground water quality for the entire state, it is also true for the San Luis Valley. In the reporting section of this report, many agencies and organizations were identified as information generators, information recipients, or both with respect to ground water quality in the San Luis Valley. Information about the quality of the unconfined aquifer is needed by a variety of people for a number of reasons. If the system is to be successful in meeting all the information goals at a minimum of cost to the tax payer, a design/management team may be an appropriate way for everyone to have input into the design (Ward *et al.,* 1990). This team might consist of a representative from each government agency or organization, a chemist and a field sampler (preferably the ones who will ultimately be analyzing and collecting samples), an accountant, and a statistician well versed in handling data record attributes found in water quality monitoring data sets.

EPA has been collecting environmental data for resource management, regulation implementation and legal action for decades. EPA's "Guidance for Planning for Data Collection in Support of Environmental Decision Making Using the Data Quality Objectives Process" (EPA 1993) provides "a series of planning steps based on the Scientific Method that is designed to ensure that the type, quantity, and quality of environmental data used in decision making are appropriate for the intended application" (EPA 1993). EPA's requirements (EPA 1993) for a Use Category I - Direct Support to Rulemaking, Enforcement, Regulatory, or Policy Decisions may prove exceptionally useful in the planning process.

The following quotes from Freeman *et al.* (1989) also may be helpful during planning:

> "Anytime an outside altruist–e.g., an irrigation bureaucracy [or perhaps a regulatory agency]–invests in supplying a resource with the characteristics of a public good (e.g., irrigation works, schools, sewage systems, trees for reforestation [a ground water monitoring system]), provision must be made for an appropriately designed organization to accept local responsibility for that good, to operate it, maintain it, and manage conflicts which arise in the course of creating and distributing its stream of benefits [e.g., ground water quality information]."
>
> "Armed with local organizational capacity, rural people can produce public goods, allocate them, maintain the necessary commonly held property, and manage the inevitable conflicts. Such organizational capacity is an essential engine of social development."
>
> "...Organizations which can mobilize local resources, possibly supplemented by centrally provided subsidies, to hire staff for continuous maintenance will obtain greater resource control than those which rely solely on periodic mobilizations ..."
>
> "... the limited administrative resources of state bureaucracies cannot be expected to be fitted to all the variety of special conditions in the countryside. Hope must lay in effective self-sustaining autonomous local organizations productively linked to state bureaucracies."

B. CONCLUSIONS

1. SUMMARY

This investigation began by looking at why data analysis and reporting protocols are needed in general and in the San Luis Valley in specific. Regulatory information goals were broken down into more specific and measurable monitoring information goals for a long-term ground water quality monitoring system in the San Luis Valley. These monitoring information goals were subsequently examined to determine methods for providing the information desired, resulting in statistical information goals. Statistical methods are suggested based on anticipated data record attributes.

After the information goals were defined for the San Luis Valley, existing reports were investigated along with report content requirements and format recommendations. These investigations provided the bases for recommending content, format, and graphical means of conveying information necessary to meet the previously defined information goals.

2. Conclusions

By depicting the investigative efforts conducted in the San Luis Valley in a conceptual wheel and axle design frame as shown in Figure 2, a graphical means is provided that allows water resource managers, policy makers, and the public to see how past efforts have been disconnected and non-contributory toward long-term analyses. Figure 7 is intended to illustrate how future investigations can be connected to provide information about long-term trends in ground water quality in the San Luis Valley through coordinated data generating and data analysis protocols.

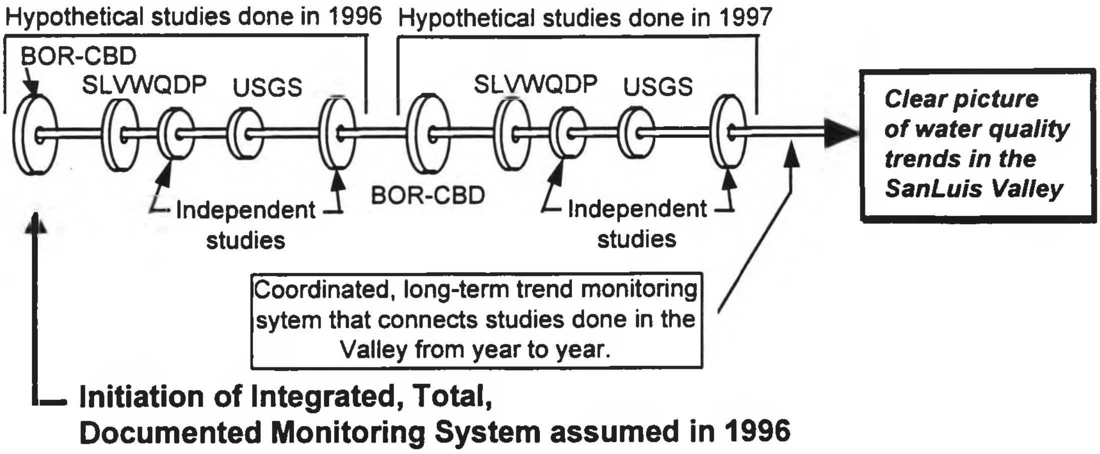

Figure 7. Model of future ground water quality monitoring in the San Luis Valley, Colorado.

The purpose of this study is to examine how legally required information can be coupled with available data analysis and reporting methods to define how the results of a long-term ground water quality monitoring system can meet information goals regarding the quality of ground water in the upper aquifer of the San Luis Valley, and hence, provide accountability for the management of ground water resources in the Valley. By documenting how the required (legal and other) information was interpreted and subsequently broken down into measurable statements, this work connects legal references to specific monitoring activities. This exercise provides the background reasons for implementing a long-term ground water quality monitoring system and justification for continued monitoring.

Examining and recommending data analysis methods, in the context of the information required, provides a clear link between the manipulation of the data and production of the desired information. Although this was done based on anticipated data record attributes, the importance of choosing data analysis methods prior to collecting data in order to minimize conflict in the future and to promote interagency cooperation, is advanced. Evaluating and suggesting report content and formats, especially graphical displays of information, defines the final product of the long-term ground water quality monitoring system.

This study demonstrates that it is possible to develop data analysis protocols and reporting formats for a regional, long-term, ground water quality monitoring system for the San Luis Valley prior to implementation of the system. Ward *et al.* (1990) identified the information generation portion of monitoring systems as the portion most often overlooked and noted that this omission may be the main cause of many monitoring systems being labeled as failures. This work represents an effort to ensure that a long-term ground water quality monitoring system in the San Luis Valley, as recommended by Durnford *et al.* (1990) is not added to the list of failed monitoring systems.

3. Recommendations for Future Work

If a long-term ground water quality monitoring system in the San Luis Valley is to become a reality, the following may provide a checklist of items that remain to be completed.

1. Form a design/management team, possibly as described in the Cooperation and Coordination Section.
2. Formally define and agree on monitoring information goals. Monitoring goals presented provide a base for discussion among team members.
3. Formally define and agree upon data analysis, interpretation and reporting protocols as introduced and quantified in this work.
4. Choose physical properties and analytes that will serve as water quality indicators.
5. Review all reports addressing water quality for specific data record attributes of the indicators chosen and agree on the best statistical tests and estimators to be used. Statistical goals previously agreed upon should be re-examined to ensure the information can be produced.
6. Delineate strata ensuring maximum homogeneity within each stratum and maximum heterogeneity between strata. (This assumes stratified random sampling is chosen as the sampling method as recommended in this study.)

7. Choose the number of wells and well locations and decide whether new wells must be drilled and/or how existing wells are to be screened for use in the monitoring network.
8. Document sample collection, handling, and laboratory analysis protocols. Determine sampling frequency for routinely measured indicators (quarterly is recommended in this study) and chose a laboratory.
9. Specify the frequency of screening for new contaminants (three to five years is recommended) as well as how compounds will be chosen for inclusion in the screening. Additionally, specify the decision matrix for removing and adding compounds to the list of routinely measured indicators.
10. Document all of the above decisions and rationales for those decisions via a design report. This report is critical for future reference in the event any portion of the monitoring system is questioned or must be modified.
11. Allocate resources such as sampling equipment, computer, software, office space, other necessary office equipment; work hours for samplers, statisticians, accountants, and report writers; and prepare an overall cost estimate and budget analysis.

From the perspective of this report, the checklist above appears to include the steps necessary to design a long-term ground water quality monitoring system in the San Luis Valley. It is noted, however, that the implementation of such a monitoring program, over a long period of time, is difficult and has rarely been done.

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APPENDIX I

EPA GUIDELINES FOR PREPARING 305(B) REPORTS ADAPTED TO A REGION

OVERVIEW

Provide a brief summary overview, in narrative from, that describes the general quality of the region's ground water, including findings of major studies, issues of concern now and for the future, and progress in developing ground water protection programs.

EPA encourages regions to use the most detailed information they have readily available. EPA plans to request additional information from states on their ambient ground water monitoring programs and the designated uses of their ground water resources.

GROUND WATER QUALITY

EPA requests that the states qualitatively characterize the trends identified by the states for both the major sources of ground water quality degradation and for major contaminants. Therefore, it is reasonable for states to request that regions qualitatively characterize the trends identified by the region for both the major sources of ground water quality degradation and for major contaminants.

Major Sources of Contamination - Table 22

Using Table 22, regions should

- Check those sources of ground water contamination that are considered *major* sources of contamination in your region. Indicate "NA" for any source that is "not applicable" in your region.
- Indicate the relative priority of each source (H = high, M = medium, and L = low).
- Identify the basis used for establishing the priority ranking using the list of factors provided at the end of Table 22. Describe any additional or special factors that you would like to highlight.

Table 22. Major sources of ground water contamination.

SOURCE	CHECK	RELATIVE PRIORITY	FACTORS[b]
Animal Feedlots			
Containers			
Deep Injection Wells			
De-icing Salt Storage Piles			
Fertilizer Applications			
Irrigation practices (return flow)			
Land Application			
Landfills (permitted)			
Landfills (unpermitted)			
Material Transfer Operations			
Material Stockpiles			
Mining and Mine Drainage			
Pesticide Applications			
Pipelines and Sewer Lines			
Radioactive Disposal Sites			
Salt-water Intrusion			
Septic Tanks			
Shallow Injection Wells			
Storage Tanks (above ground)			
Storage Tanks (below ground)			
Storm Water Drainage Wells			
Surface Impoundments			

SOURCE	CHECK	RELATIVE PRIORITY	FACTORS[b]
Transportation of Materials			
Urban Runoff			
Waste Tailings			
Waste Piles			
Other (specify)[a]			

[a] Include other sources of concern in your region.

[b] **Factors for Establishing Relative Priority**

(1) Number of sources.
(2) Location of sources relative to ground water used as drinking water.
(3) Size of the population at risk from contaminated drinking water.
(4) Risk posed to human health and/or the environment from released substances.
(5) High to very high priority in localized areas of the region, but not over the majority of the region.
(6) Hydrogeologic sensitivity.
(7) Findings of the State's ground water protection strategy or other reports.
(8) Other criteria (please specify).

Ground Water Contaminants - Table 23

At a minimum, regions should report the qualitative information in Table 23. Regions also should start thinking about quantitatively identifying contaminant occurrence based on data collected by region-wide ground water monitoring programs. This may include reporting the actual number of documented occurrences of contaminants, the number of sites with ongoing investigations or cleanup activities that have documented specific, contaminants, and the total number of sites assessed or wells monitored. EPA is asking each state to provide a list of those contaminants for which it tests ground water as well as the detection level for each contaminant. Therefore, a region may be asked to provide a list of those contaminants for which it tests ground water as well as the detection level for each contaminant.

Regions should:

- Check which of the contaminants listed are found in the region's ground water as a result of the sources listed.
- Provide the relative priority of each contaminant (H = high, M = medium, and L = low).
- Identify the basis used for establishing the priority ranking using the list of factors provided. Describe any additional or special factors that you would like to highlight, including whether or not your region monitors for it.

Table 23. Ground water contaminants.

CONTAMINANT CATEGORY	CHECK	RELATIVE PRIORITY	FACTORS[B]
Organic Contaminants			
Pesticides			
Other agricultural chemicals[a]			
Petroleum compounds			
Other Organic Chemicals:			
Volatile			
Semi-volatile			
Miscellaneous[a]			
Microbial Contaminants			
Bacteria			
Protozoa			
Viruses			
Inorganic Compounds			
Pesticides			
Other agricultural chemicals[a]			
Nitrate			
Fluorides			
Brine/Salinity			
Metals			
Arsenic			
Other metals[a]			

CONTAMINANT CATEGORY	CHECK	RELATIVE PRIORITY	FACTORS[B]
Radionuclides			
Other[a]			

[a] Specify any other contaminants of concern in your region. If necessary add an additional sheet.

[b] **<u>Factors for Establishing Relative Priority</u>**

(1) Areal extent of contamination.
(2) Location of contamination relative to ground water used as drinking water.
(3) Size of the population at risk from drinking water threatened by this contaminant.
(4) Risk posed to human health and/or the environment from this contaminant.
(5) High priority in localized areas of the region, but not over the majority of the region.
(6) Hydrogeologic sensitivity to this contaminant.
(7) Findings of the State's ground water protection strategy or other reports.
(8) Other criteria (please specify).

GROUND WATER INDICATORS

The ground water indicators described below are a limited set of selected data that, when taken together, give a relative indication of the condition of the ground water resource. As these indicators are collected over time, the data will be used to help determine trends in the progress that regions, states, and the Nation are making in improving and protecting this resource. [EPA's Guidelines for Preparation of the 1994 State Water Quality Assessments (305(b) reports) supplies the rationale behind choosing these indicators.]

Ground Water Indicator 1: MCL Exceedances

Regions should:

- For the three contaminant groups–metals, VOCs, and pesticides–identify the five contaminants for which MCLs are most often exceeded.
- For nitrates and each of the contaminants listed in the other three groups:

- report the number of samples that exceeded MCLs during the latest 12-month period for which data are available. Report such violations only for ground water-based or partial ground water-supplied community PWSs.
- Report the number of samples monitored for MCLs during the 12-month reporting period.

MCL exceedances are preferred for raw water rather than treated water, however, it is assumed that exceedances are provided for treated water unless otherwise specified. If information is available on MCL exceedances by a specific wellhead or wellfield rather than by PWS, this information is preferable.

Table 24. Number of MCL exceedances for ground water-based or partial ground water-supplied community PWSs for selected contaminants in four contaminant groups.

CONTAMINANT GROUP	CONTAMINANT	NO. OF MCL EXCEEDANCES	NO. OF SAMPLES
Metals			
VOCs			

CONTAMINANT GROUP	CONTAMINANT	NO. OF MCL EXCEEDANCES	NO. OF SAMPLES
Pesticides			
Nitrate			

Ground Water Indicator 2: Number of PWSs with MCL Exceedances

Regions should:

- Report the total number of ground water-based or partial ground water-supplied community PWSs in the region.
- List the population served by the total number of ground water-based or partial ground water-supplied community PWSs in the region.
- Report the *number* of PWSs (i.e., ground water-based or partial ground water-supplied community PWSs) that had MCL exceedances during the 12-month reporting period for the contaminants listed. Do not report the number of MCL exceedances.
- Estimate the population served by the number of ground water-based or partial ground water-supplied community PWSs that had MCL exceedances.

Table 25. Number of ground water-based or partial ground water-supplied community PWSs with MCL exceedances.

	GROUND WATER-BASED OR PARTIAL GROUND WATER-SUPPLIED COMMUNITY PWSS	GROUND WATER-BASED OR PARTIAL GROUND WATER-SUPPLIED COMMUNITY PWSS WITH MCL EXCEEDANCES
Total No.		
Population Served		

Ground Water Indicator 3: Detections of 50 to 100 Percent of MCLs

Regions should:

- For the same priority constituents identified, report the number of sample detections between 50 and 100 percent of the established MCL that occurred during the 12-month reporting period. Report such violations only for ground water-based or partial ground water-supplied community PWSs.

Table 26. Number of sampling detections between 50 and 100 percent of MCLs for four contaminant groups.

CONTAMINANT GROUP	CONTAMINANT	NO. OF SAMPLES BETWEEN 50 AND 100% OF THE MCL
Metals		
VOCs		
Pesticides		
Nitrate		

Ground Water Indicator 4: Local Wellhead Protection Programs in Place

Regions should report:

- The number of ground water-based or partial ground water-supplied community PWSs and the number of people served by those systems. This information is available form Table 25.
- The number of ground water-based or partial ground water-supplied community PWSs that have local wellhead protection programs (WHPPs) is place and the number of people these PWSs serve.

Table 27. Number of ground water-based or partial ground water-supplied community PWSs that have local wellhead protection programs in place.

NUMBER OF GROUND WATER-BASED OR PARTIAL GROUND WATER-SUPPLIED COMMUNITY PWSs	POPULATION SERVED	NUMBER OF GROUND WATER-BASED OR PARTIAL GROUND WATER-SUPPLIED COMMUNITY PWSs WITH LOCAL WHPP IN PLACE	POPULATION SERVED