THESIS

# COOPERATIVE DESIGN OF A WATER QUALITY MONITORING SYSTEM FOR THE BIG THOMPSON RIVER WATERSHED, COLORADO

Submitted by

Adrienne I. Greve

Department of Chemical and Bioresource Engineering

In partial fulfillment of the requirements

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We hereby recommend that the thesis prepared under our supervision by Adrienne Irene Greve entitled Cooperative Design of a Water Quality Monitoring System for the Big Thompson River Watershed, Colorado be accepted as fulfilling in part the requirements for the degree of Master of Science.

Dr. Robert Ward, Committee Member

Melinda T. Laituri

Dr. Melinda Laituri, Committee Member

Jim C Loftis

Dr. Jim Loftis, Advisor

V. G. Murphy

Dr. Vince Murphy, Department Head

# ABSTRACT OF THESIS

## COOPERATIVE DESIGN OF A WATER QUALITY MONITORING SYSTEM IN THE BIG THOMPSON RIVER WATERSHED, COLORADO

Water from the Big Thompson River and the Colorado-Big Thompson Project (a trans-mountain diversion of Colorado River water to the Big Thompson River) is a valuable resource to the North Front Range region of Colorado. The water is utilized for many purposes (e.g. municipal, irrigation, industrial, recreation, and ecosystem health). Over half a million people depend on the Big Thompson system for drinking water. In recent years a slow decline in water quality has been observed at some locations, particularly in reservoirs lower in the watershed. This trend, coupled with increased pressure to provide accurate data about water quality, has lead a group of stakeholders in the Big Thompson Watershed to seek a better way in which to monitor and manage their water, through cooperation.

Stakeholders within the Big Thompson Watershed, who make up a group called the Big Thompson Watershed Forum (BTWF), formed a partnership with Colorado State University to design a water quality monitoring network. The design process was broken down into five steps: objectives, variables, monitoring locations, sampling frequency, and cost analysis. Each step was completed in a cooperative manner, through a series of meetings with BTWF members. The meetings provided an opportunity for members of the BTWF to shape the monitoring system based upon concerns and priorities specific to the watershed.

The resulting water quality network is governed by five objectives. The objectives address regulatory requirements within the watershed, eutrophication of reservoirs, and the estimation of loads, spatial trends, and temporal trends.

A variable list of 38 water quality parameters was defined as the minimum group of variables that meet the informational goals laid out in the objectives. The list included 12 inorganic variables, nine metals, five organic parameters, seven microbiological variables, and five field parameters.

Monitoring locations were defined based on the objective list, already existing monitoring sites, and watershed hydrology (e.g. mixing distance, confluence locations, diversions). Thirty-nine monitoring locations were chosen; 29 moving water sites and 10 reservoir sites. Each site was given a priority rating of high or low. The group of 31 high priority sites is the smallest network that satisfies the needs of all BTWF participants. The seven low priority monitoring locations will be sampled if financially feasible.

Sampling frequency was determined on a seasonal basis. Three seasons were determined based on annual flow and water temperature cycles. It was originally hoped that historical data could be used to estimate background variability, allowing the sample size required for a specified level of accuracy in mean and trend detection to be determined. Only 11, of the 38 variables on the variable list, had historical data available, and only three, of the 11, had enough data to accurately estimate background variability. Sampling frequencies for variables with inadequate historical data were based a maximum frequency set for each season. During seasons one and two, no

variable is to be sampled at a frequency higher than twice a month except for biological parameters. The maximum frequency during season three is monthly.

The cost estimate step was utilized as a feasibility check on the monitoring program. The aim for the cooperative monitoring program was more thorough information for the same or less cost. If the monitoring program cost exceeded the sum of all current monitoring budgets, adjustments were made in variables, monitoring sites, and sampling frequency. The final cost estimate was $405,259.00 per year, roughly the same as the $401,500.00 currently spent.

In order for an undertaking such as this design and monitoring program to succeed, all participants must be willing to compromise and devote large amounts of time in order to allow for a truly cooperative effort. Those individuals most active in the design process typically represented local entities. The resulting monitoring network therefore gave higher priority to local water quality concerns, highlighting the differences between local informational needs and those defined by state and federal governments. The monitoring system currently includes a set of objectives, variable list, monitoring network, and sample frequency. They have been developed, discussed, and agreed upon by all BTWF participants. The completion of the monitoring network indicates that the BTWF is on its way towards the final goal of a long-term monitoring program operated by, and benefiting all agencies involved.

Adrienne Irene Greve
Department of Chemical and
Bioresource Engineering
Colorado State University
Fort Collins, CO 80523
Fall 1999

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

Watershed management describes an approach to water quality protection that attempts to account for the complexity and interdependence of activities (e.g. landuse, recreation, wildlife, and urbanization) within a given watershed. This approach draws many of its principles from the ideology of sustainable development. Sustainable development, advocated by the Brundtland Report in 1988, demands the integration of environmental, economic, and sociological management, and therefore cooperation between agencies that govern each type of management. This integration of agencies and disciplines also necessitates an expansion of both temporal and spatial scales. The smallest possible area is a watershed, a single hydrological unit. In order to manage a watershed in this holistic manner, a consistent, scientifically sound source of information about the watershed is necessary. This project aimed to design a system to act as this informational source.

This is a description of the collaborative project of designing a monitoring system, undertaken by a group of stakeholders in the Big Thompson Watershed located in Northern Colorado. The design is a product of the partnership between Colorado State University and the stakeholders of the Big Thompson Watershed who form a group called the Big Thompson Watershed Forum (BTWF).

## 1.1 Development of Watershed Management Approach

In order to better understand where the task of collaborative monitoring design fits into a larger environmental management framework, it is helpful to review the evolution of the watershed-based approach.

In 1992, the concept of sustainable development emerged as a primary theme of the Earth Summit in Rio de Janeiro and of Agenda 21, a document drafted at the conference. Principle 11 of the Rio Declaration on Environment and Development states that "environmental issues are best handled with the participation of all concerned citizens, at the relevant level" (United Nations, 1992). The principle defines public involvement as access to information and participation in the decision making process. Steps that must be taken in order to meet the goals set out in the Rio Declaration are detailed in Agenda 21. In chapter 18 of Agenda 21, seven programs were identified for the freshwater sector. The first of these programs was "Integrated Water Resources Development and Management." This program advocated approaching water management on a "catchment basin level." It also called for a management strategy that recognized the diversity of threats and interests in a single water source.

The Rio Declaration and Agenda 21 recognized the need for public involvement and cooperation between agencies on multiple levels of government. Mirroring the international efforts, an emphasis on cooperative efforts within the United States began to gain momentum in the early 90's with the Intergovernmental Task Force on Monitoring Water Quality (ITFM) and the President's Council on Sustainable Development (PCSD).

The President's Council, established in 1993, developed a set of goals in order to implement the sustainable development ideals described in the Rio Declaration.

Steps leading to the formation of the ITFM began a year earlier, in 1992. The US Office of Management and Budget (OBM) issued a statement requiring the review and evaluation of water-quality monitoring activities on a national scale. This review resulted in a series of recommendations for improvement. The recommendations led to the formation of ITFM, a group that met many of the guidelines for sustainable development laid out in Agenda 21. The ITFM was one of the first official collaborative efforts to address the challenge of producing scientifically sound data needed to interpret and evaluate water quality (Spooner and Klein, 1999). The task force was made up of representatives of all levels of government and members of the private sector. The ITFM produced a final report in 1995, which included recommendations covering a broad spectrum of issues. One of the primary recommendations of the ITFM was the need to provide both interstate and regional mechanisms for coordination. The ITFM pointed out that in order to succeed there was the need for framework. A technical and institutional framework allows for the success of collaborative monitoring by addressing the logistical challenges of water quality monitoring; data collection methods, data management, quality control, assessment, and reporting methods. The five primary recommendations of the ITFM were as follows: (1) work together; (2) share data; (3) use comparable methods; (4) define monitoring goals and a design approach; and (5) determine a reporting method.

In 1997, a permanent successor to the ITFM was named, called the National Water Quality Monitoring Council and the Methods and Data Comparability Board. The

Monitoring Council is co-chaired by the USGS and EPA and is comprised of a diverse group of representatives from federal, regional, state, tribal, local, municipal, academic, and citizen entities. The Council has seven defined objectives that cover a broad spectrum of issues within water quality monitoring and assessment (Spooner and Klein, 1999).

1. Coordinate and provide guidance and technical support for the voluntary implementation of the recommendations presented in the ITFM's original Strategy for Improving Water Quality Monitoring in United States by government agencies and the private sector.
2. To champion and support water quality information aspects of natural resources management and environmental protection.
3. Provide guidance for the collection, management, and use of water quality information needed to assess status and trends.
4. Identify and set priorities for addressing existing and emerging problems.
5. Identify research needs.
6. Develop and implement management and regulatory programs.
7. Evaluate compliance and environmental requirements in the effectiveness of programs and projects.

In addition, the Council has been assigned to produce three summaries by The Clean Water Action Plan (CWAP). The first summary is a description of the current state of monitoring within the United States. This includes the identification of critical gaps, areas in need of monitoring and modeling, research on polluted runoff, and recommendations for improvement, including institutional roles and reporting of results at various levels of government. The second task requires the monitoring council to take steps towards standardizing sampling and laboratory methods on a national level. The final charge to the council is very similar to the second task. It requires, in collaboration with the EPA, the standardization of monitoring and reporting by point source dischargers.

Following the example of the National Monitoring Council, several statewide monitoring councils began to take shape (Ward and Martin, 1999). These councils provide a variety of services to their respective regions such as encouraging open dialog among water managers within the state, promoting a standardization of methods, and supporting the efforts of community-based watershed groups. Community-based watershed councils have begun to crop up in much larger numbers over the last few years (University of Colorado Natural Resources Law Center, not dated). The BTWF is one example.

# CHAPTER 2

# BIG THOMPSON WATERSHED FORUM HISTORY

In 1996, the North Front Range Water Quality Planning Association (NFRWQPA), with funding from several key stakeholders, completed a preliminary study of the Big Thompson River watershed. This study recommended the establishment of a collaborative watershed management effort aimed at addressing the needs for increased communication between stakeholders, scientifically sound studies of the effects of human activities on water quality, and an educational program to increase public awareness of the watershed and associated water quality. When the final report was presented to the public, a group of concerned people representing private citizens and government agencies endorsed the formation of a watershed forum. The Big Thompson Watershed Forum was born.

One of the first tasks undertaken by the new forum was to establish an identity. This resulted in the development of a set of bylaws, a logo, a mission, and a set of BTWF objectives. This project is a direct result of the mission and objectives of the BTWF. The following is an excerpt from a BTWF handout (distributed 6/98).

> *Mission and Goals*
> The mission of the big Thompson watershed forum is to assess and protect the quality of water in the Big Thompson watershed.

Our goals are to serve as a forum that foster stakeholder teamwork in conducting watershed assessment, identifying priority protection measures, educating affected stakeholders, and promoting voluntary practices that protect the Big Thompson Watershed and the quality of its waters. Water quantity issues are an integral and indispensable aspect of water quality and will be addressed as such by this Forum.

*Objectives*
In pursuit of its mission and goals the Big Thompson Watershed Forum will endeavor to:

1) build an effective voluntary watershed protection program that fosters open communication among stakeholders, with strong public and financial support based on documented accomplishment of its objectives.
2) facilitate cooperative water quality assessment and a voluntary exchange of information in order to identify and address water quality concerns in a proactive manner.
3) reduce or eliminate existing and potential water quality problems in the Big Thompson Watershed by providing educational programs that increase awareness of water quality and related quantity issues; by developing and/or supporting voluntary operating practices that address existing and potential water quality problems; and by providing water quality and watershed related information to any party that has the potential to impact water quality within the Big Thompson Watershed.

Currently, a coordinator and an elected board of directors run the Forum. It is organized into two standing committees, watershed assessment and public outreach. In addition to the monitoring program design, the Forum is currently involved in a number of other projects. A self-guided interpretive tour of the watershed, web site, hydrologic model, and an inventory of septic systems within the watershed are all projects at varying stages of completion. Work by the Forum is funded through a combination of contributions paid by members and through grants received for specific work, such as the Environmental Protection Agency Regional Geographic Initiative grant received to fund the monitoring program. The Forum has forged strong ties with Colorado State University; several graduate students work on Forum projects along with representatives from government agencies, utilities, and private citizens.

# CHAPTER 3

# DESCRIPTION OF THE WATERSHED

The Big Thompson Watershed is located east of the continental divide in northern Colorado. The watershed resides primarily in Larimer County (Figure 1), draining 625 square miles of mixed mountainous and plains land. Water flows over an elevation change of approximately 9,500 feet, from the top of Longs Peak, 14,225 ft., to the watershed outlet at 4,750 ft. The mountainous region includes large amounts of tree cover and a low population density. Estes Park, with a population under 5,000 in 1997 (University of Colorado, 1999), is the only city in the upper watershed. The plains region boasts the majority of both the agricultural and urban areas. Nearly two-thirds of the water within the watershed originates west of Continental Divide. Water from the Colorado River is diverted through the Alva B. Adams Tunnel to the Platte River Basin, of which the Big Thompson is part. This transmountain diversion is part of the Colorado Big Thompson Project (C-BT).

## 3.1 Colorado Big Thompson Project

The Northern Colorado Water Conservancy District (NCWCD) is a public agency that controls the distribution of water from the C-BT (Figure 2). The

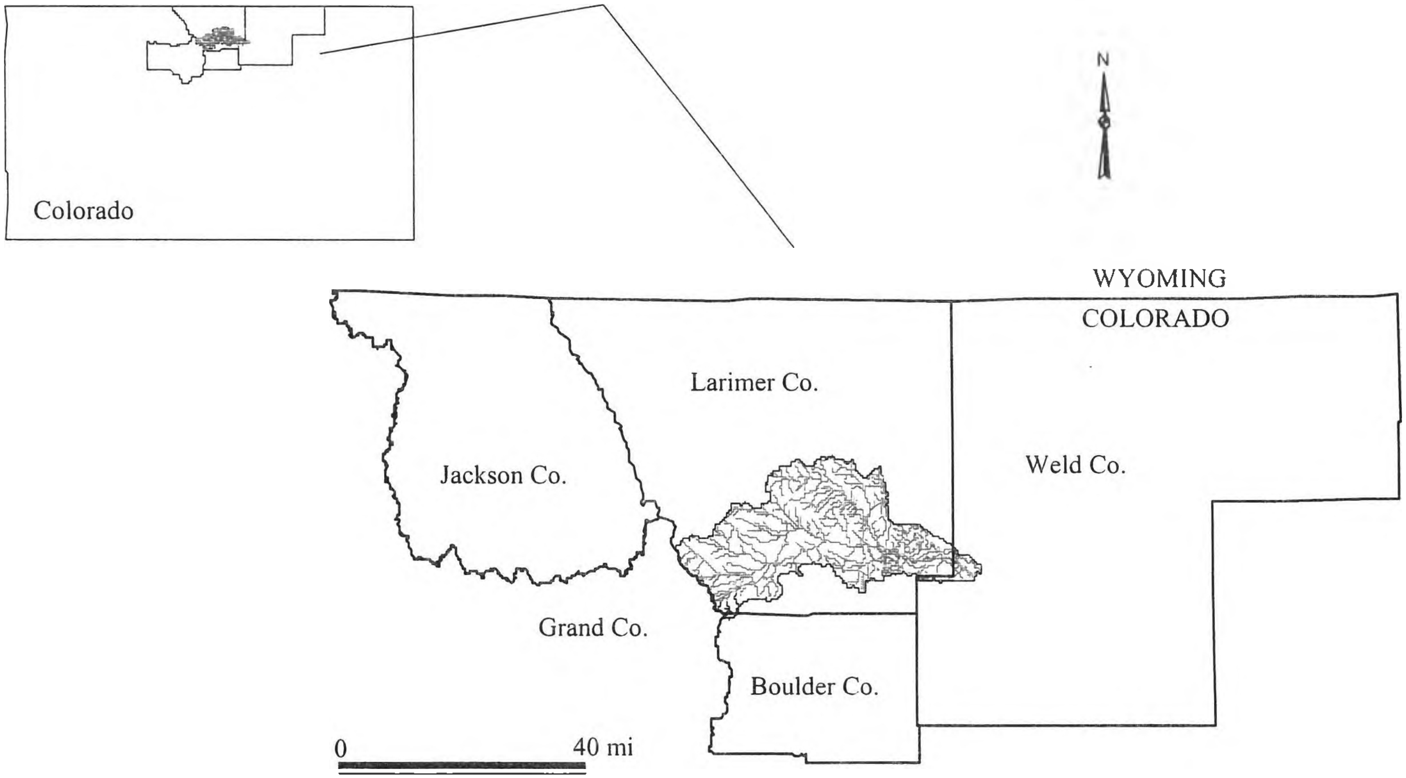

Figure 1. Big Thompson Watershed Location. The Big Thompson Watershed is located in Northern Colorado on the east side of the continental divide. The watershed resides almost entirely within Larimer County. Geographic data were obtained from EPA BASINS (1998).

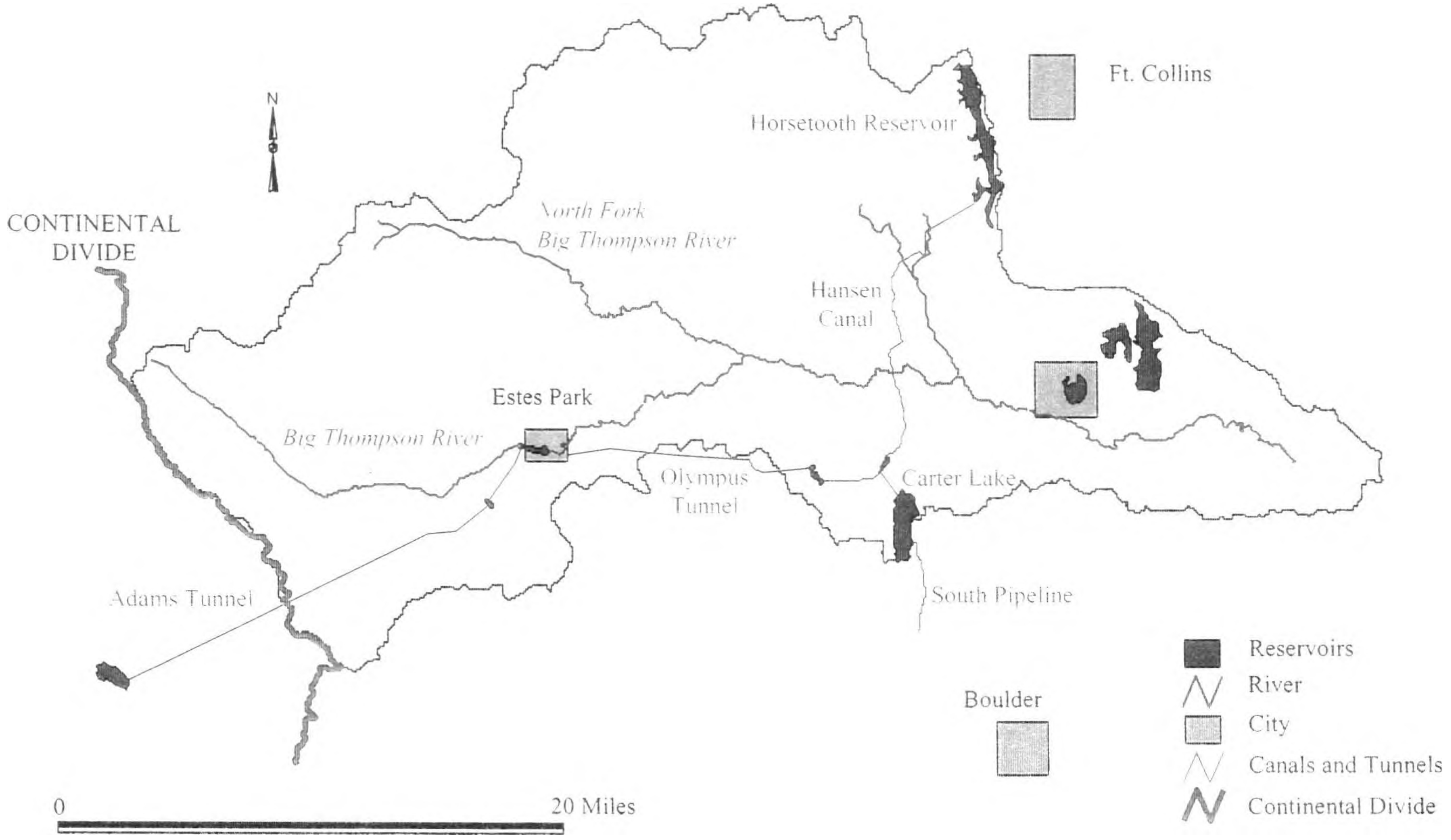

Figure 2. The Colorado Big Thompson Project Eastern Slope Distribution.

following is a description of the C-BT Project provided by NCWCD on their web page: http://www.ncwcd.org/ (accessed 10/31/99).

> The Colorado Big Thompson Project is the largest transmountain water diversion project in Colorado.
>
> Built from 1938 to 1957, the C-BT provides supplemental water to 30 cities and towns. The water is used to help irrigate 615,000 acres of northeastern Colorado farmland.
>
> Twelve reservoirs, 35 miles or tunnels, 95 miles of canals, and 700 miles of transmission lines comprise the complex collection, distribution, and power system. The C-BT system spans 150 miles east to west and 65 from north to south.
>
> West of the Continental Divide, Willow Creek and Shadow Mountain reservoirs, Grand Lake and Lake Grandby collect and store the water of the upper Colorado. It is pumped into Shadow Mountain Reservoir where it flows by gravity through Grand Lake. From there, the 13.1 mile Alva B. Adams Tunnel transports the water under the divide to the East Slope.
>
> Once the water reaches the East Slope, it is used to generate electricity as it falls almost half a mile through five power plants on its way to Colorado's Front Range. Carter Lake, Horsetooth Reservoir, and Boulder Reservoir store the water. C-BT water is released as needed to supplement supplies for irrigation in the South Platte River Basin or for cities and industries in northeastern Colorado.
>
> The C-BT Project annually delivers 230,000 acre-feet of water to northeastern Colorado for agriculture, municipal and industrial uses.

### 3.2 Physical Description

*Water Mass Balance on the Big Thompson Watershed* written by Troy Monroe (1999) includes a detailed segment-by-segment description of the Big Thompson River and the Colorado Big Thompson Project. In his report, major flows into and out of the mainstem of the river have been quantified and described. This report was completed using Stream Flow Data for Colorado published by the Office of the State Engineer, Division of Water Resources (1994).

### 3.3 Watershed Boundary

The Watershed Boundary used for this project was not the natural hydrological boundary. The boundary was changed for both practical and political reasons. The Big Thompson is a highly controlled system with transmountain diversion and a vast network of tunnels, canals, and reservoirs. In order to accommodate the human-made water controls and the interests of the BTWF members, the boundary was shifted. The two major changes in the boundary were to exclude the Little Thompson River drainage and include Horsetooth Reservoir (Figure 3). The decision to exclude the Little Thompson was made because stakeholders in the BTWF were not serviced by this water source. Although Horsetooth Reservoir lies outside the hydrological boundary, it is fed by water from the Big Thompson River and the Colorado Big Thompson Project. The water is used to supply drinking water to the City of Fort Collins, a BTWF participant.

### 3.4 Water Use

Water from the Big Thompson Watershed supports agriculture, municipal drinking water supplies, industry, recreation, and ecosystem health. NCWCD distributes roughly two-thirds of the water that travels down the Big Thompson Watershed. Of this water, over 70% is used to support over 600,000 acres of irrigated agriculture. The remaining 30% is split between municipal and industrial uses. Although the water comes through the Big Thompson Watershed, the majority of the municipalities dependent on

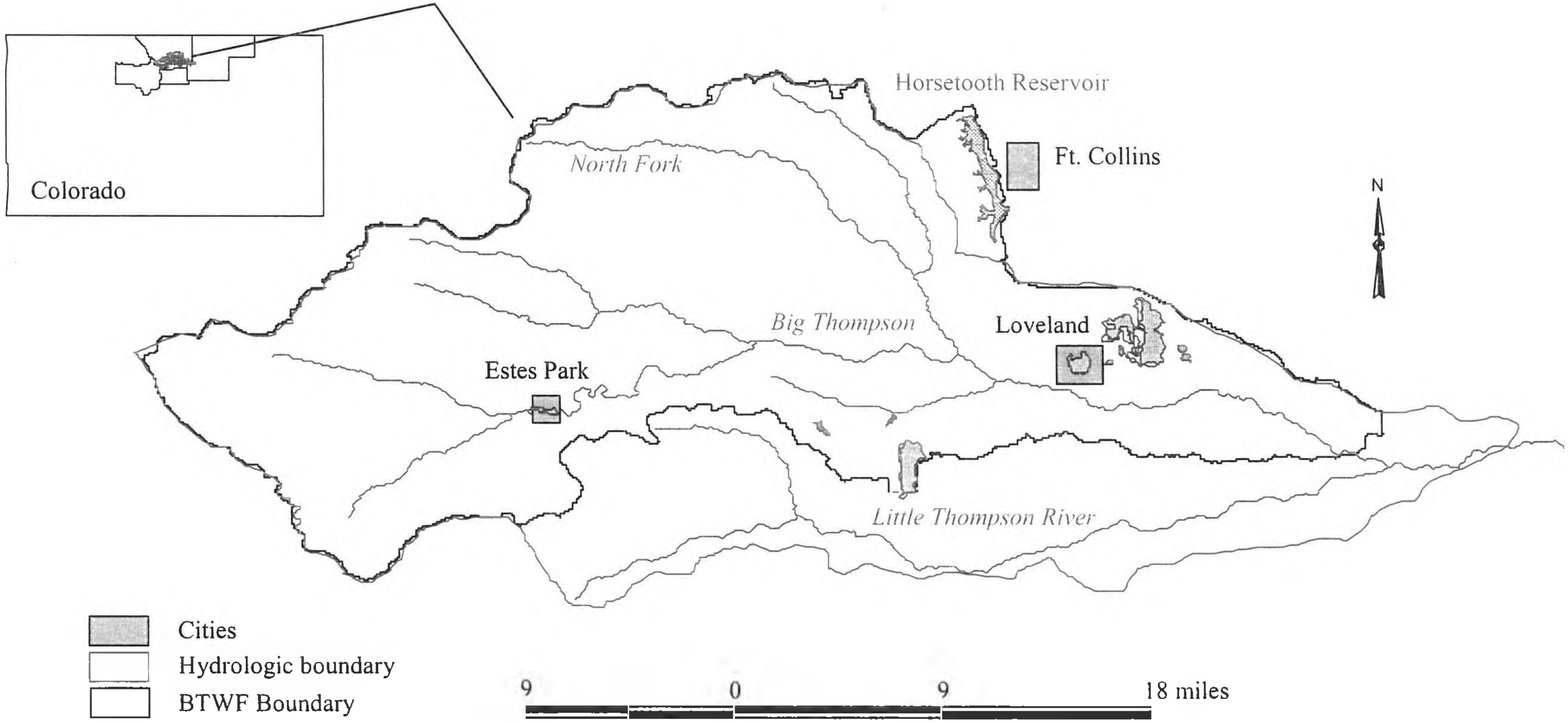

Figure 3. Big Thompson Watershed Forum Boundary. The BTWF boundary excludes the Little Thompson River and adds Horsetooth Reservoir within the hydrological boundary

this water reside outside the watershed boundaries. Only two of the thirty cities and towns that receive drinking water from the CB-T reside within the BTWF boundary (NCWCD, 1999).

The distribution of the natural flow of the Big Thompson River is very similar to that of the water from the CB-T. According to the US Geological Survey, nearly 90% of the water is used for agricultural purposes. The remaining 10% is used as mainly public drinking water supply (Table 1). These data are based on the hydrological boundary of the watershed and therefore the water use breakdown within the BTWF boundary may be slightly different due to the inclusion of the Little Thompson River in these numbers.

Table 1. Water Use. The breakdown of water use determined for the natural flow of the Big Thompson. (Mgal/d = million gallons per day)

| **Withdrawal Type** | **Percent** | **Withdrawal Amount** |
|---|---|---|
| Total withdrawals | 100% | 138.78 Mgal/d |
| Total consumptive use | 68.09% | 94.5 Mgal/d |
| Commercial/Industrial | 1.17% | 1.63 Mgal/d |
| Public Supply | 8.96% | 12.44 Mgal/d |
| Irrigation/Agricultural Use | 89.59% | 124.33 Mgal/d |

### 3.5 Land Use

The upper portion of the watershed is mountainous with large regions designated as national park (Rocky Mountain National Park) or as national forest (Arapahoe-Roosevelt National Forest). Most land use falls under the label "natural lands", 89% of which is evergreen forest (Table 2., for further breakdown see Appendix A). Urban areas comprise only half a percent of the land use within the watershed, just three square miles. The percent of urban land use is less than the percent of urban water use because all but two municipalities dependant on Big Thompson water are outside the BTWF boundaries.

Table 2. Land use Within the BTWF Boundary. Information was supplied by the USGS utilized in the EPA's BASINS Model (1998).

| **Land use** | **% area** | **area, $mi^2$** |
|---|---|---|
| Urban Use (commercial and services, industrial, mixed urban, other urban, and utilities) | 0.48% | 2.99 |
| Agricultural Use (confined feeding ops, cropland and pasture, orchard, grove, vineyard, and other agriculture) | 25.43% | 158.86 |
| Natural Lands (exposed rock, bare ground, evergreen forest, forested and nonforested wetland, herbaceous tundra, lakes, mixed forest, mixed and herbaceous rangeland, mixed tundra, reservoirs, and shrub and brush tundra) | 74.06% | 462.61 |
| Other (transitional areas, strip mines) | 0.03% | 0.21 |
| **TOTAL** | **100.00%** | **624.67** |

### 3.6 Population Growth

Both areas within the Big Thompson Watershed, and those dependant on its water, have experienced rapid growth over the last decade. The growth has increased development within the watershed and the demand on this water source. Between 1990 and 1997, Boulder and Larimer Counties were among the fastest growing in the state of Colorado, experiencing a 17.6% and 21.6% increase in population respectively. This growth has been seen in nearly every municipality within these counties (Figure 4). This population boom is not predicted to slow any time soon (Figure 4).

This presents a two-fold challenge to those who depend on water for a variety of uses. First, the number of people living within the watershed will continue to grow, meaning there will be changes in land use, continued development, and increased recreational use. Each of these changes poses a potential threat to water quality. Second, the growing population of people outside the watershed who depend on Big Thompson water for drinking, increases pressure on utilities to provide high quality drinking water. Both of these challenges must be met through a greater emphasis on effective management of water resources and protection of water quality.

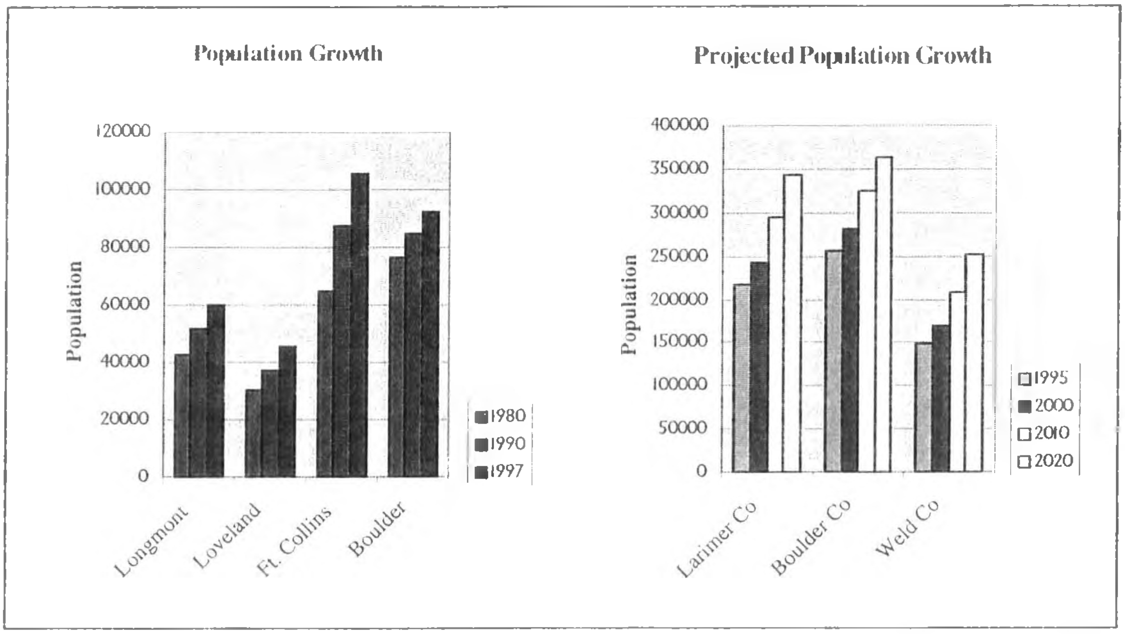

Figure 4. Population Growth. Since 1980 cities in the front range have experienced growth, and the projections for the counties doesn't show any slowing of growth. Demographic data were obtained from the University of Colorado (1999).

### 3.7 Monitoring Efforts within the Watershed

Over 12 different entities have gathered water quality data in the Big Thompson watershed (Table 3). These efforts have varied in length and scope. Among the ongoing monitoring efforts there is a large amount of duplication of efforts (Figure 5). As the monitoring is currently being conducted, this overlap is impossible to eliminate because the agencies use different field and laboratory procedures making the data incompatible.

Table 3. Monitoring Agencies. These are entities who have gathered data within the Big Thompson Watershed (Writer, 1996 and Renner, 1997).

| **Agency Name** | **Sampling Conducted** |
|---|---|
| Northern Colorado Water Conservancy District | Conducts ongoing water quality monitoring at four sites within the watershed |
| Bureau of Reclamation | Cooperates with the USGS to gather flow data |
| US Forest Service | Does not conduct ongoing monitoring, however water and habitat data is gathered on an irregular basis |
| USGS | Gathers long terms flow and water quality data at several sites within the watershed |
| Water Quality Control Commission | Currently do not gather data in the watershed, but have taken irregular samples and may monitor there in the future |
| City of Fort Collins | Has a drinking water intake on Horsetooth Reservoir and conducts ongoing monitoring on the Hansen canal, Carter Lake, and Horsetooth Reservoir |
| City of Loveland | Gathers ongoing data from several points on the mainstem of the Big Thompson |
| City of Greeley | Has recently begun an ongoing program that tracks water quality along the mainstem and through the canal systems connecting Lake Loveland and Boyd Lake |
| Estes Park Sanitation District | Has gathered data off and on both above and below its wastewater discharge point |
| Upper Thompson Sanitation District | Gathers ongoing data below its discharge |
| National Park Service | Maintains long-term water quality monitoring in the Loch Vale area |
| City of Estes Park | Gathers ongoing data at drinking water intakes |
| Colorado Dept. of Wildlife | Has gathered data in the past with respect to aquatic life |
| Ft. Collins, SWAT | Ongoing data gathered along the entire length of the mainstem by high school students in the Riverwatch program |

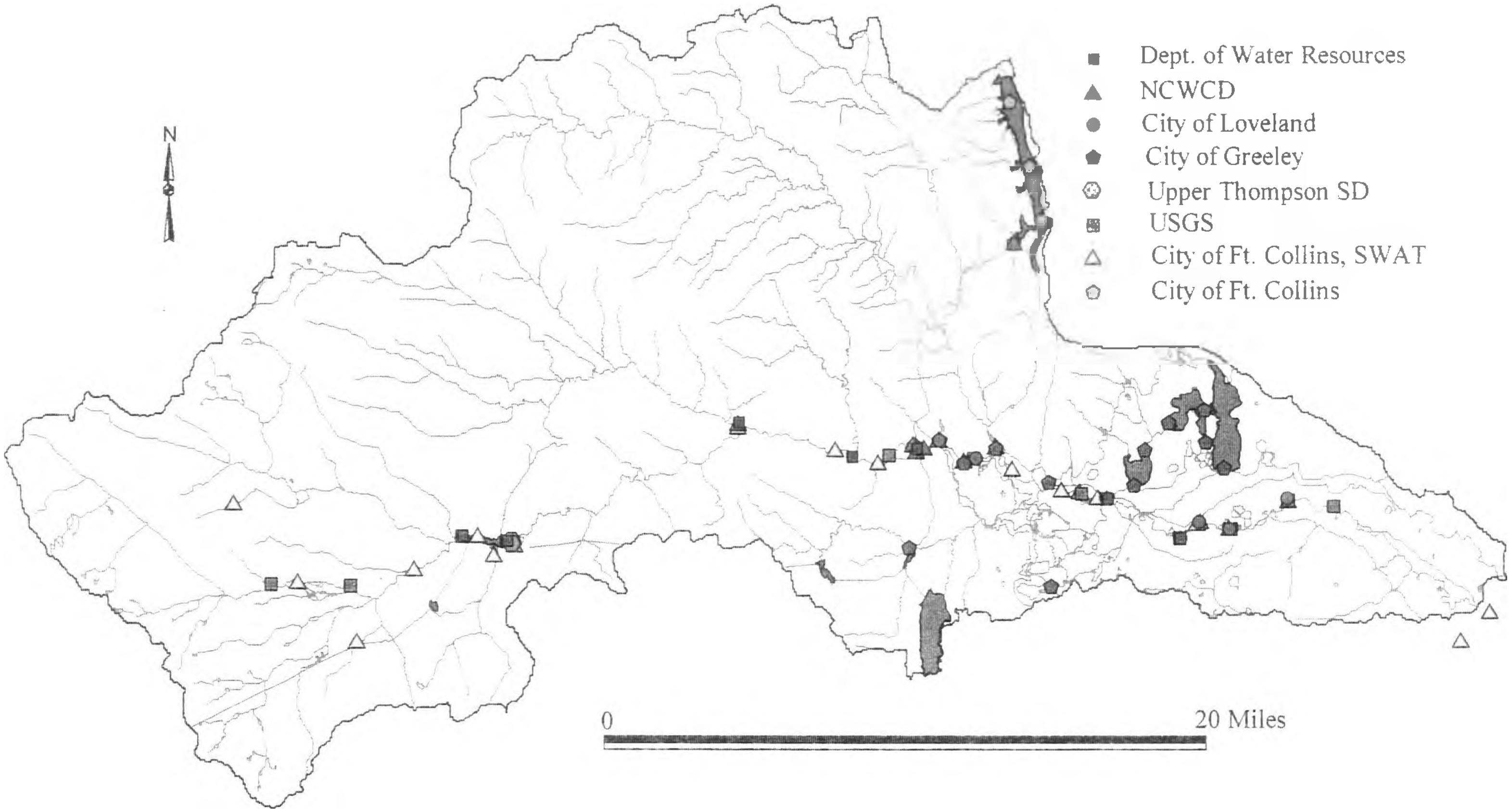

Figure 5. Current Monitoring in the Big Thompson Watershed.

# CHAPTER 4

# METHODS

The approach used to design this monitoring program focused on producing water quality information as opposed to water quality data. The concept of a water quality information system, introduced by Ward et al. (1990), makes a distinction between data collection and information generation. The "nuts and bolts" of a monitoring program makes up the data collection system: variable selection, network design, and laboratory analysis. In order for a monitoring program to be an information system, the data must be analyzed, reported, and ultimately used. Outcome-based monitoring focuses on the desired informational product and builds each part of the design towards that end. The first step, therefore, in designing a monitoring system is a description of the informational product, a set of objectives.

Dixon and Chriswell (1996) emphasize that effective monitoring must be undertaken with a specific purpose in mind. The determination of a specific purpose dictates the approach taken for network design. Network design includes variable list development, sample site locations, sampling frequency, data analysis protocol, reporting format, QA/QC measures, sampling protocol, laboratory analysis methods, and data storage/handling methods. Each of these components must relate to the objectives.

The implementation of a collaborative water quality information system in the

Big Thompson watershed is several years away (Figure 6). The design described in this report is the first step towards this aim, the design of a monitoring network: definition of objectives, variable list development, sample site designation, and determination of a sampling frequency. This portion of the monitoring information system makes up the first four steps listed within the box labeled “Monitoring Design” in Figure 6.

### 4.1 The Design Process

The success of a collaborative monitoring effort is dependant upon satisfying a diversity of interests and priorities with one monitoring system. It was critical to assure that all involved would be able to meet their information needs. In order to gather as much input as possible, the network design was broken into stages: objectives, variable list, monitoring locations, monitoring frequency, and cost analysis. Each stage in the design process was carried out through a series of meetings (Figure 7). The meetings began with the primary funding agencies listed below, followed by a public meeting at a General Assembly of the Forum. Each meeting resulted in a revised draft of the stage in the design being discussed. Decisions were made by group consensus, rather than “majority rule” to assure that the monitoring program would satisfy all participants in the monitoring.

*Funding Agencies* City of Ft.Collins
City of Greeley
City of Loveland
Northern Colorado Water Conservancy District
Tri-Districts Water Treatment Plant

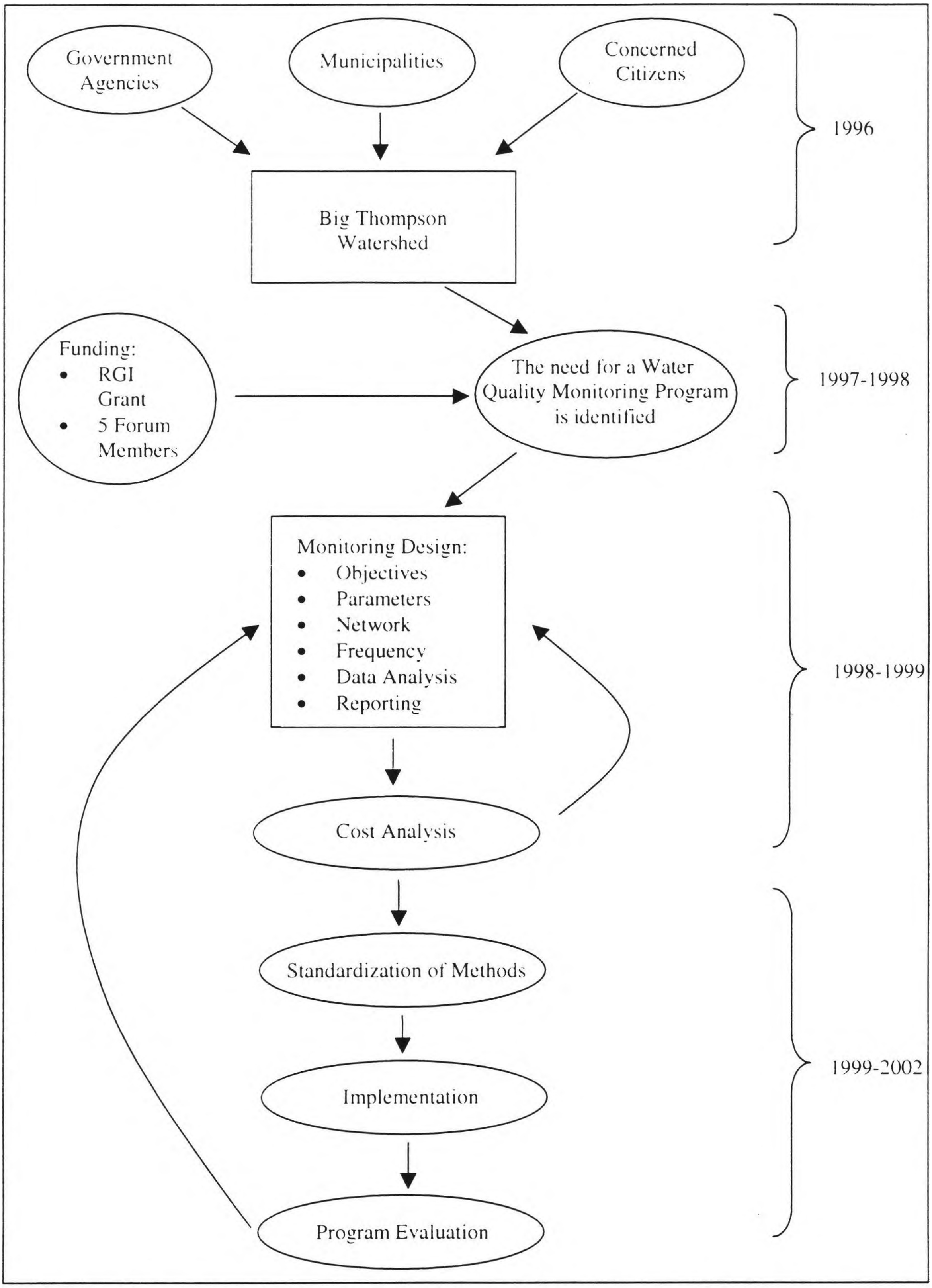

Figure 6: Big Thompson Timeline. The Big Thompson water quality monitoring system described from inception to completion.

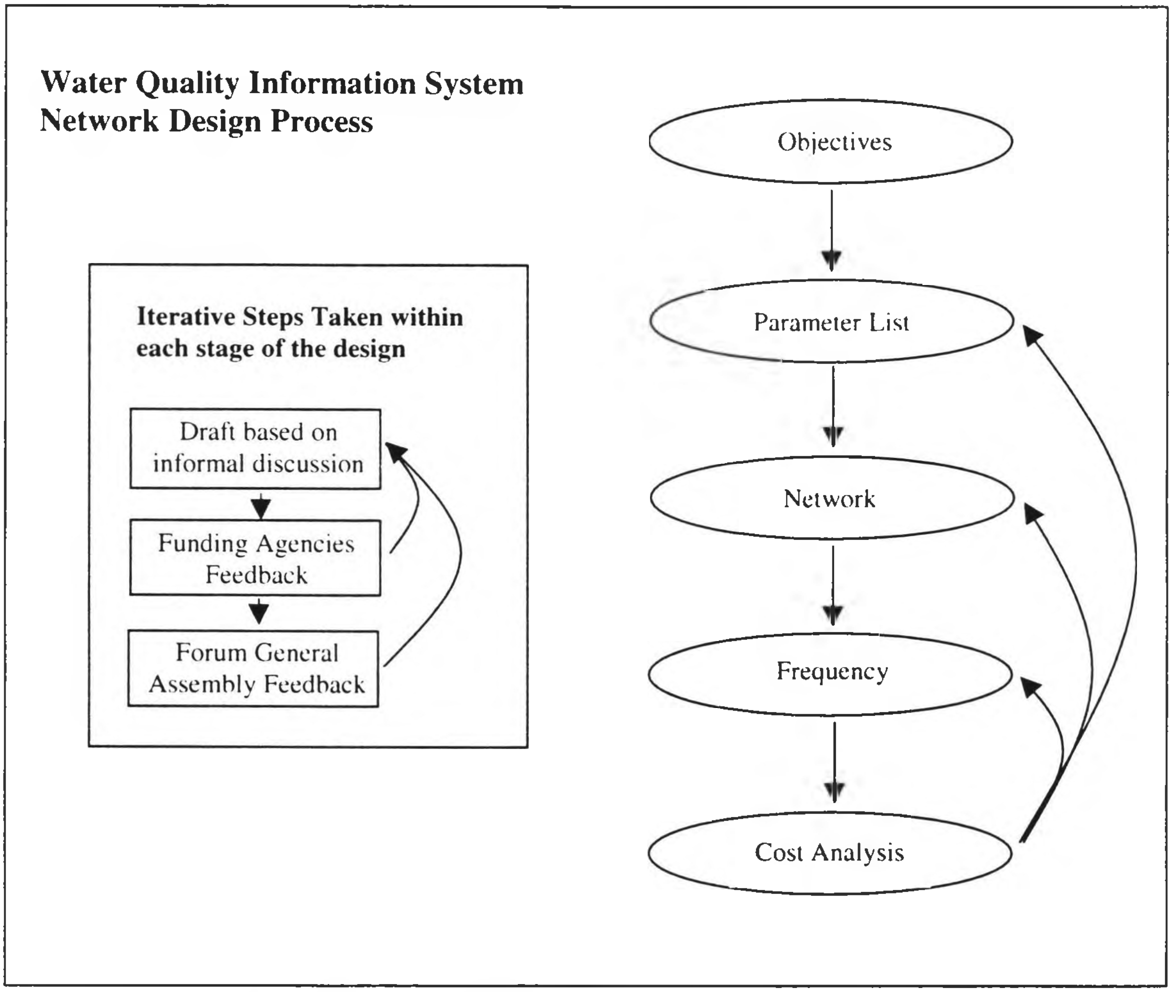

Figure 7. Design Process Flowchart. The iterative set of meetings used to gain feedback from the involved agencies assured that each step in the design met the participants' needs.

The steps of the network design were first taken in an effort to design an "ideal" monitoring network, one that satisfied all interested members of the BTWF without addressing potential cost constraints. For example, during variable list development, any variable that a BTWF member deemed important was added to the list, and no variables, once added, were removed. The same policy was applied to the monitoring network and sampling frequency. The completion of these three steps provided enough information for a preliminary cost estimate to be developed. Based on the cost estimate, each design step, except the objectives, was re-evaluated in an effort to reduce cost. Iterations due to financial limitations will continue throughout the development of the information system. The most current changes made to the variable list, monitoring network, and sampling frequency are reflected in this report.

## 4.2 Monitoring Objectives

Among all the steps in the network design, the largest amount of time was devoted to the development of the program objectives. This step was critical for three reasons.

1. The objectives determine the approach for the entire design. Each subsequent step refers back to the objectives.
2. Because objective development was first stage in the design process, it served as an opportunity to set the tone for group interactions.
3. It served as an opportunity to educate BTWF members about the steps involved in monitoring network design.

The final step in a monitoring system design is the evaluation of success once the project is completed. A program is evaluated by comparing the final product to the goals detailed in the objectives. In order to evaluate program success, the objectives must be quantitative and specific (Soballe, 1988 and ITFM Final Report, 1995). For example, a goal to "detect changes in water quality within the watershed" should be more specific. It can be stated as, "the ability to detect a change in water quality, one standard deviation in magnitude, over a five year period." In order to communicate the need for detailed, quantitative objectives to the BTWF members, a preliminary set of objectives was developed to act as an example and discussion piece.

### 4.3 Variable List

The development of the parameter list was done concurrently with objective development. Participants identified variables seen as meeting each of the objectives. As explained above, a conscious decision was made at this point to only add to the list rather than try to pare it down. This resulted in a lengthy list of constituents.

The initial list of variables was left until the network and frequency were determined, allowing for a cost analysis to be done. One of the most effective ways to lower costs was to drop the number of constituents being monitored. This kept the network and frequency intact, allowing for high quality data on fewer constituents as opposed to sacrificing accuracy for more variables. The first step in trying to scale back costs was the development of a "base" variable list. These were to be variables monitored at all sites within the system. Other parameters could only be added on a site-specific basis.

The preliminary base list removed any variables that could be measured in the field from the list of parameters that required laboratory analysis. The next step was to include all variables required by the Colorado Water Quality Control Commission (WQCC), as these variables must be monitored by law. Other variables that have been deemed critical by the funding agencies were also added to the list.

The base list of constituents was distributed to the five funding agencies for feedback. The response from the five agencies resulted in an edited variable list and a new set of cost estimates. Unfortunately, many variables were added to the base list in order to accommodate the responses from the participants. The revised variable list did not lower costs a great deal. It was clear that the only manner in which to effectively trim the parameter list was a meeting with all funding entities present. On July 21, 1999 the five funding entities, and a representative of Larimer County, met to develop the minimum variable list that would meet the needs of all participants. The effort to shorten the variable list began by discussing the merits of each variable individually. A variable was debated until a consensus was reached on its inclusion or removal from the variable list. The resulting list was dramatically smaller in size and still met the needs of the BTWF members.

### 4.4 Monitoring Network

Monitoring sites were chosen using three criteria: (1) the objective list; (2) the hydrology of the watershed (i.e. confluence locations, and diversions); and (3) the location of water gages and/or already existing monitoring sites. This final criterion was used in order to improve the accuracy of load calculations and to provide some continuity with historical data sets.

Each proposed monitoring station location was discussed both individually and with the entire group of funding members until all were in agreement to include or exclude a given location. This lengthy discussion period was deemed necessary in order to pave the way for a smooth transition to the implementation phase. The participating agencies will, in order for successful implementation of the program, need to adjust their individual monitoring station locations to match that of the proposed system. It is hoped that by assuring that all financially committed agencies had a voice the network formation, they will be more willing to make the adjustments needed for implementation.

Similar to variable list development, the network was re-evaluated following cost analysis. A work session on July 20, 1999 was held in order to reassess the reasoning behind each site location. Due to the extensive amount of discussion already contributing to the choice of sampling location, fewer changes were made to the network than the variable list. Instead of permanently removing sites from the system, it was decided to give sites either a low or high priority rating. High priority sites were those deemed critical to meeting the informational goals of the BTWF. The low priority sites would be included if funding was available to do so.

### 4.5 Sampling Frequency

The frequency of sampling is dependant upon the variability of the population being sampled. The more variable a population, the more samples required to obtain an accurate representation. The first step in determining sample frequency, therefore, is to estimate the variability of the population being sampled. The variability of water quality parameters may change over the course of a year due to fluctuations in flow and temperature. Designating sampling seasons based on flow and water temperature allowed for shifts in variability to be identified. An indicator of variability, standard deviation, was determined for each water quality variable with adequate historical data, during each season. Using standard deviation, a series of sampling frequencies (monthly, biweekly, weekly) were evaluated based on the level of accuracy achieved in estimating mean concentration and trend over a five and ten year period.

### 4.51 Designation of Seasons

Seasons were designated based on annual water temperature and flow cycles. Monroe (1999) utilizes mean daily flow data, obtained from the Office of the State Engineer (1994), to calculate an average daily flow for each month over a 20 year period. These data were plotted to produce the annual hydrographs for 15 locations within the Big Thompson Watershed. A similar process was carried out for water temperature. Average water temperature for each month was determined using data collected by the US Geological Survey (EarthInfo, 1996). These two graphs were overlaid, and three seasons were designated: high flow and high temperature, low flow and high temperature, and low flow and low temperature.

### 4.52 Moving Water Sampling Frequency

The sample frequency that provided the best compromise between accurate estimations of means, trend detection, and economics was chosen. Using historical data gathered within the watershed, the degree of accuracy for various frequencies for mean estimation and trend detection was determined. It was hoped that historical data could provide an accurate estimation of background variability. For the analysis, historical variability was assumed to be representative of the variability currently found in water quality constituents.

The first step in the analysis was to identify those variables that were seasonally distributed. Differences in variable concentrations between seasons were identified through the use of a one-way analysis of variance (ANOVA) performed using MINITAB®. If the p-value (calculated based on the degrees of freedom and the f-statistic) was less than 0.05, the constituent was assumed to be seasonal, with three individual seasons. If the p-value was greater than 0.05, a series of two-sample t-tests were conducted to compare each of the seasons individually. This allowed a variable that was only affected by one seasonal parameter, temperature or flow, to be identified and the subsequent seasons lumped. If the p-value for a given comparison was less than 0.05, the seasons were assumed distinct.

The distribution of each variable for its defined seasons was determined through the use of probability plots. For the ease of calculations, the data were assumed to be either normally or log normally distributed.

The mean and standard deviation of each parameter, for each season, were calculated. For those variables that were log normally distributed, the mean and standard deviation were of the log of the data. Based on the calculated standard deviation, the accuracy of a mean estimate was determined for various sampling frequencies; daily, weekly, twice a month, and monthly. An equation for sample size that assumed independent data and random sampling was used for the analysis. The t distribution was used for two reasons: (1) the means and standard deviations were calculated based on historical data; and (2) the t distribution offered a more conservative estimate of sample size (larger). These calculations were done on an EXCEL spreadsheet.

Normal Distribution

$$E = \frac{t_{\alpha/2} s}{\sqrt{n}}$$

E = half width of confidence interval
$t_{\alpha/2}$ = students t value at $\alpha = 0.05$
s = standard deviation of the log of the historical data
n = number of samples taken for given frequency
(Ott, 1993)

Log Normal Distribution

$$E_y = \frac{t_{\alpha/2} s_y}{\sqrt{n}}$$

$E_y$ = half width of the confidence interval in log space
$s_y$ = standard deviation of the log of the historical data
(Helsel and Hirsch, 1992)

The percent error for the estimation of means was then calculated by dividing the half width of the confidence limit by the estimated mean. In the case of the log normally distributed parameters, the upper and lower limits of the confidence interval were not symmetric. In order to calculate the half width, the full width of the confidence interval was divided by two.

Normal Distribution:

$$error = \frac{E}{\bar{x}}$$

$\bar{x}$ = mean

Log Normal Distribution:

$$UB = e^{\bar{y}+E_v}$$

$$LB = e^{\bar{y}-E_v}$$

$$error = \frac{(UB - LB)/2}{e^{\bar{y}}}$$

$e^{y}$ = estimate of the geometric mean
UB = upper bound of the confidence interval
LB = lower bound of the confidence interval

The mean and variance of historical data were also used to estimate the size of trend detectable with each sampling frequency over five and ten year periods. All parameters, for all seasons, were assumed normally distributed. Changes in distribution observed in the data set indicate that nonparametric statistics were likely the most appropriate for detecting trends. However, due to the nature of nonparametric approaches, they are difficult to use to estimate sample size. In addition, some of the data were markedly log normal; however, trends in log space describe exponential growth. This program is most likely going to be identifying linear trends. The trend detection analysis was done in order to get a “ball park” estimate of the size of the trend that may be detectable for a give sampling frequency.

The trend detection analysis used a 90% confidence level and a power of 80%. Confidence level refers to the likelihood of a Type I error and power is the likelihood of a Type II error.

$$trend = \sqrt{\frac{12\left(s^2\right)\left(t_{\alpha,\nu} + t_{\beta(1),\nu}\right)^2}{n}}$$

$s^2$ = variance
$t_{\alpha\cdot v}$ = confidence level
$t_{\beta(1),v}$ = power
n = sample size
(Lettenmaier, 1976 and Howell, 1998)

Trends will be calculated over a number of years, meaning that seasonal variation must be accounted for. The only term in the trend estimation equation that is derived from the historical data is the variance. In order to account for seasonal variation over many years, a deseasonalized variance was calculated for use in the trend analysis.

Deseasonalized Variance:

$$s^2 = \frac{\sum_{i}^{n_m} \sum_{j}^{m} \left(x_{ij} - \bar{x}_j\right)^2}{\left(N - m\right)} \qquad (1)$$

$s^2$ = overall variance
n = number of samples in each season
m = number of seasons

This equation can be simplified via substitution. The formulas for the individual variance of each season can be substituted in to an expanded version of (1), (1a).

$$\hat{s}^2 = \frac{\sum_i^{n_1}(x_{i,1} - \bar{x}_1)^2 + \sum_i^{n_2}(x_{i,2} - \bar{x}_2)^2 + \sum(x_{i,3} - \bar{x}_3)^2}{(N - m)} \qquad (1a)$$

$$s_1^2 = \frac{\sum_i^{n_1}(x_{i,1} - \bar{x}_1)}{n_1 - 1} \qquad (2)$$

$$s_2^2 = \frac{\sum_i^{n_2}(x_{i,2} - \bar{x}_2)}{n_2 - 1} \qquad (3)$$

$$s_3^2 = \frac{\sum_i^{n_3}(x_{i,3} - \bar{x}_3)}{n_3 - 1} \qquad (4)$$

Substituting (2), (3), and (4) into (1a) gives:

$$\hat{s}^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + (n_3 - 1)s_3^2}{(N - m)}$$

### 4.53 Reservoir Sampling Frequency

The reservoir monitoring scheme was developed with the aid of Dr. Brett Johnson, a faculty member at CSU in Fishery and Wildlife Biology. Dr. Johnson has been monitoring both Horsetooth Reservoir and Carter Lake over the last year and has analyzed historical data on Horsetooth. Horsetooth is the only reservoir in the watershed with an extensive historical data record. Due to the lack of data, reservoir sampling frequency was based upon the behavior of reservoirs similar in size, temperature, and residence time to those in the watershed, instead of a statistical analysis of data. The reservoirs in the watershed were divided into three groups based upon physical characteristics. A sample frequency was assigned to each group. Once monitoring data is available, the frequencies can be adjusted for the specific behavior of each reservoir.

### 4.6 Cost Analysis

Cost estimates were calculated using the price lists provided by Acu Labs in Golden, Colorado, CH Diagnostics in Loveland, CO, and by Dr. Brett Johnson at CSU. The estimate assumed external companies, for example, a consulting firm and a private lab, would implement the entire monitoring program. This was done to give a maximum cost.

The estimate was broken down into field and laboratory analysis costs. Analysis costs were determined by multiplying the total number of samples per year by the number of sampling sites, to obtain the total number of samples to be analyzed per year. The total was multiplied by the analysis cost for each variable and summed to give a total annual cost.

$$S_1 + S_2 + S_3 = S_y$$

$$S_y(N_T) = S_T$$

$$S_T(L) = C$$

$S_1$, $S_2$, $S_3$ = number of samples in seasons 1, 2, and 3
$S_y$ = total annual samples at one site
$N_T$ = total number of sampling locations
$S_T$ = total annual samples for entire monitoring network
L = laboratory analysis cost
C = annual analysis cost for a given variable

Field costs were broken down into labor, materials and supplies, and vehicle costs. Labor costs assumed a sampling team of three people, 45 minutes per site, and an hourly wage of $50. Reservoir sites assumed five hours per site. The following is an example calculation for moving water labor costs.

*3 people (0.75 hours) $50.00 per hour = $112.50 per site*

*$112.50 (total site visits per year) = annual labor costs*

Annual materials cost estimates for moving water assumed five dollars per site visist and $50 per site visit for reservoir sampling. This value was simply multiplied by the total number of site visits per year for total annual materials costs.

Sampling sites were assumed to be an average of 15 miles apart with a vehicle operation cost of $0.35 per mile.

*15 miles per site ($0.35 per mile) total site visits per year = annual vehicle costs*

A new cost estimate was determined for each adjustment to the variable list, monitoring network, or frequency. The cost was deemed reasonable when it was approximately equal to the sum of the funding members' monitoring budgets.

# CHAPTER 5

# MONITORING OBJECTIVES

It was expected that the Big Thompson monitoring system would include several types of monitoring components. The most important of these being the establishment of a baseline monitoring network to function as a backbone to all other monitoring efforts. Ongoing monitoring efforts lay an informational groundwork needed to address future episodes of poor water quality (Soballe, 1998). It is this routine baseline monitoring at which the following objectives were aimed. Once the specifics of this base monitoring network have been determined, areas of concern that require intensive, short term monitoring may be identified to supplement the baseline monitoring.

The development of the following objectives began with the identification of the primary water quality issues and management concerns within the watershed. "Water quality issues" is a list of water conditions that most concerned the participating agencies. The "management issues" refer to the management decisions that impact water quality. It is hoped that the information generated by a BTWF monitoring program would be used to make informed decisions regarding the types of land and water management listed in "management issues".

### *Key Issues in the Big Thompson Watershed*

#### Water Quality Issues

- Eutrophication: Referring to the presence of increased nutrient loads and the frequency of algae blooms
- Agriculture: Concerned with both the suitability of water for agricultural use and the impact of agricultural return flows
- Drinking Water Quality: The presence of contaminants that pose health, taste, or odor problems for the use of water as a drinking water supply
- Ecological Integrity: Habitat protection and the food web structure of streams and reservoirs
- Recreational Uses: Referring to both the suitability of water for recreational use, and the subsequent impact on water quality due to recreational use

#### Management Issues

- Rural Use/Development: The primary concern is rural growth that relies upon septic systems.
- Urban Areas/Urban development: Expanding urban areas increase runoff and the construction has the potential to create erosion.
- Recreational Use/Growth: Rising populations mean that more people will be in contact with the water, requiring protection for the user from potential waterborne threats and protection of the water from user contamination. This is particularly important for marina management on some of the reservoirs.

- Forest and Range Management: Most of the Big Thompson watershed is forested. The management of these lands, particularly for runoff control, is critical for water quality.
- Agricultural Management: The BTWF members were concerned with the quality of agricultural return flows.
- Open Space Management (river corridors, etc.): City or county protected open space has the potential to improve water quality and protect habitat critical to riparian biological diversity.
- Stormwater Management: Especially in the growing urban areas, runoff from roads is a threat to water quality. Currently, in Loveland, street runoff drains directly into the river.
- Fisheries Management: Water quality affects fish health, and fish population dynamics can affect water quality.

**Objective 1**. Assess the degree of compliance with existing and anticipated water quality or stream standards and classifications related to the beneficial uses of water within the watershed.

As a cooperative monitoring system, it is hoped that all data generated by participating agencies within the watershed will be shared, including all monitoring required by law. The first objective accounts for regulated variables, advocating that all data generated within the watershed should be gathered in a standardized manner to allow data sharing.

**Objective 2.** Determine the trophic state of selected reservoirs in the watershed.

- Average concentration for trophic indicators on a seasonal basis
- Characteristic high and low values of trophic indicators determined on a seasonal basis
- Factors affecting primary productivity

Objective two addresses the health of reservoirs within the watershed, calling for the mean and extreme values of trophic indicators on a seasonal basis.

**Objective 3**. Assess the impact of feeder system (streams, canals, groundwater) loads on reservoirs.

- Using the water balance values, determine seasonal and annual flows through each sampling site, and flows into and out of each reservoir.
- Determine seasonal and annual mass loads of nutrients and metals through the watershed, into each reservoir, and out of each reservoir, for assessing impacts on reservoir water quality.

In order to better understand the key reservoirs within the watershed, detailed information about the water systems feeding each reservoir is needed. Monroe (1999) completed at a hydrologic balance of the watershed. Using his work, in conjunction with stream gages, the mass loads (amount of a given constituent by weight) can be calculated.

**Objective 4**. Assess the magnitude and statistical significance of temporal and spatial trends in quality constituents for both concentrations and mass loads at each monitoring site in the system.

Objective four indicates a specific type of data analysis. It requires that all monitoring sites and variables be analyzed for both temporal and spatial trends. Spatial trends refer to the change in water quality as water moves down the watershed. The change in water quality over time is demonstrated by temporal trends. Identifying a change in water quality over time usually requires between five and ten years of data. The five to ten year wait period allows for a trend to emerge from the "noise" of the underlying variability in water quality data.

**Objective 5**. Distinguish between flow-related variation, and variation related to changes in land use.

- Determine flow-adjusted average concentrations on a seasonal basis.

Objective five is also a data analysis goal. It aims to separate natural variation, due to precipitation, and variation due to changes in land use. This advocates the deseasonalization of water quality data in hopes of being able to identify trends over the noise of natural climatological change.

# CHAPTER 6

# PARAMETER LIST

The original parameter list was developed in conjunction with the objectives. It included 46 variables (Table 4). Following the first cost analysis, a base list of variables was distributed for feedback (Table 5). The base list included 36 variables. In an effort to reach consensus on a variable list, the funding entities gathered in July 1999. The resulting list of 38 variables (Table 6) was the minimum variable list that met the informational needs of all funding entities.

Table 4. Original "Ideal" Variable List.

**Original Ideal Variable List, developed 9/98**

**Inorganic Constituents**

Alkalinity
Biochemical Oxygen Demand
Total Organic Carbon
Chloride
Fluoride
Hardness
Nitrogen, Ammonia
Nitrogen, Total
Nitrogen, Total oxidized (nitrate + nitrite)
Oxygen, Dissolved
pH
Phosphorus, orthophosphate
Phosphorus, Total
Specific Conductance
Solids, Total dissolved
Solids, Total suspended
Solids, Total
Sulfate
Turbidity

**Organic Constituents**

Benzene
Ethylbenzene
Toluene
Xylene
Total Petroleum Hydrocarbons

**Metals**

Arsenic
Cadmium
Calcium
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Potassium
Selenium
Silica
Silver
Sodium
Zinc

**Microbiological**

E. Coli
Fecal Coliform
Fecal Streptococci
Total Coliform

**Biological Constituents**

Chlorophyll-a
Phytoplankton
Zooplankton

Table 5. Base List. The proposed base list of variables was made as a first effort to reduce the number of variables sampled within the monitoring program.

**Proposed Base List Variable List, developed 6/99**

**Inorganics**
Total Organic Carbon, TOC
Chloride
Nitrogen, Ammonia
Nitrogen, Nitrate
Nitrogen, Nitrite
Phosphorus, Orthophosphate
Phosphorus, Total
Sulfate
Nitrogen, Total
Solids, Total

**Metals**
Arsenic
Copper
Iron
Lead
Silver
Nickel
Zinc
Manganese
Sodium

**Microbiological**
E. Coli
fecal coliform
Total coliform

**Organic**
Benzene
Toulene
Ethylbenzene
Xylene

**Biological**
Chlorophyll a
Phytoplankton

**On-Site Parameters**
Dissolved Oxygen
Temperature
pH
Turbidity
Alkalinity
Hardness
Specific Conductance
Secchi Disk

Table 6. Trimmed Variable List. It is this trimmed variable list that meets both the informational needs of the BTWF participants and the financial constraints on the monitoring program.

**Trimmed Variable List, developed 7/99**

**Inorganics**
Alkalinity
Hardness
Chloride
Nitrogen, ammonia
Nitrogen, nitrate+nitrite
Nitrogen, TKjdl
Phosphorus, orthophosphate
Phosphorus, total
Phosphorus, total soluble
Solids, total
Sulfate
Turbidity

**Metals**
Arsenic
Copper
Iron
Lead
Manganese
Mercury
Nickel
Silver
Sodium

**Organics**
Benzene
BTX
Ethylbenzene
TOC(NPOC)
UV 254

**Microbiological**
E.Coli
Fecal colif
Total colif
Algal Species
Chlorophyll-a
Phytoplankton
Zooplankton

**Field**
DO
pH
Secchi Disk
Sp Conductance
Temperature

# CHAPTER 7

# MONITORING NETWORK

The monitoring network was divided into reservoir and moving water sites. Moving water refers to flow in tunnels, canals, tributaries, and the mainstem. The initially agreed upon network included 29 moving water sites and nine sites on five reservoirs, in addition to each of the drinking water intakes.

During the work session held on July 20, 1999, one site was added, a reservoir site on Horseshoe Reservoir, and seven sites were designated as "low priority". The prioritization of the sites is listed in Table 7 and displayed in Figures 8 and 9. A detailed description of site location and the reasoning behind each monitoring site is included in Appendix B.

Table 7: Sampling Site List. The list was generated at the July 20, 1999 meeting.

**Big Thompson Watershed Monitoring - Site Selection**

| **Reservoirs** | | **Priority** | **Monitoring Entities** | **Segment** |
|---|---|---|---|---|
| **R10** | L. Estes | low | USGS | 2 |
| **R20** | Horsetooth | low | Ft. Collins | Poudre 14 |
| **R30** | Horsetooth | low | USGS, Ft. Collins | Poudre 14 |
| **R40** | Horsetooth | high | Ft. Collins | Poudre 14 |
| **R50** | L. Loveland | high | Greeley | 12 |
| **R60** | Boyd L. | high | Greeley | 12 |
| **R70** | Boyd L. | high | Greeley | 12 |
| **R80** | Carter L. | high | USGS, Ft. Collins | 11 |
| **R90** | Carter L. | high | Ft. Collins | 11 |
| **R100** | Horseshoe L. | high | Greeley | 12 |
| **Cannals/Tunnels/Ditches** | | **Priority** | **Monitoring Entities** | **Segment** |
| **C10** | East Portal | high | USGS | |
| **C20** | Olympus (@ L. Estes) | high | USGS | |
| **C30** | Hansen at Flat Iron Reservoir | high | Greeley, Northern | |
| **C40** | Hansen @ tri-f | low | Greeley | |
| **C50** | Hansen at Horsetooth inlet | high | Northern, Ft. Collins | |
| **C60** | Big Barnes (at L. Love.) | high | Greeley | |
| **C70** | Dry Creek, L.Loveland outlet | high | Greeley | |
| **C80** | Dry Creek, Horseshoe Res. Inlet | high | Greeley | |
| **C90** | Inlet to Boyd L. from Horseshoe | low | Greeley | |
| **C100** | Inlet to Boyd L. from Heinricy L. | low | Greeley | |
| **C110** | Inlet to Boyd L. from G-L Canal | high | Greeley | |
| **Tributaries** | | **Priority** | **Monitoring Entities** | **Segment** |
| **T10** | N. Fork @ confluence with BT | high | usgs | 7 |
| **T20** | Buckhorn @ confluence with BT | high | usgs, Greeley | 7 |
| **T30** | Buckhorn u/s of Redstone confluence | low | | |
| **Mainstem** | | **Priority** | **Monitoring Entities** | **Segment** |
| **M10** | d/s Moraine Park | high | usgs | 1 |
| **M20** | u/s EPSD | high | EPSD | 2 |
| **M30** | d/s EPSD | high | EPSD | 2 |
| **M40** | d/s Olympus Dam | high | usgs, UTSD | 2 |
| **M50** | d/s UTSD | high | UTSD | 2 |
| **M60** | Drake, u/s of North Fork confluence | high | | 2 |
| **M70** | u/s Dille | high | | 2 |
| **M80** | d/s Thompson PP | high | Northern | 2 |
| **M90** | Loveland WTP | high | Loveland, Greeley | 2,3 |
| **M100** | u/s of Buckhorn confluence (d/s of diversions) | low | Loveland | 3 |
| **M110** | BT at Big Barnes headgate | high | Greeley | 3,4 |
| **M120** | G-L canal headgate | high | Loveland, Greeley | 4 |
| **M130** | u/s Loveland Wastewater (St. Louis St.) | high | Loveland, usgs | 4 |
| **M140** | d/s Loveland Wastewater (Co. Rd 9E) | high | Loveland | 4 |
| **M150** | I-25 | high | Loveland | 4,5 |

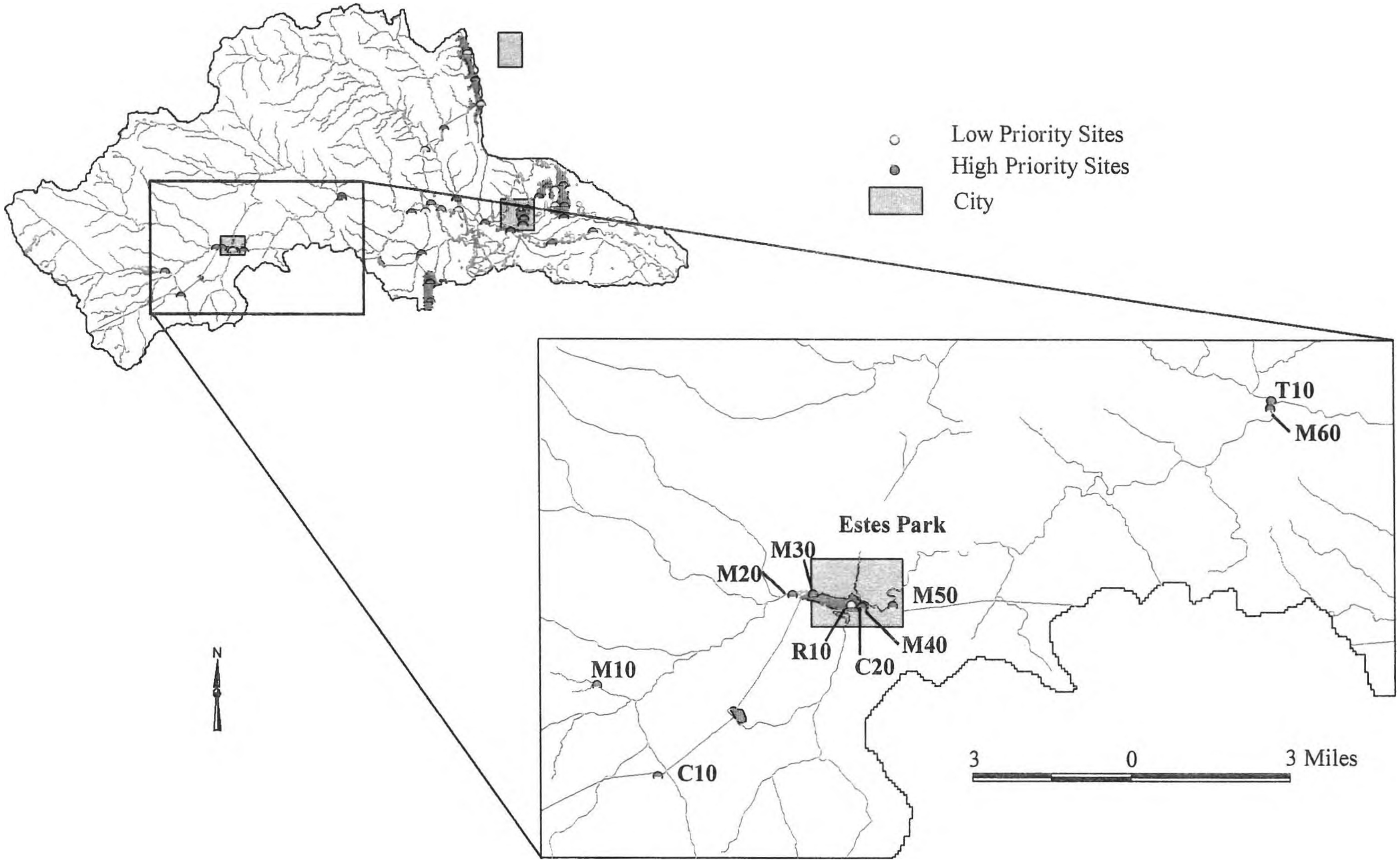

Figure 8. Upper Watershed Monitoring Sites. The letter "M" denotes a mainstem site, "C" is for canal or tunnel, "T" represents tributary sites, and "R" indicates a reservoir sampling site.

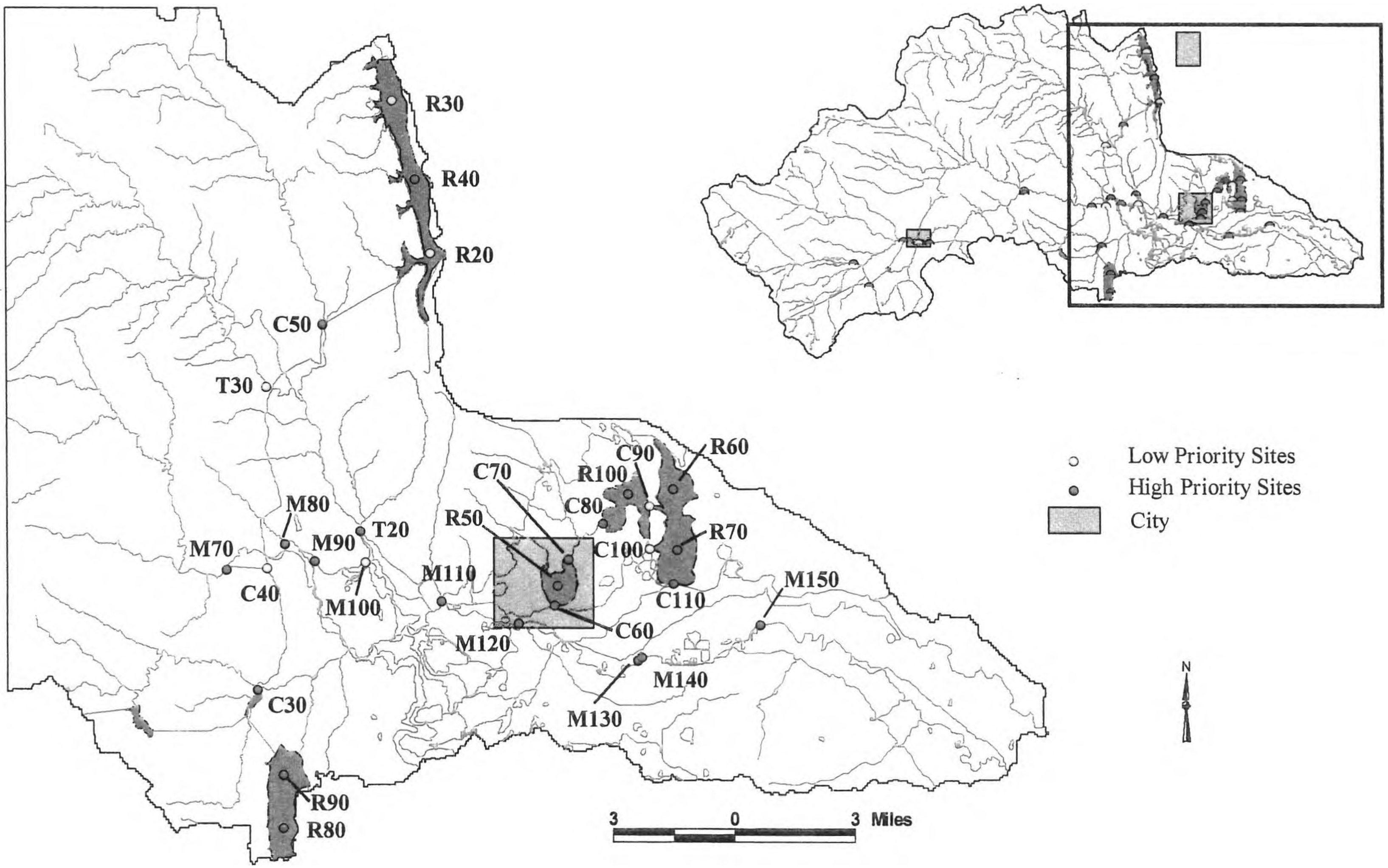

Figure 9. Lower Watershed Monitoring Sites. "M", "C", "T", and "R" indicate mainstem, canal, tributary, and reservoir sites respectively.

# CHAPTER 8

# SAMPLING FREQUENCY

It was hoped that the sampling frequency for a majority of the listed variables could be determined through an analysis of historical data. The longest and most complete data set available within the watershed was gathered by the US Geological Survey (EarthInfo, 1996). Unfortunately, the historical data set included only a small subset of the desired variables. Seasons were designated in order to more easily interpret both historical and future data gathered in the watershed. For the variables with historical data, sampling frequencies were calculated.

## 8.1 Designation of Seasons

Three seasons were identified using historical temperature and flow data. Monroe (1999) includes flow calculations based on data made available by the Office of the State Engineer. Figures 10, 12, 14, 22, and 29 within his report display monthly flow averages from the mainstem of the Big Thompson over a twenty-year time period. The locations within the watershed represented by the graphs follow a typical seasonal flow pattern, with high flows recorded each spring. The season designations were based on these points. These designations accurately represented the observed annual flow cycles in most regions of the watershed. However, some of the highly controlled segments of the water conveyance system do not follow a typical seasonal pattern (Figures 4, 7, and 20 in Monroe, 1999). Agricultural demand and maintenance of reservoir levels determine the flow in these locations, all canals or tunnels. Flow dependent water quality parameters are not likely to follow the three seasons set up for this analysis on these segments. The different seasonal patterns found for these segments must be taken into account during data analysis.

Flow is not the only environmental factor that can cause seasonal cycles in water quality data. Temperature can have a similar effect and was also used to determine the seasons. Average water temperature for each month was calculated using data collected by the USGS (EarthInfo, 1996). The historical data record for average monthly temperature was not consistent through all monitoring sites within the watershed. The years in which data were collected are listed with the numerical calculations in Appendix C. As Figure 10 illustrates, the high temperature season lasts longer than that of the high flow. By combining temperature and flow seasonal patterns, three seasons were designated: high flow/high temperature, low flow/high temperature, and low flow/low temperature. Table 8 lists those months that fit into each season.

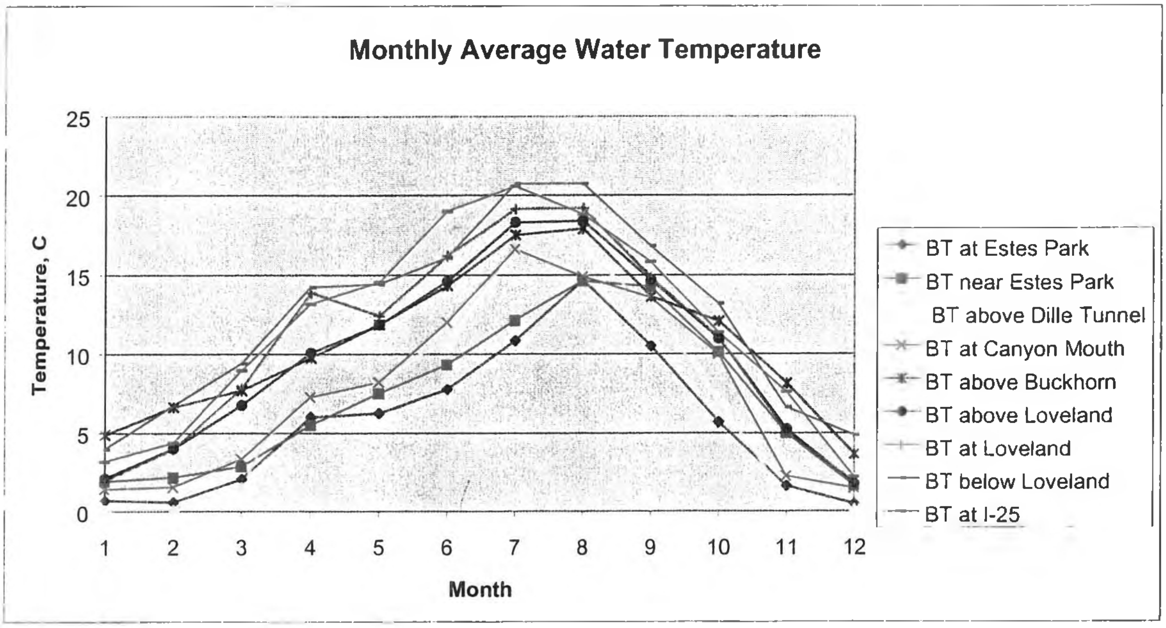

Figure 10. Average Monthly Temperature. The average water temperature on a monthly basis at nine USGS monitoring sites within the Big Thompson Watershed was calculated.

Table 8. Designation of Seasons.

| Season Number | Flow and Temperature | Months |
|---|---|---|
| 1 | High Flow/High Temperature | May - July |
| 2 | Low Flow/High Temperature | August – October |
| 3 | Low Flow/Low Temperature | November - April |

### 8.2 Moving Water

Only eleven of the 38 variables on the most recently developed variable list had historical data. Of those eleven, eight had samples sizes under 50 for at least one season designated for a particular variable. Two had sample sizes less than 30 for at least one season. Low sample sizes add uncertainty to the calculations, inflating the estimated frequency.

For the variables with historical data, the frequency that allowed for an error as close to 20% as possible was chosen for the estimation of means. The frequency that would detect a 25% change in mean over a ten-year period was chosen for the trend analysis. These frequencies are summarized in Table 9, with example calculations in Appendix D.

Table 9. Sampling Frequency. Sampling frequencies were determined based on mean and trend estimation

| **Parameter** | **Frequency based on means for designated seasons** | **Frequency based on trend detection** |
|---|---|---|
| Specific Conductance | S1: weekly<br>S2: weekly<br>S3: twice per month | weekly |
| Dissolved Oxygen | S1 & S2: monthly<br>S3: daily | monthly |
| PH | S1: monthly<br>S2 & S3: monthly | monthly |
| Nitrogen, Ammonia | S1 &S 2: daily<br>S3: monthly | daily |
| Nitrogen, Nitrate +Nitrite | S1: daily<br>S2: daily<br>S3: daily | daily |
| Phosphorus, Dissolved | S1, S2, & S3: weekly | daily |
| Sodium, Dissolved | S1 & S2: daily<br>S3: weekly | daily |
| Sulfate, Dissolved | S1 & S2: daily<br>S3: weekly | daily |
| Iron, Dissolved | S1: daily<br>S2 & S3: weekly | weekly |
| Manganese, Dissolved | S1 & S2: daily<br>S3: weekly | daily |
| Alkalinity | S1: daily<br>S2: weekly<br>S3: twice per month | weekly |

The frequencies obtained using the analysis were unreasonably high given the financial constraints on the program. Such high frequencies would also create problems in data analysis due to increased serial correlation, which reduces the usefulness of data for making long-term projections. There are 29 high priority moving water sites, seven high priority reservoir sites that require top and bottom sampling, and 38 constituents. The cost of laboratory analysis involved in implementing a monitoring system of this size is large. In order to keep costs down, maximum sampling frequencies were set. During seasons one and two, no constituent is to be sampled at a frequency higher than twice a month, except for biological parameters in Lakes Loveland and Boyd. The maximum frequency for season three is monthly. These maximum frequencies are lower than those returned by the statistical analysis. The accuracy with which the historical data are able to estimate the true background variability may not be very high. Smith and McBride (1990) estimates that a sample size of 50 to 100 samples is the minimum amount needed to identify a trend one standard deviation in size. Four of the eleven constituents listed above had fewer then 100 samples for the trend analysis. For the mean analysis the samples were broken down by season, further shrinking the individual sample sizes.

At the conclusion of each year of data collection, all sampling frequencies should be evaluated in order to assure that the data are accurately providing the desired information.

## 8.3 Reservoirs

The reservoirs within the Big Thompson Watershed can be loosely divided into three groups based on volume, water temperature, and residence time.

*Group 1*: Mary's Lake, Lake Estes, Pinewood Reservoir, and Flatiron Reservoir

- Short Residence Time
- Small Volume

Of this group, only Lake Estes will be actively monitored. Generally speaking, this group can be treated as moving water. The residence times are short enough that significant changes in water quality due to biological activity are possible, but unlikely. The residence time, using average outflow and a maximum storage capacity, is only three days.

*Residence Time Calculation:* The equation used for this calculation simply took the total volume of the lake divided by the outflow (Chapra, 1997).

$$\tau = \frac{V}{Q_{out}}$$

*Residence Time:*

Maximum Volume (Bureau of Reclamation, 1947): 2,855 acre-ft

Annual Average Olympus Tunnel Outflow (Monroe, 1999): 374.7 $ft^3/s$

Annual Average Big Thompson Outflow (Monroe, 1999): 75.2 $ft^3/s$

Residence Time: 3.2 days

Lake Estes will be monitored monthly for all parameters during season three. During seasons one and two inorganics and chlorophyll will be monitored twice monthly over the summer months. This includes temperature and dissolved oxygen depth profiles.

*Group 2*: Carter Lake and Horsetooth Reservoir

- Longer Residence Time
- Potential for Top Down Control

Top-down control refers to the food web and suggests that predation may have a significant impact on water quality, especially with regards to trophic state. Monitoring in this group of reservoirs has the potential to provide predictive information about water quality. Information gathered at these lakes should allow for the relationship between food web dynamics and water quality to be identified. Lakes such as these are more prone to spatial variation, requiring more monitoring sites. However, population change in higher trophic levels occurs over longer time periods than that of organisms that occupy the bottom of the food web. These lakes, therefore, do not require as high a sampling frequency as warmer, nutrient dominated lakes. During the summer months inorganic and all biological parameters will be gathered twice a month.

*Group 3*: Lake Loveland and Boyd Lake

- Longer Residence Times
    - Lake Loveland: 6 weeks to 2 months (Pers. Com. Ron Brinkman, 1999)

    - Boyd Lake: 3 to 4 months (Pers. Com. Ron Brinkman, 1999)
- Bottom Up Control

Lake Loveland and Boyd Lake are most likely to be controlled from the bottom up, due to warmer temperatures and higher nutrient loads. Bottom-up control suggests that nutrient availability, rather than food web dynamics, controls the trophic state. Such reservoirs often have less spatial variation, but can be subject to dramatic changes in conditions over very short time periods. Therefore, Lake Loveland and Boyd Lake will be monitored with only three sites between them, but at a higher frequency than other reservoirs in the watershed. In order to place more emphasis on gathering data on lower trophic levels at a high frequency, zooplankton data will not be gathered.

# CHAPTER 9

# MONITORING PROGRAM COST ANALYSIS

The agencies involved in this project have participated with the assumption that combined monitoring budgets will provide more thorough and higher quality data than any one entity would be able to generate on its own for the same or lower cost. Therefore, a good barometer for program affordability is the sum of the current monitoring budgets of the committed entities.

## 9.1 Current Monitoring Spending within the Watershed

Each of the funding entities currently gathering samples in the watershed were asked to estimate the amount of funds they devoted to monitoring. The estimates included field, laboratory, and labor costs. This was an easy task for some entities, such as NCWCD, who subcontracts their entire monitoring program to a consulting firm. Entities that conducted "in house" analysis and sent salaried staff into the field, had a much harder time defining how much was spent on monitoring. In April 1999, each monitoring entity provided an estimate of current monitoring spending (Table 10).

Table 10. Monitoring Spending by Funding Agencies.

| Monitoring Agency | Current Monitoring Costs |
|---|---|
| City of Ft.Collins | $275,000.00 |
| City of Greeley | $60,000.00 |
| City of Loveland | $30,000.00 |
| NCWCD | $36,500.00 |
| **TOTAL** | **$401,500.00** |

### 9.2 Proposed Monitoring Program Costs

A cost estimate was completed for the initial program, the interim base variable list, and the program as it currently stands (Table 11).

Table 11. Cost Estimates.

| Program | Cost |
|---|---|
| Initially proposed program | $716,140.50 |
| Interim base list and initial network and frequency | $479,686.50 |
| Current Program (trimmed variables, sites, and frequency) | $404,259.00 |

A complete break down of the cost estimates is listed in Appendix E.

# CHAPTER 10

# SUGGESTED FUTURE WORK

The completion of the monitoring network is the first step towards implementation of a cooperative monitoring program. A considerable amount of work remains before the Big Thompson cooperative monitoring system will produce information. The tasks include standardization of field and laboratory methods, design of a data analysis protocol, establishment of quality assurance measures, and development of a reporting format. The most important of the remaining tasks is the standardization of methods.

Consistency in sampling, analysis, and data manipulation is critical for the monitoring system to successfully gather and produce information about water quality variation in the long term. Protocols should be used in order to ensure such consistency. This standardization process represents a challenging area in which the participating agencies must find common ground. All water quality and flow data in the watershed must be gathered and analyzed in a manner that allows for comparisons between all sites. Therefore, the participating groups must modify their field sampling procedures, lab use, and data analysis prior to the start of data collection.

## 10.1 Data Analysis Protocol

Ward et al. (1990) and Smith and McBride (1990) emphasize the importance of developing a data analysis protocol as part of the design process, prior to gathering any samples. The careful design of a data analysis protocol provides several advantages to the BTWF for the implementation and long-term operation of the monitoring program.

- Preparation of a data analysis protocol prior to the start of monitoring allows discussion to focus on the scientific merits of the data analysis methods as opposed to the anticipated results. This allows for the analysis to be based on informational goals instead of politics.
- A detailed protocol insures that the statistical analysis will be carried out correctly.
- The continuity of the analysis and subsequent information is assured even if the individual carrying out the analysis changes. This is especially critical for the BTWF where the likelihood of different agencies and individuals conducting the analysis is high.
- The documentation of the data analysis steps also allows for them to be easily amended.
- Sampling data will be more quickly converted into information.

The BTWF is currently working on the design of a data analysis protocol in collaboration with CSU. The expected time of completion is December 1999.

### 10.11 Statistical Goals

The statistical methods must refer directly to the informational goals detailed in the objectives. Based on the objectives, a series of statistical tasks can be identified.

*Loads*: The central tendency (in mass/time) for each season will be identified with a 95% confidence interval. An estimate of total mass for each constituent will be calculated both seasonally and annually.

*Compliance*: Each sample, as well as the central tendency of the data, will be compared with the applicable standard. The proportion of standard violations will be reported for each season.

*Temporal Trends*: A minimum of five years of data must be available. A trend is identified when the 95% confidence limit on the time series slope does not include zero.

*Spatial Trends*: This will be graphically displayed with the lower axis displaying the central tendency for monitoring sites in order from upstream to downstream. Correlation can be established using, Pearson's r, Spearman's rho, or Kendall's tau (Helsel and Hirsch, 1992). Upstream sites may also be compared to downstream sites using a two-sample t-test or similar test to identify differences in water quality.

*Trophic Indicators and Primary Productivity*: The central tendency, maximum, minimum, and variability will be calculated for variables that affect or indicate the trophic state of a reservoir. The first several years of data collection will allow for the study of those factors that control algal growth, in order to refine the analysis.

### 10.12 Data Record Attributes

Environmental data sets are prone to many characteristics that can create difficulties in analyzing data. These include missing values, changing sampling frequencies, multiple observations, censoring of data, seasonality, outliers, nonnormality, serial correlation, and uncertainty introduced by the measurement procedures (Thas et al., 1998 and Ward et al., 1990). Each of these attributes must be addressed by the data analysis protocol.

*Missing Values:* Missing values can occur in a data set due a variety of reasons including bad weather, equipment failures, and sample contamination. The subsequent gaps in the data record can cause problems for data analysis methods that require equal sample sizes or regularly spaced data. In order to solve this problem, there are two options: (1) fill in the missing data point with a value interpolated between the surrounding data; (2) leave the data as missing. Missing data should be noted in the analysis comments and resulting information.

*Changing Frequency:* In order to keep costs down, this program has variable frequencies throughout a year. For example, the variability of many constituents goes up during the high flow season, and therefore requires an increased sampling frequency. This causes similar problems to that of missing data; the data points are not regularly spaced. Because many of the analyses will be done on a seasonal basis, this problem should be limited. However, in order to calculate annual values the various frequencies must be accounted for to avoid weighting one time period over another. A common way to do this is by collapsing data down to the lowest frequency, or by calculating a weighted average using time or flow.

*Multiple Observations:* Multiple observations can occur when QA/QC replicates are combined with the regularly collected data. Again, for statistical methods that require regularly spaced, equal sample sizes, this can cause problems. One manner in which to deal with this problem is to use an average when a single value is required.

*Censored Data:* Labs will report a value as less than (<) or as “not detected” when a measured concentration is below the analysis method detection limit. Ideally, it would be hoped that a lab would report all data, even if it is less confident in the lower values. If data is censored, it is common for values to be replaced by some fraction of the detection limit, or the limit itself.

*Seasonality:* This is a cyclical pattern in a data set that reflects the influence of seasonal variations in flow and/or temperature. The data collection periods have been divided into seasons, which should account for some of this variability. However, some monitored segments of the watershed do not fit the seasons that have been selected. These segments may have to be evaluated on a month by month basis. Seasonal variation poses the largest challenge to trend detection. Most often, some manner of "deseasonalization" is required to be able to look at changes occurring over multiple years. A commonly used approach is the seasonal Kendall test for trend.

*Outliers:* Outliers are data points that are obviously much higher or lower than the rest of the data set. If an outlier is found within a data set, every effort must be made to verify that it is not due to sampling, analysis, or data entry error. If the point is determined to be valid, the choice becomes whether or not to use it. This question is most important for the use of parametric statistics, where the outlier could influence central tendency and variability depending on sample size. When using nonparametric statistics, outliers are less of a concern because the rank of the data points, as opposed to the numerical value is used.

*Nonnormality:* Many standard statistical methods assume data are symmetrically distributed (the normal or Gaussian distribution). Environmental data rarely display this distribution due to the lower bound of zero, and the presence of a few "high" values (Thas et al., 1998). Other distributions better describe typical environmental data, such as the log normal distribution. However, in order to assume a different underlying distribution, it typically needs to be identified before the analysis. A better option for dealing with nonnormality is the use of nonparametric approaches, which assumes no underlying distribution.

*Serial Correlation:* Serial correlation describes a relationship between consecutive samples, a form of redundancy. This violates the assumption of independence underlying most statistical methods. The presence of serial correlation can add uncertainty to an analysis that attempts to describe long-term behavior with short-term data. If the analysis is being used to describe the data within the time period that the data were collected, correlation can increase the precision of the estimate.

*Measurement Uncertainty:* Environmental sampling inherently will introduce uncertainty into a data set. The best manner in which to deal with this uncertainty is to utilize detailed sampling, analysis protocols, and a strict system of QA/QC checks.

### 10.13 Data Analysis Methods and Tasks

The previous discussion is simply background information needed to design an effective data analysis protocol. There remain several tasks to be completed in the development of a data analysis protocol.

- A documented system for data entry that includes labeling codes and data format.
- Data must be prepared for analysis. This preparation must include several QA/QC measures such as an ion balance, checks that measured conditions match that of calculated conditions, and assuring that the sum of the parts add to the whole (e.g. Nitrogen) (Smith and McBride, 1990).

- The general statistical approach must be established, nonparametric versus parametric.
- The individual analyses for each of the informational goals must be defined and documented. This should include the correct manner in which the results are to be interpreted.
- The manner in which each of the data record attributes will be dealt must be established.
- Following analysis of the data, a system to store both raw data and analysis results must be developed.

## 10.2 Sampling Protocols

The standardization of the field sampling protocols is critical to maintaining a high quality data record. The field sampling protocol addresses four main issues; how to collect samples, when to collect samples, where to collect samples, and QA/QC measures.

### 10.21 Sample Collection Methods

Among the monitoring entities in the Big Thompson watershed, a variety of field procedures are represented. The longest data record is that of the USGS, whose current sites are included in the monitoring program. Due to the national scope of the USGS sampling programs, it is unlikely that the agency will (or should) adjust their sampling protocols. In order to provide continuity with both historical data records and current monitoring, the Big Thompson sampling methods should be as similar as possible to USGS methodology.

Once field methodology has been selected, a detailed field checklist must be developed to remind the sampling teams of each step that needs to be taken. In New Zealand (Smith and McBride, 1990), a newsletter was developed to address any field protocol issues that came up. A system of communication is a good way to assure that all sampling teams are using the same protocol. This is particularly important because the sampling crews will be from a variety of agencies. In order to aid in standardization, all sampling personnel must be trained together.

### 10.22 Timing of Sample Collection

The sampling frequency will be determined by the monitoring design. However, within a sampling period there is a great deal of flexibility. For example, in a monthly sampling scheme, the week, day of the week, and time of day, all must be determined. Choosing the best time to sample depends on the purpose of the monitoring and the characteristics of the watershed.

Samples are gathered for use as input to the data analysis protocol. The statistical requirements of the data analysis protocol must be considered. One of the most important underlying assumptions of many statistical methods is that the data represent a random sample. In a systematic sampling scheme, the population itself is assumed to be randomly distributed, thus, even though the samples are systematically gathered, the data still meets the assumption of randomness. A water quality "population" however is not always randomly distributed. A number of possible influences can cause predictable fluctuations in water quality and subsequently sampling bias, a systematic tendency to over- or under-represent some part of the population (Ott, 1993).

These issues are primarily problems for sampling that is being used to accurately report current conditions. If sampling were being done exclusively to detect trends, systematic sampling would pose few problems, even if the sampling were on the same day, at the same time each month. This is because the samples would all reflect the same point in any cycles present in the system. As long as the sampling is consistent over time, this analysis is valid. In fact, less variation would appear in the data allowing trends to be more easily identified.

The BTWF monitoring program is interested in both the current conditions and long term change. This means the BTWF will need to account for all possible sources of bias in order to accurately estimate current conditions. Some of these sources of bias are easily reduced, where others may simply need to be acknowledged and the possible effects understood. The following is a discussion of some of the most common sources of bias.

> *Periodic Discharges:* If a discharge is released to a stream at a certain time of day or on a certain day of the week, there is the potential for bias. If a sample is always drawn recently after such a discharge, the results will overestimate current conditions. Similarly, if the discharge is always avoided the results will be slightly low.

*Diurnal Fluctuation:* This refers to a daily cycle in water quality. It could be caused by increased discharge volume from a point source or the effects of daily temperature variation. This means that sampling at the same time of day will introduce bias into the data set.

*Sampling Personnel Availability:* Sampling personnel typically work Monday through Friday between 8 AM and 5 PM. This immediately limits the population being sampled. Weekly or daily cycles will not be accurately portrayed. For example, the impact of the lack of sunlight and lower temperatures found at night will not be represented.

These problems can be helped through the addition of some systematic variation in the sampling. For example, a specific date each month can be chosen, so the sampling will occur on various days of the week. The only problem occurs when the sampling day falls on a weekend. The entities involved will have to discuss how to best handle this. Bias due to diurnal cycles can be reduced by a measure as simple as reversing the order in which sites are visited each sampling trip, or by varying the start time of the run. This removes some of the potential for bias, however, the hours outside a standard workweek will still be neglected.

### 10.23 Sample Location

The monitoring sites within the system have been identified. This portion of the sampling protocol assures that all samples are collected at the same location each time.

Detailed directions to each site, such that someone who is going to the site for the first time would find the exact location, must be written and included with the field sampling check sheets. It would also be helpful to use some type of marker at each site, however, this is not likely to be possible at all points within the system. The site description should include driving directions to the site and a detailed description of the point in the river to be sampled.

### 10.24 Quality Assurance/Quality Control

Quality control in the field is critical. This includes all aspects of the field sampling procedure. All personnel should be trained to correctly use all field equipment and gather samples in the same manner. Equipment calibration should be done on a standard basis. All required activities must be listed on a field check sheet to be signed by the field personnel verifying that all tasks were completed.

### 10.3 Lab standardization

This phase depends a great deal on costs. The funding entities for the project have defined the variables to be analyzed. The next step of this process is for those same entities to define the type of methodology that is acceptable to all agencies. This includes defining whether the lab used must be certified (e.g. passed an EPA proficiency test), and the precision of the analysis (e.g. the detection limit). If all samples are sent to a single external lab the standardization will be very simple. However, this scenario is unlikely due to cost considerations. Several of the entities, Ft. Collins, Loveland, and Greeley currently have the capability to analyze samples for at least a portion of the variables desired. If multiple labs are utilized for this project, the task of lab standardization becomes much more complicated. The best option may be to have each lab specialize in a small subset of the variable list, analyzing all samples for a single suite of parameters. This will complicate field and sample delivery procedures, however, it will solve a considerable QA/QC problem of comparing values between labs.

### 10.4 Reporting

In describing the approach to this monitoring system design, a large emphasis was placed on the information produced. The preparation of reports is the step that makes the monitoring meaningful. It is this step, coupled with data analysis, which converts data into useful information. The content of the reports is dictated by the data analysis methodology and results. Because the data analysis protocol is not completed at this time, a detailed description of the manner in which analysis results will be communicated is not possible. However, many aspects of reporting can be discussed without knowing the type of results to be conveyed. These include identification of the target audience, means of distribution, distribution frequency, level of detail, and the number of different reports to be produced.

#### 10.41 Report Frequency

The informational goals deal primarily with loads and trends. The more samples gathered, the more accurate the information produced. With this in mind, longer periods between reports will allow for more detailed information. Several of the BTWF members, however, are planning to use this information as a basis of decision making. In order to make timely decisions, a fast turn around time with frequent reporting is desirable. The minimum sampling frequency currently proposed is monthly. Many decisions within a management agency are made in conjunction with budget considerations on an annual basis. Annual reporting would allow for yearly cycles to be described, and convenient comparisons made between years. Once the monitoring system has been in place for several years, the full record may be utilized, particularly in identifying temporal trends. In order to avoid redundancy in reporting and provide timely information, an annual distribution frequency is suggested.

### 10.42 Target Audience

The first priority of the monitoring system is to meet the needs of the BTWF members. Second, the BTWF is required to act as a source of information for all stakeholders, regardless of BTWF membership. While the BTWF member contact list is not a complete list of all stakeholders, it is a good representation of their diversity. The most recently published list of BTWF contacts was dated July 20, 1999. The list included 367 names, affiliated with a variety of organizations (Table 12, Appendix F).

Table 12. BTWF Contact List Summary.

| Type of Entity | Number Represented on List |
|---|---|
| Federal Government Agencies | 8 |
| State Government Agencies | 7 |
| County Governments | 3 |
| Municipal Governments/Utilities | 37 |
| Private Businesses | 36 |
| Citizen, Special Interest, and Regional Groups | 19 |
| Regional Organizations | 4 |
| Press | 4 |
| Academia | 3 |
| Private Citizens | >60 |

The BTWF members comprise the primary audience at which the reports will be aimed. However, in order to truly reach the goals of the BTWF, a much wider audience must be considered. The next step to expanding the audience is to reach the constituencies of the Forum members. This refers to the customers of the involved utilities and water managing agencies, local clients of the private firms, and the members of the various citizen groups. The groups and individuals that are considered stakeholders, but fall outside the current Forum contacts, are as diverse as the groups on the list. The groups of contacts simply need expanding. The involvement of these groups and individuals depends a great deal on the means of distribution and the media used to communicate the information.

### 10.43 Report Content

The diversity of the audience list poses a considerable challenge to the authors of the annual reports. To best meet the various needs of those using the information, a number of reports may need to be produced. First, a general summary of the major findings for the year must be written. Such a summary is useful to all stakeholders, even those desiring much more detailed information. This summary will be the most widely distributed of the reports. For interested individuals and water managing entities, a series of technical appendices can be developed to accompany the summary report that will provide detail on each statistical procedure and list important data in tables.

The summary section should be written such that prior knowledge about water quality or the watershed itself is not necessary. It should highlight the key findings for the year using simple illustrations and commonly recognized statistical terms, such as percentages used to describe change, or amount of time above a particular threshold. The writing of this portion of the report will require a close relationship between the public outreach committee of the forum and the individual analyzing the data. Such a partnership will allow for statistical analyses to be accurately portrayed and clearly communicated.

The technical appendices can be focused by topic, such as nutrients and metals, or by region, such as the RMNP headwaters, canyon, and plains. In these appendices, more detailed graphical representations requiring technical explanation can be included along with explanations of error, confidence limits, and tables of raw data. These appendices can be distributed to those entities within the BTWF that require such information. They should also be available by request to any community member that expresses interest.

### 10.44 Report Distribution

In order to reach the largest number of individuals, a variety of communication methods should be used. Once again, using those tools already available within the

BTWF is a good place to start. The forum currently maintains a web page where the summary report can be posted. In time, the web page may also be a place where the appendices and a database of all gathered data are accessible. Outside of the web page, the task of reaching the largest possible audience falls on the shoulders of the BTWF members. Possible means of distribution include the following:

- Distribution and display at the public education kiosks maintained by the BTWF
- Inclusion in newsletters or pamphlets distributed by Forum members, especially the environmental and citizens groups
- Placement on member agencies' office handout displays
- Distribution of the summaries to the constituencies of member agencies
- Addition to the holdings of public, as well as academic, libraries

# CHAPTER 11

# CONCLUSION

The Big Thompson Watershed Forum set out, at its inception, to build an effective voluntary watershed protection program; improve cooperation and communication among stakeholders; educate watershed residents about their responsibility and impact on their water resource; and reduce or eliminate existing and potential water quality problems. A scientifically sound, long-term source of information about the water within the watershed is critical to achieving each of these goals.

The goals of the BTWF accurately reflect the approach to water management encouraged within sustainable development ideology. The success of watershed groups, such as the BTWF, contributes to meeting the goals laid out in the Rio Declaration and Agenda 21. Community watershed efforts offer an opportunity for local citizens to learn more about their water resource and to become involved in its management. The watershed councils also provide the opportunity for different branches and levels of government to work together.

Thus far, the Big Thompson Watershed Forum has succeeded both as a council and it in its effort to implement collaborative monitoring in the watershed. The success is due to the strong commitment of the BTWF members to work together. Water quality has the potential to be a divisive issue. The network design process, and BTWF in general, appear to avoid the potential divisiveness of water quality issues by focusing on the common need for information. Additionally, decisions were made during the design process by group consensus, instead of "majority rule". Although building consensus involves a large time commitment, it was invaluable in promoting a sense of trust among stakeholders and highlighting common priorities within the watershed.

The BTWF represents a diverse group of stakeholders, however, the most active members seemed to most often represent local utilities, governments, and citizens. Active participation in the monitoring design process by representatives of state and national agencies was limited. The resulting monitoring program reflected their absence. The monitoring design focuses on the water quality informational needs specific to the Big Thompson watershed. At the outset of the design process, the need for monitoring information to satisfy state and federal regulations was identified as a priority. However, when adjustments were made to meet cost constraints, it became clear that regionally specific informational needs were more important to the local entities than state and federally mandated informational needs. A good illustration of this is final variable list; it does not include seven variables that are listed in the Colorado Water Quality Control Commission stream standards (1997). The stakeholders within the watershed did not deem these variables important. The monitoring network that has been designed caters to needs specific to the Big Thompson River watershed.

The monitoring system currently includes a set of objectives, variable list, monitoring network, and sample frequency. They have been developed, discussed, and agreed upon by all BTWF participants. The standardization of methods and implementation of the design remain. The success of the remaining steps in the design depends on the continued commitment of the BTWF members. In order for an undertaking such as this design and monitoring program to succeed, all participants must be willing to compromise and continue to devote large amounts of time in order to allow for a truly cooperative effort. The final goal of a long-term monitoring program operated by, and benefiting all agencies involved, was been kept in mind throughout the entire design period. By providing opportunities for all involved parties to give feedback during each stage of the design, it is hoped that the standardization and implementation process may proceed as smoothly as the design phase.

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# APPENDIX

## APPENDIX A

Land Use Classification Breakdown

| Classification | Area Sq. Miles | % of Total |
|---|---|---|
| BARE EXPOSED ROCK | 0.035 | 0.006% |
| BARE GROUND | 3.415 | 0.547% |
| COMMERCIAL AND SERVICES | 0.352 | 0.056% |
| CONFINED FEEDING OPS | 0.000 | 0.000% |
| CROPLAND AND PASTURE | 158.798 | 25.420% |
| EVERGREEN FOREST LAND | 413.122 | 66.131% |
| FORESTED WETLAND | 0.070 | 0.011% |
| GLACIERS | 0.000 | 0.000% |
| HERBACEOUS RANGELAND | 2.394 | 0.383% |
| HERBACEOUS TUNDRA | 9.190 | 1.471% |
| INDUSTRIAL | 0.070 | 0.011% |
| LAKES | 0.106 | 0.017% |
| MIXED FOREST LAND | 2.887 | 0.462% |
| MIXED RANGELAND | 27.605 | 4.419% |
| MIXED TUNDRA | 0.599 | 0.096% |
| MXD URBAN OR BUILT-UP | 0.106 | 0.017% |
| NONFORESTED WETLAND | 0.141 | 0.023% |
| ORCH, GROV, VNYRD, NURS, ORN | 0.035 | 0.006% |
| OTHER AGRICULTURAL LAND | 0.035 | 0.006% |
| OTHER URBAN OR BUILT-UP | 0.317 | 0.051% |
| RESERVOIRS | 1.092 | 0.175% |
| RESIDENTIAL | 1.268 | 0.203% |
| SHRUB AND BRUSH TUNDRA | 1.972 | 0.316% |
| STRIP MINES | 0.141 | 0.023% |
| TRANS, COMM, UTIL | 0.880 | 0.141% |
| TRANSITIONAL AREAS | 0.070 | 0.011% |

## APPENDIX B

### Monitoring Site Location and Reasoning

### Mainstem Monitoring Sites

**M10** Location: Downstream of Moraine Park, inside the Rocky Mountain National Park boundary at the USGS gage site.

Entities Currently Monitoring Site: UGSG gage site

This site acts to provide background information for water originating on the east side of the divide, the natural headwaters of the Big Thompson. The location is placed downstream of Moraine Park in order to coincide with the USGS gaging station, allowing for accurate load calculations. This site is near the transition between the segment one and segment two as designated by the Water Quality Control Commission (WQCC) stream standards.

**M20** Location: The upstream side of the public footbridge located above the Estes Park Sanitation District effluent discharge.

Entities Currently Monitoring Site: Estes Park Sanitation District

This site should catch the change in water quality due to runoff within Estes Park. It is also used to identify the water quality upstream from the Estes Park Sanitation District discharge.

**M30** Location: The upstream side of the public footbridge located below the Estes Park Sanitation District effluent discharge. This is the last bridge prior to the Big Thompson emptying into Lake Estes.

Entities Currently Monitoring Site: Estes Park Sanitation District

This site identifies the change in water quality due to the EPSD effluent. It also marks the quality of the Big Thompson influent water quality to Lake Estes.

**M40** Location: Immediately downstream of Olympus Dam at the USGS gage site.

Entities Currently Monitoring Site: USGS gage site, Upper Thompson Sanitation District

Lake Estes serves as a large mixing bowl, blending natural flow originating in RMNP with CBT water. It is this water that flows down the natural riverbed of the Big Thompson. This site acts as a background site for the rest of the river. This also acts as a site to determine the water quality prior to the Upper Thompson Sanitation District discharge.

**M50** Location: Downstream of the Upper Thompson Sanitation District effluent discharge. The site must be far enough downstream to have allowed for adequate mixing.

Entities Currently Monitoring Site: Upper Thompson Sanitation District

The site identifies the change in water quality due to the UPSD discharge and the effects of Dry Creek. These two can be differentiated using discharge data from the UPSD.

**M60** Location: Upstream of the confluence with the North Fork of the Big Thompson off Highway 34 in the town of Drake, on the upstream side of the bridge.

Entities Currently Monitoring Site: None

This is the only site between the Estes Park and the Dille Tunnel. Its purpose is to determine the effect of the homes and businesses in the upper canyon and serve as a background site prior to influx from the N. Fork of the Big Thompson River.

**M70** Location: Upstream of the Dille Tunnel diversion structure

Entities Currently Monitoring Site: None

The Dille Tunnel supplements the Hansen Canal. In order to account for the water quality in the Hansen Canal the quality of water entering Dille Tunnel needs to be determined. This site also serves to assess the impact of the North Fork of the Big Thompson and non-point sources within the lower canyon.

**M80** Location: Approximately 600 feet east of the Big Thompson Hydroelectric Power Plant on upstream side of the County Road 31-D bridge.

Entities Currently Monitoring Site: NCWCD

Water diverted by the Dille Tunnel is mixed with water from Flatiron Reservoir. A portion of this water is returned to the Big Thompson either directly, or through the Big Thompson Power Plant. This site assesses the change in water quality due to the addition of this mixed water. This site also acts as a background site for water quality impact occurring downstream of the canyon mouth.

**M90** Location: At the Loveland Water Treatment Plant intake

Entities Currently Monitoring Site: City of Loveland, City of Greeley

This site determines the quality of the water at the Loveland WTP intake. It also marks the end of the WQCC stream standard segment two and beginning of segment three.

**M100** Location: Off Highway 34 west of the City of Loveland in the Riverview Campground.

Entities Currently Monitoring Site: City of Loveland

Buckhorn Creek is believed to adversely affect water quality in the Big Thompson. In addition, it is a likely site for future development. The site is intended to identify the water quality upstream of the Buckhorn Creek confluence.

**M110** Location: Headgate of the Big Barnes Ditch

Entities Currently Monitoring Site: City of Greeley

This site's purpose is threefold. First, it is placed downstream from the Buckhorn Creek confluence, allowing for the impact of the Buckhorn to be determined. Second, it identifies the water quality entering the Big Barnes Ditch that feeds the Greeley reservoir system. Last, it provides data on the transition between segments three and four as designated by the WQCC standards.

**M120** Location: Headgate of the Greeley-Loveland Canal

Entities Currently Monitoring Site: City of Loveland, City of Greeley

The Greeley-Loveland Canal under some conditions feeds Boyd Lake, a source of drinking water for Greeley. This site identifies the water quality entering the canal. This site is also downstream of the exchange ditch that joins the Big Thompson from Boedecker Lake.

**M130** Location: Upstream of the Loveland Wastewater Treatment Plant effluent discharge on the upstream side of the St. Louis Street bridge.

Entities Currently Monitoring Site: City of Loveland, USGS water quality site

This site is meant to determine the water quality prior to the addition of the Loveland Wastewater Treatment Plant's discharge.

**M140** Location: Immediately upstream of the County Road 9-E bridge

Entities Currently Monitoring Site: City of Loveland

This site aims to assess the impact of the Loveland Wastewater Treatment Plant's discharge.

**M150** Location: The upstream side of the river where it crosses interstate 25

Entities Currently Monitoring Site: City of Loveland

This site serves as the watershed exit point and as the final WQCC segment transition, between segments four and five.

## Canals/Tunnels/Ditches Monitoring Sites

**C10** Location: The east portal of the Adams Tunnel at the USGS site

Entities Currently Monitoring Site: USGS water quality site

This site serves to determine the background water quality for Colorado Big Thompson Project and WQCC stream segment two.

**C20** Location: The Inlet to Olympus Tunnel in Lake Estes at the USGS site

Entities Currently Monitoring Site: USGS water quality site

Within Lake Estes, water from the CBT Project is mixed with that of the Big Thompson. It is this water that enters the Olympus Tunnel to the Carter/Flatiron/Pinewood system. This site determines the quality of water entering the Olympus Tunnel from Lake Estes.

**C30** Location: Hansen Canal at its exit from Flatiron Reservoir

Entities Currently Monitoring Sites: City of Greeley, and NCWCD

The Hansen Canal feeds both Green Glade and Horsetooth reservoirs. This site determines the initial water quality in the Hansen as it leaves Flatiron Reservoir.

**C40** Location: The Hansen Canal at the tri-furcation

Entities Currently Monitoring Sites: City of Greeley, NCWCD

The Hansen Canal feeds both Green Glade and Horsetooth reservoirs. This site determines the quality of water in the Hansen after mixing with water from the Dille Tunnel.

**C50** Location: Hansen Canal upstream of the tunnel near the inlet to Horsetooth Reservoir

Entities Currently Monitoring Sites: City of Ft. Collins, NCWCD

Horsetooth Reservoir is fed by the Hansen Canal. This site checks the water quality as the Hansen enters the reservoir. This allows for any change in water quality within the canal to be detected.

**C60** Location: The Big Barnes Ditch at the inlet to Lake Loveland

Entities Currently Monitoring Site: City of Greeley

Lake Loveland serves as a drinking water source for Greeley. This site determines the water quality entering Lake Loveland from the Big Barnes Ditch.

**C70** Location: Dry Creek at Lake Loveland outlet

Entities Currently Monitoring Site: City of Greeley

The Dry Creek drainage is viewed as a threat to the water quality in the Greeley reservoir system. This site determines the water quality before the confluence with Dry Creek. It also determines the water quality exiting Lake Loveland.

**C80** Location: Dry Creek at inlet to Horseshoe Reservoir

Entities Currently Monitoring Site: City of Greeley

This site is meant to determine the impact of Dry Creek on water quality. It also allows the water entering Horseshoe Reservoir to be assessed.

**C90** Location: Inlet to Boyd Lake from Horseshoe Reservoir
**C100** Location: Inlet to Boyd Lake from Heinricy Lake
**C110** Location: Inlet to Boyd Lake from Greeley-Loveland Canal

Entities Currently Monitoring Sites: All sites monitored by the City of Greeley

The objectives determined by the Forum included the determination of the loads into and out of selected reservoirs. Boyd Lake serves as a source of Greeley's drinking water. These three sites all determine the quality of water entering Boyd Lake.

## Tributary Monitoring Sites

**T10** Location: On the North Fork of the Big Thompson River on the upstream side of the Highway 34 bridge near the confluence with the mainstem of the Big Thompson River

Entities Currently Monitoring Site: USGS gage site

This site seeks the determine the effect of the North Fork on the water quality of the Big Thompson. It also provides data on the WQCC stream segment seven.

**T20** Location: Buckhorn Creek on upstream side of [Road Name] bridge near confluence with Big Thompson River

Entities Currently Monitoring Site: City of Greeley, USGS gage site

This site measures the effect of Buckhorn Creek on the water quality of the Big Thompson and provides information on the WQCC stream segment seven.

| | |
|---|---|
| **T30** | Location: Buckhorn Creek upstream of the confluence with Redstone Creek on the upstream side of the County Road 38-E bridge. |
| | Entities Currently Monitoring Site: None |
| | This site attempts to determine whether impacts on water quality downstream in Buckhorn Creek originate in the Buckhorn (T20) or in the Redstone. |

**Reservoir Monitoring Sites**

| | |
|---|---|
| **R10** | Location: Near Olympus Dam in the deepest portion of the lake |
| | Entities Currently Monitoring Site: None |
| | Lake Estes is the mixing point of Big Thompson natural flow, CBT water, as well as point and nonpoint sources within Estes Park. |
| **R20,30,40** | Ft. Collins is currently restructuring their monitoring approach to Horsetooth Reservoir. This will result in three primary monitoring sites, these sites will run longitudinally down the reservoir. The three sites chosen by the city will be utilized by BTWF. |

Entities Currently Monitoring Site: City of Ft.Collins monitors all three, R40 is a USGS water quality site

Horsetooth Reservoir is a very long, narrow lake. In addition, it has the potential for influence by higher trophic levels that are more spatially variable. Thus, there are three sites along the length of the reservoir.

**R50** Location: The City of Greeley has established a site near the center of the Lake which will be used for BTWF monitoring.

Entities Currently Monitoring Site: City of Greeley

Lake Loveland serves as a drinking water source for the city of Greeley. It is lower in the watershed and nearly circular in shape, thus requiring only one site.

**R60,70** Location: Greeley has established two monitoring sites in Boyd Lake, north bay and south bay. These are the same site that will be used by the BTWF.

Entities Currently Monitoring Site: City of Greeley

Boyd Lake also serves as a drinking water source for Greeley. It is larger than Lake Loveland, requiring two sites.

**R80,90** Location: The first site is that currently being monitored by the City of Ft. Collins. It is located near the dam on the south end of the Lake. A second site will be added in the north bay.

Entities Currently Monitoring Site: USGS water quality (1 site), City of Ft. Collins (1 site)

Carter Lake is a drinking water reservoir servicing the South Pipeline and St.Vrain Supply Canal. Similar to Horsetooth, Carter Lake has the potential for higher trophic levels to influence water quality.

## APPENDIX C

### Monthly Average Temperature Calculations Used to Designate Seasons

Data was not gathered at a constant frequency, resulting in unequal number of temperature samples for each month. The years during which data was gathered is listed following the name of the USGS sample site. The samples used for calculate the montly average are listed below the month in which they were sampled.

**BIG THOMPSON RIVER AT ESTES PARK, CO. (Data Collected 1953, 1958, 1973-1983)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 1 | 13 | 9 | 5 | 10 | 14 | 5 | 9 | 0 | 1 |
| | 1 | 0 | 3 | 11 | 4 | 5 | 13 | 12 | 12 | 6 | 6 | 1 |
| | 1 | 0.5 | 1 | 0.5 | 7 | 8 | 5 | 13 | 10 | 8 | 0.5 | 2 |
| | 2 | 1 | 4 | 3 | 6 | 8 | 13 | 19 | 12 | 5.5 | 3 | 0.5 |
| | 2 | 1 | 9 | 6 | 6 | 8 | 13 | 14 | 9 | 8 | 0 | 0 |
| | 0 | 0.5 | 1.5 | 10 | 5.5 | 9.5 | 12 | 16 | 13 | 4 | 2.5 | 0.5 |
| | 0 | 0.5 | 0.5 | 0.5 | 8.5 | 8 | 10 | | 9 | 4 | 0.5 | 0 |
| | 0 | 0 | 1 | 4 | 8 | 10 | | | 12 | 1 | 0.5 | 0.5 |
| | 0 | 1 | 5 | | 0 | 7 | | | 10 | | | 0.5 |
| | 1 | 0 | 0.5 | | 9 | 8 | | | 13 | | | 0 |
| | 0.5 | 0.5 | 0 | | 3 | 9 | | | | | | 0 |
| | 1 | 1 | 2 | | 9 | | | | | | | 0 |
| | 0.5 | 1 | 0 | | | | | | | | | 0.5 |
| | | 0.5 | 0 | | | | | | | | | 0.5 |
| | | 0.5 | 0 | | | | | | | | | 0.5 |
| | | 1.5 | 3.5 | | | | | | | | | |
| | | | 3 | | | | | | | | | |
| | | | 0.5 | | | | | | | | | |
| | | | 2.5 | | | | | | | | | |
| | | | 3 | | | | | | | | | |
| | | | 5 | | | | | | | | | |
| | | | 0.5 | | | | | | | | | |
| | | | 1 | | | | | | | | | |
| **Average** | 0.69 | 0.59 | 2.07 | 6.00 | 6.25 | 7.77 | 10.86 | 14.67 | 10.50 | 5.69 | 1.63 | 0.50 |

**BIG THOMPSON RIVER NEAR ESTES PARK, CO. (Data Collected 1972, 1978-1983)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.5 | 1.5 | 2 | 5 | 8 | 8 | 12 | 15 | 15 | 12 | 9 | 2 |
| | 2.5 | 3 | 2.5 | 8 | 6 | 9 | 15 | 15 | 13 | 11 | 5 | 1 |
| | 1 | 0.5 | 3.5 | 4.5 | 7 | 9 | 11 | 16 | 14 | 12 | 6 | 1 |
| | 1.5 | 2 | 2 | 3 | 8 | 9 | 5 | 15 | 13 | 11 | 2 | 2 |
| | 2 | 2.5 | 3 | 7 | 8 | 10 | 15 | 6 | 14 | 12 | 6 | 2 |
| | | 3.5 | 3.5 | 8 | 8.5 | 11 | 17 | 18 | 17 | 7 | 4 | 2 |
| | | | 3.5 | 5 | 4 | | 10 | 16 | 13 | 9 | 3 | |
| | | | 3 | 3 | 9 | | | 16 | 15 | 7 | | |
| | | | | 6 | 9 | | | | | | | |
| **Average** | 1.90 | 2.17 | 2.88 | 5.50 | 7.50 | 9.33 | 12.14 | 14.63 | 14.25 | 10.13 | 5.00 | 1.67 |

**BIG THOMPSON R ABOVE DILLE TUNNEL, NR DRAKE, CO. (Data Collected 1970-1980)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 0 | 10.5 | 9 | 13 | 17.5 | 17.5 | 18 | 7.5 | 2 | 0.5 |
| | 0 | 0 | 2.5 | 10 | 8 | 13 | 15 | 16.5 | 9 | 8 | 0 | 0 |
| | 0 | 0 | 1 | 10 | 6 | 7.5 | 16 | 14 | 13 | 6 | 0.5 | 0 |
| | 0 | 0 | 0 | 9.5 | 12.5 | 14.5 | 16.5 | 14 | 8.5 | 8 | 0 | 0 |
| | 0 | 0 | 3 | 4.5 | 6.5 | 9 | 14 | 16.5 | 12.5 | 7 | 5 | 0 |
| | 0 | 0 | 0 | 13.5 | 8 | 10.5 | 16 | 19 | 10.5 | 4.5 | 0.5 | 1.5 |
| | 0 | 0 | 2 | 11 | 16 | 16 | 20 | 18.5 | 13 | 10 | 0.05 | 0 |
| | 0 | 0 | 0.5 | 14.5 | 8 | 8 | 19.5 | 15 | 17 | 8 | 0 | 0 |
| | 0 | 0 | 6.5 | 8 | 2.5 | 9 | 19.5 | 17 | 15.5 | 3 | 0 | 0 |
| | 0 | 0.5 | 0 | | 8 | 10 | 14 | | | | | 0 |
| **Average** | 0.10 | 0.15 | 1.55 | 10.17 | 8.45 | 11.05 | 16.80 | 16.44 | 13.00 | 6.89 | 0.89 | 0.20 |

### BIG THOMPSON R AT MOUTH OF CANYON, NR DRAKE, CO. (Data Collected 1972, 1978-1984)

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 0.5 | 1 | 3 | 10 | 9 | 1 | 14 | 13 | 18 | 13 | 1.5 | 1 |
|  | 1.5 | 2 | 2 | 1.5 | 6 | 13 | 15 | 13.5 | 10 | 6 | 2 | 1 |
|  | 1 | 1.5 | 2.5 | 9.5 | 3 | 15 | 17 | 16 | 17 | 13 | 0.5 | 0.5 |
|  | 0.5 | 1 | 3 | 0.5 | 10 | 19 | 18 | 16 | 14 | 7 | 0.5 | 0 |
|  | 0 | 2.5 | 9 | 12 | 4 |  | 18 | 16 | 18 | 11 | 7 | 5 |
|  | 5 | 0 | 2 | 7 | 13 |  | 17 |  | 12 |  | 2 |  |
|  |  | 5 | 4 | 7 | 15 |  | 17 |  | 6 |  |  |  |
|  |  | 0.5 | 3 | 8 | 6 |  | 17 |  |  |  |  |  |
|  |  | 1 | 1.5 | 10 | 8 |  | 16 |  |  |  |  |  |
|  |  | 1 |  |  |  |  | 16 |  |  |  |  |  |
|  |  |  |  |  |  |  | 18 |  |  |  |  |  |
| **Average** | 1.42 | 1.55 | 3.33 | 7.28 | 8.22 | 12.00 | 16.64 | 14.90 | 13.57 | 10.00 | 2.25 | 1.50 |

### BIG THOMPSON R AB BUCKHORN C, NEAR LOVELAND, CO. (Data Collected 1987- 1992)

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 3 | 7 | 8.5 | 14.5 | 10.5 | 13.5 | 20 | 20 | 11 | 16 | 9.5 | 0 |
|  | 5 | 3 | 4 | 12 | 13 | 15.5 | 17 | 19 | 11.5 | 8 | 5 | 8 |
|  | 8 | 8 | 5 | 4 | 15.5 | 17 | 18 | 16 | 16.5 | 11.5 | 12 | 3.5 |
|  | 3.5 | 8.5 | 9 | 8.5 | 12 | 12.5 | 17 | 19 | 12 | 11 | 7.3 | 6 |
|  |  |  | 14.5 |  | 9 | 13.5 | 17 | 16 | 17.1 | 12.5 | 6.9 | 2.3 |
|  |  |  | 5.2 |  | 13 | 14 | 16 | 17.4 |  | 14.5 |  | 2.1 |
|  |  |  |  |  | 10 | 14.1 |  |  |  | 11 |  |  |
|  |  |  |  |  |  | 14.4 |  |  |  |  |  |  |
| **Average** | 4.88 | 6.63 | 7.70 | 9.75 | 11.86 | 14.31 | 17.50 | 17.90 | 13.62 | 12.07 | 8.14 | 3.65 |

**BIG THOMPSON RIVER ABOVE LOVELAND, CO. (Data Collected 1979-1992)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 6.5 | 6 | 7 | 13 | 18.5 | 14 | 13 | 7 | 0 | 1 |
| | 2 | 2 | 6 | 14 | 17 | 10 | 19.5 | 20 | 18 | 16 | 7 | 3 |
| | 1 | 4.5 | 1.5 | 16.5 | 10 | 20.5 | 22.5 | 20.5 | 16 | 11 | 11 | 2.5 |
| | 2 | 2 | 5 | 8 | 13 | 17 | 19 | 22 | 10.5 | 10 | 4 | 0 |
| | 0 | 3 | 5.5 | 10 | 11 | 10 | 17.5 | 17 | 22 | 10.5 | 1 | 0 |
| | 0.5 | 1 | 7 | 8.5 | 8 | 13 | 17 | 17 | 15 | 5.5 | 1 | 3 |
| | 2 | 5 | 9 | 10 | 14 | 12 | 15.5 | 16 | 9 | 10 | 7.5 | 1 |
| | 4.5 | 8 | 5 | 11 | 9.5 | 11 | 13 | 19 | 11 | 11 | 5 | 0 |
| | 0.05 | 4.5 | 7 | 8.5 | 16 | 14.5 | 24 | 21 | 14 | 15 | 7.5 | 0 |
| | 5 | 4 | 7.5 | 10.5 | 12 | 18 | 19 | 19.5 | 15 | 7 | 6 | 3 |
| | 3.5 | 5 | 9 | 9.5 | 13.5 | 14.5 | 17 | 16 | 11 | 10 | 7.5 | 2.5 |
| | 4.8 | | 11 | 8 | 11.2 | 12.5 | 16 | 18 | 14.5 | 11 | | 2 |
| | | | 8.5 | 8.5 | | 18 | 16.5 | 17 | 19 | 17 | | 4.4 |
| | | | 6.2 | 12 | | 15.5 | 21.2 | 20.7 | 16.9 | 8.5 | | 2.5 |
| | | | | | | 16.6 | | | | 18 | | |
| | | | | | | 17.4 | | | | 8 | | |
| **Average** | 2.11 | 4.00 | 6.76 | 10.07 | 11.85 | 14.59 | 18.30 | 18.41 | 14.64 | 10.97 | 5.23 | 1.78 |

**BIG THOMPSON RIVER AT LOVELAND, CO. (Data Collected 1979-1995)**

| **Months** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.5 | 7 | 5 | 9.5 | 7.5 | 15.5 | 21 | 16.5 | 15.5 | 8.5 | 0 | 2 |
| | 3.5 | 6 | 8 | 18 | 20 | 10 | 22 | 21 | 19.5 | 13.5 | 4 | 4 |
| | 1 | 5 | 12 | 18.5 | 7 | 21 | 23.5 | 21.5 | 18 | 12.5 | 9.5 | 3.5 |
| | 0.5 | 1 | 4 | 15.5 | 11.5 | 22.5 | 18.5 | 26 | 12.5 | 10.5 | 3 | 0 |
| | 0 | 4 | 5 | 10 | 13 | 11 | 15.5 | 18 | 20 | 10 | 2 | 0 |
| | 0 | 2 | 9 | 12 | 12 | 13 | 22 | 20 | 18 | 8 | 2 | 4 |
| | 2 | 5 | 6 | 11 | 13 | 13.5 | 19.5 | 18.5 | 9 | 12 | 0 | 0 |
| | 4 | 3 | 3 | 18 | 12 | 14 | 14 | 20 | 5 | 11.5 | 7 | 0 |
| | 0 | 4.5 | 10.5 | 19 | 13.5 | 21 | 19 | 18 | 15 | 12 | 9.5 | 0 |
| | 4 | 5 | 8 | 10 | 17.5 | 18 | 20 | 18.5 | 16 | 12 | 10 | 5 |
| | 5 | 7 | 14.5 | 18.5 | 13.5 | 19.5 | 22 | 18 | 11.5 | 11.5 | 6 | 2 |
| | | 1 | 10 | 16 | 13 | 16.5 | 22 | 18.5 | 18 | 13.5 | 7.6 | 2.5 |
| | 2 | 1.5 | 9 | 11 | 11.3 | 17 | 18 | 18 | 18 | 11 | 7 | 2.9 |
| | 0 | 3.5 | 8.4 | 12 | 10 | 17 | 16 | 15.6 | 16.5 | 11 | 3.5 | 1.8 |
| | 2 | | 7.5 | 15.2 | 11.5 | 15.3 | 17.8 | 17 | 13 | 10.3 | | 0 |
| | 3 | | 7 | 7.8 | | 17.5 | 17.5 | 17.5 | | 9.5 | | 2 |
| | | | 6.5 | | | 14.5 | 20 | 24 | 13.5 | 10 | | |
| | | | | | | 14.5 | 16.5 | | 13 | | | |
| **Average** | 1.97 | 3.96 | 7.85 | 13.88 | 12.42 | 16.18 | 19.16 | 19.21 | 14.82 | 11.02 | 5.08 | 1.86 |

**BIG THOMPSON RIVER BELOW LOVELAND, CO. (Data Collected 1979-1992, 1994)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 7.5 | 5 | 11.5 | 9 | 17 | 19 | 18.5 | 18.5 | 13 | 2.5 | 5.5 |
| | 8 | 13.5 | 9 | 21 | 25.5 | 13 | 23.5 | 23.5 | 17.5 | 12.5 | 4 | 7.5 |
| | 2 | 9 | 11 | 12 | 6.5 | 20 | 25 | 17.5 | 21.5 | 14 | 9 | 8 |
| | 2.5 | 2 | 4 | 17 | 10.5 | 18.5 | 17.5 | 26 | 14.5 | 13 | 4 | 4.5 |
| | 3 | 8 | 6 | 10.5 | 13 | 9.5 | 14 | 19 | 20 | 9 | 4 | 1 |
| | 3 | 5 | 18 | 17 | 14.5 | 13 | 24 | 22 | 20.5 | 10.5 | 1 | 9 |
| | 5 | 6 | 6 | 12.5 | 16 | 17 | 25 | 22.5 | 12 | 15 | 8 | 3 |
| | 2.5 | 5 | 3.5 | 19 | 18 | 13 | 16 | 20 | 15 | 11.5 | 8 | 0 |
| | 4 | 7 | 11.5 | 19.5 | 12 | 19 | 25 | 21 | 18.5 | 19 | 11.5 | 3 |
| | 4 | 3 | 11 | 15 | 16 | 18 | 24 | 19.5 | 18 | 14 | 12.9 | 9 |
| | 8 | 8 | 16 | 11.5 | 21.5 | 16.5 | 23 | 19 | 11.5 | 13.5 | 8 | 8.5 |
| | 2.6 | | 7 | 9 | 10.5 | 15 | 19 | 24.5 | 16.5 | 12.5 | | 2 |
| | | | 12 | 11 | | 20 | 18.5 | 18 | 15 | 13.5 | | 4.7 |
| | | | 12 | 10 | | 18.5 | 16.5 | 19.5 | 16.5 | 12 | | 2.5 |
| | | | | 17 | | 13.3 | 21 | | | 13.5 | | |
| | | | | | | | | | | 14.5 | | |
| **Average** | 3.97 | 6.73 | 9.43 | 14.23 | 14.42 | 16.09 | 20.73 | 20.75 | 16.82 | 13.19 | 6.63 | 4.87 |

**BIG THOMPSON RIVER AT I-25, NEAR LOVELAND, CO. (Data Collected 1987-1992)**

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1.5 | 7.5 | 17 | 13 | 16 | 24 | 20 | 17.5 | 15 | 9.5 | 0.5 |
| | 3 | 3.5 | 5.5 | 17 | 17 | 18.5 | 23 | 21 | 11 | 8.5 | 11 | 4.5 |
| | 4.5 | 2.5 | 10 | 13 | 12 | 23 | 23 | 17 | 21 | 13.5 | 4 | 3 |
| | 5.2 | 10 | 12 | 10 | 15 | 19.5 | 18.5 | 21 | 15 | 9.5 | 6 | 0.5 |
| | | | 12.5 | 13 | 15.7 | 17 | 17.5 | 20 | 14.6 | 12 | | 4.8 |
| | | | 6.4 | 9 | | 16 | 17.5 | 14 | | 10 | | 0 |
| | | | | | | 16.1 | | | | 15 | | |
| | | | | | | 26 | | | | 7.5 | | |
| **Average** | 3.18 | 4.38 | 8.98 | 13.17 | 14.54 | 19.01 | 20.58 | 18.83 | 15.82 | 11.38 | 7.63 | 2.22 |

## APPENDIX D

**Sample Size Based on Estimation of Means**
**At Loveland**

| Sample # | Seasonal | monthly | 2xmonth | weekly | 2xweek | daily |
|---|---|---|---|---|---|---|
| **S1** | 1 | 3 | 6 | 13 | 26 | 92 |
| **S2** | 1 | 3 | 6 | 13 | 26 | 92 |
| **S3** | 1 | 6 | 12 | 26 | 52 | 181 |
| **1&2** | 2 | 6 | 12 | 26 | 52 | 184 |
| **2&3** | 2 | 9 | 18 | 39 | 78 | 273 |
| **all** | 3 | 12 | 24 | 52 | 104 | 365 |

| 95% T-value | Seasonal | monthly | 2xmonth | weekly | 2xweek | daily |
|---|---|---|---|---|---|---|
| **S1** | NA | 4.303 | 2.571 | 2.179 | 2.06 | 1.989 |
| **S2** | NA | 4.303 | 2.571 | 2.179 | 2.06 | 1.989 |
| **S3** | NA | 2.571 | 2.201 | 2.06 | 2.008 | 1.975 |
| **1&2** | 12.706 | 2.571 | 2.201 | 2.06 | 2.008 | 1.975 |
| **2&3** | 12.706 | 2.306 | 2.11 | 2.052 | 1.994 | 1.96 |
| **all** | 4.303 | 2.201 | 2.069 | 2.008 | 1.985 | 1.96 |

The above tables are the number of samples associated with each frequency within each individual season and grouped seasons. The frequency calculation based on the estimation of means begins with a listing of the distribution of the historical data as normal (N) or log normal (LN). Based upon the ANOVA and t-tests the seasonality of each variable was determined. The breakdown of the seasons is listed in the season column. The seasons used are followed by the number of samples and the mean of the historical data, "y hat" refers to the mean of the log of the data and "x hat" is the mean of the data. Under the labels monthly, biweekly, weekly, and daily, is the percent error associated with each frequency.

| Name | Dist | season | n | y or x, hat | std dev. | monthly | biweekly | weekly | daily |
|---|---|---|---|---|---|---|---|---|---|
| Specific Conductance, us/cm @25 deg C | LN | S1 | 51 | 5.774 | 0.806 | 363.58% | 95.06% | 95.06% | 16.79% |
| Specific Conductance, us/cm @25 deg C | N | S2 | 50 | 764.600 | 367.000 | 119.25% | 50.38% | 50.38% | 9.95% |
| Specific Conductance, us/cm @25 deg C | N | S3 | 92 | 1244.500 | 417.400 | 35.20% | 21.31% | 21.31% | 4.92% |
| Osygen Dissolved (mg/L) | LN | 1&2 | 100 | 2.270 | 0.166 | 17.49% | 10.55% | 10.55% | 2.41% |
| Osygen Dissolved (mg/L) | N | S3 | 89 | 12.099 | 1.868 | 16.21% | 9.81% | 9.81% | 2.27% |
| pH, water, whole, Lab, std. Units | N | S1 | 43 | 7.981 | 0.322 | 10.04% | 4.24% | 4.24% | 0.84% |
| pH, water, whole, Lab, std. Units | N | 2&3 | 129 | 8.106 | 0.256 | 2.43% | 1.57% | 1.57% | 0.37% |
| Nitrogen Ammonia Dissolved (mg/L as N) | LN | 1&2 | 174 | -2.703 | 1.516 | 235.30% | 111.92% | 111.92% | 22.25% |
| Nitrogen Ammonia Dissolved (mg/L as N) | LN | S3 | 76 | 0.058 | 0.037 | 3.90% | 2.36% | 2.36% | 0.54% |
| Nitrogen, Nitrite Dissolved, mg/L as N | LN | all | 187 | -4.393 | 0.398 | 25.58% | 16.90% | 16.90% | 4.09% |
| Nitrogen Ammonia Plus Organic Total (mg/L as N) | LN | all | 94 | -0.519 | 0.611 | 39.83% | 26.11% | 26.11% | 6.28% |
| Nitrogen Nitrite plus Nitrate Dissolved, (mg/L as N) | LN | S1 | 41 | -1.977 | 0.709 | 282.44% | 81.48% | 81.48% | 14.76% |
| Nitrogen Nitrite plus Nitrate Dissolved, (mg/L as N) | LN | S2 | 36 | -1.547 | 0.774 | 334.72% | 90.48% | 90.48% | 16.12% |
| Nitrogen Nitrite plus Nitrate Dissolved, (mg/L as N) | LN | S3 | 67 | -0.848 | 0.725 | 83.71% | 47.74% | 47.74% | 10.67% |
| Phosphorus Dissolved (mg/L as P) | LN | all | 134 | -3.929 | 0.740 | 48.74% | 31.75% | 31.75% | 7.59% |
| Calcium Dissolved (mg/L as Ca) | LN | S1 | 45 | 3.452 | 0.845 | 401.88% | 100.79% | 100.79% | 17.61% |
| Calcium Dissolved (mg/L as Ca) | N | S2 | 45 | 85.030 | 43.810 | 128.00% | 54.08% | 54.08% | 10.68% |
| Calcium Dissolved (mg/L as Ca) | N | S3 | 86 | 136.210 | 42.310 | 32.60% | 19.74% | 19.74% | 4.56% |
| Magnesium Dissolved (mg/L as Mg) | LN | S1 | 45 | 2.431 | 0.998 | 592.50% | 124.99% | 124.99% | 20.84% |
| Magnesium Dissolved (mg/L as Mg) | N | S2 | 45 | 31.030 | 18.200 | 145.71% | 61.56% | 61.56% | 12.16% |
| Magnesium Dissolved (mg/L as Mg) | N | S3 | 87 | 54.880 | 23.460 | 44.87% | 27.16% | 27.16% | 6.28% |
| Sodium Dissolved (mg/L as Na) | LN | 1&2 | 38 | 2.786 | 0.837 | 99.60% | 55.72% | 55.72% | 12.22% |
| Sodium Dissolved (mg/L as Na) | N | S3 | 29 | 60.840 | 29.460 | 50.82% | 30.77% | 30.77% | 7.11% |
| Potassium Dissolved (mg/L as K) | LN | 1&2 | 30 | 0.475 | 0.627 | 70.66% | 40.90% | 40.90% | 9.14% |
| Potassium Dissolved (mg/L as K) | N | S3 | 21 | 3.229 | 1.076 | 34.98% | 21.17% | 21.17% | 4.89% |
| Chloride Dissolved (mg/L as Cl) | LN | 1&2 | 38 | 1.396 | 0.798 | 93.90% | 52.90% | 52.90% | 11.64% |
| Chloride Dissolved (mg/L as Cl) | N | S3 | 29 | 14.552 | 6.226 | 44.91% | 27.18% | 27.18% | 6.28% |
| Sulfate Dissolved (mg/L as SO4) | LN | 1&2 | 38 | 4.758 | 0.972 | 120.66% | 65.76% | 65.76% | 14.20% |
| Sulfate Dissolved (mg/L as SO4) | N | S3 | 30 | 515.300 | 210.300 | 42.84% | 25.93% | 25.93% | 5.99% |
| Fluoride Dissolved (mg/L as F) | N | S1 | 30 | 0.227 | 0.110 | 120.06% | 50.72% | 50.72% | 10.02% |
| Fluoride Dissolved (mg/L as F) | N | S2 | 26 | 0.300 | 0.089 | 74.07% | 31.29% | 31.29% | 6.18% |
| Fluoride Dissolved (mg/L as F) | N | S3 | 54 | 0.396 | 0.099 | 26.21% | 15.87% | 15.87% | 3.67% |
| Silica Dissolved (mg/L as SiO2) | LN | all | 110 | 1.802 | 0.303 | 19.37% | 12.83% | 12.83% | 3.11% |
| Iron Dissolved (ug/L as Fe) | LN | 2&3 | 70 | 3.412 | 0.580 | 46.08% | 29.25% | 29.25% | 6.89% |
| Iron Dissolved (ug/L as Fe) | LN | S1 | 23 | 3.874 | 0.759 | 321.93% | 88.36% | 88.36% | 15.80% |
| Manganese Dissolved (ug/L as Mn) | LN | 1&2 | 48 | 2.873 | 0.837 | 99.60% | 55.72% | 55.72% | 12.22% |
| Manganese Dissolved (ug/L as Mn) | LN | S3 | 45 | 3.664 | 0.702 | 80.53% | 46.10% | 46.10% | 10.32% |
| Solids, Sum of Constituents, Dissolved (mg/L) | LN | 1&2 | 23 | 5.627 | 0.819 | 96.95% | 54.42% | 54.42% | 11.95% |
| Solids, Sum of Constituents, Dissolved (mg/L) | N | S3 | 19 | 860.400 | 327.500 | 39.95% | 24.18% | 24.18% | 5.59% |
| Solids, Dissolved (tons per day) | LN | 2&3 | 31 | 3.341 | 0.790 | 64.53% | 40.31% | 40.31% | 9.39% |
| Solids, Dissolved (tons per day) | LN | S1 | 11 | 4.081 | 1.422 | 1709.40% | 211.18% | 211.18% | 29.92% |

**Sample Size based on Trend Detection**

| | 5-year, measured units | | | | | 5-year, % of mean | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| name | monthly | 2xmonth | weekly | 2xweek | daily | seasonal | monthly | 2xmonth | weekly | 2xweek | daily |
| Specific Conductance, us/cm @25 deg C | 578.896 | 405.743 | 274.383 | 193.643 | 103.223 | 182.3% | 85.6% | 60.0% | 40.6% | 28.6% | 15.3% |
| Osygen Dissolved (mg/L) | 2.668 | 1.870 | 1.264 | 0.892 | 0.476 | 57.4% | 27.0% | 18.9% | 12.8% | 9.0% | 4.8% |
| pH, water, whole, Lab, std. Units | 0.405 | 0.284 | 0.192 | 0.135 | 0.072 | 10.6% | 5.0% | 3.5% | 2.4% | 1.7% | 0.9% |
| Nitrogen Ammonia Dissolved (mg/L as N) | 1.670 | 1.170 | 0.791 | 0.558 | 0.298 | 1133.7% | 532.6% | 373.3% | 252.4% | 178.1% | 95.0% |
| Nitrogen, Nitrite Dissolved, mg/L as N | 0.014 | 0.010 | 0.007 | 0.005 | 0.002 | 206.8% | 97.1% | 68.1% | 46.0% | 32.5% | 17.3% |
| Nitrogen Ammonia Plus Organic Total (mg/L as N) | 0.705 | 0.494 | 0.334 | 0.236 | 0.126 | 201.9% | 94.8% | 66.5% | 45.0% | 31.7% | 16.9% |
| Nitrogen Nitrite plus Nitrate Dissolved, (mg/L as N) | 0.463 | 0.324 | 0.219 | 0.155 | 0.083 | 399.8% | 187.8% | 131.6% | 89.0% | 62.8% | 33.5% |
| Phosphorus Dissolved (mg/L as P) | 0.036 | 0.025 | 0.017 | 0.012 | 0.006 | 303.2% | 142.4% | 99.8% | 67.5% | 47.6% | 25.4% |
| Calcium Dissolved (mg/L as Ca) | 61.798 | 43.314 | 29.291 | 20.672 | 11.019 | 176.3% | 82.8% | 58.0% | 39.2% | 27.7% | 14.8% |
| Magnesium Dissolved (mg/L as Mg) | 31.146 | 21.830 | 14.762 | 10.418 | 5.554 | 239.0% | 112.2% | 78.7% | 53.2% | 37.5% | 20.0% |
| Sodium Dissolved (mg/L as Na) | 38.732 | 27.147 | 18.358 | 12.956 | 6.906 | 401.5% | 188.6% | 132.2% | 89.4% | 63.1% | 33.6% |
| Potassium Dissolved (mg/L as K) | 2.071 | 1.452 | 0.982 | 0.693 | 0.369 | 225.6% | 105.9% | 74.3% | 50.2% | 35.4% | 18.9% |
| Chloride Dissolved (mg/L as Cl) | 10.386 | 7.279 | 4.923 | 3.474 | 1.852 | 367.1% | 172.4% | 120.9% | 81.7% | 57.7% | 30.7% |
| Sulfate Dissolved (mg/L as SO4) | 267.219 | 187.291 | 126.655 | 89.386 | 47.648 | 347.4% | 163.2% | 114.4% | 77.3% | 54.6% | 29.1% |
| Fluoride Dissolved (mg/L as F) | 0.147 | 0.103 | 0.070 | 0.049 | 0.026 | 115.4% | 54.2% | 38.0% | 25.7% | 18.1% | 9.7% |
| Silica Dissolved (mg/L as SiO2) | 2.985 | 2.092 | 1.415 | 0.998 | 0.532 | 110.5% | 51.9% | 36.4% | 24.6% | 17.4% | 9.3% |
| Iron Dissolved (ug/L as Fe) | 38.544 | 27.015 | 18.269 | 12.893 | 6.873 | 184.4% | 86.6% | 60.7% | 41.0% | 29.0% | 15.4% |
| Manganese Dissolved (ug/L as Mn) | 45.454 | 31.858 | 21.544 | 15.205 | 8.105 | 338.6% | 159.0% | 111.5% | 75.4% | 53.2% | 28.4% |
| Solids, Sum of Constituents, Dissolved (mg/L) | 479.859 | 336.328 | 227.442 | 160.514 | 85.563 | 255.3% | 119.9% | 84.1% | 56.8% | 40.1% | 21.4% |
| Solids, Dissolved (tons per day) | 112.336 | 78.735 | 53.244 | 37.577 | 20.030 | 369.4% | 173.5% | 121.6% | 82.2% | 58.0% | 30.9% |
| Specific Conductance microsiemens/cm @ 25 deg C | 582.606 | 408.342 | 276.141 | 194.883 | 103.884 | 179.4% | 84.3% | 59.1% | 39.9% | 28.2% | 15.0% |
| Alkalinity, Titration to pH 4.5, Lab (mg/L as CaCO3) | 67.415 | 47.250 | 31.953 | 22.551 | 12.021 | 137.5% | 64.6% | 45.3% | 30.6% | 21.6% | 11.5% |

The above table represents the change in population mean, over a five year period, required for a given frequency to detect a change. The first section of the table represents the change in mean in measured units. The second half of the table lists the number of units as a percentage of the historical mean. Recall that trend analysis assumes a normal distribution of data and uses a deseasonalized variance.

**Sample Size based on Trend Detection**

| | 10-year , measured units | | | | | 10-year, % of mean | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| name | monthly | 2xmonth | weekly | 2xweek | daily | seasonal | monthly | 2xmonth | weekly | 2xweek | daily |
| Specific Conductance, us/cm @25 deg C | 405.743 | 285.680 | 193.643 | 136.794 | 72.969 | 123.4% | 60.0% | 42.3% | 28.6% | 20.2% | 10.8% |
| Osygen Dissolved (mg/L) | 1.870 | 1.317 | 0.892 | 0.630 | 0.336 | 38.9% | 18.9% | 13.3% | 9.0% | 6.4% | 3.4% |
| pH, water, whole, Lab, std. Units | 0.284 | 0.200 | 0.135 | 0.096 | 0.051 | 7.2% | 3.5% | 2.5% | 1.7% | 1.2% | 0.6% |
| Nitrogen Ammonia Dissolved (mg/L as N) | 1.170 | 0.824 | 0.558 | 0.395 | 0.210 | 767.5% | 373.3% | 262.8% | 178.1% | 125.8% | 67.1% |
| Nitrogen, Nitrite Dissolved, mg/L as N | 0.010 | 0.007 | 0.005 | 0.003 | 0.002 | 140.0% | 68.1% | 47.9% | 32.5% | 23.0% | 12.2% |
| Nitrogen Ammonia Plus Organic Total (mg/L as N) | 0.494 | 0.348 | 0.236 | 0.167 | 0.089 | 136.7% | 66.5% | 46.8% | 31.7% | 22.4% | 12.0% |
| Nitrogen Nitrite plus Nitrate Dissolved, (mg/L as N) | 0.324 | 0.228 | 0.155 | 0.109 | 0.058 | 270.7% | 131.6% | 92.7% | 62.8% | 44.4% | 23.7% |
| Phosphorus Dissolved (mg/L as P) | 0.025 | 0.018 | 0.012 | 0.008 | 0.004 | 205.3% | 99.8% | 70.3% | 47.6% | 33.7% | 18.0% |
| Calcium Dissolved (mg/L as Ca) | 43.314 | 30.497 | 20.672 | 14.603 | 7.790 | 119.3% | 58.0% | 40.9% | 27.7% | 19.6% | 10.4% |
| Magnesium Dissolved (mg/L as Mg) | 21.830 | 15.370 | 10.418 | 7.360 | 3.926 | 161.8% | 78.7% | 55.4% | 37.5% | 26.5% | 14.1% |
| Sodium Dissolved (mg/L as Na) | 27.147 | 19.114 | 12.956 | 9.152 | 4.882 | 271.8% | 132.2% | 93.1% | 63.1% | 44.6% | 23.8% |
| Potassium Dissolved (mg/L as K) | 1.452 | 1.022 | 0.693 | 0.489 | 0.261 | 152.7% | 74.3% | 52.3% | 35.4% | 25.0% | 13.4% |
| Chloride Dissolved (mg/L as Cl) | 7.279 | 5.125 | 3.474 | 2.454 | 1.309 | 248.5% | 120.9% | 85.1% | 57.7% | 40.7% | 21.7% |
| Sulfate Dissolved (mg/L as SO4) | 187.291 | 131.870 | 89.386 | 63.144 | 33.683 | 235.2% | 114.4% | 80.5% | 54.6% | 38.6% | 20.6% |
| Fluoride Dissolved (mg/L as F) | 0.103 | 0.073 | 0.049 | 0.035 | 0.019 | 78.1% | 38.0% | 26.8% | 18.1% | 12.8% | 6.8% |
| Silica Dissolved (mg/L as SiO2) | 2.092 | 1.473 | 0.998 | 0.705 | 0.376 | 74.8% | 36.4% | 25.6% | 17.4% | 12.3% | 6.5% |
| Iron Dissolved (ug/L as Fe) | 27.015 | 19.021 | 12.893 | 9.108 | 4.858 | 124.8% | 60.7% | 42.7% | 29.0% | 20.5% | 10.9% |
| Manganese Dissolved (ug/L as Mn) | 31.858 | 22.431 | 15.205 | 10.741 | 5.729 | 229.2% | 111.5% | 78.5% | 53.2% | 37.6% | 20.0% |
| Solids, Sum of Constituents, Dissolved (mg/L) | 336.328 | 236.806 | 160.514 | 113.392 | 60.486 | 172.8% | 84.1% | 59.2% | 40.1% | 28.3% | 15.1% |
| Solids, Dissolved (tons per day) | 78.735 | 55.437 | 37.577 | 26.545 | 14.160 | 250.1% | 121.6% | 85.6% | 58.0% | 41.0% | 21.9% |
| Specific Conductance microsiemens/cm @ 25 deg C | 408.342 | 287.511 | 194.883 | 137.671 | 73.437 | 121.5% | 59.1% | 41.6% | 28.2% | 19.9% | 10.6% |
| Alkalinity, Titration to pH 4.5, Lab (mg/L as CaCO3) | 47.250 | 33.269 | 22.551 | 15.930 | 8.498 | 93.1% | 45.3% | 31.9% | 21.6% | 15.3% | 8.1% |

The above table represents the change in population mean, over a ten year period, required for a given frequency to detect a change. The first section of the table represents the change in mean in measured units. The second half of the table lists the number of units as a percentage of the historical mean. Recall that trend analysis assumes a normal distribution of data and uses a deseasonalized variance.

## APPENDIX E

### Program Cost Breakdown

### Initially Proposed Program

The calculations were broken in to stages. The number of samples for each variable was determined based on the frequency. The number of samples was used determine lab cost for all moving water samples. A similar set of calculations was completed for the reservoirs. The final set of calculations is the labor costs.

| **TOTAL COST** | |
|---|---|
| Moving Water Sampling | $64,075.50 |
| Reservoir Sampling | $73,800.00 |
| Moving Water Analysis | $330,078.00 |
| Reservoir Analysis | $248,187.00 |
| **TOTAL** | $716,140.50 |

| **Budgets** | |
|---|---|
| Ft. Collins | $275,000.00 |
| Greeley | $60,000.00 |
| Loveland | $30,000.00 |
| Northern | $36,500.00 |
| TOTAL | $401,500.00 |

**Initially Proposed Program**

**MOVING WATER SAMPLING FREQ. AND PARAMETERS**

| | |
|---|---|
| **ACU LABS** | $330,078 00 |

| | |
|---|---|
| 2M | biweekly |
| M | monthly |

**Inorganics**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| Alkalinity | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| Biochemical Oxygen Demand | 2M | 2M | M | 6 | 6 | 6 | 522 | $30.00 | $15,660.00 |
| Carbon, Total Organic Carbon | 2M | 2M | M | 6 | 6 | 6 | 522 | $30.00 | $15,660 00 |
| chloride | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Fluoride | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| hardness | 2M | 2M | M | 6 | 6 | 6 | 522 | $22.00 | $11,484.00 |
| Nitrogen, Ammonia | 2M | 2M | M | 6 | 6 | 6 | 522 | $10.00 | $5,220.00 |
| Nitrogen, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $42.00 | $21,924 00 |
| Nitrogen, Total oxidized (nitrate + nitrite) | 2M | 2M | M | 6 | 6 | 6 | 522 | $17.00 | $8,874.00 |
| Oxygen, Dissolved | 2M | 2M | M | 6 | 6 | 6 | 522 | $10.00 | $5,220.00 |
| pH | 2M | 2M | M | 6 | 6 | 6 | 522 | $10.00 | $5,220.00 |
| Phosphorus, ortho-phosphate | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Phosphorus, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| Solids, Total dissolved | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Solids, Total suspended | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Solids, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Sulfate | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| Turbidity | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| | | | | | | | | **TOTAL** | **$158,166.00** |

**Metals**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| Arsenic | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Cadmium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Calcium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Copper | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Iron | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Lead | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Magnesium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Manganese | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Mercury | M | M | M | 3 | 3 | 6 | 348 | $20.00 | $6,960.00 |
| Potassium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Selenium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Silica | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Silver | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Sodium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Zinc | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| | | | | | | | | **TOTAL** | **$60,552.00** |

**Microbiological**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| E. Coli | M | M | M | 3 | 3 | 6 | 348 | $50.00 | 17,400.00 |
| fecal coliform | M | M | M | 3 | 3 | 6 | 348 | $35.00 | 12,180.00 |
| fecal streptococci | M | M | M | 3 | 3 | 6 | 348 | $35.00 | 12,180.00 |
| total coliform | M | M | M | 3 | 3 | 6 | 348 | $35.00 | 12,180.00 |
| | | | | | | | | **TOTAL** | **$53,940.00** |

**organic contaminants**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| BTEX | M | M | M | 3 | 3 | 6 | 348 | $85.00 | 29,580.00 |
| total petroleum hydrocarbons | M | M | M | 3 | 3 | 6 | 348 | $80.00 | 27,840.00 |
| | | | | | | | | **TOTAL** | **$57,420.00** |

**Initially Proposed Program**
**Reservoirs**

| | **Frequency** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **inorganics** | **# samples** | **metals** | **# samples** | **microbio** | **# samples** | **organic** | **# samples** | **bio** | **# samples** |
| Carter 1 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Carter 2 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 1 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 2 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 3 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| L. Loveland | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| L. Estes | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| **Total Samples** | | 183 | | 108 | | 108 | | 108 | | 183 |

| | **Frequency** | | | | | |
|---|---|---|---|---|---|---|
| | **chloro** | **# samples** | **phyto** | **# samples** | **zoo, sp** | **# samples** |
| Carter 1 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Carter 2 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 1 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 2 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 3 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| L. Loveland | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| L. Estes | 12(2m), 3m | 18 | 1-3m | 12 | | |
| Total Samples | | 183 | | 156 | | 90 |

**Initially Proposed Program**

**Reservoir Cost Est.**

| ACU LABS | $248,187.00 |
|---|---|

| **Inorganics** | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| Alkalinity | 366 | $15.00 | $5,490.00 |
| Biochemical Oxygen Demand | 366 | $30.00 | $10,980.00 |
| Carbon, Total Organic Carbon | 366 | $30.00 | $10,980.00 |
| chloride | 366 | $12.00 | $4,392.00 |
| Fluoride | 366 | $15.00 | $5,490.00 |
| hardness | 366 | $22.00 | $8,052.00 |
| Nitrogen, Ammonia | 366 | $10.00 | $3,660.00 |
| Nitrogen, Total | 366 | $42.00 | $15,372.00 |
| Nitrogen, Total oxidized (nitrate + nitrite) | 366 | $17.00 | $6,222.00 |
| Oxygen, Dissolved | 366 | $10.00 | $3,660.00 |
| pH | 366 | $10.00 | $3,660.00 |
| Phosphorus, ortho-phosphate | 366 | $12.00 | $4,392.00 |
| Phosphorus, Total | 366 | $15.00 | $5,490.00 |
| Solids, Total dissolved | 366 | $12.00 | $4,392.00 |
| Solids, Total suspended | 366 | $12.00 | $4,392.00 |
| Solids, Total | 366 | $12.00 | $4,392.00 |
| Sulfate | 366 | $15.00 | $5,490.00 |
| Turbidity | 366 | $12.00 | $4,392.00 |
| | | | **$110,898.00** |

| **Metals** | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| Arsenic | 216 | $11.00 | $2,376.00 |
| Cadmium | 216 | $11.00 | $2,376.00 |
| Calcium | 216 | $11.00 | $2,376.00 |
| Copper | 216 | $11.00 | $2,376.00 |
| Iron | 216 | $11.00 | $2,376.00 |
| Lead | 216 | $11.00 | $2,376.00 |
| Magnesium | 216 | $11.00 | $2,376.00 |
| Manganese | 216 | $11.00 | $2,376.00 |
| Mercury | 216 | $20.00 | $4,320.00 |
| Potassium | 216 | $11.00 | $2,376.00 |
| Selenium | 216 | $11.00 | $2,376.00 |
| Silica | 216 | $11.00 | $2,376.00 |
| Silver | 216 | $11.00 | $2,376.00 |
| Sodium | 216 | $11.00 | $2,376.00 |
| Zinc | 216 | $11.00 | $2,376.00 |
| | | | **$37,584.00** |

| **Microbiological** | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| E. Coli | 216 | 50.00 | 10,800.00 |
| fecal coliform | 216 | 35.00 | 7,560.00 |
| fecal streptococci | 216 | 35.00 | 7,560.00 |
| total coliform | 216 | 35.00 | 7,560.00 |
| | | | **$33,480.00** |

| **organic contaminants** | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| BTEX | 216 | 85.00 | 18,360.00 |
| total petroleum hydrocarbons | 216 | 80.00 | 17,280.00 |
| | | | **$35,640.00** |

| **Biological** | | | |
|---|---|---|---|
| **Constituent** | **samples/yr** | **cost/sample** | **cost/yr** |
| chloro-a | 183 | $45.00 | $8,235.00 |
| phytoplankton | 156 | $100.00 | $15,600.00 |
| zooplankton | 90 | $75.00 | $6,750.00 |
| | | | **$30,585.00** |

NOTE - phytoplankton prices based on CHDiagnostics

## Initially Proposed Program

### Labor

| | |
|---|---|
| TOTAL | $137,875.50 |

### Moving Water Sampling

| | | |
|---|---|---|
| **vehicle prices** | $/mile | $0.35 |
| | miles/site | 15 |
| | # site visits/yr | 522 |
| | cost | $2,740.50 |

| | | |
|---|---|---|
| **Labor Costs** | # people | 3 |
| | hours/site | 0.75 |
| | $/hour | $50.00 |
| | # site visits/yr | 522 |
| | cost | $58,725.00 |

| | | |
|---|---|---|
| **materials/supplies** | $/site visit | $5.00 |
| | # site visits/yr | 522 |
| | cost | $2,610.00 |

**TOTAL** $64,075.50

### Reservoir Sampling

| | | |
|---|---|---|
| **Zooplankton** | $/person hr | $50.00 |
| | hours/sample | 5 |
| | # samples | 90 |
| (labor) | TOTAL | $22,500.00 |
| | $/samplet | $50.00 |
| | # samples | 90 |
| (supplies/equip/travel) | TOTAL | $4,500.00 |
| | **TOTAL** | $27,000.00 |

| | | |
|---|---|---|
| **Phytoplankton** | $/person hr | $50.00 |
| | hours/lake visi | 5 |
| | # lake visit | 156 |
| (labor) | TOTAL | $39,000.00 |
| | $/lake visit | $50.00 |
| | # lake visits | 156 |
| (supplies/equip/travel) | TOTAL | $7,800.00 |
| | **TOTAL** | $46,800.00 |

**TOTAL** $73,800.00

## Proposed Base List

The calculations were broken in to stages. The number of samples for each variable was determined based on the frequency. The number of samples was used determine lab cost for all moving water samples. A similar set of calculations was completed for the reservoirs. The final set of calculations is the labor costs.

| **TOTAL COST** | |
|---|---|
| Moving Water Sampling | $64,075.50 |
| Reservoir Sampling | $73,800.00 |
| Moving Water Analysis | $191,922.00 |
| Reservoir Analysis | $149,889.00 |
| **TOTAL** | $479,686.50 |

| **Budgets** | |
|---|---|
| Ft. Collins | $275,000.00 |
| Greeley | $60,000.00 |
| Loveland | $30,000.00 |
| Northern | $36,500.00 |
| TOTAL | $401,500.00 |

**Proposed Base List**

**MOVING WATER SAMPLING FREQ. AND PARAMETERS**

| **ACU LABS** | $191,922.00 |
|---|---|

| | |
|---|---|
| 2M | biweekly |
| M | monthly |

**Inorganics**

| Constituent | Frequency S1 | S2 | S3 | Number of Samples S1 | S2 | S3 | Samples/yr | ACU LABS cost/sample | ACU cost/yr |
|---|---|---|---|---|---|---|---|---|---|
| Carbon, Total Organic Carbon | 2M | 2M | M | 6 | 6 | 6 | 522 | $30.00 | $15,660.00 |
| chloride | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Nitrogen, Ammonia | 2M | 2M | M | 6 | 6 | 6 | 522 | $10.00 | $5,220.00 |
| Nitrogen, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $42.00 | $21,924.00 |
| Nitrogen, Total oxidized (nitrate + nitrite) | 2M | 2M | M | 6 | 6 | 6 | 522 | $17.00 | $8,874.00 |
| Phosphorus, ortho-phosphate | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Phosphorus, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| Solids, Total | 2M | 2M | M | 6 | 6 | 6 | 522 | $12.00 | $6,264.00 |
| Sulfate | 2M | 2M | M | 6 | 6 | 6 | 522 | $15.00 | $7,830.00 |
| | | | | | | | | **TOTAL** | **$86,130.00** |

**Metals**

| Constituent | Frequency S1 | S2 | S3 | Number of Samples S1 | S2 | S3 | Samples/yr | ACU LABS cost/sample | ACU cost/yr |
|---|---|---|---|---|---|---|---|---|---|
| Arsenic | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Copper | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Iron | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Lead | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Manganese | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Nickel | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Silver | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Sodium | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| Zinc | M | M | M | 3 | 3 | 6 | 348 | $11.00 | $3,828.00 |
| | | | | | | | | **TOTAL** | **$34,452.00** |

**Microbiological**

| Constituent | Frequency S1 | S2 | S3 | Number of Samples S1 | S2 | S3 | Samples/yr | ACU LABS cost/sample | ACU cost/yr |
|---|---|---|---|---|---|---|---|---|---|
| E. Coli | M | M | M | 3 | 3 | 6 | 348 | $50.00 | $17,400.00 |
| fecal coliform | M | M | M | 3 | 3 | 6 | 348 | $35.00 | $12,180.00 |
| total coliform | M | M | M | 3 | 3 | 6 | 348 | $35.00 | $12,180.00 |
| | | | | | | | | **TOTAL** | **$41,760.00** |

**organic contaminants**

| Constituent | Frequency S1 | S2 | S3 | Number of Samples S1 | S2 | S3 | Samples/yr | ACU LABS cost/sample | ACU cost/yr |
|---|---|---|---|---|---|---|---|---|---|
| BTEX | M | M | M | 3 | 3 | 6 | 348 | $85.00 | $29,580.00 |
| | | | | | | | | **TOTAL** | **$29,580.00** |

**Proposed Base List**

**Reservoirs**

| | **Frequency** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **inorganics** | **# samples** | **metals** | **# samples** | **microbio** | **# samples** | **organic** | **# samples** | **bio** | **# samples** |
| Carter 1 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Carter 2 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 1 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 2 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Horsetooth 3 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| L. Loveland | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | Sw, 12(2m), 3m | 25 |
| L. Estes | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 | 1-2(2m), 3m | 18 |
| **Total Samples** | | 183 | | 108 | | 108 | | 108 | | 183 |

| | **Frequency** | | | | | |
|---|---|---|---|---|---|---|
| | **chloro** | **# samples** | **phyto** | **# samples** | **zoo, sp** | **# samples** |
| Carter 1 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Carter 2 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 1 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 2 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | 12(2m), 3m | 18 |
| Horsetooth 3 | 12(2m), 3m | 18 | | 18 | 12(2m), 3m | 18 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| L. Loveland | Sw, 12(2m), 3m | 25 | 12(2m), 3m | 18 | | |
| L. Estes | 12(2m), 3m | 18 | 1-3m | 12 | | |
| Total Samples | | 183 | | 156 | | 90 |

**Proposed Base List**

**Reservoir Cost Est.**

| | |
|---|---|
| **ACU LABS** | **$149,889.00** |

**Inorganics**

| Constituent | Samples/yr | ACU LABS cost/sample | ACU LABS cost/yr |
|---|---|---|---|
| Carbon, Total Organic Carbon | 366 | $30.00 | $10,980.00 |
| chloride | 366 | $12.00 | $4,392.00 |
| Nitrogen, Ammonia | 366 | $10.00 | $3,660.00 |
| Nitrogen, Total | 366 | $42.00 | $15,372.00 |
| Nitrogen, Total oxidized (nitrate + nitrite) | 366 | $17.00 | $6,222.00 |
| Phosphorus, ortho-phosphate | 366 | $12.00 | $4,392.00 |
| Phosphorus, Total | 366 | $15.00 | $5,490.00 |
| Solids, Total | 366 | $12.00 | $4,392.00 |
| Sulfate | 366 | $15.00 | $5,490.00 |
| | | | **$60,390.00** |

**Metals**

| Constituent | Samples/yr | ACU LABS cost/sample | cost/yr |
|---|---|---|---|
| Arsenic | 216 | $11.00 | $2,376.00 |
| Copper | 216 | $11.00 | $2,376.00 |
| Iron | 216 | $11.00 | $2,376.00 |
| Lead | 216 | $11.00 | $2,376.00 |
| Manganese | 216 | $11.00 | $2,376.00 |
| Nickel | 216 | $11.00 | $2,376.00 |
| Silver | 216 | $11.00 | $2,376.00 |
| Sodium | 216 | $11.00 | $2,376.00 |
| Zinc | 216 | $11.00 | $2,376.00 |
| | | | **$21,384.00** |

**Microbiological**

| Constituent | Samples/yr | ACU LABS cost/sample | ACU LABS cost/yr |
|---|---|---|---|
| E. Coli | 216 | $50.00 | $10,800.00 |
| fecal coliform | 216 | $35.00 | $7,560.00 |
| total coliform | 216 | $35.00 | $7,560.00 |
| | | | **$25,920.00** |

**organic contaminants**

| Constituent | Samples/yr | ACU LABS cost/sample | ACU LABS cost/yr |
|---|---|---|---|
| BTEX | 216 | $85.00 | $18,360.00 |
| | | | **$18,360.00** |

**Biological**

| Constituent | samples/yr | cost/sample | cost/yr |
|---|---|---|---|
| chloro-a | 183 | $45.00 | $8,235.00 |
| phytoplankton | 156 | $100.00 | $15,600.00 |
| | | | **$23,835.00** |

NOTE - phytoplankton prices based on CHDiagnostics

**Proposed Base List**

**Labor**

| | |
|---|---|
| **TOTAL** | $137,875.50 |

## Moving Water Sampling

| | | |
|---|---|---|
| **vehicle prices** | $/mile | $0.35 |
| | miles/site | 15 |
| | # site visits/yr | 522 |
| | cost | $2,740.50 |

| | | |
|---|---|---|
| **Labor Costs** | # people | 3 |
| | hours/site | 0.75 |
| | $/hour | $50.00 |
| | # site visits/yr | 522 |
| | cost | $58,725.00 |

| | | |
|---|---|---|
| **materials/supplies** | $/site visit | $5.00 |
| | # site visits/yr | 522 |
| | cost | $2,610.00 |

| | |
|---|---|
| **TOTAL** | $64,075.50 |

## Reservoir Sampling

| | | |
|---|---|---|
| **Zooplankton** | $/person hr | $50.00 |
| | hours/sample | 5 |
| | # samples | 90 |
| (labor) | TOTAL | $22,500.00 |
| | $/samplet | $50.00 |
| | # samples | 90 |
| (supplies/equip/travel) | TOTAL | $4,500.00 |
| | **TOTAL** | $27,000.00 |

| | | |
|---|---|---|
| **Phytoplankton** | $/person hr | $50.00 |
| | hours/lake visit | 5 |
| | # lake visit | 156 |
| (labor) | TOTAL | $39,000.00 |
| | $/lake visit | $50.00 |
| | # lake visits | 156 |
| (supplies/equip/travel) | TOTAL | $7,800.00 |
| | **TOTAL** | $46,800.00 |

| | |
|---|---|
| **TOTAL** | $73,800.00 |

## Current Reduced Program (Based on the July 20 and 21, 1999 meetings)

The calculations were broken in to stages. The number of samples for each variable was determined based on the frequency. The number of samples was used determine lab cost for all moving water samples. A similar set of calculations was completed for the reservoirs. The final set of calculations is the labor costs.

| **TOTAL COST** | |
|---|---|
| Moving Water Sampling | $44,190.00 |
| Reservoir Sampling | $49,500.00 |
| Moving Water Analysis | $173,304.00 |
| Reservoir Analysis | $132,117.00 |
| **TOTAL** | $399,111.00 |

| **Budgets** | |
|---|---|
| Ft. Collins | $275,000.00 |
| Greeley | $60,000.00 |
| Loveland | $30,000.00 |
| Northern | $36,500.00 |
| TOTAL | $401,500.00 |

**Current Reduced Program (Based on the July 20 and 21, 1999 meetings)**

**MOVING WATER SAMPLING FREQ. AND PARAMETERS**

| **ACU LABS** | $173,304.00 |
|---|---|

| | |
|---|---|
| 2M | biweekly |
| M | monthly |

**Inorganics**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| Alkalinity | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 15.00 | $5,400.00 |
| chloride | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 12.00 | $4,320.00 |
| hardness | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 22.00 | $7,920.00 |
| Nitrogen, Ammonia | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 10.00 | $3,600.00 |
| Nitrogen, Total Kjeldahl | 2M (summer) | 2M (summer) | | 5 | 4 | 6 | 360 | 25.00 | $9,000.00 |
| Nitrogen, Total oxidized (nitrate + nitrite) | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 17.00 | $6,120.00 |
| Phosphorus, ortho-phosphate | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 12.00 | $4,320.00 |
| Phosphorus, Total | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 15.00 | $5,400.00 |
| Phosphorus, total soluable | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 20.00 | $7,200.00 |
| Solids, Total | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 12.00 | $4,320.00 |
| Sulfate | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 15.00 | $5,400.00 |
| Turbidity | 2M (summer) | 2M (summer) | M | 5 | 4 | 6 | 360 | 12.00 | $4,320.00 |
| | | | | | | | | **TOTAL** | **$67,320.00** |

**Metals**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| Arsenic | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Copper | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Iron | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Lead | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Manganese | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Mercury | M | M | M | 3 | 3 | 6 | 288 | 20.00 | $5,760.00 |
| Nickel | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Silver | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| Sodium | M | M | M | 3 | 3 | 6 | 288 | 11.00 | $3,168.00 |
| | | | | | | | | **TOTAL** | **$31,104.00** |

**Microbiological**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| E. Coli | M | M | M | 3 | 3 | 6 | 288 | 50.00 | $14,400.00 |
| fecal coliform | M | M | M | 3 | 3 | 6 | 288 | 35.00 | $10,080.00 |
| total coliform | M | M | M | 3 | 3 | 6 | 288 | 35.00 | $10,080.00 |
| | | | | | | | | **TOTAL** | **$34,560.00** |

**organic contaminants**

| | Frequency | | | Number of Samples | | | | ACU LABS | ACU |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **S1** | **S2** | **S3** | **S1** | **S2** | **S3** | **Samples/yr** | **cost/sample** | **cost/yr** |
| BTEX (Benzene, toulene, ethylbenzene, xyl | M | M | M | 3 | 3 | 6 | 288 | 85.00 | $24,480.00 |
| Carbon, Total Organic Carbon | 2M | 2M | M | 3 | 3 | 6 | 288 | 30.00 | $8,640.00 |
| UV254 | 2M | 2M | M | 3 | 3 | 6 | 288 | 25.00 | $7,200.00 |
| | | | | | | | | **TOTAL** | **$40,320.00** |

**Current Reduced Program (Based on the July 20 and 21, 1999 meetings)**
**Reservoirs**

| | Frequency | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | inorganics | # samples | metals | # samples | microbio | # samples | organic | # samples |
| Carter 1 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| Carter 2 | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| Horsetooth | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| L. Loveland | Sw, 12(2m), 3m | 25 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| L. Estes | 12(2m), 3m | 18 | 1-3m | 12 | 1-3m | 12 | 1-3m | 12 |
| Horseshoe | 12(2m), 3m | 19 | 1-3m | 13 | 1-3m | 13 | 1-3m | 12 |
| **Total Samples** | | 147 | | 84 | | 84 | | 84 |

| | Frequency | | | | | |
|---|---|---|---|---|---|---|
| | chloro | # samples | phyto and algal sp. | # samples | zoo, sp | # samples |
| Carter 1 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | | 6 |
| Carter 2 | 12(2m), 3m | 18 | 12(2m), 3m | 18 | | 0 |
| Horsetooth | 12(2m), 3m | 18 | 12(2m), 3m | 18 | | 6 |
| Boyd L. 1 | Sw, 12(2m), 3m | 25 | Sw, 12(2m), 3m | 25 | | 0 |
| Boyd L. 2 | Sw, 12(2m), 3m | 25 | Sw, 12(2m), 3m | 25 | | 0 |
| L. Loveland | Sw, 12(2m), 3m | 25 | Sw, 12(2m), 3m | 25 | | 0 |
| L. Estes | 12(2m), 3m | 18 | 12(2m), 3m | 18 | | 6 |
| Horseshoe | 12(2m), 3m | 19 | 12(2m), 3m | 19 | | 6 |
| Total Samples | | 147 | | 147 | | 18 |

**Current Reduced Program (Based on the July 20 and 21, 1999 meetings)**

**Reservoir Cost Est.**

| ACU LABS | $132,117.00 |
|---|---|

| Inorganics | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| Alkalinity | 294 | $15.00 | $4,410.00 |
| chloride | 294 | $12.00 | $3,528.00 |
| hardness | 294 | $22.00 | $6,468.00 |
| Nitrogen, Ammonia | 294 | $10.00 | $2,940.00 |
| Nitrogen, Total Kjeldahl | 294 | $42.00 | |
| Nitrogen, Total oxidized (nitrate + nitr | 294 | $17.00 | $4,998.00 |
| Phosphorus, ortho-phosphate | 294 | $12.00 | $3,528.00 |
| Phosphorus, Total | 294 | $15.00 | $4,410.00 |
| Phosphorus, total soluable | 294 | $20.00 | $5,880.00 |
| Solids, Total | 294 | $12.00 | $3,528.00 |
| Sulfate | 294 | $15.00 | $4,410.00 |
| Turbidity | 294 | $12.00 | $3,528.00 |
| | | | **$47,628.00** |

| Metals | | | |
|---|---|---|---|
| **Constituent** | **Samples/yr** | **ACU LABS cost/sample** | **ACU LABS cost/yr** |
| Arsenic | 168 | $11.00 | $1,848.00 |
| Copper | 168 | $11.00 | $1,848.00 |
| Iron | 168 | $11.00 | $1,848.00 |
| Lead | 168 | $11.00 | $1,848.00 |
| Manganese | 168 | $11.00 | $1,848.00 |
| Mercury | 168 | $20.00 | $3,360.00 |
| Nickel | 168 | $11.00 | $1,848.00 |
| Silver | 168 | $11.00 | $1,848.00 |
| Sodium | 168 | $11.00 | $1,848.00 |
| | | | **$18,144.00** |

| **Microbiological** | | | |
|---|---|---|---|
| | | **ACU LABS** | **ACU LABS** |
| **Constituent** | **Samples/yr** | **cost/sample** | **cost/yr** |
| E. Coli | 168 | $50.00 | 8,400.00 |
| fecal coliform | 168 | $35.00 | 5,880.00 |
| total coliform | 168 | $35.00 | 5,880.00 |
| | | | **$20,160.00** |

| **organic contaminants** | | | |
|---|---|---|---|
| | | **ACU LABS** | **ACU LABS** |
| **Constituent** | **Samples/yr** | **cost/sample** | **cost/yr** |
| Benzene | 168 | | 0.00 |
| Ethylbenzene | 168 | | 0.00 |
| Toluene | 168 | | 0.00 |
| Xylenes | 168 | $85.00 | 14,280.00 |
| Carbon, Total Organic Carbon | 168 | $30.00 | $5,040.00 |
| UV254 | 168 | $25.00 | $4,200.00 |
| | | | **$23,520.00** |

| **Biological** | | | |
|---|---|---|---|
| **Constituent** | **samples/yr** | **cost/sample** | **cost/yr** |
| algal species | 147 | $100.00 | $14,700.00 |
| chloro-a | 147 | $45.00 | $6,615.00 |
| phytoplankton | 147 | $100.00 | $14,700.00 |
| zooplankton | 18 | $75.00 | $1,350.00 |
| | | | **$22,665.00** |

NOTE - phytoplankton prices based on CHDiagnostics

## Current Reduced Program (Based on the July 20 and 21, 1999 meetings)

### Labor

| | |
|---|---|
| TOTAL | $93,690.00 |

### Moving Water Sampling

| | | |
|---|---|---|
| **vehicle prices** | $/mile | $0.35 |
| | miles/site | 15 |
| | # site visits/yr | 360 |
| | cost | $1,890.00 |

| | | |
|---|---|---|
| **Labor Costs** | # people | 3 |
| | hours/site | 0.75 |
| | $/hour | $50.00 |
| | # site visits/yr | 360 |
| | cost | $40,500.00 |

| | | |
|---|---|---|
| **materials/supplies** | $/site visit | $5.00 |
| | # site visits/yr | 360 |
| | cost | $1,800.00 |

**TOTAL** $44,190.00

### Reservoir Sampling

| | | |
|---|---|---|
| **Zooplankton** | $/person hr | $50.00 |
| | hours/sample | 5 |
| | # samples | 18 |
| (labor) | TOTAL | $4,500.00 |
| | $/samplet | $50.00 |
| | # samples | 18 |
| (supplies/equip/travel) | TOTAL | $900.00 |
| | **TOTAL** | $5,400.00 |

| | | |
|---|---|---|
| **Phytoplankton** | $/person hr | $50.00 |
| | hours/lake vis | 5 |
| | # lake visit | 147 |
| (labor) | TOTAL | $36,750.00 |
| | $/lake visit | $50.00 |
| | # lake visits | 147 |
| (supplies/equip/travel) | TOTAL | $7,350.00 |
| | **TOTAL** | $44,100.00 |

**TOTAL** $49,500.00

## APPENDIX F

## Big Thompson Watershed Forum Contact List – July 20, 1999
## Summary of Groups Represented

### Federal Government Agencies
National Parks Service
US Bureau of Reclamation
US Department of Agriculture
US Environmental Protection Agency
US Fish and Wildlife Service
US Forest Service
US Geological Survey
US Department of Education

### State Government Agencies
Colorado Department of Transportation
Colorado Department of Education
Colorado Department of Wildlife
Colorado State Parks
Colorado Water Conservation Board
Thompson Valley School District
Water Quality Control Commission

### County Government
Larimer County
Clear Creek County
Weld County

### Municipal Governments/Utilities
City of Boulder
City of Broomfield
City of Ft. Collins
City of Ft. Lupton
City of Ft. Morgan
City of Greeley
City of Johnstown
City of Longmont
City of Loveland
City of Westminster
Denver Water
Eden Valley Institute
Longs Peak Water District
Pinewood Springs Water District
Soldier Canyon Treatment Plant
Spring Canyon Water & Sanitation District
Town of Lyons

### Municipal Governments/Utilities (cont'd)
Town of Ault
Town of Eaton
Town of Estes Park
Upper Thompson Sanitation District
Town of Berthoud
Carter Lake Water Treatment Plant
Superior Metropolitan District No. 2
Town of Firestone
Left Hand Water District
City of Louisville
North Weld County Water District
Platt river Power Authority
Town of Erie
City of Evans
City of Dacono
Town of Fredrick
Superior Metropolitan District No. 1
Town of Windsor
Little Thompson Water District
Central Weld County Water District

### Academia
Colorado State University
Mesa State College
The Montana Watercourse
University of Colorado
Thorne Ecological Institute

### Private Firms
Camp, Dresser, and McKee
CHDiagnostic
Colorado Mosquito Control, Inc
EIS Consulting
Fischer, Brown, and Gunn, P.C.
Ford Research Group
Frank Farrar Graphics
Frontier Environmental Technologies
Getz Communications, Inc.
Global Visionaries
Hach Company

**Private Firms (cont'd)**
Hope Photography
Hydrosphere
Infovision, Inc.
Jim Morris T-shirt
Loveland Ready Mix
McCulley, Frick, and Gilman, Inc.
Mithril consultants, In
Rocky Mountain Adventures
Sandra and Company
Sylvan Dale Guest Ranch
The Jensen Group, Inc
Thorne Ecological Institute
Waste-Not Recycling
Waterdrum Communications Group
Wright Water Engineers, Inc.
HDR Engineering, Inc
Sue Lorenz Accounting, Inc
ERO Resources Corp.
Brown and Caldwell
RMA, Inc.
Leader's Edge Consulting, Inc.
Interface, Inc.
Quadrant Media
Western Exposure
A&W Restaurant

**Citizen, Special Interest, & Regional Groups**
Boulder Creek Watershed Initiative
Citizen, Special Interest, and Regional
  Clover Creek Council
Colorado Rivers Alliance
Colorado Rural Water Association
Earth Watch
Friends of the Poudre
Horseshoe Lake Yacht Club
League of Women's Voters
Newell-Warnock Water Association
Northern Colorado Water Association
Outdoor Writers Association of America
River Watch Network
Silver Lake Homeowners Association
The River Network
Thompson Water Users Association

**Citizen, Special Interest, & Regional Groups (cont'd)**
Three Lakes Watershed Association
Trees, Water, & People
Upper Colorado River Lakes Protection Association
Watershed Committee of the Ozarks

**Regional Organizations**
Colorado River Water Conservation District
North Front Range Water Quality Planning Association
Northern Colorado Water Conservancy District
Northwestern Colorado Council of Governments

**The press**
Kevin Cook (Nature Writer)
Longmont Times-Call
Loveland Reporter-Herald
nickMolle Productions/EPTV

**Concerned Citizens (Names not Listed)**
Over 60 Individuals