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Development of a Low-cost, Self-calibrating Stream Gaging Station

Final Report to the
Utah Division of Water Resources

By

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June 2001

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Executive summary

The present report presents a review of the state-of-the-art technologies for the development of a low-cost, self-calibrating stream gaging station. The research was conducted by the Utah Water Research Laboratory with funding provided by the Utah Division of Water Resources through Project RP110080, March 1998.

The report presents a review of the current practices in stream gaging and how technologies such as remote data telemetry through the use of satellite, cellular phone communications, and radio telemetry can be used for the real-time transmission of data. The study also includes the use of Global Positioning Systems (GPS) for the locating and mapping of stations. A review of laser technologies, including infrared and green lasers, is included for possible application on stage height, water depth, and cross-section measurements. A review is also presented of ultrasonic, sonar, radar, and microwave technologies for the measurement of water velocity.

The report concludes with a discussion of possible applications of the technologies reviewed to the design of a low-cost, self-calibrating stream gaging station.

A list of references and of technology manufacturers is also provided.

It must be indicated that, although it was originally intended to produce a prototype of the gauging station, the cost and size of the instrumentation prevented us from implementing such prototype. As the technology improves and the size and cost of the instruments becomes more reasonable, it will be possible to build such prototype. At this stage, however, the technology is not yet at the point of producing the low-cost, self-calibrating gaging station originally intended.

1.0 INTRODUCTION

Water is precipitated to the earth from the atmosphere in various forms, such as rain, snow, and dew. Part of this water returns almost immediately to the atmosphere by evaporation; part is evaporated from water surfaces; part flows over the ground as surface water; and part enters the ground. This process is known as the hydrologic cycle; movement of water from the atmosphere to the earth and back. This cycle is essential to the Earth's ecosystem. This report considers the surface water that flows across the country or streamflow.

Streamflow is the combined result of all climatological and geographical factors that operate in a drainage basin. It is the only phase of the hydrological cycle in which the water is confined in a well-defined channel, which permit accurate measurements to be made of water quantities. Good water management therefore is founded on reliable streamflow information. Today there are many hydrological models that are being used and developed. The only variable that will increase the accuracy of these models, is the accuracy of the input or data. Therefore, the stream data collected is of utmost importance.

There are many different uses of streamflow data within the broad context of water management. This information could be used in the management of water supply, pollution control, irrigation, energy generation, industrial water, understanding the biological effects of contamination, evaluating surface and ground water interaction, allocating water and many other applications. Another consideration is when this streamflow occurs in excess, thus creating a potential hazard to people and property. This flood information is then used in the development of bridges, culverts, dams, and flood control structures. Thus, the data that is collected for a particular stream becomes extremely instrumental in the lives of potentially millions of people. However, there is a cost to obtaining the most accurate data possible.

1.1 Project Background

The Utah Division of Water Resources provided funding to the Utah Water Research Laboratory at Utah State University to perform research into the present functionality of their gauging stations, and to develop a modern self-calibrating gauging station.

Stream gauging stations, in the state of Utah, are currently using technology that was developed and implemented before the 1940's. In order to obtain the data, an operator has to visit the station and manually read the recorder's data. According to Dr. Upmanu Lall, Associate Director of the Utah Water Research Laboratory and Professor of Civil and Environmental Engineering at Utah State University, the cost associated with maintaining each stream flow gauging station averages between $15,000 to $35,000 per year, and is consistently increasing. The data is currently minimal, therefore, not only is the data accuracy low, but it is gathered at an immense cost. New technology has the potential to greatly enhance stream-gauging design. A self-calibrating stream gauging station would greatly reduce the cost and improve data accuracy.

1.2 Scope of Work

The USGS and the Utah GS have substantial funds and time invested in maintaining gauging stations and hydrology data. The hydrology data needed for each river include: (1) Flow, (2) Sedimentation load, (3) Velocity, (4) Accurate cross section geometry, and (5) Water surface elevation. Current technologies require travel time and man-hours to collect data, ensure data integrity, and develop rating curves to predict flow.

The purpose of this project was to: (1) Evaluate existing systems, (2) Investigate new technologies like GPS, lasers, sonar, and remote sensing devices, (3) Analyze each technology based on the objectives and, (4) Design a theoretical self-calibrating stream flow gauging station.

Technologies used for the self-calibrating stream flow gauging station need to be accurate, dependable, and provide measurements on a schedule similar or superior to present methods.

The stream gauging station located at the mouth of Logan Canyon, in Logan Utah, was chosen for the investigation, design, and analysis of a new stream gauging station. The technology investigated will address the information currently reported and possible designs/operations to obtain this information in a more accurate way.

The overall objectives in completing the technology review, design and implementation are listed below:

1. Design a self calibrating station with a capital cost of less than $20,000
2. Design a self calibrating station with an operating costs of less than $5,000/year
3. Research method that provide accurate measurements to insure quality data
4. Provide data at an increased rate
5. Analyze methods that can reduce the dependence of rating curves
6. Design a station that is non-intrusive

This report describes the findings of The Utah Water Research Laboratory at Utah State University and the possibilities of implementing new technology to improve on current operations.

2.0 Current Operations

There are various organizations across the globe that desire streamflow data and construct gauging stations for their benefit. The Utah Geological Survey (USGS) and Division of Water Resources maintain stations across the nation and in the State of Utah, respectively. The USGS established the first stream-gauging station in 1889, since this time, the number of stations has grown to 7,292 as of 1994 and are funded by more that 600 State, Federal, and local agencies (USGS, Internet).

One of the first steps in developing a stream-gauging station is the selection of the location of a site. Although all of the following factors rarely exist in a given location, the following criteria constitute a list of an ideal site:

a) The general course of the stream is straight for about 100 meters upstream and downstream from the gauge site;

b) The total flow is confined to one channel at all stages and no flow bypasses the site as subsurface flow;

c) The stream-bed is not subject to scour and fill and is free of weeds;

d) Banks are permanent, high enough to contain floods, and are free of brush;

e) Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle for low flow and a channel constriction for high flow;

f) A pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow, and to avoid high velocities at the streamward end of stage recorder intakes during period of high flow;

g) The gauge site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gauge site;

h) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site. It is not necessary for low and high flows to be measured at the same stream cross-section;

i) The site is readily accessible for ease in installation and operation of the gauging station.

After the site is selected a stilling well or gauging station is erected. This is a selected site on a stream equipped and operated to furnish basic data from which systematic records off discharge may be derived.

2.1 Equipment

The float-tape gauge is used mainly as an inside stilling well reference gauge for a water level recorder and consists of a float attached to a counterweight by means of a stainless steel tape. The tape is normally graduated and passes over a pulley. A water level recorder actuated by a float and counterweight normally produces the record of water stage. The movement of the float is used to operate a recording mechanism such as a punching head that can produce a record on punched tape. Essentially the recorder consists of a time element and a water height element, which operate together and produce on the tape a record of the rise and fall of the water surface with respect to time. This type of measuring device, though, has many sources of error. Some of these include:

a) submergence of counterweight and float line

b) backlash in gearing

c) friction in mechanism

d) inadequate diameter of float or badly matched float and counterweight

e) overriding or displacement of wires on float or counterweight pulleys

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f) overriding or displacement of wires on pen carriage movement

g) kinks in float suspension cables

h) human error in reading the tape recorder

The water level in the stilling well is to be maintained at the mean water level of the stream. This is accomplished with the use of intake pipes. The intake pipe allows water to flow in and out of the stilling well, maintaining the same water elevation as the river. Often, two or more intake pipes are installed to insure proper operation. This will often times help in the case one of the pipes becoming clogged. Also, the ends of the pipes are often fitted with static tubes. These static tubes are capped sections of pipes with small holes through which the water flows. These static pipes help in eliminating draw-down at intakes to gauge wells. This draw-down is caused by the head loss in the intake system. Thus during periods of rapid change of stream height, water levels in the stilling well may lag behind those in the stream.

Once the water stage or height of the stream is obtained it must be converted to a flow measurement. The conversion of a record of stage into a record of discharge is predicted on what is called the stage-discharge relation. Unfortunately for the accuracy and cost of stream gauging, that relationship varies in stability from essential permanence to constant change. It is by this relationship, however, unstable though it may often be that a continuous or intermittent record of stage is converted into a record of discharge, which, of course, is the ultimate purpose of a gauging station. These instabilities are often caused by the physical characteristics of the site, thus, reinforcing the importance of site selection as stated above.

This stage discharge or rating curve is established by means of measurements of discharge and coincident observations of water surface elevation made under normal stream conditions. These measurements are made intrusively with various equipment, including hand-held current meters. Each measurement is then plotted, usually with

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stage height on the vertical axis and discharge on the horizontal. Multiple measurements of flow must be made, well distributed through the range of height, to define the position of the rating curve through that range. Also, enough flow measurements must be made to extend the curve to new ranges of stage as needed. This insures the applicability of the curve at all times. This curve must be established for each gauging station, for no two sites will have the same rating curve. This curve is then used to convert the measured stream height to a discharge. This discharge measurement, with the cross sectional area of the channel, can then be equated to the stream velocity.

A typical gauging station is shown in Figure 2.1.
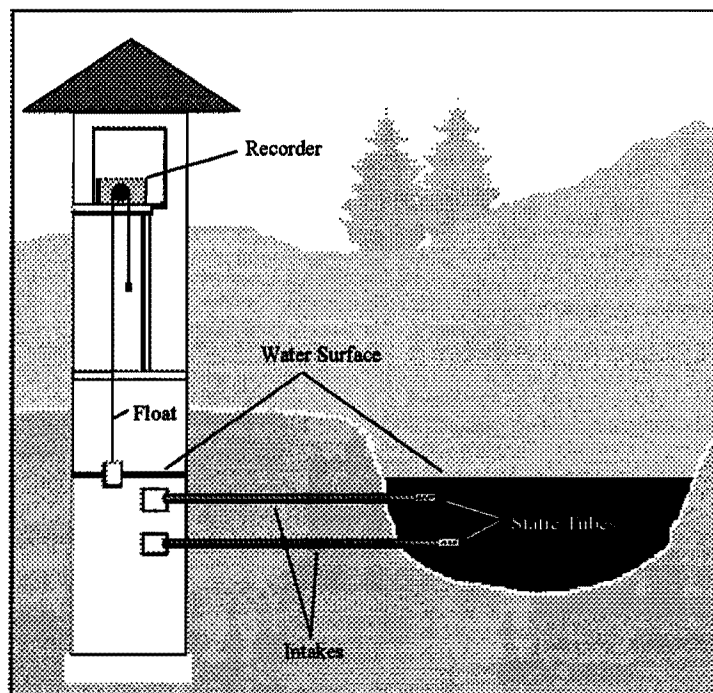

Figure 2.1. Schematic of a typical gauging station

However, in order to obtain this data, personnel must be sent to the site. The data from the tape recorder is then read. This data in ideal situations, represent the water surface

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elevation over a given period of time, and requires a person with significant experience to read the information that is being produced. However, if there was a malfunction during this extended period of time, no one was alerted. Therefore, it is possible that the data obtained from the tape gauge may be of no use.

This method for calibrating flow data has been used in stream flow measurements for decades. Stream flow data is used to monitor rivers, analyze watersheds, and build hydrologic models. As the demands for water resources and maintenance costs increase the need for an accurate, self-calibrating gauging station has become essential. Some of the new technology available today may be the solution for a modern self-calibrating gauging station.

3.0 Technology Research

This report will discuss different methods for measuring velocity, cross section, and water surface elevation. Some of the technologies researched included: (1) Remote data telemetry, (2) Global Positioning Systems (GPS), (3) Lasers, (4) Ultrasonic, (5) Sonar, and(6) Microwaves, and (7) Radar. Each technology was evaluated based on the objectives stated above and its ability to produce accurate data at an increased rate. One of the primary concerns of this research is to find technologies that can perform these functions non-intrusively.

3.1 Remote Data Telemetry

During current operations the stream gauging station is visited every 6 months and the tape from the stilling well float is read. This information is then written down and taken back to the office for use in management and in modeling rivers, streams, and watersheds. One of the problems with this is the unavailability of real-time data. Also,

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if the gauge is not working properly the data for that duration is of no use and will not be fixed until someone visits the station.

A solution to this problem is the use of technology in transferring this data directly to the people that need it by the use of remote telemetry. This will greatly enhance the effectiveness of the data and will reduce cost. Data can be gathered at a much greater volume, daily/hourly/monthly, without the cost of sending someone to the gauge to take velocity measurements and read the data. Another advantage of this is the ability to monitor the measurement, device to detect any malfunctions. With the increase of data being gathered, outlying or odd data points will alert operators of possible malfunctions to the equipment. This will enable them to get this fixed quickly with very little data being lost.

To date there are basically three types of remote telemetry available with varying costs. They include transferring data via satellite, radio, and cellular phone. The following discusses the uses of these systems.

3.1.1 Satellite

There are three satellite telemetry platforms that will be discussed in this report. These include INMARSAT-C, GOESM, and ARGOS.

The INMARSAT-C is a bi-directional satellite system that is in geosynchronous orbit and is available for data transfer 24 hours a day for users located between ±70 degrees latitude. This satellite system was created by the International Maritime Organization in 1979 (INternational MARitime SATellite). The INMARSAT system currently consists of nine satellites and about 40 Land Earth Stations in 31 countries. Campbell Scientific of Logan Utah currently has a data logger that is compatible with this system. The antenna system of this data logger has a GPS (Global Positioning System) receiver

built into it for timing and positioning information. Position data is then sent from the satellite system to a Land Earth Station (LES). The user then obtains the data from this station. With this bi-directional system, data can be sent at any time and the amount of data that can be transferred in unlimited. This system also allows communication to the gauging station, thus allowing any parameters/programs to be changed and confirms data transfer.

The next two satellite systems are one-directional and provide no communication from the base station to the gauging station. They also do not provide the gauging station with a confirmation of data transmittal. Therefore, this data must often times be sent in succession to ensure transmittal.

Using the Geostationary Operational Environmental Satellite (GOES) is another satellite alternative. This one-way broadcast medium that transmits environmental data during an assigned time slot typically 1 to 2 minutes in length every 3 to 4 hours. Ordinarily within a 1-minute window a user can send about 118 data points. If a user is sponsored by a Federal, State or Local Government Agency access to this system is usually granted. The data that is sent from the satellite system is then retrieved by calling the computer bulletin board system in Wallops Island, VA.

The third satellite possibility is the ARGOS system. This systems satellite broadcast can transfer data from a platform located anywhere in the world. Once again, the number of passes this system makes over a specific location is a function of the latitude. Basically, there are approximately 28 passes a day at the poles and about 8 passes a day at the equator. The user can then send approximately 48 datapoints in the 10 minutes the satellite is overhead, depending on the data transfer mechanism used. However, at the North or South Pole it is possible to send up to 1344 data points a day. Data is then retrieved when a computer bulletin board system is called. A typical satellite set-up is shown in the figure below.
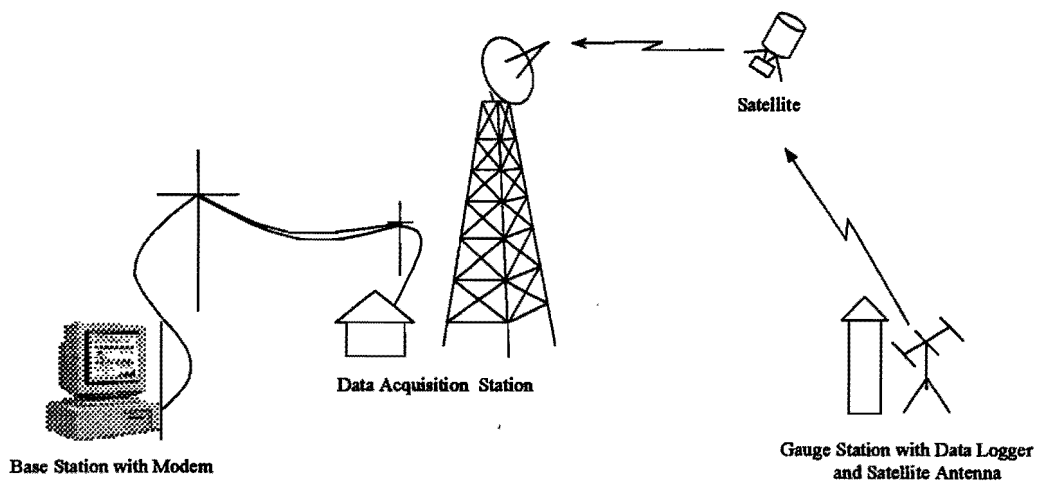
10

Figure 3.1. Typical Satellite System

All of these satellite systems require application approval with each service provider and the user must also obtain permission to transmit on frequencies designated by the satellite system.

3.1.2 Cellular Phone

Cellular phones may be used to transfer the data obtained from a site to a base station personal computer and database. The cellular phone offers bi-directional communication with the gauge station and allows program capabilities from the office, thus reducing the time in the field. Also real time data can be obtained by calling the gauging station when data is needed. Another advantage of the cellular is the ability to program the system to call the appropriate location if there is any significant change in conditions. This provides advance warning of malfunctions and/or emergencies. This system can also be equipped with a voice synthesizer, allowing

Access from any conventional phone. Typical data transfer is shown in Figure 3.2.
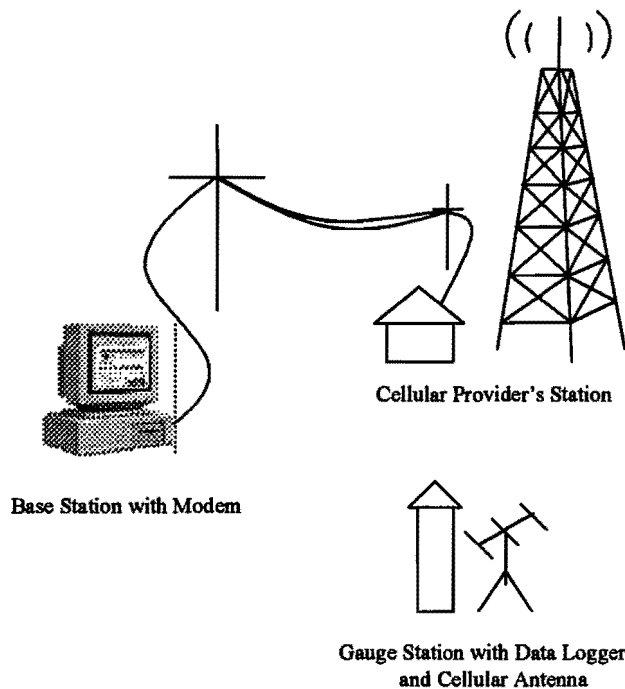
11

Figure 3.2 A Typical Data Transfer with Cellular Phone

If this alternative is chosen, a subscription(s) to a cellular network with coverage at the datalogger site will be needed, as well as a modem that is capable of receiving the data via the telephone.

3.1.3 Radio Telemetry

The use of radio telemetry networks is the third alternative that is available for the needed data transfer. Once again the datalogger is at the gauging station site and is equipped with an antenna for the transfer of the data through radio waves. The station must be in the line of site of the base station and/or a repeater with a maximum distance of approximately 25 miles. Another field station can also be used for a repeater.

At the field station there will need to be a datalogger that is recording the reading taken by the measuring devices, radio, modem, antenna, power supply, and any enclosures and mounting devices needed for protection.

A base station is normally comprised of a computer to collect and utilize the data, necessary software, a radio, and an antenna to receive the data. A base station can also be equipped with a telephone modem, so that other parties can obtain the data without the need of a radio. Another advantage of this system is the ability to use a mobile base station, such as a laptop computer. A repeater, if needed, acts as a relay between two communicating devices that are either separated by too much distance or if there is an obstacle which is inhibiting communication. As stated earlier, a field station can act as a repeater. A repeater station requires a radio, modem, antenna, power supply, and any enclosures and mounting devices needed.

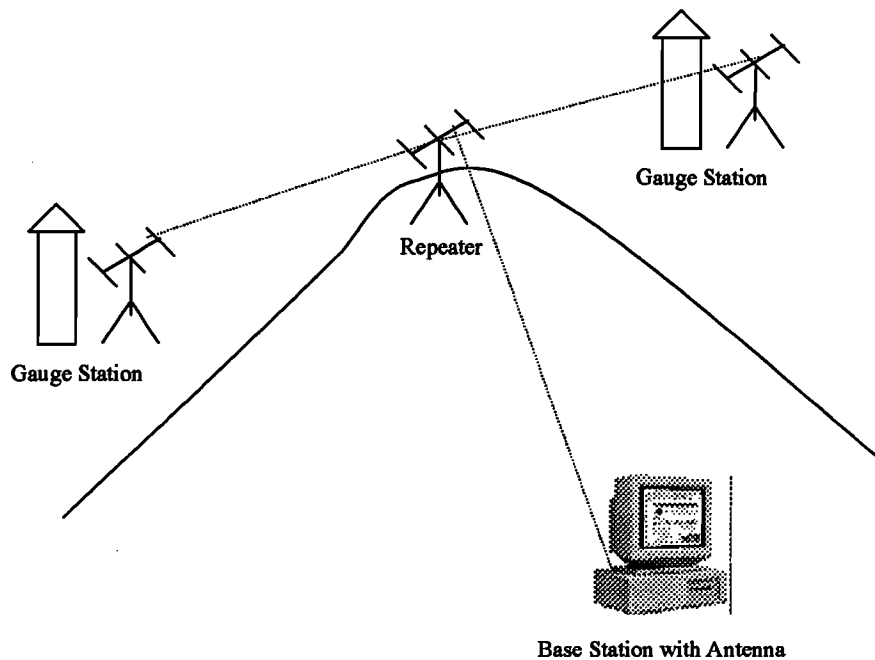A typical radio telemetry system is shown in the following figure.

Gauge Station

Repeater

Gauge Station

Base Station with Antenna

Figure 3.3 Typical Radio Telemetry System

However, in order to use this technology a radio frequency must be obtained. An application must be sent to the appropriate coordinator depending on the type of user the applicant is. These include governmental, non-governmental, and state university. The coordinator will process the application and then send it to the FCC, where a frequency may be granted.

All of these systems vary in cost and also depend on the existing equipment available. A basic cost estimate is provided below, based on the price list obtained from Campbell Scientific. This list does not, however, contain the cost for the data logger. A data logger is needed with all types of data telemetry and costs approximately $1100. Therefore, $1100 would need to be added to each estimate, unless a data logger is currently available.

Table 3.1 Cost Estimation for Remote Data Telemetry

Telemetry Method	Link	Max # of Data Points per day	Approx. Cost per Data Point	Availability	Cost
Satellite					
INMARSAT -C	2-way	Unlimited	$0.02	<10 min	$5,710
GOES	1-way	2,832	No-Charge	<5 min	$2,695
ARGOS	1-way	Function of Latitude	$10-$20/day	<6 hours	$1,929
Cellular Phone	2-way	Unlimited	Provider Dependent	<1 min	$1,045
Radio	2-way	Unlimited	No-Charge	<1 min	$1,430

As can be seen from the above table, the least expensive alternative is the use of cellular phone to obtain the data remotely. This would have a cost of $2245. This cost includes the cost of the datalogger.

3.2 Global Positioning Systems (GPS)

Reducing the amount of man hours it takes to manage a gauging station and increasing the accuracy of the stream data received are some of the benefits of using GPS. A

Global Positioning System would also be very useful in locating or mapping the gauging station geographically. However the GPS would require an annual visit to the gauging station site and would be and intrusive method for measuring the river bed.

There are many types of Global Positioning Systems and many different companies. The main difference between the types of GPS is accuracy, and companies compete over ease of use and price. Mapping grade GPS is considered 1 to 3 meters accurate. Real Time Kinematics (RTK) or survey grade GPS is 1 cm accurate in the X and Y direction and 1 to 3 cm accurate in the Z. Survey accurate GPS would be the best tool for streams or rivers, but they can cost $50,000 dollars. However the equipment is portable and could be used for many or all of the gauging stations in a given region, and is more accurate than traditional methods.

Measuring an accurate cross section is a very important variable for calculating stream flow, and developing rating curves. Using a stick or a measuring rod is a traditional method for measuring the cross section of a river. A level string or a rope is stretched across the river and the measuring rod is used to determine the distance from the bottom of the river to the string. The measurement can be taken several inches or several feet apart depending on the level of accuracy required. This method requires a person to be in the water to do each measurement and record the data at each point, which exposes the technician to substantial risk.

A river's cross section can be measured with a GPS quickly and accurately. Real Time Kinematics (RTK) is convenient, however the equipment would require a trained operator. The receiver is placed on a rod of a known length and carried into the river. The GPS records the X, Y, and Z at the bottom of the rod in one second and then it can be moved to the next location. The GPS results are, automated, accurate, and the process is probably faster than traditional methods.

There are many different ways to measure the cross section of a river. GPS and a measuring rod are two intrusive methods that have been discussed. GPS is accurate and faster, however, the cost of GPS and the additional training would need to be considered. One GPS system could be used for multiple gauging stations. A measuring rod requires more time in the water, and an increased chance for human error, however, it is cheaper and the accuracy is very good.

3.3 Laser

The application of lasers to stream gauging is in its infancy. Currently, using a reflective float and shooting the float with the laser to obtain the water depth is the technology currently being used. There are many types of lasers that will potentially work in this application include (1) Red Lasers, and (2) Green Lasers. By using different colored lasers, emitting different wavelengths of light one can penetrate the water hitting the bed of the stream channel and obtain the distance to the channel

bottom as well as bouncing the laser off the surface of the water to determine the water surface elevation. With these two measurements, the cross-sectional area of a channel, and water surface elevation could be obtained.

The Utah Water Research Laboratory at Utah State University assessed the application of lasers using both non-intrusive and intrusive methods. A non-intrusive method will require some site-specific parameters (turbid, well mixed) to accurately determine the water depth. Additionally, intrusive systems could be used to modify the current technology and current methods to determine the water depth.

The application of the laser we are pursuing is a non-intrusive way of measuring stage height, water depth, streambed cross-section, and upland bed cross-section. A presentation of a potential stream-gauging station using a laser would look like the picture in Figure 3.4. This shows a laser that will shoot a cross-section of the channel by rotating the laser to multiple angles. The laser could also be adjusted to shoot the stage height, and upland bed cross-sections. This application would require research and testing to determine its accuracy and effectiveness. Information provided in this section discusses laser types, specific applications and recommendations.

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Figure 3.4 Potential use of a laser for measuring stage height, streambed depth, and upland cross sections.

3.3.1 Infrared Laser

Infrared lasers are used for any applications in which distances need to be calculated fast. The technology uses a laser and an internal compass to determine vertical distances using angles. It also will calculate horizontal and vertical distances simultaneously. Technicians from The Utah Water Research Laboratory at Utah State University have used infrared laser in transportation applications to safely measure road distances, and heights. Infrared lasers are also used in GIS applications, along with GPS to give distances and bearings to targets being inventoried. Specifications for different lasers can be obtained from the manufacturers listed in Appendix B.

The current technology lends itself to be used as an intrusive measurement tool. The current method of having a stilling well and a float could remain in place while the only modification would be a reflective surface on the float. The floating device currently used is made into a reflector for the laser. The laser is then programmed to shoot at the reflector and the water height is recorded. This application is not being used and further investigation of this application needs to be done.

An infrared laser has some limitations when shooting at water. The depth at which the laser penetrates the water before the light is refracted can vary. The application of an infrared laser may be dependent on the turbidity of the water. Water that has high turbidity will reflect light at the surface and therefore will give a more accurate measurement. Water with little or no turbidity will not be as accurate.

The Utah Water Research Laboratory at Utah State University conducted an experiment to test the practicality of using an infrared laser on a still bucket. The data showed that a relationship may be developed between the amount of penetration and the depth of the water, however one problem was the water had to be at least 15 inches deep. Although, the infrared laser gathered inconclusive results in this situation, the overall application was enough to warrant further testing of the infrared laser in the laboratory, and the further involvement of companies that use lasers in other applications.

The location of the laser is an important factor in considering this application. The laser needs to be housed in an environment that will allow the laser to be serviced periodically, but also providing the necessary security for the laser. The intrusive application of the infrared laser may lend itself to be protected from vandalism and theft. For the non-intrusive laser application steps will have to be taken and the design of a secured area in which to shoot the laser will need to be assessed. The laser is waterproof, durable, and can take temperatures from $-20^{\circ}C$ to $120^{\circ}C$.

In conclusion here is a list of some to the potential problems and possible advantages.

The **potential problems** involved in a measuring stream data with an infrared laser are:

- The infrared laser penetrates the water and at shallow depths may not give a useful measurement.

- The laser will not penetrate through glass with consistent accuracy (this poses a problem for keeping the laser accurate over long periods of time at the gauging station.)

- Changes in turbidity of the water will affect the accuracy of the laser and any relationship previously developed will become a poor estimate because the depth of laser penetration will vary.

- Research and development are required to adjust the laser to eliminate errors

Advantages of this application for use over current technology are:

- It can be automated to take several shots when taking a measurement.

- Potentially it could determine overall channel characteristics (upland bed) if automated from a non-intrusive viewpoint.

- The data can be readily exported to satellite or radio telemetry equipment.

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- The laser is very durable and the effect of temperature is minimal.

- The laser is very small and could go unnoticed by potential vandals.

3.3.2 Green Laser

A green laser is designed to pass through a multiple mediums without a loss of accuracy. The green laser could be a useful tool in shooting cross-sectional bed characteristics and giving stream depth. Literature on this type of laser reveals a potential for use in the stream-gauging arena although much of the testing is in its infancy.

The green laser in conjunction with an infrared laser could provide the results we are looking for in this project. It would be possible to gather cross sectional data and stage height information accurately, quickly, and non-intrusively. The green laser could be used in a range of river systems and will not be affected as much as the infrared to changes in turbidity and other variables. The laser could be located in an undisturbed area away from the stream as shown in Figure 3.4, or it could be put above the stream on a structure.

3.4 Ultrasonic

While researching the discussed technologies it becomes apparent that each gauging scenario requires different application of design based on both the physical, and structural limitations of housing the instruments and the geological, dimensional and environmental state of the stream/river. It therefore seems reasonable to present the

technologies in a generic exhibition of the advantages and disadvantages of each.

Technologies reviewed in sections 3.4 through 3.6 include ultrasonic, sonar, and radar

and microwave technologies.

Sonar and ultra sonic approaches utilize sound waves where as radar and microwave

techniques involve radio and microwaves respectively. Understanding each of these

requires a rudimentary familiarization with wave properties. The wavelength of a wave

is the distance from one crest of the wave to the next (Figure 3.5a). The phase of a

wave, measured in degrees or radians, where 360 degrees or 2π radians equals one

wavelength, indicates the position of the wave relative to some fixed location. Figure

1b. and 1c. Individually show the relative position of a wave at time one (T_1) and time

two (T_2). The difference in phase or position between the two times is ¼ wavelength or

90 degrees. This change in position is called phase shift.

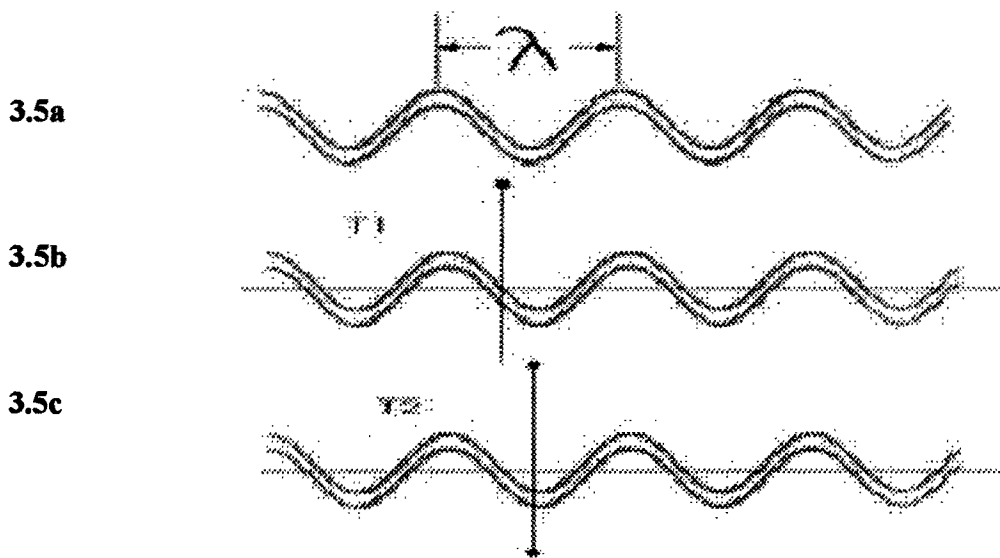**Figure 3.5 Wavelength and Phase Shifts**
Source: http://ww2010.atmos.uiuc.edu

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In all of these techniques a wave is transmitted into either the air or the water at a given

frequency and amplitude consistent with that medium's physical properties. This wave

Continues at a nearly constant speed until it comes into contact with a material foreign

to the medium it is travelling through. At this point, the wave or wave energy is

Scattered, slowed or shifted, some of which goes back in the direction of the

transmitter. This energy is received and the information such as travel time and wave
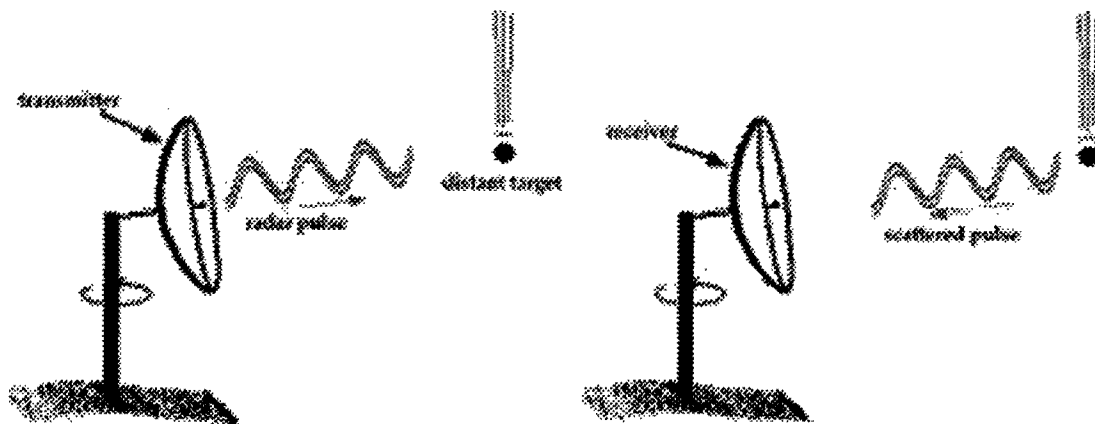
energy is used to calculate information such as distance and size of target. Figure 3.6

shows this relationship.

Figure 3.6 Sending and Receiving Signals
Source: http://ww2010.atmos.uiuc.edu/

This type of application simply identifies the presence and location of a target. To

identify the direction of movement or the radial velocity of the object, a second,

independent reading must be taken. Figure 3 illustrates this functionality.

At time T1 a distance D is recorded as the distance to the target. Immediately following

a second distance is recorded as D+A. This results in a phase shift between the return

signals. Knowing the values for the phase shift, the difference between T1 and T2 and

the wavelength, the velocity away from or toward the receiver can be calculated

(ww2010, 1997). Understand this is a one-dimensional velocity and can not account for

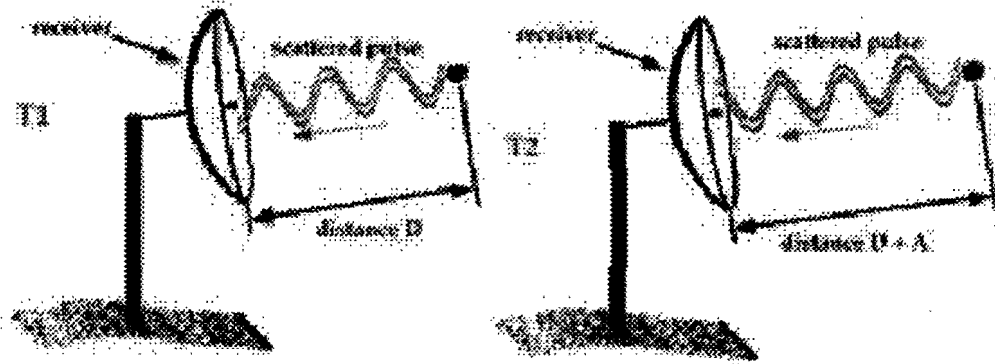velocity vectors in other directions.

Figure 3.7 Relative Velocity from Two Distances
Source: http://ww2010.atmos.uiuc.edu/

3.4.1 Ultrasonic Applications

Ultrasonic wave patterns have been applied in applications such as distance

measurements, flow-metering in closed and open systems, and non-destructive surface

and integrity testing.

Distance measuring utilizes an ultrasonic wave generator that emits a series of high

frequency sound waves transmitted in a cone shaped pattern by the transducer. The

sound waves reflect off the target (a reflective surface) and are received by a sensor.

The sensor is capable of measuring the time interval between transmission and

reception and converts this time into a distance based on the speed of sound through the
liquid, (gaseous) medium (Hooper, 1997). Equation 1 shows this relationship.

$$l = \frac{(t * C)}{2}$$ **Equation 3.1**

Where: t = time
           l = distance
           C = speed of sound through medium

Utilizing ultrasonic technology, distance measurements are independent of surface
velocity (because the speed of sound is >> surface velocity), and surface color and
material.

As stated historical methods that derive flowrate from measurements of water level
only, (through a relationship between stage and flowrate) are inadequate. Part of this
problem (approximately ± 5%) can be attributed to human error in reading the
instrument (Terrell Fletcher, 1998). Retrofitting existing stilling wells with an
ultrasonic distance sensor can be a low cost alternative for decreasing the human error
factor. Additionally, remote transmission of data can be achieved through the use of an
accompanying microprocessor control fitted with an RS 232 port. This technology can
also be applied in cases where a structure (bridge, pipe, et.) cross the river to provide a
non-intrusive means of detecting water level. The major advantage of this mounting

option is that it alleviates the need for a piezometric well and the subsequent problems associated with clogging and damage.

Lundahl Instruments Inc., a local manufacturer of ultrasonic sensors has been contacted, and has several sensor models suitable for these applications. The model DCU-7110 fits the criteria the best and is reviewed as an example here. Contact information and technical specifications are attached in Appendix B.

Table 3.2 Technical Specifications of Model DCU-7110

Operation Range	1' - 16' (.3- 4.9 m)	Accuracy	+- 0.2% of range with No temp. gradient
Outputs	0 - 5 V	Sensor Adjustments	Computer Interface RS232
Supply Voltage	10 - 30 V DC	Operating Temperature	-30 C to 60 C
Total Current Draw	70 mA @ 24 V	Temp. Compensation	internal
Housing	PVC	Sample Rate	12 Hz
Transducer Type	Ceramic, PVC faced	Beam Pattern	9 degrees off axis
Rating	NEMA 4X, IP65	Cable	8 conductor 22 AWG PVC jacket, 6' (1.83m)
Response Time	5 seconds from power up	Dimensions	2.35" dia. X 8"

Source: Lundahl Instruments Inc. Technical Manual.

As displayed in Table 3.2, this instrument has an operating range of one to sixteen feet and operates at a current draw of 70 mA @ 24 Volts. The company claims it is weather proof and resistant to corrosion. Accuracy is reported to be ± 0.2 % of distance with no

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temperature gradient. Cost per unit at time of transmittal is $600 (US). As stated this application offers a low cost, low maintenance means of upgrading existing stilling well gauging stations. It offers an accurate, remote, single measurement technique of estimating flow in a regular or known channel. It does not however alleviate the need of establishing a rating curve and still has the error associated with a single measurement for flow.

Ultrasonic technology can be and has been applied to a potentially intrusive, but more accurate application of obtaining multistage velocity as well as stage depth to define flow in a channel. This 'multi-path acoustic transit-time system' has been well documented and can be non-intrusive if the sound waves can be introduced externally. (Accusonic, 1998). In this case the acoustic flow meter is connected to multiple pairs of transducers at varying depths in a given cross section. Velocity is measured by comparing the differential velocity of sound traveling upstream and downstream to the flow. It is based on the assumption that a sound wave travelling in water will increase in velocity while travelling downstream, and decrease in velocity while travelling upstream (USBR, 1997). In other words the velocity of the sound pulse transmitted downstream will increase proportional to the stream velocity and inversely the sound pulse transmitted upstream will decrease proportional to the stream velocity. Figure 8 and Equations 3.2 and 3.3 show this relationship.
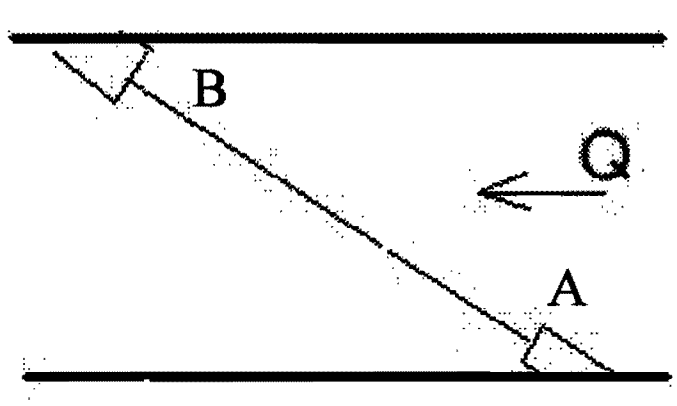
Figure 3.8 Diagram of Multi-path Acoustic Transit Time System

$$T_1 = \frac{L}{(C - V * \cos(\theta))}$$ **Equation 3.2**

$$T_2 = \frac{L}{(C + V \cos(\theta))}$$ **Equation 3.3**

Where:

T1 = Travel time of the acoustic pulse between transducer B and transducer A
T2 = Travel time of the acoustic pulse between transducer A and transducer B
C = Speed of sound in water
L = Distance Between Transducer A and Transducer B
V = velocity of water
θ = Angle between the acoustic path and the direction of water flow.
Source: Accusonic, 1997

Setting Equations 1 and 2 equal to one another and solving for V yields an equation

independent of the speed of sound in water (C) and therefore is independent of the fluid

properties such as temperature, viscosity and density. It is shown by Equation 4.

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$$V = \left(\frac{(T_1 - T_2)}{T_1 * T_2} \right) * \left(\frac{L}{(2 * \cos(\theta))} \right)$$ Equation 3.4

Where:

V= average fluid velocity at the level of the path,
T_1 = acoustic transit time in the upstream direction,
T_2 = acoustic transit time in the downstream direction,
L = acoustic path length between transducers,
θ = Acoustic path angle relative to the flow axis.
Source: Accusonic, 1997

As can be seen from equations 2, 3 and 4, the velocity of the water at the level of the

transducers can be measured independently from the speed of sound in water. This

indicates variations in the density of the water due to temperature will be compensated

for automatically. Obviously a series of several transducer- sensor pairs can give a

velocity profile at varying depths within the stream. Coupled with an accurate cross

section and height, these two measurements can provide very accurate estimations of

flow at the gage location. Although most applicable in conventional pipe and regular

(rectangular or trapezoidal)) open channels, this technology is currently being tested in

over 200 river systems (Accusonics, 1998). For further information, contact

Accusonics' representatives listed in Appendix B.

Equation 3.4 was developed assuming the angle θ is constant. This can be accomplished

easily in long man-made channels, and pipelines with smooth walls. It is very often not

the case however in natural systems or rough walled, curved or elbowed pipe systems.

These inconsistencies are best approached by incorporating a correction factor and /or by using multiple paths.

A similar method outlined in the American National Standards Institute/ American Society of Mechanical Engineers (ANSI/ASME) standard MFC-5M-1985 (USBR, 1997). This method utilizes frequency differences in the upstream and downstream signals to compute velocity.

Lundahl Instruments has expressed an interest in a partnership to develop an instrument that utilizes this frequency change concept. Basically, it is assumed that instead of pulsing the sound wave through the water, they can be bounced off the surface of the water parallel to the direction of flow at an angle θ from normal to the surface. Similar to the previous technique claimed by Accusonic, the upstream leg would be decelerated by the velocity of the water and the downstream leg would be accelerated. Using an equation similar to Equation 3.3 differences in the time would yield a surface velocity value. Advantages to this technique are the lack of excavation and true non-intrusive nature. Drawbacks would obviously be susceptibility to vandalism and theft, exposure to elements and questionable accuracy. This method of non-intrusive velocity measurement would eliminate traditional rating curves and could eliminate the need for routine trips to each sight. However this method needs to be tested for accuracy and quality.

3.5 Sonar

Cross sectional area, as discussed, is a necessary measurement when calculating flow. Historically the cross sectional topography has been measured in small streams with surveying equipment. This process requires an operator to wade the river carrying equipment and resulting in a risk to the operator and to equipment loss. Sonar technology was investigated as a replacement technique to the surveying method to decrease danger and increase time effectiveness and accuracy.

Depth measurement is a routine sonar application and works very well in boat navigable rivers and lakes. It also has the possibility of giving information about sediment loading and substrate condition. However, there are several major obstacles in using this technology. For one, it is currently not possible to get a sonar reading non-intrusively. That is to say, the energy required to emit a sound wave through two different fluid media (i.e. air and water) would melt the wave generator (Shoemaker, 1998). Second, range resolution is limiting in small (shallow) tributaries (Runsom, 1997). Last, excessive feedback interference is produced at shallow depths.

In conclusion, sonar devices are best applied in finding cross section geometry in large, boat-navigable waterways, but do not currently have a use in a remote, non-intrusive gauging station. Never the less, contact information for several sonar manufacturers is included in Appendix B and C.

3.6 Microwave and Radar

Radar is currently employed extensively in calculating velocity measurements of vehicles, sports, and weather systems. Velocity measurements of this type are generally calculated using the Doppler Shift concept. This concept, as discussed earlier, employs a microwave signal that is bounced off a target. The reflected signal has a new frequency, consisting of the original transmission frequency and a frequency related to the speed of the moving object. The instrument then filters out the original frequency to gain the frequency specific to the target. The preprogrammed instrument then relates this frequency to the velocity of the target.

Again as discussed earlier, the Doppler concept assumes the direction of travel is toward or away from the instrument. This is not possible in a non-intrusive application of this technology. Nor is it known what angle of refraction (above the water) would result in the microwave being bounced back to the instrument. It is known however, that with an increasing angle θ from parallel, the difference between the actual velocity and the displayed velocity increases. This is known as cosine error and its relationship is shown in Equation 3.5.

$$V_{actual} = \frac{V_{displayed}}{\cos\theta} \qquad \text{Equation 3.5}$$

This technology definitely warrants further investigation and should be compared in a lab environment against the ultrasonic methods discussed previously.

There are several manufacturers of radar/microwave instruments. The Utah Water Research Laboratory at Utah State University. contacted a company named Decatur Electronics whose contact information can be found in Appendix B. For a cost comparison, Decatur Electronics advertises radar guns from $595 to $2000 (US) at time of report. More importantly they sell speed sensors or microwave transceivers that provide a raw doppler signal and can be augmented with speed interface boards, data loggers, and visual output devices and applied to a wide range of uses.

4.0 Results and Discussion

Stream gauging stations are, for the most part; using technology that was developed in the 40's to provide us with the information needed to manage water-sheds, rivers, and basins. The purpose of this research was to design a self-calibrating stream flow gauging station that would:

1. Reduce costs per year

2. Make water surface elevation, cross sections, and velocity measurements non-intrusively

3. Provide accurate data at an increased rate for hydrologic models

4. Produce information from remote locations

5. Eliminate the need for the traditional rating curves

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Water surface elevation is one of the most important variables in calculating flow, so it is essential that each measurement is extremely accurate. There are two methods that are accurate and provide a non-intrusive solution, ultrasonics and lasers. Further testing would need to be done to look at the capabilities, accuracy, and durability of each piece of equipment.

In many rivers, as the river stages increase and decrease the riverbed doesn't stay the same. Minor changes in the cross-sectional area can greatly effect water surface elevation and through off the rating curves. The man-hours and equipment involved in visiting each sight is a major cost, and a safety issue. A system could be designed with a green laser that would measure the cross section of the river automatically. Lasers can be calibrated and fired remotely using a simple program, enabling a cross section to be measured daily, weekly, or monthly.

To eliminate the need for traditional rating curves to calculate flow, a gauging station would need to be able to measure the velocity. According to Lundahl Instruments it may be possible to design an ultrasonic sensor system that can measure the surface velocity of a river non-intrusively. Two ultrasonic sensors would need to be about 4 feet off the water and approximately 2 feet apart. Using a time relationship between the return of the upstream and the downstream flow the velocity could be calculated.

To design an operating self-calibrating stream flow gauging station these technologies need to be tested, and a preliminary structure developed to mount each piece of equipment. We recommend that a controlled flume be used to test the accuracy of each method and validate the use of each technology. After it has been tested in a controlled environment then it can be installed at the gauging station, at the mouth of Logan Canyon, and compared to the data being produced by the existing system.

The final concern is getting the data from a remote location using remote data sensoring. This would provide all the information need quickly and efficiently. The options for remote data collection are many, and each could be used. The data logger at each gauging station needs to be compatible with multiple sensors and provide storage for the data that is collected. The data logger sold by Design Analysis Associates seems to have all the connections needed to design a self-calibrating, non-intrusive, remote stream gauging system.

Power requirement for this theoretical system is hard to quantify, however with a combination of a large solar panel and a battery the system could run without a problem.

A self-calibrating stream flow gauging system would reduce cost, increase safety, increase data, and improve accuracy. The Utah Water Research Laboratory at Utah State University. Has determined that the technologies listed above are the key to a non-intrusive system.

Appendix A
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Appendix B

Manufacturers of different technologies

Ultrasonic

Lundahl Instruments, Inc
429 South Main
Logan UT 84321 USA
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Fax: (435) 753-7490
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Web Page: http://www.lundahl.com

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Sonar

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