Remote Environmental Sensor Array System

By

Geoffrey G. Hall

A thesis submitted to the Department of Civil Engineering in conformity with the requirements for the degree of Doctor of Philosophy

Queen’s University
Kingston, Ontario, Canada
December, 2007

Copyright © G. Hall 2007
Abstract

This thesis examines the creation of an environmental monitoring system for inhospitable environments. It has been named The **Remote Environmental Sensor Array System** or RESA System for short. This thesis covers the development of RESA from its inception, to the design and modeling of the hardware and software required to make it functional. Finally, the actual manufacture, and laboratory testing of the finished RESA product is discussed and documented.

The RESA System is designed as a cost-effective way to bring sensors and video systems to the underwater environment. It contains a water quality probe with sensors such as dissolved oxygen, pH, temperature, specific conductivity, oxidation-reduction potential and chlorophyll a. In addition, an omni-directional hydrophone is included to detect underwater acoustic signals. It has a colour, high-definition and a low-light, black and white camera system, which turn are coupled to a laser scaling system. Both high-intensity discharge and halogen lighting system are included to illuminate the video images. The video and laser scaling systems are manoeuvred using pan and tilt units controlled from an underwater computer box. Finally, a sediment profile imager is included to enable profile images of sediment layers to be acquired. A control and manipulation system to control the instruments and move the data across networks is integrated into the underwater system while a power distribution node provides the correct voltages to power the instruments.
Laboratory testing was completed to ensure that the different instruments associated with the RESA performed as designed. This included physical testing of the motorized instruments, calibration of the instruments, benchmark performance testing and system failure exercises.
Acknowledgements

This thesis was an exciting journey into a field with which I have been fascinated for as long as I can remember. The underwater environment is a special place and I am grateful to have had the opportunity to explore it in such a unique way.

Although there are many people that shaped my experience during this thesis, there are several to whom I wish to express my appreciation.

In particular, I would like to thank Dr. Kevin Hall for his insight, patience and support during this thesis. I have learned a great deal under his guidance and he has opened a world of opportunity for which I am grateful.

I would also like to thank my parents for their love and support. Throughout my life, they have always accepted the “big ideas” and I hope they have enjoyed the ride.

Finally, I would also like to thank Chris Heffernan and Curtis Ireland for their assistance in the RESA project. Countless late nights and design challenges describe this endeavour well.
Glossary of Terms

**ADCP** – Acoustic Doppler Current Profiler. A current measurement instrument which uses sound waves to detect minute changes in velocity and direction of particles suspended in water.

**Advanced Network** – An advanced network is a term applied to fibre optic networks, as opposed to conventional networks. They can be either single-mode fibre or multi-mode fibre based. Advanced networks can be connected to a conventional network to form a hybrid loop. Data transmission speeds of 1 to 100 gigabit per second are currently possible on an advanced network, as are transmission distances of many km without relays and signal boosting equipment.

**CA*Net 4** – Canada’s research fibre optic network which spans Canada from east to west with a satellite link to Iqaluit.

**Cathodic Protection** – The use of dissimilar metals in a beneficial way to prevent corrosion underwater.

**Conventional Network** – A conventional network is a network made of cabling of metallic construction (usually copper). Most office Ethernet connections are of the conventional variety. They can be connected to an advanced network to form a hybrid loop. Speeds up to 1 gigabit per second are possible, but 100 megabits per second is the norm. Distances of 300 m without relays are possible on conventional networks.

**Galvanic Corrosion** – Corrosion caused by metals with dissimilar electrical potential in close proximity to one another. One material acts as an anode and one a cathode.

**Gbps** - Gigabit per second data transmission rate.

**Gig pop** – A junction point for advanced networks.

**Hypolimnion** – The point of greatest temperature change for depth increase underwater. The Hypolimnion is also known as the thermocline.

**Mbps** - Megabits per second data transmission rate.

**Media Converter** – A device designed to take data traveling over one form of network and convert it for travel over another. For the RESA system, media converters are used at the junction between the conventional network required by the underwater computer and the single-mode fibre optic networks into which the RESA units feed.

**Multi-mode Fibre** – A fibre optic cable that is capable of carrying different distinct bands of traffic over the same strand of fibre. This is accomplished by multiplexing the signals into different carrier wavelengths. Multi-mode fibre is acceptable for shorter distance runs, such as that found within a building.
ORION – Ontario Research and Innovation Optical Network, which is Ontario’s fibre optic research network.

ORAN – Optical Regional Advanced Network. A regional fibre optic network which is often used by CA*Net 4 to provide end-point connectivity to institutions. An ORAN can be owned or operated by a semi-public organization such as ORION or a privately owned, for profit organization.

Piscivorous – Fish-eating organism.

RESA – Remote Environmental Sensor Array.

Sediment Profile Imager (SPI) – A unit which takes a profile image of the sediment along a 2 dimensional plane.

Single Mode Fibre – A fibre optic cable that is optimized to carry one wavelength of data across a single fibre strand and in one direction. Single mode fibre is capable of transmitting data over distances of several km without the need for a relay or booster station. As such, it is the most common form of fibre found along utility corridors and within ORANS.

Temperature Stratification – A layer of water with a different temperature and hence a different density than the surrounding water.

User Controlled Lightpath (UCLP) – A means for a user, usually through software, to establish an end-to-end dedicated fibre optic link. This is opposed to manual establishment of a dedicated end-to-end link by a trained networking technician.
# Table of Contents

Abstract...............................................................................................................................................ii  
Acknowledgements.........................................................................................................................iv  
Glossary of Terms...........................................................................................................................v  
Table of Contents..........................................................................................................................vii  
List of Tables.......................................................................................................................................viii  
List of Figures.........................................................................................................................................ix  
Chapter 1. Introduction....................................................................................................................1  
Chapter 2. Literature Review ..........................................................................................................4  
  2.1. Where and Why .....................................................................................................................5  
  2.2. Government Mandates and Regulations...........................................................................7  
  Labour Regulations .......................................................................................................................9  
  2.3. Underwater Environmental Sensor Networks.................................................................11  
  2.4. Hydroacoustic Surveys of Fish Populations.....................................................................21  
  2.5. Water Quality .....................................................................................................................23  
  2.6. Fish Telemetry and Tracking ............................................................................................26  
  2.7. Transmission and Communication Technologies...........................................................29  
  2.8. Underwater Observatories ...............................................................................................32  
  2.9. Conclusion .........................................................................................................................35  
Chapter 3. The RESA System........................................................................................................36  
  3.1. Overview ..........................................................................................................................36  
  3.2. Motivation .........................................................................................................................36  
  3.3. RESA System Design Criteria .........................................................................................37  
  3.4. Initial Challenges ..............................................................................................................38  
  3.5. Basis for the RESA System ..............................................................................................41  
  3.6. Coarse Scale Description .................................................................................................42  
  3.7. Material Overview ...........................................................................................................45  
  3.8. Base Platform ....................................................................................................................49  
  3.9. Underwater Computer Box ..............................................................................................52  
  3.10. Computer ........................................................................................................................52  
  3.11. Pan and Tilt ......................................................................................................................69  
  3.12. High-Definition Camera .................................................................................................78  
  3.13. Low Light Camera ..........................................................................................................84  
  3.14. Laser Scanning System ....................................................................................................87  
  3.15. High-Intensity Discharge Lighting .................................................................................92  
  3.16. Halogen Lighting ............................................................................................................96  
  3.17. Infrared Lighting .............................................................................................................99  
  3.18. Environmental Sensor Array ........................................................................................100  
  3.19. Hydrophone .....................................................................................................................107  
  3.20. Sediment Profile Imager .................................................................................................109  
  3.21. Power .............................................................................................................................115  
  3.22. Cathodic Protection ........................................................................................................120  
  3.23. Control System ...............................................................................................................122  
  3.24. Network Description ......................................................................................................137  
Chapter 4. Laboratory Performance and Testing ........................................................................143  
  4.1. Component Testing ...........................................................................................................143  
    4.1.1. System Testing ............................................................................................................173  
    4.1.2. Performance Testing .................................................................................................173
List of Tables

Table 1 - Conventional Ethernet options for connecting an environmental sensor network (Winkelman, 2007). ....................................................................................................................... 31
Table 2 - Galvanic potential of common metals in seawater (Dexter, 2007). ......................... 120
Table 3 - Target #1 length measurements and standard deviation values .......................... 155
Table 4 - Target #2 length measurements and standard deviation values ....................... 157
Table 5 - Distance to target board from the camera .............................................................. 159
Table 6 - Target #1 length measurement averages and standard deviation values taken with the low-light camera ................................................................. 161
Table 7 - Target #2 length measurement averages and standard deviation values taken with the low-light, black and white camera ...................................................... 163
Table 8 - Distance to target board average measurements and standard deviation values taken with the low-light camera ............................................................... 165
List of Figures

Figure 1 - The Remote Environmental Sensor Array System.......................................................... 41
Figure 3 - RESA System base underwater platform. All associated instruments and electronics are ultimately attached to this platform................................................................................. 49
Figure 4 - RESA System base platform peripheral basket assembly. This basket is attached to the underside of the main base platform. The computer and Hydrolab are attached to this basket... 50
Figure 5 - RESA System base platform foot and anchor unit.............................................................. 51
Figure 6 - SubConn underwater connector bank on the Pelican Case computer box .................. 53
Figure 7 - Exploded view of the computer box showing SubConn connector bank...................... 53
Figure 8 – A view of a portion of the cross-bracing and reinforcing used to ensure the integrity of the pelican case for underwater use. .......................................................................................... 54
Figure 9 - SubConn Connector example. 2 conductor series, HB2M (left) and IL2F (right) are shown................................................................................................................................. 56
Figure 10 - Support rack for RESA System. Only minimal equipment and electronics are shown for clarity. Jack stands are shown without associated locking nuts for clarity. ................................. 57
Figure 11 - 5 and 12 VDC power distribution bank ......................................................................... 58
Figure 12 - Ground bus for all the direct current circuits in the RESA System.............................. 58
Figure 13 - NOVA-8890 PC 104 board with associated ports and connections (JenLogix Ltd, 2007). ............................................................................................................................................. 62
Figure 14 - RESA computer system for option 1. It is based on a pc104 design. ......................... 62
Figure 15 - RESA computer system for option 2. This figure shows the bottom level of the support rack (upper level is removed for clarity). .............................................................. 64
Figure 16 - Pololu serial 8-servo control board (Pololu, 2007). .................................................... 65
Figure 17 – Optolinx Ethernet / single-mode fibre media converter ............................................ 66
Figure 18 - RESA computer system showing upper and lower levels of the support rack during testing. ................................................................................................................................. 67
Figure 19 – Photo rendition of the pan and tilt unit created for the RESA System....................... 69
Figure 20 - Pan and tilt unit used on the RESA System. ............................................................... 70
Figure 21 - Pan and tilt vertical cartridge. Horizontal cartridge illustrates the same design but is longer to accommodate the lilting platform. .................................................................................. 71
Figure 22 - Exploded RESA pan and tilt unit illustrating the additional required horizontal sealing end cap .............................................................................................................................................. 72
Figure 23 - Exploded view of the vertical pan unit. Horizontal tilt unit is of the same construction, but longer. ................................................................................................................................. 72
Figure 24 - RESA 1:1 ratio gear set properly meshed. .................................................................. 76
Figure 25 - Sony HDR-HC1 high-definition camera used on the RESA System.......................... 80
Figure 26 – High-definition camera and housing 3d photo rendition ........................................... 82
Figure 27 - Exploded view of the high-definition camera and housing including the camera assembly bracket. Lens mounting bolts excluded for clarity......................................................... 82
Figure 28 - Low light camera photo rendition ............................................................................. 84
Figure 29 - Low light camera housing exploded view. Camera module is removed for clarity... 85
Figure 30 - Low-light camera used on the RESA System ............................................................. 85
Figure 31 - Theory of operation of the laser scaling system. Lasers 1 and 2 are a known, parallel distance apart. Laser 3 is at a known angle to the other two lasers. Therefore relative size of the object being imaged as well as its distance to the video camera can be calculated............ 88
Figure 32 - Photo rendition of additional configuration for the laser scaling system ............... 88
Figure 33 - 3D model of laser module used on the RESA underwater scaling system ............. 90
Figure 34 - Exploded view of laser module used on the RESA underwater scaling system. Note simplicity of design.............................................................................................................. 91
Figure 35 - HID light module used in the RESA System ............................................................... 92
Figure 36 - 3D rendering of the HID lamp module used on the RESA System ......................... 94
Figure 37 - Exploded view of HID lamp module used on the RESA System ........................................... 95
Figure 38 - Housing of the halogen lighting system for the RESA System ........................................... 98
Figure 39 - Exploded view of the halogen lighting system used on the RESA System. Lens retaining bolts removed for clarity ........................................................................................................... 97
Figure 40 - RESA System halogen lighting system .............................................................................. 98
Figure 41 - Hydrolab DS 5X environmental sensor package used in the RESA System ................. 100
Figure 42 - Hydrolab sensors. The view of the temperature sensor is blocked by the conductivity and DO sensors. Scale not included due to the angle of the photograph ........................................... 101
Figure 43 - Aquarian Audio hydrophone on plastic mount ................................................................. 107
Figure 44 - Typical image taken with a camera-based sediment profile imager ............................... 110
Figure 45 - Camera-based sediment profile imager .......................................................................... 111
Figure 46 - Photo rendition of the RESA System SPI ........................................................................... 112
Figure 47 - Coarse scale networking for the example scenario of RESA Systems in Halifax Harbour ............................................................................................................................... 125
Figure 48 - Screen shot of log in service for the RESA Systems ........................................................... 126
Figure 49 - Directory of available RESA Systems ............................................................................. 127
Figure 50 - RESA System session lock-out feature ........................................................................... 128
Figure 51 - RESA01 dashboard website .............................................................................................. 129
Figure 52 - Example high-definition video stream screen shot taken during laboratory testing 131
Figure 53 - Example of the low-light black and white video stream taken during laboratory testing. The test was conducted in a well lit room which caused the image to appear “washed out” ........................................................................................................................................... 132
Figure 54 - CANARIE CA*Net 4 Research Network (CANARIE, 2007) ............................................. 138
Figure 55 - The Ontario Research and Innovation Optical Network (ORION, 2006) ....................... 140
Figure 56 - Sediment profile image of uniform sediment ................................................................. 146
Figure 57 - Sediment profile image taken in a small tributary of a typical bog environment. Note the frog which sat undisturbed during the process of inserting and scanning the sediment ...... 148
Figure 58 - Close-up of frog sitting on the surface of the channel which was imaged ........................ 149
Figure 59 – Two sediment layer types in a shallow area of the channel ........................................... 150
Figure 60 – Sediment can in a deeper portion of the shallow channel (Depth 0.5m) ....................... 150
Figure 61 – Solid line edge detection filter applied to Figure 59 ....................................................... 151
Figure 62 – Edge contour tracing filter applied to Figure 59. Note tracing of leaf ............................... 152
Figure 63 – Example acoustic signature taken in the laboratory using the Spectrum Laboratory software analysis package ................................................................................................................. 153
Figure 64 - Laser testing target scale for the high-definition camera. Test was conducted underwater in a 5m x 300 m test tank ............................................................................................................. 155
Figure 65 – Target #1 length as measured with the laser scaling system. The actual value (show as a green line) was 14.9 cm in length ............................................................................................. 156
Figure 66 - Target length means and standard deviation error bars for target #1 with the high-definition camera. The actual value of 14.9 cm is shown as a green line ........................................................................... 156
Figure 67 - Target #2 length measurements for the high-definition video camera. The actual value of 15.1 cm in length is shown as a green line ................................................................................... 158
Figure 68 - Target #2 mean length measurement and standard deviation error bars for the high-definition video camera. The actual value of 15.1 cm is shown as a green line ........................................................................... 158
Figure 69 - Distance to the target board measurements from the high-definition camera .............. 159
Figure 70 - Distance to the target board measurement averages and standard deviation error bars for the high-definition camera ........................................................................................................... 160
Figure 71 - Laser scaling system testing target scale for the low-light camera. Testing was conducted in the same test tank as the high-definition video camera ......................................................... 161
Figure 72 - Target #1 length measurements for the low-light camera. The actual value of 14.9 cm is shown as a green line ................................................................................................................. 162
Figure 73 - Target #2 length means and standard deviation error bars for the low-light camera.
The actual value of 14.9 cm is shown as a green line................................................................. 163
Figure 74 - Target #2 length measurements for the low-light camera. The green line illustrates
the actual length of 15.1 cm........................................................................................................ 164
Figure 75 - Target #2 length means and standard deviations for the low-light camera. The actual
length of 15.1 cm is displayed as a green line. ........................................................................... 164
Figure 76 - Distance to target board measurements taken with the low-light camera............... 166
Figure 77 - Distance to target board averages and standard deviation error bars taken with the
low-light camera. ......................................................................................................................... 166
Figure 78 - Hydrolab temperature data..................................................................................... 167
Figure 79 - Hydrolab dissolved oxygen data. .......................................................................... 168
Figure 80 - Hydrolab specific conductivity data.......................................................................... 169
Figure 81 - Hydrolab pH data. .................................................................................................... 170
Figure 82 - Hydrolab REDOX data. .......................................................................................... 171
Figure 83 - Hydrolab chlorophyll a data.................................................................................... 172
Figure 84 - Black and white video streaming. One computer streaming is shown on the left, two
computer streaming is shown on the right. .................................................................................. 174
Figure 85 - HD Video Streaming. One computer streaming is shown on the left, two computer
streaming is shown on the right.................................................................................................. 175
Figure 86 - Video streaming data for both the high-definition video and the black and white
video. Streaming to one computer is shown on the left, streaming to two computers is shown on
the right........................................................................................................................................ 176
Figure 87 - Video dropping rate for the ultra low-light black and white camera during an intense
streaming event. Note that the stream bitrate displayed is for the receiving computer and does not
represent the total bitrate for that particular data transmission................................................. 177
Figure 88 - Video frame drop rate for the high-definition video camera during an intensive
streaming event. As in Figure 70, the stream bitrate displayed is for the receiving computer and
does not represent the total bitrate for that particular data transmission................................. 177
Figure 89 - Critical system temperature monitoring software screenshot taken during an intensive
data streaming session. Note that the “Temp1” parameter is a sensor position that was not used in
the RESA System and as such feeds a constant 80ºC false reading. ....................................... 178
Figure 90 - Critical system temperature monitoring software screen shot showing consistent
temperature profiles for all monitored sensors........................................................................... 180
Chapter 1. Introduction

The study of natural processes in dangerous or inhospitable environments is a frontier through which science is increasingly being called upon to cross, in order to understand the complex interactions between human health and ecosystem sustainability. The need exists to allow geographically distant research groups to study these environments through the remote access of scientific instrumentation from the safety and convenience of their respective institutions. In particular, many of these instruments are increasingly becoming highly data-intensive, and in a multi-instrument format, often requiring bandwidths not available with conventional networks. The control of those sensors is also as important as the data flow. The control system should be intelligent and able to accept a wide variety of generic type control modules with the least amount of user configuration. Simple terrestrial devices, which do not require large bandwidth data transmissions or remote access, can be accommodated by existing wireless and wired systems. The use of sensor systems in remote, inhospitable locations, and which require large bandwidths, however, present many challenges.

This thesis will develop a complete underwater instrument platform to sense a variety of important environmental variables, in order to provide a research platform from which to conduct studies which require data-intensive instruments. Studies of this nature include fisheries and habitat studies which use the fine-scale imaging capabilities of a high-definition camera. In addition, a web-based control system will be developed to allow precise control and streaming of data from the underwater video and environmental
sensor array. The end product has been named the Remote Environmental Sensor Array or RESA System.

The device developed in this thesis will not only allow researchers to conduct long-term underwater studies in environments not conducive to human interaction, but has many applications beyond underwater study; from earthquake monitoring to ice level observations. The use of high-definition cameras will allow researchers to collect information not possible with standard-resolution systems. Most importantly, the use of fibre-optic networks (a necessity with the HD cameras) will showcase this technology and its function to its full capacity.

The scope of this thesis is as follows: To develop the RESA System and test it within the confines of a laboratory setting. This will set the stage for future work which will see the unit deployed in the field and tested over an extended period of time and in conditions which hopefully prove the durability of the system. As such, this thesis will document the initial testing required to bring the RESA System to the point at which it can be deployed in the field. The lifecycle expectations for this system are that the main support structure be capable of remaining on the bottom indefinitely, while the removable main instruments and associated components be capable of remaining in place for a period of five years between major maintenance procedures (Hydrolab excluded as it must be calibrated yearly).
This thesis is divided into several parts. First, a literature review is presented which discusses the current trends in environmental monitoring and underwater environmental sensor networks. Second, a general overview will guide the reader through the RESA system on a coarse scale and will investigate how the RESA System functions in its deployed form. Third, the fine details concerning the design, construction and testing of the components which make up the RESA System will be examined. Next, the laboratory testing phase of the thesis will be described and discussed. Finally an exploration of the future possibilities of continued research with the RESA System will be examined.
Chapter 2. Literature Review

In researching this field of study, it became apparent that small-scale underwater environmental “observatories” are extremely rare. It is disappointing that those that exist, do not fill the literature with their accomplishments or their design criteria. In addition, the RESA System contains a wide range of technologies, each with their own wealth of literature. In an attempt to prevent being overwhelmed by the breadth of research surrounding each technology, this review will focus on the trends pertinent to the RESA System. To start, this literature review will explore the background need for the RESA System in order to set the stage for the technologies and instruments which were ultimately incorporated into the System.

Environmental monitoring is quickly becoming the norm for governments and industry professionals to quickly and easily identify problem areas or potential problem areas at an early stage. The question then becomes; is it better to have people collecting data manually, rather than having completely autonomous or semi-autonomous monitoring systems? The literature is filled with studies which have identified themselves and others as being plagued by the labour intensive processes currently available to scientists (Hastie et al, 2004; Porter et al, 2005). The answer, in most cases, is the utilization of an autonomous or semi-autonomous system which can reduce the manual labour requirements for monitoring. This is particularly true in an economic and social environment which demands quick answers, low cost and robust and defensible results (Minns, 2001).
2.1. Where and Why

In many cases, the placement requirements for monitoring systems are not in those environments which are comfortable or accommodating to humans. In addition, many of the environments which have been recently recognized as significant or sensitive to environmental change are not in areas which are easily accessible, i.e. the Artic (Wrona et al., 2006). As such, a monitoring system which is effective under these conditions must be built to operate in the specific environment in which it will be placed, and must function without compromise in durability or design for extended periods of time (i.e. low maintenance requirements).

The use of automated systems allows collection of data over extended periods of time and at sampling frequencies that would typically not occur using conventional techniques. Field seasons are relatively short, and labour funding only provides for discrete sampling periods in most cases. The use of remotely controlled sensor platforms can only enhance the scientific data being collected as sample sizes, both temporally and spatially, can be increased by orders of magnitude over conventional sampling techniques. Porter et al. (2005), conducted an interesting survey of 52 randomly sampled papers in the journal Ecology. They concluded that in those studies which used sensor networks (wireless in their case) the sampling frequency and geographic range over which the data was collected were consistently much greater than those studies using conventional techniques. They also noted that sensors were very useful in unobtrusive environmental monitoring of sensitive areas.
There has been a great deal of interest in using sensors for ecological study, although much of it centers on small wireless, terrestrial sensor networks (Suri et al, 2006). More and more, however, sensing of the aquatic and marine environments is becoming important.
2.2. Government Mandates and Regulations

In order to set the stage for how the RESA Systems can be integrated into a monitoring strategy, a look at monitoring in Canada is in order. The following is a brief discussion of environmental monitoring as it currently exists in Canada, as a function of government agencies.

Federal Mandates

The Department of Fisheries and Oceans Canada, or DFO, is the federal arm of responsibility with regards to fisheries and aquatic / marine habitat protection in Canada. From this arm, other agencies branch with similar or partial responsibilities. DFO’s mandate reads as follows:

“On behalf of the Government of Canada, DFO is responsible for developing and implementing policies and programs in support of Canada’s scientific, ecological, social and economic interests in oceans and fresh waters.

DFO is a national and international leader in marine safety and in the management of oceans and freshwater resources. Departmental activities and presence on Canadian waters help to ensure the safe movement of people and goods. As a sustainable development department, DFO will integrate environment, economic and social perspectives to ensure Canada’s oceans and freshwater resources benefit this generation and those to come.

The Department’s guiding legislation includes the Oceans Act, which charges the Minister with leading oceans management and providing coast guard and hydrographic services on behalf of the Government of Canada, and the Fisheries Act, which confers responsibility to the Minister for the management of fisheries, habitat and aquaculture. The Department is also one of the three responsible authorities under the Species at Risk Act.” (Fisheries and Oceans Canada, 2007).
In addition, other Federal Agencies such as Environment Canada, have a mandate to monitor and study the environment. Environment Canada’s mandate reads as follows:

“Environment Canada’s mandate is to preserve and enhance the quality of the natural environment; conserve Canada's renewable resources; conserve and protect Canada's water resources; forecast weather and environmental change; enforce rules relating to boundary waters; and coordinate environmental policies and programs for the federal government.” (Environment Canada, 2007).

### Provincial Mandates

Throughout Canada, the provinces take on a protective and monitoring role of the environment. For simplicity of discussion, this thesis will deal with Ontario. In Ontario, the Ministry of Natural Resources or MNR is responsible for many aspects of the natural environment and for resource protection. The Ontario Ministry of Natural Resources mandate is:

“The ministry is committed to protecting and managing the province's natural resources, or its "natural capital", and making the interest from that capital available for individuals, communities and economies that depend on it. In doing so, the Ministry contributes to the environmental, social and economic well-being of the people of Ontario, meeting not only today's needs, but also ensuring these resources are available for future generations.” (Ontario Ministry of Natural Resources, 2007).

The Ontario Ministry of the Environment or MOE is responsible for environmental monitoring of issues such as water quality. The Ontario Ministry of Environment mandate reads as follows:

“Ontario’s Ministry of the Environment (MOE) has been protecting Ontario’s environment for over 30 years. Using stringent regulations, targeted enforcement and a variety of innovative programs and initiatives, the ministry continues to address environmental issues that have local, regional and/or global effects.

The Ministry of the Environment is responsible for protecting clean and safe air, land and water to ensure healthy communities, ecological protection and sustainable development for present and future generations of Ontarians.” (Ontario Ministry of the Environment, 2007).

A step down from the Federal and Provincial government agencies, but still a large
player in the compliance, monitoring and permitting system in Ontario and Canada are
the Conservation Authorities. The Conservation Authorities are mandated by the
Governments, both Federal and Provincial, to run permitting and application procedures,
as well as to survey and enforce prescribed monitoring in Ontario and Canada.
The overall Conservation Authority mandate reads as follows:

“Conservation Authorities, created in 1946 by an Act of the Provincial Legislature, are
mandated to ensure the conservation, restoration and responsible management of
Ontario's water, land and natural habitats through programs that balance human,
environmental and economic needs.” (Conservation Ontario, 2007)

As can be seen, much of the responsibility for environmental protection and
sustainability
and hence the need for corresponding monitoring strategies, falls to a few government
agencies. Unfortunately, due to fiscal cutbacks, these agencies are stretched thin and
desperately require systems and techniques which reduce the manual labour requirements
of monitoring.

Labour Regulations

An additional reason for the creation of the RESA System is due to the current labour
requirements for those engaging in monitoring activities either underwater or in hostile
environments. In Canada, the regulations governing the rules and responsibilities as
applied to potentially high-risk activities are two-part, those mandated by the Federal
Government and those mandated by Provincial Governments. In order to illustrate the
regulations and hence the need for a technology such as the RESA System, the example
of diving for scientific observation and habitat monitoring will be used.
In Canada, any member of the Federal Civil Service automatically becomes the jurisdiction of the Federal Government and is not covered by applicable labour regulations of the particular province in which the employee works. For diving operations, the particular Federal Government Ministry is responsible for developing and maintaining standards of practice which protect the worker engaging in the activity. As such, maintaining employees to this level of training and practice is relatively easy once the employee has been established and trained within the agency. The learning curve or delay in producing such competent employees can be long, with employee turnover a critical concern for maintaining such capabilities.

For other such workers, who are not Federal employees, the regulations affecting them are much different. It must be noted that Provincial employees and other non-government employees, such as industry professionals and those in academia, are often treated the same. In Ontario, for example, all occupational diving, meaning any diving where financial compensation is given, is classified and regulated by the Ontario Ministry of Labour. This government agency mandates minimum competency requirements for diving professionals, which often leaves many organizations, companies and universities without the ability to perform diving operations due to compliance issues (CSA, 2002, CSA, 2004 and Government of Ontario, 2007). In addition, retaining the capabilities and services required to perform diving operations often becomes an issue, both due to the cost of training and worker turnover. For these reasons, the RESA System has been developed to reduce the costs of environmental monitoring and to allow groups with smaller budgets, the capability to apply modern technology to the study of the underwater environment.
2.3. Underwater Environmental Sensor Networks

The term underwater environmental sensor network can be used to generically describe all underwater remote sensing applications. Although the actual purpose for the sensor network may be quite different from application to application, several design challenges are common to most systems.

Sensor Network Design

Networks are often used to link environmental sensors within a monitoring system. The design of a sensor network ultimately dictates its end application. For example, Martinez et al (2004), discuss the architecture of several sensor networks. Certain networks, they discuss, must remain relatively modular and self-contained, in order to allow the sensors to complete their tasks (i.e. movement within a glacier). In other situations, direct cabling and stationary networks are completely acceptable. They discuss the need for the required hardware to be appropriate for the environment and operating conditions under which the network must perform (redundant systems in remote locations, etc). Of key note is the fact that remote management of the network and its associated instruments and sensors is a requirement of building robust scientific systems. One of the main challenges which was identified, is the integration of commonly available commercial products with specialty, often custom, scientific instruments. This lack of standardization has been shown to be problematic.

Communications strategies, such as wireless connections, must balance the need to provide a stable and reliable link under potentially difficult environmental conditions (i.e. storm events) while at the same time observing economies of scale. Economy of scale
often results in other savings such as the energy requirements of sensors and their associated electronics. In keeping with the theme of economies of scale, Torfs et al (2004), discuss their approach to conserving battery power in an environmental sensor network where communication and sensing duties follow a series of wake and sleep cycles. Security of the data being collected by a sensor network has also been identified as a design challenge (Martinez et al, 2004). This security issue is not only to protect from intentional disruption of data, but also to guard against accidental data loss.

The network, although required for a successful environmental monitoring system, cannot collect the required data alone. Environmental sensors are required, and come in as wide a variety as the variables they are tasked with measuring.

**Current Measurement and Water Level Data**

Determination of currents and surge within an area can be important in classifying local and regional habitats. In addition, water level data can be an important parameter to measure in systems which experience seasonal and long-term fluctuations in water levels, as these changes can impact the suitability of an area as productive habitat. For instance, for fish species using shallow water sites for spawning, fluctuating water levels can have disastrous effects on eggs and the rearing of larval fish (Fernandez-Alaez, et al, 1999).

Many underwater environmental sensor networks collect current and water level data. Current velocities can be measured using a variety of techniques (NOAA, 2001). These techniques can include die tracers, released in the water, and their movement timed. Die tracer measurements can be used, particularly with underwater video documentation, to
record and chart turbulent flow in an area, changes in the flow due to thermal
stratifications and internal wave activity (seiches, etc). An early attempt at advanced, in-
situ current monitoring, beyond the simple die tracer studies, was conducted by Irish et al
(1991). They used a Savonius rotor design to chart current movements past the sensor.
They also used an interesting LED to fibre optic communication system to overcome the
need to penetrate the underwater electronics housing. Although simple methods like die
tracers, and even more advanced rotor designs, can be very useful in the study of currents
and surge conditions, a new generation of oceanographic instrumentation has proven
invaluable for highly accurate, in-situ measurements. These are known as acoustic
doppler current profilers (ADCP’s). These instruments use sonar to track changes in the
movement of suspended particles in order to create a 3D map of currents and water flow
patterns in a localized area. Pressure transducers or surface sonar reflections are used to
measure the depth at which the ADCP is deployed. Such examples include the Sontek
(Sontek, 2007) range of ADCP’s, most of which have provisions for underwater acoustic
communication and direct connection through an RS232 port.

ADCP use in underwater studies are numerous and their applications varied. Although
the goals may be quite different, the common use of ADCP’s illustrate their value in
underwater monitoring. For instance, Kamminga and Visser (1999), used a horizontally
positioned ADCP to measure the current flow in a busy European river, where
conventional techniques were not be appropriate. Holtschlag and Kaschik (2002), used a
boat-mounted ADCP to chart flow patterns in the St. Clair and Detroit Rivers in
Michigan and Ontario, in order to provide the baseline data for an intake protection
study. Mitsuzawa (2003), used a towed and submersible-deployed ADCP to measure
currents in the deep-sea environment. The use of a mobile ADCP platform, however, introduces errors in the currents being measured. For a boat or submersible traversing a body of water, even corrected GPS and sonar positioning does not give the precision of dedicated, statically deployed, ADCP’s for critical current measurements. Mitsuzawa (2003) experienced substantial difficulty in accurate current measurements as a consequence of errors associated with the movement of their surface vessel.

**Sediment**

Sediment and substrate analysis are important components of a thorough underwater ecological assessment. The exact substrate composition can dictate the type of macrophyte and invertebrate species which can be supported in an area. This often translates into the ability of the area to support different aquatic and marine species during different phases of their lifecycles (Nielson and Johnson, 1981). In particular, benthic invertebrate studies have been shown to be important indicators of underwater ecosystem health (Resh, 1995; Corkum, 1990).

Traditionally, sediment samples are collected using a variety of techniques and equipment, which generally fall into three categories: coring devices, dredge/grab devices and scraping devices (NOAA, 2001; Cummins, 1962; Armitage, *et al*, 1974; Brooker and Morris, 1980a and 1980b; Eadie and Keast, 1982 and 1983; Jenkins, *et al*, 1983 and Wade, *et al*, 1989). They are labour intensive and often costly to operate on a large scale. A new type of sediment analysis system has emerged which can compliment traditional sediment sampling regimes. This system, called a Sediment Profile Imager (SPI) and described and used by a variety of researchers, takes a profile image of the sediment in-
situ (Rhoads and Germano, 1986; Boyer and Hedrick, 1989; Diaz et al, 2003; Badino et al, 2004; Bona, 2006 and Patterson et al, 2006). The image can later be analyzed using a number of image processing software packages to extract vital information about the physical and biological nature of the local sediment.

Settlement substrates can be used successfully to sample benthic invertebrates living in an area, as well as to study colonization/settlement rates. This method consists of the placement of materials cleaned of invertebrates, along the substrate interface. This placement is traditionally timed, with the eventual removal of the settlement substrates (Khalaf and Tachet, 1980 and Watton and Hawkes, 1984).

**Plankton**

Plankton, as one of the fundamental pillars on which many aquatic and marine ecosystems rest, are a growing concern for monitoring. This comes from both a defensive position, with the increasing levels of toxic cyanobacteria and dinoflagellates, as well as a tool to assess the diversity and health of plankton populations. The traditional approach to studying plankton populations with nets is gradually being superseded by in-situ sensors and image processing software.

Sonar can be used to track the diel vertical migration of plankton. Although many types of sonar systems are capable of detecting this movement, Miller (2003), tracked distinct migrations on a daily basis, using an ADCP.
Although sonar can be used to visualize the coarse-scale movements of plankton, ventures into the application of technology to identify and classify plankton populations occurred as early as the 1970’s and 1980’s. Edgerton et al (1981), tested a system which used a still camera attached to a conventional plankton net to take silhouette images of the plankton in the net’s cod end.

Akiba and Kakui (2000), described a system they had developed which allowed them to identify free-swimming plankton using a video microscope system and image recognition algorithms. They do admit though, that accuracy was not as high as conventional microscope identification and that open-water imaging of the plankton resulted in a shallow field-of-view and subsequent errors associated with blurred and out-of-focus images. They did, however, have success with the image recognition algorithms they employed with the digitized pictures.

Broughton and Lough (2006) used a plankton video recorder to sample plankton while comparing it to a netting method. They showed the value in the video system in documenting the performance of the nets. Skebo at al (2006), used a high-magnification colour camera attached to a remotely operated vehicle to assess the abundance of plankton in a section of the Juan de Fuca Ridge. They found that they were able to discern distinct spatial distribution patterns at a finer scale than netting techniques.
**Biological and Habitat Assessments**

The use of sensors and technology to assess habitat has been slowly emerging as a viable alternative to manual sampling techniques. From the physical aspects of underwater habitat, Doucette *et al* (2002), used stereo videography to map and measure bedforms. They found that without a laser scaling system, however, complete measurement of the bedforms was not possible. In addition to physical assessment, habitat assessment is becoming an important application of underwater sensors. Mantyka and Bellwood (2007) used underwater video systems to assess the impact of grazing fish on their local habitat. Unfortunately, they used film cameras which had to be removed for processing. Winfield *et al* (2007), used sonar to measure the density and abundance of macrophytes. Their survey, however, did not distinguish between different types of macrophytes, nor were they able to make determinations of the suitability of the habitat for aquatic organisms.

There has been a concerted effort to advance the use of object recognition and image processing in order to automate the collection of habitat-related data from underwater video systems. In particular, Lebart *et al* (2003), have proposed and developed change detection algorithms which allowed them to automatically chart changes in major habitat types. Shumway *et al* (2007), have approached this challenge by developing an image analysis system which allowed them to make digital determinations of habitat complexity.
Fisheries Assessments

The use of environmental sensors to study fish populations is rapidly advancing, particularly in the use of underwater video. Underwater video observations can be used to provide fish species census data in deployed locations. Stobart et al (2007), used a baited camera to attract marine fish species to a stationary underwater video camera. Often, however, simple fish abundance measurements are not sufficient for scientific study. Estimates of biomass and animal condition are equally important when conducting fisheries surveys. Vital statistics taken from fish can be important clues to their overall condition and that of their associated populations and habitats. Underwater video observations and measurements can be made of fish using both conventional video, video with a scaling system and stereo video systems (Rutecki et al, 1983 and Johnson et al, 2005).

Data collected by underwater video often presents a problem for those interpreting the images. This is a labour intensive, exhausting process and can be compounded by differences in analyst experience. Edgington et al (2006) were trying to overcome this issue with some success by the development of software algorithms for tracking fish in a video image. The software would will then automatically eliminate video frames which did not contain the required information. Trucco and Plakas (2006), discuss the challenges of enabling this tracking of objects in a video image. The challenges are great and include the ability to determine the area of the image in which to continue tracking the object (i.e. where it is going?) and how to identify the object of interest from frame to frame.
In addition, much work has been occurring in the field of underwater photogrammetry / videogrammetry (here-to simply referred to as photogrammetry). The field of photogrammetry uses a variety of techniques to extract 2 and 3-dimensional information from objects in stereo images. One of the difficulties of using photogrammetry techniques in the underwater environment is that standard, land-based applications use two cameras which image objects on the same plane. The underwater environment, however, makes this more difficult. Variability in water clarity and backscatter particles can play an important role in achieving the image quality required to properly triangulate and measure objects.

Okamoto et al (2000) and others have used stereo video and laser scaling systems to extract information such a length, height and girth, to estimate the weight and overall biomass of fish species in an area. In a related move, Ishii et al (1998), used stereo video to chart the 3-dimensional position and movements of underwater animals (dolphins in this case). Their goal, in which they had some success, was to extract complex positional information from a video image clip with less manual effort. Li et al (1997), also discuss their approach to using photogrammetry which does not require the use of lasers or light grids.

**Laser Scaling Systems**

Laser illumination can represent a simple, yet powerful way to extract range and object measurement data from a video image. Generally, a laser scaling system consists of a trio of lasers, two which are set parallel to one another and a third placed at a known
angle. The laser system, however, can be upgraded to allow the measurement and profiling of 3 dimensional structures. For instance, Crawford and Hay (1998), developed a laser system consisting of two high-powered laser diodes with line generating optics to produce fan-shaped light beams. These light beams were then used to distinguish bedform profiles on the ocean bottom. Marks et al (1995), developed methods to actively detect the laser spot being reflected to the video camera which could be used to automatically triangulate the position of the targeted object. Chen et al (2004) continued on this theme by investigating ways to automatically detect the spot of light generated by an underwater laser scaling system on a video image. These approaches were ultimately in order to facilitate the development of autonomous algorithms which could detect and measure image objects without manual analysis. In an interesting study, Rochet et al (2006), compared the ranging abilities of a laser scaling system with that of an auto-focus video camera. The auto-focus camera was designed to give a feedback signal based on the focal length of the lens. They found that the laser scaling system was consistently more accurate than the auto-focus camera at providing range data.
2.4. Hydroacoustic Surveys of Fish Populations

Sonar instruments can be used alone or to augment the information collected by video systems, both in turbid water and over distances outside the video system’s field of view. The use of sonar for the detection and estimation of biomass within a waterbody, started with the realization in the 1930’s that sound signals could be used to detect fish suspended in the water column (Nielson and Johnson, 1985). Acoustic sonar profiling for suspended fish uses much of the same equipment as sonar mapping for bathymetry. Although traditional acoustic fish surveys have employed vertical beam sonar as the primary method of imaging underwater fish, research in the late 1990’s have shown that horizontally directed beams, combined with vertical beams are increasingly important is finding fish inhabiting shallow water areas (Kubecka and Wittingerova, 1998). In an interesting study conducted on the Columbia River, Steig and Iverson (1998), used a split-beam scanning sonar to chart the movement of fish in the currents created by the opening and closing of two dams. Split-beam sonar is an adaptation on traditional sonar designs. The emitting source for the sonar unit is divided into four quadrants, each of which process their own return signal. This allows the determination of the differences in phase of each signal. Processing of these phase differences allows the measurement of fish size along with its location within the water column (Nielson and Johnson, 1980). Gaudreau and Boisclair (1998), showed that horizontal movements of fish schools throughout a lake could be determined using acoustic sonar surveys.

Some disadvantages of acoustic sonar surveys for determining the density of fish populations are discussed by several authors. Lyons (1998), discussed the difficulty in resolving individual targets in areas with high fish densities. Also, several authors have
described difficulty in assessing fish populations which inhabit the benthic environment, an area where fish cannot be easily resolved from bottom features (Lyons, 1998). Also, macrophyte cover and bottom structure can hide fish and interfere with acoustic signals (Hughes, 1998).

There is currently research being devoted to detecting the minute differences in a reflected sonar signal to classify the type or even species of fish being detected. Jech and Michaels (2006), have been working towards the classification of fish to the species level with some success. What is equally important to determining the species being detected, however, is to estimate, with a degree of accuracy, the size and weight of the fish.

The ability of fish and other underwater organisms to inhabit a site, however, is often dependent on the quality of that water.
2.5. Water Quality

Water quality is a concern in many parts of the world and as such, water quality analysis is an important part of any environmental assessment. Since most organisms have specific water quality requirements, assessment of the current conditions of a site can be used to predict potential use or explain the absence of species. The effect of differing water quality factors as they affect the fisheries diversity of an area has been well studied and clear links established. Robertis, et al (2003), found that increased turbidity levels resulted in a corresponding decrease in the ability of piscivorous fish to consume prey items.

There are many different water quality parameters which can be measured, depending on the ultimate goals of a study. The most common parameters measured by solid state, in-situ sensors are: temperature, dissolved oxygen, conductivity, salinity, oxidation reduction potential, pH, turbidity and algal pigments. The quality of water in the environment is affected by a large number of variables. First, there are the natural processes which are constantly occurring in, on and around the water. Plant matter is continuously being produced and ultimately decaying. Invertebrates and vertebrates are reproducing, growing and ultimately decaying. In addition, the very lifecycles of many of the animals found in aquatic ecosystems affect the cycling of inorganic and organic substances. Natural processes outside the system can also play an important role in the quality of the water. Precipitation transports nutrients and chemicals from the surrounding watershed and erodes exposed susceptible material. Anthropogenic affects and changes to watersheds can directly affect the water’s chemical and biological composition (Papatheodorou et al, 2006).
Much of the water quality monitoring which presently occurs is an intensive process in which much time and effort is imparted collecting, processing and analyzing the water for specific parameters of interest. For instance, Carrick et al (2005), described a large study which looked at the water quality connections to planktonic and benthic invertebrate assemblages. This huge expenditure of resources could be have been substantially reduced with a deployed network of in-situ sensors. In addition such studies could be conducted over a much longer period of time. Eimers et al (2005) also illustrate the labour intensive requirements of conducting water quality monitoring on a relatively large scale. They have monitored eight stations in Lake Simcoe, Ontario, with sampling intervals of approximately two weeks. This type of monitoring could be done autonomously with a network of sensors.

There has been some movement towards monitoring techniques which are more automated. Denkenberger et al (2007), used a YSI DataSonde 6600 (YSI, 2007) to autonomously monitor water quality parameters over a period of two years. Their system used a computer box located at the surface to automatically record the values measured by the YSI sensors. Their system did not, however, send the data back to a land-based system or network. Halfman (1993), conducted a twenty-eight station sampling regime on Lake Malawi in Africa, with what at the time were state of the art sensors. This system, again, required field trips to collect the data.
Irvine et al (2005), combined manual sampling techniques and a Hydrolab Datasonde 4a (Hach, 2007) to monitor water quality in the Buffalo River, New York State. They found that the integration of the Hydrolab in their study provided consistent and reproducible results.

Many studies have illustrated the importance of water quality monitoring in order to assess the changes occurring in fish stocks. This can be particularly important in lakes and rivers which are being rehabilitated (Fielder et al, 2007).

As important as water quality is to fish populations, equally important is an understanding of the complex movements and migrations which occur throughout the various stages of their lifecycles.
2.6. Fish Telemetry and Tracking

The field of animal telemetry is an established field with a small number of manufacturers producing products which allow researchers to track the movements of an animal using an implanted or externally attached device. There are basically two very different techniques which can be used to track fish. The first is through the use of acoustic tags, which use sound as a locator signal. The second uses radio frequency transmission as a locator signal.

Acoustic Telemetry

The tracking of animals using acoustic transmitters is basically restricted to the underwater environment as acoustic signals are quickly attenuated when traveling through air. Underwater, however, acoustic tags become a powerful technique to track the movements of underwater animals such as fish. All acoustic tags work by the principle of listening for an expected signal using a hydrophone. Then, by triangulation of the received signal, an approximate location can be found. This is usually accomplished by trained listeners in a mobile boat and can be very labour intensive.

Acoustic tags generally operate in two different ways. The tag can be designed to emit a signal pulse of a known frequency which is specific to that tag. Thus by listening at a certain frequency for a specific pulse code and by using the triangulation method, the location of that tag in a two-dimensional area can be determined. This method can be expanded with the addition of encoding information in the signal being produced. For instance, the depth of a particular tag can be transmitted using pulsed or coded information in the acoustic signal (Lotek, 2007). Acoustic tags can also function by using one or a small range of frequencies on which more than one tag can operate. Thus,
a carrier frequency is used and each tag is programmed with a specific identifier code. Again, this method can be expanded to transmit coded environmental data (such as depth).

A survey of several of the larger acoustic telemetry equipment manufacturers shows that there are no set standards for specific telemetry transmission frequencies. For instance, Lotek, Inc (Lotek, 2007), uses a frequency of 76 kHz for many of their transmitters, while Sonotronics (Sonotronics, 2007) uses a range of frequencies, from 32 to 83 kHz.

**Radio Telemetry**

The use of radio telemetry tags is extensive in tracking applications. It provides for extended range tracking and the spatial investigations of fish movement (Adlansvik *et al*, 2007 and Hodder *et al*, 2007). Radio telemetry underwater is primarily used for animal species which are predominantly found in shallow water or in thick cover where acoustic signals are attenuated and/or scattered.

Although there has been some research on developing the equipment for radio telemetry (Beeman *et al*, 2007), little has occurred for underwater antenna placements. Cooke *et al* (2000), are among a rare group who used stationary underwater radio antennas to monitor the movement of several tagged smallmouth bass (*Micropterus dolomieu*).

The literature is filled with studies which use telemetry to track the movements of fish and other underwater animals both using acoustic (Dresser and Kneib, 2007, Jorgensen *et al*, 2007 and Mayer *et al*, 2007) and radio (Enders *et al*, 2007, Geeraerts *et al*, 2007)
tagging technologies. The current developments, however are in the ability to encode additional information about fish physiology and environmental parameters into the tag transmissions. A discussion of this topic however, is beyond the scope of this thesis and will therefore not be covered.
2.7. Transmission and Communication Technologies

Once an environmental sensor system has been selected, a communication strategy must be developed in order to allow the system to transmit the data being collected.

Acoustic Communication

When examining any environmental sensor system, but particularly one which will be placed at the bottom of the ocean, lake or river, the ideal candidate for the movement of the data generated by such systems is a transmission strategy that does not have to break the surface of the water to operate. This, coupled with an ideal power source which can operate for extended durations without regeneration (refuelling or recharging), results in a sensor system that is resistant to being compromised by inclement weather (storm action, icing, etc) and is basically hidden on the bottom, without the surface indicators of its presence (buoy, etc). Not only will such a strategy result in greater security for the potentially expensive instruments, but it also negates the costly infrastructure and maintenance that typifies a wired communication option. This also naturally leads to the use of acoustic transmission to either a surface station or shore station.

The very nature of the underwater environment, however, is that there are many confounding factors which contribute to high data error rates in acoustic transmission systems (Shevenell and Winn, 1984 and Kilfoyle and Baggeroer, 2000).

Sozer et al (2000), discuss the problems associated with creating reliable underwater acoustic communication systems, particularly as in the case of many underwater platforms connected together as a network. They note that, particularly in shallow water
environments, the signals are often scattered and lost, resulting in low data transmission rates.

Some of the highest data transmission rates achieved by researchers using underwater acoustic modems has been 500 kbps (Kilfoyle and Baggeroer, 2000).

**Wireless Radio Communication**

Wireless radio sensor networks are quite common for lower bandwidth instrumentation. Most communicate directly with either a shore-based radio or satellite link. For larger bandwidth instruments, these wireless communication strategies do not, at present, provide adequate bandwidth to move the data. For example, OceanNet, which is a grid of environmental sensors spread across the world’s oceans for oceanographic monitoring, is one of the fastest wireless environmental networks, but still is only capable of 1 Mbps data transmission (OceanNet, 2007).

**Wired Communication**

There are several options for wired communication connections to underwater sensor networks. First, standard Ethernet connections can be used. A standard CAT 5 Ethernet line is acceptable for this application. The next step up in this type of communication strategy is the use of gigabit Ethernet. This can also be accomplished using CAT 5 or 6 Ethernet line. Distance limitations and data transmission speeds are shown in table 1.
Table 1 - Conventional Ethernet options for connecting an environmental sensor network (Winkelman, 2007).

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>Cable Format</th>
<th>Speed</th>
<th>Maximum Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Base2</td>
<td>Copper</td>
<td>Thin Coaxial</td>
<td>10 Mbps</td>
<td>185 m</td>
</tr>
<tr>
<td>10Base5</td>
<td>Copper</td>
<td>Thick Coaxial</td>
<td>10 Mbps</td>
<td>500 m</td>
</tr>
<tr>
<td>10BaseT</td>
<td>Copper</td>
<td>Cat 5</td>
<td>10 Mbps</td>
<td>100 m</td>
</tr>
<tr>
<td>100BaseT</td>
<td>Copper</td>
<td>Cat 5</td>
<td>100 Mbps</td>
<td>100 m</td>
</tr>
<tr>
<td>1000BaseT</td>
<td>Copper</td>
<td>Cat 6</td>
<td>1 Gbps</td>
<td>220 m</td>
</tr>
</tbody>
</table>

There do not appear to be standards or performance data on the use of Ethernet cabling in an underwater application.

Fibre optic connection provides a very clean option for moving data at high bandwidths. Fibre optic capability is currently limited to multi-mode and single-mode fibre. Fibre optic connections are very sensitive to proper termination of the fibre strands. Improper, or sub-standard termination results in increased resistance to transmission at the terminals, resulting in lower bandwidth capabilities and shorter line runs. Properly terminated fibre optic cable allows approximately 2 km of transmission before a signal relay is required.
2.8. Underwater Observatories

The science of underwater observatories is an exciting field which is currently in its early stages of expansion. An underwater observatory can be viewed as a collection of sensors and instruments, connected to a network and deployed at a dedicated location. The RESA System itself is a self-contained underwater observatory and as such a discussion of the current trends in underwater observatory science is in order. The first such initiatives were connected with ocean condition observing networks. A prime example of this is the Eastern Consortium of Coastal Ocean Observatories (ECCOO) which is a conglomerate of ocean monitoring stations stretching along the Eastern Seaboard of the United States (ECCOO, 2007). This network of observatories is primarily focused on measuring weather and ocean conditions. For their intended purpose, they are more than adequate, but are basically permanent, expensive installations and cannot be rapidly redeployed to other locations without a significant re-networking of the area.

Many underwater observatories have also been created in order to monitor geologically unstable areas for potential earthquake activity. This type of observatory carries mostly seismic sensors, but have contributed greatly to the advancement of underwater deployable sensor networks. Some notable seismic observatories include Hawaii-2, in Hawaii, and the Real Time Offshore Seismic Station (RTOSS) in Grenada (Duennebier, et al, 2002).

The Long-term Ecological Observatory (LEO-15) at Rutgers University in New Jersey, USA, contains a variety of sensors, including video, current meters and other oceanographic instruments. It is permanently deployed at a depth of 15 m. (Schofield et
Leo-15 collects a variety of data, from meteorological parameters to underwater video. The LEO observatory requires an extensive command and control facility which the authors liken to mission control of a space program. This unit does not have the ability to transmit high-definition video signals, cannot be rapidly mobilized and redeployed and requires substantial funds to operate and maintain.

On a similar scale to LEO-15, Canada has two underwater observatories located in relatively shallow water. First, the Bonne Bay Observatory of Memorial University in Newfoundland, is a permanent installation containing relatively large oceanographic equipments (BBO, 2007). Second, the Victoria Experimental Network Under the Sea (VENUS) observatory is located off the coast of British Columbia in the Saanich Inlet (VENUS, 2007). It is operated by the University of Victoria and has a planned expansion of two addition study sites. The current observatory is located in approximately 100 m of water along the path of a decommissioned telecom cable (of which the observatory now uses). The infrastructure for the VENUS and Bonne Bay observatories require a ship for deployment and are basically permanent installations once deployed. The costs are also substantial and like the LEO-15, require dedicated staff and surface infrastructure to operate.

On a much larger scale, several multinational ocean observatory networks, spanning many locations and over large geographic areas, are currently being planned with some even in the early stages of construction. For example, the North-East Pacific Time-Series Underwater Network Experiments (NEPTUNE), is a Canadian and American joint venture to deploy a cabled observatory off the west coast of Canada and the U.S.,
stretching to the Juan de Fuca Ridge (NEPTUNE, 2007). This observatory has seen the most progress in construction of the large planned observatories. It consists of large underwater sensor and processing “nodes” which require a ship for deployment and maintenance. Although the actual numbers are tightly guarded, an estimate of 100 million dollars is anticipated from the Canadian side to make this system a reality. The NEPTUNE project is a very complex system which only lends itself to be a permanent installation which requires sophisticated and skilled personnel to operate and maintain (El-Sharkawi et al, 2005).

The European Seafloor Observatory Network (ESONET) (Priede and Solan, 2002), similar in scale to the NEPTUNE observatory, is planned in the future, as is an observatory off Japan called the Advanced Real-time Earth monitoring Network in the Area (ARENA).

Unfortunately, for freshwater science, there are only a handful of freshwater sensor systems around the world. They are mostly simple water quality monitoring sensors, which feed the small amount of data back to a central computer. The Global Lake Ecological Observatory Network (GLEON) is the most visible example of this phenomenon (GLEON, 2007).
2.9. Conclusion

In researching the idea for this thesis, it became apparent that a small, low-cost, but high quality monitoring system for aquatic and hostile environments did not exist. Large units, costing significantly more in both dollars and labour do exist, but are well outside the reach of most research and monitoring budgets. As discussed above, there are some small sensor based deployments around the world, but they tend to be for short durations and definitely do not allow the users to move large amounts of data back to a research laboratory.

Small, modular environmental sensor platforms which would allow the development of low-cost, easily managed underwater observatories appear elusive. The development of such a system would be an important advancement in understanding the complex realm which is the underwater environment.
Chapter 3. The RESA System

3.1. Overview

The following chapter describes the Remote Environmental Sensor Array (RESA) System and its associated technologies. Each component of the system is detailed, along with the design schematics and pictures where appropriate.

3.2. Motivation

There has long been a need for scientists to move fisheries research and aquatic and marine ecology into the 21st century. The technological progress made in other fields have far outpaced those in the ecological sciences.

The reason for pursuing this line of research was that much of the world’s most precious and sensitive environments are located in remote areas. In addition, with respect to concentrating on an underwater application, the majority of the earth is covered by water, a resource that needs to be further understood. Finally, much of the science to which one is exposed, is traditional and uses conventional sampling techniques to collect data. Although these methods are time-tested and trusted, they are extremely labour intensive and strain even the most well-funded budgets.
3.3. RESA System Design Criteria

The RESA System is basically a two-part monitoring technology. The first part, the active sensor components, are specific to the environment in which they will perform their required tasks. For this reason, the underwater environment will be discussed at length throughout this thesis. The second part of the system is the communication, control and data acquisition software. This part of the system is not specific to the underwater environment, but instead is designed to accept a myriad of sensor types and interfaces for any encountered environment which must be monitored. The second part is akin to the software “plug and play” models used in modern computer design.

In designing the RESA System, there were several overriding criteria which were critical to a system which could be successfully used by a variety of end users. These were as follows:

- Low cost
- Reliable and robust
- Ease of deployment and maintenance
- High quality data collection instrumentation
- Expandable for the integration of additional and emerging instrumentation
- Capable of operating in a grid environment
- Use of the internet as the primary user interface
3.4. Initial Challenges

There were many challenges associated with the design and building of a robust remote environmental sensor system.

Environment

The environment into which the RESA Systems are designed to be placed presents several difficulties. First, deployments will be in an inherently harsh underwater environment. The systems are ultimately designed for either fresh or salt water and for this reason, special consideration was given to the materials used to protect the underwater instrumentation. In addition to a wet and potentially salty environment, the RESA Systems must also perform in a pressurized environment. A design depth for the first RESA System of 15 m was chosen based on the expected deployment test sites. Since the systems are designed to be placed in potentially remote locations, or at depths which inherently make them remote, they must be reliable and capable of operating for long periods of time without the need for frequent site visits or recovery for maintenance.

Deployment also presents a challenge for this type of system. Typically, other systems of this nature are large and bulky, often requiring a ship and large crane for deployment. This would have defeated the purpose of this project, resulting in a system which would only be suitable for large-scale users. As such, the development of the system followed the ideal of a relatively compact unit, meant to be deployed by a minimum of personnel and from a small vessel.
Maintenance was also seen as a potential issue for the RESA System. The overall design criteria was one of a modular nature; one which would facilitate the underwater removal of individual instruments and components without disrupting the operation of the system as a whole.

**Network Communication**

Design of the communication system had to take into account the fact that the nearest link to an advanced or conventional network could possibly be a long distance away. Thus, the system had to be designed with the ability to communicate using a variety of methods, depending on the most appropriate one for local conditions. Wireless, satellite and wired links were investigated and the RESA System was designed to accommodate all these various communication strategies.

**Underwater Protection**

In order for the RESA System to be reliable under a variety of conditions, several methods of protecting the underwater instruments and components were investigated. The final decisions were based on the overall end user’s ease of use and maintenance while in the field.

**Instrument Protection**

The instruments used on the RESA System required armouring to protect them from the pressures which would be experienced at depth (for example, at 15 m the pressure is equal to approximately 1.5 atmospheres), protection from water ingress, a by-product of the pressure protection, and finally chemical protection (i.e. saltwater corrosion).
Protection was afforded by placing the various instruments in suitable housings or cases. Assuming these housings or cases were pressure-proof, they would also be inherently waterproof. Selection of suitable materials was critical to ensuring that corrosion would not jeopardize the integrity and durability of the System. It must be noted that although the instruments were designed for 15 m depth capability, availability of materials often dictated the actual useable design depth. For this reason, failure calculations presented in this thesis often result in depth capabilities greater than 15 m.
3.5. Basis for the RESA System

Since the RESA is basically a collection of different instruments and an underwater box, its construction necessitated that it be adaptable to a wide range of instruments and deployment environments. To this end, the design of the RESA System had several important parts. First, a base unit was required, to attach the currently selected instruments as well as those which might be added at a later date. Second, for those instruments which were not commercially available for the underwater environment, suitable protection housings were required. Third, an underwater computer and power distribution centre which would interface with the instruments was required. Finally, a mechanism to connect the RESA System to an external power supply and data connection was devised. A 3D rendering of the RESA System is found in Figure 1.

![Figure 1 - The Remote Environmental Sensor Array System.](image-url)
3.6. Coarse Scale Description

The RESA System is an integrated environmental monitoring unit complete with an array of sensors described below. It has been specifically designed for the underwater environment and uses a web-based control system to interface with the underwater sensor platform. This in turn allows users to access and control the sensors from geographically remote locations.

The RESA System is designed to use dedicated scientific fibre optic networks on the provincial scale (Optical Regional Advanced Network or ORAN) and the national scale (CA*Net 4) in order to facilitate the movement of large volumes of data to end users.

The RESA System is also designed to operate in a grid environment, with multiple RESA Systems acting as a larger field of sensors and instruments (Figure 2).
Figure 2 - Coarse level schematic of RESA Systems in a grid environment.
The RESA System contains a suite of water quality sensors which are used to measure specific environmental parameters. These parameters include: depth of water, dissolved oxygen, pH, temperature, conductivity, oxidation reduction potential, chlorophyll a and salinity.

In addition to water quality sensors, a hydrophone (underwater microphone) is attached to the underwater platform. Two cameras, one high-definition colour and one low-light, black and white, are mounted on independently controlled pan and tilt units. A laser scaling system is provided for the video systems and is mounted on the pan and tilt units. Lighting is accomplished using two high-intensity discharge and two halogen lamps which can either be mounted with the cameras on the pan and tilt units or on the platform in a fixed position. Finally, a sediment profile imager is provided with 10 m of cable for deployment away from the main platform in undisturbed sediments.

The RESA System uses a web-based client software system where researchers can use their own web browser to connect with and control a deployed RESA System. The software allows customized manipulation of the data collecting capabilities of the RESA System in a secure, on-line environment. In addition, research working-groups can be established which can simultaneously share and control the RESA sensors and data.
3.7. Material Overview

Several materials were investigated for this project. They are as follows: a high impact thermoplastic product (Delrin®), aluminum, stainless steel and titanium. Titanium was quickly excluded due to the cost. Titanium, however, does not corrode like other metal materials and is exceptionally strong. It is thus the preferred choice for deep-sea saltwater deployments.

**Delrin®**

Delrin® is a medium viscosity acetyl polymer thermoplastic (Matweb, 2007) developed by Dupont which has become a mainstay of the oceanographic industry. It is easily machined and can be threaded much like conventional metals. Since it is not a metal, it does not corrode when exposed to moisture and does not participate in galvanic corrosion. The drawback to Delrin® as a housing material is that, unlike many of the metals, it does not withstand the extreme pressures of underwater service. Also, it is more susceptible to abrasion and shock damage than many of the metals. It is primarily for the latter reason, that Delrin® was not selected for this project.

**Aluminum**

Aluminum is a versatile material for building underwater housings and pressure cylinders. Although there are a variety of alloys available, 6061 and 5052 aluminum alloys were investigated for this project. These alloys are easily machined, have good weldability and resistance to weld cracking and are generally easily obtained (Efunda, 2007). The use of 5052 aluminum alloy for the plate segments was governed largely by the availability of the aluminum plate. The standard aluminum plate in the metal industry
is 5000 series aluminum. It is a much harder material than the 6061 aluminum and as such is more difficult to machine and form. Weldability is maintained however, and it will readily fuse with 6061 aluminum using a variety of filler materials (Efunda, 2007).

The high strength of aluminum when compared to Delrin® makes it an attractive choice for deeper applications. Aluminum does have a major drawback however, that of corrosion. Corrosion, either natural or electrically induced can quickly compromise the structural integrity of a pressure housing. This is of particular concern in a saltwater environment. This drawback can also be compounded when different metals are used, either in the immediate vicinity (i.e. another instrument made of stainless steel, or in actual contact (such as stainless steel fasteners). This type of corrosion is known as galvanic corrosion and is discussed in the section 3.22, titled Cathodic Protection. Stray currents, always a concern with a powered underwater instrument, can actually set-up an electrolytic reaction which corrodes the most sacrificial metal in the area (aluminum in this case). The most reliable method of protecting aluminum is that of anodizing, an electrical method of polishing and then forming a hard, resistant coating. It must be clearly understood though, when in saltwater, the smallest compromise in this coating such a small scratch, will corrode, thus eroding the protective coating. In the freshwater environment, aluminum is a much better choice. If planned correctly, aluminum can withstand the rigours of this environment with little corrosion.
Stainless Steel

Stainless steel is an ideal material for the construction of underwater instruments and their protective housings. There are several grades of stainless steel, each with their own strengths and weaknesses when it comes to their application underwater. The two most common alloys used in the marine and oceanographic industries are 308 and 316 stainless steel as they provide excellent resistance to corrosion in the marine environment. Stainless steel alloy, grade 316, was chosen for use in the RESA System and is present almost exclusively in the form of fasteners.

Titanium

Titanium is considered the ultimate material for the fabrication of underwater instrumentation. This is due to titanium’s high tensile strength and its increased resistance to corrosion over other metals. This allows a lighter, smaller housing to be designed than is possible with most other materials. The downside to the use of titanium for underwater instrumentation is the high cost of the material, which must often be specially ordered rather than found as a stock item at most metal distributors. Titanium is also a very hard material, which necessitates the use of hardened machining implements such as carbide and cobalt steel tooling. The life of such expensive tooling is greatly reduced when used on titanium. Titanium also presents difficulties when it comes to welding. Electric fusion welding can be used to join pieces, however, only the more expensive tungsten inert gas (TIG) welding process will reliably give a structurally acceptable weld. Shielding requirements for welding titanium are also much more rigorous, with the use of a minimum of full front and back-shielding argon being mandatory. 6AL-6V titanium alloy was investigated for use on the RESA System, but
was rejected due to the cost and due to the lack of suitable equipment to machine and weld the housings

**Lens Material**

Optically clear polycarbonate called Makrolon® and manufactured by Sheffield Plastics, Inc, was chosen for the housing port material for all but the low-light black and white camera which came from the manufacturer with a glass lens. Polycarbonate was selected for several reasons. First, it is incredibly clear, with a transmission rate of 86% (9.525 mm thick) (Bayer, 2007). Second, this material is extremely easy to machine and is relatively low cost, allowing different designs to be prototyped and tested for best performance.

**Failure Analysis**

Calculation of failure or yield of the fabricated housings was completed using the Under Pressure software created by DeepSea Power and Light (DeepSea Power and Light, 2001). The results are presented in each respective section. Note that one very important assumption was made in these calculations: that the pressure limit of the sealing o-rings was 34,474 KPa (3515 m) in a static compression, within an o-ring groove exerting an average compression of 20-32 % of its total diameter (O-rings, Inc, 2007). The o-rings used were 3.18 mm in diameter and were made from butyl rubber with a standard durometer rating of 70 Shore A. The depth of the o-ring groove was the best method to facilitate achieving the average compression of 20-32 % of the o-ring diameter. Due to the precision of the equipment used to manufacture the housings and lenses, however, this value can only be an approximation.
3.8. Base Platform

The RESA System relies on a sturdy underwater platform to maintain stability for the imaging systems, as well as to prevent damage during storm events. The basic design of the platform can be seen in Figure 3.

The platform is made from two alloys of aluminum. The plate segments, comprising the main platform, leg feet and attaching plates are made from 6.35 mm, 5052 aluminum alloy. The leg channels are made from 50.8 mm, round corner, square, 6061 aluminum alloy tubing.

The segments of the platform are held together with 9.5 mm diameter x 31.75 mm long grade 316, stainless steel bolts (NC 18 thread) and 9.53 mm stainless steel nuts (NC 18 thread).
The platform also contains an aluminum basket which is attached to the underside of the main plate. This basket is made from 25.4 mm round corner, square, 6061 aluminum alloy tube (3.18 mm wall) and 6.35 mm thick x 76.2 mm wide x 762 mm long 6061 aluminum alloy bar (Figure 4).

![Figure 4 - RESA System base platform peripheral basket assembly. This basket is attached to the underside of the main base platform. The computer and Hydrolab are attached to this basket.](image)

Each foot of the platform is made from a 609.6 mm x 609.6 mm and a 152.4 mm x 152.4 mm piece of 6.35 mm thick 5052 aluminum alloy plate. A 762 mm piece of 50.8 mm, round corner, square 6061 aluminum alloy tube, with ends cut at 45°, is welded between the two plates. Each foot also has two 15.88 mm diameter solid 6061 aluminum alloy rods bolted upright with 9.53 mm grade 316 stainless steel bolts, to accept at variety of weight types such as lead ballast or concrete blocks (Figure 5).
Figure 5 - RESA System base platform foot and anchor unit.

The top of the platform has four, 38.1 mm diameter, grade 316, stainless steel lifting eyes bolted to it in order to facilitate lifting from a maintenance vessel, or other deployment device. The top of the platform also has the required mounting holes for attaching the pan and tilt units, lights and other devices.
3.9. Underwater Computer Box

The underwater computer box and internal peripherals provide several functions. First, environmental protection is afforded to the electronic components inside, second, power is provided to the RESA System and its instruments and finally, it houses the communication, control and data acquisition system.

Environmental Protection

Since the RESA System is designed to operate in a wide variety of environments, a choice exists, both on the scale of the budget and the environmental parameters under which it is expected to function. For this project, a Pelican Case (Pelican, 2007), model 1550, was selected to provide waterproofing and pressure protection for deployments of the RESA System down to 11 m of water. This type of case was chosen for availability and affordability ($150.00). The Pelican Cases are also easily modified. It measures 530 x 440 x 220 mm. This unit was modified to accept a bank of SubConn (SubConn, 2007) underwater male bulkhead connectors and associated locking sleeves (Figures 6 and 7).
Figure 6 - SubConn underwater connector bank on the Pelican Case computer box.

Figure 7 - Exploded view of the computer box showing SubConn connector bank.
The Pelican Cases feature an overpressure relief valve to minimize expansion damage to the case. This feature was maintained, although the need for such a device on a system without any off-gassing potential is not required. In the event a small back-up battery is used internally, suitable hydrogen absorbing media and the overpressure relief valve are mandatory. Pelican recommends the installation of bulkheads or other such reinforcing devices in order to prevent collapse or distortion of the case when used at depth (Pelican, 2007). The cases come with mounting bosses. Aluminum cross-bracing was installed in the Pelican case and attached to these points in order to prevent potential distortions (Figure 8).

Figure 8 – A view of a portion of the cross-bracing and reinforcing used to ensure the integrity of the pelican case for underwater use.
Deepwater Deployments

For more demanding environments and for deployment depths greater than 15 m, a stronger, all metal box must be designed for future RESA Systems.

Underwater Connectors

At all electrical junction points underwater, there is exists two options for connectivity. The first is the use of electrical connectors specifically designed for use underwater. The second is the use of compression fittings to seal around the wire where it enters a pressure housing. Although the first option is preferable due to its inherent robustness under pressure, the costs can be substantial when large numbers of connectors are required. Therefore, in order to test both options, the RESA System contains a hybrid mix of connectors and compression fittings. This hybrid design can be accomplished by ensuring that at least one end of the electrical system of each instrument has an underwater connector. This allows the removal of an instrument by a diver or remotely operated vehicle (ROV) without the need to retrieve the entire RESA System.

The underwater connectors chosen were made by SubConn (SubConn, 2007) and are a wet-mateable design capable of being connected and disconnected at the operational depth of the RESA System (Figure 9). Once connected, however, they are rated for operation at a depth of 13.7 km. Therefore, for the failure analysis of the different housings, the presence of the SubConn connectors will not be considered.
Containment Rack

The RESA System computer box contains all the associated electronics for the computer, control circuitry and the electrical distribution centre and thus space is at a premium. As such, a special two-level rack was designed to increase available space. At its most basic level, it is made from two sheets of 12.7 mm clear acrylic. These two sheets are held apart by four, 316 grade stainless steel alloy threaded rods and associated stainless steel nuts. These act as jack stands for the two sheets, allowing them to be adjusted for a variety of applications and equipment (Figure 10).
Figure 10 - Support rack for RESA System. Only minimal equipment and electronics are shown for clarity. Jack stands are shown without associated locking nuts for clarity.

**Power Distribution**

The underwater computer system provides the power necessary to operate all the instruments associated with the RESA System. This means that, due to the differences of all the sensors and the fact that the sensor components are often made by manufacturers who follow different design criteria, the power requirements are varied. For the instruments currently incorporated in the RESA System, 3 basic voltages are required: 5 volts DC, 12 volts DC and 120 volts AC. Each component, due to its sensitive nature, also requires a conditioned or regulated signal. A power distribution bank for each of the 5 and 12 volts supplies are located on the upper support rack sheet (Figure 11). A splice from the 5 and 12 volts supplies are attached to the end of each electrical supply bank. A ground bus is attached to the upper support rack sheet to complete the circuit (Figure 12).
Figure 11 - 5 and 12 VDC power distribution bank.

Figure 12 - Ground bus for all the direct current circuits in the RESA System.
The 120 volts AC requirement is provided by a modified power bar located on the lower support rack sheet. Each AC component is attached to this power bar.

The necessary power requirements were calculated for all the components. The DC power supply used for the RESA System is a 350 W unit. This, combined with the additional 120 VAC requirements of the halogen lighting (180 W) and the Hydrolab (12 W), put the maximum total wattage requirements of the RESA System at approximately 550 W.

**Circuit and Ground Fault Protection**

Protection must be afforded to the electrical system from shorts and surge conditions. Due to the remote location potential of the RESA System, it does not make sense to have a protection system that must be manually reset. In particular, for underwater deployments, this becomes impractical very quickly, as it would require bringing the unit to the surface and opening the sealed computer box in a dry environment simply to reset a tripped breaker.

In order to overcome this problem, the DC electrical distribution system contains an automatic reset circuit breaker within the regulated power supply. Each instrument also contains its own fusible link if a short occurs within the instrument itself. In the event of such an occurrence, the faulty instrument can be removed from the RESA System underwater by a diver or ROV, without the need to bring the entire unit to the surface. Each of the instruments are designed to be unplugged at depth without affecting the operation or performance of the other instruments or underwater computer.
The AC distribution bar is powered through a ground-fault interrupt socket which can be manually reset above the water without moving the RESA System.
3.10. Computer

Two computer options were developed; one uses specialized and miniaturized components (option 1) while the second uses conventional computer components (option 2). In computer technology, a trade-off is always made between performance and cost. For this thesis, the components selected were the most current “mainstream” components available in most computer stores. They are more than adequate for the challenges of the RESA System and as such did not require special customized equipment.

Option 1

Option 1 is based around a pc104 board (Figures 13 and 14). This board is much smaller than a conventional computer motherboard and can accept a variety of processor speeds and peripherals. A Nova-8890 PC 104 board with 512 Mb of ram and an Intel 2.4 GHz CPU was selected. A Western Digital, 80 Gb SATA 2.5” (laptop) drive was used.
Figure 13 - NOVA-8890 PC 104 board with associated ports and connections (JenLogix Ltd, 2007).

Figure 14 - RESA computer system for option 1. It is based on a pc104 design.
Initially a completely solid-state system was envisioned in order to eliminate any moving parts and to maximize energy efficiency. As such a bare-boned Mandrake Linux operating system image was installed on a 2 gigabyte compact flash memory card. At the moment, LINUX distributions have difficulty in the use of firewire to stream video images. This necessitated that the Linux operating system be replaced by the less reliable Windows XP operating system. This also necessitated installing a harddrive, a device that increases the power requirements of the system. As future LINUX distributions are able to interface more robustly with firewire, a change to LINUX on a memory card will be possible. All other peripherals, such as the video input devices and servo controller cards are identical as in the option 2 setup, and will be described below.

Option 2

Option 2 uses a conventional motherboard (MSI K9NBP6M2 AM2) with 512 Mb of RAM and an AMD Semperon 3200 CPU. Due to the use of Windows for this machine, a solid-state drive was not an option due to the large overhead consumed by the Windows Operating System. As such, an 80 gigabyte Western Digital harddrive was used. A 350 watt, regulated power supply with an internal, automatic reset circuit breaker was selected to power the RESA System (Figures 15 and 18).
Figure 15 - RESA computer system for option 2. This figure shows the bottom level of the support rack (upper level is removed for clarity).

Video Input

Video input to the computers is accomplished in several ways. Both computers have the capability to receive firewire or IEEE 1394 input. This allows cameras such as the high-definition camera to input directly in a digital format to the computer as it supports up to 400 Mbps data transmission rates.

The RESA System also uses a USB video input card, in which video in the form of an analog composite or s-video signal is imported into the computer. There is also available room to install a component input or SDI video input card for use with professional production equipment. The USB device selected is a Hauppauge WinTV USB2 external
card (Model # 01021) (Hauppauge, 2007). This setup allows scaling of the video input as additional Hauppauge units can be added to the motherboard. The Hauppauge unit was selected for availability and cost ($110.00) and is necessary for attaching analogue devices such as the low-light camera.

**Pan and Tilt Servo Motor Control**

Servo motor control is provided by a Pololu serial 8-servo control board (model #0727) (Pololu, 2007). This board controls the motors which drive the movement of the pan and tilt units. As the user clicks on one of the icons to move a pan and tilt unit, commands are sent to this board via a serial port connection (Figure 16). The board then commands the servo motors to move incrementally in the direction which the user desires. Coding for control of the Pololu board is written in C and is incorporated into the web-based user interface. The Pololu board was selected for its low energy requirements (10 mA) and low cost ($30.00).

![Figure 16 - Pololu serial 8-servo control board (Pololu, 2007).](image-url)
**Media Converter**

When a fibre optic connection is desired to the shore or surface, a suitable media converter is required to convert the signal from Ethernet (either 1 Gbps or 100 Mbps) from the computer to either multi-mode (short distance communication) or single-mode fibre. The current RESA System is designed to accommodate a media converter. The converter selected is the Optolinx 1000BaseTX to 1000BaseFX (Model FCU-3002SC) (Aaxeon, 2007). This particular media converter is capable of transmitting data at 1 Gbps for a one-way distance of 20 km on two strands (one receive, one transmit) of single-mode fibre optic line (Figure 17). The Optolinx was chosen for its low cost ($200.00).

![Optolinx Ethernet / single-mode fibre media converter](image)

*Figure 17 – Optolinx Ethernet / single-mode fibre media converter.*
Temperature

Operating temperature is critical to ensuring that the computer components operate efficiently and are not damaged by heat. This can be a real concern since the box is sealed and is relatively congested. A temperature monitoring program called SpeedFan (almico, 2007) is installed in the RESA System to monitor internal operating temperatures of the specific components of the computer system. The following temperature parameters are monitored: CPU, video processor, harddrive, motherboard and power supply.
Thus far in testing, with a water temperature of approximately 5 ºC, none of the components monitored even approached a precautionary temperature. All were found to be within optimal operating temperatures (see Figure 89 in section 4.1.2 titled Performance Testing). Further testing while deployed will monitor for any additional temperature issues. CPU fan speed and computer operating conditions can be controlled remotely to compensate for temperature fluctuations.

**Humidity**

Humidity within the underwater computer box must be controlled, as extreme changes in temperature throughout the seasons are expected to cause condensation problems without such protection.

First, excess humidity in the air is removed using silica gel, placed in a permeable bag in the computer box. This affords a permanent measure of protection providing the box is not opened once the unit has been deployed. If opening at the surface is required, a new bag of silica gel is recommended to renew the humidity protection. Second, the wires used in the underwater bulkhead connectors are fully tinned, marine grade wires.
3.11. Pan and Tilt

Several pan and tilt units were required to move the camera and light arrays. Upon closer inspection, however, it was identified that the pricing was very high (approximately $5000.00 per unit) and that in-house design and fabrication was possible for a fraction of the cost.

The pan and tilt unit requirements had the following criteria:

1) Close to 180º pan
2) Close to 90º tilt
3) Must be capable of operating in 15 m of water depth

A design was developed and constructed for a pan and tilt unit which would function successfully at a depth of 15 m (Figures 19 and 20).

Figure 19 – Photo rendition of the pan and tilt unit created for the RESA System.
Housing

The unit was constructed from readily available 88.9 mm outer diameter schedule 80, 6061 aluminum alloy pipe (Figure 20). The pipe was then cut into suitable lengths of approximately 305 mm long and 230 mm long. The 230 mm lengths were notched to allow them to mate to the 305 mm pieces at mid-length. TIG welding was used to join the two lengths. The ends were then bevelled to prevent damage to the o-ring seals used on the end sealing units of the motor/drive cartridges.
**Motor / Drive Cartridge**

The drive components for each pan and tilt unit were designed as removable cartridges (Figures 21, 22 and 23). Although the units are designed to provide maintenance-free service for an extended period of time, the ability to replace malfunctioning units with a rebuilt cartridge can significantly reduce the downtime associated with planned and unplanned maintenance. As such, each pan and tilt unit contains 2 drive cartridges. The horizontal tube of the housing has an additional sealing cap as seen in Figure 22.

![Figure 21 - Pan and tilt vertical cartridge. Horizontal cartridge illustrates the same design but is longer to accommodate the tilting platform.](image-url)
Figure 22 - Exploded RESA pan and tilt unit illustrating the additional required horizontal sealing end cap.

Figure 23 - Exploded view of the vertical pan unit. Horizontal tilt unit is of the same construction, but longer.
The end of each cartridge has a sealing unit designed to allow the rotating shaft to exit the housing without allowing water ingress (Figure 22). It was decided that an oil-compensated pan and tilt unit would provide the most reliable service and would also allow the unit to be capable to a much greater depth than the original design requirements. Each end sealing unit contains two oppositely positioned axial shaft seals as recommended by SKF, the seal manufacturer. The seals used were SKF model 5068. This allows the end sealing unit to have the ability to keep water out, with the outer facing seal, while keeping the compensating oil inside the housing, with the inside facing seal. Although the seals are mounted flush against one another, the small void between the sealing lips is filled with waterproof grease. This grease prevents a compressible region in the sealing system and thus transmits the outside water pressure through to the compensating oil. Interior to the seals, each end sealing unit has a ball bearing mounted as a friction fit. The bearings chosen are single row, radial, RBI 1600 series ball bearings (RBI, 2007). This bearing, by the design of the pan and tilt units, accepts a vertical load (to the plane of the bearing race), not an axial load. The RESA instruments which are mounted to the pan and tilt units are configured to be neutrally buoyant using small lead ballast weights. If the pan and tilt units were required to move an instrument with an inherent weight, a suitable thrust bearing could be installed to account for this axial load.

The end sealing units are sealed to the housing using a 4.76 mm rubber o-ring and held in place in the housing by a 7.94 mm 316 grade stainless steel bolt.
**Motors and Drivetrain**

Futaba high-torque, all metal gear servo motors (Model S3305) were used to power the units (Futaba, 2007). Again, availability and cost were prime reasons for using these motors (approximately $50.00). These servo motors are capable of exerting 0.87 Nm of torque at 6 VDC. Each servo is positioned in a tray made of 12.7 mm thick clear polycarbonate by four 12.7 mm long, #6, grade 316 stainless steel screws. The clear polycarbonate allows for an unobstructed view when adjusting the servo and gear positions. The servo tray is held in place by three jack screws, made of 6.35 mm 316 grade stainless steel threaded rod (NC 24 thread), and 6.35 mm 316 grade stainless steel nuts (NC 24 thread). This allows the tray to be moved up and down axially along the length of the rotating rod and to be locked in position once aligned.

Finally, a bearing carrier is used at the end of the cartridge. This provides longitudinal stability for the pan and tilt unit. It is a flush fit with the inside diameter of the housing pipe and is designed to restrict free-play of the interior rotating shaft end. The bearing carrier consists of an aluminum plate 0.79 mm smaller in diameter than the housing pipe. The aluminum plate is fixed in position at the end of the stainless steel jack screws used to hold the servo tray in place. The carrier, through a friction fit, holds a bearing of the same type used in the end sealing unit, thus giving the rotating shaft stability.

Spur gears were used to transmit the power from the servo motor to the drive shaft. The use of gears at this location affords the ability to fine-tune turning radius by using gear sets of different ratios. A 1:1 gear ratio was chosen for these pan and tilt units due to the fact that the servo control boards are capable of overriding the inherent motor control
circuitry of the servo motors and providing almost 180 degrees of safe rotation (as opposed to the approximately 90 degrees of rotation of which the servo motor is designed to move). Boston Gear, gear number S2424 were used to transmit the power from the servo motors to the rotational shaft (Boston Gear, 2004). The spur gears had a 14.5° pressure angle, a bore of 12.7 mm, a pitch diameter of 25.4 mm and 24 teeth. The diametral pitch of the gears was 24. A spur gear with a pressure angle of 14.5° instead of 20° was chosen due to the fact that 14.5° gears are much more forgiving of errors associated with concentricity (Boston Gear, 2004). It was felt this may have been an issue in the first generation of these pan and tilt units. The material options for these types of gears are nylon, steel and brass. For durability and corrosion resistance, brass gears are the obvious choice. Although the correct size of gear was calculated prior to ordering, a set of steel gears were ordered instead of brass in the event modifications to the gears were required. The use of an oil bath to compensate for pressure differences at depth reduced the issue of corrosion of the gear sets. Steel gears are also roughly half the cost of brass and are readily machined. In the end, the gear-size calculations were correct and the steel gears fit as designed.

The spur gears were attached to the servo motor terminal and the drive shaft in two different ways. First, at the servo motor, the existing actuator plate was epoxy glued to the spur gear. Once dry, the spur gear / actuator assembly was drilled and bolted using 12.7 mm long, 316 grade, #6 stainless steel bolts and nuts. The spur gear for the drive shaft was brazed to a stainless steel lock collar, specifically fabricated for this application.
Proper backlash of the gear drivetrain was achieved once the servo motors were in place. The servo motor mounting locations are adjustable to allow for proper backlash. For the torque and particularly the speed of this application, however, and due to the fact that the units are continually bathed in oil, proper backlash adjustments will likely have no impact on the longevity of the gear sets (Figure 24).

![Diagram of gear set and servo motor](image)

**Figure 24 - RESA 1:1 ratio gear set properly meshed.**

The servo wiring connects to a six-wire cable inside the vertical portion of the housing. From there, the six-wire cable exits the housing through a waterproofed junction. The servos operate on 5 volts DC. This is provided by the power supply in the underwater computer box. The two servos per pan and tilt unit run off a common power supply line and feed to a common negative line. Only the signal lines are specific to each servo and are fed directly from the Pololu servo controller in the underwater computer box.
The resulting cartridges can be placed into the t-pipe to create a functioning pan and tilt unit (Figure 22).

**Mounting Plate**

A mounting plate measuring 381 mm x 76.2 mm x 6.35 mm thick (6061 aluminum alloy) is fixed to the top horizontal rotating shaft. This plate is designed to accept a variety of instruments, from the cameras to the lights. Although not shown in Figure 22 for clarity, the mounting plate can be attached either by directly bolting to the driveshaft, or through an intermediate, keyed plate. Currently the keyed plate design is used for ease of removal of the mounting plate during testing.

A bottom plate measuring 127 mm x 127 mm x 6.35 mm thick (5052 aluminum alloy) is attached to the vertical rotating rod to provide a stable point at which to attach the pan and tilt unit to the base platform.

The pan and tilt units are attached to the main base by four 9.53 mm x 25.4 mm 316 grade stainless steel bolts and nuts.
3.12. High-Definition Camera

One of the main goals of this project was to create an underwater platform from which video signals of a variety of types could be streamed to shore-based computers. This goal would then open the door to the creation of intelligent underwater fish and ecosystem monitoring systems. First, however, a system which would be cost-effective, reliable and easily manipulated had to be developed.

In order to accurately identify an underwater object, two key requirements from a video system can be identified. First, the video system must be capable of delivering a picture that contains sufficient information for, at first, a scientist, and later a computer algorithm, to extract valuable data. This means that although under ideal conditions (light levels and clarity) any standard video camera can see, for example, a lake trout, that camera may not be able to tell if it has any distinctive markings (hatchery fin clips, scars, etc). Furthermore, that video camera would most likely not be capable of resolving small details specific to the fish (external parasite loadings, etc). Under less than ideal conditions a standard camera quickly becomes a less than adequate instrument. This is where the field of high-resolution cameras becomes important. A brief discussion of the resolution of cameras, however, is key to further investigation of imaging abilities.

Camera Imaging Characteristics

Camera resolution is a somewhat unclear misnomer. Many cameras are advertised as having “ultra-high” resolution capabilities, or “stunning clarity”. These are often misleading comments which are designed to sell cameras and have absolutely no place in
science. In addition, buzz-words such as “high-definition” also do not adequately describe the capabilities of a camera, as there are several formats. At least, however, the high-definition designation appears to have been reserved for resolutions of a specific benchmark and higher. Therefore a high-definition camera capable of imaging a scene at the accepted high-definition standard of 1080i was chosen. In future, however, the compliance with the 720p or 1080i high definition standards is not something to which a scientific study need pay attention. What is important is the overall quality of image produced by the camera for the specific application.

Interlacing is also a concern when dealing with cameras used for scientific study. Interlacing was important during the use of CRT-based monitors and early television broadcasts. An interlacing camera scans every second line per pass of an image, then scans the skipped lines during the next pass. This unfortunately means that half of the effective data is not recorded per scanning pass of the image. While this is often not an issue for normal videography, for scientific purposes, this can introduce image artefacts which are not desired. Flat panel displays have superseded most CRT monitors for desktop and certainly for laptop viewing and manipulation of video data. These displays are not inherently interlaced and do not natively accept an interlaced image.

The high-definition video cameras chosen for the RESA System are a commercially available unit from SONY, the HDR-HC1 (Figure 25). The HDR-HC1 is a single, 1/2” CMOS sensor-based camera which is capable of 1080i format. It is capable of imaging with a minimum illumination of 2 lux, has a pixel count of 3,200,000 pixels and carries a 10x optical zoom lens (Sony, 2006). These cameras were chosen for a number of
reasons. First, they provide a high-definition video signal which is standardized at a very modest cost ($2000.00 CAN). Second, they are the base camera unit used by the large oceanographic equipment supply companies for the same specifications ($25,000.00 CAN). Finally, they have the capability to be controlled using wired and wireless controllers.

![Sony HDR-HC1 high-definition camera used on the RESA System.](image)

**Figure 25 - Sony HDR-HC1 high-definition camera used on the RESA System.**
Control System

Control of the camera features on the HDR-HC1 can be either through lanc jack control, or infrared control. Lanc jack control is a proprietary format which uses a 2.5 mm phono plug to interface between the computer and the control architecture of the camera. Infrared control was chosen for the camera on the RESA System, so that a diver can control the camera underwater from outside the housing, while still enabling feedback through the infrared controller to the end user. Infrared control through the RESA System is via a serial port infrared emitter.

Video Housing

The video housing is constructed of 127 mm inner diameter, schedule 80, 6061 aluminum alloy pipe. The pipe segment is 305 mm long. A flange measuring 152.4 mm in diameter by 12.7 mm thick was welded onto one end, while a 127 mm diameter, 12.7 mm thick cap was welded to the other side (both made from 5052 aluminum alloy) (Figures 26 and 27). A 152.4 mm diameter, 12.7 mm thick lens was constructed from polycarbonate and attached with 4.76 mm x 38.1 mm long grade 316 stainless steel nuts and bolts.

Housing Failure Analysis

Using the Under Pressure software, the housing water depth of failure was calculated as such:

- Collapse pressure of aluminum cylinder: 2060 m.
- Collapse pressure of polycarbonate lens: 170 m.
Figure 26 – High-definition camera and housing 3d photo rendition.

Figure 27 - Exploded view of the high-definition camera and housing including the camera assembly bracket. Lens mounting bolts excluded for clarity.
Video Connection

Video is exported from the camera via firewire to the underwater computer. This allows a direct link to the computer with minimal processing. The camera pre-processes the video image into the MPEG-2 format.
3.13. Low Light Camera

The low-light camera chosen for the RESA System is a high-sensitivity, low-light, black and white camera. This camera is built into a stainless steel housing and is rated for 2000 m of seawater (Figures 28, 29 and 30).

Figure 28 - Low light camera photo rendition.
Figure 29 - Low light camera housing exploded view. Camera module is removed for clarity.

Figure 30 - Low-light camera used on the RESA System.
The low-light, black and white camera is manufactured by Outland Technologies and is designed to be used in extremely low light environments with a minimum illumination rating of 0.0003 lux (OutlandTech, 2007). It uses a 1/3” CCD imaging chip with a pixel count of 410,000 pixels. It has a 5-conductor SeaConn underwater connector, although only three conductors are active for the RESA application. A short wiring whip allows conversion to the SubConn connector series chosen for the RESA System. Three-conductor SubConn connectors (BH3M and IL3F) were used.

The low-light camera is also infra-red sensitive, and as such can use infra-red illumination to image objects in total darkness. This capability is planned for future versions of the RESA System.

As stated earlier, the video feed from these cameras is taken through the Hauppauge analog input device in order to be accepted by the computer.
3.14. Laser Scaling System

The RESA System uses a simple, but effective, method for measuring and determining scale underwater; a laser scaling system. The laser scaling system uses three lasers per camera to create the required offset and angular notation on an image. First, two of the lasers are spaced equally apart and mounted inline with the camera. The laser dots produced follow a parallel trajectory to the image. Thus, by knowing the distance between the lasers dots, the size of an object being imaged can be determined, either through approximation in real-time, or through later image processing. The third laser is positioned at a known angle to the other two lasers. Thus, by determining the distance between the dots of the angled laser and one of the two parallel lasers, the distance from the camera to the object being imaged can be calculated, again either by estimation in real-time, or through detailed image processing at a later date (Figures 31 and 32).
Figure 31 - Theory of operation of the laser scaling system. Lasers 1 and 2 are a known, parallel distance apart. Laser 3 is at a known angle to the other two lasers. Therefore relative size of the object being imaged as well as its distance to the video camera can be calculated.

Figure 32 - Photo rendition of additional configuration for the laser scaling system.
There are several options for laser devices used in the scaling system. First, solid-state laser diodes are the most practical, as gas-excitation lasers are much larger, require very high-voltage power supplies, and are susceptible to effects from cold temperatures. Of the diode-type lasers, the most cost-effective are the red laser products, in the 635 to 670 nm range. They can be purchased in small quantities and in small overall packages. In addition, the power requirements of such diodes are very low and can often be fed from voltage supplies as small as 5 volts DC. The downside to red lasers is the fact that red is one of the first visible wavelengths of light to be attenuated when it passes through water. This means that low-cost diodes like those found in laser pointers do not exhibit high penetration power underwater. In order to overcome this limitation, red diodes must be used with a much higher power output, which can make them more dangerous while calibrating and setting up the units. Red laser diodes do have the ability to function in a wide range of temperatures and are not prone to shifts in their spectrum. In addition, little heat is generated by red laser diodes.

An alternative to the red laser diodes are the green (532 nm) and blue (473 nm) diodes. These diodes are not true simple laser diodes, like the red laser diodes, but rely on the excitation of green and blue-emitting materials. This is achieved by using a relatively powerful ultraviolet laser diode to strike and hence excite the material. This is called a diode-pumped laser.

Problems with this type of system are that the mechanisms responsible for this to occur are sensitive to their required operating temperatures and humidity levels. This makes them more difficult to use in the underwater environment. Currently, green laser diodes
are more reliable in the underwater environment than the blue laser diodes. This will likely change in the future.

The laser units themselves consist of a 5mW, 670 nm, laser diode head with built in lens and voltage rectifier. They require a 5 volt DC feed to the rectifier. The pressure cylinder used is machined from a solid piece of 6061 aluminum alloy (Figure 33). The housing is machined to accept an underwater connector or crimp fitting. The laser diode itself is positioned into the cylinder using a friction fit (Figure 34). The lens of the laser unit is made from 4.76 mm thick optical-grade polycarbonate. The lens can be affixed to the cylinder using either an o-ring and snap-ring configuration or by simply sealing the lens to the cylinder using a suitable silicone or polyurethane sealant and the overall unit protected with internal sealant shrink-wrap.

Figure 33 - 3D model of laser module used on the RESA underwater scaling system.
Figure 34 - Exploded view of laser module used on the RESA underwater scaling system. Note simplicity of design.

Housing Yield Calculation

Using the Under Pressure housing analysis software, the following failure points were found for the housing:

- Collapse pressure of aluminum housing: 10,554 m
- Collapse pressure of polycarbonate lens: 254 m
3.15. High-Intensity Discharge Lighting

In order to simulate actual sunlight in a shallow-water environment, high-intensity lighting (HID) produced by Underwater Kinetics was chosen (Figure 35). These lights come with a ballast system and function on 12 volts DC. The bulb itself is an 11 W unit. The input voltage is 12 volts DC, while the operational voltage of the HID bulb is 6000 volts DC (UK International, 2007).

The HID system is preferable to many other types of lighting since it more closely simulates the spectrum emitted by the sun. This is particularly important for colour rendition underwater. The colour spectrum of the Underwater Kinetics light module is 6000 K and emits 450 lumens of light (UK International, 2007).
There are several disadvantages to the HID system. First, the cost is significantly more than conventional incandescent and halogen systems. Second, the units require a “warm-up” period prior to emitting full spectrum and intensity. This is also followed by a “cool-down” period during which time the unit must not be re-energized. Although relatively short (approximately 30 seconds) this warm-up and cool-down period can interfere with rapid illumination of unexpected underwater subjects. Finally, the HID systems must operate at full intensity and voltage in order to ensure longevity of the expensive bulbs. Thus, if dimming is a requirement, the units must have a shutter system or other similar feature to lessen the light intensity. A dimming feature is not currently present on the RESA System.

**Construction and Design**

The HID system consists of a pressure cylinder constructed from 6061 aluminum alloy, machined to accept the ballast unit, reflector, bulb, lens port and underwater connector. The lens was made from 9.53 mm thick Makrolon® polycarbonate. A 3D rendering of this unit is shown in Figure 36.
A SubConn, 2 conductor, male bulkhead underwater connector (Model BH2M) was installed in the back of the cylinder and was internally attached to the leads on the light cartridge (Figure 37).
Figure 37 - Exploded view of HID lamp module used on the RESA System.

**Housing Yield Calculation**

Using the Under Pressure analysis software, the following failure points were calculated.

- Collapse of the aluminum cylinder: 2782 m
- Collapse of the polycarbonate lens: 347 m.
3.16. Halogen Lighting

The halogen lighting chosen were 90 W sealed floodlight units made by General Electric. Halogen lights provide an attractive alternative for non, colour-temperature critical applications. These units can be found in both DC and AC voltage applications and in a large variety of sizes. Typical wattage requirements range from small, sub-unit wattages to several thousand watt units. One of the most desirable features of halogen systems is the ability to function without a ballast. Halogen systems are also among the cheapest lighting system to buy.

Three significant disadvantages of the halogen systems are that they often have much higher current requirements per lumen of light output than comparable systems in HID. Second, they tend to generate a significant amount of heat and third, the colour temperature is not that of the sun.

Housing

Each halogen light housing was constructed of 127 mm inner diameter, schedule 80, 6061 aluminum alloy pipe. The pipe segment is 230 mm long. A flange measuring 152.4 mm in diameter by 12.7 mm thick was welded onto one end, while a 127 mm diameter, 12.7 mm thick cap was welded to the other side (both made from 5052 aluminum alloy). A 152.4 mm diameter, 12.7 mm thick lens, was constructed from polycarbonate and attached with 4.76 mm x 38.1 mm long grade 316 stainless steel nuts and bolts (Figures 38, 39 and 40).
Figure 38 - Housing of the halogen lighting system for the RESA System.

Figure 39 - Exploded view of the halogen lighting system used on the RESA System. Lens retaining bolts removed for clarity.
Figure 40 - RESA System halogen lighting system.

Housing Yield Calculation

Using the Under Pressure analysis software, the water depth of failure of the housing was calculated at:

- Collapse pressure of aluminum cylinder: 2060 m.
- Collapse pressure of polycarbonate lens: 170 m.
3.17. Infrared Lighting

Infrared lighting can be used to illuminate scenes imaged by an infrared sensitive camera. The low-light, black and white camera system used on the RESA System is also capable of sensing infrared light. There are basically two wavelengths that are commonly used for infrared video, 880 nm and 940 nm (SCD, 2007). The shorter 880 nm wavelength IR systems provide further distance of coverage, as the light undergoes less attenuation as it travels through the water, but is just on the edge of the visible spectrum. As such, the shorter wavelength systems produce a dull-red glow at the element. The longer wavelength units do not penetrate as far underwater, but cannot be seen by humans. A 940 nm infrared lighting system was chosen due to the fact that the depth of field of the video system underwater is low, and absence of any detectable light from the emitters could be advantageous when studying fish.
3.18. Environmental Sensor Array

An environmental sensor array must accomplish several tasks in a robust and reliable fashion. First, it must provide for in-situ sensors which are capable of collecting the desired data in a specific environment. Second, it must be capable of making sense of the output from the sensors. Finally, it must integrate this information into a form which is acceptable to the end user.

The environmental sensor package chosen for this project is a self-contained multi-parameter unit called the Hydrolab DS5X (Figures 41 and 42). The unit is 8.9 cm in diameter, 58.4 cm long and weighs approximately 3.35 kg (HACH, 2005).
Figure 42 - Hydrolab sensors. The view of the temperature sensor is blocked by the conductivity and DO sensors. Scale not included due to the angle of the photograph.

The Hydrolab communicates with the underwater computer using a standard RS232 interface. The connection to the Hydrolab is through a SeaConn underwater connector at the Hydrolab end and a SubConn 6 conductor male/female junction at the underwater computer box (BH6M and IL6F).

**Temperature**

Temperature is obviously an important parameter to measure when collecting environmental data. Most aquatic life have a specific range of temperatures in which they can comfortably survive. In addition, other parameters such as dissolved oxygen are
critically affected by the ambient temperature of the area. Changes in the hypolimnion in lakes for example, can be directly monitored by a temperature sensing system.

The flux of oxygen throughout a system can vary much depend on the mixing of that system due to wind-induced change. The temperature stratification which normally is the driving force behind oxygen levels deep in a lake can be upset by extreme or prolonged abnormal wind events (Arnsbrak and Wing, 1998). It is important to be able to study the temperature regimes of a water system for extended periods and from a specific, reliable location.

Most modern, conventional temperature sensors use a thermocouple device which produces a voltage based on the conductance of the specific sensor material at a specific temperature. The temperature sensor which has been integrated into this unit has a range of -5 to 50º C with an accuracy of ± 0.10º C (HACH, 2005).

**Depth**

Depth is a critical parameter with which to correlate with other measurements. It is key to understanding the dynamics which may be occurring above, at, or below the thermocline. Depth measurements using solid-state devices use a pressure transducer, which deforms and emits an electrical signal (voltage) upon the application of pressure. The depth sensor has an accuracy of ± 0.05m (HACH, 2005).
Dissolved Oxygen

Measuring dissolved oxygen (DO) is important for many reasons. First, it is often a critical limiting factor for the survival of many fish and aquatic invertebrate species. In addition, DO concentrations can be used to track changes in the nutrient loading of lakes.

Dissolved oxygen (DO) sensors have evolved substantially with increases in technology and the implementation of optical sensors. An earlier type of DO sensor, known as the Clark Cell, with which the RESA System is designed to communicate, uses a non-optical sensor interface. Since the RESA System may be deployed with an earlier Hydrolab for certain locations, specifics of the Clark Cell sensor are as follows: This sensor has a range of 0 to 50 mg/L with an accuracy of ± 0.2 mg/L at DO concentrations ≤ 20 mg/L and ± 0.6 mg/L at DO concentrations ≥ 20 mg/L (HACH, 2005).

The newer generation of dissolved oxygen sensors, which the RESA System currently uses, are an optical fluorescence design (the HACH LDO sensor). Optical fluorescence sensors work on the principal of a consumable module, which, when exposed to oxygen, is oxidized, releasing a fluorescent marker of a specific wavelength. The strength of reflectance is recorded by a spectrometer specifically tuned to the given wavelength and is converted into a measure of the level of DO in the water (Hydrolab, 2007).

This sensor has a range of 0 to 30 mg/L with an accuracy of ± 0.01 mg/L for concentration of DO from 0 to 8 mg/L and ± 0.02 mg/L for concentrations of DO greater than 8 mg/L (HACH, 2005).
**pH**

pH is a reading of the hydrogen ion concentration of the water. It, like DO, can be an important limiting parameter for the survival of many aquatic species. In addition, however, the level of pH can play an important role in the state of many compounds and how they interact with biological organisms. The pH sensor has a range of 0 to 14 units with an accuracy of ± 0.2 units (HACH, 2005).

**REDOX or ORP**

The REDOX level is a measure of the oxidation-reduction potential of the water being tested. Generally, a degraded aquatic ecosystem will show a lower REDOX level than a healthy system (U.S. EPA, 2007).

The ORP sensor has a range of -999 to 999 mV with an accuracy of ± 20 mV (HACH, 2005).

**Specific Conductivity**

Specific Conductivity is a measurement of the ionic concentration in the water. Generally, sodium (Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), bicarbonate (HCO₃⁻), sulphate (SO₄²⁻) and chloride (Cl⁻) ions contribute the most to the overall specific conductivity. This can be due to natural causes (geology) or anthropogenic causes (agriculture, road run-off). As such, conductivity often rises with the spring flush in temperate regions (U.S. EPA, 2007).
The specific conductance sensor has a range of 0 to 100 mS/cm with an accuracy of ± 1% of the reading or ± 0.001 mS/cm, whichever is higher (HACH, 2005).

**Salinity**

Salinity is derived from the measure of conductivity. It is a calculation which has a range of 0 to 70 ppt with an accuracy of ± 0.2 ppt (HACH, 2005).

**Chlorophyll a**

Chlorophyll a is a measure of the “greenness” of the water at the wavelengths generally associated with the reflectance of the chlorophyll a pigments in free floating algae. It is occasionally used to assess the level of nutrients in an aquatic system, as algal blooms can be associated with rises in nutrient levels. Chlorophyll a levels have also been linked with the levels of phosphorous in a system.

The sensor used on the Hydrolab is an optical fluorescence spectrometer which is tuned to sense reflectance corresponding to the pigments present in chlorophyll a. The sensor illuminates the water column with 460 nm wavelength “blue” light. This wavelength is preferentially absorbed by the chlorophyll a pigments. Upon absorbing the light, the chlorophyll a pigments emit 620 to 715 nm “red” light which is detected by the sensor (Turner Designs, 2007). The intensity of the emitted red light is converted into a measure of concentration of chlorophyll a and hence a prediction of the relative concentration of free-floating algae in the water column.
The chlorophyll a probe has a self-switching range of 0 to 500 µg/L, 0 to 50 µg/L and 0 to 5 µg/L with an accuracy of ± 3% (HACH, 2005).

Cyanobacteria

Cyanobacteria are another type of free floating algae, but are a much more concerning species group for issues related to human health. Many cyanobacteria, or blue-green algae as they are often called, produce toxic substances. For this reason, new research has been focused on the ability to detect this group of organisms in a water column. The ability to detect specific toxin producing species has not, however, moved down to cost-effective, in-situ sensors. As such, current commercial sensors are capable only of detecting the presence and abundance of cyanobacteria as a group.

The RESA System Hydrolab can contain a cyanobacteria sensor which functions in the same manner as the chlorophyll a sensor. In this case, cyanobacteria contain a pigment known as phycocyanin (in freshwater). This pigment absorbs 590 nm “orange” light and emits a corresponding 650 nm “red” light (Turner Designs, 2007).

The cyanobacteria probe has a self-switching range of 100 to 2,000,000 cells/mL, 100 to 200,000 cells/mL and 100 to 20,000 cells/mL with an accuracy of ± 3% (HACH, 2005).
3.19. Hydrophone

The hydrophone is an important component of the RESA System. A variety of species are known to make noise, whether vocalizations or natural by-products. In addition, there are a wealth of anthropogenic sounds in the water, many of which are not well understood in their impacts on aquatic and marine species. Finally, the use of sonar tags and other scientific transducers are increasingly being used in aquatic and marine studies. It was important that the RESA System be capable of detecting and processing these sounds and signals.

The hydrophone assembly which was finally selected is the Aquarian Audio AQ15 (Figure 43).
This omnidirectional hydrophone consists of an extremely sensitive element which is capable of picking up and processing sounds from 10 Hz to 100 kHz. To put this in perspective, a healthy human ear can sense sounds ranging from 20 Hz to 20 kHz. This allows the RESA System to “listen” in the subsonic and ultrasonic ranges. This is important for distinguishing many natural sounds (mammals) as well as picking up the specific signatures of sonar tags.

The hydrophone is attached to 15m of shielded, coaxial cable which is then attached to a SubConn 3 conductor female connector (IL3F). This then mates to a SubConn 3 conductor male bulkhead connector (BH3M) on the underwater computer. The hydrophone feed is then connected to the microphone port on the underwater computer with a 3.5 mm phono plug. Finally, the main RESA System platform has a white plastic rod, 38.1 mm in diameter and 152.4 mm long, bolted upright with a 9.53 mm grade 316 stainless steel alloy bolt. This plastic rod is designed to accept the hydrophone element while buffering and damping vibrations from the metal portions of the RESA System (Figure 43). In the event that the operational signals produced by the RESA System overload, it can be attached to an underwater tripod and deployed up to 15 m from the main RESA System. The hydrophone is positioned pointing up in order to maximize its effectiveness while being deployed on the lake/ocean bottom. Provisions for a directional hydrophone assembly coupled to a pan and tilt unit have been made for future upgrades to the RESA System.

A variety of software packages such as Spectrum Laboratory (Buescher, 2007) can then be used to analyze the acoustic signals.
3.20. Sediment Profile Imager

Sediment profile imaging represents a powerful technique for studying sediments at the bottom of a lake, river or ocean. Sediment profiling can quickly identify the presence of pollution, as well as indicating the level of health of the immediate benthic ecosystem. There are basically two designs for sediment profile imagers (SPI’s), a traditional, camera-based system and a newer, scanner-based system.

Regardless of which type is used, the SPI is deployed to the lake/ocean floor and allowed to penetrate the sediment to a predetermined depth. An image is then taken of the sediment in “profile” (Figure 44).
Figure 44 - Typical image taken with a camera-based sediment profile imager.
The camera-based system has been around the longest. It consists of a film or digital camera and strobe, mounted at 90° to the sediment plane of interest. A 45° mirror allows imaging of the sediment profile (Figure 45).

![Camera-based sediment profile imager](image)

The scanner-based SPI is different in design, but not in overall function. The scanner design is much thinner, and does not require a strobe or camera assembly. Instead, a flatbed scanner is modified within a pressure unit to protect the scanner (Figure 46).
The depth of field of view of a scanner-based SPI is much more limited than with the camera-based system. Patterson, et al, 2006 found that the field of view with their system was limited to a focal length of approximately 2mm from the lens face plate, which they noted could be important for automatic classification of images. This can be a disadvantage if imaging of more distant objects or organisms on the surface of the sediment is desired.

The scanner-based systems are significantly cheaper to build and operate. Patterson, et al, 2006 estimated that their unit costs approximately $5000.00 to build. This figure is quite high compared with the unit that was built for the RESA System which costs approximately $1000.00.

Scanner-based systems are able to penetrate the sediment to a much greater degree and
with much less disturbance than the camera-based systems. This is due to the thinner profile afforded by the scanner assembly. The scanner-based systems also give a much larger physical image size of the sediment. This allows a larger sample size for image analysis (Patterson, et al, 2006).

Sediment image profiling allows the study of a variety of parameters connected with underwater sediments. For instance, the following parameters can easily be measured.

- Depth of penetration of the SPI
- Sediment
  - Types and layers
  - Grain size
- Surface boundary roughness
- Depth of detritus layer
- Depth of oxic layer
- Depth of apparent RPD (Redox Potential Discontinuity)
- Oxic voids
- Epifauna
- Benthic invertebrates
- Depth of bioturbation layer
- Methane bubbles and production
- Presence and thickness of contaminants
- Bedform processes
- Organism-Sediment Index calculation

The capabilities of sediment profile imaging have also been exploited to observe changes in benthic communities over a period of time. For instance, Solan and Kennedy, 2002, used a conventional, camera based SPI to image benthic communities over 24 hour periods with sampling times of approximately 30 minutes.
The scanner-based system used on the RESA System consists of a Canon Lide 25 scanner head mounted in an aluminum alloy pressure housing (Figure 46). A 6.35 mm plate glass lens is used to prevent distortion to the imaging plane. USB communication is used to transmit the images back to the RESA System. The RESA System SPI can be deployed up to 7 m from the main platform.
3.21. Power

Delivering power to a RESA System presents many challenges and must be semi-customized for each deployment location, expected duration of deployment and other environmental concerns.

In its simplest context, a RESA System can be powered from shore-based alternating current in the form of 110 volt AC from any ground-fault protected circuit. Since the underwater computer and some of the components run on 110 volt AC, a single feed is all that is needed. The effective deployment distance from shore-based power is dependent on the current draw of the instruments. Higher voltages can be used, allowing a longer run from the shore, but require a step-down transformer underwater to return to the operational voltage of 110 AC. Larger diameter conductors on the power-feed cable are also a consideration to prevent heat build-up and resistance losses.

A second option is that of a buoy-based power supply. This can be in the form of either AC or DC supply. A straightforward approach would be to use a photovoltaic panel to charge a deepcycle battery; the battery would be required for extreme service and would require sealing to prevent water ingress. Power could be transmitted to the RESA System using an inverter of rated capacity.

The use of batteries represents an opportunity to investigate the different types of primary power cells and their application to an underwater device. There are a few standardized battery types which can be readily acquired and connected to a RESA System.
**Alkaline Battery Power**

Alkaline battery power is only to be considered where an application of the RESA System involves an area where access to charging systems is not possible and the instruments will not draw a great current. For example, water quality probes, along with a lower resolution camera would operate acceptably with an alkaline power supply. The computer running the unit would have to be solid state, with no moving parts (i.e. harddrives and fans). In addition, the pan and tilt units would likely not be possible.

Alkaline batteries do have a tendency to off-gas hydrogen, so hydrogen absorption media is advisable for the battery container (Bradley et al, 2001). In addition, the rating of approximately 1.5 V per cell necessitates the building of battery packs to achieve the desired voltage of the inverter (12 or 24 V DC) or the operational voltage of the system hardware (5 and 12 V DC).

**Lead Acid**

Lead acid batteries are a common and cost effective option for powering a RESA System. They are easily obtained in a variety of capacities and voltages (although 12 V is the most common). Lead acid batteries can be found in gel and sealed formats which allow them to be placed in unstable locations without the threat of a spill. Although sealed and gel battery formats are claimed to be sealed, in actual fact some hydrogen off-gassing may occur during recharging (Bradley et al, 2001). This potential hazard must be dealt with using hydrogen absorbing material (if enclosed underwater), or with a breathable surface protective box.
Ni-Cad

Ni-Cad, or nickel cadmium batteries present a high energy power option for the RESA System. They can be attached to a charging station, either prior to deployment, or during, such as a buoy-mounted photovoltaic panel. If improperly charged, Ni-Cad batteries are prone to developing an internal resistance, better known as memory, which can reduce the effective current it can supply over its lifetime. Cost is generally greater than an equivalent lead acid system (Bradley et al, 2001).

NiMH

Nickel Metal Hydride (NiMH) batteries are an attractive option. They do not exhibit the same “memory” problems as NiCads, and have excellent discharge characteristics (Digikey, 2007). The cost, however, is often more than conventional Ni-Cad batteries.

Lithium

Due to the danger associated with unstable current draws on lithium-based (primary, ion and polymer) batteries, they will not be considered at this time for deployment in an unforgiving environment.

120 V AC Shore Deployment

When a shore-based deployment is desired, the RESA System may be powered using conventional 120 volt alternating current. In order to effectively deliver suitable power to the system, the conductor must be sized according the output capability of the RESA System. For most applications, where the wire is simply laid along the bottom, armouring is desired to prevent damage from anchors, possible wind-induced rock
movement and animal life. It is also desirable to use aluminum armouring. In the event of a compromise to the waterproof exterior, internal rusting will not occur.

It is recommended that “TEK” type cable be employed for shore-based power options. This cable, from a variety of manufacturers, is basically a core of stranded or solid copper conductors and is surrounded by a water blocking material (gel or fibre). This inner conductor weave is then covered with a waterproof coating. This coating is then overtopped with a wound metal armour. The armour is then coated with a second waterproof coating. This type of cable can then be laid along the bottom without the need for trenching.

**Main Power Feed**

The main power feed is through a double sealed “TEK” type cable. This cable features a wound metal armour sheath between the seals. The conductors are standard stranded copper conductors. The Kingston test site is approximately 100 m from its shore-based electrical connection. For an expected maximum current of 4.5 amps at 110 VAC and an acceptable line loss of 3%, a #10 conductor is required. The main power feed cable is laid along the bottom from the shore to the RESA System and enters the computer box through a 3-conductor SubConn connector set (BH3M and IL3F).
Wiring Diagrams

The wiring system for the RESA System is designed around a common distribution system for the different voltages and ground requirements. Where possible, colour coding for the different DC voltages was maintained from the power supply in order to prevent confusion. Please see Appendix 1 for detailed wiring diagrams for the instruments currently installed on the RESA System.
3.22. Cathodic Protection

The nature of materials underwater present a dilemma as far as the protection of the instruments against galvanic corrosion. Galvanic corrosion occurs because each metal has an inherent electrical potential voltage (table 2).

Table 2 - Galvanic potential of common metals in seawater (Dexter, 2007).

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Voltage Range of Alloy versus Reference Electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>-1.60 to -1.63</td>
</tr>
<tr>
<td>Zinc</td>
<td>-0.98 to -1.03</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>-0.70 to -0.90</td>
</tr>
<tr>
<td>Cast Irons</td>
<td>-0.60 to -0.72</td>
</tr>
<tr>
<td>Steel</td>
<td>-0.60 to -0.70</td>
</tr>
<tr>
<td>Manganese Bronze</td>
<td>-0.25 to -0.33</td>
</tr>
<tr>
<td>300 Series Aluminum</td>
<td>-0.00 to -0.15</td>
</tr>
<tr>
<td>Titanium Alloy</td>
<td>+0.06 to -0.05</td>
</tr>
</tbody>
</table>

As one moves up the table, the metals become more reactive and behave as an anode. Corrosion occurs in the anode material. The greater the difference in potential voltages, the faster the anode material will corrode. Thus combining a titanium alloy with magnesium underwater would result in a rapid corrosion of the magnesium material.

One way to reduce the effects of galvanic corrosion is to design the underwater components to have as small a cathode to anode (C/A) area ratio as possible. For the
RESA System, a very low C/A ratio was accomplished by using all aluminum for the underwater structures and stainless steel only for the fasteners and low-light, black and white camera.

Upon deployment, if corrosion does appear to be an issue, sacrificial zinc anodes can be attached to the System to protect the overall structure from damage.
3.23. Control System

The RESA System control software, although it uses a web interface, uses Service Oriented Architecture (SOA) for its basic services. Service Oriented Architecture or SOA is a new field of programming philosophy which has developed in the last few years. It aims to develop a reusable style of programming which is designed to reduce the overhead required for typical programming.

A basic analogy is required. For example, if it is desired to move the pan and tilt unit on a RESA System to the right 5 degrees, instead of writing a command script to move the pan and tilt specifically to the right by 5 degrees, a SOA program would call a generic service. This service, call it “MOVE SERVO”, is generic for all servo movement. The “MOVE SERVO” service will contain all the required information to properly move a servo motor, and can be reused to move the pan or tilt servos in any of the pan and tilt units in any direction and by whatever specific amount without the need to write specific scripting.

This philosophy carries over into all the areas of the programming for the RESA System. For example, authentication routines for authorized users are accomplished using an “AUTHENTICATE USER” service as is a generic “SWITCH LIGHT” service for turning the RESA System lights on and off.

This new way of thinking is still in its maturation stage and some of the features which were originally in its concept have not been ratified in the most recent released of the standards. The following, however, are modules within the current standard.
SOAP

SOAP is basically the service command script. It is what makes the service accomplish its intended tasks. SOAP is a basic language which contains a header of information and a command sequence.

WSDL

WSDL can be seen as a descriptor language which basically tells the system how to interpret and use the service command script.

UDDI

UDDI is a directory system which is currently in the design phases, but basically it contains a repository of available services, a description of their intended function and where they can be found. A program using the SOA philosophy can use this directory to find and activate services.
Client Interface

Control and manipulation of the RESA System is through a web-based interface. It is basically a website portal that is housed on the underwater computer. This feature is important as it allows any authorized user with an internet connection to access and control a RESA System.

Workflow Example

In order to understand how the RESA System control works, a hypothetical walk-through from deployment to access by a user is presented below. Please refer to Figure 47 for a coarse scale overview of the possible networking for such a scenario.

A RESA System (called RESA01) is hypothetically deployed in the Atlantic Ocean in Halifax Harbour. It will be joining a group of 5 other RESA Systems already in place in the Harbour. The shore connections are established and the RESA01 is powered-up underwater for the first time. Immediately, RESA01 automatically establishes contact with a central directory service housed back at the researcher’s laboratory at Queen’s University, Kingston, Ontario. RESA01 tells the directory service that it is functioning and ready to feed data. The central directory service then adds RESA01 to its list of available units.
Figure 47 - Coarse scale networking for the example scenario of RESA Systems in Halifax Harbour.
Now, for example, a researcher, in Kingston, who is authorized to access the Halifax Harbour RESA Systems, connects to the directory service, using the login screen (Figure 48).

![RESA Control](RESA_Control.png)

*Figure 48 - Screen shot of log in service for the RESA Systems.*
Once logged in as an authorized user, the researcher is presented with a list or “directory” of RESA Systems currently available to him or her (Figure 49). The RESA Systems (1 to 6) in Halifax Harbour will be listed in the directory. Depending on the researcher’s involvement with other projects, there may be additional RESA Systems available to him or her and will be listed along with the Halifax Harbour group.

The researcher, interested in RESA01, selects the “Connect” feature and is connected directly to RESA01 at the bottom of Halifax Harbour.
The software systems can be configured to lock access to any of the RESA Systems when another user is currently connected (Figure 50). For instance, if requested, RESA01 could be locked from additional user access during the current session. Other RESA Systems in the grid, however, would remain active and accessible.

![RESA Control](image)

**Figure 50 - RESA System session lock-out feature.**
Upon connection to RESA01, the researcher is presented with an instrument “dashboard”. This dashboard presents the researcher with control modules for each of the instruments RESA01 carries (Figure 51).

The researcher is then free to record and stream any data from RESA01.
Hydrolab Data

The water quality sensor data can be viewed in real-time from the website, or can be streamed in real-time to the user’s computer and stored. Streaming the data comes in the format of a delimited text file which can then be imported into any spreadsheet package.

Underwater Lighting

The underwater lighting consists of an on/off switch (for HID, halogen and infrared) and a brightness dimmer function for the halogen lighting.

Laser Scaling System

The laser scaling system is activated using the on/off switch on the web interface.

Video Streaming Service

The high-definition and low-light video cameras use the VLC Media Player video server to move the video data. This video device is an open source package which is freely available from www.videolan.org. The RESA System contains scripts which automatically initiate the video streaming server and transmit the video data to the requesting user. As such, concurrent streaming sessions are possible (i.e. streaming high-definition and low-light video at the same time) although bandwidth requirements are significant for this to occur. The user can then record the video stream in most conventional video formats.

One requirement of using the video features on the RESA System is that the user must download and install VLC prior to initiating a successful video feed. Once installed,
however, activation of VLC is automatically initiated by the RESA System from which the video stream is requested.

An example of the video feed from the high-definition camera (Figure 52) and low-light, black and white camera (Figure 53) are shown below.

Figure 52 - Example high-definition video stream screen shot taken during laboratory testing.
The video data is streamed to the user in the following encapsulation formats: MPEG TS, MPEG PS, MPEG 1, Ogg, ASF, MP4, MOV, WAV and Raw depending on the user’s preference. MPEG TS has been selected as the default format and will automatically stream in this form without user input. Laboratory testing during the development of the RESA System showed that this format was the most robust and produced the cleanest video results.

The native video data formats from the cameras are different from the stream format. The high-definition camera encodes the video data into the MPEG 2 format, which is
then exported to the underwater computer. The low-light camera exports its video in the RAW format. This is then encoded by the underwater computer into the MPEG 2 format. The video can, however, be transcoded into another encoding format of the user’s choice as it is streaming. The following video encoding formats are available to the user: MPEG 1, MPEG 2, MPEG 4, Divx 1, Divx 2, Divx 3, H263, H264, WMV1, WMV2, MJPG and Theo.

When choosing an encoding option, there are a few things the user must consider. First, when discussing video encoding, the first decision which must be made is whether the goal is a lossless encoding or a lossy encoding. The differences, although possibly not overly apparent when viewing small video files, become an important consideration when discussing large images and video files and those which will be used for scientific study.

**Lossless Encoding**

Lossless encoding is designed to shrink the overall data size of a video file while at the same time maintaining the overall image quality of the original. Basically all the information contained in the original video file are contained in the encoded image and file but with a smaller data size. The H263 and H264 image compression standards are examples of lossless image compression algorithms (Sikora, 2005). Unfortunately, the ability to compress to a high degree is often not possible with this form of compression.
Lossy Encoding

Lossy encoding is a method by which the data associated with an image and video file is reduced and results in a smaller file size (Sikora, 2005). The resulting image quality is less than the original and as such, can result in substantial reductions in file size and bit rate. JPEG, MPEG and ITU are examples of lossy compression algorithms. Since video quality will naturally be degraded, it is a fine balancing act between size and quality, which may be reduced to a point at which the scientific use of the image may be compromised.

The ability to compress a video file with a lossy encoding algorithm very much depends on the nature of the original video file. A video file with simple, rather than complex images and motion will undergo less degradation of the image quality (Sikora, 1997).

In the end, however, each scheme, whether lossless or lossy, simply approaches the problem of enormous data files created from movie images and attempts to reduce their size while having the least affect on the overall quality (Sikora, 1997).

The second consideration to the end user is the ability of the video file to be scaled. Scaling allows a full-sized video image to be quickly reduced in size in real-time, while theoretically not effecting the overall video image. This can be an important feature for moving a large video image to a colleague’s computer for simple video review, not in-depth scientific analysis.
**Nonscalable Video Compression**

Nonscalable video compression creates a single feed of compressed video (Wu et al., 2001). This means that if a signal is compressed at full quality, then the destination user can only view and manipulate this full quality feed. This presents problems for quick viewing or viewing over networks without the dedicated quality of service to handle such data flow. In addition, a computer capable of decoding this compressed feed is also required, to prevent the dropping of video frames and other quality degradation issues. MPEG-1 is an example of a nonscalable video compression standard (Ohm, 2005).

**Scalable Video Compression**

Scalable video compression on the other hand adds the capability to compress multiple streams of video data at different resolutions (Wu et al., 2001). This allows the base, low resolution feed, to be the initial feed for a video transmission. For instance, a user with a slower computer or who is on a slow network, can receive the low bandwidth, low resolution feed first, before deciding to receive the full quality feed. If the full quality feed is chosen, then the two signals can be combined for the best possible quality. The data feeds can often be “scaled” with respect to one or more of the following criteria: image quality, image size, or frame rate (Wu et al., 2001). MPEG-2 is an example of a scalable compression standard (Ohm, 2005).

**Streaming Style**

The RESA System has an important additional feature for the end user, that of re-streaming capabilities through the VLC service. The user can stream in real-time to other colleagues after receiving the main video stream from the RESA System. This allows the
user to maintain control of the RESA System while still sharing the video data. This can be accomplished by streaming directly to the additional user’s IP address using what is known as a unicast transport scheme. This allows only the user specified to view the video to gain access. On the other hand, if a larger group of researchers is involved with viewing the video, a multicast transport scheme can be used. This method effectively turns the user’s computer into a video broadcast hub to which any user can connect and receive the video feed.

**Hydrophone**

The acoustic data sent by the hydrophone is transmitted to the user in much the same fashion as the video feed. It uses the audio streaming capabilities of VLC. The user, after selecting the hydrophone feed, automatically receives the acoustic data with similar scripting to the video streaming. The audio feed can then be recorded in a variety of formats to the user’s preference.

Like the video streaming service, the audio streaming service uses a streaming format. The same formats are available to stream the audio and like the video, the MPEG TS is automatically set as the default format. The audio from the hydrophone is in the form of a raw audio feed. It can also be transcoded into a variety of formats depending on the user’s preference. The following encoding options are available: mpga, mp2a, mp3, mp4a, a52, vorb, flac, spx, s16l and fl32.
3.24. Network Description
In order to fully understand how the RESA project works, a discussion of the available networks in Canada and networking in general is in order. For this discussion, an advanced network will be used to denote a single or multi-mode fibre optic network.

High Level Fibre
On its coarsest scale, there is a fibre optic backbone which traverses Canada, from east to west which is dedicated to scientific high-bandwidth applications. It is called CA*Net 4. Traditionally this network has been used for data-mining exercises between universities (High Performance Computing Lab, Queen’s University for example) and to provide data pipelines for large scale users (Synchrotron, University of Saskatchewan). This fibre backbone consists of single mode fibre running from major centers (Figure 54).
Most often, this fibre is bought or leased from the original deployers (utilities, etc) although recent additions can be traced to deployments by CANARIE directly (CANARIE, 2007). The connection of Canada’s north however, was accomplished by a satellite link to CANARIE from Iqaluit. For obvious reasons, the accompanying corridors conventionally used for laying fibre (utility lines) do not exist in a connective web to the north.
CA*Net 4 functions on two levels. First, through User Controlled Lightpaths (UCLP’s) and second, through conventional shared internet infrastructure. The UCLP capabilities of CA*net 4 are especially suited for users requiring large bandwidths and dedicated quality of service. UCLP’s can be established dynamically using special software systems created by CANARIE which basically lock a portion of the bandwidth along a corridor of CA*net 4 so that a dedicated amount of bandwidth is available to a specific project. This has the benefit of allowing data intensive activities to proceed without disruption, however it is not as user-friendly as the conventional system. In addition, streaming data to multiple users is not as easy with the UCLP system.

The conventional internet system in CA*net 4 is basically an ultra-high speed internet system which is shared amongst its users. This can lead to quality of service issues if the bandwidth requirements are extremely high. For the RESA application, the conventional internet system functionality of CA*Net 4 will be used as a default since it is more than adequate for this thesis. In the event, however, that a large number of RESA Systems are deployed for a given project, particularly in a localized region, the UCLP’s would be advantageous, as the bandwidth coming from that region of deployment would be such that a dedicated quality of service is required.

CA*Net 4 is a hybrid system, in that it only connects to certain institutions and facilities throughout its range. Most connections to CA*Net 4 come through connectivity provided by what is called an Optical Regional Advanced Network (ORAN). An ORAN is basically the provincial equivalent of CANARIE and is a research network established and maintained by a similar non-government, provincially-funded organization. It is this
regional network which connects the vast majority of research users within a province and ultimately, if required, makes the connection to CA*Net 4. For the RESA project several ORANS were used. Specifically Ontario’s ORAN, called the Ontario Research and Innovation Optical Network (ORION) was used (Figure 55). ORION is the connection that Queen’s uses to communicate with other Ontario-based partners, as well as a gateway to CA*Net 4.

![New ORION Network Topology - Fall 2006](image)

**Figure 55 – The Ontario Research and Innovation Optical Network (ORION, 2006).**

Use of this fibre is donated to scientific applications on a needs basis and is provided at 6 month windows of use.
Local Connectivity

The connectivity of the RESA System is very custom and ultimately depends on the proximity of an advanced network loop if high-bandwidth intensive instruments such as the high-definition cameras are to be used outside of the immediate vicinity. For example, a direct connection to a RESA System by an organization which does not intend to move the data outside its own facility does not normally require an advanced network. If on the other hand, multiple users at different facilities wish to acquire data from and manipulate a RESA System, or there are multiple RESA Systems connected in a grid fashion, then some type of advanced network or hybrid network is required to prevent bottlenecking of the data and loss of quality of service.

For the connection at the Utilities Kingston long-term test site in Kingston, a conventional 1 Gbps Ethernet connection is planned from the shore to the RESA System. There will be a shore-based media converter which will be used to convert the signal to an optical signal capable of being transmitted over the fibre optic network of Utilities Kingston. The single-mode fibre will run a distance of approximately 50 m to the main filtration plant building where it will be added to a network switch, giving access to Kingston Utilities’ fibre optic corridor running along King Street. From there, the signal will be passed to the Queen’s Central Heating Facility at the Junction of O’Kill Street and King Street. From the Central Heating Facility, the data then will then be relayed to one of the main Queen’s network switches which then gives direct access to ORION as well as any office or lab located within Queen’s University.
The connection at the Cornwall test site will be slightly different. Approximately 2 km of single-mode armoured fibre will be connected directly with the underwater computer. This fibre then connects to a media converter on-shore at the St. Lawrence River Institute of Environmental Sciences. The data will then be transmitted through the St. Lawrence College network infrastructure, back to Kingston and through Queen’s networks, to ORION.
Chapter 4. Laboratory Performance and Testing

The RESA System was tested in a controlled environment at the Coastal Engineering Laboratory at Queen’s University. Testing occurred in the following format: component testing, system testing and performance testing.

4.1. Component Testing

Each of the components were tested for a variety of parameters specific to their ultimate function. Unless otherwise specified, testing was conducted in a 2 m x 30 m test tank.

Pan and Tilt

The pan and tilt units are controlled by the Polulu servo controller. Since the servo controller is capable of over-riding the inherent electronic stop-point of the servos, it was necessary to calibrate the degree of rotation and tilt in order to ensure that the motor/drive units did not physically bind at the extremes of their movement. Initially, the pan and tilt units were set-up to allow the full movement of the servo motors. It was quickly determined, particularly for the tilt motor/drive units, that this resulted in the instrument mounting plates contacting the main housing of the pan and tilts causing jamming of the servo motors and gear assemblies. Binding leads to stall loading of the servo motors lessening their service life.
The pan units were calibrated first. It was found that a rotation scheme allowing 225 ° of rotation was the maximum range of motion which did not result in binding of the servo motors. This was accomplished using the following pulse-width values, sent from the Pololu control board to the servos:

Minimum rotation point (0°) using a 125 microsecond pulse  
Neutral or centre point (112.5°) using a 750 microsecond pulse  
Maximum rotation point (225°) using a 1350 microsecond pulse

For the tilt motor/drive units, a rotation of 90 ° was found to provide the maximum range of motion, while protecting the servo motors from stall loading. The following pulse-widths, sent from the Pololu control board to the servos, were used to accomplish this tilt range:

Minimum tilt point (0°) using a 475 microsecond pulse  
Neutral or horizontal point (45°) using a 820 microsecond pulse  
Maximum tilt point (90°) using a 1160 microsecond pulse

During laboratory testing, it was found that the pan and tilt motor/drive units returned to the same locations when given these specific duration electrical pulses.
Sediment Profile Imager

The sediment profile imager was tested in the laboratory to ensure that the components operated freely within the underwater housing. Although it was not within the scope of this thesis to perform field testing, a lack of suitable and realistic underwater sediment profiles at the laboratory prompted testing of the scanner in the field to ensure that profile images of sediment could be obtained. The sites which were imaged represent easily accessible locations. Future testing at an actual deployment site will be required to chart changes in the measurable parameters outlined in Chapter 3 (REDOX discontinuity, bioturbation, etc)

First, a section of fairly uniform clay bottom was tested. The profiler was inserted approximately 20 cm into the bottom and an image was taken (Figure 56).
Figure 56 - Sediment profile image of uniform sediment.
As can be seen from Figure 56, the profiler was able to image both gas and water filled voids within the bulk sediment. In addition, the surface texture is visible along with light variations in composition of the sediment.

Next, profiles were taken in a small, slow flowing tributary of a bog-type wetland. This location, transited extensively by beavers, presented an excellent site to image sediment and rich organic matter, which is regularly re-suspended and mixed.

The first image taken at this site was in shallow water (Figure 57) where the imager was inserted approximately 20 cm into the sediment. The water-surface interface can be clearly seen, along with the fine upper sediments. Denser sediments and organic material can be observed lower in the image. Of interest is the presence of a green frog (*Rana clamitans*) which was not disturbed with the insertion of the profiler (Figures 57 and 58).
Figure 57 - Sediment profile image taken in a small tributary of a typical bog environment. Note the frog which sat undisturbed during the process of inserting and scanning the sediment.
Figure 58 - Close-up of frog sitting on the surface of the channel which was imaged.

A second image was taken in the same vicinity (Figure 59) and clearly illustrates the profiler’s ability to image sediment layers of differing composition.
The profiler was then moved to a deeper section of the channel and an image taken (Figure 60). There is a clear difference between the fine sediments and the darker, denser sediments and debris.
As can be observed in Figures 56 to 60, the SPI produces high clarity images which are suitable for additional image processing. The SPI carries a native resolution of 1200x1200 pixels per square inch. As such, pixel size counts can be used to determine the parameters discussed in Chapter 3 (sediment depth, grain and particle size, etc). In addition, this type of image is also suitable for further image classification analysis, such as edge detection and contour tracing. Please refer to Figure 59 as the image to be analyzed and note that Coral Photo-Paint X3 was used for this analysis (Corel Corporation, 2005). First, but applying an edge detection classification, the regions of different sediment / material type can be quickly identified (Figure 61). The depth of the different layers can then be easily measured. For instance, the depth to of the coarse sediment, from the water surface at point A, is measured at 252 pixels. When calibrated against the image scale, a depth of 2.15 cm results. The depth of the fine sediment itself, at point B, measures 117 pixels. This translates to a depth of 1.0 cm.

Figure 61 – Solid line edge detection filter applied to Figure 59.
Edge contour tracing can also be used to distinguish the complexities and discontinuities found within the interface between different sediment types. Figure 62 illustrates a contour tracing filter applied to Figure 59. This tracing reveals the uneven nature of the interface between the fine sediment and the deeper, coarse sediment / material. Of note is the tracing of the leaf found in Figure 59.

![Fine Sediment / Coarse Sediment Interface Outline of Leaf](image)

**Figure 62 – Edge contour tracing filter applied to Figure 59. Note tracing of leaf.**

Additional image classifications can be applied to the images produced by the SPI, such as classified and unclassified spectral classifications.

**Hydrophone Data**

Like the other components, the hydrophone testing was conducted at the Coastal Laboratory. This environment did not present the natural and human noises which would be expected in a lake, river or ocean setting. There was, however, a substantial amount of background noise from machinery and electrical systems which were present during
the testing. Figure 63 illustrates a sample underwater acoustic recording which was taken at the coastal laboratory and visualized using Spectrum Laboratory.

![Figure 63 - Example acoustic signature taken in the laboratory using the Spectrum Laboratory software analysis package.](image)

The acoustic recording taken within the Coastal Laboratory detected frequency specific signals. It is likely that these signals represent the background machinery and electrical noise within the laboratory and the RESA System itself. This illustrates the requirement to undergo a detailed background calibration of the hydrophone once it has been deployed, in order to account for background noise specific to the deployed location. This will assist in the filtering of unwanted or extraneous noises during deployment. It was noted that the hydrophone is extremely sensitive to noises and movement transmitted through the structure to which it is attached. Upon deployment for long-term testing, a decision will have to be made as to whether the hydrophone must be positioned away from the actual RESA structure in order to reduce noise transmission from the RESA
electronics and motor drives. The hydrophone assembly, as described in Chapter 3, was provisioned with a 15 m cable to allow for this configuration.

**Laser Scaling System**

As stated in Chapter 3, the requirements of the laser scaling system were to measure the size of objects imaged by the video camera, as well as their relative distance to the camera. As such, the laser scaling system was tested for its performance in two ways. First was its ability to allow the user to measure the length of a target underwater and second, to determine the distance of the target from the camera.

Both testing phases were completed using a scaled board with lines of known distance separation (targets #1 and #2) (Figure 62). Although initially both targets were set-up to measure 15 cm in length, during deployed underwater, the target lengths were disrupted slightly. Target #1 was then found to be 14.9 cm in length while target #2 was 15.1 cm in length. The targets were imaged an average of 30 times at distances from the camera of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5, 5.5 and 6.0 metres. The open-source image analysis package, ImageJ (NIH, 2007) was used to calibrate the number of pixels per cm in each image. This was then used to measure the target lengths as well as the separation of the angled laser from the left parallel laser mark. The latter was used to determine the distance of the target board from the camera.

The laser scaling system was first tested with the high-definition camera (Figure 64). Although images were taken from 0.5 m to 6.0 m, the ability to properly and accurately distinguish the targets was not possible at distances greater than 5 m. The angled laser
was not clear in the images beyond 4.0 m. This is due to variability in the quality of the laser diodes.

![Figure 64 - Laser testing target scale for the high-definition camera. Test was conducted underwater in a 5m x 300 m test tank.](image)

Using the high-definition camera, it was possible to measure target #1 to within an average of 0.3 cm in length, with its highest accuracy of 14.9 cm at a distance of 50 cm from the camera (Table 3 and Figure 65). Accuracy appeared to increase, the closer the target was to the camera (Figures 66).

<table>
<thead>
<tr>
<th>Distance to Target #1 (cm)</th>
<th>Measured Length of Target #1 (cm)</th>
<th>Standard Deviation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>14.90</td>
<td>0.04</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>15.11</td>
<td>0.05</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>15.09</td>
<td>0.04</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>15.13</td>
<td>0.05</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>15.14</td>
<td>0.06</td>
<td>30</td>
</tr>
<tr>
<td>300</td>
<td>15.11</td>
<td>0.09</td>
<td>30</td>
</tr>
<tr>
<td>350</td>
<td>15.20</td>
<td>0.09</td>
<td>30</td>
</tr>
<tr>
<td>400</td>
<td>15.22</td>
<td>0.07</td>
<td>29</td>
</tr>
<tr>
<td>450</td>
<td>15.10</td>
<td>0.11</td>
<td>12</td>
</tr>
<tr>
<td>500</td>
<td>15.28</td>
<td>0.19</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 65 – Target #1 length as measured with the laser scaling system. The actual value (shown as a green line) was 14.9 cm in length.

Figure 66 – Target length means and standard deviation error bars for target #1 with the high-definition camera. The actual value of 14.9 cm is shown as a green line.
The measurement of target #2 was slightly different than target #1. It was possible to measure target #2 to within an average length of 0.64 cm, with its closest value being 15.17 cm at a distance of 400 cm from the camera (Table 4). The average measured values for target #2 had a higher accuracy above 150 cm distance than when closer (Figures 67 and 68).

Table 4 - Target #2 length measurements and standard deviation values.

<table>
<thead>
<tr>
<th>Distance to Target #2 (cm)</th>
<th>Measured Length (cm)</th>
<th>Standard Deviation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>N/A</td>
<td>0.04</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>15.65</td>
<td>0.07</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>15.33</td>
<td>0.04</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>15.23</td>
<td>0.04</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>15.25</td>
<td>0.06</td>
<td>30</td>
</tr>
<tr>
<td>300</td>
<td>15.22</td>
<td>0.08</td>
<td>30</td>
</tr>
<tr>
<td>350</td>
<td>15.20</td>
<td>0.06</td>
<td>30</td>
</tr>
<tr>
<td>400</td>
<td>15.17</td>
<td>0.08</td>
<td>29</td>
</tr>
<tr>
<td>450</td>
<td>15.24</td>
<td>0.11</td>
<td>30</td>
</tr>
<tr>
<td>500</td>
<td>15.26</td>
<td>0.18</td>
<td>29</td>
</tr>
</tbody>
</table>
Figure 67 - Target #2 length measurements for the high-definition video camera. The actual value of 15.1 cm in length is shown as a green line.

Figure 68 - Target #2 mean length measurement and standard deviation error bars for the high-definition video camera. The actual value of 15.1 cm is shown as a green line.
Next, the ability of the high-definition video camera and laser scaling system to measure the distance to a target was tested. The high-definition camera was able to measure the distance of the target board to within an average distance of 6.36 cm of its actual value (Table 5, Figures 69 and 70). The highest accuracy was found at an actual distance of 150 cm with an average measured value of 150.36 cm.

<table>
<thead>
<tr>
<th>Actual Distance (cm)</th>
<th>Measured Distance (cm)</th>
<th>Standard Deviation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>58.78</td>
<td>0.86</td>
<td>26</td>
</tr>
<tr>
<td>100</td>
<td>103.22</td>
<td>1.37</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>150.36</td>
<td>1.39</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>198.72</td>
<td>1.38</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>245.50</td>
<td>1.77</td>
<td>30</td>
</tr>
<tr>
<td>300</td>
<td>297.06</td>
<td>2.36</td>
<td>30</td>
</tr>
<tr>
<td>350</td>
<td>347.10</td>
<td>3.23</td>
<td>30</td>
</tr>
<tr>
<td>400</td>
<td>397.14</td>
<td>4.05</td>
<td>17</td>
</tr>
<tr>
<td>450</td>
<td>446.36</td>
<td>N/A</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 5 - Distance to target board from the camera.

Figure 69 - Distance to the target board measurements from the high-definition camera.
Next, the laser scaling system was tested with the low-light, black and white camera (Figure 71). The high sensitivity of the low-light camera made determining a distinct, small, laser point difficult, as the intensity of the spot tended to overwhelm the image at close range. Since this is a factor of the image-intensifying capabilities of the camera, the only feasible way to address this issue would be to reduce the power of the laser diodes. This would have the negative effect of reducing the viewable distance of the lasers.
The low-light, black and white camera, using the laser scaling system, was able to measure the length of target #1 to within an average of 0.72 cm, with its closest average measurement of 15.18 cm at a distance of 2.0 m (Table 6).

As can be seen from Figures 72 and 73, the ability of the black and white camera to measure objects with confidence falls within an “optimal” area of 0.5 m to 2.0 m. The difference noted at greater distances is likely to due to the fact that the clarity of the image makes measuring fine details at length difficult, and the wide-angle lens associated
with the camera may be introducing artefacts which may impede the accuracy of the measurements.

Figure 72 - Target #1 length measurements for the low-light camera. The actual value of 14.9 cm is shown as a green line.
Figure 73 - Target #2 length means and standard deviation error bars for the low-light camera. The actual value of 14.9 cm is shown as a green line.

The black and white camera was able to measure, using the laser scaling system, the length of target #2 to within an average of 0.75 cm with its closest average measurement being 15.20 cm at a distance of 1.5 to 2.0 m (Table 7).

Table 7 - Target #2 length measurement averages and standard deviation values taken with the low-light, black and white camera.

<table>
<thead>
<tr>
<th>Distance to Target #2 (cm)</th>
<th>Measured Length (cm)</th>
<th>Standard Deviation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>15.71</td>
<td>0.22</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>15.25</td>
<td>0.14</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>15.20</td>
<td>0.13</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>15.20</td>
<td>0.26</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>14.76</td>
<td>0.62</td>
<td>30</td>
</tr>
<tr>
<td>300</td>
<td>15.63</td>
<td>2.10</td>
<td>30</td>
</tr>
</tbody>
</table>

As can be seen from Figures 74 and 75, the accuracy of the laser scaling system began to decrease from a distance of 2.0 m from the black and white camera.
Figure 74 - Target #2 length measurements for the low-light camera. The green line illustrates the actual length of 15.1 cm.

Figure 75 - Target #2 length means and standard deviations for the low-light camera. The actual length of 15.1 cm is displayed as a green line.
The distance to target measurements were also conducted for the low-light, black and white camera. It was not possible to distinguish the third, angled laser at a distance greater than 3.0 m. The black and white camera was able to measure the distance to the camera to within an average of 17.72 cm of its actual value (Table 8). The highest accuracy was observed at an actual distance of 50 cm with an average measured value of 52.98 cm.

Table 8 - Distance to target board average measurements and standard deviation values taken with the low-light camera.

<table>
<thead>
<tr>
<th>Actual Distance (cm)</th>
<th>Measured Distance (cm)</th>
<th>Standard Deviation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>52.98</td>
<td>2.61</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>115.26</td>
<td>1.86</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>166.78</td>
<td>2.35</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>217.72</td>
<td>4.89</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>264.65</td>
<td>5.92</td>
<td>30</td>
</tr>
<tr>
<td>300</td>
<td>314.90</td>
<td>26.83</td>
<td>30</td>
</tr>
</tbody>
</table>

Like the target length measurements, the distance measurements dropped in accuracy the further the target was from the camera (Figures 76 and 77).
Figure 76 - Distance to target board measurements taken with the low-light camera.

Figure 77 - Distance to target board averages and standard deviation error bars taken with the low-light camera.
Hydrolab Data

In a similar fashion to the sediment profile imager, the conditions at the laboratory were such that fluctuations in readings from the Hydrolab were not suitable for investigating the instrument’s capabilities. Therefore, the Hydrolab was deployed for an 18 hour period in Lake Ontario and allowed to continuously collected data at one second intervals (October, 2007). Prior to deployment, however, the Hydrolab had been professionally calibrated by the distributor to the tolerances listed in Chapter 3 and were assumed to be functioning as manufactured. Figures 78 to 83 illustrate the fine scale clarity of data available with the Hydrolab.

Temperature measurements fluctuated from 18.38 to 18.96 ºC (Figure 78). This is expected near the surface, in a temperate lake in Ontario. The rise of temperature observed is likely in response to day time heating.

![Figure 78 - Hydrolab temperature data.](image)
The dissolved oxygen readings were found to be fairly consistent at 9.26 to 9.82 mg/l (Figure 79). This is consistent with what would be expected from a lake such as Lake Ontario and mirrors results recorded by other studies (USGS, 1981).

Figure 79 - Hydrolab dissolved oxygen data.
Specific conductivity was found to fluctuate from 0.298 to 369 mS/cm (Figure 80). The USGS (1995) recorded values of 0.333 mS/cm (1981) and .320 mS/cm for Lake Ontario thus confirming the validity of these value ranges.

![Specific Conductivity Chart](image)

**Figure 80 - Hydrolab specific conductivity data.**
The pH measurements were found to fluctuate between 8.64 to 9.34 (Figure 81). Again, a similar reading of 8.3 was recorded by the USGS for Lake Ontario (USGS, 1995).

Figure 81 - Hydrolab pH data.
Oxidation Reduction Potential was found to measure between 265 and 289 mV (Figure 82). This is consistent with what is expected in a well oxygenated lake with a pH higher than 7.0 (Nurnberg, 1995)

Figure 82 - Hydrolab REDOX data.
Finally, chlorophyll a was found to measure between 1.12 and 1.36 µg/l (Figure 83). A study by Nichols (2001) found that chlorophyll a values varied between approximately 1.2 and 2 µg/l near Kingston in Lake Ontario (after the colonization of zebra mussels (*Dreissena polymorpha*)), validating the values recorded.

![Chlorophyll a](image)

**Figure 83 - Hydrolab chlorophyll a data.**

The Hydrolab measurements appear consistent with the ambient parameters expected from Lake Ontario. Further testing, outlined in Chapter 5, will be required to test the long-term stability of these readings.
4.1.1. System Testing

System testing comprised testing all the components of the RESA System with the underwater computer. All components were tested for their ability to interface and interact with the underwater computer. Control commands were tested with the motorized components. Data movement was also tested with the various sensors and video cameras to ensure that data movement was proceeding as expected.

4.1.2. Performance Testing

Video Streaming Performance

The ability to move the high-definition video signals through the local networks and into the CA*net 4 system was critical to the project. A software system called NetStat Live, developed by Analog X, was used to monitor the current, average and peak data transmission rates and CPU usage from the RESA System (AnalogX, 2000).

For the low-light, black and white camera, an average outgoing data transmission rate of 12.1 Mbps was recorded with a peak of 49.4 Mbps occurring during the initiation of the video stream (Figure 84). CPU usage average 82% during this transmission. When two computers began to stream from the RESA System, data transmission rates increased to 24.5 Mbps with an additional 49.4 Mbps peak upon initiation. CPU average usage climbed to just 84%. In both cases, CPU usage reached 100% during the initiation of the data stream. The maximum CPU capacity event did not appear to have affected the integrity of the low-light, black and white video stream once it was initiated.
Next, the streaming performance of the high-definition camera was tested (Figure 85). First, with one computer connected to the RESA System, an average data transmission rate of 28.4 Mbps was recorded. When the number of computers accessing the video stream was increased to two, the average data transmission rate increased to 53.1 Mbps. CPU usage remained relatively constant with averages of 83% and 84% respectively. Like the black and white camera, CPU usage reached 100% during initiation of the data stream, but did not appear to affect the integrity of the transmission once initiated.
Figure 85 - HD Video Streaming. One computer streaming is shown on the left, two computer streaming is shown on the right.

The final test conducted to assess streaming performance was that of streaming both the low-light, black and white camera and high-definition camera simultaneously (Figure 86). First, with only one computer accessing the video data streams, an average transmission rate of 41.5 Mbps was recorded. A peak transmission rate of 49.4 Mbps was observed during initiation of the data stream. The transmission rate increased to 90.5 Mbps when a second computer accessed the data streams. This time, a peak of 162.3 Mbps was observed during initiation of the data stream. CPU average usage was
recorded at 89% and 97% respectively. CPU usage routinely reached 100% during this testing phase, however, stream integrity did not appear to be affected once transmission had been initiated (discussed below).

Figure 86 - Video streaming data for both the high-definition video and the black and white video. Streaming to one computer is shown on the left, streaming to two computers is shown on the right.
In order to assess the integrity of the data streams, framerate information was collected during the most intensive testing, that of using both camera streams transmitting to two different computers.

The low-light, black and white data stream lost 28 frames upon initiation of the transmissions, however this rate stabilized after initiation and the stream did not continue to lose frames (Figure 87).

![Stream and Media Info](image)

**Figure 87 - Video dropping rate for the ultra low-light black and white camera during an intense streaming event.** Note that the stream bitrate displayed is for the receiving computer and does not represent the total bitrate for that particular data transmission.
The high-definition data stream lost more frames (160) during initiation, but like the low-light, black and white stream, this stabilized once initiation of the transmissions had occurred (Figure 88).

![Stream and Media Info](image)

**Figure 88 - Video frame drop rate for the high-definition video camera during an intensive streaming event. As in Figure 70, the stream bitrate displayed is for the receiving computer and does not represent the total bitrate for that particular data transmission.**

Data feed from the hydrophone was tested and was found to be negligible at approximately 500 kb/s as a full uncompressed wave format. In addition, data feed from the Hydrolab is a relatively simple text file transmission and was not benchmarked due to its low bandwidth requirement.
During the testing phase of the RESA System, close monitoring of the temperature of the computer system was undertaken to ensure that all critical components operated under acceptable conditions. As stated earlier in this thesis, a software monitoring package called SpeedFan was used to monitor the integrated temperature sensors in the motherboard, CPU, harddrive and power supply. All parameters were observed to be operating within acceptable levels (Figure 89) and remained stable throughout the testing (Figure 90).

Figure 89 - Critical system temperature monitoring software screenshot taken during an intensive data streaming session. Note that the “Temp1” parameter is a sensor position that was not used in the RESA System and as such feeds a constant 80°C false reading.
Figure 90 - Critical system temperature monitoring software screen shot showing consistent temperature profiles for all monitored sensors.

Further monitoring of system temperatures during field testing will be required to validate the temperature fluctuations throughout a normal deployment cycle.
Chapter 5. Discussion

5.1. General

To summarize, a system was developed to integrate underwater, high-definition colour and low-light black and white video, with environmental sensing instruments (temperature, dissolved oxygen, pH, specific conductivity, oxidation-reduction potential and chlorophyll a). In addition, a laser scaling system for measurements and a hydrophone to record underwater acoustic signals was included, along with a sediment profile imager, for recording parameters associated with the first 30 cm of bottom sediment. These components and instruments communicate with an underwater computer and power distribution centre, which in turn can interface with most networked environments. Laboratory testing was conducted to bring the System to the point at which it could be deployed in the field for long-term testing.

The RESA System has set the stage for the use of remote, data-intensive monitoring systems as autonomous data collectors. Much research and development is still required, however, to further this goal. In order to ensure that the RESA System is usable in a variety of fields and that it will be durable for long-term deployments, further testing and refinements are required. The following plan has been developed to help guide the long-term field testing required to prove the value of this system for real-world applications. In order to achieve this, an eight-month field trial with regular scuba diving inspections is recommended.
5.2. Future Long-Term Testing

The RESA System’s structure and protective housings are made primarily from aluminum. During regular inspections, the System must be examined for obvious evidence of corrosion both at the junctions of dissimilar metals, as well as in less accessible crevice locations such as the visible o-ring sealing glands. If corrosion does appear to be an issue, sacrificial zinc anodes can be attached to the structure. This will have the affect of corroding the zinc at a preferential rate to the aluminum. The watertight housings must also be inspected by the diver for visible signs of water intrusion. Upon completion of the deployment, the System must be brought back to the laboratory where all components must be disassembled and inspected for corrosion, leakage and wear.

Hydrolab

The Hydrolab data must be collected throughout the field trial period. This data must be compared to regular sampling of the water quality in the immediate vicinity of the RESA System using a calibrated Hydrolab with the same sensors as on the RESA. This can then be used to calculate the level of drift of the sensors. The Hydrolab attached to the RESA System is configured with a motorized brush for cleaning the sensors underwater. Using the second, calibrated Hydrolab, an estimate as to the frequency of cleaning required during that particular deployment can be made.
Lighting

The HID and halogen lighting systems need to be tested for their performance and durability during the field trial. This must include a software-mediated count of the number of on/off cycles experienced throughout the year, along with the ambient temperatures experienced during these cycles. This can be compared to any documented bulb failures. Clouding of the lens due to bacteria, algae or chemical reactions can be noted during diver inspections and after completion of the deployment.

Pan and Tilt

The pan and tilt units will require monitoring for movement characteristics and on/off cycling during the field deployment. This can be accomplished by logging the movement commands sent to the units. Environmental data from the Hydrolab must be combined with this data to track the performance of the unit as conditions such as temperature change. During deployment, a diver must check for range of movement. Upon completion of the deployment, each pan and tilt unit must be completely disassembled and examined for such factors as water ingress and component wear.

Laser Scaling System

In a similar manner to the lighting system, the laser scaling system must be monitored for on/off cycling and can be tied to the environmental data collected by the Hydrolab. In addition, a calibration scale must be used so that any drift in directionality, focus or intensity of the beam from the laser diodes can be detected. During inspections, the level of biological growth on the laser lenses must be noted. Upon completion of the deployment, an examination for water ingress and corrosion must be performed.
**Sediment Profile Imager**

The sediment profile imager must be tested to ensure that it continues to function over time. Unlike the other instruments which will be located above the sediment, the SPI will be located within the sediment layers for an extended period of time. This means that cleaning the lens of the instrument would result in disruption of the sediment profile. It is unknown at this point, what level and rate of biological growth can be expected below the sediment surface. It is recommended that an initial scan be used as a comparator for future calibration scans and that pixel smearing over time be used to determine the level and rate of biological growth. The SPI can be inspected above the sediment by the diver, however, at the end of the test deployment, a true evaluation of the integrity of the instrument must be performed in the laboratory. This will entail an inspection for corrosion and water ingress.

**Video Systems**

One of the main concerns with respect to the performance of the video systems, over time, is that of clouding of the lens due to growth of algae and/or bacteria. This issue is difficult to track due to the lack of underwater ambient light-level and turbidity sensing instruments on the RESA. One possible test for this is to track changes in recorded pixel intensity and smearing over time, at night, while using the lighting system to illuminate the laser calibration targets.
Hydrophone

Initially, the hydrophone must be calibrated for the location of its deployment. This is necessary to establish the level of background noise both from the RESA System and the local environment. It is recommended that several sample recordings be taken at night and during the day, during conditions of low wind and low boat traffic. These can then be saved to use as comparisons and filters for future recordings. Tracking the performance of the hydrophone will be slightly more difficult. An underwater speaker, lowered to a predetermined point near the RESA System, can be used to emit an acoustic signal of known frequency spread and intensity. This, coupled with temperature data, can be used to track changes in the performance of the hydrophone over time.

Future Developments

There are several areas which can be improved upon with the RESA. First, the System has the potential to be miniaturized in order to make deployment easier and allow the RESA to be installed in conditions for which it may be too large at present. For example, shallow water or highly turbulent zones would benefit from a smaller system.

In addition, research into the use of stereo cameras and photogrammetry holds great promise for the extraction of additional three-dimensional information from images which traditionally have not been possible (i.e. object relief, etc). The future integration of this field of research in the RESA System is encouraged.
The requirement to attach the RESA System to the shore was dictated by the need to move large volumes of data over the only realistic mediums available (Ethernet and fibre). Advancements in broadband data transmission, coupled with high-capacity energy sources (fuel cells, etc) would be a substantial leap forward in the ability to deploy these types of data intensive instruments in remote locations. In addition, however, improvements to the energy efficiency of the existing System would allow it to be deployed with a much smaller diameter power cable; possibly eliminating the need for shore power. Exploration of low-power components such as LED lighting and solid state technology would substantially reduce the energy requirements of the System.

Advances in video systems are also required for furthering this field of underwater science. As stated earlier, interlaced video has no place in the 21st century. Expensive video cameras have only a limited place as they can quickly drain even the most well-funded research budgets. As such, developments in consumer cameras will be required to make these future underwater systems affordable.
5.3. Concluding Remarks

This thesis was a journey from the inception of an idea to create a novel, low-cost environmental sensor platform, through the design, construction and laboratory testing of its components to the eventual assembly as an environmental monitoring research platform.

The ability to monitor the environment without the labour intensive processes that are currently the norm is a significant advancement for science. Traditionally, these systems have been developed by large conglomerates which have resulted in bulky and extremely expensive monitoring devices. The RESA System changes that, with the development of a relatively low-cost device, which can collect data on a scale difficult to reach using traditional methods.

The greatest challenge now will be to prove to scientists, which have relied on traditional field collection methods and techniques, that remote monitoring technologies such as the RESA System, are a viable addition to their research.
References


ECCO. 2007. ECCO Website. www.whoi.edu/mvco/other_data/ECCOO.


USGS, 1995. Water Quality Record 04219640. Niagara River (Lake Ontario) at Fort
Niagara New York.


macroinvertebrates assemblages to predict stream acidity in upland Wales.
Hydrobiologia. 171: 59-78.


and M.L. Yallop. 2007. Assessment in two shallow lakes of a hydroacoustic system for

http://fcit.usf.edu/network/glossary

2006. Climate impacts on Arctic freshwater ecosystems and fisheries: background,
rationale and approach of the Arctic climate impact assessment (ACIA). Ambio. 35(7):
326-329.

internet: approaches and directions. IEEE Transactions on Circuits and Systems for
Video Technology. 11(3): 282-300.

Appendix 1 – RESA Wiring Diagrams

Overall RESA System Component Wiring
High-Intensity Discharge Lighting Wiring

*Legend*
- **Brown**: 120 VAC
- **Gray**: Ground
- **Light Yellow**: 12 VDC
- **Red/Yellow**: 5 VDC
- **Pink**: RS-232
- **Green**: High Voltage

*Diagram Components*
- Main Power
- Underwater Case
- 120 VAC Power Distribution Block
- DC Ground Block
- Power Supply
- 5 VDC Power Distribution Block
- Light Switch Controller
- HID Lamp
- HID Ballast
- Light Switch
- Computer Motherboard
Hydrolab Wiring

Legend
- 120 VAC
- Ground
- 12 VDC
- 5 VDC
- RS232 Cable
Hydrophone Wiring

Diagram showing the connection of a hydrophone to various components including a 120 VAC power distribution block, power supply, DC ground block, 12 VDC power distribution block, hydrophone amplifier, and computer motherboard.
Laser Scaling System Wiring
Low-Light, Black and White Camera Wiring

Legend:
- Brown: 120 VAC
- Gray: Ground
- Orange: 12 VDC
- Red: 5 VDC
- Green: Video Signal
- Pink: USB Cable
Pan and Tilt Unit Wiring
Sediment Profile Imager Wiring