INTRODUCTION

The concept that "aquaculture is agriculture" has finally been accepted and like modern livestock production agriculture, aquaculture is moving toward intensive, controlled environment production units (i.e. intensive recirculation systems). With this technology comes a significant increase in production potential, but at the cost of increased risk of catastrophic loss due to equipment or management failures. In addition, managers of these intensive production facilities need accurate, real-time information on systems status and performance in order to maximize their potential. Current technologies are allowing stocking densities of fish to over one pound per gallon of water. At this density, failure of a circulation pump or aeration system can result in severe stress to the fish or even significant losses within minutes. Expensive and sophisticated systems and components from other industries, wastewater and petroleum, have been successfully modified for use in aquaculture. But usually only a small fraction of their potential power is employed, due to aquaculture's relatively simple monitoring and control demands (i.e. digital inputs/outputs). With the rapid decrease in costs for computers, software and off-the-shelf monitoring hardware, monitoring and control systems are within the reach of even small producers and mandatory for large scale production facilities.

Before going any further though, it must be emphasized that the most sophisticated (and normally under appreciated) monitoring and alarm system is an attentive human operator. Experienced staff can detect the moment he or she steps into a facility whether something is amiss, often just from the change in background noise. In general though, most facilities are not staffed 24 hours a day. Moreover, the watery environment of aquaculture is totally different from what most "air-breathing" operators are accustomed too, requiring the need for continuous monitoring of critical water quality parameters and system components.

What follows are answers to some of the basic questions about monitoring and control systems in aquaculture: who, what, where, how and why? The answer to the first question is obvious, anyone who hopes to be successful in aquaculture. To this end, several types and levels of monitoring and control systems will be described that should be affordable and appropriate for the simplest single tank system to the sophisticated commercial producer.

Trade names are used for clarity only and do not imply endorsement of products by the Conservation Fund's, Freshwater Institute, nor is criticism implied of other manufacturers of similar products, which are not included.
Factors to consider in determining how sophisticated the monitoring/control system should be, include:

- **Type and size of the facility**: is it a hatchery, fingerling production or growout system, broodstock maintenance, high school project, cold water or warm water facility, located in a single building or multiple buildings.

- **Type and number of tanks/systems**: tanks, raceways, aquariums, numerous small rearing tanks or large production tanks, aeration with air or oxygen injection, degree of recirculation.

- **Stocking density and value of fish**: semi-intensive, intensive or super "just keep them wet" intensive systems, broodstock, quick turn around fingerling production, grow-out, trout, tilapia or expensive show Koi.

- **Location and management style**: remote location or on-site staff 24 hours per day, full or part-time operators.

- **Budget**: just an audible alarm in the office, or a microcomputer controlled system with automatic back-up response, telephone dialer, with remote access through the Internet.

The answer to "why" is also obvious when working with any live animal, be it a simple algae to an endangered sturgeon. *What, where, and how* to monitor make up the majority of this manual, with hopefully enough detail so that decisions can be easily made and systems designed to meet individual needs.

**WHAT CAN GO WRONG?**

Murphy's Law states simply: if anything can go wrong, it will (author note: "and usually at 4:00 am on a Sunday morning"). Determining what can go wrong and making a list of worst case scenarios is a never-ending quest. From personnel experience, no matter how hard you try or how long your list is, there will always be a surprise waiting around the next corner and usually at the worst possible moment. A short list of some potential "emergencies" is presented in Table 1. It makes a good place to start, after that let your imagination go wild, anything is possible! Remember though, that it is also important during this initial design process not to go overboard in terms of technological complexity or in the sheer number of monitoring points and alarms. Sophisticated alarm systems are of little use, if the part-time help disarms them due to their unreliability and frequent false alarms.
Table 1. A short list of potential "emergencies" in Aquaculture

<table>
<thead>
<tr>
<th>Type/System</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;beyond your control&quot;</td>
<td>flood, tornadoes, wind, snow, ice, storms electrical outages, vandalism/theft</td>
</tr>
<tr>
<td>Staff Errors</td>
<td>operator &quot;errors&quot;, maintenance overlooked causing failure of back-up systems or systems components, alarms deactivated</td>
</tr>
<tr>
<td>Tank Water Level</td>
<td>drain valve opened, standpipe fallen or removed, leak in system, overflowing tank</td>
</tr>
<tr>
<td>Water Flow</td>
<td>valve shut or opened too far, pump failure, loss of suction head, intake screen plugged, pipe plugged</td>
</tr>
<tr>
<td>Water Quality</td>
<td>low dissolved oxygen, high CO₂, supersaturated water supply, high or low temperature, high ammonia, nitrite, or nitrate</td>
</tr>
<tr>
<td>Filters</td>
<td>channeling/plugged filters, excessive head loss</td>
</tr>
<tr>
<td>Aeration System</td>
<td>blower motor overheating because of excessive back-pressure, drive belt loose or broken, diffusers plugged or disconnected, leaks in supply lines</td>
</tr>
</tbody>
</table>

While compiling this list, keep in mind the relative importance and the required response time for each of the water quality parameters or monitored components (Table 2). Life support priorities in aquaculture start with water, followed immediately by adequate levels of dissolved oxygen. Then come the other water quality parameters, correct temperature, pH, and alkalinity, and finally low concentrations of ammonia-nitrogen, nitrite, nitrate, and carbon dioxide. At high stocking densities (greater than 1/3 lb./gal), dissolved oxygen requires the most rapid response time. If the water flow or aeration is cut for any number of reasons, low oxygen and the resulting stress can lead to disease problems and/or mortality within minutes. Thus in the design of intensive systems, a simple audible alarm in the office may not be adequate, or even a pager if the manager lives 20 minutes away. Thus in addition to the monitoring, some form of backup aeration must be provided for and automatically engaged to insure survival of the fish. The other water quality parameters listed above change more slowly than dissolved oxygen and can take hours or days to reach levels of concern. Thus allowing more time to analyze the problem and take the necessary steps to correct them.
Table 2. Life Support Priorities in Aquaculture

**High** (fast response time – minutes)
- electrical power
- water level in tank
- dissolved oxygen – aeration system

**Medium** (moderate response time – hours)
- temperature
- carbon dioxide

**Low** (normally slowly changing – days)
- pH
- alkalinity
- ammonia-nitrogen
- nitrite-nitrogen
- nitrate-nitrogen

**WHERE TO MONITOR?**

At low stocking densities (less than 1/3 lb/gal), basic parameters to be monitored include system electrical power, tank water level (high and low), aeration system pressure, and water flow through the filters and tank. All of these parameters can be monitored as simple digital sensors, i.e. either on or off. Analog sensors, such as dissolved oxygen levels, are more expensive to utilize and are more important at high stocking densities or where pure oxygen aeration is used. For all these systems, it is as important *where* you monitor critical parameters, as *what* you monitor. For example, it helps little to monitor flow from a pump into a tank, if the drain line is left open, and all the water is flowing out as fast as it is flowing in. What is important here is the tank water level. Similarly, there is no advantage in monitoring power to a pump, if the discharge valve is shut or the motor thermal-overload switch has turned it off. The critical parameter to monitor is whether there is flow from the pump. Finally measuring air pressure next to the aerator is of little help, if there is a major leak at the far end of the distribution system, resulting in low air pressure for the last tanks on the line. The aeration pressure should be measured at the farthest point in the system from the air blower. Table 3 lists some of the important systems and parameters that need to be monitored in intensive recirculation systems.
Table 3. Important Systems or Parameters to Monitor

<table>
<thead>
<tr>
<th>System</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Power</td>
<td>single and three phase supply individual systems on GFIC’s</td>
</tr>
<tr>
<td>Water Level</td>
<td>culture tank (high/low) supply sumps to pumps (high/low) head tanks/ reservoirs (high/low) chemical storage tanks filters (high/low)</td>
</tr>
<tr>
<td>Aeration System</td>
<td>air pressure</td>
</tr>
<tr>
<td>Water Flow</td>
<td>supply line pumps culture tanks submerged filters (low) in-line heaters</td>
</tr>
<tr>
<td>Temperature</td>
<td>culture tanks (high/low) heating/cooling systems (high/low)</td>
</tr>
<tr>
<td>Security</td>
<td>high temperature/smoke sensors intruder alarm</td>
</tr>
</tbody>
</table>

**WHAT TO MONITOR?**

Sensors in aquaculture can be roughly divided into two major types: digital (on/off signals) such as water level, aeration pressure and water flow switches and analog (continuous output) such as dissolved oxygen, temperature, pH, conductivity and ammonia-nitrogen probes. In addition, most analog probes require some additional hardware or controllers to convert the probe output to a usable signal, provide a digital display and allow for calibration and zeroing. Thus the higher cost for these types of measurements, compared to simple switch closures. Below is a short review of important monitoring parameters:

**ELECTRIC POWER**

Power failure is probably the most common emergency situation and the one most easily monitored. This is especially important when systems such as filters or supply pumps are located some distance from the main building. Three-phase power can be especially confusing, because if only one phase is down, it is possible to lose power to some systems, but not all. Murphy's Law assures that the monitoring system will not be on the one phase that goes down. In addition, when this happens, severe damage can occur to three-phase motors and pumps, if not
properly protected. One often overlooked result of power outage is the loss of lights, which means that either numerous flashlights need to be maintained in good working order or back-up emergency lighting provided.

**WATER LEVEL**

Probably the easiest and most inexpensive parameter to measure, water level should be monitored for both high and low levels at the minimum in each production tank. High/low water level sensors will detect plugged drain lines, fallen standpipes or drain lines accidentally left open. Level sensors need to be protected, so that active fish do not accidentally trigger them. Other locations to monitor include the intake side of pumps in wells or sumps. These should provide for automatic shutdown of the pumps to prevent their damage in the case of low water levels. Supply reservoirs or head tanks need to be monitored for both high and low levels. High levels can indicate unusual change in normal water demands, due to clogged pipes or valves accidentally turned off. Low levels can be caused by pump or water supply failure. If immersion heaters are used, low level monitoring should be designed to turn them off, to prevent overheating and burning out of the heaters. Alarm levels should be set so that normal operating transient do not activate an alarm. This can be accomplished either by setting the levels optimistically or by allowing some time delay before an alarm is activated after a sensor is triggered.

**AERATION SYSTEM PRESSURE**

The aeration system is one of the most critical systems in any intensive recirculating aquaculture system. Response time to failure is very short, and both monitoring and backup systems are important. Low pressure in the system may mean a ruptured airline, open or jammed pressure relief valve, disconnected diffusers or blower failure. Although not as often monitored, excessive high pressure could indicate blocked supply lines, valves turned off or clogged diffusers.

**WATER FLOW**

In some cases, the actual measurement of flow rate is important, such as chemical injection systems for dechlorination or for monitoring system performance. Normally, monitoring whether water is actually flowing (flow/no-flow) with a digital sensor is adequate. One example is in-line heaters that require continuous water flow to prevent overheating and meltdown. Another example is submerged biological filters, where anaerobic condition due to pump failure can be damaging to the nitrifying bacteria.
**DISSOLVED OXYGEN**

Dissolved oxygen is one of the most expensive and difficult to monitor continuously. Thus deciding whether to continuously monitor it is dependent on the overall economics of the system, stocking density and degree of risk a manager is willing to accept. Normally the actual value of dissolved oxygen is not need, just whether it is above or below a given set point. Thus what should be a simple digital signal, ends-up requiring both an expensive probe and a sophisticated hardware interface. The availability and costs of both oxygen probes and hardware has improved in the last few years.

**TEMPERATURE**

The continuous and precise monitoring of temperature in production tanks is important to optimize production, reduce stress and minimize risk of disease. Systems should be monitored for both excessive high and low temperatures, keeping in mind the two extremes are not equal. While low temperatures may reduce growth, excessive high temperatures may yield a new career path. Since most temperature controllers are cyclic in nature (either on or off), temperature alarm limits should not be set too close together, to prevent unnecessary alarms due to short term transients.

**OTHER WATER QUALITY PARAMETERS**

Other water quality parameters, pH, ammonia-nitrogen, nitrite, nitrate, alkalinity, and carbon dioxide vary relatively slowly in comparison to dissolved oxygen. Although probes and systems are available at a high cost to monitor these parameters, the most cost-effective method is daily or weekly monitoring with inexpensive off-the-shelf test kits.

**PHYSICAL PLANT SECURITY**

Readily available, intrusion alarms, smoke and high temperature sensors (fire) are commonly used to protect against fire, theft and vandalism. Often existing systems can be connected to the proposed monitoring system.

**HOW TO MONITOR?**

Over the past few years, the cost of computer hardware and software has dramatically decreased, while the processing power and computer programming sophistication has greatly increased. Sensor technology has become more reliable and sophisticated with
such innovations as embedded microchips in the sensors for signal processing and linearization. A large number of sensors and monitoring systems components have been borrowed from the wastewater treatment and chemical and petroleum industry. In many cases, the sophistication and corresponding expense of these types of monitoring and control equipment are not necessarily required in aquaculture facilities. Nevertheless, until specific equipment becomes available for aquaculture and for high valued products, the added costs of this equipment may be justified. Keep in mind, that for any monitoring system, its overall reliability is determined by the most unreliable part (i.e. weakest link).

The following description of sensors represents the simplest and most cost-effective solutions to monitoring each individual parameter. For each of these thought, there exists a multitude of solutions, some more expensive, more accurate, more reliable, more precise, with better interface capabilities, or simply available. There is no simple right or wrong solution, and this is where the engineering and design comes to play.

**WATER LEVEL – Float Switches**

Water level is probably the easiest and most inexpensive parameter to measure. The basic float switch is designed to monitor a single, discrete, preset liquid level. Simple float switches are constructed with a float containing a small magnet, which moves with the water level and actuates a hermetically sealed reed switch within the stem or body of the float switch. The rugged construction of this design provides for long and trouble free service with minimum maintenance requirements. Several different designs are available for mounting either vertically or horizontally in the tank or sump. Two float switches can be wired in series to monitor both high and low levels in a tank. Although most float switches are designed to handle 110 VAC at small currents, they should be powered by low voltages (i.e. 24 VAC or DC) to minimize danger to personnel and fish. Float switches are simple, foolproof, and relatively inexpensive. Examples of two float switches that are commonly used are Aquatic Eco-Systems Liquid Level Switch ST-3M for $13.95 and Grainger Liquid Level Switch 2A554 for $10.50.

Other options for monitoring water level include optical liquid-sensing sensors that use an internal infrared circuit and the light refracting properties of water. Non-contacting ultrasonic level sensors measure the time required for the ultrasonic pulse to travel to the water surface and return. Conductivity level switches operate by detecting a small electric current between a single electrode probe and a grounded metal tank or between two electrodes. Finally, pressure sensing systems use a pressure transducer to measure the pressure required to bubble air through an immersed pipe in the water column.

**AERATION SYSTEM PRESSURE**

Pressure is defined as a "force per unit area", which is to be used to produce a deflection, distortion or some other physical change in a sensor. A pressure control switch uses this deflection to trip an electrical switch at a preset pressure setting. Low and high pressure
switches are available in a wide variety of configurations and price scales, from numerous manufacturers. One example of a pressure switch that have been commonly used is Aquatic Eco-Systems Pressure Switch, B601 at $26.90.

It is important to remember when specifying pressure switches that one psig is equal to 27.68 inches of water. Thus for typical aquaculture aeration systems, the pressure required for an aeration system will usually be below 5 psig or 140 inches of water. Some pressure switches are rated high enough in load switching capacity, that they can be used directly to activate back-up aeration blowers. Others will require some intermediate stage, such as a solid-state relay or an audible alarm with manual start-up.

**WATER FLOW - Drag discs, paddle and vane flow switches**

Drag discs, paddle and vane flow switches are all designed to monitor flow/no-flow or low flow conditions. Each operates on the drag force of the moving water against a small disk, paddle or vane in its path, which controls a small micro-switch. They are available in a wide range of flow rates and pipe sizes. Normally drag discs and paddles are installed using a "Tee" fitting and vane types are installed in-line. An example of a flow switch that has been commonly used is Aquatic Eco-Systems Flow Switch, ST-9 for $26.

Other options for monitoring flow are rotameters. As the water flows through the rotameter, it raises a float in a tapered tube, increasing the area for passage of the fluid. The greater the flow, the higher the float raises in the tube, which is directly proportional to the flow rate. The float reaches a stable position, when the upward force exerted by the flowing water is equal to the downward force exerted by the weight of the float. These flow meters can be used to monitor flow by mounting a proximity switch externally, which is switched at a predetermined flow rate by a small magnet in the float. A second more expensive option is to use a turbine or paddlewheel flow meter. The flowing water turns a small turbine blade or paddlewheel and an electrical pulse is generated. This is sent to the appropriate hardware, where the flow rate or the total flow can be displayed and alarm conditions set and low/high flow alarm relays activated.

**DISSOLVED OXYGEN**

Over the past few years, there have been introduced a number of dissolved oxygen probes and analyzers designed specifically for the aquaculture industry. Most of these are microprocessor-based instruments capable of measuring levels of dissolved oxygen up to 100 PPM, important for monitoring oxygen injection systems. Standard recorder outputs (0 – 5 VDC) are built-in and many include 4-20 mA current loop outputs. Several models also provide serial outputs (RS-232, or RS-485) for direct interfacing with microcomputers and local area networks (LAN's). These also include high/low set point control relays for controlling external devices such as aerators, pumps, valves or other alarm monitoring equipment. Although the initial investment in this equipment can be high, it must be weighed against the potential loss and poor growth due to low dissolved oxygen levels.
Dissolved oxygen meters designed specifically for aquaculture are available from Point Four Systems, Inc., YSI, Inc. and Royce Instrument Corp.

OTHER WATER QUALITY PARAMETERS

pH, temperature and other water quality parameters usually have a relatively long response time when compared to dissolved oxygen or the effects of pump or aeration failures. Thus these and other slowly changing parameters are probably best measured as part of a regular water quality monitoring program using bench-top laboratory equipment. Although equipment exists for continuous monitoring of pH and temperature for example, except for research purposes, it is not normally required in production aquaculture. On-line ammonia monitoring is feasible, but very expensive and difficult in practice.

AUTOMATIC PHONE DIALERS

The final step is to bring each of these potentially catastrophic alarms to the attention of the manager, especially when he or she is away from the facility. A very inexpensive, simple and versatile monitoring system can be constructed around readily available automatic telephone dialers/alarm systems. These units are readily available for a wide range of costs. One such unit, the Sensaphone (Phonetics, Inc., Aston, PA) has been used in numerous facilities with excellent results (Aquatic Eco-Systems Telephone Alarm System A2 - $389). The Sensaphone unit automatically monitors the following conditions:

- AC electric power – checks for power failure.
- Temperature – monitors temperature, checks for high or low limits, and reports actual temperature.
- High sound level – fire/smoke alarm, intruder alarms.
- Battery – condition of its battery back-up.
- Four additional digital alert inputs or 3 digital and 1 temperature.

All monitoring is continuous and when a problem occurs, the unit announces the alarm condition locally for 30 seconds. If no response is received, it then sequentially dials up to four user-programmed telephone numbers with an alarm message. It will state in English the existing problem, disconnect and wait for an acknowledging telephone call or coded response. It will continue dialing-out, up to sixteen attempts, until its message is properly acknowledged. It is also possible to call in and listen to a status report on the monitored conditions and hear the background sounds through a built in microphone. For most systems, this would provide the necessary digital inputs for monitoring tank water level (high/low), aeration systems pressure, water flow and, in addition, system water temperature.
THE BASIC SYSTEM

The basic monitoring system is designed for low-density (less than 1/3 lb./gal) recirculating systems, with aeration only and moderate feed rates, such as broodstock holding tanks or high school systems. Basic system parameters are monitored by digital sensors, i.e. either on or off. Analog sensors, such as temperature and dissolved oxygen levels, are more difficult and expensive to utilize and are important only at much higher stocking densities or where pure oxygen aeration is used. Basic parameters to be monitored at this production level include electricity, tank water level (high and low), aeration system, and water flow. The actual number of subsystems monitored, depends on the specifics of the system design and the operating conditions. In most cases, only a few monitoring points should be necessary. Parameters and sensors used include:

- **System Electrical Power**: monitored directly using the Sensaphone or indirectly due to loss of other subsystems (pump flow, aeration, etc).
- **Tank Water level (high/low)**: Aquatic Eco-Systems, Liquid Level Switch ST-3M - $13.95, or Grainger Liquid Level Switch 2A554 - $10.50
- **Aeration system**: Aquatic Eco-Systems, Pressure Switch B601 – $26.90
- **Flow-sensing switch**: Aquatic Eco-Systems, Flow Switch ST-9 - $26.40
- **Telephone Dialer**: Aquatic Eco-Systems Telephone Alarm System A2 - $389

Each of the sensors is wired directly into the Sensaphone input, with the two float switches wired in series to monitor both high and low water level. The fourth input on the Sensaphone could be used to monitor either temperature of the water or an additional alarm. With this system, a single tank or perhaps several could easily be monitored for the basic system parameters.

INTERMEDIATE SYSTEM

The next stage up from the basic monitoring package is to literally add ‘bells and whistles’ to the system. One of the primary disadvantages of the above system is that it works fine for a single tank, but is difficult to expand to multiple tank systems. It is also difficult to disable a single alarm input during routine cleaning operations, such as the tank low-level alarm. To overcome these limitations and to add visual indicators that systems are active, several modifications and additions were added over the years to the basic design. The first was a 24 VAC DPDT (Double Pole, Double Throw) relay, that is always energized when the sensor is in its normal state (Figure 1). The primary advantage of this system is that failure of the sensor or a break in the connections causes an alarm condition. In addition, the sensor is operated with low voltage (24 VAC or DC), thus minimizing risk to operator and fish. Adding a 24 VAC LED (Light Emitting Diode), allows the operator visually to quickly determine the status of the alarms. The additional relay contacts can then be used to provide several additional outputs, such as audible alarms and switch closures for a telephone dialer. In addition, a SPST (Single Pole, Single Throw) switch can added to the alarm output, allowing it to be turned off during routine maintenance or when the production system is down. This also causes the alarm status green LED to turn
off, indicating its deactivation. Thus an operator can tell at a quick glance the system status and alarm status.

Figure 1. Intermediate System wiring schematic for a basic relay.

This system was installed at a research facility and monitored tank water level (high/low), sump level, aeration pressure, and water flow. One set of relay contacts from each sensor was connected in parallel. Thus if any of the relays was turned off (alarm condition), the normally open (NO) contacts are closed and an audible alarm is sounded both in the production room and the research lab. In addition, after some preset time interval, the phone dialer is activated. With this system, four production tanks are monitored using the four inputs to the Sensaphone dialer. Complete plans, construction details, parts lists and sources of equipment are included in the papers: Monitor/Control for recirculating aquaculture systems based on a centralized computer using LabVIEW and a stand-alone module, 1997 and Engineering design and construction details of distributed monitoring and control systems for aquaculture, 1995.

COMPUTER BASED SYSTEMS

Once it becomes necessary to monitor analog inputs, such as dissolved oxygen, pH, temperature or output analog signals, some form of computer based system must be employed. The utilization of computer control and monitoring systems in aquaculture has until recently been limited, with only a few systems custom-designed for research or large commercial operations. The vast majority of small producers have had neither the expertise nor the resources to custom-design systems. However, in the past ten years, there has been a revolution in low-cost, high performance microcomputers and intuitive and
relatively low cost process control software. With the rapid development of microcomputer technology, numerous ‘user-friendly’ software and hardware systems are becoming available for control and monitoring of industrial processes. These software packages use object-oriented programming that allows even inexperienced programmers to create customized programs. In addition, standardized data acquisition components and systems, software drivers and communication software are available for several different computer platforms and over a wide range of costs. With this added capability though, comes the cost of additional requirements for calibration of the probes and sensors and maintenance of the system.

Computer control and monitoring systems in aquaculture can be separated into two design strategies, either stand-alone programmable logic controller (PLC) systems or a centralized microcomputer based system (Figure 2 and 3). The first design strategy can also be called a distributed process control system, where each of the stand-alone monitor/control units relays data to a central supervisory microcomputer. Examples of the stand-alone units are dissolved oxygen analyzers (YSI, Royce, Balanced:AquaSystems, and Point Four Systems, Inc.) and temperature controllers (Cleveland Process Corp.). Each of these stand-alone systems is normally equipped with both control relays and high/low alarm relays. In general, these units have limited data display capabilities and normally do not store data, but are equipped to transmit the data to a central, supervisory microcomputer. With stand-alone systems, individual sensors are easy to service and calibrate, since each has its own hardware and display unit. In addition, monitoring and control is performed at the lowest system level, which provides a high degree of overall system stability and robustness. If a failure occurs in the supervisory microcomputer, the stand-alone units will continue to monitor and control critical processes. If a failure occurs in the stand-alone system, the supervisory microcomputer can by comparing to previous measurement or measurements from other sensors detect the abnormal conditions and alert the operator.

An example of such a system is based on the duTec ‘I/OPLEXER’ remote input/output system. The I/OPLEXER is an industrial-grade data acquisition and control system, which communicates with a host computer through a serial communications link (RS-232, or RS-422/485). Controlled by a host computer, the I/OPLEXER is located near the sensors or stand-alone monitoring/control units. The system has a wide range of I/O modules, both analog and digital. At a recent installation, this basic system design is monitoring oxygen levels at four locations, temperature, three flow rates, pH, electrically actuated valve status, aeration pressure and several level alarms in the production tank and sumps. The stand-alone monitoring units directly control critical backup systems, such as oxygen, with alarm and additional backup provided by the central supervisory microcomputer. The control software being used (GENESIS for Windows from Iconics), allows for graphic display of system status, as well as graphic display of system parameters such as dissolved oxygen and temperature, logging of data for trend analysis and alarm logging and individual alarm response windows. The system was relatively easy to install using existing outputs from each of the stand-alone monitors and the appropriate input module for the I/OPLEXER.

Other examples of hardware interface between the supervisory computer and the stand-alone modules include Campbell Scientific CR10X Measurement and Control System,
Figure 2. Stand-alone programmable logic controller (PLC) systems

Figure 3. Centralized microcomputer based system
Craig Ocean Systems, Inc., and Aqua Monitrol. Examples of other commercially available control system software include Intellution, LabView from National Instruments, and WonderWare from InTouch. Aquadyne has introduced a complete system designed to both monitor and control individual systems with a stand-alone system, AquGuard hardware networked to a centralized computer via AquaNet. Several companies also provide system design and installation services such as AquaTrak software and BalancedAquaSystems.

The second design strategy utilizes commercially available data acquisition boards, that are either located in existing expansion slots in the computer or communicated to it via a serial interface link. There is a wide selection of data acquisition boards available over a wide range of cost, performance and sophistication, including analog to digital (A/D) cards for monitoring voltages or currents from sensors, digital to analog (D/A) cards for outputting analog control voltages, and input/output cards (I/O) for monitoring and outputting digital control signals. They are easy to use, “just-plug-in”, and come with a set of standard drivers and application software programs. Many types of sensors can be connected directly to these boards and most meters usually have some form of recorder output (0-5 V or 0-20 mA). In contrast to the distributed system, the microcomputer operates as the primary controller, monitoring and recording data and controlling alarm functions. These systems are not as inherently reliable as the distributed systems, but overall systems cost is less, since they are based on fewer and less expensive components.

A typical system installed at an aquaculture research center consisted of a single data acquisition card from National Instruments Corporation, AT-MIO-16X, with 16 single-ended or 8 differential analog input channels, two 16 bit analog output channels, eight digital I/O lines and three independent 16-bit counter/timers. In four separate research tanks, dissolved oxygen is monitored using OxyGuard probes inputted directly into the analog inputs, temperature with a thermistor probe, and water level, sump level, and backup oxygen monitored or controlled by the digital output line.

SYSTEM DESIGN AND MAINTENANCE

Listed below are some general suggestion about overall system design and maintenance.

System Design:

- choose sensors carefully, use the fewest possible, label everything and include expansion capability in all components.
- aquaculture facilities are now included under the National Electric Code, it may not be of concern to you, but it is to your insurance agent.
- mount sensors and equipment where they are visible and easily accessible for service and calibration.
- remember that water and electricity make for a fatal combination, so use low signal voltages (5 VDC, 12 VDC or 24 VDC or AC) to protect you and the fish.
- clearly label the sensor's armed and unarmed modes preferably with LED's at each station to show sensor status.
System Maintenance:

- have a well prepared maintenance manual accessible to the staff.
- maintain a weekly/monthly/yearly maintenance scheduling plan and files of major service records and equipment manuals.
- daily/weekly/monthly instrument check lists.
- regular and some unannounced system checks, including triggering of each sensor and checking operation of the automatic backup systems and phone dialer.
- staff training to handle routine alarms.
- staff familiarization with complete operating system, including water supply, aeration and emergency backup systems.

CONSTRUCTION HINTS

Probably the most important rule during design and construction is to keep it simple, known as the "KISS" principle. The other rule is to always assume that someone else will have to repair it, thus design notes, wiring diagrams, and labels are important. In addition, system components should be readily available from local or reliable sources. A "one-of-its-kind" is just that, and will soon become extinct. While designing and constructing, plan for expansion and leave room for additional systems or more "bells & whistles".

As much as possible, all materials used for system housing and hardware should be PVC, fiberglass or stainless steel to minimize corrosion. Water-resistant PVC junction boxes and fiberglass electrical cabinets, corrosion resistant and easy to drill holes into, are ideal housing to protect the electrical components. All external sensors should be low voltage, (i.e. 24 VAC or 24 VDC, ON-OFF), to minimize danger to operators and fish. Crimp style quick disconnect tab connectors on switches allow for easy construction and later modification. Solder joints should be covered with shrink-wrap tubing whenever possible. When buying individual components, look for extra options that may be useful in the future, such as extra alarm relays, voltage or current outputs and computer interfacing capabilities.

One simple trick to minimize the effects of aquaculture's harsh environment is to pressurize the control system housing using the aeration air supply. In this manner, relatively dry air is forced into the housing, preventing the high humidity and salt air from getting in. Alternatively, the step-down transformer in many of the systems provides a source of heat, thus preventing condensation from occurring.
REFERENCES


SOURCES OF EQUIPMENT

Aquadyne Computer Corp.  
7343-P Ronson Rd.  
San Diego, CA 92111  
619-569-2082  
http://www.aquadyne.com

Aquatic Eco-Systems, Inc.  
1767 Benbow Ct.  
Apopka, FL 32703  
800-422-3939  
http://www.aquatic-eco.com

AquaTrak Systems  
P.O. Box 1756  
Brattleboro, VT 05302  
800-655-1047

Balanced AquaSystems  
1332 Washington Avenue  
San Jacinto, CA 92583  
909-652-2612

Campbell Scientific, Inc.  
815 W. 1800 N.  
Logan, UT 84321-1784  
435-753-2342  
http://www.campbell.com

Cole-Palmer Instrument Co.  
7425 North Oak Park Ave.  
Chicago, IL 60641  
800-323-4340  
http://www.coleparmer.com

Cleveland Process Corp.  
127 SW 5th Ave  
Homestead, FL 33030  
800-241-0412

Craig Ocean Systems, Inc.  
9625 Brookside Ave  
Ben Lomond, CA 95005  
408-336-3403  
http://www.cos-inc.com/

DuTec  
P.O. Box 964  
Jackson, MI 49204-0964  
517-750-4708

ICONICS  
100 Foxborough Blvd.  
Foxborough, MA 02035  
508-543-8600  
http://www.iconics.com

Intellution  
One Edgewater Drive  
Norwood, MA 02062  
800-526-3486  
http://www.intellution.com

National Instruments  
6504 Bridge Point Parkway  
Austin, TX 78730-5039  
512-794-0100  
http://www.natinst.com

Newark Electronics  
4801 N. Ravenswood Ave.  
Chicago, IL 60640  
312-784-5100  
http://www.newark.com

OMEGA Engineering, Inc.  
P.O. Box 2284  
Samford, CT 06906  
800-826-6342  
http://www.omega.com

Phonetics, Inc.  
901 Tryens Rd.  
Aston, PA 19014  
610-558-2700  
http://www.sensaphone.com

Point Four Systems, Inc.  
2704 Clarke St.  
Port Moody, BC  
Canada V3H 1Z1  
604-936-9936  
http://www.pointfour.com

Royce Instrument Corp.  
13555 Gentilly Rd.  
New Orleans, LA 70129  
504-254-8888  
http://royceinst.com

Wonderware  
100 Technology Drive  
Irvine, CA 92618  
714-727-3200  
http://wonderware.com

W.W. Grainger, Inc.  
See local listings  
http://www.grainger.com

YSI, Inc.  
P.O. Box 279  
Yellow Springs, OH 45387  
800-765-4974  
http://www.ysi.com

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