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SELECTION OF WATER SUPPLIES

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Careful selection and prudent use of water sources will provide an environment which maximizes fish health. To be suitable, the water supply should be adequate to provide for the level of fish production required. Ideally, the water should be clean and moderately hard and there should be no fish in the water supply. The water should be of a uniform temperature (9-15.5°C) but warm or cool enough to promote satisfactory growth of the cultured species. The pH should be slightly alkaline and the water should be buffered to resist the effects of organic acids and ammonia. The hatchery design and operation should promote and maintain optimal water quality parameters (see Table 1).

Potential water supplies should be tested with an experimental group of fish to determine its suitability before initiating a fish culture project. The fish should be held in well-aerated tanks or troughs for an entire season or as long as seems practical to obtain the maximum test results. If the fish grow, remain healthy, and are active over the test period, the water can be considered to be suitable for raising fish.

TABLE 1. Water quality standards for fish culture (U.S. EPA 197940)

Alkalinity (hardness as $CaCO_3$)	20 ppm at least
Aluminum (Al)	<.01 ppm

Ammonia (NH,) <. 02 ppm	
Arsenic (As)	<.05 ppm
Barium (Ba)	5 ppm
Cadmium (alkalinity< 100)	.0005 ppm
(alkalinity>100)	.005 ppm
Calcium (Ca)	52 ppm at least
Chlorine (Cl)	<. 003 ppm
Chromium (Cr)	.03 ppm
Carbon dioxide (CO,)	1.5 ppm is best (no more than 15 ppm)
Copper (alkalinity < 100 ppm)	.006 ppm
(Cu) (aIkalinity> 100 ppm)	.03 ppm
Dissolved oxygen (DO)	75% of saturated level, never less than 5 ppm
Fluoride (F)	<.5 ppm
Hydrogen cyanide (HCN)	<. 005 ppm
Hydrogen sulfide (H_2S)	<. 003 ppm
Iron (Fe)	<. 1 ppm
Lead (Pb)	<.02 ppm
Magnesium (Mg)	<15 ppm
Manganese (Mn)	<.01 ppm
Mercury (Hg)	<.2 ppm
Nitrogen (N)	<110% total gas pressure, 103% nitrogen gas
Nitrate (NO,)	<1.0 ppm
Nitrite (NO,)	<1.0 ppm
Nickel (Ni)	<.01 ppm
PCB	.002 ppm
pH	6.7 - 8.6
Potassium (K)	<5.0 ppm
Salinity	<5 ppt
Selenium (Se)	<.01 ppm
Silver (Ag)	<. 003 ppm
Sodium (Na)	<75 ppm
sulfur (S)	<1.0 ppm
Sulphate (SO,)	<50 ppm
Total Dissolved Solids (TDS)	<400 ppm
Total Suspended Solids (TSS)	<80 ppm
Uranium (U)	<.1 ppm
Vanadium (V)	<.1 ppm
Zinc (Zn)	.005 ppm
Zirconium (Z)	.1 ppm

WATER CHARACTERISTICS

OXYGEN

Dissolved oxygen is one of the most critical aspects of water quality for culturing fish. It varies according to the source of the water, temperature, altitude, and biochemical activity of the water. The amount of dissolved oxygen required for fish culture should never be less than 75% of the saturation level. This level can be maintained by proper hatchery design or by the use of mechanical aeration devices.

Ammonia

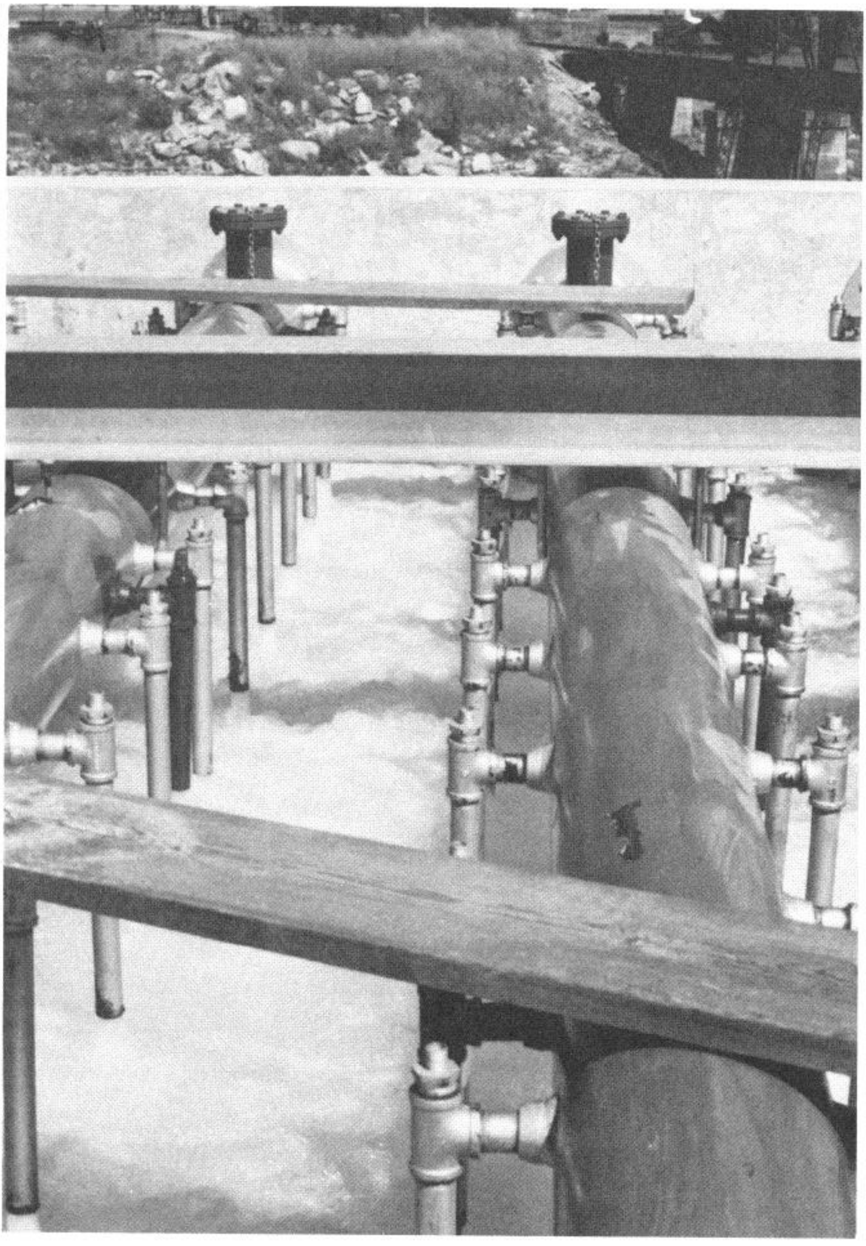
Ammonia in the water is generally a biological by-product; in its un-ionized form, it is very toxic to fish. Normally, the ammonia found in hatchery waters is produced by the fish themselves. Consequently, the production potential of a given water supply is determined by the quality of water available and by the number, size, and weight of fish present. For these reasons, the incoming water should contain little or no background ammonia to avoid or reduce potential problems.

NITROGEN

Waters in equilibrium with air contain dissolved nitrogen gas as well as dissolved oxygen in accordance with Henry's Law. Even though nitrogen constitutes about 78% of normal air by volume, its solubility in water is comparatively low. Water at sea level in equilibrium with air at 10° C contains about 14.89 ml/l of dissolved nitrogen gas — Handbook of Chemistry and Physics (Anon. 1950-51). Unlike oxygen, dissolved nitrogen is inert and is not consumed in biochemical processes, so that its content in water fluctuates only in accordance with temperature and pressure changes. Under normal conditions of less than saturation, no detrimental effects toward fish are anticipated. Supersaturation is not likely to occur in surface waters. However, if for some reason, the air over the water is under pressure, the amount of dissolved nitrogen will increase and can become a potential hazard to fish health. A review of dissolved gas supersaturation problems is provided in Weitkamp and Katz (1980).

Supersaturation of nitrogen can result from a number of causes, including the following:

1. Air drawn into the water supply due to faulty pumps, leaking pump seals, broken intake lines, and packing glands or connections which are not kept air tight.
2. Air drawn into a gravity flow water system through a partially submerged water standpipe or perforated line.
3. Air drawn into aquifers with seepage from surface precipitation (especially at low temperatures); or from subterranean pools with nitrogen-filled air domes held under pressure. Artesian wells and springs are often supersaturated with nitrogen gas (Wood 1968).



Aeration system for increasing oxygen and reducing nitrogen saturation in a hatchery water supply (T. G. Carey)

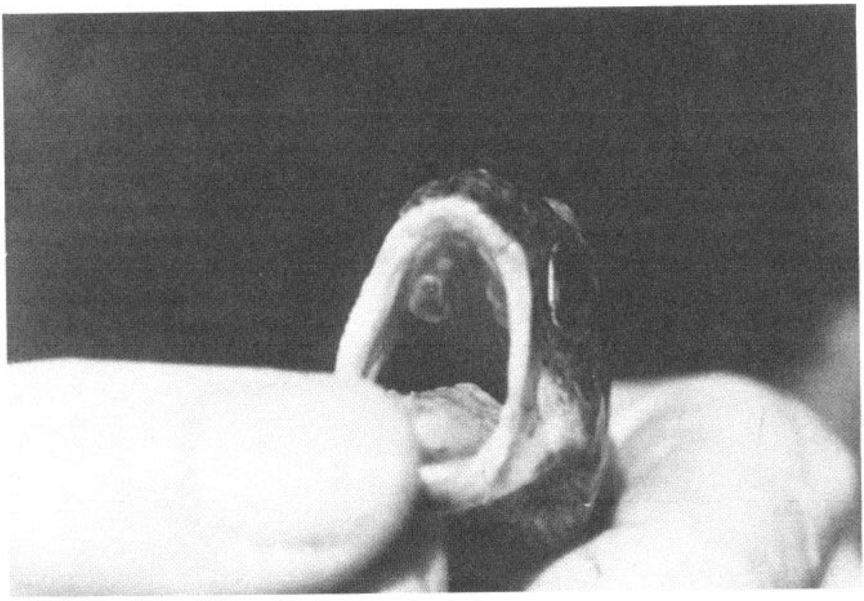
4. Plunge pools, where water passes over a dam or falls from a steep gradient, will entrain air and cause supersaturation in the water at the base of the waterfalls (Harvey and Cooper 1962).

Wood (1968) reported that the following levels of nitrogen saturation appeared detrimental or caused death in salmon of various ages:

- Advanced yolk-sac and newly "buttoned-up fry" — 103-104%
- Fingerlings and yearling — 113% (death); 105-112% (eye damage and blindness)
- Adults — 118% (eye damage)

A sudden change in the partial pressure of nitrogen gas in water, as from a rapid rise in water temperature, can be a serious threat to fish health. The essential cause being that the exchange of gases by diffusion at the gill-water interface is unable to maintain equilibrium between internal and external pressures (van Duijn 1966; Economon 1980). This temperature-induced phenomenon is not unlike the "bends disease" caused in divers due to sudden pressure changes.

Supersaturation of nitrogen in a water supply can be remedied by vigorously breaking up the water so that excess gas can escape to the atmosphere. The most practical devices, such as columns of pipe packed with Koch rings (Owsley 1981), operate by gravity flow. Other methods include spraying, dripping, formation of a thin sheet of water, or forcing air bubbles into water. Rucker and Tuttle (1948) designed a simple aerator for hatchery operations that allowed the water to flow as a shallow sheet. This was accomplished by allowing the water to flow over the sides of a series of troughs, one above the other.



In situations of a supersaturated water supply, fish may develop gross gas bubbles in the less dense tissues. Note the large bubbles in the mucous membranes lining the mouth of this fish. (U.S. Fish and Wildl. Serv.)

To accurately test for the level of nitrogen gas dissolved in water, it is necessary to analyze the water by either the Van Slyke technique, as modified by Oesting (1934), by the gas chromatography procedure of Swinnerton et al. (1962), by mass spectrometer (Benson and Parker 1961), by the Weiss saturometer (Fickeisen, et al. 1975), or by the recently developed gasometer (Bouck 1982).

HARDNESS

Hard water may be undesirable because it sometimes contains toxic gases, such as hydrogen sulfide, methane, carbon dioxide and nitrogen. For fish culture, the hardness (as $CaCO_3$) should be at least 20 ppm or more; around 120 ppm is ideal. Generally, an alkalinity or hardness greater than 20 ppm is preferred because of its capacity to buffer the effects of contaminating substances. Also, hard water is more productive, especially for pond culture.

IRON AND MANGANESE

Iron and manganese are detrimental to fish culture in both the ionized and unionized forms. Alkaline waters favor the development of insoluble hydroxide precipitates which can settle on the gill filaments, which, of themselves, have an alkaline reacting surface. A tenacious film may be formed that seriously limits respiratory function. In addition, saprophytic iron bacteria can proliferate on the ferric hydroxide that coats the gills, further promoting mechanical injury and blockage of the respiratory channels. Incubating eggs can be similarly affected. Wells that are drilled in areas of iron bearing deposits are the primary sources of dissolved iron (van Duijn 1966). Manganese can accumulate in the hypolimnion of reservoirs impounded over substrates containing this metal. If hatcheries allow such waters to be used as part of the water supply, manganese toxicity may result.

DISSOLVED SOLIDS

Dissolved solids represent a variety of substances including carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates and other metallic elements. At levels above 440 ppm, these dissolved solids can cause excessive stress to cultured fish and result in loss of feeding, decreased growth, poor reproduction, and mortality.

TURBIDITY

Turbidity caused by suspended solids is a measure of the particulate matter in the water column. This condition interferes with feeding and may block or seriously irritate the gills causing faulty respiration, poor growth, stress, and susceptibility to infections. Dissolved and suspended solids present additional hazards by reacting synergistically with pollutants to produce a totally unsatisfactory aquatic environment for raising healthy fish.

CONTAMINANTS

Less common contaminants, such as heavy metals, industrial chemicals, Cl, Cu, Hg, etc., are usually introduced through contamination. These water quality abnormalities are best corrected at the point of origin. Items or practices to be avoided inlcude the use of paints containing heavy metals, galvanized equipment or containers, the use of copper piping over fish culture tanks, and the use of stream water that may be contaminated from the washing of agricultural equipment or by live-stock use.

WATER SOURCES

Ground Sources

1. springs

Springs occur when a flowing aquifer is exposed at the surface of the ground or when a crack or other fault occurs in an otherwise impervious layer above a confined aquifer allowing water to escape to the surface. Water from springs reaches the surface either as a single point source or as a large area of seepage. Most springs with a large enough discharge to be useful for aquaculture are of the point source type and a sizable stream often flows from such springs.

Springs generally have high quality water of a constant temperature and require no pumping to get the water to the surface. Since pumping costs are a significant part of most production expenses, this factor can greatly reduce operating costs of a culture system. Spring water, like most other groundwater sources, generally has a low oxygen concentration and may require oxygenation. Care should be taken to quantify the discharge of a spring during dry weather. Small springs, and even some large ones, may have significant reductions in discharge during periods of dry weather. Springs exhibiting this characteristic should be avoided.

More specific help with design of a spring development as an aquaculture water source may be available from the local Soil Conservation Service (SCS). Most SCS offices have the services of a professional engineer available free of charge, or at a nominal charge to the user. Private consultants can also be retained for design purposes when necessary,

2. Wells

Except for high quality springs, wells are the best source of water for aquacultural enterprises. Well and spring waters are of comparable quality, but wells are less desirable because of the cost of pumping. Well water is usually free from pollution, although some well waters contain undesirable gases (e.g., hydrogen sulfide) or chemicals (e.g., high iron or sulfur concentrations). Well water normally travels considerable distances through the soil and may dissolve many substances along the way. Low dissolved oxygen is a common problem, but aeration can remedy this. A water table well is essentially a hole opened into an aquifer below a confining overlay of rock and water is removed by pumping. The yield from a well of this type is dependent on the permeability and vertical thickness of the aquifer. The diameter of the well also influences yield. Generally, greater aquifer permeability and/or thickness allows greater yields. These wells, sometimes referred to as shallow wells, tend to be more susceptible to yield variations during dry weather than deeper wells.

Artesian or flowing wells are those from which water begins to flow without pumping as soon as drilling is complete. Essentially, artesian wells occur when drilling penetrates an aquifer confined between two relatively impermeable layers. The recharge area (area where water can enter the aquifer) must be higher than the outlet of the well. Water entering the recharge area flows under gravity through the aquifer toward the well. Since some energy is required to cause flow through the permeable aquifer, the recharge area must be sufficiently higher in elevation than the outlet of an artesian well to overcome head losses caused by flow through the aquifer. The head loss experienced during flow through an aquifer is dependent on flow velocity, permeability of the aquifer, and the distance water must move through the aquifer. Thus, free discharge from an artesian well is a direct function of aquifer permeability and an inverse function of velocity of flow through the aquifer and distance from well to recharge area.

SURFACE SOURCES

Surface water supplies can be divided into four major sources; streams, lakes, ponds, and salt or brackish bodies of water. All surface water supplies have the undesirable characteristic of being exposed to sources of pollution and should be used with caution. However, most surface waters are well oxygenated, which is advantageous for aquatic enterprises.

1. Streams

Streams, like other water sources, offer advantages and disadvantages that are related to stream characteristics. Because turbulence is prevalent in most streams, the dissolved oxygen content usually is high. The pH and dissolved mineral content are determined by the topography, by the type and solubility of substrate of the area through which the stream flows, and by biological activity within the stream. Latitude, altitude, season, rainfall, stream depth, width, and turbulence influence the flow, temperature, and concentrations of dissolved solids and suspended organic matter in a stream. Radiant energy and dissolved inorganic mineral concentrations affect photosynthesis, respiration, and decomposition which, in turn, determine the amount of organic material present in the water. Stream discharge characteristics are important when the stream is the sole source of water for an aquacultural enterprise. If the discharge varies greatly during the year, a stream may not furnish sufficient water during dry periods when demands for water by aquatic organisms are highest. High temperatures often occur during these same periods and increase evaporation rates and the risk of thermal death or thermal stress.

States and provinces have regulations covering water diversion. Legal problems may arise if water quality of a stream is reduced by the effluent from an aquaculture installation. All aquatic organisms add waste products to the water. Agencies concerned with environmental control may require monitoring or treatment if the effluent contains excessive levels of waste products.

2. Lakes, ponds, and reservoirs

Water drawn from lakes, ponds and reservoirs has many similarities to that in rivers. However, oxygen concentrations tend to be lower, particularly if water is drawn from below the thermocline. Temperatures of lake water and, to a lesser degree, pond waters are more stable and predictable than the temperature of water from streams. Water temperatures change markedly with seasons and this factor must be considered when designing an aquacultural facility. Other water quality parameters, such as pH and dissolved and suspended nutrients, tend to be more constant in lake and/or pond water than in stream water. The larger the body of water, the smaller and less abrupt the changes will be in all environmental parameters.

Permits may be required from the necessary federal, state, or provincial governmental agencies to pump out of or discharge into a lake, pond or reservoir.

3. City water

Another source of water for aquaculture is a city water supply. Cities supply water mainly as a source of potable water for people, and their major concern is to maintain water quality such than humans can drink without endangering their health. To maintain this water quality, chemicals such as chlorine and/or fluorine may be added. Unfortunately, the chemicals added to increase the acceptability of the water for humans may make it very unsatisfactory for aquatic organisms. The most common example is the addition of chlorine to kill bacteria. Chlorine is highly toxic to fish.

WATER TRANSMISSION

1. Materials

Supply lines are developed to move water to the hatchery and within the hatchery so it can be presented to the fish in a condition that promotes good growth and health. Before one discusses the subject of hatchery water transmission, it is necessary to consider the possible toxicity of materials used to convey or contain hatchery water.

All equipment, regardless of its material makeup, must be seasoned or leached before it can be used to hold or transport water that will be used to grow fish. For equipment, this can be done by submerging the item for several hours downstream from the hatchery. In the case of new tanks, troughs, incubators or other rearing containers, allow water to flow through the filled containers for at least 24 h before they are stocked with fish or eggs. Preferably, the water leaving the containers should be diverted to the effluent to avoid contact with fish or any other equipment utilized by the hatchery.

The following materials are nontoxic in flowing water systems if leached before initial use:

- aluminum
- asphalt
- concrete
- Plexiglas
- polyethylene
- polypropylene

- fiberglass
- glass
- gravel and rock
- heavy metal-free paints
- iron
- nylon
- polyvinyl chloride (PVC) Type I
- rubber
- silicone and hot melt adhesives
- stainless steel
- wood

Questions concerning the toxicity of a material can best be answered with a bioassay. This involves introduction of the material in question into a container of hatchery water with a small number of fish (at least 10) and leaving it for 24 h. If the fish show abnormal behavior there is reason to suspect that the material tested is toxic.

The following lists some of the more common toxic materials that find their way into a hatchery. *Avoid these materials:* cadmium (Cd) — usually a plating material for tools; copper (Cu) anything brass, an alloy of Zn & Cu; city water (chlorinated at .002 ppm); detergents; heavy metals; neoprene; PVC type II; zinc (Zn) — anything galvanized — if the water is less than 50 ppm in hardness.

PUMPS

Pumps are mechanical devices used in hatchery water supply systems to provide head pressure and flow. If improperly installed or malfunctioning, pumps can also present fish health problems such as supersaturation with gases or an unreliable water flow.

1. Centrifugal pumps

These pumps have an impeller than spins the water, forcing it against the pump housing and out the discharge port. An oil or water-sealed bearing is located between the impeller's drive shaft and pump housing. To avoid toxicity problems, water-sealed bearings are preferred in hatchery use. The discharge of a centrifugal pump decreases as the head increases. In a situation where water must be pumped to considerable heights, this requirement may dictate the use of a different pump. The outlet or discharge of a centrifugal pump can be choked without risk of damage to the power source equipment but there is a significant loss of efficiency.

2. Rotary pumps

The impeller in this category of pumps simply pulls water through the housing. This type of design is referred to as a positive displacement pump since there is no water slippage around the impeller. For this reason, a rotary pump's discharge should never be restricted or choked and an outlet relief valve is mandatory.

A bearing between the end of the impeller shaft and the housing bears the thrust created by the impeller. This force can be substantial and represents a maintenance problem.

Power requirements for rotary pumps increase as the pressure head increases. Rotary pumps are best in situations involving a low head and a high discharge.

SUMMARY

Water supplies for aquacultural enterprises must meet both quantity and quality requirements. The available water quantity must be sufficient to make up for evaporative and seepage losses, to supply the necessary amount of oxygen, and to provide adequate flushing to remove waste products. Sufficient water must also be available to supply other uses such as irrigation, domestic needs, and fire protection, if necessary. Water quality for aquaculture must meet certain high standards. The temperature, oxygen content, pH, and hardness must be at optimal levels for fish, or it must be economically feasible to alter them to needed levels. Pollutants and undesirable organisms in the water supply must be eliminated.

Groundwater is the most desirable water supply source for aquacultural enterprises if adequate precautions are taken to assure that sufficient oxygen concentrations are present in the water. Good springs are most desirable, since pumping costs are eliminated. Wells are also good but pumping may be expensive. If depression of the water table occurs, wells should be used only after careful thought and planning. Chemicals are added to the water in most city systems, so pretreatment is necessary before such water can be used in fish culture systems.

Surface water sources (e.g. streams, lakes, ponds) all exhibit greater variations in environmental parameters than groundwater sources. Surface waters are normally high in oxygen concentration when compared to groundwater but a greater risk for pollution problems exists.

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