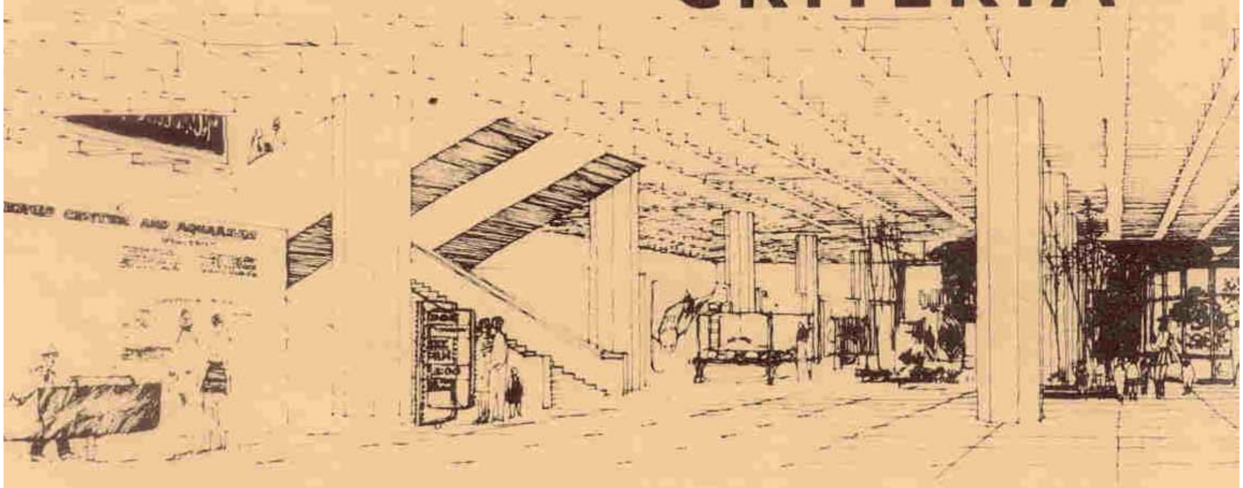
AQUARIUM

DESIGN

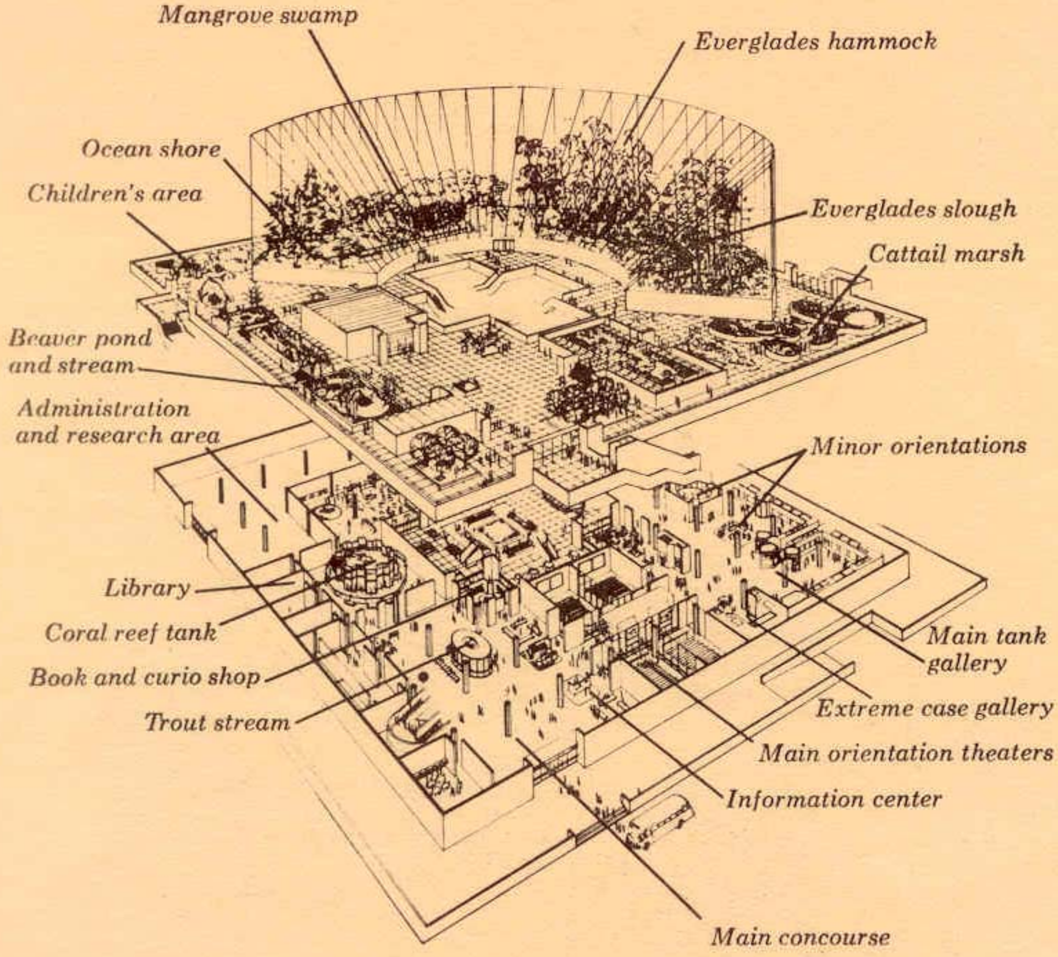
CRITERIA



SPECIAL EDITION

DRUM & CROAKER

SEPTEMBER 1970



NATIONAL FISHERIES CENTER AND AQUARIUM

SPECIAL EDITION

DRUM AND CROAKER

September 1970

A Q U A R I U M   D E S I G N   C R I T E R I A

Wm. Hagen

Assistant Director - Operations

National Fisheries Center and Aquarium
U. S. Department of the Interior
Washington, D. C. 20240

with
authored contributions

*Prepared by the National Fisheries Center and Aquarium,
U. S. Department of the Interior, Washington, D. C. 20240,
under authority of Public Law 87-758, 76 Stat. 753,
as a service to aquariums generally.*

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Critical review by the following is gratefully acknowledged:

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Review by the above does not necessarily imply that each is in agreement with all of the statements, methods or procedures contained herein.

2002 Editor's Notes

Photographic images that appear indistinct on your computer monitor will be reasonably clear when printed. Since this issue contains many images, printing a copy will be your best way to enjoy it.

I used OmiPage 9.0 software to scan each page of an original copy that was loaned to me by Tom Frakes (Mentor, OH, USA). This optical character recognition (OCR) software was ~95-99% accurate in reproducing the original text. The pages were then reformatted and edited individually. Most images were scanned separately and reinserted into the text later (due to limited imaging properties of this version of Omnipage). Hopefully a minimal number of errors have crept into this document as part of the editing and OCR process.

Pete Mohan
Kent, OH, USA
Fall 2002

FOREWORD

It would appear that the time is ripe for construction of new aquariums and for renewed interest in old ones. Our ecological conscience has grown by leaps and bounds and our awareness of the aquatic environment has even penetrated popular television.

That this is good, is obvious; that it will force some changes upon us is equally obvious - and equally good. The facility which we have long termed an "aquarium," but which is often little more than a fish menagerie, or a collection of it curios," can no longer expect to receive the same rapt attention from today's audience that it received from yesterday's relatively unsophisticated clientele.

The public is no longer so impressed by the fact that certain fishes give birth to living young and that others shoot their prey out of trees. That one of them is able to live on land, is no longer startling to today's evolution-oriented teenager and the fact that another can generate enough electricity to stun a man is simply more evidence of the operation of natural selection in the evolutionary process.

This is as it should be. It is also a clear warning that the public will not long continue to accept the standard practice of displaying a fish in a transparent cage with a little note giving its country of origin and its "scientific" name.

Today's youth wants to know about adaptation, behavior, physiology, convergent and divergent evolution and, since it is already aware of continental drift, about speciation through isolation. Accounts of Darwin's voyages are now popular reading and the concept of evolution through natural selection and mutation is discussed at the junior high school level.

Thus, in addition to the considerable recreation it might offer, an aquarium will be expected to provide the visitor with an introduction to those disciplines that go with a more serious study of water animals and their environment.

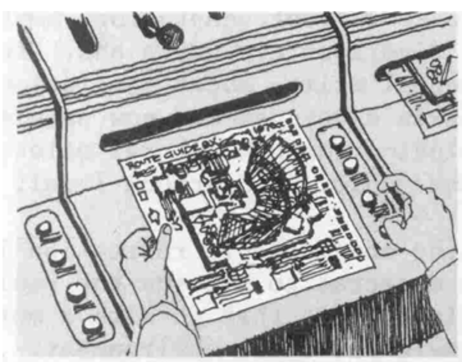
Involvement in these disciplines could enrich the visitor's life, broaden his point of view and his fields of interest. It could prepare him to meet some of the rapid changes that are taking place in our world. It might help make him even more aware of the earth's water as a beautiful and productive resource to be both used and protected. We are obliged to make the attempt!

The chapters which follow in this publication are primarily concerned with design for the maintenance of specimens, with water quality, and with the operational problems often encountered in aquariums. The ability to solve these problems, however, is only one necessary prerequisite to having a successful aquarium; much as having a good janitorial and engineering staff is a necessary prerequisite to having a successful theater. Without an audience-stimulating presentation, both would fail.

We have lived in an era when even a mediocre fish menagerie could be a box-office success. We are approaching an era when we will be expected to teach and to explain biological concepts rather than to merely exhibit specimens.

Unfortunately, the software of our profession is not nearly so well developed as the hardware. We are, herein, presenting the extant hardware. We urge that you give equal attention to the software.

Warren J. Wisby, Director
National Fisheries Center and Aquarium



Programmed inquiry station

Information center

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INTRODUCTION

The National Fisheries Center and Aquarium has received numerous requests for books, pamplets, designs or plans from people who plan to build an aquarium. From Hong Kong and Singapore, South Africa and North Africa, Brazil and Argentina, these requests have come. Most often the incoming letter does not provide enough information on which to base meaningful answers. We are not told whether the inquiry concerns the usual aquarium, or what is now termed an oceanarium.

It seemed to us that the basics of aquarium planning should be available to provide criteria necessary for efficient operation, the welfare of the living exhibits, and the presentations for the visitor. Without such basics, or the assistance of a professional aquarist, an exhibit specialist, and an engineer, architects and owners are prone to plan first for the admission fees, the exterior appearance, and the interior public areas. Once the need for the display and, therefore, the probable success of the venture have been established, the planning ought to start with the objective - the display of healthy aquatic organisms.

To these ends the author has prepared those sections without by-lines, has called upon others to contribute articles on various phases of aquarium design, and has included pertinent articles that have appeared in DRUM AND CROAKER. These are not concerned with the specimens themselves, or decorations -- except to the extent that water quality and treatment, adequate work and holding areas, food preparation space, and other design factors lend themselves to efficient operations and healthy and attractive exhibits. Included is a section on people-handling and the desirable features for the comfort and enjoyment of the visitors.

Aquariology is a changing science -- If it can yet be called a science. Unfortunately, many aquariums are content merely to have living fishes on display -- no effort is made to search for better methods. Other institutions, however, are continually improving.

In only a few instances are bibliographic references provided. Generally, the content of the articles reflects the experience of the authors. Trade names are generally not given.

This collection of articles is not expected to remain up-to-date for very long. New materials and improved equipment and techniques are becoming available.

Nor is this group of articles expected to be in agreement with the thinking of all aquarists. We can say with some assurance that no aquarium operation is perfect and that no one in the field could supply all of the answers leading to a perfect operation. Many aquarists have gained their experience at only one establishment and thus have somewhat limited knowledge, although their own operation may be excellent. We feel that no single method will always prove to be the best. Rather, circumstances undoubtedly will require a combination of methods or techniques. It is with these convictions in mind that we have assembled this packet, simply to provide the basics for aquarium planners. This is not a detailed, "in depth" effort, nor for its purpose, need it be.

We invite aquarists, and others, to write us of their views differing from those presented herein, or of new techniques. Nothing is final. This effort may be revised over and over again. We hope it is, as this will indicate progress in the aquarium design field.

THE NEED AND CONCEPT

An aquarium built almost anywhere will prove to be a popular attraction. Nevertheless, to be successful, whether financially or in terms of education or recreation, it must be sited where a real need exists.

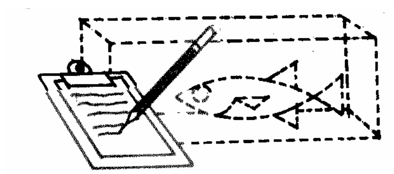
The concept of the aquarium -- what it will be and do -- must be determined early. Within the funds available, what usual and what special features will be included.

An initial simple design should be prepared which presumably will provide adequate space for the expected visitors and will also provide the necessary operating areas. These must then be considered with knowledgeable persons and be modified as required. If the aquarium is to be more than a house for living aquatic animals and plants, an exhibit specialist should be at hand to design presentations to meet the objectives of the institution.

Public aquariums are leaning more and more toward educational recreation for their visitors. It is felt that a mere line-up of tanks containing specimens identified by photographs, names, and range may be interesting, but is not sufficiently informative. Groupings of specimens may be made to illustrate environmental preferences, means of locomotion, sight, hearing, food habits, schooling, use by man, and any number of other interesting and informative themes. If these are properly presented the visitor will unknowingly absorb and retain much knowledge of aquatic life.

Planners should, then, include in the design particular configurations of tanks, in separated groups, as a means by which a theme can be effectively carried to the audience. Contributing information can be furnished by push-button film strips, guide books, and by lighted legend boxes.

A word about money. Many aquarium designers have found, after their plans are complete, that the available funds are not adequate. hen they start cutting, here and there, generally to the eternal detriment of operations. This has happened so often that it seems wise to recommend that the design should intend to use only about 65% of the available funds for construction.



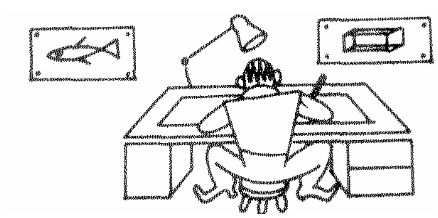
THE PLANNERS

We shall assume that the promoters of the aquarium have the necessary financial backing and that they realize that at least 60% of the cost will be for facilities, equipment and design, most of which is peculiar to aquariums, and most of which is not visible to the public.

The promoters have a site that appears to be suitable. It should be readily accessible by both public transportation and private vehicles, and should, if possible, be easily reached by tourists. Adequate vehicle parking in the area is desirable.

The most vital factor is the water supply. Usually the promoters are not competent to judge this essential ingredient, the quality of which must be known before the project can be further developed. Too often promoters assume that the water is of good quality and of sufficient, continuous volume.

At this point in the planning the promoters should seek professional advice, both as to the quality of the water and the volume required for the proposed facility. From here on the planning staff should include individuals competent in the aquarium field.

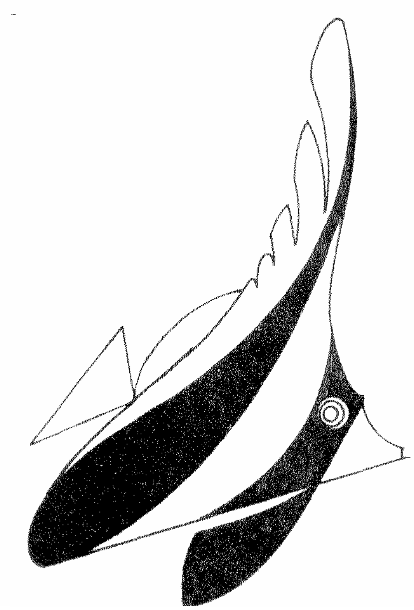


COORDINATION

Throughout the period of planning and design of the aquarium there must be constant communication and thorough understanding among the architects, the aquarist, and the design-mechanical engineer. Failure in this area will most certainly result in late changes, expensive change orders after construction is underway, and some overlooked design faults that will plague operations continually.

The person who is planning the exhibits and presentations should be consulted frequently to assure meshing of building design and exhibit plans.

As design proceeds, plans and specifications should be carefully and more or less continuously reviewed by the supervising aquarist and his staff. Desired changes should be discussed with the architect and resulting agreements should be entered on paper and initialed.



DESIGN AND PEOPLE

Too often we find an aquarium tucked into a small building on a small plot of land. Such a situation precludes expansion and does not permit innovations to attract more visitors. Public aquariums are most often in such ' a situation. Perhaps this is so because of politics as well as the desire for ready accessibility for the public. Also, it should be noted, the public aquarium is usually non-profit and probably not self-supporting. In most instances, however, had original planning been adequate, such institutions could very well survive and actually expand without grants or subsidies.

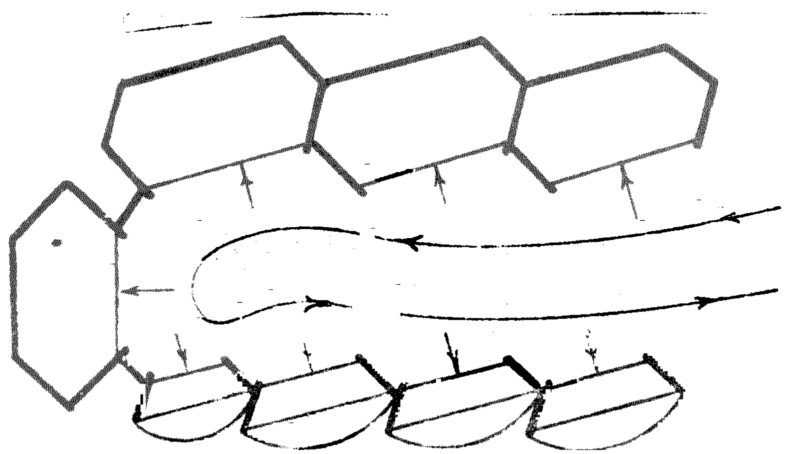
Most major commercial oceanariums and aquariums in the U. S. have generally been very successful in presenting programs to entertain the paying visitor but have provided little toward his education. Success of these showplaces can be attributed to a study of economics, people, and catering to their likes. Oceanariums generally are located on large sites permitting the dispersal of visitors. They usually are in populous areas, and on major tourist routes.

Most public aquariums cannot serve very large numbers of people at one time. The oceanariums, with much space, can and do attract and keep large crowds. Not only do they profit from the initial admission charge, the longer people stay, the more they will tend to spend on food and concession items. The public aquarium, on the other hand, very often is in the position of having too many visitors for its size.

The first United States oceanariums were constructed with some design faults. The more recent ones, with one exception, have been adequately designed with the help of experienced professionals. All of them are oriented to visitors and profit, but all have, at last, recognized the need for adequate operating areas. Some have substantial research facilities.

Designing for visitor guidance will be based upon the building and site size and an estimate of the expected visitor load. More often than not the funds available for a public aquarium will dictate the size, regardless of expected visitations. Hopefully, if the site is large enough, the original design will provide for future expansion.

It is desirable to have a flow pattern for visitors. Design can quite readily lead the visitor into the desired path in most situations. Upon entering, a visitor will generally turn right, provided no attractions draw him elsewhere. By placing display tanks at an angle, with the viewing glass facing the oncoming visitor, he will normally proceed in that direction. Open-floor exhibits can serve as shields and also continue to draw the visitors along the desired path.



Monotony is to be avoided in the placement of display tanks. They should not be lined up like railway car windows. All of them should not be set at an angle. Alcoves and jut-outs will provide variety and surprises, and can serve as dividers between special exhibits. Variety also serves to orient the visitor.

Handrails to keep the public about three feet from the viewing glass may be desirable. Opinion is divided among aquarists regarding rails. When large numbers of visitors are present, a rail keeps them back from the glass and permits more people a better view. On the other hand, close inspection of small organisms is then not possible.

A step-up for small children is often provided. This usually is about one foot high and one foot wide, and should be part of the building structure and continuous.

Resting areas are desirable and may be incorporated with a dry floor exhibit.

Floor or other electrical outlets should be available to provide lighting or operating power for special exhibits out in the public area.

A convenience for photographers is a 2-inch hole through the wall above each tank. A cable through the hole permits operation of flash units over the tanks.

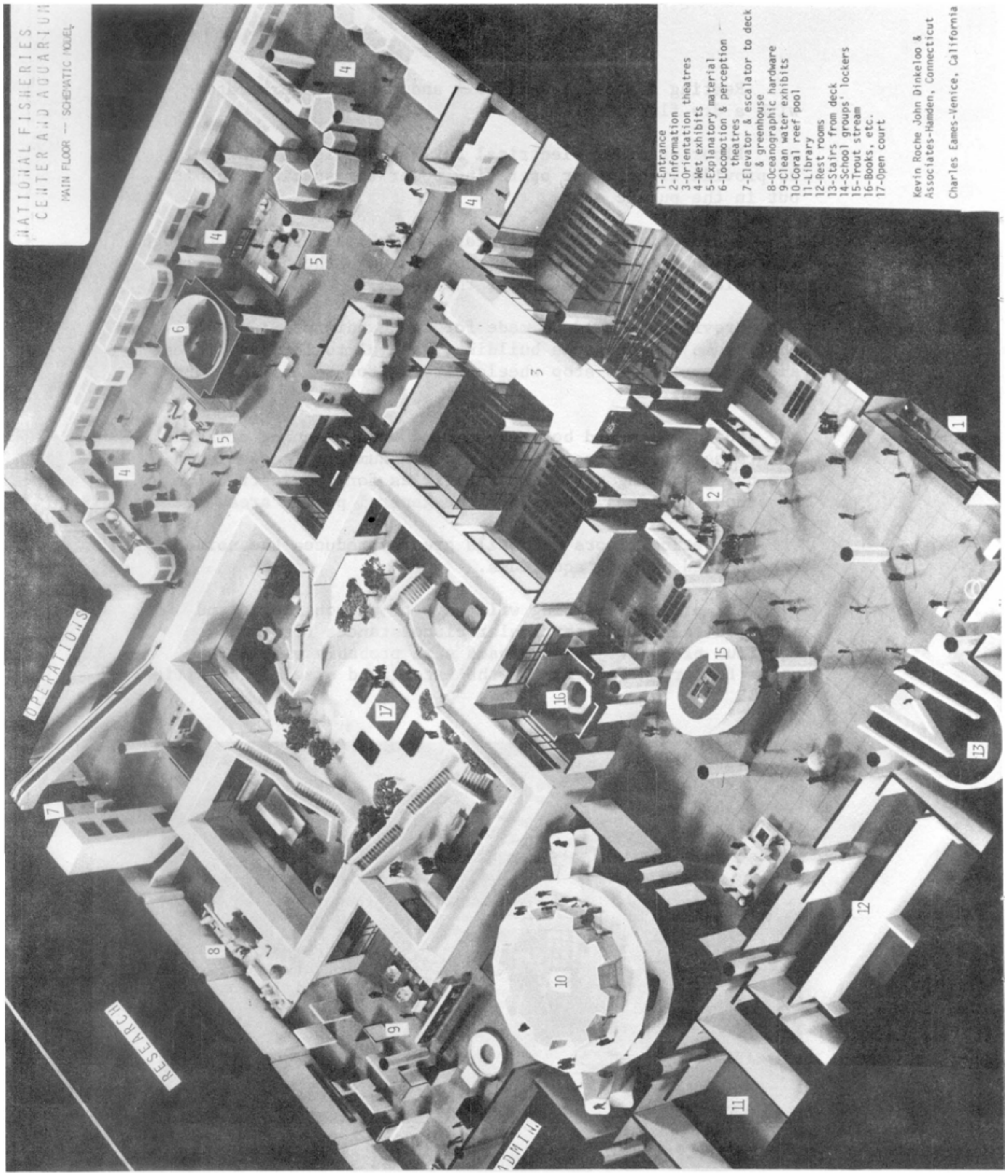
Provision should be made for the handicapped: a wheelchair ramp to enter the building, special toilet facilities, and no barriers to stop wheelchair visitors. An elevator may be required.

Children should be kept in mind when planning drinking fountains, toilet facilities, etc. A number of aquariums are now providing space and facilities for the instruction of school children, away from the general public area.

Carpeting floors and walls greatly reduces the noise experienced in most aquariums.

All of the foregoing will have to be considered and modified to fit the particular circumstances for each aquarium planned. The proposed size probably will be the major factor in determining the extent and size of facilities.

View in the main concourse


NATIONAL FISHERIES CENTER AND AQUARIUM
MAIN FLOOR -- SCHEMATIC MODEL
OPERATIONS
RESEARCH
ADMIN
1-Entrance
2-Information
3-Orientation theatres
4-Wet exhibits
5-Explanatory material
6-Locomotion & perception theatres
7-Elevator & escalator to deck & greenhouse
8-Oceanographic hardware
9-Clean water exhibits
10-Coral reef pool
11-Library
12-Rest rooms
13-Stairs from deck
14-School groups' lockers
15-Trout stream
16-Books, etc.
17-Open court
Kevin Roche John Dinkeloo & Associates-Hamden, Connecticut
Charles Eames-Venice, California

THE OPERATIONS AREA

As previously stated, planners of aquariums often consider the facility only from the visitor's viewpoint. They do not realize that the welfare and attractiveness of the specimens, and minimum costs for operation and maintenance depend upon the attention given to behind-the-scenes design.

The immediate work area behind the display tanks may be considered first. The work-area floor should be about three feet higher than the public area floor. This is dictated by the height of the average visitor looking into the approximate center of the viewing glass of the average large display tank. Most display tanks are placed on the floor of the work area, Obviously, very small and very large tanks will have to be placed differently. Tanks should be placed to permit ease of cleaning by aquarists.

Holding tanks to receive new specimens for quarantine, and space to hold surplus or sick specimens should be placed along the rear wall of the work area, or in any other convenient locations. Each of these holding tanks should have its own recirculating system. The total holding capacity should be equal to about 1/3 of the display volume, but may vary considerably, depending upon the sizes of display tanks and specimens, as well as the mortality rate and replacement need.

All quarantine tanks should be provided with drain valves to permit rapid drainage after treatment procedures. All tanks should have removable pump screens.

Many aquarists feel that practically all healthy specimens ought to be on display since they use space when held in reserve and require the same care as specimens on display. Nevertheless too few quarantine or treatment tanks can greatly hamper operations. The exhibit/holding ratio should be carefully considered

The various main supply pipes from the reservoirs should extend around the aquarium over the display tanks. These should be a minimum of seven feet above the work-area floor and should have frequent tap valves from which, by flexible hose, replacement water or a continuous flow may be fed to the tanks, depending upon the system. It is important to have shut-off valves conveniently located along the major supply lines to facilitate plumbing repairs.

To reduce the possibility of accidental flooding to a minimum, automatic cut-off switches, built-in overflow drains and failsafe devices should be planned in connection with tanks and reservoirs that are periodically drawn down and refilled.

All electrical appliances and equipment, including connector boxes, must be grounded. Outlets should not be located near the floor. Fixtures over the tanks should be protected to avoid breakage and possible danger to personnel working in water. Poles attached to brushes or other cleaning devices should be of wood or other non-metallic material.

Natural .light should be held to a minimum, unless completely controllable. Natural light promotes algae growth on interiors of tanks.

A flexible lighting system over each tank should include the capability of being lifted out of the way when cleaning tanks or feeding specimens. Sufficient waterproof outlets should be provided for auxiliary or special lighting.

A clear passageway about six feet wide should extend along the back of all display tanks in order to permit the easy transport of tanks, incoming specimens, etc., by forklift truck or 4-wheel flatbed. No stairs or other obstacles should be located in this passageway.

The surface of the work-area floor should have a nonskid finish. Floor drains with sand traps are absolutely necessary and floors should be sloped to drains. Water-resistant materials should be used in all places adjacent to tanks.

Storage space for tools, nets, chemicals, and other items in frequent use should be provided. Refrigerators often are convenient for the storage of special foods, and may reduce trips to the food preparation room.

Stairs should be placed conveniently from the work area to the public area, with lock doors. Small wall desks may be provided for record-keeping.

Deep wash basins with hot and cold water and towel boxes should be located conveniently in the work areas. Also, suitable containers for net sterilization should be provided.

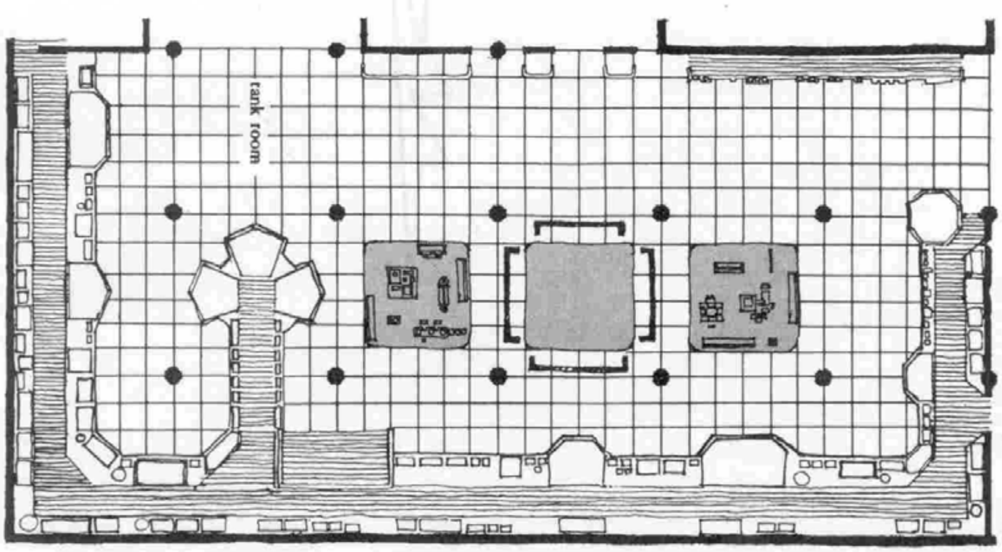
Centrally located and convenient to the live exhibits should be the grouping of loading dock, food preparation room and freezer, offices for the biologist and chief aquarist, room for the shipping and receiving of live specimens, and crew-room with showers and toilets. Space for the chief engineer and control and monitoring panels should be provided. The size of each of the foregoing, as well as the necessity for offices and crew-room, will depend upon the size of the aquarium and the number of personnel involved in operations.

The above can be located on either the work-area level or the public-area level. If the latter is the case, a ramp should extend from the loading dock area to the work level. It is also desirable to have easy rolling access to the public area and to the administrative offices.

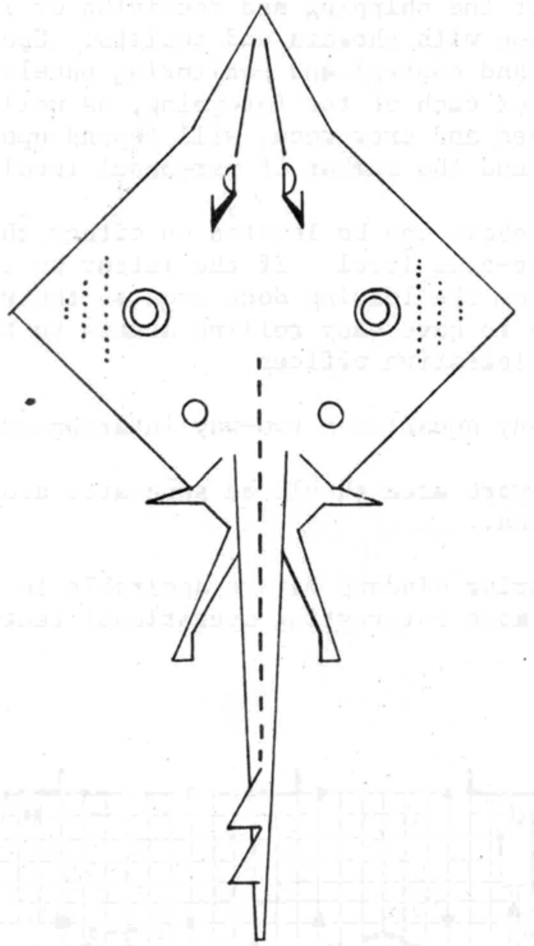
In any aquarium a two-way intercom system is very important

The work area should be separated acoustically from the public area.

Interior windows may be desirable to permit visitors to view the more interesting operational features.



Plan of tank gallery



WATER QUALITY

James W. Atz
Associate Curator

The American Museum of Natural History

The chemical condition of the water in which fishes and aquatic animals without backbones (invertebrates) are kept is vital to their health. Anything suspended or dissolved in the water comes into the most intimate contact with these animals, mostly through their gills, and there is little they can do to keep harmful substances from entering their bloodstream or body. For, example, only two parts of copper dissolved in a hundred million parts of water can kill some fishes within 24 hours, while acutely toxic concentrations of pesticides like Endrin need have a strength of less than one part per billion. The invertebrates are even more sensitive than fishes.

In order to keep animals as sensitive as this alive in captivity, there is only one safe rule to follow: all aquaria and other parts of water systems must be made of chemically inert materials.

The source of any water that is to be used in aquariums must be scrutinized to make certain it always has the proper chemical composition and never contains substances harmful to the exhibits. Ordinary standards of water purity are not adequate because perfectly potable freshwater or seawater perfectly safe for bathing may be deadly to fishes and aquatic invertebrates. As far as their water supply is concerned, these animals are much more delicate than man. Frequent trouble makers in municipal tap water are chlorine, excessive hardness, and brass or galvanized piping. A single small, metallic fixture can quickly bring about the death of fish when the water running thru it is soft.

As far as the aquarium's visitors are concerned, the only necessary water quality is clarity so that they can easily see the exhibits. For large tanks (500 gallons or more) the water must be very clear indeed; the water of some municipalities contains colloidal clay and although it looks crystal clear in small tanks, its milky appearance in large ones makes viewing through it quite unsatisfactory. (Animals may live in such cloudy water without any difficulty, but water that is cloudy from the presence of myriads of bacteria is unsatisfactory for both visitor and exhibit animal, although for different reasons.)

In some aquarium water systems, the water is used only once and is then discarded. These are called open systems. Closed systems are those in which the water is recirculated, being used over and over again.

Sometimes it is necessary to treat the water as soon as it enters the aquarium building, usually by filtering it. Natural seawater should always be filtered before being put into reservoirs or closed systems of any kind in order to remove the tiny animals and plants (plankton) that inhabit it. These floating mites cannot live under the conditions of captivity and when they die, they decompose and temporarily make the seawater toxic to larger forms of marine life . Even filtered seawater "rots" to some extent and may have to be stored in the dark for as long as six weeks before becoming fit to use, particularly in small tanks. For the great majority of exhibits, however, fresh, filtered seawater may be used without delay, if it has not originated from polluted sources and if each water system contains at least one thousand gallons. On the other hand, untreated natural seawater can be used in open systems, provided it is clear enough not to obstruct the view of the exhibits. An important advantage of this kind of arrangement is that it makes easy the exhibition of plankton-feeding animals, which subsist on the small plants and animals they strain out of the water.

Unless the aquarium can be built near a dependable source of water of the proper quality and sufficient quantity, closed water systems will be a necessity, but water that is used over and over accumulates waste products from the animals living in it, and as time goes on, the concentration of these substances becomes intolerable. Their removal, however, presents special problems.

Aquarium animals, just like terrestrial ones, must consume oxygen to stay alive and at the same time must get rid of the carbon dioxide they produce. If the water in which they find themselves has either too little oxygen or too much carbon dioxide, they will die. Fortunately, the atmosphere provides an unlimited supply of oxygen and can take up unlimited amounts of carbon dioxide - at least the small amounts produced by aquariums . Therefore all that needs to be done is to expose enough of the aquarium water to air above the vessel so that the two gases will be exchanged at a sufficiently rapid rate. This is most easily done by the use of aerators, although circulating the water and otherwise agitating it is also very helpful.

The animals' other wastes are not so easily disposed of, however; in fact, no economically-feasible way has yet been devised to remove them from aquarium water. Most important of all is ammonia. This is the principal waste product in the urine of fishes, and these animals excrete ammonia through their gills as well. Ammonia is also the principal excretory product of aquatic invertebrates. Other waste products, such as urea, are broken down into ammonia by bacteria in the water. In addition, ammonia is produced when bacteria bring about the decomposition of fecal fish wastes as well as any uneaten food or plants and animals that have died in the tank. It would not be far wrong to state that every bit of food put into an aquarium, except that utilized in the growth of its inhabitants, eventually turns into ammonia.

Ammonia is exceedingly toxic to almost all fishes and invertebrates. For example, trout living in water with as little as six parts per billion of ammonia show abnormal gills. Even freshwater pondfishes, which are much less sensitive to ammonia than trout or coralreef fishes, should not be exposed to concentrations of more than one part in ten million of water.

At the present time, there is only one economical way to avoid ammonia poisoning in closed aquarium systems, and this is by taking advantage of the bacteria that change ammonia into nitrate (by oxidation), a chemical that is much less harmful to aquatic animals. These nitrifying bacteria occur naturally in all aquariums and water systems, but not in large enough numbers to quickly convert the toxic ammonia into relatively harmless nitrate. In a well-managed tank, these bacteria thrive on the walls and other surfaces, but not in the water itself, because they must be attached to some kind of solid material in order to grow and multiply. There are not enough surfaces in an aquarium to provide "homes" for sufficient numbers of nitrifying bacteria to keep the concentration of ammonia as low as it needs to be, that is, virtually zero. One of the principal functions of a filter is to provide living-space for nitrifying bacteria, and countless numbers of them cover the grains of sand or gravel of the filter bed. In the future, other ways of eliminating ammonia may be found, but biological filtration is now the only practical way to do so.

In addition to the solid surface they require, nitrifying bacteria need oxygen; the water should be aerated both before and after filtration - afterwards in order to replace the oxygen used up by the filter bacteria. Nitrifying bacteria are slow multipliers (as compared with many other bacteria), and cold temperatures, acid waters, high salinity, and lack of calcium slow them down even more. Whenever an aquarium or a water system is put into operation, the number of animals put into it ought to be limited until the filter has acquired its full complement of nitrifying bacteria.

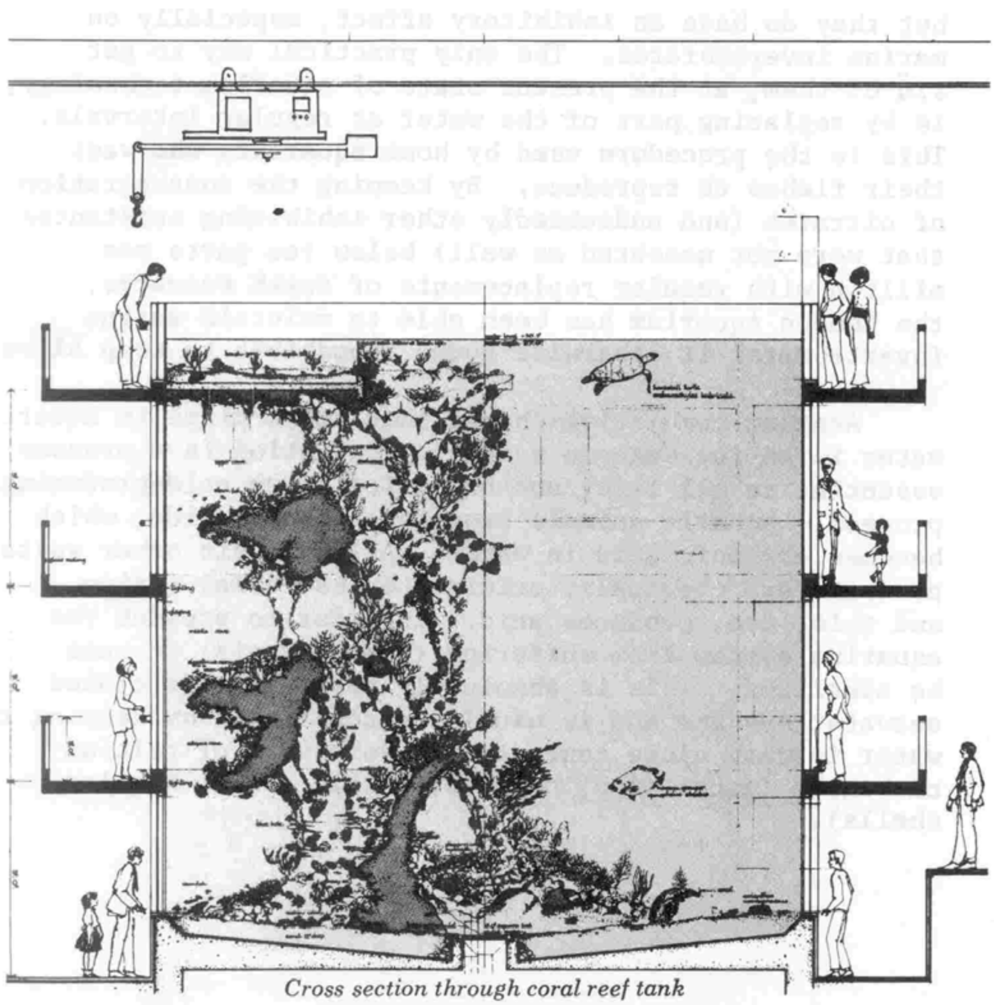
A "healthy" filter is essential to a "healthy" closed aquarium water system and vice versa.

The longer the aquarium or water system is in operation, the greater the amount of nitrate that accumulates in the water. Although certain aquatic bacteria (denitrifiers) change nitrates into nitrogen gas and thus eliminate the nitrogen from the system, this process does not take place rapidly enough to prevent the build-up of nitrate in aquarium water. Moreover, there are other less well-known substances that accumulate in the water in which animals are living. None of these is at all as toxic as ammonia, but they do have an inhibitory effect, especially on marine invertebrates . The only practical way to get rid of them, at the present state of aquarium technology, is by replacing part of the water at regular intervals. This is the procedure used by home aquarists who want their fishes to reproduce. By keeping the concentration of nitrates (and undoubtedly other inhibiting substances that were not measured as well) below ten parts per million with regular replacements of fresh seawater, the London Aquarium has been able to maintain marine' invertebrates it otherwise found impossible to keep alive.

Another cumulative change that takes place in aquarium water is an increase in acidity. Oxidation is a process essential to all life, and oxidation is an acid-producing process. Aquatic animals produce carbon dioxide, which becomes carbonic acid in water. All of their other waste products are eventually oxidized by bacterial action, and this, too, produces acid. In order to prevent the aquarium system from suffering from acidosis, it must be alkalized. This is absolutely essential for closed seawater systems and is usually accomplished by keeping the water in very close contact with some form of calcium carbonate (coral sand, calcite, marble chips, bivalve shells).

Proper aquarium water quality depends primarily on the following factors:

Chemically inert material.
Suitable source of water.
Adequate circulation, aeration, and filtration.
Cleanliness, achieved mostly by avoiding overcrowding and overfeeding.
Control of waste end-products, by filtration, alkalization, and dilution.



Cross section through coral reef tank

WATER SYSTEMS

The water system includes, in whole or part, the incoming line, a clarifying or sterilizing unit if required, storage reservoirs, the pipelines furnishing types and temperatures of water serving the display tanks, the display tanks, inflow and outflow and drainage, and filters.

Piping should be of non-metallic materials (see Plumbing section). Water should come in contact with metal only as absolutely necessary. Metal or other piping may be used to serve cetaceans, seals, penguins, and aquatic reptiles, but expensive replacement may be necessary because of corrosion.

1. Open system (use and waste)
   This method is the least complicated and least trouble some, provided an adequate source of excellent disease free water is available. The requirement that metal not come in contact with water may not be quite so important here, as the animals are exposed to water that has passed over the metal only once, and as the toxicity potential decreases due to the formation of inert oxides, etc., on the interior of metal pipes thus forming an insulating barrier, but corrosion is a factor to be considered.

   Economics must be considered when water is to be discarded after one use. As a general rule of thumb, the average display tank of specimens loaded at the rate of one pound of fish per 100 gallons of water should have a turnover or replacement rate of one volume each one to two hours. If the gallonage of all display tanks is 100,000 gallons, a flow of 50,000 to 100,000 gallons per hour would have to be maintained. Thus, 1.2 to 2.4 million gallons would be required each 24 hours. An added cost would arise if some waters had to be heated or cooled.

When water is used only once and discarded the rate of turnover usually need not be as great as in closed systems, as waste products from the specimens are continually carried away.

It should be noted that the rule of thumb cited above is just that. Many species of fish can be loaded heavier, and some species, particularly invertebrates, may require a more rapid turnover of water.

2. Closed system (recirculating total system)
   Water continuously enters the display tanks and the over flow and returns to the reservoirs after passing through filters. In theory, this method requires only the replacement of water lost by evaporation or in the process of cleaning a tank or backwashing a filter. However, seawater should be replaced at the rate of one-third of the total volume every two weeks, if possible. If this cannot be done, monitoring of nitrite, nitrate and urea build-up becomes very important.

   One serious disadvantage in a closed system is the real possibility of disease organisms from one tank being carried to all tanks. Filtration will not remove many of these. Ultra-violet radiation or passage through a reverse osmosis process, however, is effective in removing or destroying organisms both desirable and undesirable. Reverse osmosis cannot be used with salt water.

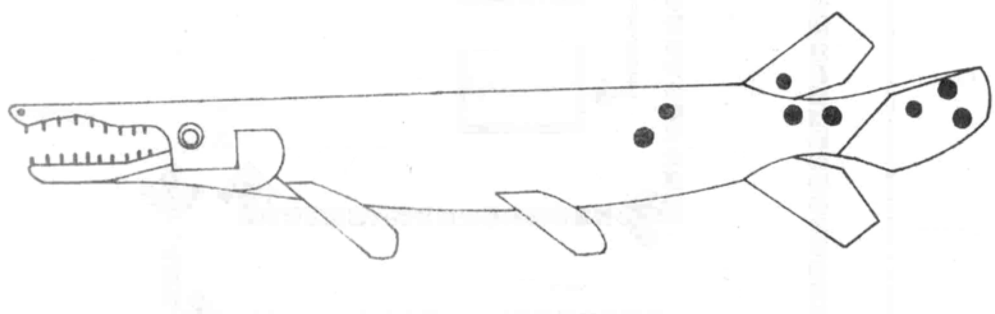
3. Closed system (recirculating individual systems)
   Each display tank is provided with its own recirculating water system. Filling and minor replacement is from the main supply lines. In operation, the overflow passes through a biological filter and is pumped back to the display tank. Desired temperature range can be maintained by cooling or heating units placed in the filter or line.

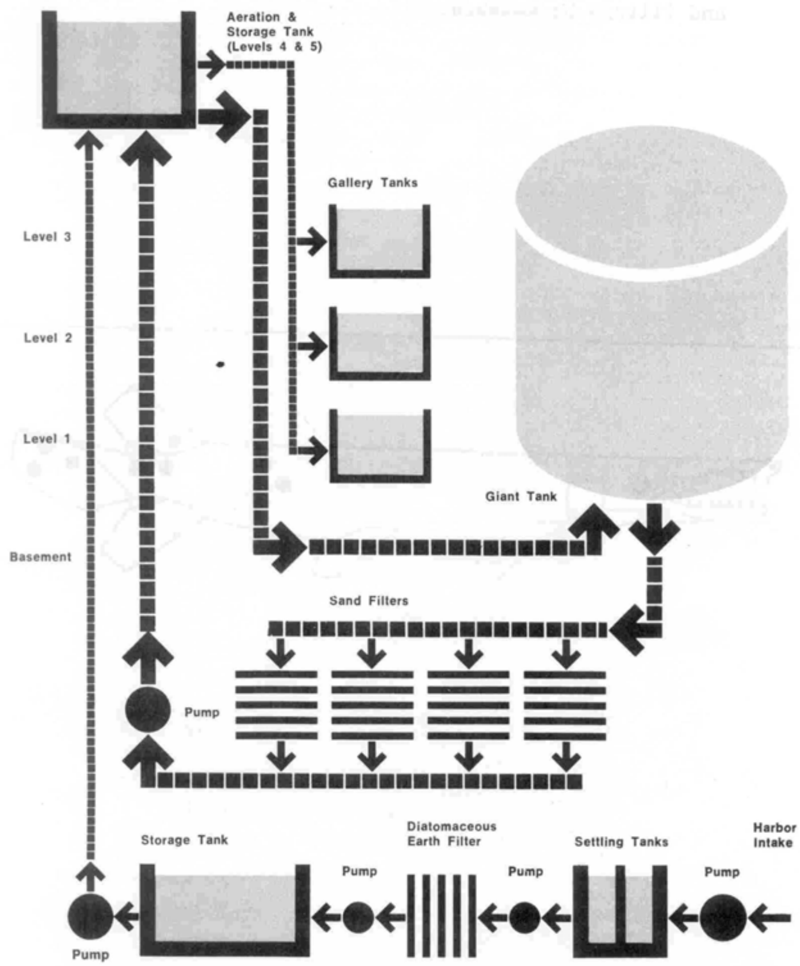
   In the recirculating systems the main supply lines of water, preferably overhead, also are continually circulating at a low rate to preclude dead water and the growth of organisms in the pipes.

The plans for the National Fisheries Center include the above system (3). The city water supply contains traces of zinc and copper, detergents and chlorine. After all display and reservoir tanks are filled (approximately 3.5 million gallons) the replacement water estimated to be required is 100 gallons per minute. It is planned to pass this incoming water through the reverse osmosis process to remove the metals and detergents. The chlorine will be removed by aeration or charcoal filtering.

Display tanks of up to 2,000 gallons can, for some species, be recirculated through bottom filters with water circulation controlled by air-lift pumps.

In recirculating systems it is desirable to replace at least 10% of fresh water and at least 40% of salt water each month to avoid a build-up of harmful substances. Usually a greater amount than this is replaced when the display tanks are regularly cleaned and filters backwashed.




Aeration &
Storage Tank
(Levels 4 & 5)
Gallery Tanks
Level 3
Level 2
Level 1
Basement
Giant Tank
Sand Filters
Pump
Storage Tank
Diatomaceous
Earth Filter
Pump
Settling Tanks
Pump
Harbor
Intake
Pump
Pump

THE NEW ENGLAND AQUARIUM

Water System (1)

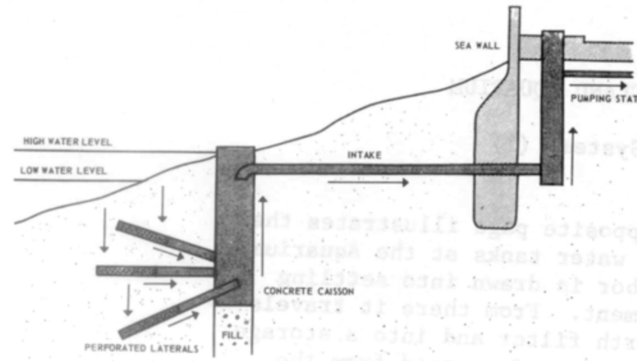
The diagram on the opposite page illustrates the filtering system for salt water tanks at the Aquarium. Sea water from Boston Harbor is drawn into settling tanks located in the basement. From there it travels through a diatomaceous earth filter and into a storage tank. As needed each day, water is pumped from the basement to the top of the building for aeration and storage. From this level it descends by gravity, one system distributing salt water to the galleries and another to the Giant Tank..

Individual filtering systems are used for the smaller tanks, each of which recirculates its own water. Most of these display tanks contain a layer of sand held on a perforated sheet of fiberglas a few inches from the bottom of the tank. The sand acts as a filtering medium, allowing the water to pass through to the space below. It is then drawn into a vertical tube in one corner of the tank, and recirculated with the aid of an air stone. Bubbling of the water through the porous air stone causes this lighter water to rise through the tube to the surface.

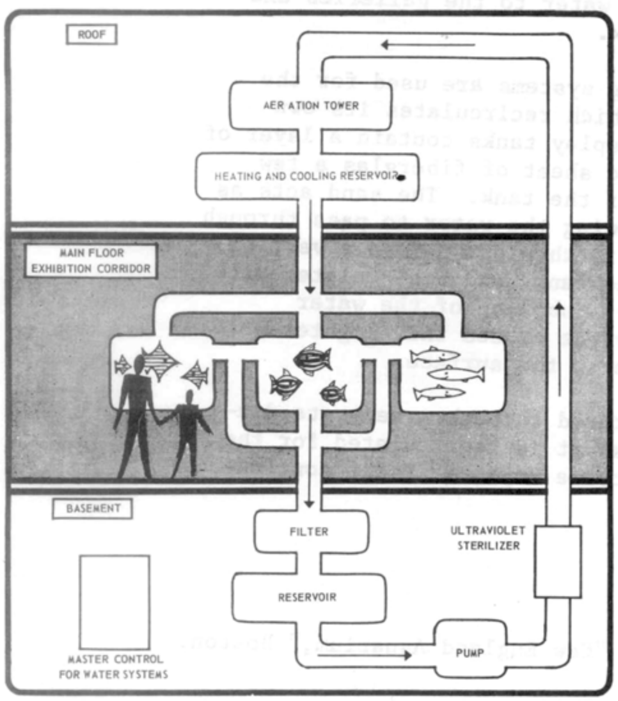
Fresh water is filtered through a separate diatomaceous earth filter as it is recirculated for the Fresh Water Tray. The cycle repeats itself continuously.

(1) From the guide book "New England Aquarium," Boston, Massachusetts.

STEINHART AQUARIUM



The Ranney collector obtains, from beneath the beach sand, clear salt water which is then pumped 3 1/2 miles through Golden Gate Park to the Aquarium. Back-washing is not required.



Simplified diagram of the Aquarium Water System.

THE STEINHART AQUARIUM WATER SYSTEM (1

Earl S. Herald
Associate Director

The least complicated aquarium water system is that found in an oceanarium and in many small coastal aquariums in which the water is pumped directly into the tanks and then thrown away. At a few of these installations it has been necessary to install filters and recycle the water during part of the time, and at least one oceanarium maintains three temperature systems of seawater.

Contrasted with this is the multi-system type aquarium operation. This is the category to which Steinhart belongs with nine separate systems of water, each capable of being operated as a closed system by constant recycling without addition of new water. To avoid the chemical analysis problems of constantly rebalancing the waters of a totally closed system, Steinhart replaces the water in each system at least once a month; hence the designation "semiclosed" system.

Salt water for the aquarium is secured from below about six feet of sand at the Pacific Ocean beach and pumped 3 1/2 miles to the aquarium. The three perforated laterals, shown in the sketch, are six-inch spun fiberglass with many small slots. Other materials are concrete and compressed asbestos pipe. Freshwater is secured from the water mains of the City of San Francisco.

From the Steinhart basement pumping plant the water moves through an ultraviolet sterilizer to the roof aeration tower, then into a reservoir where the heating or cooling takes place. Gravity flow moves the water from there to the main floor display tanks at a rate of 5 gallons per minute to each 1,000 gallons in the exhibition tanks. Water enters each tank near the bottom of the viewing glass and travels across the tank and out the top of the opposite side through swimming-pool-type scuppers. Pipes then channel the water to the basement filters where the work of removing turbidity takes place. Below the filter is a sump reservoir from which the pump again recycles the water to the roof.

(1) Taken from "The New Steinhart Aquarium," Earl S. Herald, Pacific Discovery, Vol. XVI, Nov. 4, 1963.
DRUM AND CROAKER SPECIAL 27

This is the basic plan on which six of the nine Steinhart systems operate. The other two systems, the alligator-swamp water and the porpoise tank, operate without the use of reservoirs and aeration towers.

One feature of the water systems is automatic replacement of water; whenever an aquarist cleans a tank, the water that is lost is automatically added to the system from a series of reservoirs holding 200,000 gallons. All of the water systems circulate through the main laboratory and through the collector's area in the garage. Thus, the biologist in the laboratory, merely by turning a valve, has instant access to any water system, and the collector has the same access for use in shipments of aquatic animals.

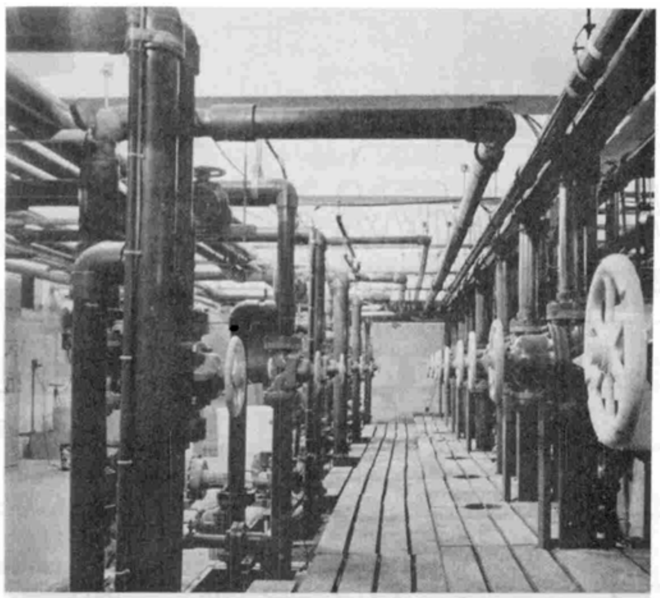
Why so many water systems? This is a natural question and can be answered by study of the temperatures of the natural environment of the fishes and other animals involved. For example, trout and salmon require 50-degree fresh water; in the new Aquarium the water system for these fishes contains 15,411 gallons which circulate through 20 tanks. Marine fishes from the North Pacific and North Atlantic require salt water of about 50 degrees (20,894 gallons; 24 tanks). Two more systems are accounted for by the fishes living in temperate water (60-65 degrees) of both fresh water (10,454 gallons; 13 tanks) and salt water (29,180 gallons; 15 tanks). The last two kinds of fishes are those of the tropics (75-85 degrees); those living in fresh water (26,971 gallons and 49 tanks) and those living in sea water (29,720 gallons and 34 tanks). In addition, there are three systems that operate without the roof reservoir tanks; the alligator swamp system at 80 degrees (11,132 gallons), and the marine porpoise-dolphin system at 50-55 degrees (88,303 gallons), and the fresh water dolphin system at 80 degrees (13,000 gallons).

Small special systems are set up for invertebrates, electric eels, brackish water forms such as four-eyed fishes and archers, and others as required.

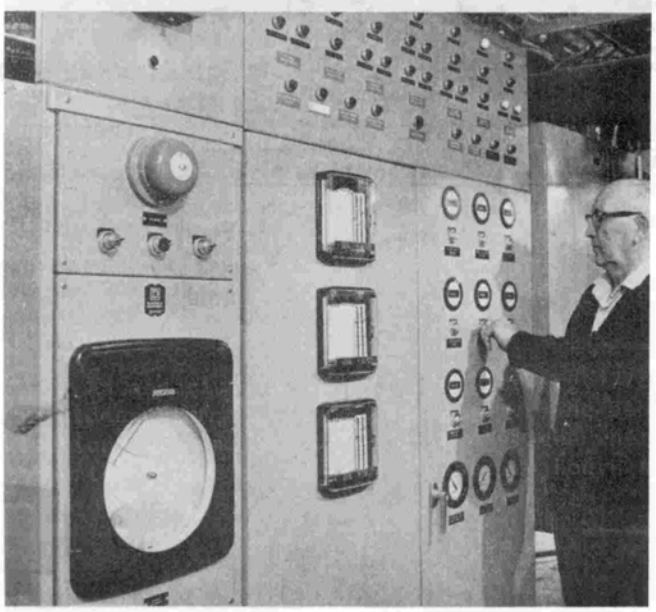
Tanks range in size from 5 gallons to 62,000 gallons, with many of the smaller tanks being made of fiberglass. Around the alligator swamp are a series of 65 reptile tanks and 30 amphibian tanks, some of which receive water from the main systems.

Some 250,000 gallons are circulated in the aquarium requiring some 44 pumps, 90 electric motors, 1,383 valves, 124 gauges, etc. All of these items and many more provide the necessary control over the 392 tanks in the building (200 display and 192 reserve).

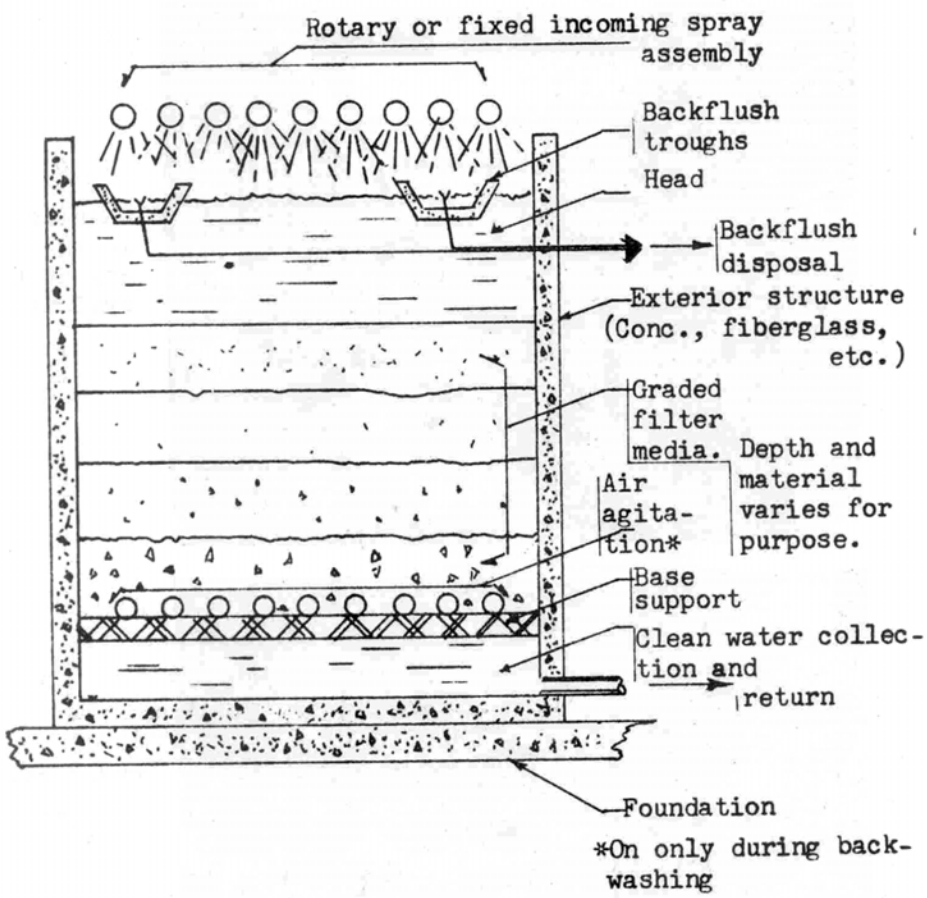
An aquarium is much like an iceberg, 7/8ths of which is hidden from view under the water. The behind-the-scene sections of a modern aquarium are places where prodigious amounts of unseen work takes place 24 hours a day, seven days a week.



Complexity of piping in the filter area for six of the nine water systems.



Chief Engineer at the master control panel.



TYPICAL BIOLOGICAL FILTER

FILTRATION (1)

Edward J. Peterson (2)
U. S. Bureau of Sport Fisheries and Wildlife
Lamar, Pennsylvania

Probably the most important, yet least understood, facet of aquarium management is filtration. Generally, aquariums have devices designed to reduce turbidity, the visible parameter of water quality. Undoubtedly, there are equally important invisible parameters. Aquarists have recently shown considerable interest in reduction or alteration of these invisible contaminants or pollutants. This complicates filtration techniques because generally a device designed to remove particulate matter will do little to remove colloids or dissolved substances.

Consequently, aquarium filters have evolved from four basic principles i.e., mechanical, chemical, biological and electrostatic methods of contaminant removal. Each type of unit has specific functions and applications but they can be used singly or in any combined configuration. This discussion of aquarium filtration will include some information on devices based on the four rudimentary principles. No single filtration method or technique now available will simultaneously provide water that is physically, biologically and chemically clean.

Mechanical Filters

Three basic mechanical filters are in general use by aquarists. These are diatomaceous earth (D.E.), permanent media (P.M.), and porous cartridge-type units. Each has inherent advantages and disadvantages which must be considered before choosing any unit for a particular situation. These remove only particulate matter.

(1) Taken from "Class Notes on Aquarium Management" (unpublished material)

(2) Formerly Assistant Curator, National Aquarium, Washington, D. C.

D.E. filters are readily available in various sizes from numerous companies supplying aquarium or swimming pool equipment. Many of the pool filters are poorly designed and are not effective in aquarium use. Basically, D.E. filters depend on the small irregular particle size of the diatom skeletal silicon to trap and retain suspended particulate material. Properly coated D.E. elements can remove particles as small as 3 microns. The disposition of used diatomaceous earth often is a problem as it usually cannot be placed into sewer lines.

Permanent media P.M. filters are becoming more popular for both swimming pools and aquariums. The basic system consists of a sand layer over graded and bonded anthracite carbon layers enclosed in a water container. Water is pumped down through the sand and charcoal depositing particulate matter in the sand. A P.M. filter can remove particles down to about 10 microns. These systems also tend to clog after extended use necessitating backwashing. Gauge readings of increased operating pressure indicate time for backwashing. Waste which is backwashed from the P.M. units consists of the accumulated particles, but none of the filter media.

Porous cartridge filters are generally utilized in small tank (less than 100 gal.) filtering applications. Porous cartridges are often used in domestic water systems. These units utilize a solid porous fiber or mineral element through which the contaminated water must pass. Particulate matter collects on the cartridge finally reducing flow and efficiency of the filter system. The element may be removed and cleaned several times but ultimately it must be replaced These units have been replaced in most aquariums with D.E. or P.M. filters which are more efficient and cost less to operate per unit volume of water treated.

Chemical Filters

The most common chemical filters for aquariums are either activated carbon or ion-exchange resin types. Both of these systems are designed to remove dissolved rather than suspended contaminants.

Activated carbon has been one of the most popular filter media used by aquarists. There is, however, little evidence to prove activated carbon is effective for extended periods in aquatic systems. Generally, most people who have conducted experiments with activated carbon agree that the absorption life is rather limited. These findings do not preclude the use of activated carbon in aquarium systems.

Ion-exchange resin filters have not been employed extensively in major aquarium systems. Recently, some hobby and home-type marine ion-exchange filters have come on the market. These units are primarily designed for small tanks of less than 100 gallons, and are said to remove albumen digestion products, colloids, amino acids, etc.

Biological Filters

Most modern aquariums with closed or semi-closed water systems utilize a biological filter system. These filters have a substrate; material with a large surface area in which a bacterial culture develops. Bacteria and other micro-organisms utilize aquarium waste products, and convert ammonia to nitrites and nitrates.

The most popular biological filters are external sand and gravel units. Filter beds for these systems consist of 2-5 mm. sand over graded gravel in a container separate from the display tank. Filter sizes have been generally based on guidelines similar to the following:

1. Ratio of filtrant volume to animal weight should be 1 cubic foot / pound of animal.

2. Ratio of water volume to animal weight should be 100 gallons / pound of animal.

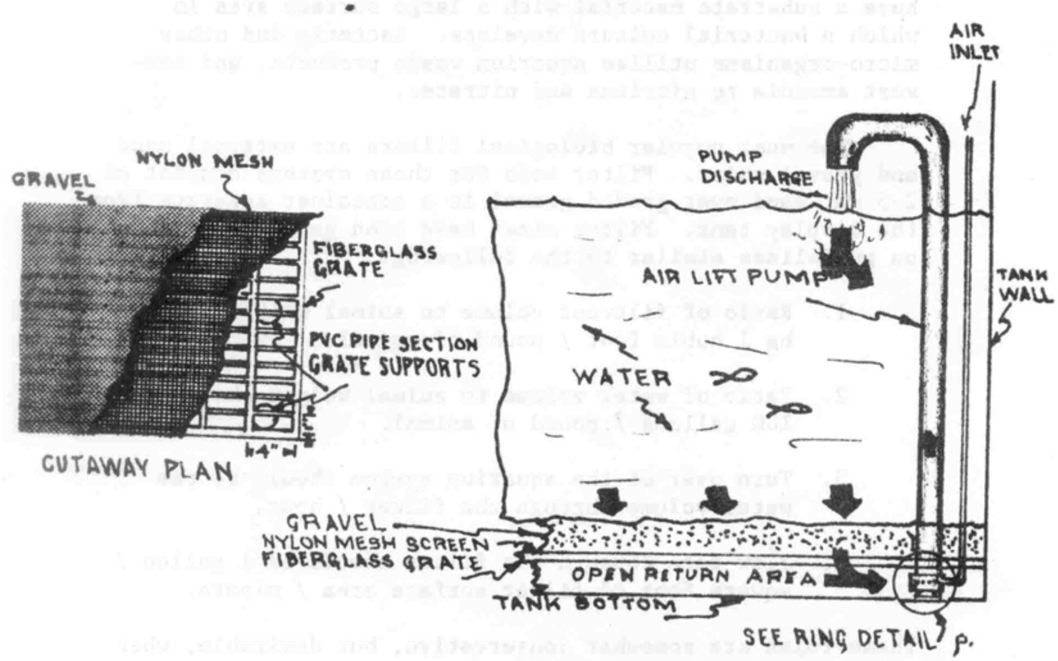
3. Turn over of the aquarium system should be one water volume through filter / hour.

4. Flow rate through the filter should be 1 gallon square foot of filter surface area / minute.

These rules are somewhat conservative, but desirable, when one has valuable specimens requiring optimum conditions.

External biological filters can be operated in normal or reverse flow i.e., down through or up through the filter bed. Both flow systems seem to operate effectively. Some aquarists like to see the visible accumulation of detritus on the surface of normal flow units while others prefer the ease of backwashing in reverse flow systems. In either case, waste products and bacterial growth ultimately impede water flow through the filter necessitating backwashing.

There are also internal biological filters available for the aquarist. These sub-sand systems utilize display tank bottom gravel and sand as the filter media and draw water down through the sand with a suitable pump. All have a false bottom or perforated pipe to gather water from under the sand. Sub-sand filters have an advantage of reducing anaerobic conditions in the bottom material, are out of sight and require very little space, but generally are limited in filtrant volume and are difficult to backwash. They are an excellent supplementary unit for an external filter system and should be employed whenever possible.



UNDERGRAVEL FILTER SYSTEM

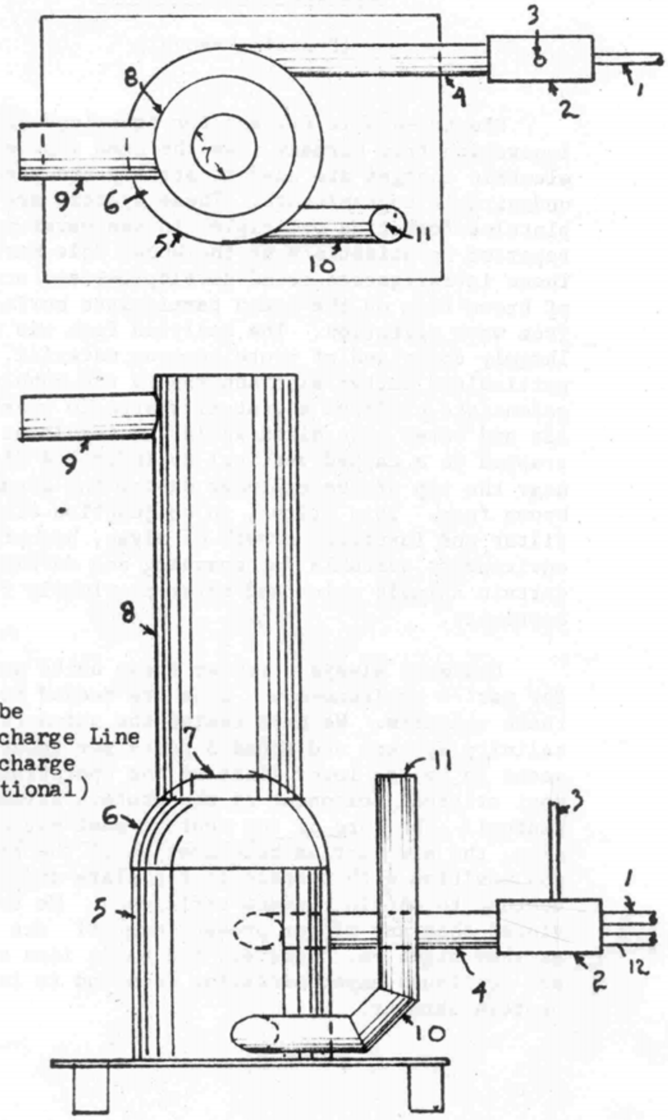
Electro-Static Filters

(Protein Removal)

Electro-static filters for aquariums are a recent innovation from Germany. As the name implies, static electric charges are used to attract and remove certain undesirable contaminants. These systems are based on the platelet formation principle in sea water as observed and reported by scientists of the Woods Hole Marine Laboratory. These investigators noted development and accumulations of brown foam on the ocean particulate surface resulting from wave agitation. The analyzed foam was found to be largely comprised of proteinaceous material, but some particulate matter also adheres to the bubbles. German scientists utilized a venturi system to create foam. Air and water were mixed while the resultant foam was trapped in a capped vertical cylinder. A discharge tube near the top of the cylinder wasted the accumulation of brown foam. This filter, in conjunction with a biological filter and luxuriant growth of algae, has provided an environment suitable for spawning and development of certain animals which had never previously reproduced in captivity.

One must always remember these units were designed for marine environments. Ions are needed to activate these skimmers. We have tested the skimmers in low salinity systems and found 5 parts per thousand salinity seems to be the lower limit of the operating range. The most critical component of the protein skimmer is the Venturi. The bore of the venturi must match the pump. the a air suction hole must be of the proper size and position with respect to the flare and bore of the venturi to obtain maximum efficiency. We are not convinced that any of our present venturi are as efficient as they might be. However, the basic idea seems to work and continued experimentation is bound to improve the protein skimmer.

PROTEIN SKIMMER



1. Water Input Tube
2. Venturi
3. Air Suction Tube
4. Conditioning Tube
5. Vortex Chamber
6. Dome
7. Opening in Dome
8. Foam Column
9. Foam Discharge Tube
10. Treated Water Discharge Line
11. Treated Water Discharge
12. Water Suction (Optional)

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The Operation of the Protein Skimmer

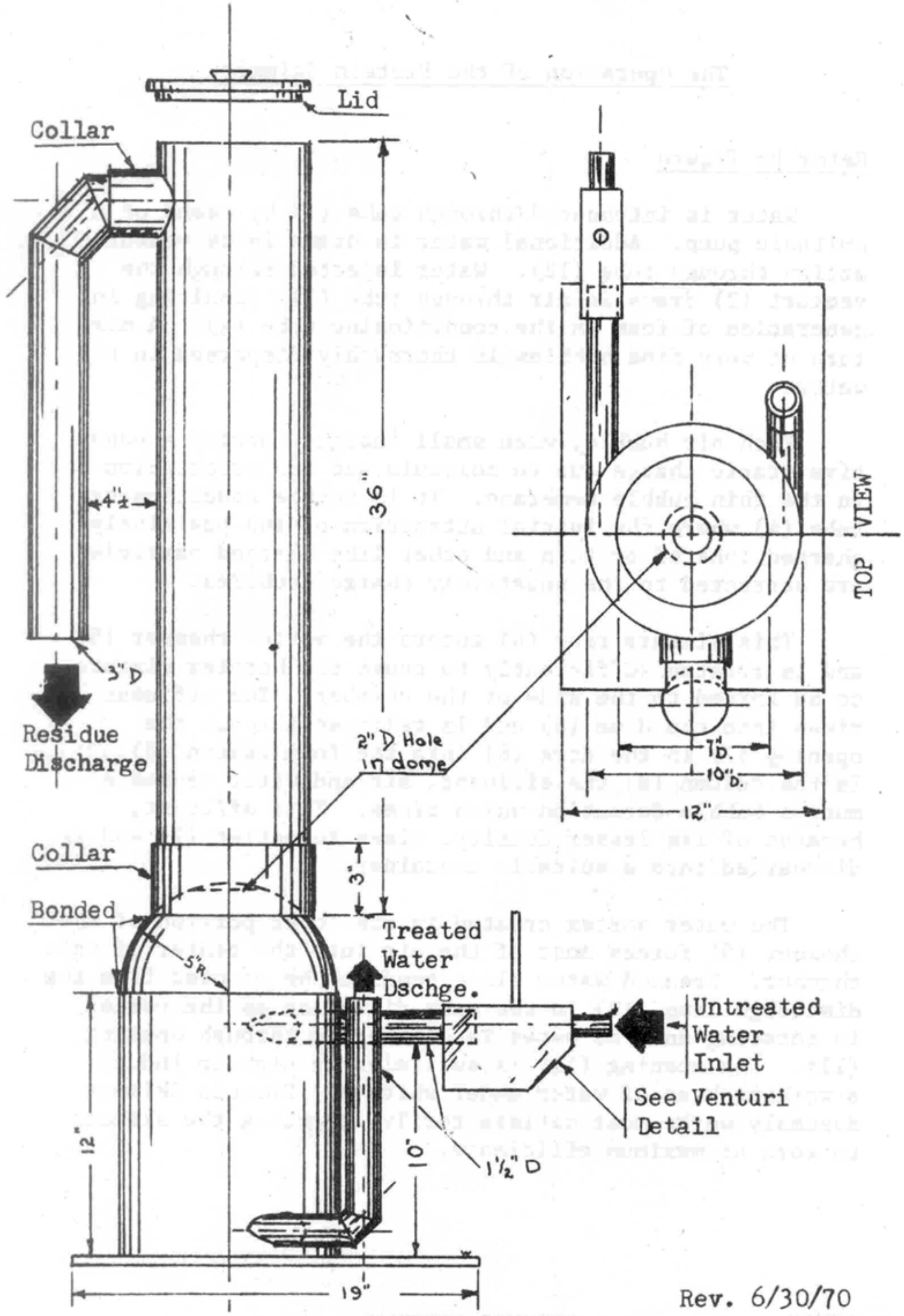
Refer to figure

Water is introduced through tube (1) by means of a suitable pump. Additional water is drawn in by venturi action through tube (12). Water injected through the venturi (2) draws in air through tube (3), resulting in generation of foam in the conditioning tube (4). A mixture of very fine bubbles is thoroughly dispersed in the water.

Each air bubble, when small enough, carries a negative static charge due to molecule and ion orientation in the thin bubble membrane. It is in the conditioning tube (4) where the initial attraction of the positively charged ions of protein and other like charged particles are attracted to the negatively charged bubbles.

This mixture from (4) enters the vortex chamber (5) and is rotated sufficiently to cause the heavier mixture, to be forced to the side of the chamber. The effluent rises into the dome (6) and is released through the opening (7) in the dome (6) into the foam column (8). In the column (8) the effluent, air and water causes a mucous bubble formation which rises. This effluent, because of its lesser density, rises to outlet (9) and is discharged into a suitable container.

The water vortex created in the lower portion of the chamber (5) forces most of the air into the center of this chamber. Treated water alone tends to be removed from the discharge line (10) in the same direction as the vortex is rotating and the water is discharged through opening (11). The opening (11) is sufficiently high to induce a working head of water under which the Protein Skimmer assembly works most satisfactorily, enabling the skimmer to work at maximum efficiency.



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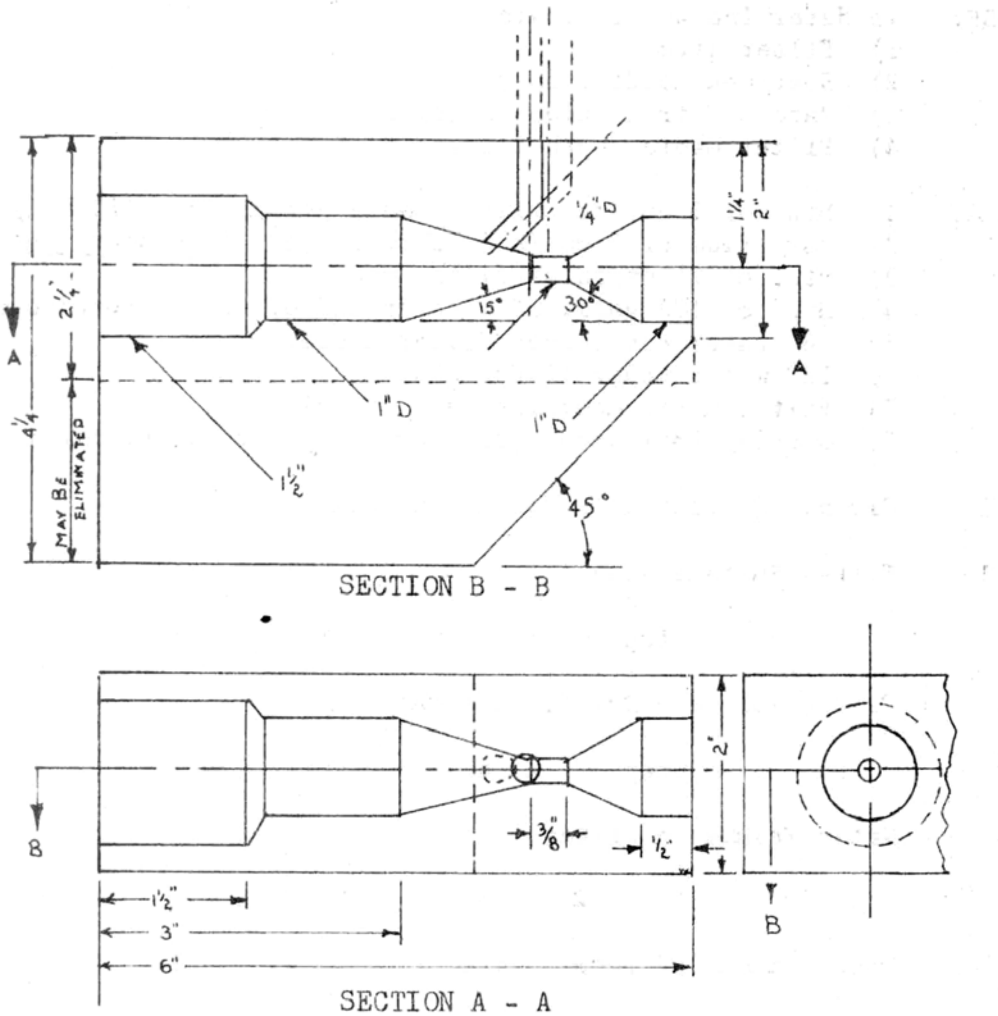
PROTEIN SKIMMER NFC&A



VENTURI DETAIL

NOTES:

(1) Protein Skimmer assembly may be constructed of P.V.C. or leucite plastic material. Bonding may be accomplished by using solvents for the particular material.

(2) The venturi/conditioning tube connection is to be a snug, unbonded fit. "O" rings may be used for this purpose.

(3) The column is to fit snug, not excessively tight, into the dome collar.

(4) The residue discharge tube is to fit snugly into the collar at the top of the column. The lid is to fit similarily.

Rev. 6/30/70

NATIONAL FISHERIES CENTER AND AQUARIUM

Determination of Water and Filter Requirements

PURPOSE: To determine the following:
1) Filter size
2) Specimen loading in pounds
3) Rate of circulation in gallons per minute
4) Filter media depth (constant at 2.24')

CRITERIA:
1) Min. of 1 cu. ft. filter media per pound of fish (governing)
2) Max. flow of 2 gpm/s.f. thru filter (secondary factor)
3) Min. of 2' depth of filter media
4) Min. of 100 gals. of water/pound of fish. (total system)
5) 18" water cover over filter media.
6) 12" water under filter media.
7) Filter media contains max. of 30% water.
8) Display tank water vol. turnover every 90 minutes.

STEP 1 Given: Display Tank Volume in Gallons

STEP 2 Filter Surface Area

Step 1 ÷200 = Square feet

STEP 3 Filter Volume - Dry (less freeboard)

Step 2 X 4.5 = Cubic feet

STEP 4 Water Volume in Filte

Step 2 X 23.714 = Gallons

STEP 5 Water Volume of Total System (less pipe runs)

Step 1 + Step 4 = Total gallons

STEP 6 Specimen Load

Step 5 ÷ 100 = Pounds

STEP 7 Volume of Filter Media (sand and gravel)

Step 5 ÷ 100 = Cubic Feet

STEP 8 Depth of Filter Media

Step 7 ÷ Step 2 = Feet

STEP 9 Rate of Water Circulation in System

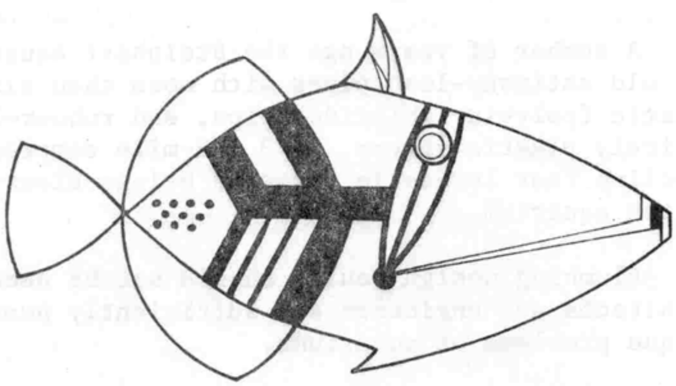
Step 1 ÷ 89.96 = Gallons per minute

NFC&A April 1, 1966

RESERVE WATER

Some aquarists recommend that the water held in the reservoirs equal the total gallonage of the display tanks. Few aquariums, however, hold such quantities in reserve - so much water is rarely necessary. In the event of disaster from pollution, disease or other reasons, which is unlikely, it may be necessary to dump all water, in which case it is almost impossible to avoid taking heavy animal losses. Reserve waters are primarily for routine replacement.

Probably reserve waters should equal about the gallonage of the largest single display tank, if this is considerably more than other tanks. In the National Fisheries Center, it is proposed to have reserve waters totaling about 50,000 each of sea- and freshwater. This total of seawater is about equal to 1/2 of the gallonage of the reef tank, but is expected to be adequate for all contingencies other than disaster. These reserve supplies will be used for routine make-up to compensate for evaporation and cleaning losses, and to provide fresh waters to avoid build-up of harmful substances.



PLUMBING

By plumbing in an aquarium we mean the water system The materials to be used must be carefully selected.

Water can dissolve a wide variety of toxic substances which may adversely affect aquatic animals. The only positive way to keep water suitable for most marine life is to use chemically inert materials throughout the water system.

Copper is particularly toxic to freshwater fish. Marine invertebrates often are strongly affected by extremely minute amounts of copper. Very little metallic copper need be exposed to seawater to produce a dangerous concentration of dissolved copper .
Many minerals normally used in construction and plumbing should be avoided, including all metals-even lead and stainless steel that are sometimes considered safe.

Hard rubber (also called vulcanite and ebonite) has long been considered safe for aquarium use. Plastics have come into common use, but all plastics are not safe to use (e.g., plasticized ones). Glass is suitable, but not practical for most installations. Fiberglass is inert, easily handled, and not too expensive. Cement (concrete) is safe after thorough "curing".

A number of years ago the Steinhart Aquarium replaced its old antimony-lead pipes with more than six miles of plastic (polyvinylchloride) pipe, and rubber-lined or entirely plastic valves. A 3 ½-mile compressed asbestos pipeline four inches in diameter brings clear ocean water to the aquarium.

Plumbing design faults should not be necessary if architects and engineers are sufficiently aware of the unique problems of aquariums.

Obviously, if the foregoing is to be followed, no metal will come in contact with water, particularly in closed systems. Piping should be of acceptable materials. Pumps and valves should be lined.

Sharp turns usually are acceptable with metal pipe, but aquarium plumbing, with plastic or fiberglass, should avoid short turns, particularly when large diameters are required. All turns should be properly reinforced externally. Most turns should include fittings for cleaning lengths of pipe.

Although it should not be necessary to mention it, piping should not be bedded in loose soil. (Two large installations have had to replace large-diameter plastic pipe in the past few years because of breakage.)

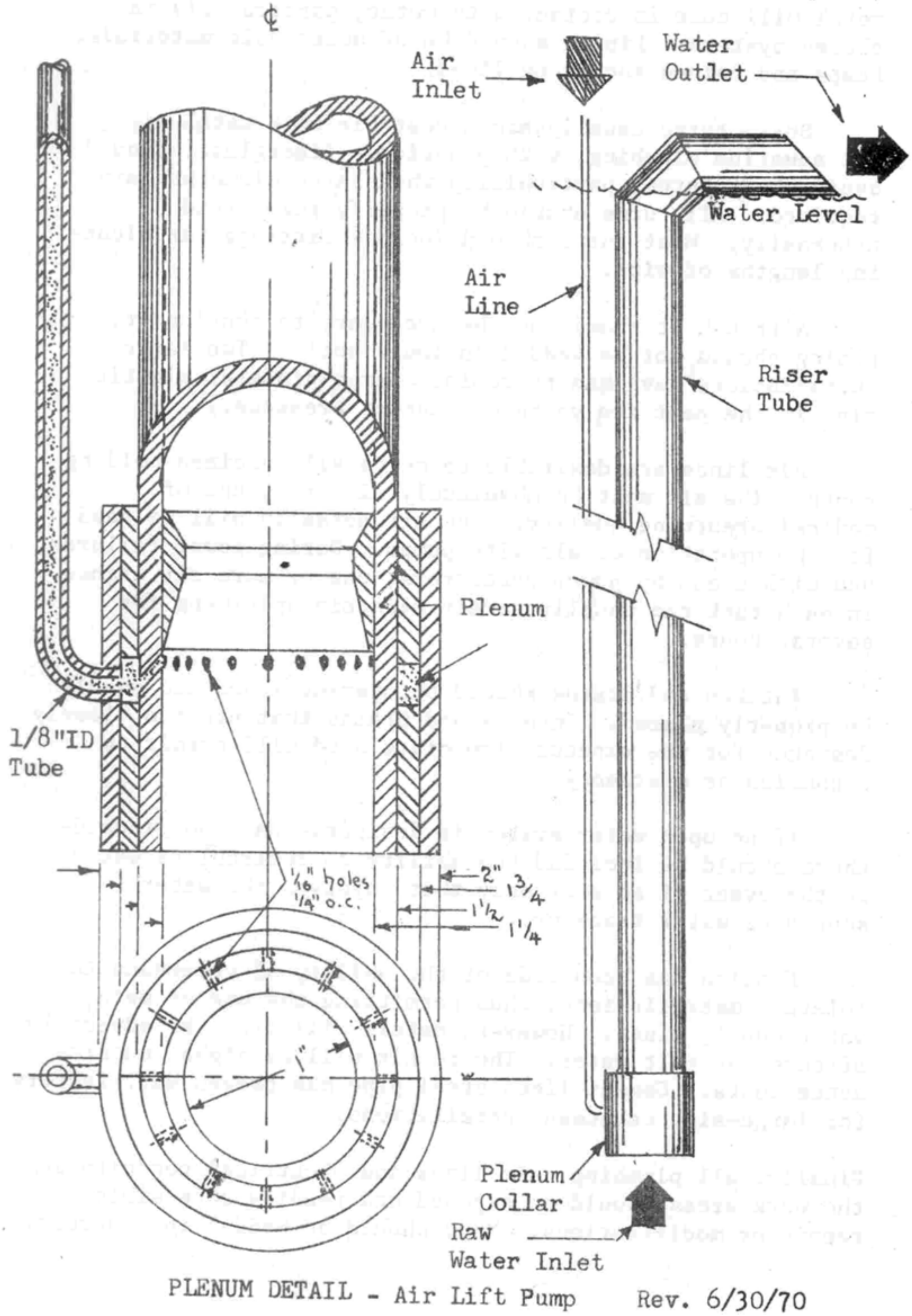
Air lines are desirable to serve all specimen-holding tanks. The air must be absolutely oil free, and of medical breathing quality. The air normally will be used for the operation of air-lift pumps. During power failures and with standby power generators, one or more air stones in each tank can usually safely maintain specimens for several hours.

Intakes and drains should be over-designed and should be properly placed. Intakes and drains that are too closely designed for the expected immediate need will permit no expansion or emergency.

If an open water system is designed - use and discard - there should be included the ability to recirculate water in the event of an emergency that involves the water source or water transport.

Mention has been made of the ability of cetaceans to tolerate metallic ions, thus permitting the use of metal water supply lines. However, metals will often be adversely affected by salt water. The result will be higher maintenance costs. Cement-lined steel pipe has proven satisfactory for large-size cetacean installations.

Finally, all plumbing, air lines and electrical conduits in the work areas should be exposed and readily accessible for repair or modifications. None should be bedded in concrete



PLENUM DETAIL - Air Lift Pump   Rev. 6/30/70

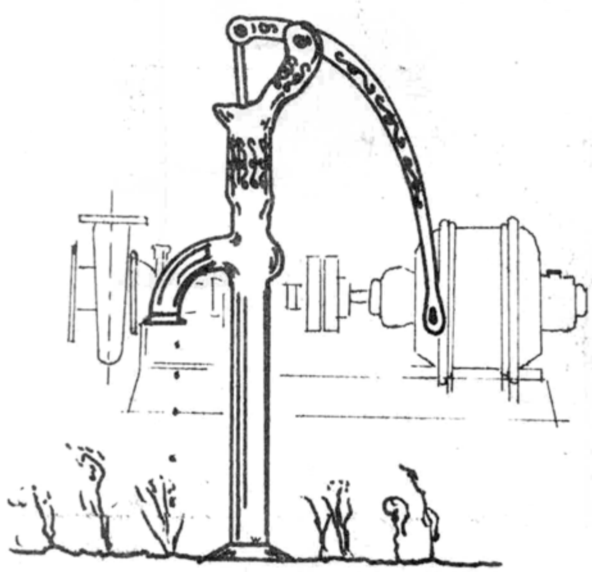
PUMPS

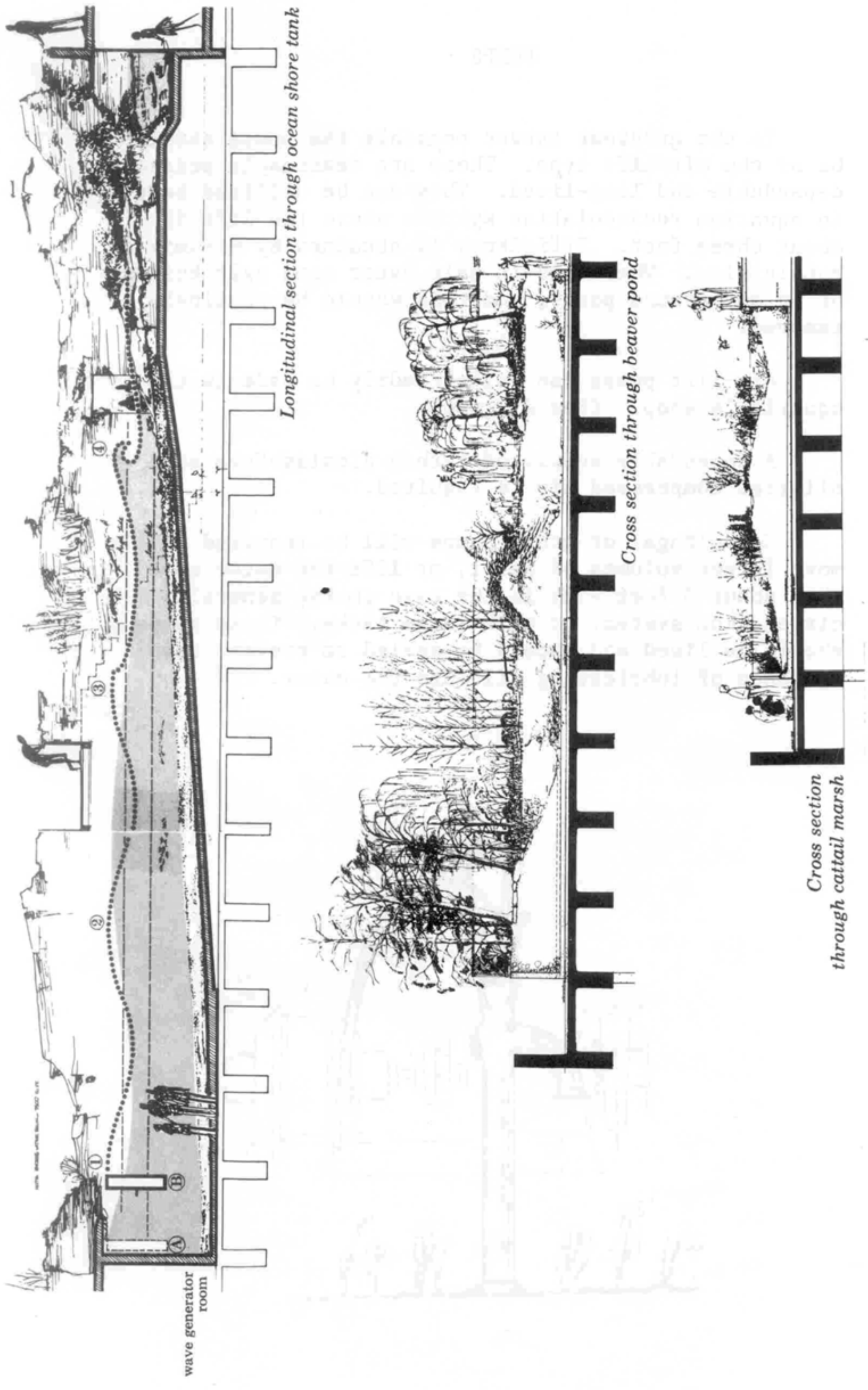
To the greatest extent possible the pumps should be of the air-lift type. These are reasonably priced, dependable and long-lived. They can be utilized best in aquarium recirculation systems where the lift is about three feet. Efficiency is attained by minimizing bubble size. When used in salt water some salt builds up in and around ports, and this should be routinely removed.

Air-lift pumps can quite readily be made in the aquarium's shop. (See diagram).

A dependable supply of carbon dioxide-free and oil-free compressed air is required.

Centrifugal or other pumps will be required to move larger volumes of water, or lift the water more than about 3 feet - as is the case in the general circulation system, or with large tanks. These pumps should be lined and should be sealed to prevent the entrance of lubricating oil into the water.





Longitudinal section through ocean shore tank

Cross section through beaver pond

Cross section through cattail marsh

TEMPERATURE

For economic reasons, it is desirable to maintain an even temperature throughout an aquarium structure. A temperature of 70-72° F, is comfortable for visitors and will permit automatic maintenance of the display tanks at about the same temperature. A great many of the fishes and other organisms held in aquaria are comfortable at this temperature range. Heat exchange equipment can be provided for individual tanks when warmer or colder water is required.

If a whole group of fishes requires warmer or cooler waters, such as the tropicals or salmonids, the work area where they are held may be sealed off and kept at the appropriate temperature.

At the Steinhart Aquarium there are five temperature-controlled rooms in which the air temperature is largely responsible for the temperature of the tanks: the tropical hatchery (80°F.) with 24 tanks; the warm animal room (75°F.), 31 tanks; the cold animal room (50°F.), 10 tanks; and two panel display rooms (80°F.), 38 tanks, for reptiles in the swamp area. Finally, there is a special hatching room designed for brine shrimp, Artemia (55-60°F.), 12 tanks.

During a power failure, which may stop water circulation, the water in most tanks will not change temperature sufficiently in several hours to affect specimens adversely. Usually only an air stone or two in each tank will be needed. A gas or gasoline operated air compressor is then required.

DISPLAY TANKS

Tanks for the display of aquatic specimens are expensive. Materials in tanks for seawater must be more carefully chosen than for fresh water. Nevertheless, all tanks should be made of inert material to the greatest extent possible.

Ideal tanks are those that are least costly, light in weight, readily altered or drilled, inert in seawater, with hard and smooth interiors, among other things. No currently available materials from which tanks may be produced quite meet all of the foregoing desirable features. For smaller tanks (up to about 2,000 gallons), fiberglass or plastic-impregnated plywood (see the following article) appear to be quite satisfactory.

A number of companies manufacture fiberglass aquaria or holding tanks. Moreover, some of these will fabricate to specifications. It is desirable to plan to install tanks of standard size;, preferably those that are available "off-the-shelf," or for which fiberglass-fabricating forms are still available.

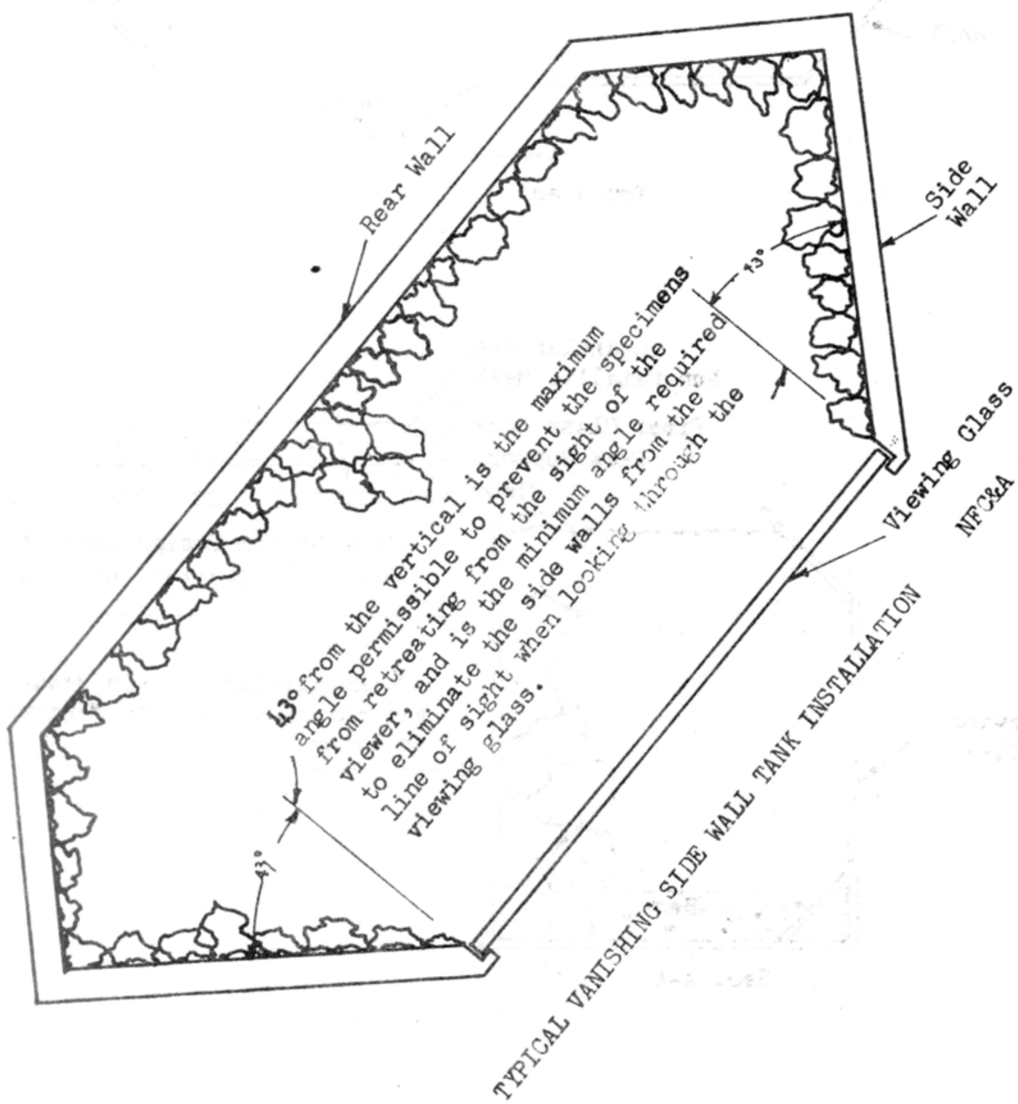
Fiberglass is completely inert, is light in weight, and can be readily altered and drilled. Some experience by aquarium personnel will permit them to make repairs. It is quite possible, with an experienced technician, for an aquarium to fabricate its own tanks of reinforced fiberglass.

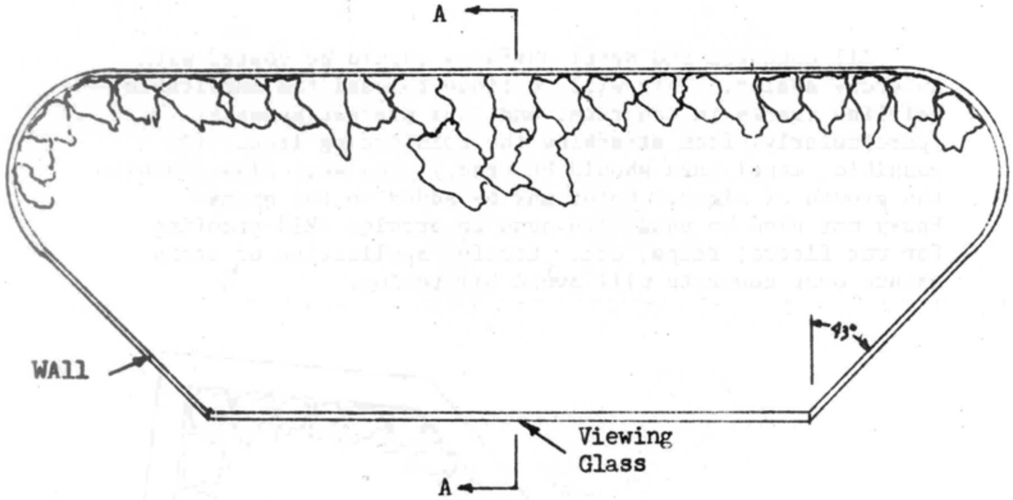
For larger tanks, reinforced concrete, steel plate, or some other substantial and suitable material will be required

Concrete tanks should never be poured as an integral part of the building. Each such tank should be an independent unit, capable of being broken up and removed without damage to the building.

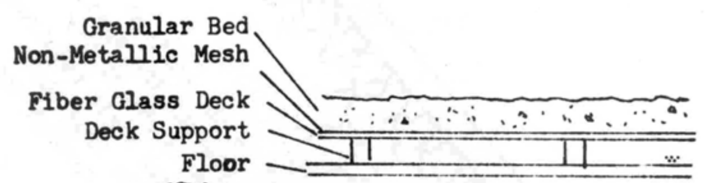
The design of tanks should consider the problems of drainage, cleaning, viewing, etc. Some tanks, because of the specimens to be held therein, may require features, e.g., scuppers at the surface to remove oily film produced by some foods. Rapid drainage is desirable. It is preferable that gravel or sand not touch the viewing glass. Disappearing side walls may be desired.

All concrete and metal surfaces should be coated with an epoxy sealer. This will continue to seal the inevitable hairline cracks in concrete, and thus prevent seawater (particularly) from attacking the reinforcing iron. (If possible, monel bars should be used.) The seal also inhibits the growth of algae. Color may be added to the epoxy. Epoxy may also be used with sand to provide skid-proofing for wet floors, ramps, etc. Careful application of epoxy paints over concrete will avoid blistering.

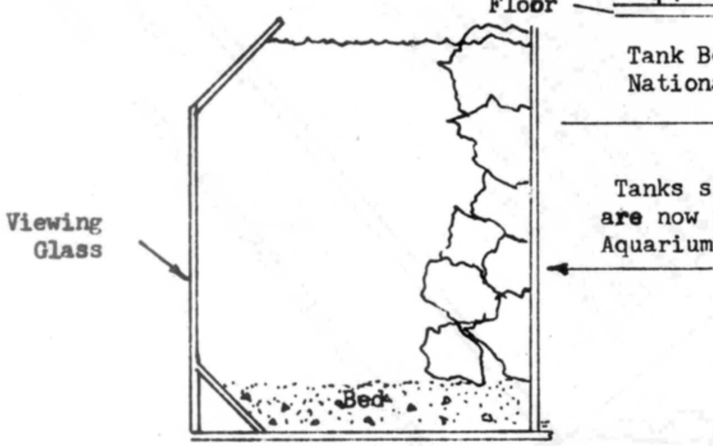




Top View



Tank Bottom Design Used at National Aquarium, Wash. DC



Sec. A-A

Tanks similar to this design are now in use at the Montreal Aquarium.

USE OF GPX HIGH-DENSITY PLYWOOD
IN THE CONSTRUCTION OF AQUARIA (1)*

By

Richard II. Reckeweg
National Fisheries Center and Aquarium

The personnel at the National Aquarium have been using a type of plywood which is impregnated and coated on both sides with a resin which renders the plywood waterproof. Known as GPX, high-density, clear, 60/60 plywood, it is manufactured by the Georgia-Pacific Corporation(2). We have used this for many applications where wood contacts water and have had no problems with the separation of layers as is the usual case with most plywoods. The largest tanks we have built are two, 750-gallon storage tanks constructed in the summer of 1965 and still in use. Many of our display aquariums are also constructed from this wood with a glass or plastic window installed on one side. These aquariums are used for both fresh and marine systems.

For a cost comparison a 4-by 8-foot sheet of ¾-inch, A-C, exterior plywood coated with fiberglas cloth and resin would cost approximately $40.50 while a sheet of GPX would cost $23.00 - a savings of $17.50. This does not take into account the man-hours involved in the numerous fiberglasing and sanding steps required to provide a smooth finish; the GPX has a smooth surface.

The construction of aquaria from this wood is relatively simple requiring a minimum of both tools and carpentry skills.

1. All pieces are cut to the desired sizes so that when put together the ends fit on the inside of the sides and the bottom fits on the outside, screwing into the sides and ends

*Presented at the 15th Annual Professional Aquarium Symposium of the American Society of Ichthyologists and Herpetologists, June 12, 1969, New York City.

2. Starting with a corner, square the edge and drill a hole at the top and at the bottom and insert a screw halfway into each hole or enough to hold the pieces square. Continue to drill the rest of the holes approximately three inches apart.

3. Remove the two screws holding the side and end together, place a bead of silicon rubber sealer(3) along the edge and place the screws into the predrilled holes and tighten firmly. Repeat the above steps for the remaining corners and the bottom.

Do not attempt to wipe off the excess sealer until it has thoroughly dried and then it may be trimmed off with a razor blade.

If a viewing window is desired a hole should be cut of the desired size and the tank laid so that the viewing side is down. Place a bead of sealer around the frame and press the glass or plastic into place. The glass should lap over the wood frame at least 2 1/2 inches. Pressure may be applied throughout the night to insure a good seal. After 24 hours the tank is ready for use. It should be noted that the viewing glass is held in place by the silicon sealer and that clamps or an indented area in the wood are not required. Also, the frame of the viewing window should be of a single piece of wood to insure maximum strength.

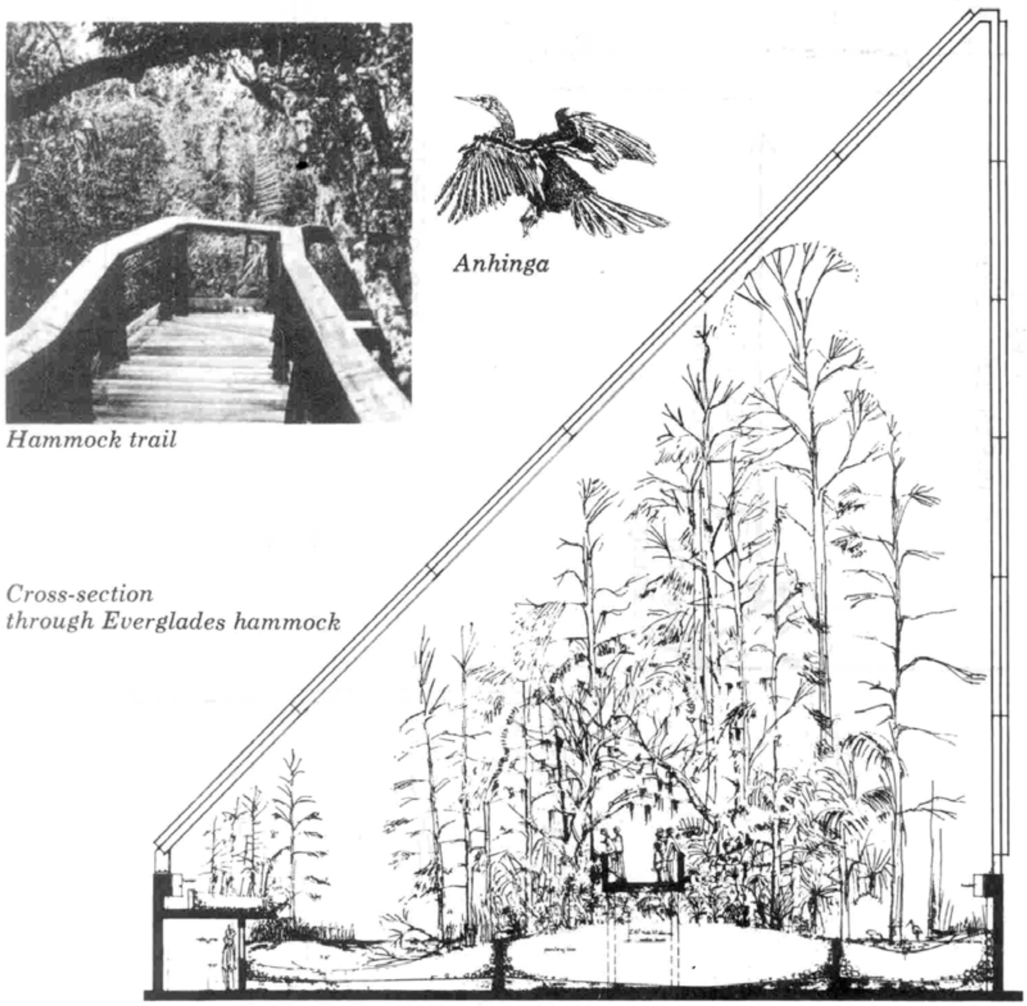
For tanks over three feet in length, it is necessary to add cross-bracing to prevent bowing. This can be accomplished by attaching 2- by 2-inch pieces of wood across the top of the tank at no more than two-foot intervals.

If a color other than that of the wood is desired, we have found that Gleem Swimming Pool Paint(4) does an excellent job. This paint is easily washed out of brushes, but holds up very well under water and the tank can be used within 48 hours of painting. We have used this paint with freshwater and marine fish and invertebrates.

Containers subject to rough use of constant movement from one area to another should be reinforced with 2- 2-inch lengths of wood and fiberglas resin on the inside seams.

This plywood may also be drilled and tapped for drains or filtration systems.

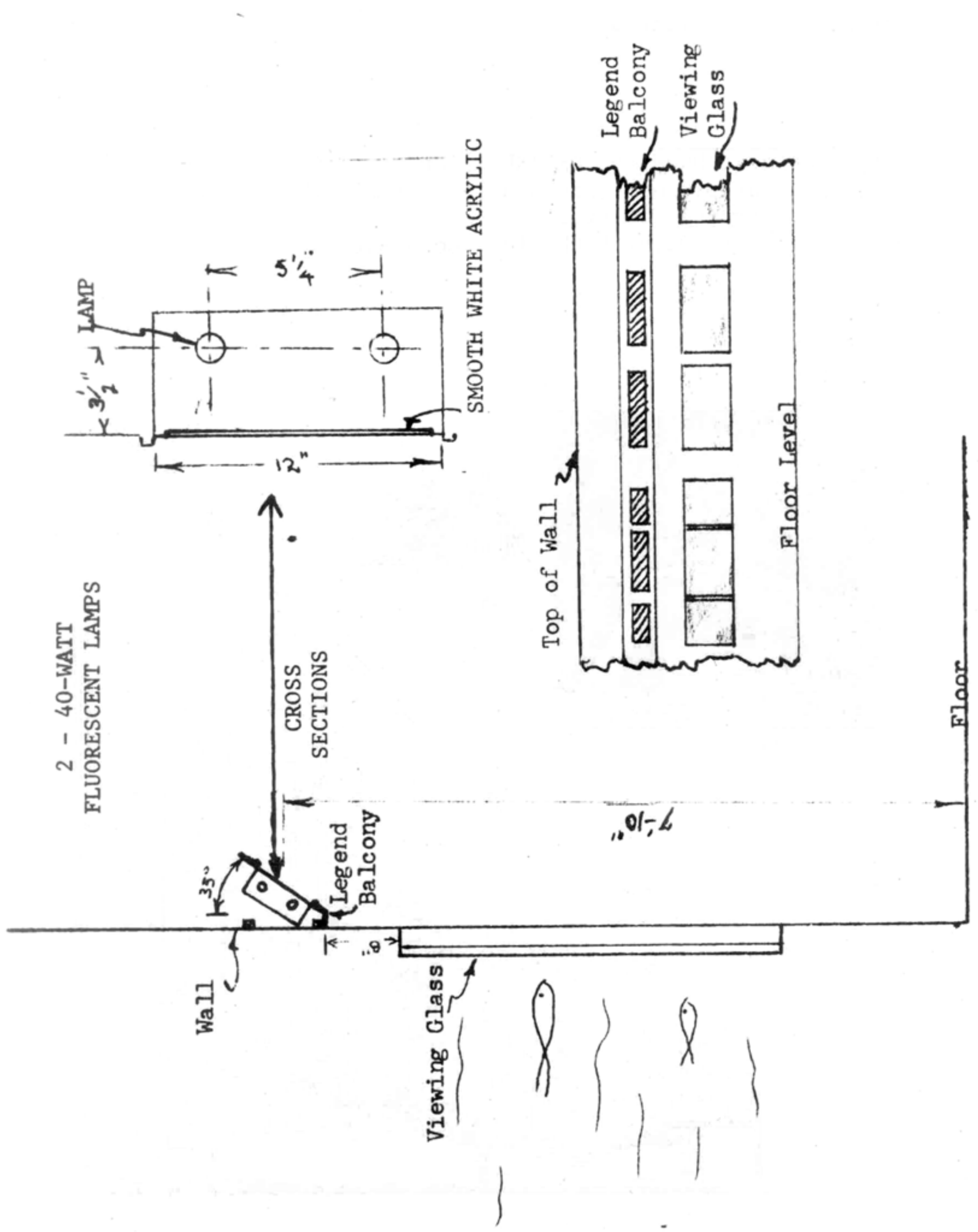
(1) See also DRUM AND CROAKER, January 1968.
(2) Similar products are available from other firms.
(3) Dow Corning Silastic
(4) Baltimore Paint & Chemical Corporation.



Hammock trail

Anhinga

Cross-section through Everglades hammock


2 - 40-WATT
FLUORESCENT LAMPS
CROSS
SECTIONS
LAMP
3 1/2"
5 1/4"
12"
SMOOTH WHITE ACRYLIC
Legend
Balcony
Viewing
Glass
Top of Wall
Floor Level
Floor
7'-10"
35°
Legend
Balcony
8"
Wall
Viewing Glass

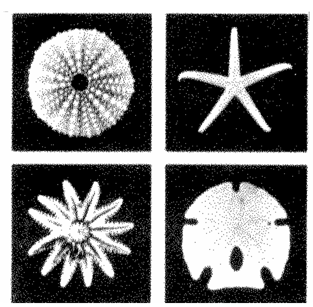
LEGEND BOXES

Legend boxes may be mounted below, beside or above the display tanks. We suggest the use of legends mounted above the tanks to permit more visitors to see the illustrations, and to discourage tampering.

It is recommended that the information boxes be the full width of each tank. The front of the box may be divided into approximately 12" x 12" sections. Slides containing transparencies with appropriate drawings, photographs, and explanatory material are placed in slots in front of ground glass or white opaque acrylic. Those sections not in use are blacked out.

Behind the glass, inside the box, two continuous rows of neon or fluorescent tubes are placed at an appropriate distance from the glass. Good diffusion of light through the glass is necessary. For that reason, incandescent lights are less desirable. However, too much light must be avoided.

In addition to the identification box, it is often desirable to have easily read special information beside the display tank.

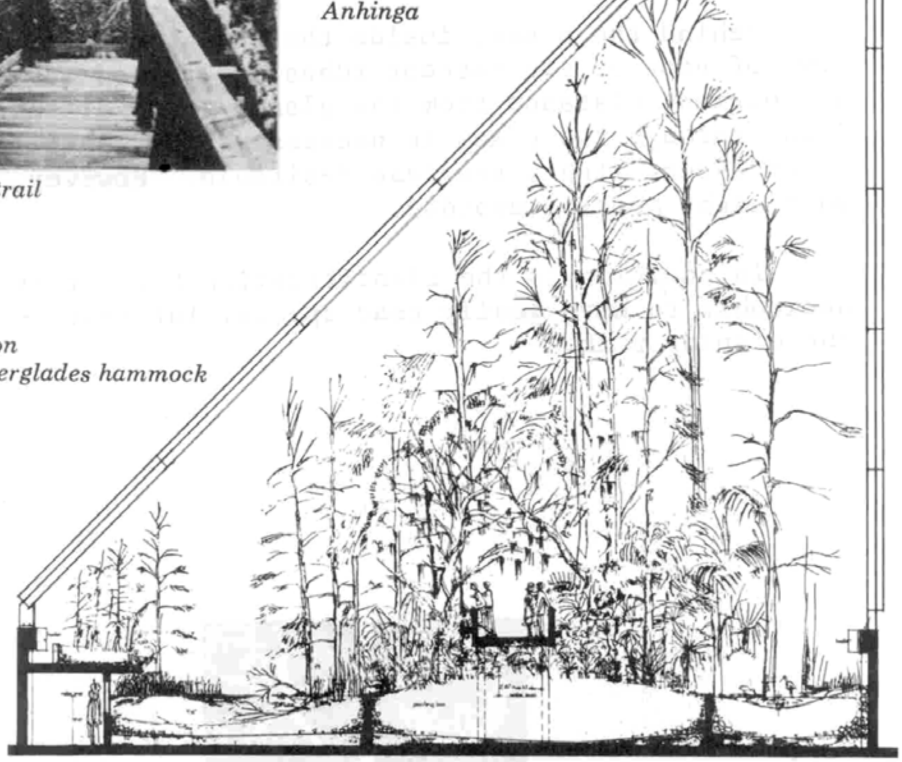


Echinoderms

Hammock trail

Anhinga

Cross-section through Everglades hammock



ULTRAVIOLET STERILIZATION OF AQUARIUM WATER*

Earl S. Herald, Robert P. Dempster, and Majorie Hunt

Steinhart Aquarium, California Academy of Sciences

During the redesign period for the rehabilitation of Steinhart Aquarium (1957-1960), the staff began a series of tests to determine the efficiency of ultraviolet rays as a means of decreasing the bacterial content of highly-crowded fish tanks. Although ultraviolet lethal effects on bacteria were first known in 1877 and ultraviolet sterilization of city water supplies was practiced as early as 1909 (3,000,000 gallons per day), it was not until 1962 that it was applied to large aquarium water systems. Ultraviolet has had effective use in England, Japan and in this country for the purification of seawater in shellfish studies as well as in commercial practice. Small home aquarium UV units have been marketed, but not on a wide scale.

The initial Steinhart UV test unit was fabricated of stainless steel and designed for use with swimming pools. It was an Aquafine 4-tube unit with a modest capacity of 50 gallons per minute. The test results, indicating that the unit was very effective in reduction of aquarium microorganism populations, were reported at the International Aquarium Symposium at Monaco in 1961 (Herald, et al. 1962).

We then asked for the manufacturers to design and construct inert UV sterilizers using polyvinyl chloride materials. During 1963 and 1964 one of these 150-gallon per minute PVC units (12-tube) was installed in the Steinhart tropical seawater system (75° F.; 23,717 gallons) and another in the tropical freshwater system (82° F.; 26,971 gallons) (Figs. 1 and 2). In addition, we installed a smaller (6-tube) unit on the alligator system (80° F.; 11,132 gallons) This was followed by a 116 gpm 8-tube unit in the freshwater dolphin system. Results and conclusions from the operation of these four units are the principal parts of this report.

*This research has been conducted under contract funds provided by the National Fisheries Center and Aquarium of the U. S. Department of the Interior and by the Office of Naval Research.

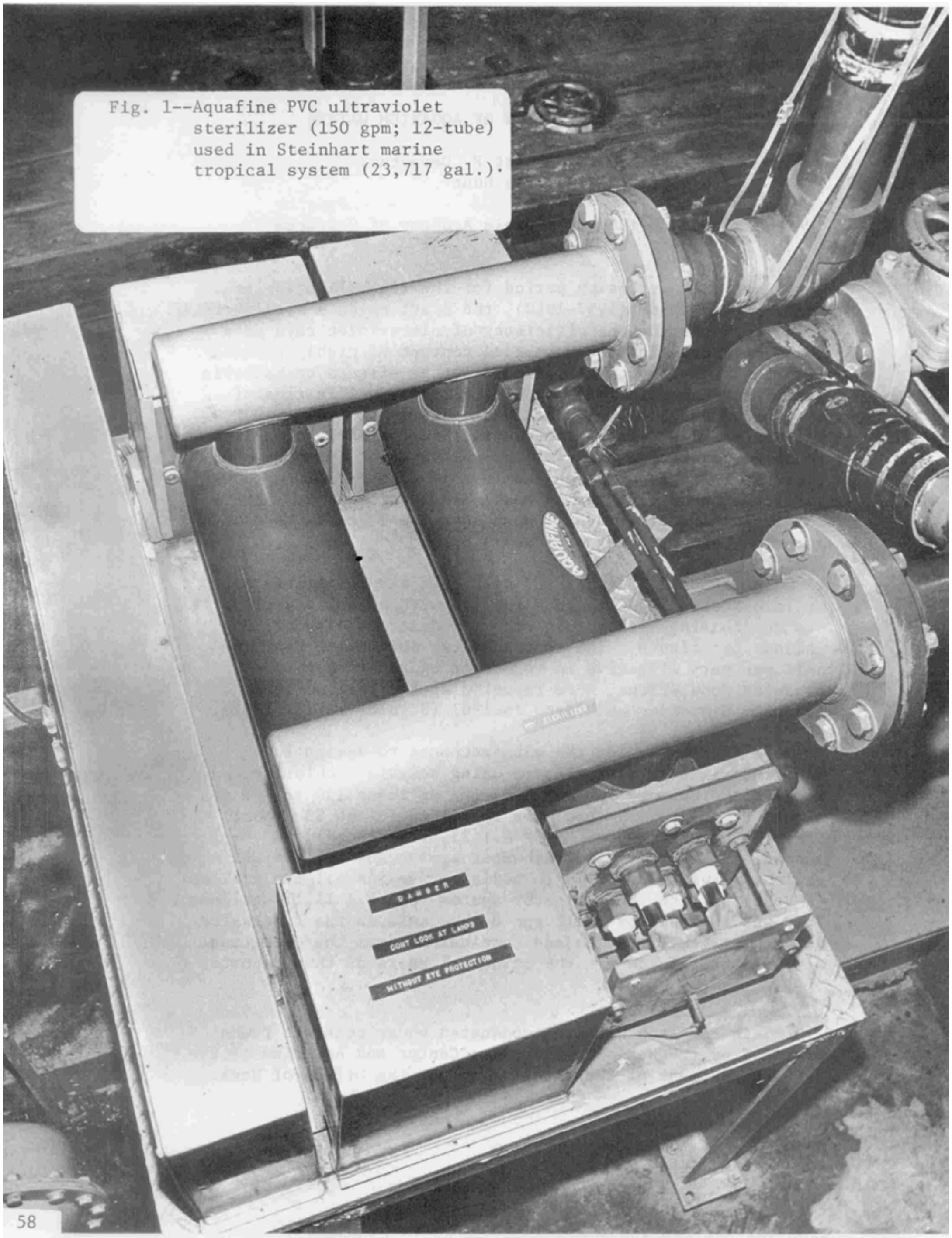


Fig. 1--Aquafine PVC ultraviolet sterilizer (150 gpm; 12-tube) used in Steinhart marine tropical system (23,717 gal.).

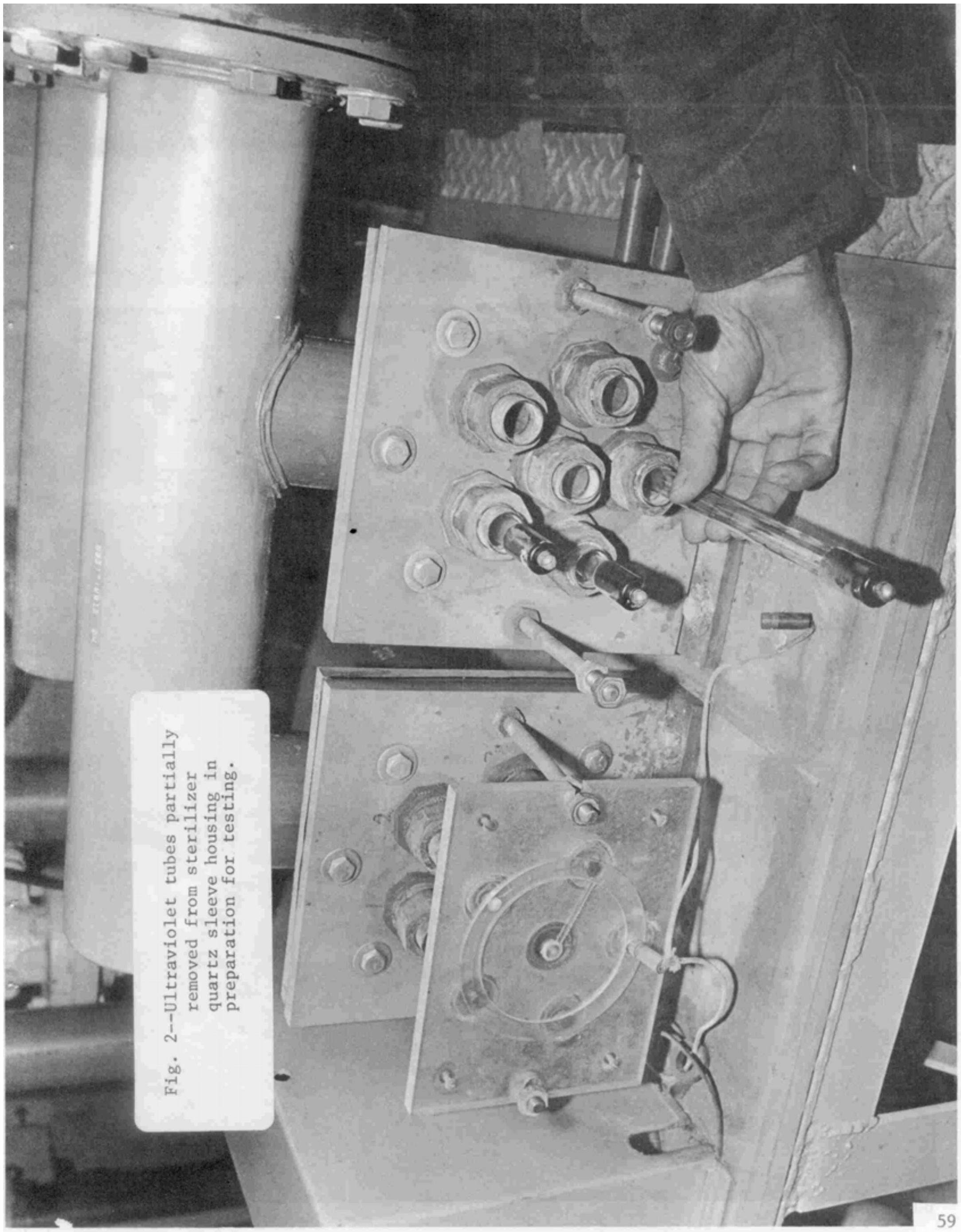


Fig. 2--Ultraviolet tubes partially removed from sterilizer quartz sleeve housing in preparation for testing.

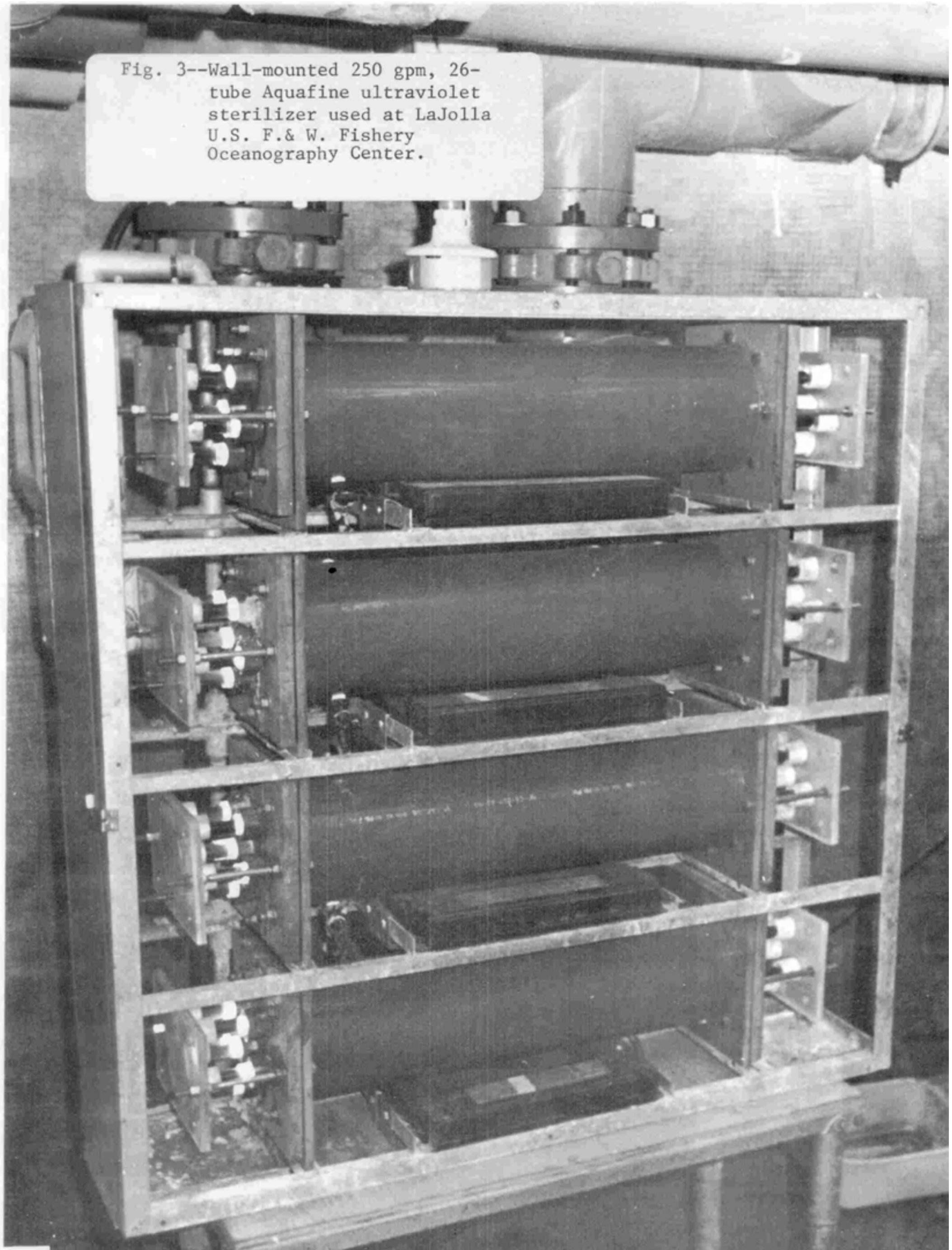


Fig. 3--Wall-mounted 250 gpm, 26-tube Aquafine ultraviolet sterilizer used at LaJolla U.S. F.& W. Fishery Oceanography Center.

Other major aquariums, oceanariums, and laboratories have also made use of ultraviolet sterilization for large water systems. Sea World in San Diego uses PVC Aquafine units for two of their sea water systems, one at 75° F., 55,000 gallons, and another at 68° F., also 55,000 gallons. Aquarama in Philadelphia, now closed, installed Ultradion units (formerly Elenite) of vinyl-lined stainless steel in two of their water systems: tropical seawater, 2,000 gallons; and tropical freshwater, 1,700 gallons. Bacteriological reports on the excellent efficiency of the Aquarama systems were generously made available to us by Mr. Don Wilkie

The LaJolla Fishery-Oceanography Center of the U. S. Bureau of Commercial Fisheries uses a 250 gpm 26-tube wall-mounted Aquafine unit (fig. 3) for their water used in the experimental laboratories (Lasker and Vlymen 1969).

Ultraviolet rays (fig. 4) are recognized as occupying that portion of the electromagnetic spectrum which lies between visible light and X-rays, i.e., the short wave lengths between 136 and 4000 angstrom units. The most active wave lengths biologically are those between 1900 and 3000 a.u. The most lethal rays upon living cells are those at 2600 a.u., that being the length which is most effective upon DNA. Sterilizing ultraviolet tubes have a peak output at 2537 a.u., which is the most desirable wave length from the manufacturing standpoint. Actually, 16% of the UV sterilization tube output is in wave lengths longer than 2537, ranging from 2652 to 5780 a.u. Ozone is produced in the 1000 and 2000 a.u. range, with ozone-producing tubes operating at 1950 a.u. From 2900 to 3100 a.u. is the antirachitic range, which stimulates the production of Vitamin D. It may be noted that Billie M. Bevan and Warren Zeiller, in a privately published, undated article on "Ultraviolet Irradiation of Marine Aquaria," have reported therapeutic effects upon fishes and turtles with the intermittent use of long-wave, or black-light UV with a maximum output at 3660 a.u. Further tests of this equipment are needed.

A knowledge of the action of ultraviolet rays is helpful in understanding its effectiveness. Along this line, chemist William Shipman presented a very significant paper at the Aquarium Symposium held at the 1967 San Francisco meetings of the American Society of Ichthyologists and Herpetologists.

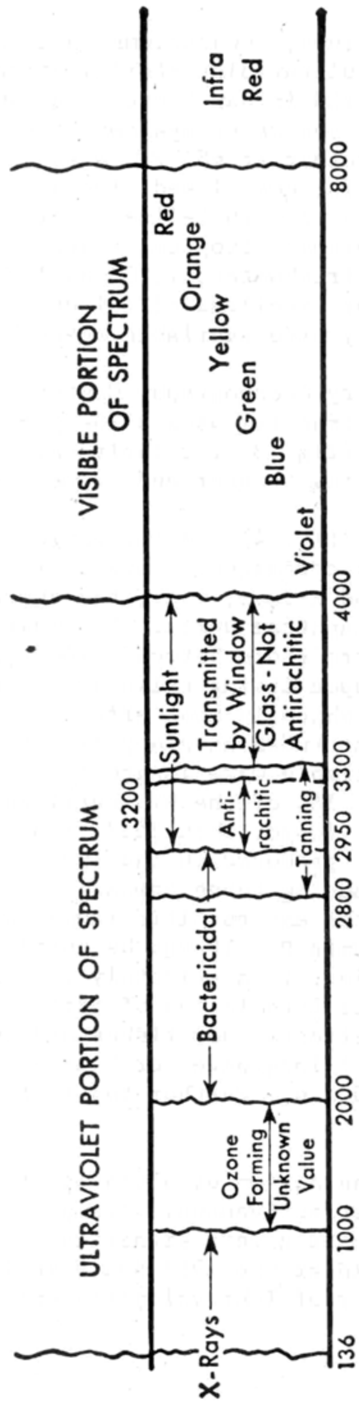


Figure 4.--Ultraviolet and visible portions of the spectrum (modified from "Sterilamp Conditioning").

He reported that in water sterilization procedures using either ultraviolet rays, ozone, or a radioactive source, some of the mechanics of the lethal effect are identical. Any one of these three sterilizing agents causes a chemical change in the water, forming peroxy compounds and other free radicals which are responsible for some of the desired lethal action. In the case of ultraviolet, this can be simply demonstrated by a careful peroxide test of a small amount of water immediately adjacent to the ultraviolet tube. The bactericidal action of peroxide is well known, being highly caustic and unstable in concentrated solution and weakly antiseptic in dilute solution. Its action is very brief, being limited by catalyzing agents.

R. S. Deering (1962) has explained the results of ultraviolet radiation as primarily being the effect of the rays upon the genetic material, deoxyribonucleic acid (DNA). Ultraviolet has long been known for the changes, including mutations, which it produces in living cells. We mention this because of the possibility that the constant use of UV sterilizers in fish-water systems could produce new bacterial strains resistant to UV in the same manner in which DDT-resistant flies have been developed, and copper-resistant diatoms have been discovered in oceanarium tanks.

Assuming that an ultraviolet sterilizer functions effectively it can then be expected to deliver treated water which is almost micro-organism free. It should be noted that high temperature increases UV penetration and low temperature decreases it. For example, an ultraviolet tube in direct contact with the water will operate at maximum efficiency if the water temperature is 105° F.; however, if the temperature of the water is only 70° F. the ultraviolet tube will operate at only 50 percent of its maximum efficiency. To solve this problem, manufacturers usually surround the ultraviolet tube with a protective jacket made of quartz or vycor. The air space between the sheathing jacket and the ultraviolet tube provides an insulating layer that permits the ultraviolet tube to operate at about 105° F. with the least amount of effect by the temperature of the water surrounding the jacket. With a properly designed ultraviolet installation in a well-filtered fish-water system, the all important coefficient of absorption of the water need not be a cause for concern.

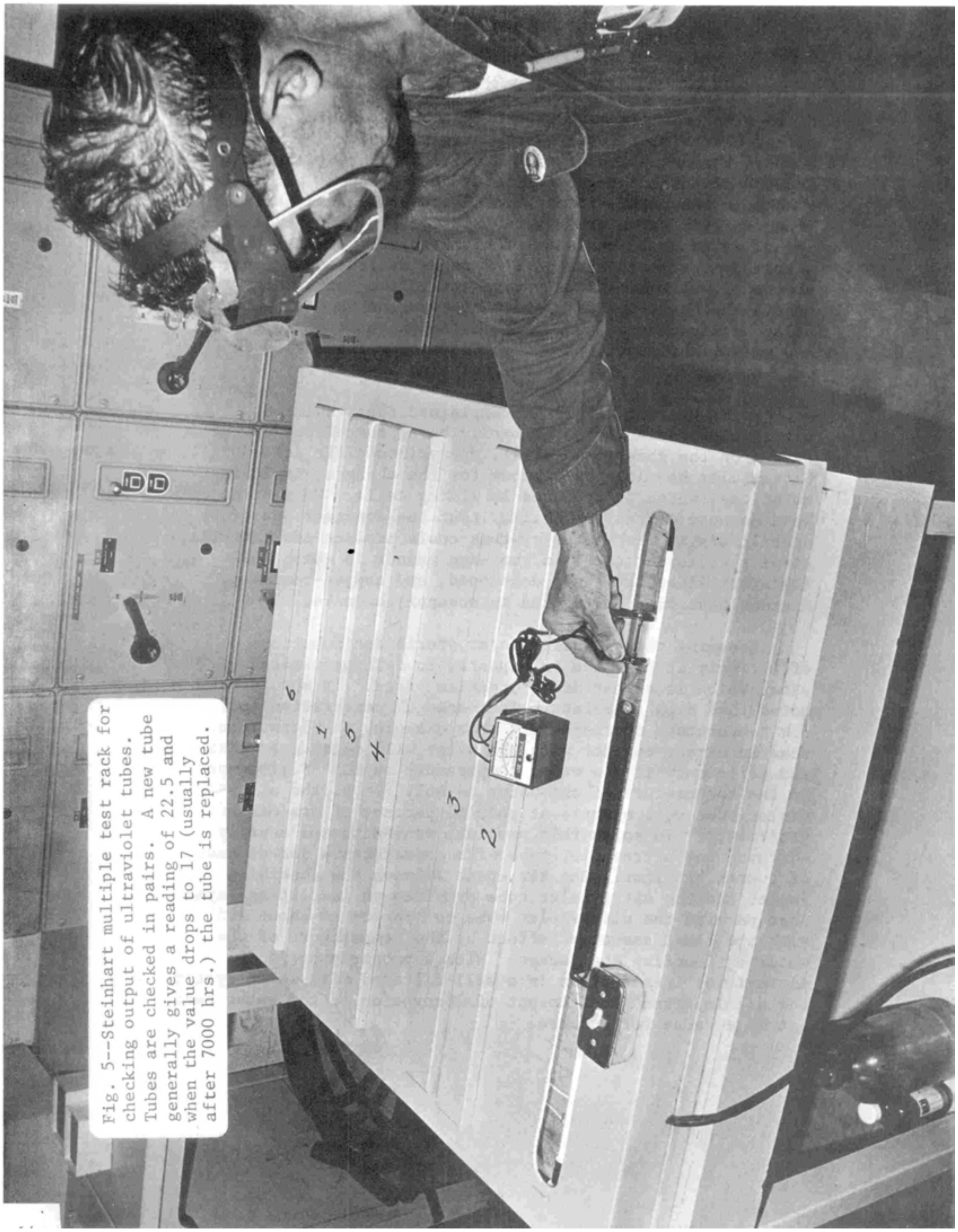


Fig. 5--Steinhart multiple test rack for checking output of ultraviolet tubes. Tubes are checked in pairs. A new tube generally gives a reading of 22.5 and when the value drops to 17 (usually after 7000 hrs.) the tube is replaced.

Under optimum conditions ultraviolet rays are generally considered to be capable of penetrating water effectively for a distance of 1 1/2 inches, but this can be diminished by at least three important factors. First is the turbidity of the water. Murky water resulting from detritus or other suspended matter will result in poor UV penetration so that in aquarium design the UV unit must be placed after the filter, not ahead of it.

The second factor is the length of life of the tube. Although UV tubes are generally guaranteed for at least 7500 hours, the effective life may be variable as shown by periodic checks made with the UV meter. The light transmitting ability of the UV tube glass is altered by the continued operation of the unit, so that, although the tube may be operating properly, the tube glass may have become opaque to the UV rays. The use of a UV-tube test rack such as that built in the Steinhart shop (fig. 5) is recommended.

The third factor which limits the output of the UV tube is the scum that invariably accumulates on the outside of the quartz sleeve within which the UV tube operates. This obviously means that the sleeves must be given a periodic cleaning. The Ultradion UV unit has a built-in push-pull sleeve cleaner, but the Aquafine unit must be disassembled once every three months in order to clean the sleeves properly (8 man hours for a 12-tube unit). Curator David Powell of San Diego's Sea World has equipped his vertically mounted Aquafine units with special screw-in plugs that can be removed to allow 20% hydrochloric acid to be poured into the swirl chamber surrounding the quartz sleeves. After one-half hour, the acid is drained and the unit washed thoroughly for at least 15 minutes before being put back into service. This method of cleaning results in a saving in the occasional breakage of the quartz sleeves ($15 each) when they are removed by the other cleaning method.

Aquarium water purified by UV sterilization will be useful only if the fish tanks have been properly designed. The flow of incoming treated water through the tank must replace all of the water within the tank. If there are dead-spots or static areas which are not a part of the normal flow pattern, the effect of the incoming UV-sterilized water will be minimized, or even totally lost. This is a very important consideration because ultraviolet-treated water is exactly the opposite of copper- and chlorine-treated water.

TYPICAL EFFECT OF ULTRAVIOLET STERILIZATION

ON BACTERIAL, COUNTS

IN LARGE SEMI-CLOSED AQUARIUM SYSTEMS

Numbers given are bacteria per cc.; UV off indicates bacterial results after 7 days turnoff.

	75° Seawater		80° Freshwater	
	UV On	UV Off	UV On	UV Off
After UV sterilizer	100		50	
Aeration Tank	46	2000	120	500
Head Tank	200	2500	100	600
TANK A	250	4400	150	700
TANK B	1200	3500	700	1500
Before Filter	3000	10,000	800	1600
After Filter	1400	4600	330	860
Cistern Reservoir	3800	5500	290	500
Gallons of Water	23,717		26,971	
Number Animals	419		589	
Pounds Animals	788		782	
Pounds of food daily	11		12	
Gallons of water per lb. of animal	28		35	
Hrs. required for complete filter turnover 1	3 1/2		3 1/2	

Once the water has passed the UV sterilizer, the lethal rays can do no further work. Chlorinated and copper-treated water usually have a surplus of free chlorine and free copper ions which enable the sterilizing materials to work for a period of time after they have been placed in the water.

For example, UV rays will kill the free swimming stages of Oodinium as the sea water passes through the sterilizer, but will not affect the adult stages securely hidden in the gills of fishes in the display tank. Similarly, the free-swimming stages of ciliates and other organisms will be killed by contact with UV rays from the sterilizer, but the same parasites clinging safely to the host fish will not be affected. By contrast, free copper ions will usually remove these parasites from the fish.

Periodically over several years we carried out a series of tests to determine the effects of UV sterilization in terms of increase or decrease in bacterial population. We have turned the UV units off and then recorded the bacterial buildup. Turning them on once again, we studied the dimunition of bacteria. We have used as controls adjacent water systems which were similar to the test systems but did not have ultraviolet units.

It is not our objective to go into detail of species of bacteria found through the various fish-water systems; however, the following were usually present in greater or lesser amounts: Pseudomonas, Aerobacter, Micrococci, Proteus, Alkaligenes, B. subtilis and E. coli.

From considerable data we have compiled a representative composite of the effects of turning the UV units off for periods of one week (Table 1) . As is typical of UV bacteriological studies, some of the sequential changes at various points in the water systems do not always show a logical pattern. For example, one would not normally expect to find the bacterial count in the seawater cistern reservoir to be higher than that of the preceding after-filter water.

At Steinhart Aquarium we have had a serious problem with bacterial buildup in our freshwater dolphin system. Actually this system is nothing more than a 8,500 gallon display tank (82° F.) together with its own heating unit and DeLaval reverse flow filter (90 gpm).

TABLE 2

EFFECT OF ULTRAVIOLET STERILIZATION ON BACTERIA

IN A TROPICAL SEAWATER (75° F.) SEMI-CLOSED AQUARIUM SYSTEM

UV Status	Without UV For 5 months	UV for 1 day		UV for 11 days	
Sample Date	Feb. 22, 1968	March 1, 1968		March 11, 1968	
	Hemolytic and Non-hemolytic Organisms	Hemolytic and Non-hemolytic Organisms	Hemolytic Organisms Only	Hemolytic and Non-hemolytic Organisms	Hemolytic Organisms Only
After UV Sterilizer	Not done (UV not operating)	2/cc	1/cc	19/cc	1/cc
Aeration tank	40,000 (approx)/cc	57	2	220	1
Head Tank	37,400	825	300	290	20
Spigot SB 11	32,000	not done		200	10
Tank 22	26,000	5000	900	1160	170
Before Filter	40,000	7400	3000	8200	3000
After Filter	36,800	2700	1300	4900	2900
Cistern	27,600	5300	4000	8600	2900

Background: Heated seawater system with 24 display and 10 reserve tanks contains 21,000 gallons of water with 419 fishes weighing 788 pounds. Bacteriological growth medium - Reutzer's with blood added.

The maximum body weight of the various animals in the tank, including Amazon and Indus dolphin and an occasional manatee was no more than 725 pounds and the highest daily food consumption was about 35 pounds. Unfortunately, a reverse flow filter does not have the same ability to remove ammonia from water as effectively as do the biological materials in the top of a good sand and gravel gravity filter. Thus, when it is not possible to bring in new water to decrease the ammonia level we sometimes operate the dolphin system as a part of the heated freshwater fish system (26,971 gallons). Because of this necessity of two-system water interchangeability, we obviously cannot use chlorine compounds in this freshwater dolphin tank as we do for the marine cetaceans. Recent installation of a new stainless steel 116 gpm Aquafine 8-tube UV sterilizer has effectively removed the high bacterial population from this dolphin system.

One place where the ultraviolet water sterilization has definitely helped us has been in the Steinhart alligator system. This 11,132-gallon tank is located in the entrance area to the Aquarium and operates at 82° F. Its population generally includes 7 alligators (7-10 ft.) and 11 smaller crocodilians (seven species) in addition to 125 turtles of 16 species. The same system also circulates through six diorama tanks housing large snakes and large lizards. The 'gators are never peaceful and considerable slashing of adjacent animals is commonplace. Before installation of the ultraviolet unit on this system, we invariably had at least one alligator constantly in sick bay. Surgery, sometimes as drastic as amputation, was usually necessary. Since installation of the sterilizer, we find that the 'gators still fight, but the lesions no longer become infected, and the previously omnipresent gangrene has disappeared.

During one five-month period when the UV unit on the heated seawater system was being repaired (Table 2) the bacterial population at seven of the checkpoints in that system climbed to impossible levels of 26,000 to 40,000 bacteria per cc.

The first day of renewed UV operation in this system resulted in a radical drop in the bacterial population, and the next sample taken ten days later showed that the lethal effect produced by the UV sterilizer was being maintained.

It would be most effective for large aquarium operation if a lowered mortality rate could be demonstrated as the result of the use of UV water sterilization. Unfortunately, this has not been the case. During all of our testing we kept very careful mortality records for acclimated fishes (30 days or more in captivity). We found that for populations ranging from 419 to 814 fishes living in our various water systems the average mortality rate was 2 1/2 percent per month. This was based on a composite of short-lived as well as long-lived fishes. During the five-month period when the UV sterilizer was non-operative in the heated seawater system, the mortality rate for that system was not appreciably higher than the 2 1/2 percent norm.

We are thus forced to the reluctant conclusion that aquarium fishes in good condition can live compatibly in a large water system of high bacterial content. However, please allow us to specify what is meant: by good condition. This is a fish or fishes without parasites or abrasions on the body or gills. This means that the animals must be handled with great care. For example, at Steinhart Aquarium we do not capture or restrain valuable fishes by netting (exceptions are sharks, triggers, and moray eels). Whenever valued fishes are to be moved for tank cleaning or other purposes, the move is made by use of quinaldine anesthetic. As soon as the fishes show the effects of the anesthetic, they are carefully and quickly bucketed from the display tank into a reserve tank containing water without anesthetic. Return to the display tank is handled in the same manner which means that the fish's body protective mucus is not disturbed and a considerable portion of its natural immunity is thus maintained.

To summarize the position of ultraviolet sterilization as it pertains to aquarium water; it is a specialty tool with capabilities which make it highly useful under certain conditions. If you have a severe disease problem in an aquarium water system, ultraviolet sterilization is obviously a desirable addition to the circulation pattern. We recommend ultraviolet sterilization for water systems containing valuable living exhibits or exhibits in which bacterial control is essential, and where chemical treatment cannot be used. Fishes in good health in an uncrowded aquarium with proper aeration and filtration can, and do, live satisfactorily without the use of UV water sterilizers . However, they will be additionally safeguarded against outside contamination through the use of ultraviolet.

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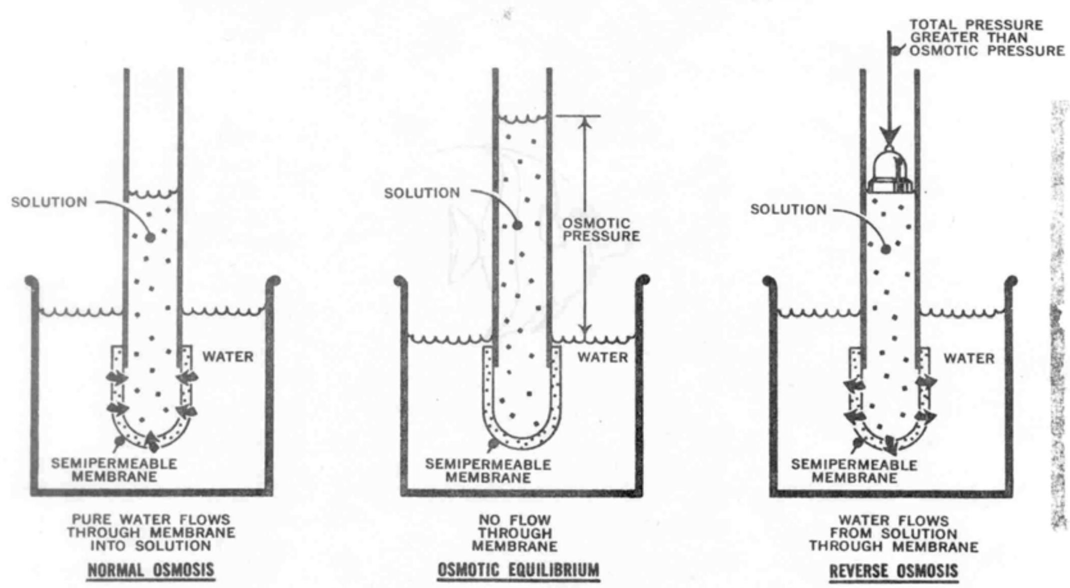
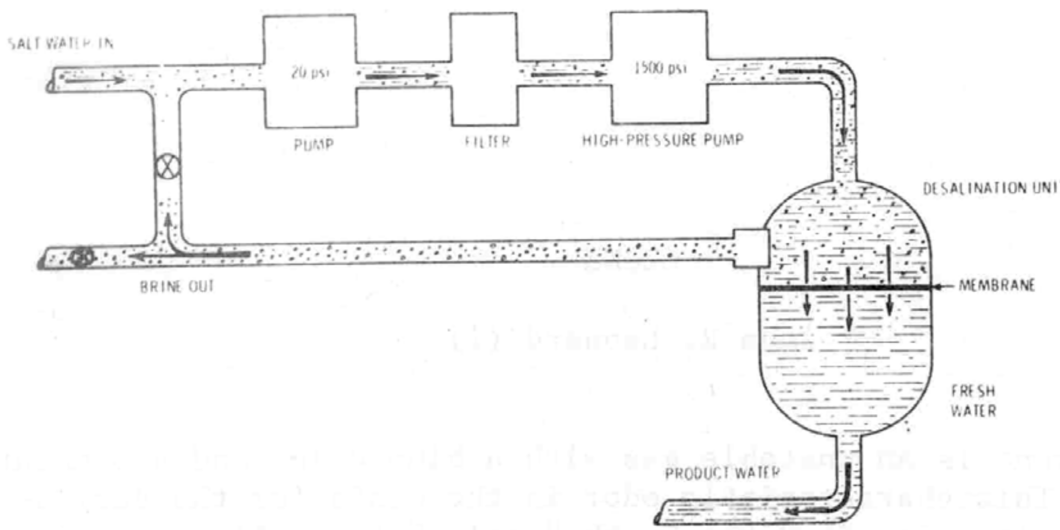
Reverse Osmosis

Reverse osmosis is a purely mechanical process which can be used for the purification of water, and for the concentration and purification of a variety of foods, pharmaceuticals and chemicals. There is no phase change in the reverse osmosis process, and therefore no temperature effect on the fluid processed. While its initial development was directed primarily to the recovery of potable water from sea and brackish water, many other applications have also been explored.

When pure water and a solution are on opposite sides of a semipermeable membrane, the pure water diffuses through the membrane and dilutes the solution. This phenomenon is known as osmosis . Because of the difference in concentration, pure water flows through the membrane as though a pressure were being applied to it. The effective driving force causing the flow is called osmotic pressure. The magnitude of the osmotic pressure depends on the concentration of the solution and the temperature of the water. By exerting pressure on the solution, the osmosis process can be reversed. When the pressure on the solution is greater than the osmotic pressure, fresh water diffuses through the membrane in the opposite direction to normal osmotic flow.





Schematic diagram of the reverse-osmosis process.

(2002 Editor's Note: Original image was of poor quality and some captions are badly damaged. Affected captions read, left to right, top row: saltwater in, 20 psi, <no label in center box>, 1500 psi; labels under boxes: pump, filter, high-pressure pump.)

The solution is first pumped through a filter where suspended solids that would damage the membranes are removed. The solution is then raised to operating pressure by a second pump and then introduced into the unit. A portion of the water permeates the membranes and is collected as product water at the bottom of the unit. The brine is discharged at the top of the unit. When desired, some of the brine may be mixed with the incoming solution and recirculated.

The most widely used membrane material is asymmetric or "skinned" cellulose acetate film which is currently available in several forms to give various flux and salt rejection performance characteristics. Operating units or modules have been designed to carry out the reverse osmosis principle in several different configurations such as plate and frame, tubular, spiral-wound and hollow-fiber designs. All are based on the common principle that the plastic membrane must have a firm support to withstand the rather high pressure drop across it.

For purification of aquarium water, the reverse osmosis process offers the advantages of low energy consumption with relatively simple processing equipment operating at normal temperatures. Commercially available membranes give rejections of 95% or more for most ionic species, detergents, bacteria, and most large organic molecules. Rejection of urea, borates, low molecular weight alcohols, ammonia and phenols is generally poor.

Reverse osmosis water treatment plants operating up to 100,000 gallons per day or about 70 gallons per minute are in use and are available today.

This principle will be applied in the removal of most undesirable elements from the city water entering the National Fisheries Center and Aquarium.

OZONE

John R. Leonard (1)

Ozone is an unstable gas with a blue color and a pungent odor. This characteristic odor is the basis for the derivation of its name from the Greek "ozein," to smell.

In nature ozone is encountered in a dilute form mixed with air; however, it may be produced on a commercial scale by passing an electrical discharge through a gaseous medium containing oxygen.

Ozone is used commercially in the preparation of chemicals, the preservation of products in storage, the deodorization of sewage and air gases, and the treatment of wastes and water. It is the latter use which interests most of us concerned with aquariology.

Under the broad topic of water treatment, Ravensdale (1967) states that in a closed system ozonizers may be used for sterilizing live food (i.e. minnows), for preventing outbreaks of epidemics, for curing diseases, and for clarifying turbid water containing bacteria. Holzmann (ca. 1965) and Probst (ca. 1965) report that the addition of ozone to an aquarium will establish a tendency for oxidation which is necessary in the conversion of ammonia and nitrite to less harmful nitrate. They recommend that ozone be used in conjunction with, but separate from, a bed of nitrifying bacteria to develop a more reliable method of nitrogen conversion. Ozone has also been successful in removing ammonia and nitrite when used with a protein skimmer (Fach, ca. 1965). Other uses as well as materials and procedures may be found in the publication by Triton Aquatics, 1968.

(1) Fishery Biologist - Research, National Fisheries Center and Aquarium.

In addition to these successful applications of ozone many failures have also been reported. Hubbs (1930) states "that all fishes experimented on exhibited irritation symptoms even in traces of ozone too slight to detect chemically." In this report I found no mention of the possibility of ammonia toxicity contributing to the irritation reported. More recently McKee and Wolf (1963) report that ozone in concentrations less than .01 mg/liter irritated fish, and nascent oxygen at a concentration of .033 mg/liter has been fatal to minnows and shiners. They also state that an ozone concentration from .1 to .3 mg/liter is sufficient for use as a bactericide or cysticide. We should be aware that concentrations of this range would destroy not only the harmful microorganisms but also beneficial forms, including nitrifiers.

Definite statements regarding "the place of ozone in aquariology must be deferred until future data can be presented because of (1) the controversy currently presented in the literature, (2) the lack of uniform experimental evidence as to the effect of ozone on aquatic organisms, and (3) the well-documented reports on the potential danger of ozone to both man and many laboratory animals.

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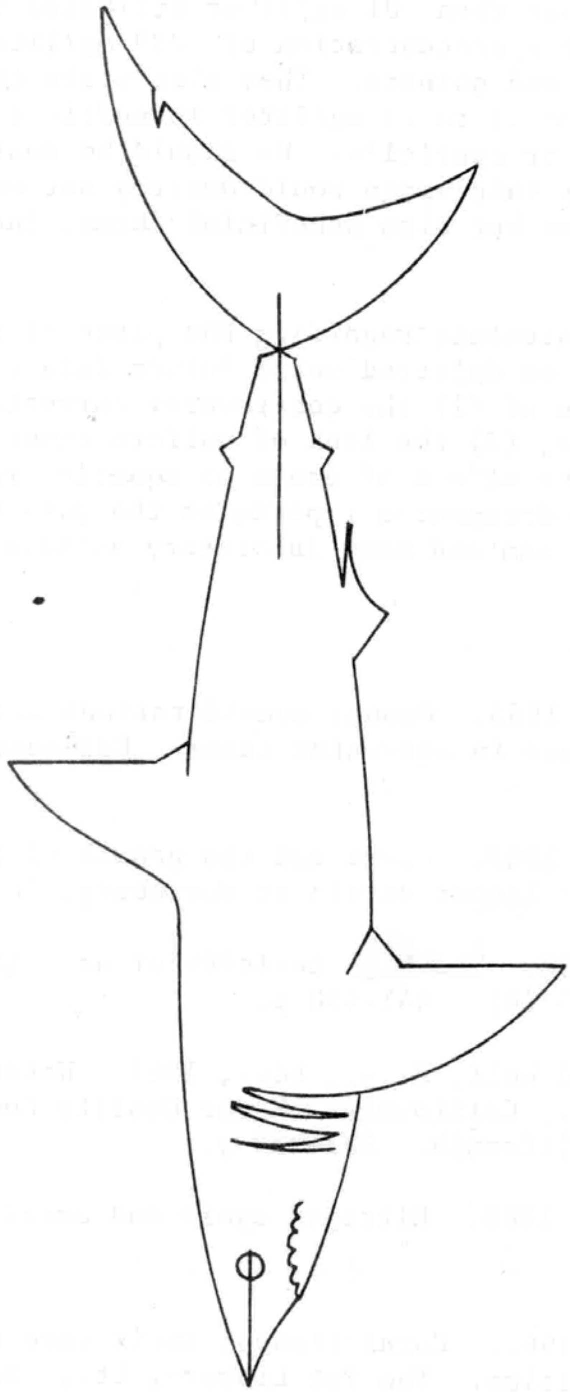


OCEANARIUM WATER INTAKE AND FILTRATION PROBLEMS (1)

C. K. Tayler, Curator
Port Elizabeth Oceanarium
South Africa

The special requirements of a water intake system and the difficulties in installing and operating such an installation, together with factors that bring about failure or poor operation of a filtered water intake system, are little understood by members of the public and give rise to complaints when water conditions are cloudy in the aquarium tanks.

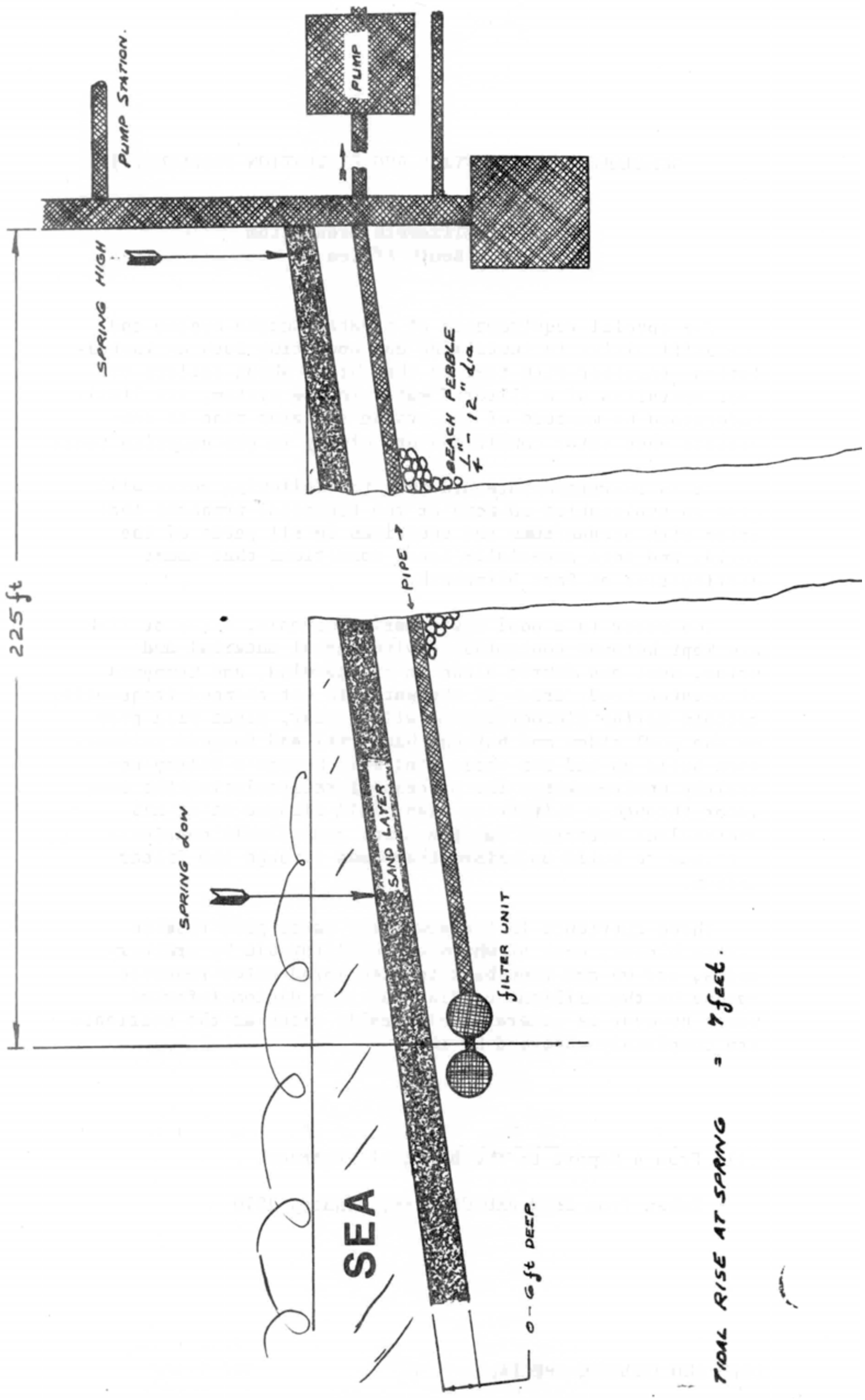
It is therefore intended that the following notes will give an explanation on some of the technical problems that arise with oceanariums and aquariums in all parts of the world, and more especially local conditions that cause difficulties at Port Elizabeth.

The water in a pool where marine mammals, birds or fish are kept becomes contaminated with faecal material and urine, dust and debris blown in by the wind, and remnants of uneaten food, etc. If the water is not changed frequently, certain marine microorganisms will appear, algae will grow on the pool sides and bottom, bacterial and fungoid cultures soon build up and the whole pool will become a filthy unhealthy environment. The process of recirculating the same water through a filtration plant will cleanse it of all undissolved material, but the urine and soluble nutrients continue to build up, since they pass through the filter medium.

These nutrients in the now clear water give rise to Diatom blooms, most of which are unfilterable by ordinary means, and we are then back to discolored water rendered opaque by the millions of diatoms. The diatom-infested water however is generally clinically clean as the nutrients are completely absorbed by them.

(1) From a Report to the Board of Trustees.

Taken from DRUM AND CROAKER, January 1970

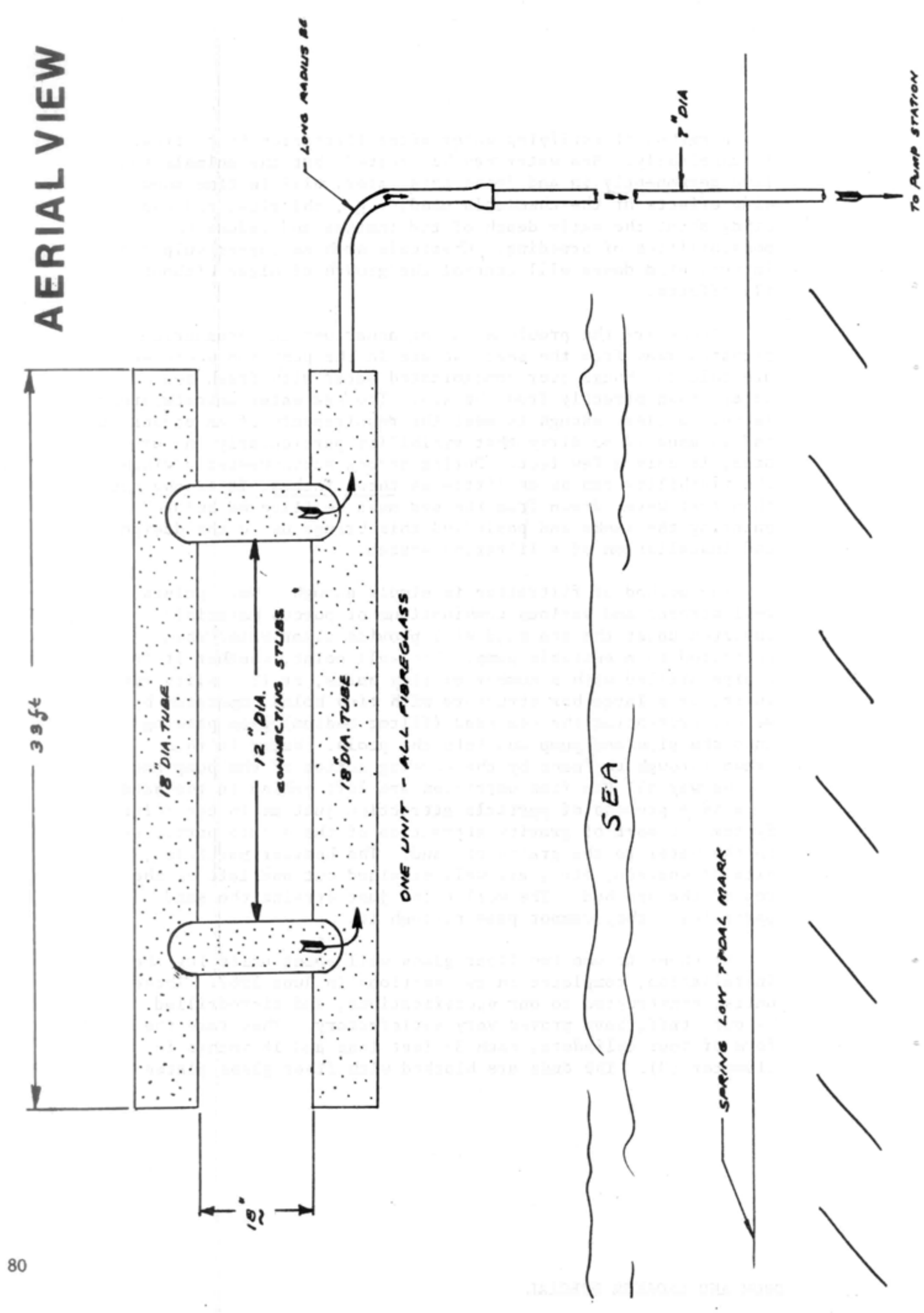

PUMP STATION.
PUMP
SPRING HIGH
BEACH PEBBLE 4" - 12" dia
225 ft
PIPE
SAND LAYER
SPRING LOW
FILTER UNIT
SEA
0 - 6 ft DEEP
TIDAL RISE AT SPRING = 7 feet.

A method of purifying water after filtration is to treat it chemically. Sea water can be treated, but the animals that live permanently in and drink this water, will in time show side effects of the chemicals used, e.g., chlorine, and can bring about the early death of the inmates and reduce the possibilities of breeding. Chemicals such as copper sulphate in very mild doses will control the growth of algae without ill effects.

These are the problems facing aquariums and oceanariums situated away from the sea. We are in the position where we are able to change over contaminated water with fresh sea water drawn directly from the sea. The sea water unfortunately is seldom clear enough to meet the requirements of an oceanarium and is usually so dirty that visibility particularly in our area, is only a few feet. During strong south-westerly winds the visibility can be as little as three inches. It is obvious then that water drawn from the sea must be filtered before entering the tanks and pools and this brings us to the design and installation of a filtering system.

The method of filtration is simple enough. Well points, well screens and various combinations of porous materials inserted under the sea sand will provide clear water when connected to a suitable pump. The well point, whether it is a pipe drilled with a number of tiny holes, or fine slits cut in it; or a large box structure with tiny holes, operates by merely preventing the sea sand (filter medium) from passing into the pipe and pump and into the pools. Water is thus drawn through the sand by the sucking action of the pump and on the way all the fine particles are left behind in the sand. This is a process of particle attraction just as in the Solar System - a sort of gravity attraction of the minute particles in the water to the grains of sand. The heavier particles, bits of seaweed, etc., are well strained out and left on the top of the sea bed. The well point just strains the sand particles - they cannot pass through it.

We chose to use two fiber glass well point units for the installation, completed in two sections in June 1967. These units, constructed to our specifications, and microdrilled by our staff, have proved very satisfactory. They take the form of four cylinders, each 33 feet long and 18 inches in diameter M. The ends are blocked with fiber glass plates and two cylinders are connected together by means of two 12-inch diameter by 3-foot stubs.


AERIAL VIEW
LONG RADIUS BE
7" DIA
TO PUMP STATION
33 ft
18" DIA. TUBE
12" DIA. CONNECTING STUBS
18" DIA. TUBE
ONE UNIT - ALL FIBREGLASS
SEA
SPRING LOW TIDAL MARK
18"

The two units thus formed are connected individually by two 7-inch D fiber glass pipes each 225 feet in length, to the pumping station.

We have, then, two units each consisting of two elements (four cylinders altogether) sited 100 feet apart. Each unit is drilled with approximately 450,000 tiny holes each 3/64 of an inch in diameter, right through the 3/8 of an inch thick fiber glass. The holes are spaced about 1/2 inch apart and drilled in all surfaces including the interconnecting stubs.

The continuance water yield is 700 gallons per minute for each unit provided they can be backwashed thoroughly and with sufficient pressure to dislodge any material that may block the tiny holes. A better continuance yield would be obtained if the cylinders were not interconnected into pairs, but rather four connecting pipes brought up the beach for more thorough backwashing. This, however, doubles the piping costs.

The material (fiber glass) has a theoretical life of 100 years in sea water. P.V.C. plastic has a comparatively short life. It becomes brittle in a few years and may collapse. Rubber, stainless steel, asbestos cement, bronze and copper, are all unsuitable due to their short life and/or rigidity. The commercially manufactured well points are of this type and intended for fresh water use where rapid electrolytic or chemical failure does not arise. Our Oceanarium commenced its long history of water intake problems with metal well points which lasted ten months. Plastic types were tried but they were washed out by wave action in heavy easterly winds. We finally licked the problem in 1967 by installing these units (of the most suitable material - fiberglass) and burying them under beach pebble, well beyond the low tide mark, by first making a cofferdam of sea sand with two bulldozers and then excavating 4-foot deep pits to contain the units. Trenches to contain the two connecting pipes were also buried under beach pebble in this manner, the whole distance up the beach to the pumpstation.

This system is completely safe in any sea and under any conditions and has been completely satisfactory and performed all its functions.

In view of the tremendous cost of fiber glass, units of the smallest possible dimensions were used, to give only the minimum water requirements.

This type of installation, unlike a well providing drinking water, has to be backwashed. The sea sand above the well points becomes saturated with debris and eventually will not pass the required amount of water. It is cleaned by stopping the pump and allowing the water to flow by gravity from the Dolphin pool back through the system and through the sea sand. The upward flow of water through the sand lifts each grain of sand slightly and washes out the debris. About 30 minutes per day of backwashing time is required.

Pumps working on high vacuums such as in this case, normally give short service. Through the corrosive action of sea water worsened by high vacuum conditions, special pumps are required. The very small quantity of highly abrasive sand that does in fact creep through the wall points does untold damage to pump parts, particularly the gland sleeve which is generally of a special abrasive resistant metal. We use a rubber lined pump with a stellite sleeve which we find gives excellent service and requires little maintenance.

TECHNICAL DETAILS OF CENTENARY AQUARIUM

DURBAN - SOUTH AFRICA (1)

By

H. Murt, Technical Manager

I. Sea Water Supply System - Primary Filtration

Sea water is supplied from a well point system, located on a jetty situated just over one hundred metres from the Aquarium complex. This system consists of 79 in number well point drive screens, each 1 ¼" (45mm) dia. x 3 ft. 6" (107 cm) long, fitted with galvanised steel riser pipes which are driven into the beach sand to a depth of 15/21 feet (5/7 metres). Well point drive screens are wire wound with a slot clearance of 0.010 inch (0.25mm), this is necessary due to the general fineness of sand particles encountered in this particular beach area.

Riser pipes, with related well point drive screen, are connected to 6" (15 cm) bore suction header pipes, one of which is installed on each side of the jetty, just above nominal beach level, and terminating at a pump house at the shore end of jetty.

The resultant filtered sea water is pumped to the Aquarium complex via a 4" (10cm) electrically driven single stage centrifugal pump, through an 8" (20cm) asbestos-cement underground pipeline. Valve manifolds are installed adjacent to the Main Fish Tank and Shark Tank to enable water distribution/control to various tank installations.

(1) The Durban Centenary Aquarium is the property of the South African Association for Marine Biological Research-a locally registered company (non-profit) founded in 1959.

The system of well points employed are relatively expensive, as due to internal/external incrustation, well point drive screens and extension riser pipes, etc., require renewing annually at a minimum cost of R2000. At optimum efficiency, sea water throughput is around 400 g.p.m. reducing to 250 g.p.m. after 18 months. Sea water is pumped continuously and distribution is roughly as follows:

		Capacity	% of Total
(i)	Main Fish Tank	186,000 galls	55
(ii)	Shark Tank	85,000 galls	30
(iii)	3 Medium Display Tanks	4,000 galls)	
(iv)	Shark Behaviour Tank	3,000 galls)	15
(v)	10 Small Display Tanks	400 galls)	
(vi)	3 Experimental Tanks	300 galls)	

II. Internal Water Circulation - Secondary Filtration

(a) Main Fish Tank

Water is drawn from tank bottom level from two points, centre and side of tank, through two electric driven centrifugal pumps, passed through a batch of four pressure sand filters at a rate of approximately 200 g.p.m. and then returned to Main Fish Tank. Pressure sand filters are two 8 ft. dia. x 6 ft. high of steel construction and two 8 ft. dia. spherical type of fibreglass construction.

Tank water level control is by a regulating "scour" valve at tank bottom level, and also by weirs constructed at maximum water level, excess water in both instances running to waste.

Algae and diatom growth control is by continuously injecting a copper sulphate solution into a return line to tank, i.e., after passing through pressure filters. Injection is by an electrically driven chemical proportionating pump - with variable setting the pump suction is fed from a small storage tank containing a proportion of copper sulphate chrystals mixed with water. Monitoring is carried out twice weekly to ensure a concentration of between 0.30 and 0.45 p.p.m.

(b) Shark Tank

Water is drawn from one point at tank bottom level, through an electrically driven centrifugal pump, passed through a batch of three pressure sand filters at a rate of approximately 250 g.p.m. and then returned to Shark Tank. Pressure sand filters are two 6 ft. dia. x 6 ft. high of steel construction and one 8 ft. dia. spherical type of fibreglass construction. Tank water level control is by weirs constructed at maximum water level, excess water running to waste.

Algae and diatom growth control is by a similar arrangement as that for Main Fish Tank, except that copper sulphate concentration is regulated to between 0..25 and 0.30 ppm.

III. Medium and Small Display and Experimental Tanks

All these tanks have open circuit water systems, all water running to waste.

IV. Plant and Water Recirculation

(a) Pressure sand filters are of the conventional pattern as used extensively in large swimming pool and water treatment installations. Graded gravel and sand used ranges from 1" dia. to 1/64" dia. Backflushing is usually necessary once weekly.

Fibreglass construction filters have not proved satisfactory in our experience, due to shell fractures which proved difficult and costly to remedy.

The original Diatomaceous Earth Filters were scrapped in 1961, being unable to cope with our high dirt load, required excessive maintenance and were costly to operate.

(b) Piping is mainly of "Durapipe" P.V.C., assembly is by solvent cement and a comprehensive range of fittings is available.

August 1969

CORROSION CONTROL (1)

Billie M. Bevan
Miami Seaquarium

The direct losses due to corrosion run into the millions of dollars every year in the United States. The marine aquarium, with its harsh saline water environment, is a classic example of the losses that can occur.

Pipe failure, pump breakdown, and tank rupture are often the direct result of corrosive forces.

Resultant losses due to shutdown of facilities, cost of replacement parts, and labor costs can be sharply curtailed by applying the concepts of corrosion control. Economically, the optimum time to consider corrosion control is in the planning and design stages of a facility. However, in all but the most advanced stages of deterioration corrosion control will be of value. In order to incorporate a corrosion control program of value, one must understand the corrosive process as well as preventative measures.

The basic illustration of corrosive process is the simple (battery) cell. This cell is comprised of an electrolyte (salt water), and anode (iron), and a cathode (copper). The two electrodes (iron and copper) are connected externally by a metallic circuit.

For our purposes the anode will always be considered the active and positive element and the cathode the negative and passive element of this cell. Current flow in the external circuit will be from negative to positive by means of electrons. In the electrolyte, ionic current flow is from positive to negative.

Iron tends to ionize more readily than copper; therefore, it is more active. At the instant a molecule of iron loses an electron it becomes an ion and enters the electrolyte. The electron travels through the external circuit to the anode where it is neutralized.

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(1) Reprinted from DRUM AND CROAKER, January 1970.

In the electrolyte, certain chemical processes take place. Normally there is some dissociation of H_20 into hydrogen ions (H+) and hydroxyl ions (OH-). The negative hydroxyl ions combine with the positive ferrous ions (Fe++) forming ferrous hydroxide, thus maintaining the chemical and electrical stability of the electrolyte. The positive hydrogen ions migrate to the copper cathode where they combine with the electrons from the anode to form stable atoms of Hydrogen.

The anodic reaction (oxidation process) is:

$$Fe + 2\ OH = Fe\ (OH)_2 + 2e^-$$

The cathode reaction (reduction process):

$$H_2O + 2e^- = H_2 + 2\ OH$$

Overall reaction:

$$Fe + 2\ H_20 = Fe\ (OH)_2 + H_2$$

Free hydrogen molecules plate the cathode in a monatomic layer. Excess molecules gradually combine with oxygen to form water.

Thus, metals corrode when their ions enter solution.

In the example, different metals served as cathode and anode. However, any metal will have impurities which produce areas of dissimulation. A difference of potential will exist between these areas and the pure metal surrounding them. In effect, we will have thousands of minute voltaic cells over the surface, each contributing to the overall corrosive action. This activity is referred to as "local cell action."

The above illustrates that a number of factors are involved in corrosion processes, control of which can be achieved with varying degrees of success in the following ways:

1. Breaking the external circuit will stop the interaction of the two metals, but would have no effect on "local cell action."

2. Coating one or both electrodes will prevent the reaction. The finest of available coatings are imperfect at best, however, and even a single break in their integrity can produce intense pitting.

3. Equalizing potentials to eliminate current flows.

Each corrosion control application is suited uniquely to specific corrosion problems due to variables and restrictions involved.

Electrolytic methods involve establishment of oxidation-reduction conditions in which hydrogen is deposited cathodically on the structure being protected, while oxidation takes place at an anode.

This is essentially the process occurring in our simple cell where the corroding iron anode was protecting the copper cathode.

Since we normally are concerned with protecting the iron, we can replace the copper with a metal such as zinc which is more active than iron. The iron now becomes the cathode and ceases to corrode.

This method of using a more active metal to protect a given structure is termed a sacrificial anode system, and is used extensively on boats, canal locks, pumps, and other isolated structures.

The second electrolytic method is termed impressed current cathodic protection.

In our original cell, inserting a battery and variable resistance in the external circuit in a manner to oppose or buck the normal flow of current, in effect, will make the copper become the anode. If the iron is made sufficiently negative with respect to the copper, it will also eliminate any local cell action.

In practice the copper would be replaced with some substance which does not ionize readily, such as carbon.

Seaquarium utilizes the impressed current system to protect the large tanks, pipes (other than P.V.C. and fiberglass), pumps, pressure filters, and steel upright monorail supports. This, in conjunction with good coatings and proper material selections, has reduced losses due to corrosion.

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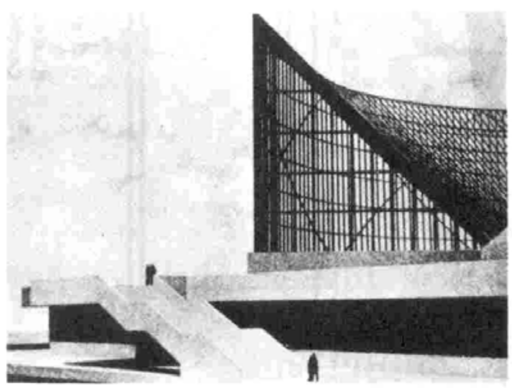
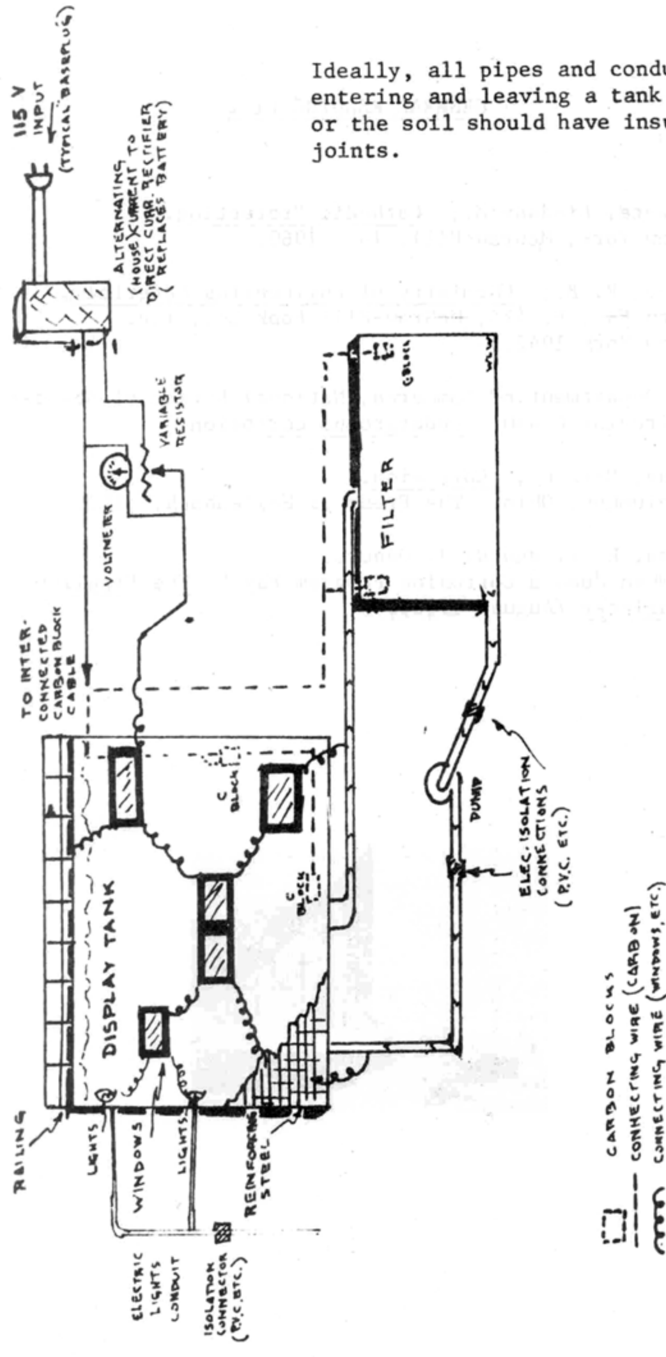


Ideally, all pipes and conduits entering and leaving a tank structure or the soil should have insulating joints.



TYPICAL TANK CIRCUITRY
TO REDUCE CORROSION

MORE ON CORROSION (1)

Walter L. West
National Fisheries Center and Aquarium

Although Billie Bevan's material is instantly clear to those technically oriented, I would like to associate it more closely, if I may, to the thinking of an aquarist as to how it is used within his aquarium. Billie has made it very clear that an external direct current source (EMF) such as a battery of plugged" into a "curcuit" will reduce, stop, or reverse electrochemical (corrosion) action. A typical aquarist would comment that no one designed a plug in the side of his tank.

All of the metal portions of a tank (window frames, railings, reinforcing rods, built-in lighting fixtures, etc.) should be interconnected or wired together, but should not be grounded. A ground is negative; therefore, grounding the interconnected metal is worse than no protection at all. The connecting wire is fed to the variable resistor (rheostat) in a system as shown in the accompanying sketch. Thence, to a series of inert conductors such as carbon blocks placed somewhere within the system - tank, piping, filter areas - the closer to the active corrosive area the more efficient. A series of blocks is generally most effective. The externally introduced current has made the steel the cathode (instead of the anode).

It is important to remember, if too much voltage is used in new concrete tanks, the concrete near the cathode metal (window frames, reinforcing, etc.) through which the current leaves the circuit becomes softened and remains brittle and friable after drying, destroying the bond between iron and concrete.

Although Billie mentioned a number of physical causes of corrosion, he did not mention a very interesting one, that of physical strain. Oxidation, or anodic areas, are created in a number of ways, but in forming a window frame from angle iron, as an example, in a cold state will put a strain concentration at that point. General practice is to cut a "wedge" from one leg of the angle and bend the other leg to 90* and weld the resultant angle. Also, the welding material, if made from a slightly dissimilar metal from the angle iron, is an invitation to corrosive pitting.

(1) From DRUM AND CROAKER, January 1970

GLASS FOR UNDERWATER WINDOWS (1)

David Miller (2

One of the nagging problems in the construction of tanks or pools for the display or holding of aquatic animals is the choice of the proper thickness and type of glass for underwater viewing windows.

Basic to the confusion that exists in everyone's mind is the bewildering array of trade names used by manufacturers to describe their products. Although there are discrete genera of formulae for making glass and systematic families of properties, applications, and products, the nomenclature is essentially random. To further cloud the issue, each manufacturer has a different name for the same product. Thus, a single type of glass may have as many names as there are manufacturers. For that reason I will avoid the use of trade names and use the more generalized "common" names where possible.

According to Webster's, glass is an amorphous, inorganic substance consisting of a mixture of silicates, sometimes borates or phosphates, fused with a flux and a stabilizer into a mass that cools to a rigid condition without crystallization. Silica sand is the principal ingredient of most glasses. A number of basic types are manufactured: sodalime, borosilicate, lead, aluminosilicate and 96% silica. Corning, for example, have in their files over one thousand separate and distinct formulations for what is basically glass.

Glass like other ceramics is non-ductile and does not plastically deform before failure. It never fails in pure compression; only from tension stresses. Its intrinsic strength is very high, perhaps as strong as steel; however, its ultimate strength is severely limited by surface imperfections. Fractures inevitably begin at the point of some surface flaw. Hence, the manufacturer takes normal surface depreciation into account when rating the strength of a particular type of glass.

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(1) Reprinted from DRUM AND CROAKER, May 1969

(2) Assistant to the Director, Marine Resources Center, Georgia University Systems.

The basic type with which we are concerned is polished plate glass. This is a soda-lime glass, drawn from a furnace in a continuous ribbon, passed through rollers which impart a textured appearance to both surfaces, then run through a series of grinders and polishers which make both surfaces smooth and parallel. Because of the size of the fabricating machinery, the maximum width is limited. The ultimate length of a panel is limited by the practical considerations involved in handling and shipping. Actual size limits are about 11' x 12' for thicknesses of one inch and greater. Maximum available thickness is 1 1/4". This is handy to know if architects propose monolithic panels 6' x 30 ' x 3". Such a panel would weigh about 7,000 lbs., by the way.

Polished plate glass is available in three strengths. Only two are available in thicknesses which aquariums might use. The strengths are dependent on the degree of tempering given to the plate, after it is initially formed. The least strong is "polished plate" or "annealed polished plate." More often than not the word annealed is not used. This kind of glass has several pseudonyms; plate glass, annealed plate glass, glazing quality plate glass, parallel-o-plate, but let's call it polished plate. Of the three types, this is the least expensive and the weakest. When polished plate fails, it fractures into non-uniform pieces. It may be cut on the job or your local dealer can cut it to your specifications from stock.

The second type is heat strengthened polished plate. This type of glass is only available in thicknesses of approximately 1/4" and so is not applicable to most aquarium glazing applications.

The third type is fully tempered polished plate which we know as "Herculite," or "Tuf-Flex." This type of glass has approximately 4 to 5 times the strength of polished plate. This increased strength results from a tempering process which puts the surface layers of the glass under compressive stress with balancing tension stresses in the center. On failure it fractures into small uniform pieces. This type of glass must be cut before the tempering process and so must be ordered from the factory in the size you intend to use. This is handy to know since a replacement panel cannot be obtained from a local distributor on short notice.

Comparing the physical properties of polished plate and fully tempered plate, we find only one major difference, the breaking strength or modulus of rupture if you prefer this less sanguine term. The breaking strength of polished plate is rated at 6,000 psi and for fully tempered 25,000 psi. The modulus of elasticity and rigidity, the specific gravity, specific heat, coefficient of linear expansion, index of refraction and hardness are approximately the same for both. Since most aquarists are concerned with the scratch resistance of glass, I might add that the two types are identical in their resistance to scratching. Corning is currently manufacturing a chemically strengthened glass which has a 20% greater scratch resistance than polished plate. This glass, however, is not yet available in thicknesses useful for aquarium glazing applications. The terms "soft" and "hard" glass used in the industry, indicate low and high softening temperatures, not mechanical hardness.

While engineering handbooks give 6,000 and 25,000 psi for the breaking strength of polished plate and fully tempered polished plate respectively, the figures to be used in computing the glass thickness for an underwater glazing application are 3,000 and 15,000 psi, when dealing with windows having a surface area of over 10 square feet. The reasoning is as follows: strengths are computed on the basis of thousands of tests performed on small pieces of glass. Actual experience with larger lights (panes) has shown that their breaking strength is somewhat less than that of small sample pieces. Therefore, if the opening to be glazed has an area of over ten square feet, the lesser value for the breaking strength should be used in computing the glass thickness to be used. In summary then, there are only two types of glass with which we have to be concerned, each composed of the same ingredients, but one 4 to 5 times the strength of the other although the remainder of their physical properties are the same.

The next order of business is laminates. Both polished plate and fully tempered polished plate can be fabricated as a sandwich of two or more sheets of glass with an adhesive vinyl plastic interlayer. The thickness of the interlayer varies with glass thickness, but is generally between .020 to .080". Thicker glass tends to warp somewhat during heat treating so that a thicker vinyl interlayer is required to allow for the slight uneveness of the glass. The purpose of laminates is not increased strength.

Actually, manufacturers rate the strength of laminates as less than single sheets (monolithic) of the same thickness. Experimental work has shown that under long-term loading, laminates behave as individual sheets. Under short-term stress (impact stress), laminates behave as a monolithic sheet. The real purpose of laminates is "breakage safety."

Although breakage safety sounds antithetical, it is not. For example, the total failure of a monolithic panel could run all the way from a janitorial inconvenience to a disaster depending on the volume and depth of water behind the glass. Since personal injury is a bug-a-boo that keeps aquarists and administrators alike awake at night, the breakage safety offered by laminates is more effective in removing these symptoms than Nytol. When a monolithic panel fails, it fails completely, that is to say a crack will extend from the viewing surface through to the wetted surface. If it's not quite your day, the panel may fracture completely, leaving nothing between the water and viewing area but gurgling sounds. Laminated glass prevents this from happening . When a laminate fails, the failure is almost invariably confined to one of the several sheets, leaving the remaining intact. Further, the vinyl interlayer bonds the broken glass together and prevents the pieces from flying about. Since glass is perfectly elastic up to the point of rupture, it is not possible to tell from observation when a piece of glass is about to fail. Laminates, however, provide a built-in warning of complete failure. If you have installed a two-ply glass with a safety factor of 10, and the glass fails, you will be left with one ply intact, a safety factor of 5 and a strong suggestion that the window in question needs replacing. Furthermore, you have a finite time to replace the glass, board up the window, disperse the crowds, call your lawyer, or skip town, whichever seems appropriate. This is breakage safety!

Since the intent here is to deal in cold hard practicalities, it must be admitted from the start that the kind of glass that is finally used in your installation may not be what you think is correct or desirable. The final decision in all probability will be in the hands of an engineer or a profit-motivated administrator. This being the case, you should be in a position to make an independent judgment, make the decision yourself, or supply the manufacturer with the data he requires to make the decision. In order to do this you should know the following:

1. The volume of the tank above the lower sill of the window.

2. Where the water would go if the window broke.

3. All other consequences if the window broke.

4. The design load in pounds per square foot. (This can be computed by multiplying the distance from the horizontal centerline of the window to the water surface in feet, times the weight of water in pounds per cubic foot; 64 pounds for sea water and 62.5 for fresh water).

5 The ratio of width to height of the window

6. The safety factor. (Between 8 and 10 is recommended.

If this information is given to the manufacturer he can then recommend the type and thickness of glass that should be used. If you want to do the calculations yourself so that you have some figures to compare with the manufacturers, use the formula below.

$$t = \sqrt{\frac{0.75\ W\ B^2\ F}{S\ (1 + 1.61 \alpha 3)\ N}} \quad \text{where:}$$

t= thickness (of each ply) in inches

W= design load in lbs/sq.ft.

B= short dimension of glass in feet

F= safety factor (8 to 10 recommended)

S= average breaking stress of glass (substitute 3,000 for polished plate and 15,000 for fully tempered polished plate for panels over 10 sq. ft.)

N= number of plys in an equal ply laminate.

α = b/a

a= long dimension of the glass

b= short dimension of the glass

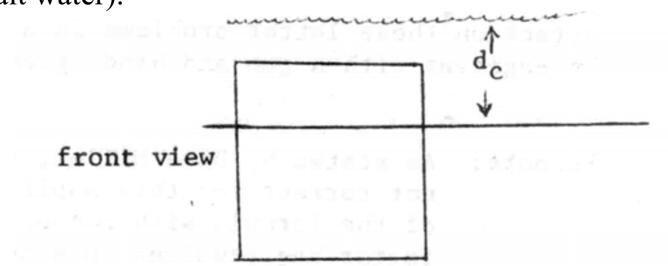
The above formula is not correct for this application, but has been used with an adequate safety factor. (Also see caution at end of article. PJM '02)

The design load may be computed as follows:

When the top of the water is above the top of the window, the design load (lbs./sq.ft.) = d c D where:

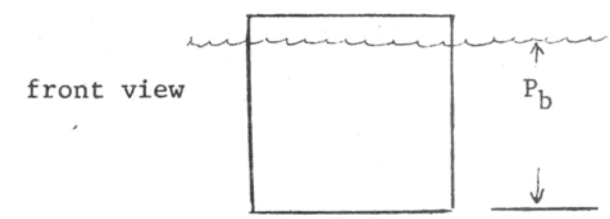
dc= distance from horizontal centerline of window to top of water

D = 62.5 lbs./sq.ft. (fresh water), or 64 lbs./sq.ft. (salt water).



When the top of the water is below the top of the window, the design load (lbs./sq.ft.) = l/2PbD where:

Pb= the distance from the top of the water to the base of the window

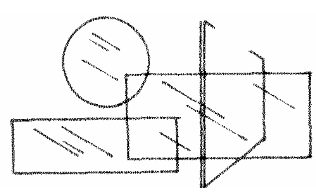


Although manufacturers do not recommend monolithic glass for any underwater glazing application, I would personally recommend the following general practices. For glazing jobs where the water volumes are small, pressures are low, and where public safety is not a primary concern, I would tend to use single sheets of polished plate glass, using a safety factor of ten in computing the thickness required. When the panels are large, pressures are high, volumes are great, and public safety is critical, I would use fully tempered polished plate in a three-ply laminate, using a safety factor of 8 in computing the thickness required. It should be remembered too, that the formula for computing thickness is a very conservative one so that the glass thickness chosen should be the next commercially available standard thickness smaller than the answer given in the formula.

The preceding covers the simple essentials of choosing the type and thickness of glass for most underwater glazing problems an aquarist might routinely encounter. Remember, however, the choice of a proper type and thickness of glass does not guarantee a successful glazing job. The problems of gasketing, caulking, mastics, frame design, frame materials, fastenings, and so forth remain, and must properly be engineered and executed to insure a totally successful and workable job. When sufficiently motivated I shall launch an attack on these latter problems in a paper entitled "Through an engineer with a gun and hand grenade."

Ed.note: As stated by Dave Miller, the formula given is not correct for this application. In fact, use of the formula with a supposed adequate safety factor has resulted in a number of aquarium glass failures. Walter West, NFCA engineer, two years ago detected the fallacies in the use of the formula and these were verified by a Corning Glass engineer. Subsequently, Walter developed a new formula which must be first checked in its mathematical computations by the Bureau of Standards before publication.

The formula in Dave's article will technically result in "the thickness of a beam supported at each end under a uniform load." Or in plain terms, similar to a piece of plywood supported by saw horses at each end and loaded uniformly with marbles. The formula does not cover the increasing load on vertical glass panels as the water depth increases, the fact that aquarium panels are supported on all four edges, greater height than width or vice versa, etc. Hopefully, a new and precise formula will be available in the near future.



AQUARIUM GLASS:
A STRUCTURAL COMPONENT
(A PROGRESS REPORT)*

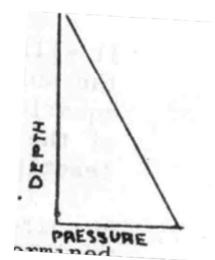
By

Walter L. West
National Fisheries Center and Aquarium

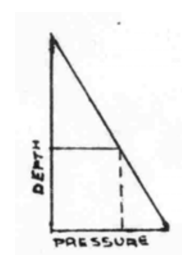
Our observations indicate that if a panel of glass breaks in a large oceanarium-type tank, it is more likely to be one of the uppermost panes rather than one of those farther down. Assuming that, except for hydrostatic pressure, all panels at whatever depth they occur, are of equal quality, are mounted in similar fashion, are adequately, or at least equally, bedded, and are subjected to an equal amount of visitor and animal abuse, why should those at shallower depth break with greatest frequency?

We believe that the fault lies in an engineering convention which in spite of added safety factors, results in glass which, near the surface, is too thin to perform reliably.

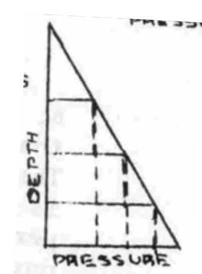
Here is our reasoning



1. The pressures to which any portion of a deep tank are subjected can be portrayed graphically. The vertical axis is depth and the horizonal axis is pressure. Note the straight line relationship.



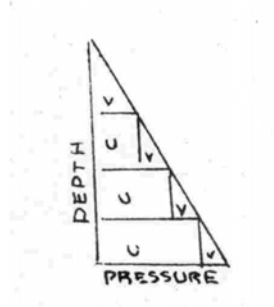
2. Pressure at any intermediate depth can be determined by drawing a line at right angles to the Y axis where it intersects the slope. The formula for a straight line with this slope is x=ay, where a y is the depth and x is the pressure.
it



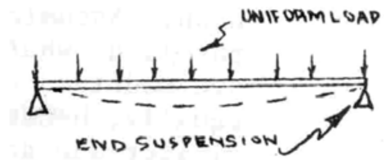
3. We draw on the same graph the top and bottom edges of each of our panels of glass and, forgetting about mullions for the moment, visualize the range of pressures to which each panel is subjected.

*Presented at the 15th Annual Professional Aquarium Symposium of the American Society of Ichthyologists and Herpetologists, June 12, 1969, New York City.

4. The figure we have constructed is called a force triangle and deserves a closer look. It can be seen that the pressures to which each of our panels is subjected can be considered as composed of a rectangle, representing the pressure to which the upper edge only is subjected, and a triangle which represents the increase in pressure from the top edge to the bottom edge.

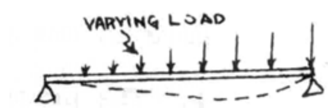


5. How then do we determine the pressures to which each panel is to be designed? Standard procedure, as used by glass engineers, requires that the mean pressure on the pane, or that measured halfway down the pane, be used in the calculation. The formula which is used in the calculation was derived from the following assumptions:



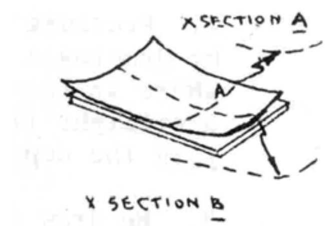
These are obviously false as concerns aquarium glass, but are satisfactory, however, when used in the calculations for window panes in a building.

6. To correct one of the assumptions requires the following:



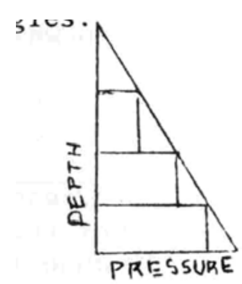
It will be found, on measuring, that the point of greatest flexure in aquarium glass occurs at about 2/3 of the-distance from the edge with least pressure, the top edge.

7. To correct the other assumption, suspension at each end, an additional computation is required:



The pane is not suspended merely from the ends, but all the way around.

8. Now, why do these two factors affect the top glass more than the bottom? Let us look again at our force triangles:
The force action on the lowermost pane is largely uniform and only a small percentage of the total force is composed of the triangle representing the change in pressure from the top of the pane to the bottom.

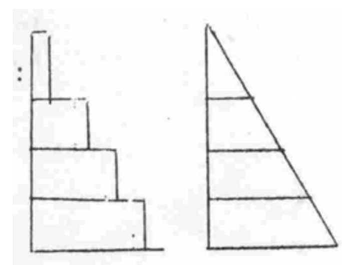


As we go up, however, we see that this triangle becomes a greater and greater portion of the total force until, at the surface pane, it is the total. If the thickness of this pane is determined by means of a formula requiring use of the mean pressure on the glass, it will be seriously under-designed and will be more liable to fracture than will lower panes.

The solution? Use in your calculations, pressures at the 2/3 point or, better yet, at the lower edge.

Use a formula which takes into account the variation in pressure from the top edge of the frame to the bottom edge as well as the fact that the glass is supported in a frame running around its periphery rather than on two ends.

A formula which takes these factors into account was developed by S. Timoshenko in the early 1900's while he was still in Russia. It has apparently never been used by design engineers for use in aquariums. The glass engineers' formulae in current use for pressure determination disregards the force triangle resulting in a situation like this:



The force triangle cannot be disregarded.

The safety factor which we ordinarily inject into a calculation may provide, in part, for uneven bedding in frames which are slightly warped, variations in strength owing to impurities, glass warping due to tempering and other factors involving uncontrollable departures from the ideal situation. It is doubtful whether, in addition to these, the safety factor would also take care of underdesign resulting from use of a formula based on fallacious assumptions. One can easily visualize what would happen to a panel of glass which happened to be warped in one direction when it is seated in a frame warped in the opposite direction and then subjected to bending produced by differential pressures which had not been taken into account in the calculation. If, in addition, the glass is clamped around the periphery preventing the corners from lifting partially from the frame, the result, rather than a simple corner crack, could be a disaster.

MECHANICAL TESTING AND BIOASSAY OF ADHESIVE/SEALANTS FOR USE IN AN AQUATIC ENVIRONMENT (1)

by
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National Fisheries Center and Aquarium

and
Philip A. Butler
Director, Biological Laboratory
Bureau of Commercial Fisheries

In 1965, specific tests were begun to determine the material best suited and commercially available as an adhesive/sealant for large and small scale aquarium use. In most cases, the materials were not initially intended for aquarium or underwater uses.

The testings were designed for two purposes:

1. Determine the toxicity of the materials to aquatic organisms.

2. Determine the suitability of the materials to seal hair-like cracks on the water side of concrete tanks, ease the removal of algae, and determine if these materials could be used to seal the periphery of viewing glass.

The testing under (1) above was done under contract at the Steinhart Aquarium, San Francisco and at the Gulf Breeze, Florida, laboratory of the U. S. Bureau of Commercial Fisheries. The testing under (2) above was by the NFCA staff and the National Fish Hatchery, Pisgah Forest, North Carolina.

(1) Reprinted from DRUM AND CROAKER, January 1968.

Of the many products tested, it was concluded that the following are satisfactory, are not toxic after curing, and will provide a lasting moisture seal:

Dow-Corning No. 92-018 (a one-component adhesive/ sealant)

Dow-Corning No. 93-046 (a two-component adhesive/ sealant)

Hercules Powder Company "Penton," a polymer, when used as a lining for pumps, valves and rigid pipe

Devcon Corp. "Devcon Epoxy, when used as a concrete moisture seal

Devcon Epoxy has been used for approximately three years at the Rhode Island Northeast Shellfish Sanitation Center with no deleterious effects on specimens. All of the above are toxic to aquatic organisms until they are fully cured.

Initial compression testing eliminated many of the caulking compounds. In shear tests some of the rubber cement sealants failed cohesively and a few of the silicone sealants were eliminated because of extensive polyp-like extrusions on the surface following abrasive tests. The compounds listed above passed these tests and others, including ultra-violet aging and submersion. As a side dividend, General Electric's "Traffic Topping" proved to be an excellent seal and non-skid surfacing material for floors that are usually wet.

After more than one year (1) of testing Devcon Epoxy on the sidewalls of a new concrete trout raceway at Pisgah Forest, the epoxy is still firmly attached, not chipped or peeling, and it is reported that the removal of algae is comparatively easy.

The technology of adhesive sealants is progressing and many new products are becoming available.

(1) Subsequent report indicates same results after three years.

DESIGN FOR EXOTIC SPECIMENS

Warren J. Wisby
National Fisheries Center and Aquarium

Designers of new aquariums and the operators of existing aquariums in the United States should be aware of the need for special operating features which may be required by law in the future.

Recent experience with exploding animal populations, as in the case of *Acanthaster* (Crown of Thorns starfish); and with exotic disease problems, as in the case of whirling disease of trout, prompt us to insert this short chapter on the possible dangers an aquarium can present to our environment.

The potential for survival of Pacific specimens, for example, in the Atlantic Ocean is very real, and therefore the possibility of deleterious and perhaps disastrous effects from such introductions must be considered. The real dangers are not always the most obvious ones. We are sure that most people would exercise extreme caution with toxic or venomous animals, such as *Pterois sp*. (Lionfish), or an animal which has demonstrated itself to be as harmful in an environment as the starfish *Acanthaster*.

Not so apparent, however, is the ever-present possibility that an organism which is quite innocuous in its own environment might change food habits and behavior patterns and become harmful upon introduction into a foreign environment. Or, in the absence of its normal predators, it could undergo a population explosion which would render even an innocuous animal harmful.

Still another possibility is that the exotic specimen may harbor parasites, bacteria, or viruses to which it has developed an immunity, but to which local organisms are susceptible. There are good examples of situations where such things have occurred. The problem, therefore, becomes more complex than simply guarding against the escape of live specimens.

For example, disposal of dead specimens which could be carrying bacteria into local waters should be prevented, as should the release of the water in which the exotic specimens are kept. Also, invertebrates are potentially far more dangerous than fishes or other vertebrates, and their escape is much more difficult to guard against - partly as a result of their diverse and often complicated modes of reproduction.

Release of exotic animals into an environment is as real a form of environmental pollution as any factory effluent and, unlike most other forms of pollution, once done the mistake cannot be corrected merely by stopping the practice.

We would therefore recommend that the following precautions be taken.

(1) Aquaria in which specimens exotic to the area are kept should be on their individual recirculation systems, with no pipe connection to any natural body of water or to other aquaria. In this sense, an overflow drain which is stoppered or which is simply not used constitutes a connection, and should not be permitted.

(2) Precautions should be taken to eliminate the possibility of exotic specimens jumping or crawling into neighboring tanks or splashing water into neighboring tanks. If this appears to be impossible to guarantee, the aquaria on either side of those occupied by exotic tropical marine specimens, for example, should be either fresh-water or cold sea-water aquaria, and thus lethal to tropical organisms, and they should also be on their own closed, recirculating system.

(3) Exotic specimens to be disposed of should be incinerated.

(4) Waste water from the exotic tanks should be heavily chlorinated and then introduced into the fresh-water domestic sewerage system, rather than into any natural body of water.

(5) All exotic specimens should be medicated and quarantined before being placed on exhibit.

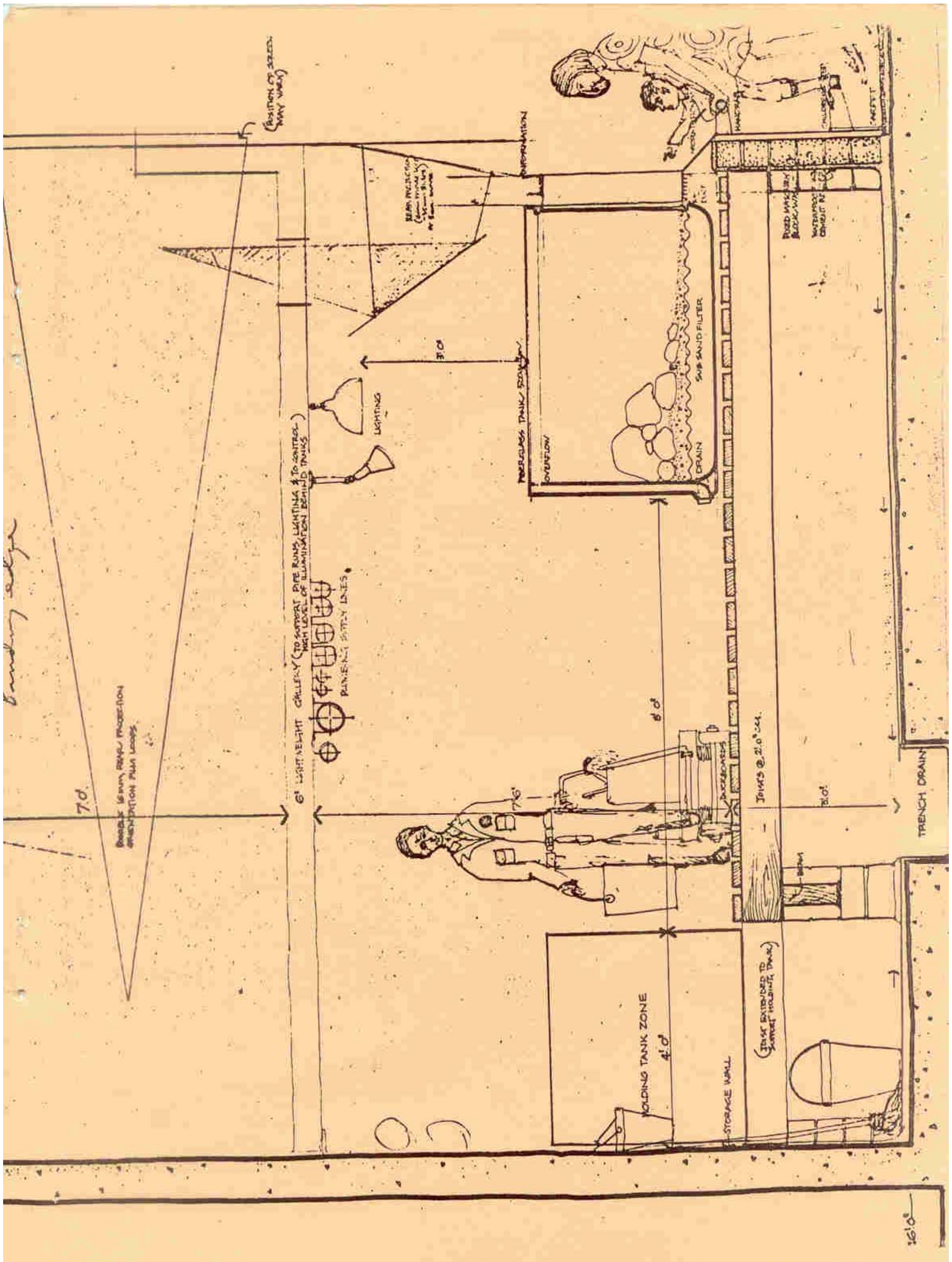
(6) Ultraviolet sterilization equipment would be very desirable on all exotic tanks, and nets and other equipment used in those tanks should be used only in those tanks.

It is quite possible, of course, that most of the operators of vulnerable aquariums are aware of the potential problems and have already taken precautions. In fact, some of the suggestions made herein are simply good aquarium practice, and mention of them is not meant to imply that they would otherwise go undone. However, the fact that they are not in general practice is not a valid argument against their use.

An exhibit of Pacific specimens could be an important aid to the education of aquarium visitors in the East, and would certainly help to impress them with the diversity of sea life. Yet, we are in danger of losing the privilege.

We already have legislation against the importation and sale of certain "harmful" animals and, in view of the disease problem encountered in cultured salmonoid fishes, legislation has been enacted against their import from certain countries. We stand to lose much if we, through negligence, are accused of having released a harmful organism into our environment - and we are vulnerable, very vulnerable, as long as we cannot demonstrate that we are taking all possible precautions against it.

Designers should consider the above when planning the operating features of an aquarium.


HOLDING TANK ZONE
STORAGE WALL
TRENCH DRAIN
LIGHTING
OVERFLOW
DRAIN