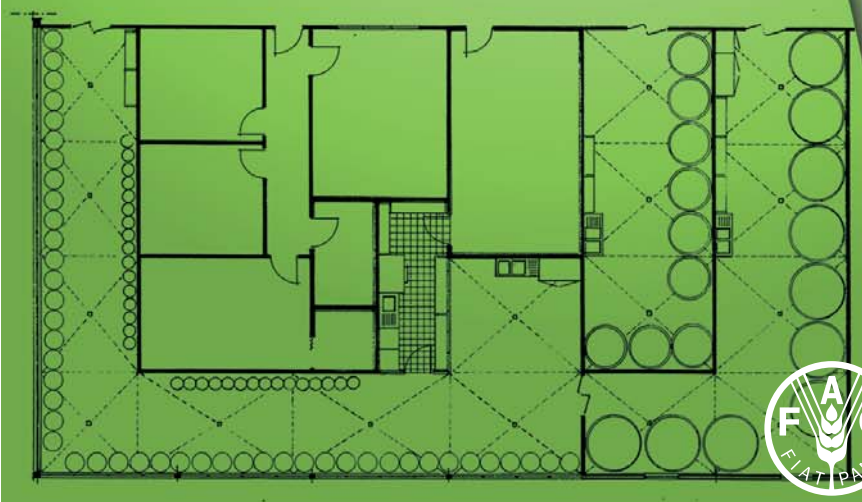
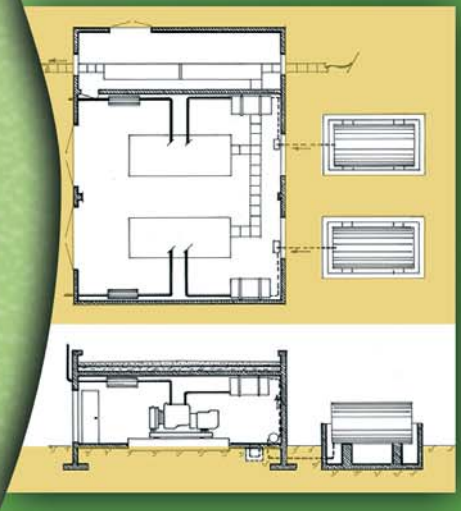
Manual on Hatchery Production of Seabass and Gilthead Seabream

Volume 2





Food and Agriculture Organization of the United Nations

Manual on Hatchery Production of Seabass and Gilthead Seabream

Volume 2

by

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Food and Agriculture Organization of the United Nations
Rome, 2005

ISBN 92-5-1053004-9

PREPARATION OF THIS DOCUMENT

This is the second and final volume of a manual on hatchery production of seabass and gilthead seabream. It is part of the programme of publication of the Inland Water Resources and Aquaculture Service (FIRI). The manual has been written based on the direct experience of technicians and managers of commercial hatcheries operating in the Mediterranean. It is intended to assist both technicians entering this field as well as investors interested in evaluating the complexity of hatchery production of seabass and gilthead seabream.

The manual has been prepared by the authors under the overall support and supervision of FIRI and direct technical coordination of Mario Pedini, Aquaculture and Fisheries Development Officer of the FAO/World Bank Cooperative Programme. Numerous colleagues have collaborated, contributing comments to sections of the manual, and ideas and assistance for its finalization. The contribution to this volume of Brigide Loix, STM Aquatrade Srl, Lamar Srl Udine, Licinio Corbari, Maribrin Srl, Massimo Caggiano, Panittica Pugliese Spa, are greatly appreciated. The assistance in the editorial work and final presentation and graphics given by José Luis Castilla, Alessandro Lovatelli, André Coche, Patrizia Ravegnani and Emanuela d'Antoni has also been invaluable.

Moretti, A.; Pedini Fernandez-Criado, M.; Vetillart, R.
Manual on hatchery production of seabass and gilthead seabream. Volume 2.
Rome, FAO. 2005. 152 p.

ABSTRACT

Seabass and gilthead seabream are the two marine fish species which have characterized the development of marine aquaculture in the Mediterranean basin over the last three decades. The substantial increase in production levels of these two species, initially of very high value, has been possible thanks to the progressive improvement of the technologies involved in the production of fry in hatcheries. As a result of this technological progress, more than one hundred hatcheries have been built in the Mediterranean basin, working on these and other similar species. At present the farmed production of these two species derived from hatchery produced fry is far greater than the supply coming from capture fisheries.

The development of these techniques, based originally on Japanese hatchery techniques, has followed its own evolution and has resulted in what could be called a Mediterranean hatchery technology that is still evolving to provide higher quality animals and to reduce the costs of production. This is a dynamic sector but it has reached a level of maturity which merits the production of a manual for hatchery personnel that could be of interest in other parts of the world. The preparation of the manual has taken several years, and due to recent developments has led to substantial revisions of sections. The manual is not intended to be a final word in hatchery design and operation but rather a publication to document how the industry works. The authors have preferred to include proven procedures and designs rather than to orient this publication to research hatcheries that are not yet the standard of the sector.

The manual has been divided in two volumes. The first one was finalized in 2000, and covered historical background, biology and life history of the two species, especially hatchery production procedures. This second volume is divided in four parts. In the first, it tries to cover the aspects related to hatchery design and construction, from site selection to hatchery layout, and description of the various sections of a commercial hatchery. The second part covers engineering aspects related to the calculation and design of seawater intakes, pumping stations, hydraulic circuits, and pumping systems. The third part deals with equipment in the hatcheries such as tanks, filters, water sterilizers, water aeration and oxygenation, temperature control, and auxiliary equipment. The last part covers financial aspects. This section, rather than explaining the way to calculate cash flows, tries to highlight aspects that managers and investors should consider when entering this business. Volume two also includes a series of technical annexes, and a glossary of scientific and technical terms used in the two volumes.

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PART 1

HATCHERY DESIGN AND CONSTRUCTION

A marine fish breeding centre is a complex facility. Because of its zootechnical characteristics, during the production season proper hatchery management requires uncommon skills and total dedication by well-trained personnel. Therefore, in designing a fish hatchery only those technical solutions that offer the best guarantees in terms of reliability, ease of use, production capacity, hygienic working conditions and cost effectiveness have to be used.

Gross mistakes in design and/or construction can risk a full production season even before it is started. In addition, temporary solutions always carry the risk of far from optimal rearing conditions, leading to disease outbreaks in fish larvae.

This second part of the manual deals with the principles and guidelines for the design and construction of a commercial hatchery for gilthead seabream and seabass.

This chapter describes how to calculate the size of the hatchery and how to select the appropriate site. It also deals with the design of production facilities. The function and the selection of hatchery systems and technical equipment are also described, focusing on the most widely adopted technical solutions in Mediterranean hatcheries. Special attention is given to the description of the seawater intake, and to water distribution, recirculation and treatment systems, as they are among the most sensitive components of the hatchery.

Fig. 1 - A hatchery under construction

1.1 CALCULATING THE SIZE OF A HATCHERY

In order to design a marine fish hatchery, the investor has to have a clear idea about its production target. A decision on the size of the hatchery is a fundamental pre-requisite before starting the search for suitable sites, or before starting the technical design or the financial plan.

In particular, the following issues should be addressed:

- main fish species (seabass, gilthead seabream or both),
- secondary species (other fish, clams, shrimps),
- yearly targets as number and size of fry of each species considered,

- origin of eggs (internal production or from other sources),
- whether photoperiod and thermoperiod manipulation to shift reproductive cycles is planned,
- marketing aspects (fish size and season for sales).

Any aspect not properly considered during the planning phase may result in difficult working conditions later on, requiring costly interventions to correct them (if at all possible) and causing production interruptions.

1.2 SITE SELECTION CRITERIA

The Mediterranean region is not uniform. Environmental conditions along its coastline vary considerably. Habits, customs and technical development of the countries bordering it also show large differences. The analysis of these local factors is the initial step in the process of proper design of a hatchery. In fact, the above mentioned aspects play a crucial role in relation to the technical feasibility, but also in keeping the running costs within manageable limits.

It may seem absurd, but the vast majority of Mediterranean hatchery sites were not decided on the basis of a thorough selection process, but were often already set at the beginning of the project. This absence or scarcity of options is common both in private and public projects. In the first case, the investor usually owns the site, whereas in the public hatcheries, local and political reasons may influence the selection of a particular location regardless of technical considerations.

In any case, when looking for a new site or when collecting information on a preselected location, the reconnaissance process should consider several well-defined aspects which fall under two broad categories: the natural environment and the socio-economic environment.

1.3 ENVIRONMENTAL FACTORS

A list of the main environmental parameters to be considered is given below. As a rule, historical series of data collected by national services (meteorology, oceanography, soil, etc.) provide more reliable information than local interviews or spot measurements, which, however, are a useful tool to make a first evaluation of the site.

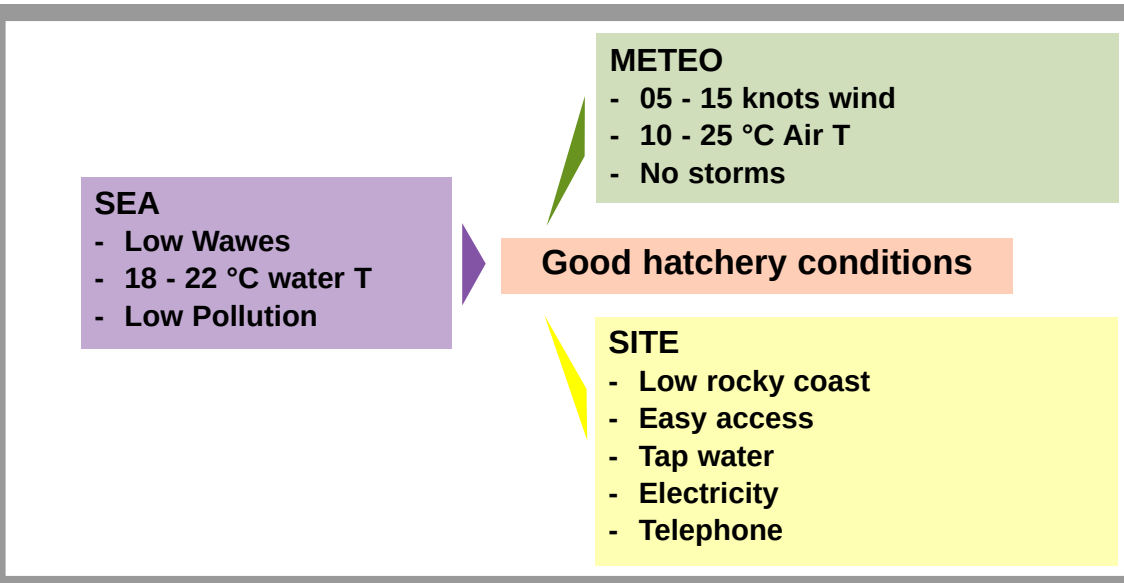


Fig. 2 - Diagram of environmental factors (and services) synergies

Sea conditions

- *Seawater temperature* is one of the most important parameters because it influences critical design components such as a seawater intake system (open or semi-closed circuit) and the heating system. It may also have an influence on operating costs and as a consequence, on the overall economic feasibility of the project. In the Northern Mediterranean, due to the fact that both seabass and gilthead seabream breed during the winter and early spring period, the rather low winter seawater temperatures mean that water heating is necessary to reduce larval rearing time.
- *Waves* (amplitude, length, direction, seasonal and storm conditions) coastal currents (magnitude, direction and seasonal variations) and tides (ranges, seasonal and storm variations, oscillations) are key factors to be considered when designing the sea water intake. They also have importance on seawater quality when pollution sources exist, even if they are located far away. Whenever possible, it is important to collect historical data series on these parameters from public authorities or other relevant sources. Local sources should be considered only when no other information is available, or to confirm collected data.
- *Seawater quality*, despite a common misconception, is usually suitable for hatchery operations in most of the Mediterranean. Sites to be avoided are those affected by severe industrial and domestic pollution. Such areas are found close to large industrial installations, towns, harbours or in river deltas or estuaries. Well-water, though interesting as it tends to have a more uniform temperature throughout the year and far lower investment costs for extraction, is not free from potential danger. It should provide a constant and reliable flow and be free from pollutants such as ammonia, sulphur compounds, heavy metals and pesticides. To a certain extent, specific treatment can improve its quality, but where dangerous heavy metals are present, their elimination is very difficult.

Meteorological factors

- *Winds. Prevailing direction and speed*. The occurrence of strong winds or seasonal storms has a great influence on hatchery design. Apart from building characteristics planned for windy areas, the main problem is the protection of the sea water intake, in particular, if it is located in an open area. Its design and size are directly linked to the occurrence of big waves and strong currents caused by storms. The seawater quality is also severely affected by strong water movements that re-suspend sediments. According to the type of sea floor, the amount of suspended solids may increase dramatically under bad weather conditions. A site located in a bay sheltered from the dominant winds has important advantages, such as the absence of strong waves and currents. Under these circumstances, the construction of the water intake is considerably simplified, as is the treatment of seawater (sedimentation and mechanical filtration). On the other hand, protected bays may suffer from low water exchange, which means waste water must be discharged far enough from the water intake to avoid any self-contamination. The cooling effect of wind in relatively shallow sites is something that should not be underestimated.
- *Maximum storm intensity and frequency*. The seawater intake is the most fragile part of the hatchery and the first to be affected by an exceptional storm. Due to its usually considerable cost, the design of intake facilities should take into account sea conditions under the strongest storm recorded in a period of 50 years at the location that is being evaluated.
- *Air temperature*. In many Mediterranean sites, air temperature is an important factor. Low air temperatures in winter do affect operating costs of the hatchery, and efficient thermal insulation will be required to keep internal air temperature around 18 to 20°C. The use of heated air blowers for the hatchery also provides the necessary ventilation. Air extractors should be combined with such blowers to reduce humidity levels inside the hatchery.
- *Solar energy*. Together with air temperature, it contributes to the thermal balance of the hatchery system. If considered at design stage, it may allow relevant savings in terms of investment and running costs. In the case of hatcheries totally or partially built in a greenhouse, shades and ventilation should be provided in late spring, summer and early autumn, according to the location, to prevent overheating.

Site related factors

- *Coast morphology*. It affects hatchery design and construction mainly in three ways: in providing a sufficiently flat area for the buildings, in relation to the design of the seawater intake system and for seawater quality. Low sandy coasts provide plenty of space, but the water intake typically requires

expensive protection (breakwaters, long inlet channels, sedimentation tanks) to prevent clogging and to minimise sand and detritus uptake. A rocky coast usually has better water quality (absence of suspended solids, quicker return to normality after a storm) and simpler and cheaper water intake designs are possible, but its hard soil complicates the construction of structures requiring excavation. The height of the coast above sea level should also be considered, since higher sites will mean, for a given flow, larger pumping stations and higher operational costs. In both cases, locations exposed to high waves and strong currents should be avoided due to the expensive works needed to protect the water intake.

- *Site accessibility*. Places isolated from the road network will require approach roads, which represent an additional cost that has to be carefully evaluated.
- *Availability of facilities such as electricity, telephone and potable water networks*. A connection to the high voltage electricity network is a prerequisite, whereas a link to potable water networks could be replaced by alternative solutions. Nowadays, a permanent telephone connection can be replaced by the use of cellular phones, although operating costs would be higher.
- *Sources of pollution from human activities* (large settlements, industrial activities, intensive agriculture, other fish farms in particular). The selection of the hatchery location should take into account the presence of important urban settlements, industrial harbours and large factories, which are sources of pollutants and could compromise water quality conditions. When intensive agriculture or industries are present in the coastal watershed they will produce pollutants that will be discharged by rivers in the coastal areas.
- *River discharges*. Even in the absence of pollution from human activities, river discharges carry sediments from surface run-off, that may contribute to excessive silting. This can rapidly clog the seawater intake, or worsen the quality of seawater at the pump intake.
- *Availability of freshwater (not potable)*. Freshwater is needed in a hatchery, especially if salinity has to be lowered or rearing water has to be cooled.
- *History of site: prior uses and experiences*. Previous uses of the sites may have an impact. Abandoned industrial areas or former warehouses and dumping sites should be carefully checked for contaminants in both soil and on the beach before deciding on a site.

1.4 INTEGRATION OF SOCIAL, ECONOMIC, LEGAL AND TECHNICAL ASPECTS

Site selection is also greatly influenced by social, economic and legal aspects.

At present, a hi-tech approach in the design of a marine fish hatchery can assure a viable economic operation, keeping production costs to a minimum and optimising control procedures for the whole production process. However, a hi-tech approach is not always possible in specific locations, both in terms of the necessary technical support, availability of assistance, services, equipment and consumables, and also in terms of socio-economic characteristics such as available manpower, political acceptance, and local traditions and habits.

Technical service and repair. Even simple equipment such as pumps, air blowers, lights, filters and sterilizers, needs servicing. The local availability of qualified personnel able to provide specialised maintenance and to intervene quickly in case of breakdown of equipment should be evaluated. Proper maintenance also requires the availability of essential spare parts: shops or agents representing the producers of the main equipment should also be easily accessible and their reliability should be carefully checked. If available, and of similar characteristics, locally-produced equipment is best because it is cheaper and easier to service.

Building materials. The materials used to build the hatchery depend strictly on the local level of industrial development and local construction standards. The choice between pre-fabricated or brick buildings should be made only after comparing local construction costs and maintenance costs.

Manpower. Marine fish hatcheries require skilled labour. The local availability of qualified manpower should be evaluated. This is also linked to the relative importance that aquaculture has in the country. That may be reflected in high school or post-graduate specialisation, fish industrial production, or

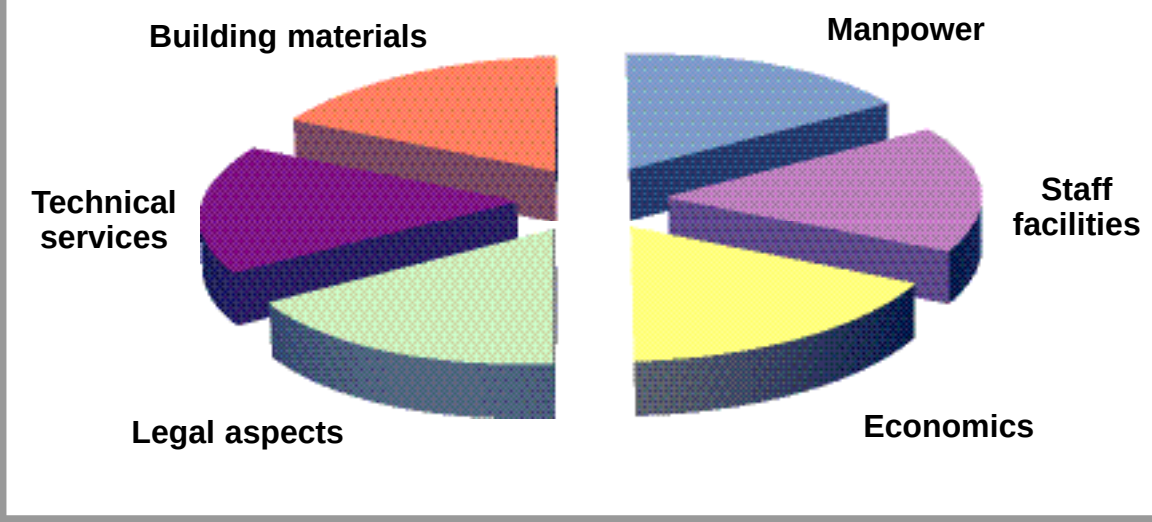


Fig. 3 - Integration of aspects to consider for site selection.

aquaculture research programmes. Previous experience with fish rearing should be essential requirements for the staff. If such experience does not exist in the country, the time and cost necessary to train farm personnel will have to be taken into account.

Staff and management facilities. When the hatchery is to be sited far away from inhabited areas, adequate accommodation should be provided for the staff. For sites that are far from important cities, provision of external technical assistance, as well as the supply of consumables (fish feed, chemical products and equipment spare parts) will become more difficult. A well-equipped workshop and adequate storerooms should then be included in the hatchery design.

Legal aspects and permits. All kinds of constraints for the use of the area, either existing or foreseeable, have to be investigated. Military, archaeological and historical areas usually mean hatcheries cannot be built but other land uses, such as wildlife protection and natural parks, may coexist with the fish hatchery. In addition, the hatchery should comply with all local legislation and regulations concerning constructions, such as maximum height/length, total volume allowed, limitations on the use of some materials and so forth.

The existence of local development plans should be verified. The planned use of the coastal area where the hatchery is to be built has to be compatible with fish farming. The existence of limitations to a possible future expansion of the hatchery, such as property boundaries under different ownership, should also be checked.

Economics. The greatest attention should be given to the financial analysis of the project to verify if it is economically sound. Economic factors also influence the general aspects of the hatchery design. A high cost of land will be an incentive to design more compact structures in order to save space. A high labour cost will lead to maximum automation of working processes to reduce manpower. A high market value of the produce will privilege high investments and the development of more technologically advanced production plants. In several Mediterranean countries, grants or loans with lower interest rates than standard loans are available for new enterprises, making more cost-effective production models possible.

1.5 EXISTING FACILITIES

The possibility of making use of existing facilities to set up a hatchery, is often an advantage. Sometimes, especially when existing industrial buildings have to be reconverted, the permission for land use is already awarded and most of the needed services (e.g. energy, freshwater, telephone lines)

are already available. This is usually attractive for the investor and it is often the main reason to decide to build a hatchery on an existing facility. But a more accurate evaluation of the advantages offered by the pre-existing facilities should always be carried out, with particular emphasis on the possible presence of pollutants in the building, soil and facing sea area, as described above. The advantages offered by the use of pre-existing facilities should be carefully considered. Adaptation of the production process to the existing site should never compromise the basic technical criteria applied to hatchery design.

1.6 HATCHERY LAYOUT

The hatchery layout (Fig. 5) is presented following its production units. Criteria to be adopted rather strictly for architectural and engineering solutions are:

- overall economic feasibility of the project with cost effective solutions,
- rational exploitation of available space and energy,
- rational choice of materials and equipment,
- maximum technical reliability, achieved through a correct choice of equipment and the organization of its maintenance,
- reliability of production methods, obtained through adoption of standard working methodologies based on proven production techniques, efficient use of resources at disposal and ergonomics,
- easy servicing and maintenance,
- adopt flexible solutions to enable future technical upgrading,
- ensure optimal hygienic conditions.

The description of hatchery production systems is divided into two main components:

- the production units, where true production activities take place;
- the service units, which provide the necessary support to production units.

1.7 BROODSTOCK UNIT

The function of this unit is the proper maintenance of adequate stocks of parent fish to assure a timely supply of fertilized eggs of the best quality to the larval rearing sector.

Broodstock units have facilities placed both outdoors and indoors. Outdoors facilities are mainly used for long term stocking purposes, but also for quarantine treatments and to recover spent or newly captured breeders. Indoor facilities are mainly used for:

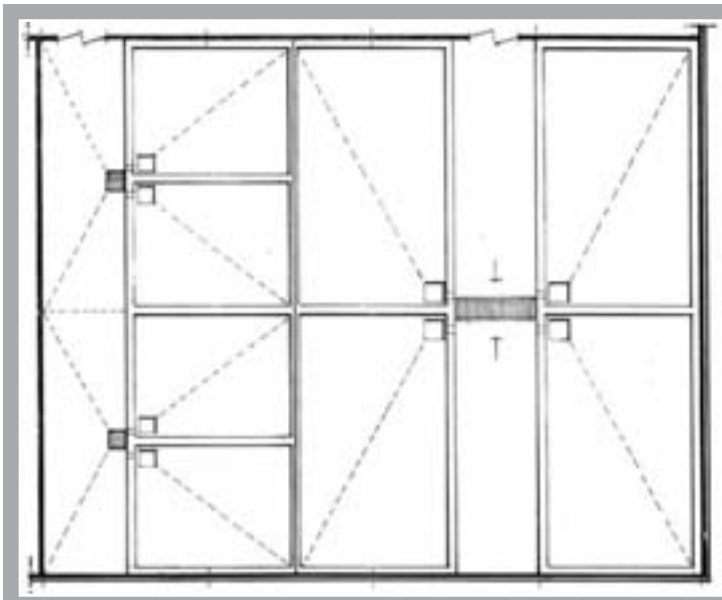


Fig. 4 - Plan of broodstock stocking and spawning section

- overwintering, where severe winter conditions could affect fish survival,
- shifting reproduction periods by manipulation of temperature and photoperiod,
- spawning.

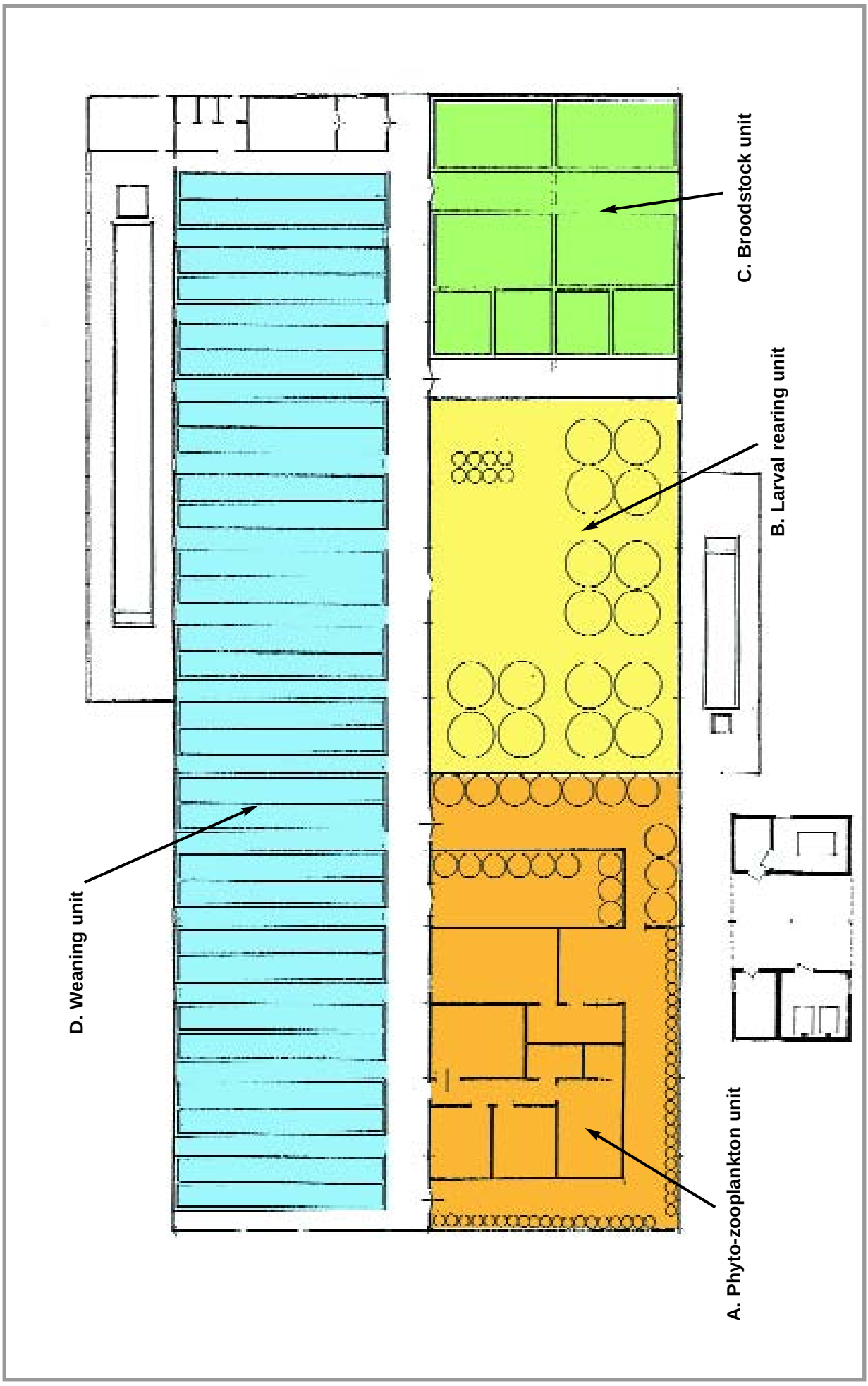


Fig. 5 - General hatchery layout

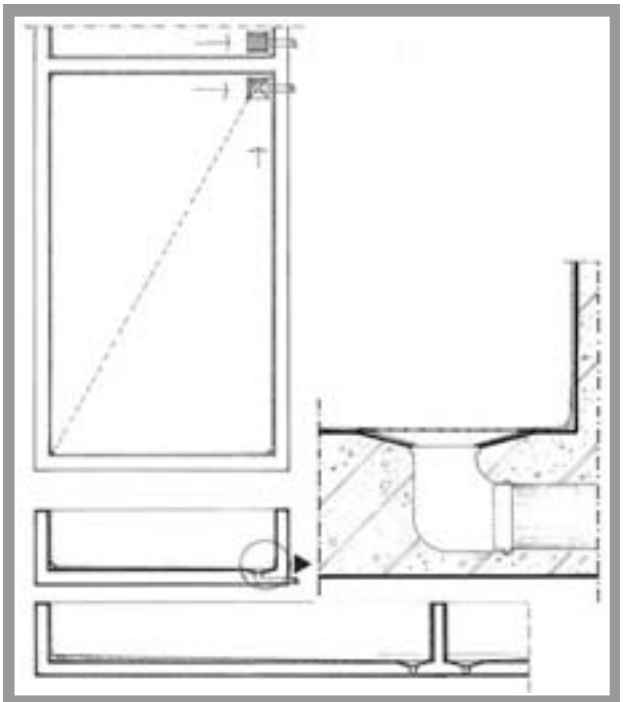


Fig. 6 - Concrete tank and PVC outlet

Different tank designs are used for different purposes. Before going into their description, it is necessary to know how to calculate the size of the facilities on the basis of the planned production.

Calculating the size of the stocking facilities

The broodstock unit requires enough space to keep breeders in healthy conditions so that they can spawn viable eggs and can be used for more than one breeding season.

The total water volume **V** required for long term rearing of broodstock can be calculated by taking into account the following points:

- the total female body weight **fbw**, which in turn depends on the quantity of eggs needed (this figure can be calculated using the already described average female fecundity, that is 120 000 two-days old larvae per kg b.w. in case of seabass and 350 000 for gilthead seabream;
- the total male body weight **mbw**, which depends on the sex ratio (number of males, normally two per female) and the average individual size of the males;
- the larval survival rates for the different species to be reproduced;
- the stocking density **D** (expressed in kg/m^3);
- the reproductive pattern (gonochoric or hermaphrodite);
- the number of spawns per year **S**, plus eventually a safety margin for the stock of 50%.

D should be 1 kg per m^3 in large earthen ponds, and up to 5 kg per m^3 in smaller plastic or concrete tanks.

The required water volume for species 1 ($\mathbf{V_1}$) expressed in m^3 is calculated as:

$$\mathbf{V_1 = [(fbw_1 + mbw_1): D_1] \times S_1}$$

The required total water volume **V** is calculated as the sum of $\mathbf{V_1} + \mathbf{V_2} + \mathbf{V_3}$..., which depends on the number of reared species and adding the 50% safety factor.

This formula refers to the final standing stock of breeders, where all the required biomass is represented at its peak. When the volume includes also the out-of-season reproduction, it must be considered that it refers to the additional tanks placed indoors for control of temperature and photoperiod.

▶ **Example**: calculation of the outdoor tank volume for a small multispecific hatchery with an annual requirement (one natural spawning season) of 4 million two-day old larvae of both seabass and gilthead seabream.

In seabass, considering the average female fecundity conservatively estimated above, we obtain:

4 000 000 : 120 000 = 33 kg of females,

which with an average individual weight of 1.25 kg corresponds to 27 females. With a sex ratio of 2:1 (males per female), the 54 males required with average weight of 0.8 kg per male add about 43 kg. Thus, the total biomass ($fbw_1 + mbw_1$) would be 76 kg (33+43) and it represents the minimal requirement of seabass spawners for one production season.

For gilthead seabream we have:

4 000 000 : 350 000 = 11 kg of females,

which with an average individual weight of 1 kg corresponds to 11 individuals. With the same sex ratio, the 22 males required, with average weight of 0.4 kg per male, add about 9 kg. Thus the total biomass (fbw1 + mbw1) would be 20 kg (11+9) and it represents the minimal requirement of gilthead seabream spawners for one production season.

To cover possible accidents, diseases and stock renewal, an extra 50% should be considered for safety reasons. Therefore, the total biomass of seabass would be around 114 kg, to which 30 kg of gilthead seabream breeders should be added.

With a long term stocking density of 1 kg per m^3 in earthen ponds, 114 m^3 would be required for seabass broodstock and 30 m^3, for gilthead seabream, hence a total volume requirement of 144 m^3.

Outdoor facilities

They are usually located close to the hatchery. The most common design being rectangular earthen ponds or round concrete tanks between 50 and 200 m^3, but which can go up to 500 m^3. This capacity is sufficient to hold a good number of fish, but at the same time allows an easy visual control of the captive broodstock and a proper water flow.

Fig. 7 - Oudoor tanks

The choice between earthen ponds and concrete tanks is often based on physical and chemical characteristics of the soil, as well as on local costs of construction, materials and labour.

When excavating earthen ponds, the following points should be considered:

- The water supply canal should fill the pond by gravity through a screened wooden or concrete-made inlet gate.
- The dyke slope (ratio of horizontal to vertical) of both ponds and canals depends on the type of soil used and the dyke elevation. With clay soils, dykes higher than 4 m should have a slope of 2:1, whereas for dykes lower than 4 m it should be 1:1. The internal side of the dyke that is moist all the time should have a gentler slope than the outer side, usually dry.
- Pond water depth should be 1.5 m on average, with a 2 to 5% bottom slope towards the drain to allow for an easy and complete drainage. The pond bottom should be properly levelled to prevent the formation of puddles when drained. Before starting the excavation, the possible presence of a high water table (fresh or sea water during high tide) should be checked, as a complete drainage of the pond may not be possible.
- The deeper area of the pond, on the side of the drain/outlet, should be lined with concrete or plastic liner to facilitate harvesting and cleaning operations.
- The external drainage canal should be deep enough to allow a complete drainage by gravity. A sufficient difference in level should exist between the bottom of the pond and that of the final water discharging point of the farm.

If concrete tanks are preferred, the same criteria concerning depth, water supply and drainage should be applied. The tank walls should be vertical to save space and material. The bottom slope should not exceed 1%. The construction of reinforced concrete structures in seawater requires a thicker cement layer around the steel bars to prevent corrosion.

When surface area is not a constraint, the separation between two adjacent tanks or ponds should be at least 4m to be used as road and to facilitate fishing and broodstock selection operations. If on a dyke, the road should have 0.6 m wide shoulders on both sides to prevent erosion. Canal crossings should be covered by steel grids, or by wooden or concrete slabs. Pipelines should be better placed in pre-fabricated concrete trenches, covered by a grid or concrete slabs required for periodic inspection.

A group of smaller tanks should be considered for quarantine of fish collected from the wild or bought for temporary stocking and for prophylactic or curative treatments. These tanks should be much smaller (4 to 6 m^3) to reduce the use of drugs and chemicals during bath treatments. Fibreglass is frequently the preferred material due to its cost and manageability. The drainage design should allow treatment of the effluent prior to its final disposal to avoid the risk of contamination of the surrounding environment with pathogens and dangerous products.

During the hottest months, at least 10% of the pond area should be covered to give the fish some shaded areas and a place to rest. If necessary, protection against fish-eating birds should also be given.

Indoor facilities

The tanks where fish are temporarily stocked to obtain fertilised eggs are usually placed in a dedicated sector. They should be located in the quietest corner of the building to reduce disturbance to broodstock. An adjacent area should be reserved to clean, disinfect and store the equipment of the spawning unit.

Fig. 8 - Indoor tanks

Windows for this indoor section are not strictly necessary as spawning requires controlled light conditions, but they can be installed to renew the air and reduce humidity inside the spawning unit. Air extractors could be used in place of windows.

The floor of this unit should be tiled or painted with epoxy coatings to facilitate cleaning, and to maintain hygienic conditions. In order to drain the tanks an adequate drainage system made of screened channels under the floor is required. It should have a slope of at least 2%.

Thermal insulation of walls and roof is advisable in locations with cold winters to save on heating costs. A framework of zinc-coated steel beams suspended over the tanks should be considered to allow the installation of the main support systems such as heating, water supply and recirculation, light and electric systems, air and emergency oxygen supplies.

When considering a water recirculation system, enough floor space close to the tanks should be planned in the design stages to house its various components such as mechanical filters, biological filters, pumps, sterilizers, and heating devices. If the drains can be placed under the floor, the gutters going to the biological filters should be built well above the floor level to prevent dirt or toxic chemicals, such as disinfectants used to wash floors, from entering the recirculation system.

Spawning tanks

The spawning tanks are usually round or square (with rounded corners) tanks of 4-20 m^3 capacity. They are made of concrete, FRP, or are PVC-lined. The complete control of environmental conditions allows a fish stocking density of up to 15 kg/m^3, considerably higher than that used for long term stocking facilities. Spawning tanks are also utilised to obtain out-of-season spawnings.

Tank depth should be limited to 1.5 m as a maximum to facilitate the work of technicians. Even if automatic egg collectors are used, enough space should be left around the spawning tanks to allow for manual collection of eggs and broodstock manipulation.

In regions with low winter temperatures, the spawning tanks are filled with heated seawater, kept at temperatures between 14 and 18°C. To reduce fuel consumption, a semi-closed recirculation system is often adopted

Regardless of shape and size, the spawning tanks should fulfil the following conditions:

- easy control of the fish population;
- easy accessibility to the tank bottom for daily cleaning;
- simple and quick cleaning routine;
- easy replacement of the screened outlet;
- simple outlet construction for accessibility and service;
- minimum stress for fish at harvest;
- optimal swimming behaviour of fish;
- absence of transport problems in case of prefabricated tanks;
- optimal use of available covered area inside the building, which calls for square or rectangular, rather than round tanks;
- simple design of support systems (water supply/drainage, air supply, power supply, lights).

According to their shape, number and available space, tanks can be arranged in groups or in rows. In any case, staff should have easy access to at least 75% of their perimeter. The space between rows or groups should be wide enough (0.8 to 1.5 m) to permit the use of trolleys for working routines.

Water circuit

Spawners require ocean-quality seawater at a fairly constant temperature. In the absence of a reliable natural source of seawater at the right temperature, seawater has to be heated or cooled. When the breeding cycle is to be manipulated, a water recirculation system is introduced to reduce heating and cooling costs. This is also used in the coldest regions where the water temperature stays below 10ºC for more than 3 or 4 months. Recycling systems require a biofilter where the toxic ammonia (the main harmful product of fish metabolism) is biologically oxidised into safer nitrites and nitrates.

PVC pipes are used to supply and drain water. The water circuit design should be planned as simply as possible with the minimum number of corners to avoid pressure losses and the appearance of dead circulation points where sediments and bacteria could accumulate. Its components should be assembled by means of fast joints and bolted flanges to facilitate dismantling for cleaning and service operations. According to the water supply system, i.e. by gravity or by pumping, PVC pipes should be NP6 or NP10 respectively to stand different water pressure levels. Each tank should be equipped with an independent inlet placed on the tank rim; a ball valve should be provided to adjust its flow according to requirements. Tap water should be easily at hand with a few delivery points and a washbasin for cleaning routines.

Lights

Light intensity should be maintained in the range of 500-1 000 lux at the water surface by means of a halogen lamp placed over each tank. Lamps should be controlled by a timer/dimmer switch giving a

twilight effect when lights are turned on and off. Emergency lights that do not disturb fish could also be installed. Large windows should be avoided to prevent direct sunlight falling on the tanks.

Aeration system

Air supply is assured by a few coarse diffusers placed on the tank bottom and should be regulated to keep eggs suspended in the water mass. Plastic needle valves for aquarium or metal clamps (much more expensive) can be used to regulate air flow.

Overwintering facilities

In locations with mild winter conditions, breeders can remain in their long term stocking facilities all year round except at spawning time. Where climatic conditions are particularly severe, some precautions have to be adopted. In these cases fish holding facilities can be:

- protected by a light cover (a greenhouse for example),
- deepened (3 to 4 m),
- sheltered from the prevailing winds by means of windscreens,
- supplied with heated water.

These precautions, sometime expensive and difficult to put in practice, do not guarantee a completely safe situation in the colder locations. In that case, the whole broodstock must be moved into indoor facilities where the temperature can be kept at 10 to 12°C. At these temperatures fish have a reduced metabolism and therefore low feeding requirements resulting in limited production of organic wastes. Compared to outdoor facilities, a higher stocking density can be maintained (up to 15 kg/m3), thus reducing the space occupied by tanks.

Conditioning facilities

In many hatcheries indoor facilities are also used for conditioning breeders to delay or advance their natural sexual maturation cycle and spawning season. In that case, the conditioning/spawning areas become permanent facilities that occupy a dedicated part of the hatchery because of the long residence period needed. For practical purposes, such conditioning tanks are usually of the same design and material of the spawning tanks. Breeders are usually kept at a density of up to 15 kg/m^3.

The area is also subdivided into several zones, isolated from each other, where different light/temperature regimes can be adopted. This requires independent systems for light and water temperature regulation. The heating system is often coupled with a cooling system, usually a heat pump, to provide out of season winter conditions.

1.8 LIVE FOOD UNIT

This unit is dedicated to the production of microalgae, rotifers and brine shrimp nauplii (*Artemia* sp.) in large quantities, to be used as live feed for fish larvae.

The unit has separate sub-units for:

- phytoplankton and rotifer pure strains and small volume cultures,
- phytoplankton and rotifer bag cultures,
- rotifer mass culture and enrichment,
- *Artemia* nauplii mass production and enrichment,
- laboratory tests.

Each sub-unit is housed in a room of variable size with tiled floor and walls and is provided with air conditioning, treated seawater supply, freshwater supply, air distribution system, working lights, safe plugs, and a drain system. Adaptations to the needs of each sub-unit are specified below.

The first three sub-units should be contiguous to simplify working routines, since they represent three different steps of the same production process. They should be placed close to the larval rearing unit to reduce transport distance. The laboratory services the entire unit, plus the other hatchery compartments. There should be, however, a pathology laboratory in a separate room, to prevent possible spread of diseases.

1.9 PURE STRAIN AND UP-SCALE CULTURE ROOM

Algae and rotifer pure strains, as well as up-scale cultures (from small vessels up to 5-10 litre flasks/carboys), should be kept in an air-conditioned room under sterile conditions to avoid possible contamination. Floor and walls in this room should be tiled for easy washing and disinfection. A small drain system is all that is required since all culture vessels are kept sealed or are drained through the washbasin outlet. An adjacent room of smaller size, with the same hygienic precautions, is reserved for culture duplication and storage of consumables.

The cultures, whether in test tubes or glass or plastic vessels, are placed on shelves with lights and are kept at a temperature range of 14-16°C. A CO_2-enriched air supply system connected to the culture vessels provides an additional source of carbon and ensures the necessary turbulence. An ideal solution for pure strains is a lighted incubator where all test tubes are stocked under optimal conditions.

As all culture volumes are sterilized and prepared in advance, this room is the only part of the live food unit without a supply of treated seawater. All glassware, water medium and nutrient solutions are sterilized before use, following the procedures explained in Volume 1 of this manual. The equipment for sterilization varies according to the system chosen (see part 3 for details), and is typically housed in the laboratory or in an adjacent service room. A germicidal lamp (UV light) should be installed to control the residual bacterial contamination in the air. Note that this UV lamp must be switched on only when no staff are inside the rooms, and therefore, security switches should be installed on the door.

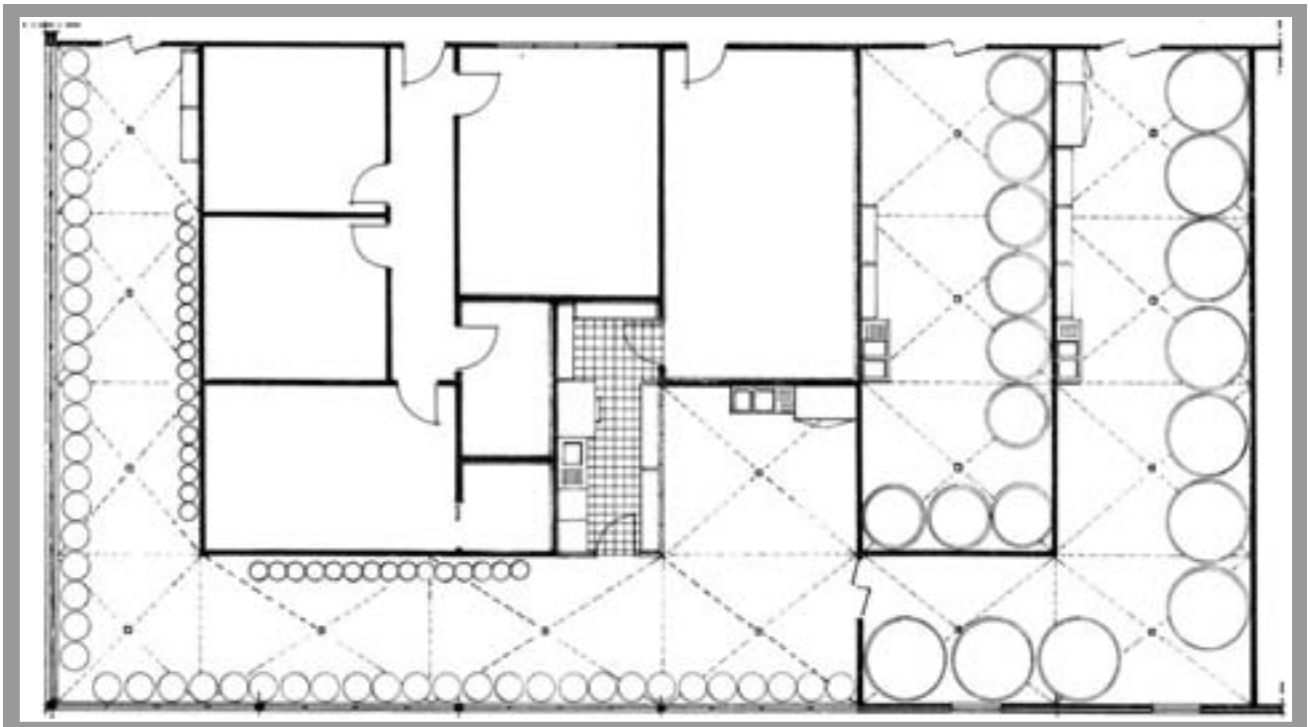


Fig. 9 - Plan of phyto and zooplankton unit and pure strain room

Fig. 10 - Plan of offices and services in phyto/zooplankton section

Support systems

Light is extremely important in algal culture. The right-size fluorescent tubes are conveniently placed to provide a light intensity of up to 1 000 lux for pure strains and up to 6 000 lux for larger vessels. They are placed horizontally under the glass shelves as well as on the sides of the shelves and are protected from water splashes by means of waterproof plugs.

Aeration is required to create turbulence and to provide oxygen for both algae and rotifer cultures. Each vessel, with the exception of test tubes, is equipped with one glass tube connected to the air pipe by a flexible plastic hose. The air is distributed through a central PVC pipe with branches going to each shelf.

To accelerate algal growth, carbon dioxide is added to the air blown into the vessels at a volume rate of 2%. Commercial grade CO_2 bottles are connected to the main pipe through a gauge and flowmeter. To monitor its flow, a bubbling flask is installed before the connection to the main air pipe. As carbon dioxide is heavier than air, some U-shaped joints are installed along this pipe to prevent stratification.

Due to the heating effect of the lights installed in the room, air conditioning is usually necessary to keep the temperature within an optimal range. The air conditioning should also work inside the replication room due to the prolonged use of Bunsen burners while preparing glassware for culture replication.

Tap water should be available and a washbasin for cleaning routines. Only the personnel in charge of this sub-unit should enter this room and they should dip their boots in a tray filled with disinfectant solution.

Equipment

The equipment in this sub-unit is mainly glassware for culture duplication and monitoring of algal cultures. Sterilized vessels of different capacity, filled with seawater, should always be available for duplication and up scaling. A cupboard is useful to store all sterilized material before use. Consumable equipment (chemicals to prepare nutrient solutions, glass tubes, etc.) should also be stored in this sub-unit. One plastic basin filled with 10% hydrochloric acid solution is required to disinfect pipettes after use. Used glassware is washed, filled and sterilized in the laboratory or in another dedicated room.

1.10 INTERMEDIATE ALGAE AND ROTIFER BAG CULTURE ROOM

In this sub-unit, algae and rotifers are cultured in large quantities in polyethylene (PE) bags. They are used directly to feed fish tanks (algae), or as inoculum for duplication and for larger volumes (algae and rotifers). The bags are housed in a dedicated room adjacent to the sub-unit described above. The floor of this room should be tiled to facilitate cleaning procedures and should have a slope of at least 2% towards drains.

Bags and stands

Two basic designs of PE bags of different capacities are utilised: a smaller single or double suspended bag (capacity 50 to 150l), and a larger one standing inside a wire mesh cylinder (up to 400l). In both cases, hot extruded tubular PE of 0.2 to 0.3 mm thickness is employed. This is a a cheap, disposable material that can be shaped according to production needs. The bottom of the bag is sealed either by hot welding, or in the case of the U-shaped double bags just by knotting. The largest bags are placed inside a wire mesh cylinder placed on a fibreglass or wooden base that has a V-shaped central cut. This V-shaped cut allows proper placement of the bottom of the bag.

Fig. 11 - Stands for large PE bags

Suspended bags hang from stands located either in the centre of the room or along the walls. The second solution is preferred when transparent walls are used, to take advantage of sunlight. Stands are preferably made of zinc-coated steel to prevent corrosion. For the same reason, wire mesh should be plastic-coated.

Whenever possible, the design should include large windows or glass walls.

Support systems

This sub-unit is connected to the heated seawater distribution system through some taps. Bags are filled using flexible hoses which can be disconnected, emptied and placed in a basin with hypochlorite solution for disinfection.

Due to the heat produced by the artificial lighting system, air conditioning may sometimes be necessary to keep temperatures within optimal ranges (18-22°C). Air temperature control is required for the hatcheries working with gilthead seabream in order to supply the large amounts of algae required for this species. In addition, it may be necessary to cool the air in the hottest months in order to maintain the algal growth within its optimal conditions.

Fluorescent tubes provide the necessary illumination. They should be placed to provide an intensity of 6 000 lux (range: 4 000 - 8 000) over the entire bag surface. They can be arranged either horizontally or vertically, but in both cases, they must be protected from water splashes by means of sealed plastic cases or waterproof plugs. Allow at least one 36 W tube per small bag, and two for larger ones. To save energy, between four and ten tubes should be grouped and connected to a single switch. Glass walls can save energy during the day. A light sensor (photocell) can turn the lights on and off. Then large windows should be installed as this will turn this room into a greenhouse, reaching very high temperatures during spring and summer.

Aeration is required to assure proper turbulence in the bags and each bag is equipped with two air hoses (best to use tubing of 6 mm inner diameter) placed near, but not on the bottom, to avoid stirring

the sediment. As the water weight keeps the PE film well stretched, air hoses can be put in place by simply forcing them through a very small hole in the desired place. The air distribution system is built with a central PVC pipe with branches going to each bag row.

Tap water should be easily available with a few delivery points and a wash-basin should be provided for cleaning routines.

Besides illumination, the electric system should be designed with a few waterproof sockets, which could be used to connect plastic pumps for harvesting, transfer and inoculum operations. All material such as switches, plugs or sockets used in the electricity network should be waterproof, with each socket controlled by a safety switch on the sub-unit control panel.

Fig. 12 - Aeration tube in PE bag

Equipment

The equipment in this sub-unit includes plastic containers to produce algae and rotifers (buckets, funnels, graduated cylinders, containers with a cap for chemicals and nutrients, etc.) and the glassware to monitor the algal and rotifer cultures (pipettes, Petri dishes, microscope slides, etc.). Bags are filled by means of flexible hoses connected to the seawater supply points.

Whereas all rotifer cultures are filtered before their re-utilization, mature algal cultures are directly transferred by means of self-priming submersible plastic pumps, whose hoses have to be carefully washed and disinfected after use.

A couple of large, flat tanks (with a capacity of about 1 000l) filled with disinfecting solution (500 ppm hypochlorite or 10% hydrochloric acid) is used to disinfect all tools after use.

Space requirement calculations

The space occupied by bags can be calculated by assessing the planned daily peak consumption of algae and rotifer cultures for up-scaling. Such calculations should therefore take into account:

- the peak daily amount of rotifers to be used as inoculum for new mass culture tanks;
- the peak daily amount of rotifers to be re-used to inoculate new bags;
- the peak daily amount of algae requirements for rotifer duplication;
- the peak daily amount of algae requirements for green water in the larval rearing unit;
- the peak daily amount of algae to be re-utilized as inoculum for new bags;
- the average number of days required to obtain a mature culture of phyto or zooplankton.

1.11 ROTIFER CULTURE AND ENRICHMENT

In this sub-unit rotifers are cultured in large quantities in tanks of larger capacity than the bags previously described, and are then enriched before being fed to fish larvae. This production is carried out in a specific room, usually adjacent to the bag culture sub-unit to facilitate the transfer of cultures from one room to the other. Floor and walls should be covered with tiles for hygienic reasons. As harvesting takes place in the same room, involving large quantities of culture water, an efficient drainage system is required.

Fig. 13 - An example of large volume room layout

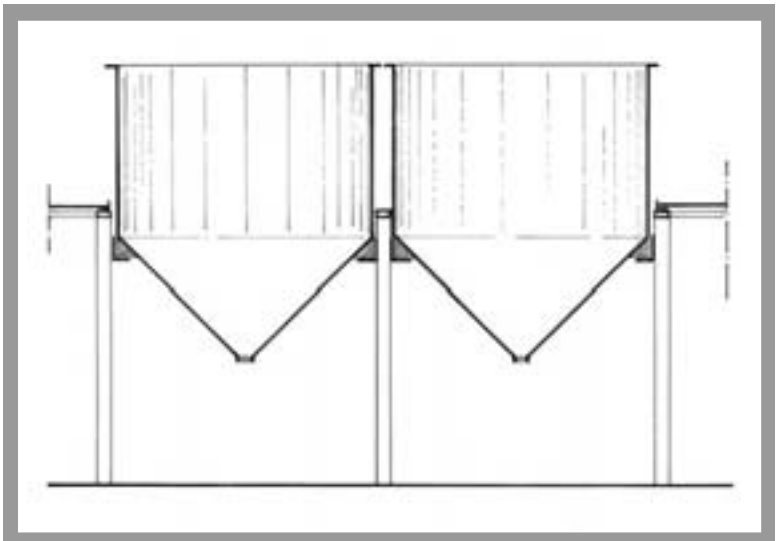


Fig. 14 - Rotifer tanks

Production facilities

Optimal rearing tanks are round tanks with a conical bottom with a capacity ranging between 1 and 4 m^3. Their inner surface can be white gel-coated to improve cleaning. An adequate drain with a valve at the cone tip is needed for harvesting operations.

As their management requires frequent observations (water quality monitoring, feeding, enrichment and cleaning), these tanks are usually placed in double rows separated by a wooden or metal walkway.

Support systems

The mass production of rotifers takes place at higher temperatures than that of algae (typical temperature is >25°C). A heated seawater circuit is therefore necessary. This circuit must be provided with a control to adjust the temperature in a very short time (see below for technical details). Because these cultures are static, the temperature in the tanks is maintained with electrical heaters made of titanium or with coiled tubing all around the tank. Due to the water masses involved, an air heater is usually not necessary.

As algae are being replaced by artificial diets, only service lights are required.

Aeration is required to maintain adequate levels of turbulence in the tanks, and each tank is fitted with air stones placed at about 15 cm from the bottom to avoid stirring the sediment. At least 5 air diffusers are used in a 2 m^3 tank: one at the centre, and the other four placed along the wall. Around 2-3 m^3/h of air flow per m^3 of culture volume is required.

Tap water should be at hand with a few delivery points and a wash basin.

The electricity system should be designed with a few waterproof sockets to connect plastic pumps for harvesting, transfer and inoculation operations. As in the other sub-units, all the material used in the electricity system should be waterproof, with each socket controlled by a safety switch on the sub-unit control panel.

Equipment

The equipment in this sub-unit should include an array of plastic containers for routine works (buckets, funnels, graduated cylinders, beakers, etc.), as well as large containers to keep the chemicals, the glassware for culture monitoring (pipettes, Petri dishes, microscope slides, etc.) and thermometers for routine checks. Flexible hoses with fast PVC joints connect the bottom valves to the filter used during harvesting. Trolleys with a flat platform are useful to transport the various containers and other equipment used in this sub-unit. Large plastic filters with a 60 μm mesh are used to harvest rotifers.

Space requirement calculation

The space occupied by this sub-unit is determined by the expected maximum daily consumption of rotifers by the larval fish unit. The calculation should therefore take into account:

- the peak daily amount of rotifers to be fed to fish larvae,
- the peak daily amount of rotifers to be re-used to inoculate new tanks,
- the individual volume and number of the rotifer mass culture tanks,
- the average density of enriched rotifer at harvest,
- the average number of days to get a mature rotifer culture.

The first point depends on the total number and age of fish larvae being reared in the larval unit and their feeding requirements, whose estimation is included in Volume 1, annexes 17 and 18, for both seabass and gilthead seabream.

The second point is a function of the mass culture system adopted: to speed up production, enriched rotifers in their log phase can be successfully utilized as inocula to start new tank cultures.

The third point is a function of the average daily consumption, adjusted to cover reduced needs during the initial and final rearing periods and adding a safety margin to take into account possible losses and culture crashes.

The fourth point depends on the rearing conditions, rotifer batches and management. A conservative output of 600 - 900 million enriched rotifers per m^3 should be considered.

1.12 BRINE SHRIMP PRODUCTION AND ENRICHMENT

The production of brine shrimp (*Artemia*) larval stages (nauplii and metanauplii) is carried out in a separate room, usually adjacent to the rotifer sub-unit for practical reasons (same treated seawater supply, air conditioning system and staff). The design should not include windows or transparent walls, as harvest of *Artemia* nauplii requires conditions of total darkness. As in the other units, the floor and walls should be tiled to help maintain good hygienic conditions. As harvesting takes place in the same room with tons of culture water being filtered daily, an adequate drainage system is necessary (a central manhole or screened channel drains).

Production facilities

Different tank designs have been adopted for brine shrimp incubation and enrichment. However, the basic round tank with conical bottom offers near ideal conditions in respect of water circulation, aeration

and harvesting. Tank capacity can be usually lower (1 to 2 m^3) than that of tanks for mass culture of rotifers, to give greater production flexibility.

The tank inner surface can be painted in white (gel-coated) to ensure a better light diffusion (important in the first hours of cyst incubation) and proper cleaning. The tanks must have a transparent window near the cone tip to attract nauplii at harvest time by means of a light source. A drain with a valve at the cone tip is used for harvesting.

Due to the limited routine work (what is required is mainly DO monitoring and enrichment diet supply every 12 hours), these tanks should be positioned along the walls to leave enough free space at the centre of the room for harvesting operations.

Support systems

The production of *Artemia* nauplii requires high temperatures (27-30°C) for optimal hatching rate and high hatching efficiency. Therefore, only heated seawater from the same circuit that serves the rotifer and algal sub-units is utilised. The heating system should be able to heat water to the optimal temperature in a very short time (see below for technical details). To prevent heat dispersion in the room and cooling of the tanks, an air heater should be installed to maintain room temperature at a nearly constant level.

The best output is obtained under strong light and aeration conditions. A lamp should therefore be installed in each tank. It should be made with 1 or 2 fluorescent tubes delivering 2 000 lux at the water surface. A sealed plastic container or waterproof plugs are recommended since the strong air bubbling in the tanks produces a vaporized salt water spray.

To provide the strong aeration needed, an open-ended PVC pipe ($^3/_4$" ø) is placed in each tank near the bottom. A ball valve allows regulation of the air flow, which should be about 6-8 m^3/h per m^3 of incubation volume.

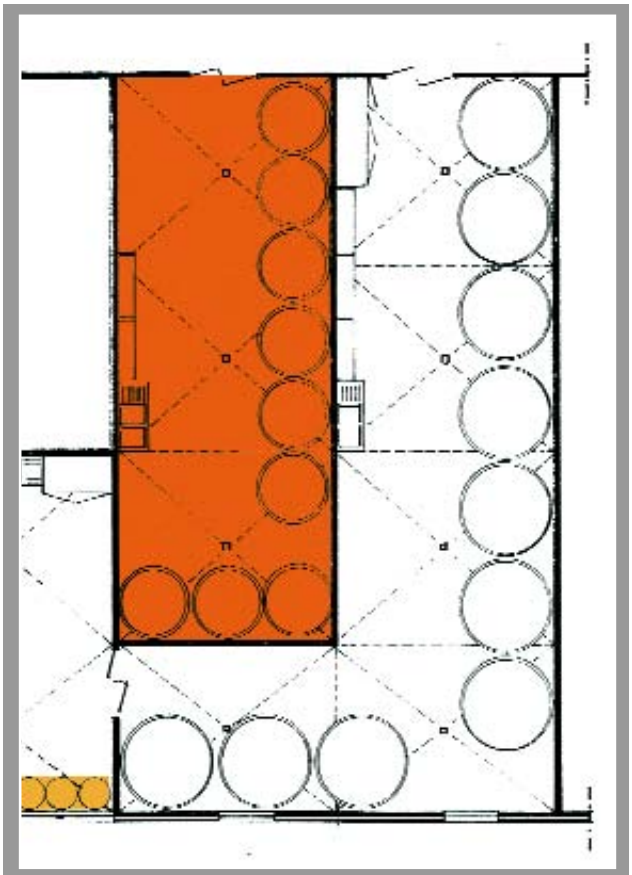


Fig. 15 - *Artemia* nauplii section

Tap water should be at hand with a few delivery points and a wash-basin for cleaning implements. The electricity system should be designed with a waterproof plug near each tank to install either a submersible electric heater or the harvesting light. As usual, the electricity system should be waterproof, with each socket controlled by a safety switch on the sub-unit control panel.

Equipment

When large amount of cysts have to be handled, it may be practical to add a separate area equipped with several smaller round-conical tanks (50 to 100l) for cyst disinfection or decapsulation. This area differs from the main *Artemia* room in that an efficient system for air renewal/extraction is needed. This is because toxic reagents that produce gases are used in the process of decapsulation.

The equipment in this sub-unit should also include plastic containers of different sizes for routine work (buckets, funnels, graduated cylinders, beakers, etc.), as well as large containers for the chemicals used in the disinfection/decapsulation process, the glassware used for culture monitoring (pipettes,

Petri dishes, microscope slides, etc.) and thermometers. Flexible hoses with fast PVC joints are used to connect the bottom valves to the filter utilized for harvesting. Trolleys with a flat platform are useful to transport equipment.

The design of the filters to harvest brine shrimp nauplii and metanauplii is similar to that used to harvest rotifers although a larger mesh size of 125 μm for nauplii and 200 μm for enriched metanauplii is used.

In addition, this sub-unit requires enough space in the cold storeroom of the hatchery to keep *Artemia* cysts and enrichment diets in proper conditions before their utilisation.

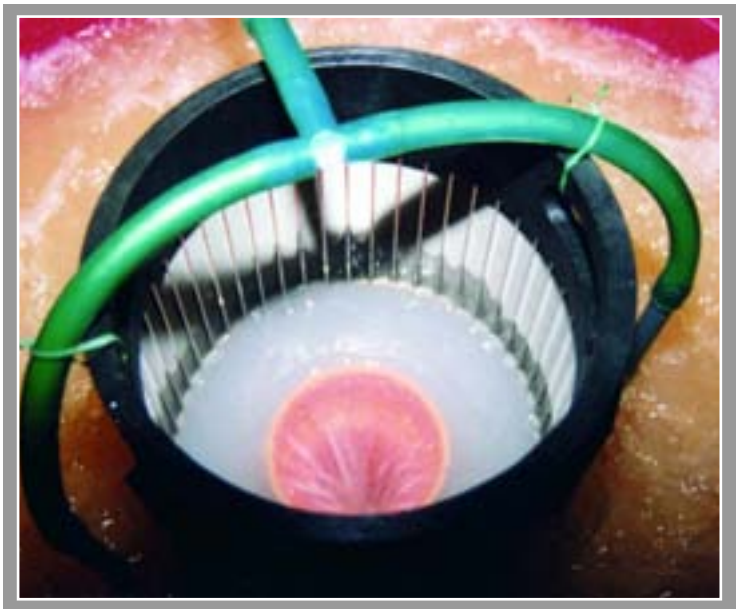


Fig. 16 - Filter for *Artemia* decapsulation, or for rinsing and enrichment after harversting

Space requirement calculation

The space occupied by the *Artemia* culture tanks is determined by the expected daily maximum consumption of brine shrimps nauplii (first larval fish feeding) and enriched metanauplii. Calculations should therefore consider:

- the peak daily amount of nauplii and enriched metanauplii consumed by fish,
- the volume of the *Artemia* tanks,
- the average output density of nauplii and enriched metanauplii,
- the number of tanks for incubation (Ti),
- the number of tanks for enrichment process (Te),
- the timing of both operations (24 hours incubation, 12 or 24 hours for enrichment).

The first point depends on the total number and age of fish larvae being reared in the larval unit and their feeding requirements.

The second point is a function of the average daily consumption and the necessary flexibility to cover reduced needs during the initial and final rearing periods.

The third point depends on the quality of *Artemia* batches: with an incubation density of 2.5 g/l, a conservative estimate would be an output of 450 000 nauplii/l for low quality cysts (to be enriched as metanauplii) and 650 000 nauplii/l for high quality cysts. The stocking density for nauplii enrichment is 300 000 nauplii/l, and the minimum survival expected after 24 hours is 90%.

Warning: batches may vary widely in terms of efficiency, hatching time and hatching rate.

▶ **Example**: If the peak demand per day is one billion enriched metanauplii, we need to stock 1.1 billion nauplii (with an estimated survival rate of 90%). If we use cysts with an average output of 220 000 nauplii per g of cyst incubated, the amount of cysts to be incubated would be 5 kg. Using an incubation rate of 2.5 g per litre a volume of 2 000 litres is required, that may be provided by a single 2 000l tank, or two 1 000l tanks. Twenty four hours later, a further 3 700 litres of tank volume would be required to enrich the nauplii (at an initial density of 300 000 nauplii/l), which means 2 tanks with a capacity of 2 000l each.

1.13 LARVAL REARING UNIT

The rearing of the fish larval stages takes place in a large room, usually located not far from the live feed production unit to facilitate the transport of algae, rotifers and brine shrimp nauplii. The same room should have enough space to house the following ancillary facilities:

- the tanks where eggs are incubated,
- an area where all the equipment required in this room could be routinely cleaned, disinfected and stored,
- the insulated tanks for the cold storage of live feed (enriched rotifers, brine shrimp nauplii and enriched metanauplii).

Fig. 17 - Larval rearing unit

Windows are not necessary as larval rearing requires controlled light conditions, but they can be installed to renew the air inside the room and to reduce humidity. Fan extractors can be used as well. Floor and walls should be tiled to secure proper hygienic conditions and to facilitate frequent cleaning. Since at harvest the tanks are emptied, an adequate drainage system is required. It should be made with screened channels under the floor, which should have a slope of at least 2%.

Thermal insulation of walls and roof is advisable in locations with cold winter conditions to save on heating costs.

A framework of zinc-coated steel beams suspended over the tanks is the cheapest solution to support all service systems (heating, water supply and recirculation, light and electric system, air and oxygen supply).

When a water recirculation system is used, enough floor space close to the larval rearing tanks should be planned to place components such as mechanical and biological filters, pumps, sterilizers and heating/cooling devices. If normal drains can be placed under the floor, it should be borne in mind that

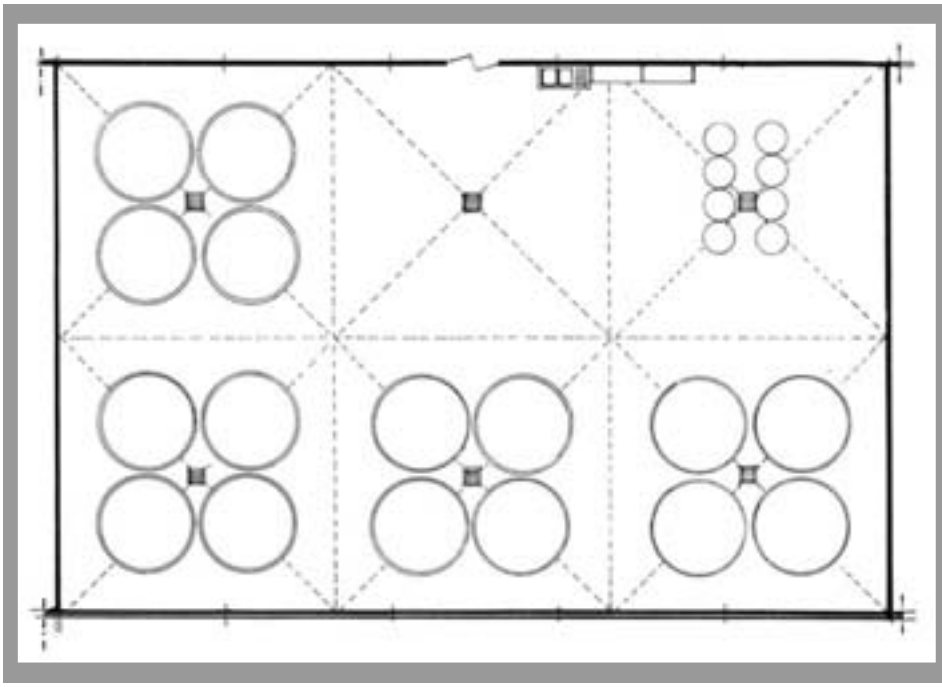


Fig. 18
An example of larval rearing room layout

this cannot be done for the gutters conveying water to the biological filter. These gutters should be placed above floor level to prevent dirt or toxic chemicals, such as disinfectants used to wash the floor, from entering into the recirculation system.

Production facilities

Egg incubation can take place either in the larval rearing tanks or in tanks designed for this purpose, usually round tanks with conical bottom due to of their near optimal water circulation. Their capacity ranges between 100 and 500l since a small volume allows for a higher water exchange rate and makes the harvest of newly hatched larvae easier. As egg incubation lasts a few days only, the tanks can be used for several hatching cycles. Materials used are fibreglass or plastic ensuring a smooth inner side to avoid damage to eggs and larvae. Due to the relatively small amounts of water required, the water supply system for these tanks is preferably of the flow-through type, i.e. new water is added continuously and not recirculated.

For the larval rearing of Mediterranean fish, different tank designs have been adopted: high round tanks with conical bottom, low circular tanks with a slightly concave bottom or flat-bottomed square tanks. On average their capacity ranges from 2 to 12 m^3. They are most commonly made of fibreglass, but reinforced concrete, PE and PVC are also used.

The shape and size of larval tanks are decided on the basis of a number of considerations:

1. *management efficiency*:
   - the larval population should be easily visible throughout the whole water volume;
   - the tank bottom should be easily accessible for daily cleaning; a white colour facilitates a better detection of dirt;
   - cleaning should be a simple and not time-consuming routine;
   - the feed should be evenly distributed;
   - the round tank walls can be painted in black to facilitate food particles detection by fish larvae;
   - easy replacement of screened outlets;
   - simple outlet construction for access and service;
   - minimum stress to fish at harvest;
2. *water circulation*:
   - absence of dead zones and related negative consequences (anoxia, ammonia build-up, etc.);
   - optimization of the aeration pattern;
   - concentration of settled wastes in a few areas of the tank bottom to allow for a faster and more efficient cleaning;
   - optimal swimming behaviour of fish;
   - optimal distribution of food particles;
3. *economics*:
   - low cost and local availability of building material;
   - transport problems in case of prefabricated tanks;
   - optimal use of space;
   - simplified design of support systems (water circulation, air supply, power supply, illumination);
   - manpower requirements for their management;
4. *risk prevention*:
   - a large number of smaller tanks offers a better protection against disease outbreaks than just a few large tanks.

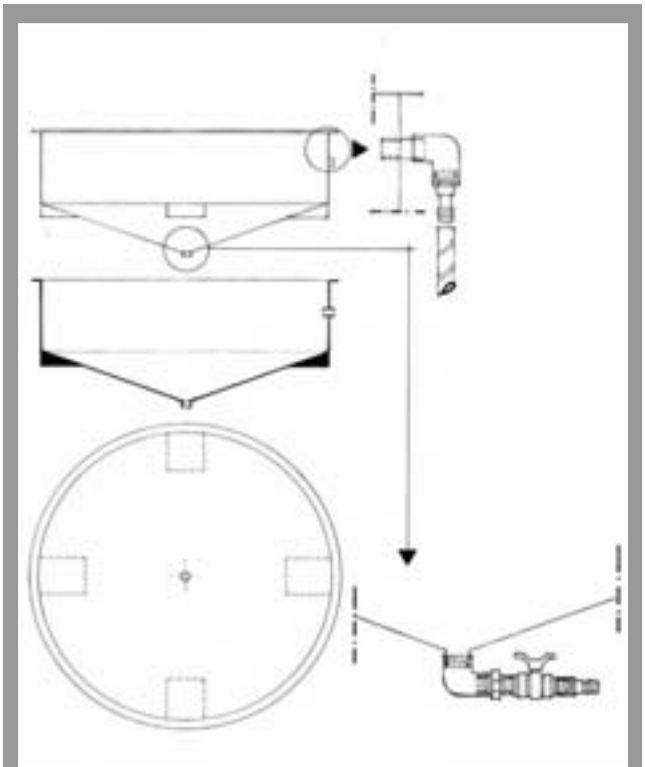


Fig. 19 - Fibreglass tank

Among Mediterranean hatcheries, small tanks with a conical bottom are being progressively replaced by larger flat tanks (5 to 10 m^3) as they simplify considerably the overall design of the larval unit and reduce staff labour. On the other hand, the use of large tanks may imply a higher risk in case of disease outbreaks.

According to their shape, number and available space, tanks are arranged either in groups or in single or double rows. In either case, staff should have access to at least 75% of their perimeter. The space between rows or groups should be wide enough (0.8 to 1.5 m) to permit the use of trolleys for live feed distribution.

Support systems

As a rule, the larval rearing unit requires ocean-quality seawater at a fairly constant temperature, in the range of 16 to 20°C. In the wild, reproduction of seabass and gilthead seabream takes place during the cold season, with lower seawater temperatures but larval growth is also slower. If a reliable natural source of warm seawater is available or when the difference in temperature with the external environment is acceptable, the larval sector is equipped with a flow-through circuit, i.e. the water that enters the tanks is not recycled at the outlet, but discharged.

Seabass and gilthead seabream water parameters

Temperature	**18 - 22 °C**
Salinity	**25 - 35 ppt**
Oxygen	**100% sat.**
pH	**7,8 - 8,1**
Unionised Ammonia	**< 0,020 mg/l**
Copper	**< 0,0010 mg/l**
Lead	**< 0,004 mg/l**
Iron	**< 1 mg/l**
Nickel	**< 0,010 mg/l**
Zinc	**< 0,050 mg/l**
Cadmium	**< 0,003 mg/l**
Chlorine	**< 0,020 mg/l**
Chromium	**< 0,050 mg/l**

Fig. 20 - Water quality. Rearing parameters

In the other cases, cold raw seawater has to be heated. To reduce the heating costs, recirculation systems are included, in which most of the rearing water is recycled instead of being replaced by new water. Recycling systems require a biofilter where toxic ammonia (product of fish metabolism) is biologically oxidised into the safer nitrites and nitrates. PVC pipes are utilised for water supply and drainage. The circuit design should avoid sharp bends and be as simple as possible to avoid large pressure losses and the establishment of dead zones where sediments and bacteria could accumulate. Components should be assembled by means of fast joints and bolted flanges to allow easy dismantling for cleaning and service operations. According to the water supply system, i.e. by gravity or by pumping, PVC pipes should be NP6 or NP10 respectively to stand different pressure levels.

Each tank should be equipped with an independent inlet placed on the tank rim; a ball valve should be used to adjust its flow according the larval rearing requirements. The angle at which water enters the tank will depend on tank design and on the age of the fish population.

Light intensity should be maintained in the range of 800-3 000 lux at the water surface when both gilthead seabream and seabass are reared. A halogen lamp placed over each tank works well and has a low electricity consumption. As a general rule, 20W for every 1.5 m^2 of water surface should be

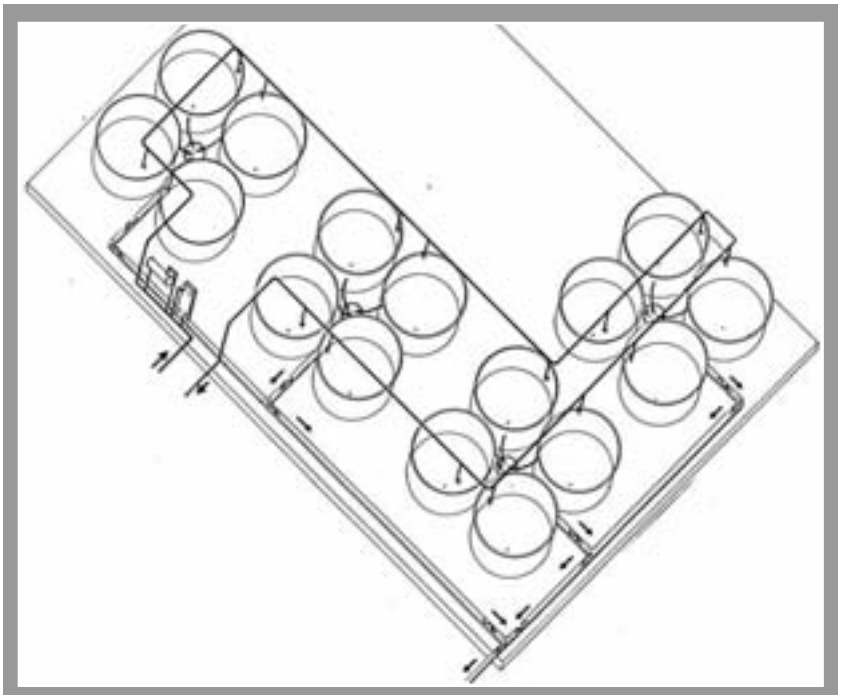


Fig. 21 - Three-dimensional sketch of a larval rearing unit with open flow circuits

sufficient. Lamps should be controlled by a timer/dimmer switch to produce a twilight effect and to reduce stress when lights are turned on and off.

A service light that would not disturb fish may also be useful in case of emergencies. Large windows should be avoided to prevent direct sunlight from reaching the larval rearing tanks, as it is a source of great stress for fish larvae.

To prevent excessive turbulence, the aeration in fish larval rearing tanks should be very gentle, with an air flow of up to 60l/minute. Aeration is assured by means of one or more fine diffusers placed on the tank bottom. The aeration, in synergy with water circulation and tank shape, should provide an even distribution of oxygen and food particles as well as gentle currents to allow fish larvae to develop their swimming behaviour. Aquarium plastic needle valves, or metal clamps (much more expensive), can be used for air flow regulation. Tap water should be at hand with a few delivery points and a wash-basin for cleaning purposes.

Space requirements

Incubation tanks

The water volume required to incubate eggs is based on the following criteria, which are valid for both fish species:

- maximum density of fish eggs: 15 000/l,
- minimum acceptable rate of viable larvae: 75%,
- number of viable larvae at the start of each larval cycle (see below),
- unit volume of incubation tanks.

Larval rearing tanks

The water volume necessary for larval rearing is determined on the basis of the following criteria:

- number of fish species to be reared,
- amount of fingerlings required per species and production cycle,
- final larval density and average survival in the larval rearing sector,
- final larval density and average survival in the weaning sector.

The last two points also depend on a number of variables such as: tank shape, rearing method, staff experience, availability of viable eggs and so on.

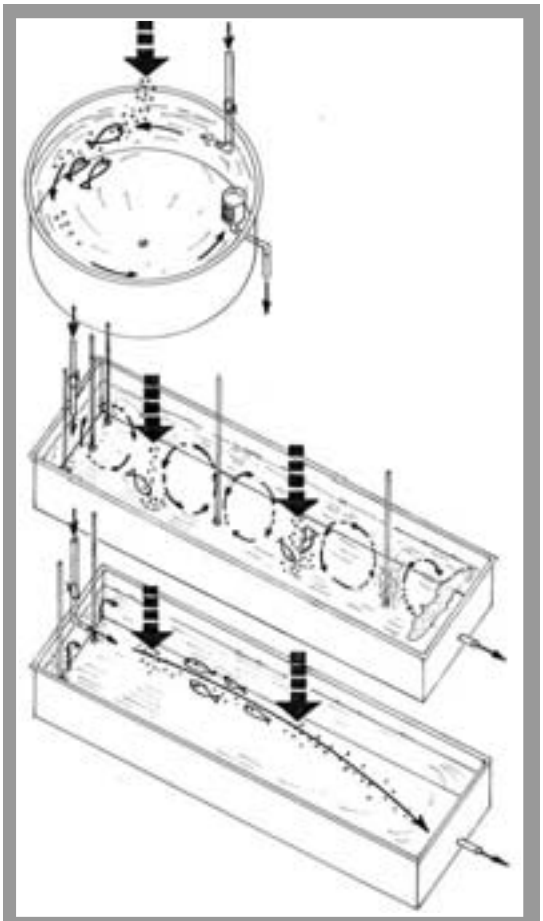


Fig. 22 - Three different solutions of tank shape and water management

The following indications on stocking densities for the two species can be used for the initial trials in a hatchery and will have to be adjusted after the first production cycles.

Gilthead seabream:

- initial stocking density in the larval unit: 200 newly hatched larvae per litre,
- final stocking density in the larval unit: 60 fry per litre (survival rate 30%),
- initial stocking density in the weaning unit: 20 fry per litre,
- final stocking density in the weaning unit: 6 fry per litre (survival rate 90% - density is different because in this sector fish are graded several times).

Seabass:

- initial stocking density in the larval unit: 200 hatched larvae per litre,
- final stocking density in the larval unit: 100 fry per litre (survival rate 50%),
- initial stocking density in the weaning unit: 20 fry per litre,
- final stocking density in the weaning unit: 8 fry per litre (survival rate 80% - density is different because in this sector fish are graded several times).

1.14 WEANING UNIT

The weaning unit is essentially organised as the larval rearing unit. Only the differences between the two units are indicated below.

Due to the larger size of the rearing tanks and to the lower initial stocking densities, the weaning sector requires much more space. It is usually adjacent to the larval rearing unit to facilitate the transfer of fish.

Windows can be installed to reduce the high degree of humidity and to renew the air. As fish grow, they should be gradually adapted to the natural light, although avoiding direct sunlight on the tanks.

The drainage system is also larger than in the larval rearing unit. Large doors are recommended to move equipment as well as large containers on wheels carrying fingerlings at the end of the weaning cycle. Preferably a tarmac road should run along one side of the building to give easy access to lorries used for the delivery of equipment and for transport of fingerlings.

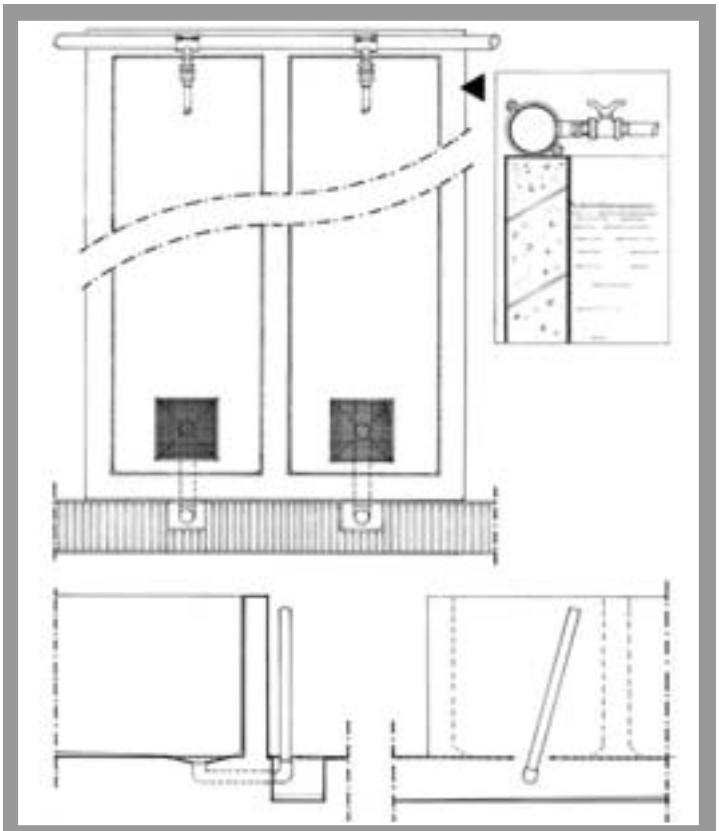


Fig. 23 - Concrete tanks

Production facilities

The weaning tanks are characterised by a larger size than the larval tanks and can be of different shapes. The models most widely adopted by

Mediterranean hatcheries are round tanks with flat or slightly concave bottom and the raceway tank. On average, their capacity ranges from 10 to 30 m^3, as larger volumes may limit the flexibility required for frequent fish grading, which is a routine practice in weaning. They are usually made of fibreglass and reinforced concrete, but masonry, plastic sheets and rigid PVC are also utilized.

The raceway design is a rectangular tank through which the water current flows from the inlet, placed at one end, to the outlet that is placed at the opposite end. Its hydraulic efficiency is satisfactory, provided that dead zones and stratification are avoided by adjusting the water inflow and aeration. To prevent circular eddies which could accumulate waste and debris in the centre, the length (l) / width (w) ratio should not be lower than 6. For easy management, water depth is usually kept at one metre, whereas the bottom slope is 1-2%.

Often a PVC pipe is used as tank outlet because of the easiness in installation and use. Another very good solution is also a monk with three sets of grooves to:

- prevent fish from escaping (inner screen),
- evacuate the bottom water and sediments by adjusting slabs (central set of grooves),
- keep the desired water level (outer set of slabs).

As the outlet covers the entire section of the tank, this type of outlet is more efficient (due to a reduced clogging risk, and its easy replacement) than a central or terminal drain with a screened pipe. Waste removal is a function of the water speed (linked to renewal rate), and of the fish biomass, since a high number of fish will stir up more sediments. The shape of the raceway is also ideal to harvest and grade fish, and at the same time makes good use of the available floor space, whereas circular tanks waste about 30% of the available room area.

Support systems

The water supply system is similar to the larval rearing unit but bigger. When a recycling system is present, an independent water circuit supplying treated, but not heated, seawater is advisable to increase management flexibility.

The light intensity should be about 1 000 lux and the weaning unit does not require the twilight effect described in the larval rearing unit. Fluorescent tubes are placed over each tank and a power of 20W every 5 m^2 of water surface is usually sufficient.

This unit requires a few additional power sockets to connect the vacuum cleaner used daily for the removal of the waste accumulated on the tank bottom. A low voltage line is also required to drive the automatic feeders used for the first time in this unit.

Space requirement calculations

The final shift from live to artificial food is achieved in the weaning unit. Combining an increased water renewal and injection of pure oxygen in the tanks, this section may reach a final fish biomass as high as 20 kg/m^3. At an individual size of 2-3 grams, this means a final density of 6 to 10 000 fingerlings/m^3, which should be used as a general indication for space requirement calculation.

1.15 SUPPORT UNITS

Pumping station

The size of the pumping station depends on the quantity of water needed and on the type, dimensions, and number of pumps installed, including stand-by units. The description of the size calculations for the pumping station can be found in the engineering section of this volume (Part 2).

The site where the pumping station is to be located should be easily accessible, to simplify transport of pumps and other equipment. Moreover, the pumping station should be located as close as possible to the hatchery to facilitate constant surveillance.

The pumping station, even when submersible pumps are used, should be protected at least by a shed and should have good lighting, to facilitate maintenance and eventual repairs. Auxiliary electrical sockets should be provided and, if at all possible, freshwater should be available to facilitate routine maintenance work. If the pumping station is located near the seashore, it should be protected, not only against wave action, but also against salty sea spray.

Horizontal pumps are normally placed inside a small room, together with the electrical control and alarm panels, to ensure a degree of protection against atmospheric agents. This room usually also includes a small workshop where the most commonly used tools for pump maintenance and repair are permanently stored.

The need for a possible urgent intervention should be contemplated in the design stage. When large submersible or vertical pumps are used, the space where they are housed should be large enough to allow technical staff to work safely on the pumps without having to remove them from their seat. Whenever the weight of a pump prevents direct handling, the pumping station should be equipped with an arm and a winch to lift the pumps and to place them on a concrete platform. This platform should be built near the pump seat, for routine maintenance or repairs in case of serious damage.

Fig. 24 - Pumping station

Seawater wells

Along sandy shores, wells dug in the beach are frequently used. On the positive side these wells supply filtered water, often at a constant temperature. However, serious problems can arise if they are over-exploited because they tend to clog the sand bed easily by sucking small particles when pumping. Such wells are suitable when water demand in the hatchery is relatively low. Even in that case, and depending on the size of the sand particle, they will have to be abandoned sooner or later and new wells will have to be dug.

Wells in rocky shores or deep enough to reach a stable but permeable rocky ground are usually very efficient and represent a permanent solution, even if their water may not be of such a good quality as that obtained from sandy wells. Well water often needs tratement before use, because of low oxygen content or because of organic or inorganic pollution. Facilities for this purpose should be considered.

Pumping station to hatchery connection and wastewater treatment

This section refers to the pipes supplying seawater to the hatchery. Pipe length and diameter depends on the location of the pumping station with respect to the hatchery buildings and also depends on the size of its components (pipelines and treatment systems). It has to be designed in relation to the quantity of water to be supplied.

A pipeline is normally used when water is distributed under pressure. It is better to place it under ground level, to cross farm roads without hampering vehicle or trolley circulation. Since pipelines require periodical maintenance and cleaning to remove sand and fouling, they cannot be completely buried. It is best to place them in a trench, well-protected by grids or concrete slabs.

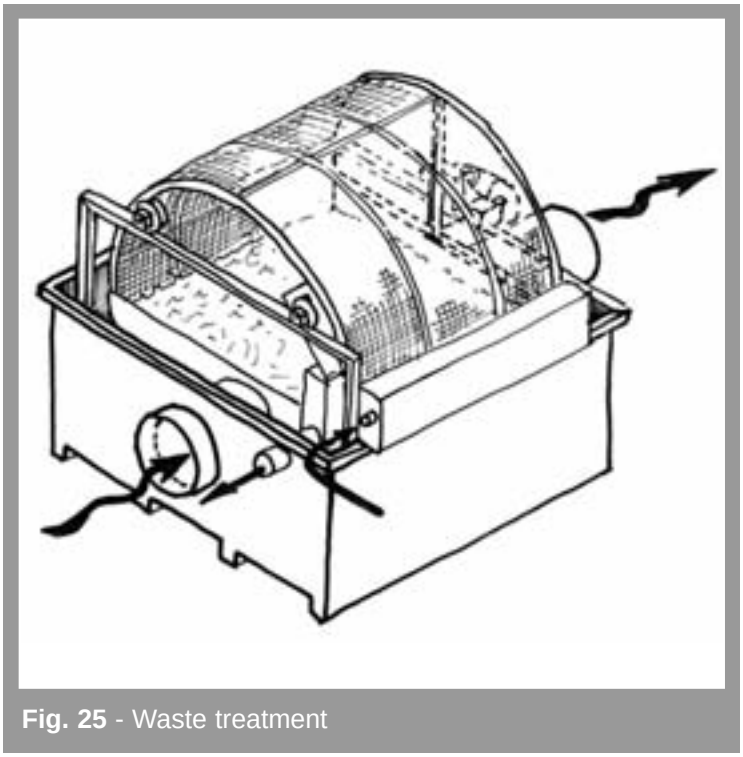


Fig. 25 - Waste treatment

Water distributed under pressure can be filtered through pressure sand filters on arrival at the hatchery. These filters should include an automatic backwash system to increase filtration efficiency and to reduce maintenance.

The seawater effluents of the hatchery should be drained by gravity. The bottom level of the waste water discharge channel must be the lowest level of the whole hatchery/farm hydraulic system. It should also be higher than the final water discharging point, outside the farm.

The waste water treatment should be carried out along the discharge channel. It should be based on filtration systems using gravity to move the water rather than pressurized systems. The most suitable system is the drum filter, which is able to retain a large amount of the insoluble organic load (suspended solids) normally present in fish farm effluent. Where space is not a problem, the wastewater produced by the hatchery can be circulated through a settlement tank. In the case of a high organic load, the water passed through a drum filter or sedimentation tank can be directed into one or more earthen ponds where the remaining organic wastes are biologically degraded (lagooning system). This system, however, may require large surfaces depending on the quantity of wastewater produced and to the quantity/type of waste to be treated.

Boiler room

This unit houses the air and water heating system. The capacity of the systems and therefore the size of the room depends on the local climatic conditions. Daily requirements are determined by the difference between external temperatures (air/water) and those to be maintained in the working areas, and by the water/air volumes of the various rearing units.

The room should contain two boilers working in rotation, with each of them having sufficient capacity to provide the calories required during the peak period of the hatchery operations. The double system prevents interruptions in heated water and air supply in case of failure of one boiler. Heating systems are usually based on fuel oil or natural gas burners. From the boiler room, two separate steel pipelines feed the heat exchangers for seawater heating and the air heaters. Each pipeline should be properly insulated to avoid heat losses.

The boiler room should be built according to national/local safety rules, which may establish its minimum size, the aeration requirements and, due to the presence of fuel reservoirs, the minimum distance between boilers and surrounding buildings. Auxiliary electrical outlets should be provided for maintenance and eventually should be placed outside the boiler room for safety reasons.

While planning the location of this unit, it is important to remember that fuel oil or gas tanks should be next to a road large enough to allow trucks to manoeuvre.

Electricity generator room

As a general rule it would be best to locate hatcheries in sites that could be easily connected to the electricity network. However, one generator (two in case of large hatcheries) should always be ready to supply energy in case of electricity blackouts.

The generator should be installed with its control panel so that, as soon as the necessity arises, it can be automatically (or manually) started to reduce to the minimum the blackout period.

When designing the power network, it is important to bear in mind the peak electrical demand generated when all engines start, which could be four to six times higher than their normal consumption. Delay switches should be installed to stop all the electrical engines and appliances starting simultaneously. Priority should be given to essential equipment, such as pumps and aerators. In order to estimate the size of the emergency generator, it will be necessary to identify the equipment that plays a vital role.

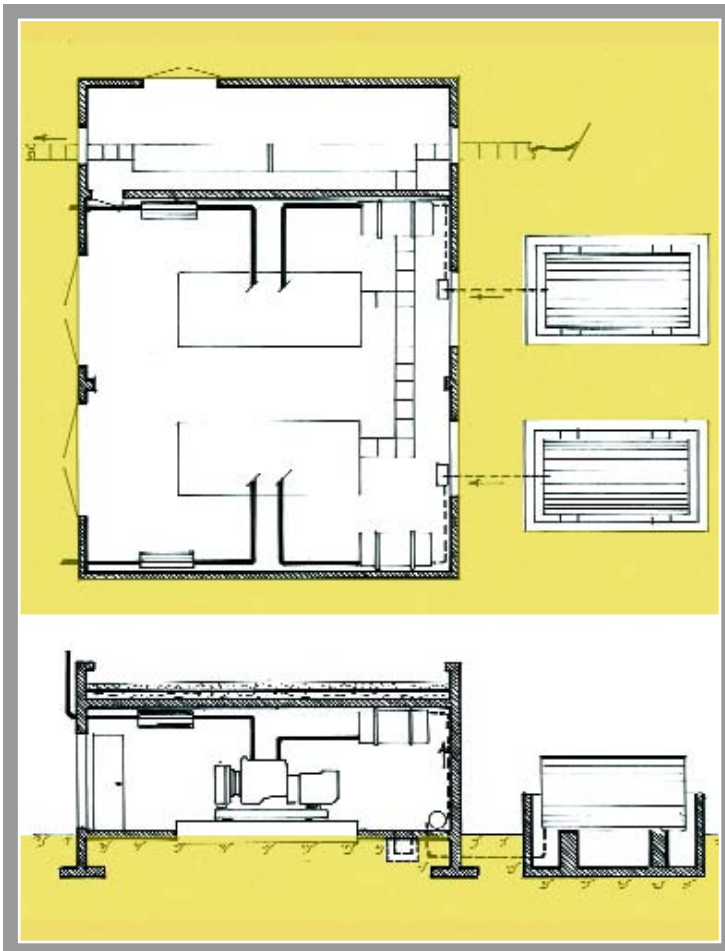


Fig. 26 - The generator room

The room housing the generator(s) should be located outside the hatchery. It should be sound-proof, to reduce the noise caused by the diesel engine of the generator. Construction standards should respect the same national/local safety rules as in the case of the boiler room, since fuel is also used in this room.

Workshop

This is the unit where most of the hatchery equipment maintenance and repair takes place. This unit should guarantee that everything runs smoothly when dealing both with routine maintenance and emergencies that may happen during the production season.

Its design follows the rules normally applied when building an industrial workshop: a relatively large free space in the centre of the room equipped with a winch and strong benches around it to facilitate work even on large and heavy equipment. This central space should be large enough to allow the entrance of small vehicles, like tractors or pickups, bringing large pieces of equipment to be serviced. A series of metal benches are placed along the walls, equipped with all the necessary tool-holders. A storeroom is usually attached to the workshop to stock spare parts. The workshop should be adequately illuminated, both inside and outside. It should also be connected to the freshwater and electricity (220 and 380V) circuits.

Feed store

This unit, which in a large fish farm occupies a large storehouse, does not require much space in a hatchery. Only a few hundred kilograms of dry feed for larvae and fry are routinely kept in stock, even during full production periods. The feed should be located in a dry, clean room, protected against rodents and easily accessible to hand-trolleys.

When moist feed is used, a small area inside the hatchery (possibly a separate small room) should be reserved for its preparation. A large bench, easily washable, should be placed close to a large sink provided with a freshwater tap. The area (or room) must also include a deep freezer (-20°C, 400 to 600l capacity) where raw materials (frozen fish or cephalopods) are stored and a large refrigerator (0 to 4°C, 200l capacity) to keep food integrators.

Hatchery laboratory

The hatchery laboratory is a room usually located close to the phyto/zooplankton unit. Its size depends on the type and number of operations and on the number of staff working there. The staff are usually responsible for the phyto/zooplankton unit, as well as for the larval and fry production units. The laboratory should be large enough to allow working together in a comfortable way while performing their routine analyses or carrying out research tests.

Walls with windows may be a convenient characteristic of this room so that the hatchery could be easily kept under continuous surveillance.

As the laboratory is a "wet room", it requires safer standards in particular for electricity circuits and slippery floors should be avoided.

The laboratory should also be equipped with some tile-lined benches for microscopes and water quality analysis and should have a large sink. A small refrigerator is used to store chemical solutions and drugs. Chemical compounds should be stored in a lockable cupboard and be protected against humidity.

Other types of laboratories may be present in the hatchery. Even if it is not a common practice, some farms are actively involved in research programmes to be later applied to production schemes. In such cases, the laboratory should be set up differently according to the research programme to be implemented. If the hatchery has a pathology laboratory, it should be separated from the production units to increase safety and avoid accidental infections.

Furniture in these laboratories should be similar to that of a research laboratory, including, for example anti-corrosion benches for scientific instruments, cupboards with transparent doors for storing glassware and chemical products, and large desks with shelves.

Cleaning areas

Special areas for cleaning procedures are mentioned here because of their particular importance in the routine work. Each production unit should have its own cleaning area where all washable equipment is cleaned after use, disinfected and stored to be readily available.

Cleaning areas should be located far enough from the culture/rearing tanks to avoid any possible contamination with detergents or chemicals used to clean the equipment. It would be essential to plan the various cleaning areas separate from each other to reduce the risk of contamination between different hatchery sections.

Each cleaning area should be large enough to allow the temporary storage of equipment. It should be provided with a table and a wall-rack where the washed equipment can be hung to dry. The concrete floor should have a good slope towards a drain to avoid accumulation of water and detergents and to facilitate washing.

Offices

Offices should be located in an adjacent building rather than inside the hatchery, which is a wet and noisy area not suitable for office work.

The number of offices will depend on the size of the hatchery and, eventually, of the adjacent farm. In a large hatchery there should be one office for the general manager, one for the personnel involved with accounting/clerical work and at least one office large enough to accommodate the technical staff.

The floor space of these offices should be distributed according to their specific activities:

- the general manager normally has frequent contacts with external visitors or may need to hold meetings with his staff. His office should thus be representative and large enough to function as a meeting room;
- the accountant and the clerical staff need appropriate furniture, for example, to store documents (correspondence, equipment and materials orders, etc.). In addition, they will require working desks, tables for telephones, faxes, photocopiers, computers, printers and typewriters;
- the staff responsible for production deal usually with technical matters. They will spend time reading or writing technical documents, and thus they will need a comfortable desk and bookshelves. If computerized control/management systems are used, the main control unit should be kept in this room on a separate table;
- technical staff spend most of their time in the hatchery, but they make frequent calls to their office. They often wear rubber boots, hence an easily washable floor should be planned for this office. This space should be organized more as a common space rather than an office. Staff should be able to keep their property and to socialize there. This room should connect with a dressing room and a lavatory.

1.16 GENERAL RELATIONSHIPS AMONG UNITS AND SYSTEMS

As mentioned above, the size of the hatchery depends mainly on:

- the production targets;
- the production strategy;
- the number of fry per production cycle.

Once these factors have been defined, the relationships among the various units and the different systems are the last step for the design of the final hatchery layout.

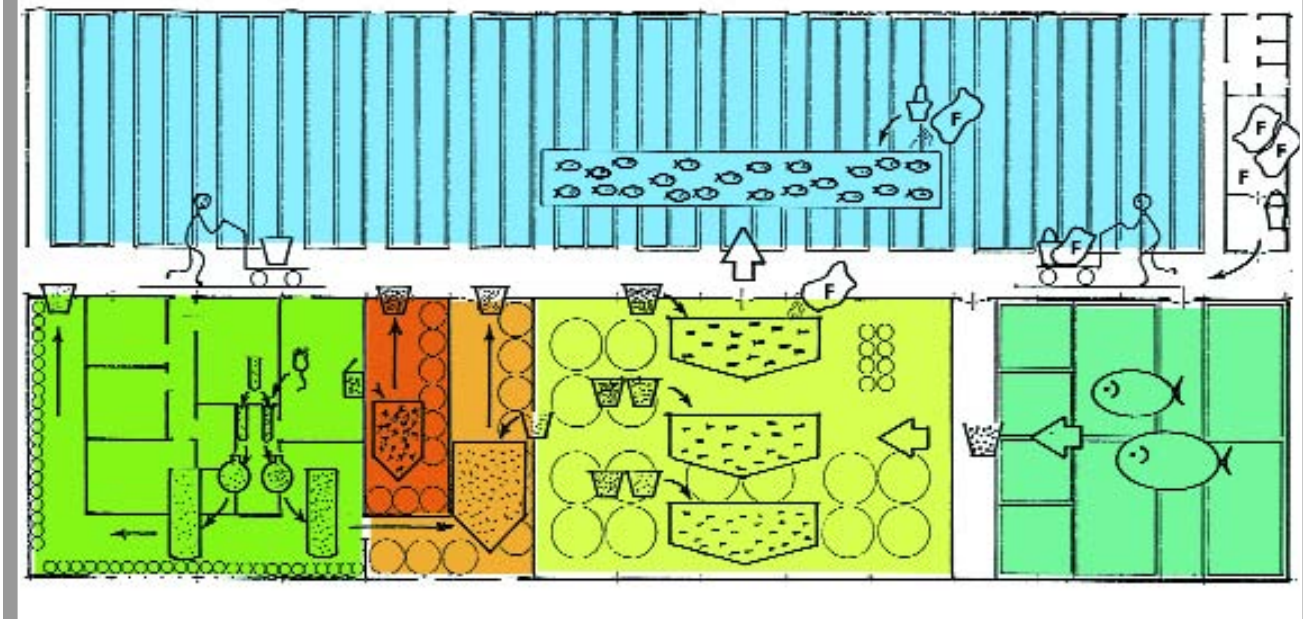


Fig. 27 - Schematic relationships among the units

A well-designed hatchery should also consider production flows, ergonomics of functions and harmonious distribution of systems to facilitate work and increase safety as well as to reduce construction and management costs.

The most important groups of relationships to be taken into consideration are those related to production, systems and work:

- production relationships between the units are those involving production flow, such as for example the typical sequence represented by phyto/zooplankton > larval rearing > weaning.
- systems relationships are those referring to the different engineering and architectural components, such as those between:
  - various support systems. For example, two or more different systems that may share the same passage or the same aerial supports;
  - all hatchery components, as is the case of several services being shared by different units. The laboratory is used for phyto/zooplankton, larvae and fry controls. The feed storage and preparation area is used for larvae and fry feeding. Water conditioning (fine filtration and sterilization) may serve both larvae and plankton units.
- work relationships are those existing between the hatchery systems and their manpower requirements. They contribute to improve the systems ergonomics by directly increasing productivity and security, and by simplifying routine activities.

Due consideration to these three groups of relationships contributes greatly to reduce the investment costs by saving on space and materials. It contributes also to make maintenance easier and cheaper.

In addition to these relationships, the hatchery design should also consider the specific characteristics of each unit. Differences exist in the temperature gradients or lighting conditions adopted in the various units and energy wastes should be avoided.

The design of a hatchery should anticipate possible future expansion. The various units should be assembled in a way that does not compromise the future expansion of the buildings. The larval rearing and weaning units, for instance, are normally designed with a communication on one side; the other sides should be kept free and tanks, aisles and pipelines should be positioned in such a way as to be easily expanded .

2.1 INTRODUCTION

The scope of this section is to describe the most widely adopted technical solutions concerning equipment and support systems used in Mediterranean hatcheries, with emphasis on hydraulic aspects. Design parameters, size calculation and installation criteria are dealt with in this section.

Each subsection is divided in two parts, both treated in detail:

1. the main support systems and,
2. their technical components.

Civil works related to buildings or roads, including concrete calculations, electrical and thermo-mechanical systems, are not dealt with because:

- they do not differ significantly from normal industrial standards in any country;
- the professionals in charge of their design and construction bear full civil liability;
- each country has its own rules, codes and standards for industrial plants, which may differ considerably.

2.2 SEAWATER SUPPLY, DISTRIBUTION AND DRAINAGE SYSTEMS

The seawater supply system is a crucial element of any hatchery project as the entire production depends on a reliable supply. It includes the following components:

- the seawater intake;
- the pumping station;
- the network connecting pumping station and hatchery;
- the first water treatment system (coarse filtration up to 100 μm);
- the internal distribution network;
- the secondary water treatment system (fine filtration up to 1 μm);
- the discharge system, that includes the drainage network, the wastewater treatment and the outlet.

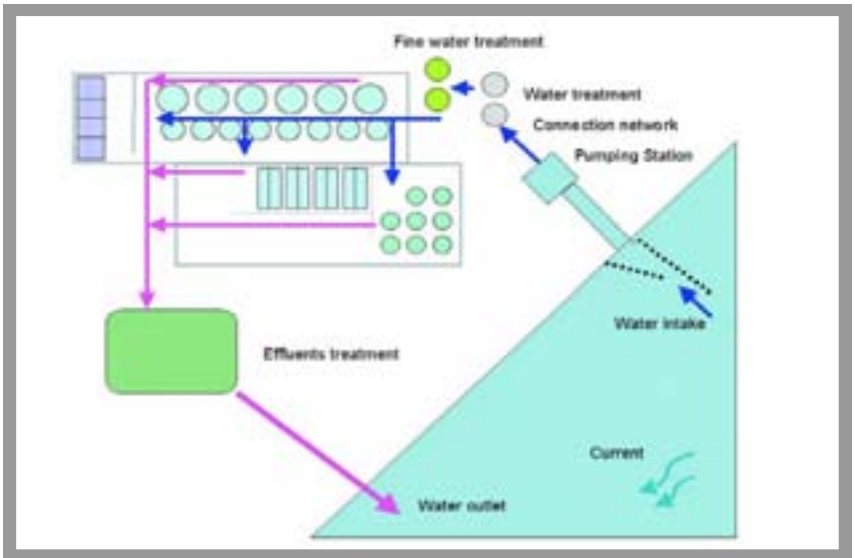


Fig. 28 - Seawater supply system diagram

2.3 SEAWATER INTAKE

In Mediterranean hatcheries, seawater can be supplied from two sources:

1. by direct pumping from the sea;
2. marine/brackishwater wells.

In both cases a reliable water supply system is a key factor for the successful production of fry and for the whole economy of the farm as it accounts for a very important part of its energy cost. A well designed system, in terms of piping and proper choice of adequate pumps and ancillary technical equipment, assures the efficient functioning of the breeding centre. This system is crucial in large commercial hatcheries, in which the requirements for treated marine water can easily exceed 150l/s.

The direct pumping of seawater is the most widespread system to supply Mediterranean seabass and gilthead seabream farms and hatcheries. It is described in detail below.

There are different types of water intakes according to the type of coastline, distance from the hatchery to the sea and type of beach and sea bottom sediment. The three most common situations encountered are described in the following sections:

- sandy coast with a low gradient,
- rocky coast,
- natural or artificial enclosure.

The peak water flow requirements of the hatchery must be carefully calculated to design properly the entire system. Future developments and system maintenance, which is an important aspect, should also be taken into consideration. If not properly kept in mind in the design phase, these two aspects may generate potential dangers such as abundance of fouling organisms in the pipelines or excessive silting in front of the water intake. These problems may easily become major drawbacks during the operation of the hatchery, requiring costly interventions to solve them.

Sandy coastline with a low gradient

Because of the risk of clogging by sediments, a water intake located on a sandy low coast would require the construction of civil works on the shore. Their design, related to their possible impact on littoral sediment transport, requires a detailed study of: wind regime, swell regime, sea level variations, tidal regime, bathymetry, and coastal currents.

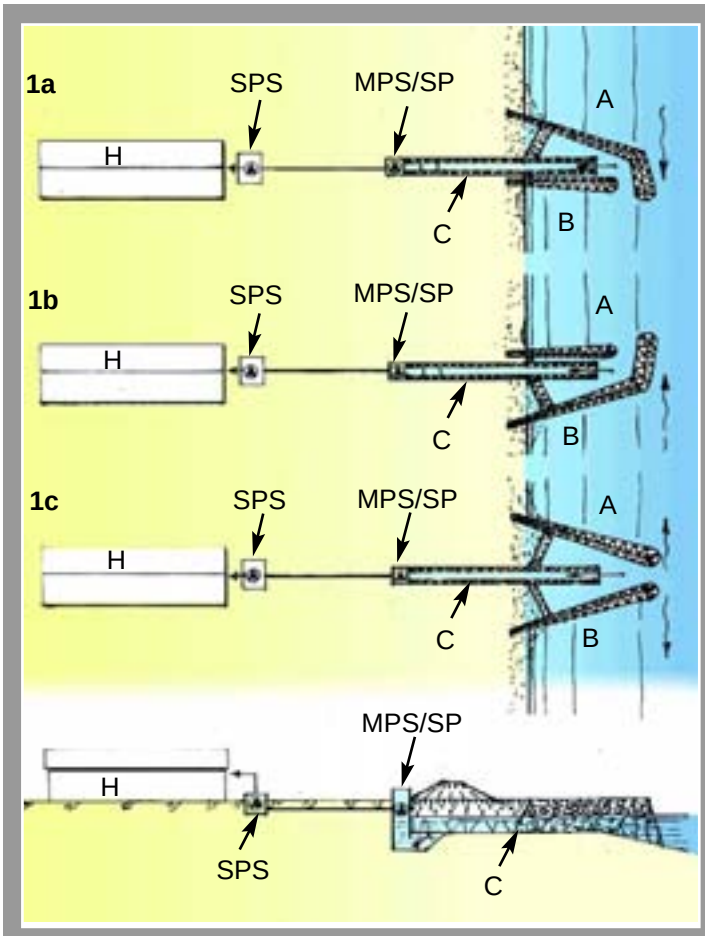


Fig. 29 - Water is pumped to a higher level at the end of the canal

- **type 1a**: protection of dyke B by dyke A when littoral drift is from (a) to (b);
- **type 1b**: protection of dyke A by dyke B when littoral drift is from (b) to (a);
- **type 1c**: converging straight dykes when littoral drift is negligible and/or equivalent in both directions.

LEGEND

MPS = main pumping station
SPS = secondary pumping station
H = hatchery
C = canal
PP = pipeline
- PP = pipeline under pressure
- PG = pipeline gravity
- PS = pipeline suction

St = strainer
PD = principal device
FPP = floating pressurized pipeline
DP = dry pump
SP = submersible pump

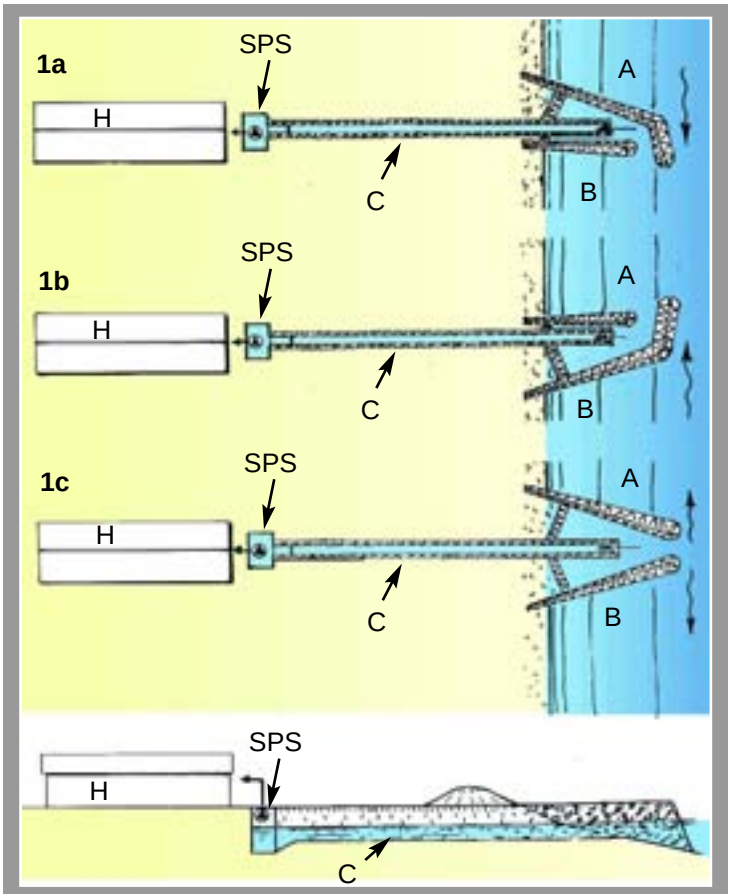


Fig. 30 - Water is not pumped at a higher level

- **types 1bis a, b, c** are identical to types 1 a, b, c, but without the main pumping station

For this typology, the two main technical solutions usually adopted are: (i) a canal protected at sea by two breakwaters and, (ii) a submersed pipeline.

Water intake through a canal protected at sea by two breakwaters

The design of these dykes depends on the direction of the littoral currents and on the transport of littoral sediment. The water intake protection at sea has to be adapted to different situations as described in Figures 29 and 30.

Both solutions are not cheap because of the construction cost of the channel. However, they assure an abundant supply of water of very good quality, also protecting the pumping station, and are easy to maintain and to build. This type of water intake is seldom used because of its cost but it is suitable when large amounts of water are needed (the case of the nursery unit). Fig. 29 differs from Fig. 30 only in the presence of a boosting pumping station.

Water intake through a protected pipeline

This is one of the most commonly adopted solutions, even if it has to be carefully evaluated because of the risk of clogging, positioning and its difficult maintenance if the pipeline has a diameter smaller than of 1 000mm. The following figures describe the possible solutions depending on material adopted, skill of the contractor and the preference of the company. If and when possible, always seek a gravity-fed water supply to bring water close to the hatchery (Fig. 31 to 34).

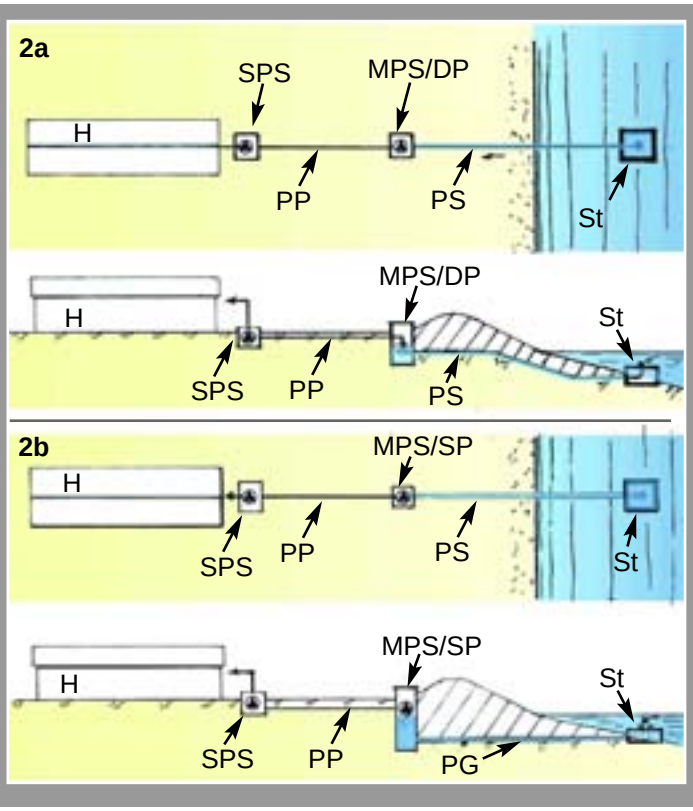


Fig. 31 - Water is pumped to a higher level at the end of the pipeline

- **type 2a**: intake pipeline buried in the beach and ending at a grating protected by a heavy concrete structure partially buried and "feeding" a pumping station equipped with a dry centrifugal pump;
- **type 2b**: intake pipeline similar to type 2a except that the pumping station is fed by gravity and is equipped with a submersible pump.

Seawater intake on a rocky coast

This type of seawater intake generally provides a good water quality due to the lower levels of sediments and suspended solids. These are intake systems generally with a marked gradient and the three types, described in the figures below, are installed depending on the type of pumping station adopted (Fig. 35 and 36).

In this typology the pipeline is fixed directly to the rocks, without protection, or to concrete

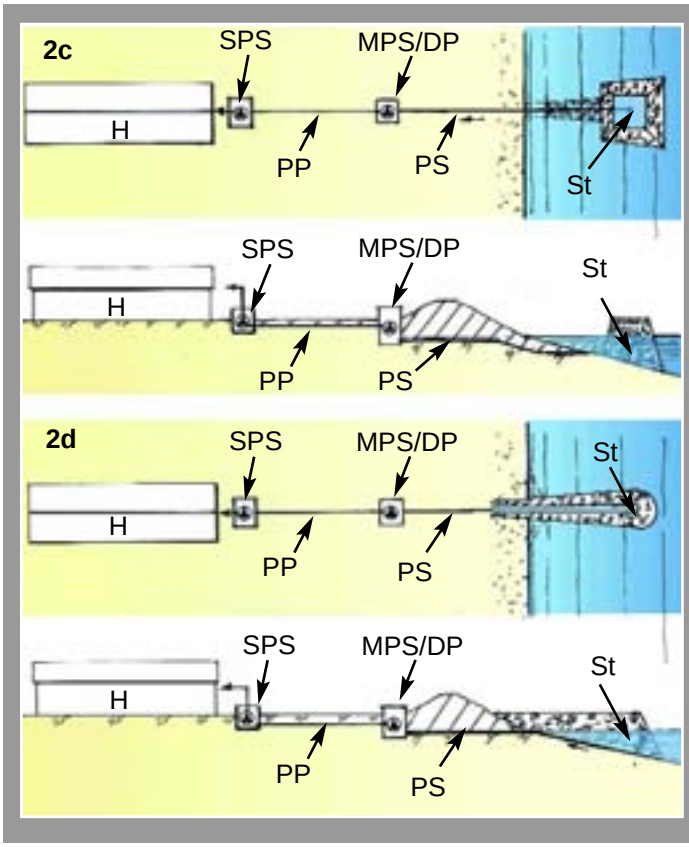


Fig. 32 - Water is pumped to a higher level at the end of the pipeline

- **type 2c**: intake pipeline buried in the beach with the suction end protected with a grate and heavy rocks;
- **type 2d**: intake pipeline laid down on the beach and protected by a dyke made with rocks.

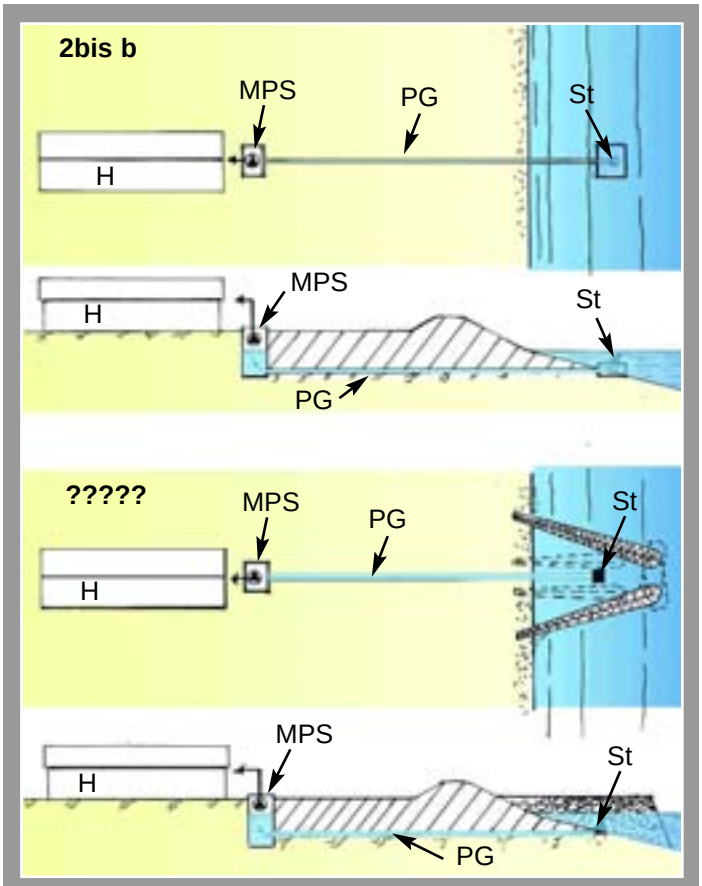


Fig. 34 - Water is not pumped at a higher level

- **type 2bis b** is identical to type 2b but with a single pumping station (direct hatchery supply);
- **types 2bis e, f, g** are identical to types 2e, f and g, but with a single pumping station.

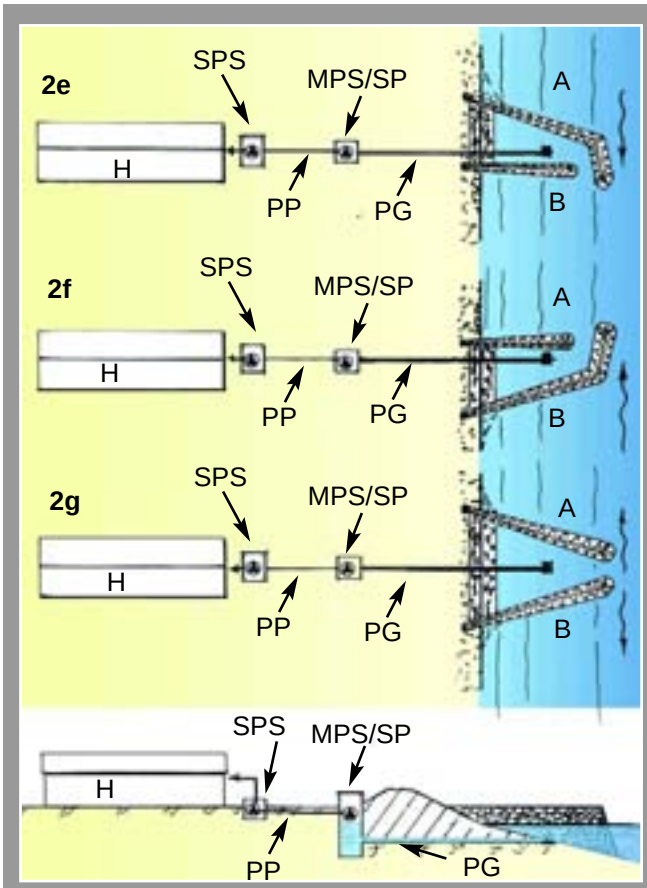


Fig. 33 - Water is pumped to a higher level at the end of the pipeline

- **types 2e, 2f, 2g:** the intake pipeline is buried in the beach and converging dykes made with rocks and whose geometry varies according to littoral drift, protect it from solids, as in the case of inlet types 1a, 1b, 1c, At sea there is a heavy concrete structure, partially buried. This solution is used when the pumping station has to be sited far from the sea and the water has to be pumped twice, either because the hatchery is higher than 2–3 meters above sea level, or because the water intake is too far for a single pumping station.

blocks or is embedded in the rocks. The design of this water intake type requires the same data as indicated for the cases above to estimate the stress or damage which could be caused by storms to the pipeline and suction protection grating.

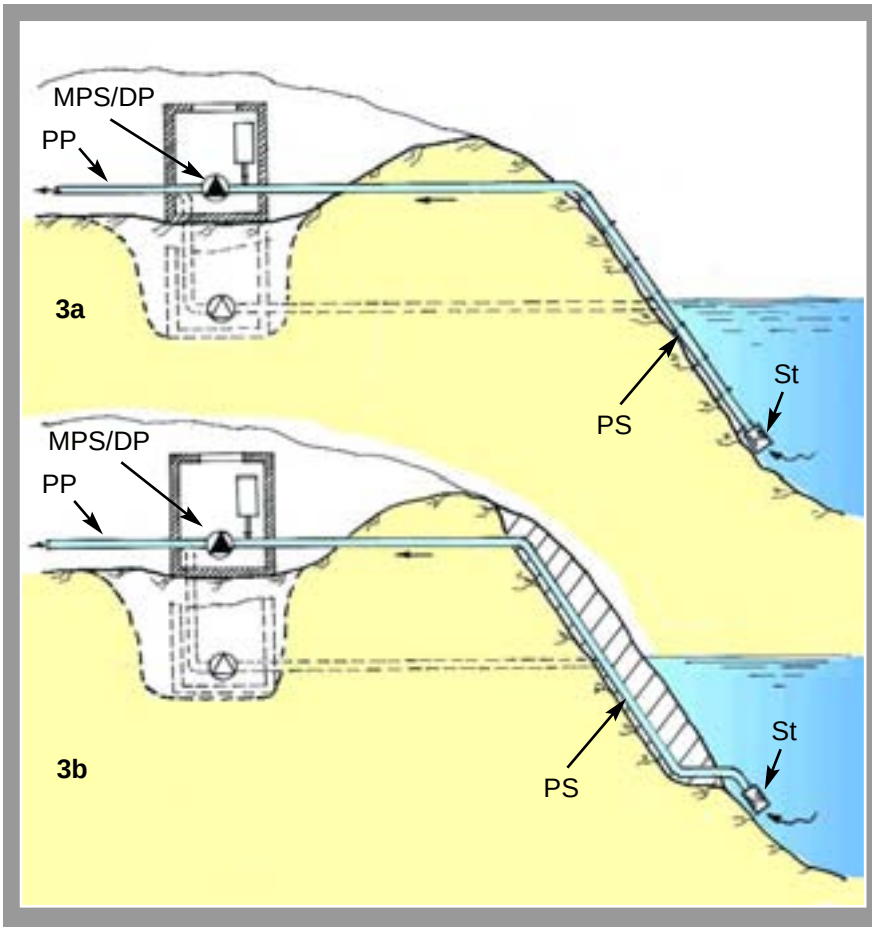


Fig. 35 - types 3a and 3b: the pumping station is equipped with a classical centrifugal pump, with or without priming cap, according to the water level. These water intakes could be :

- either a pipeline embedded into the rocks or fixed first to concrete blocks and then covered by the rocks. These two solutions are valid when the rocks are strong;
- or, a pipeline laid into a trench first dug into the rock sea bed and then filled with concrete after laying down the pipeline. This solution is chosen when the rocks are of bad quality and fragile.

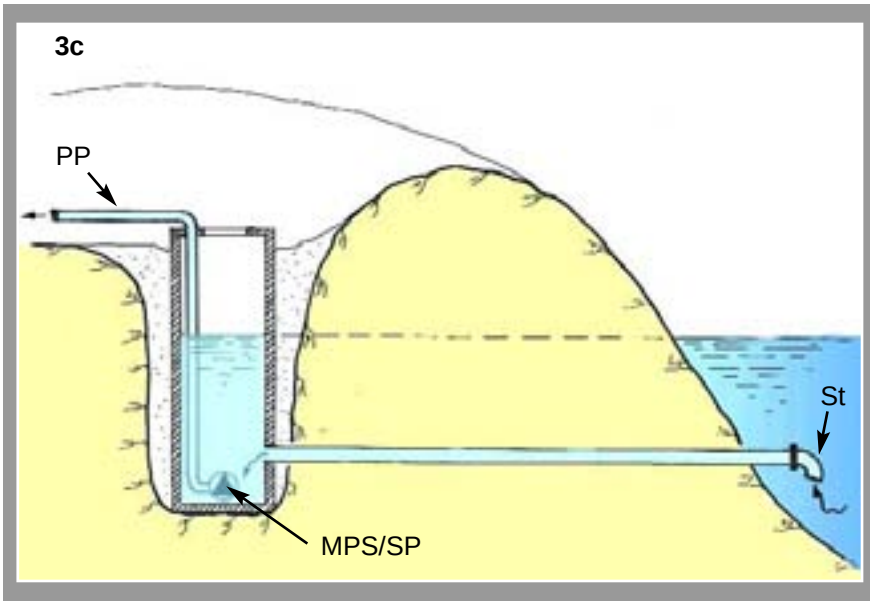


Fig. 36 - type 3c: the pumping station is said to be "wet" and is equipped with a submersible pump. This water intake is a pipeline placed in the sea bed rocks below lowest sea level (lowest point of storm swell or lowest tidal level). This avoids problems during pumping due to a shortage of water at the grating. It also allows a sufficient load to obtain the flow required.

Seawater intake placed inside a natural or artificial enclosure

A third type of water intake is the one placed inside coastal lagoons or man-made ponds connected to the sea through one or more openings in the sand bar (lagoon mouths) or which fill by seeping (percolation) through the sand. In the first case the pumping station has to be placed close to the mouth in order to pump seawater of the best quality. In the second case, the design of the water intake requires a good knowledge of the soil permeability to estimate the maximum amount of water that can be pumped (Fig. 37).

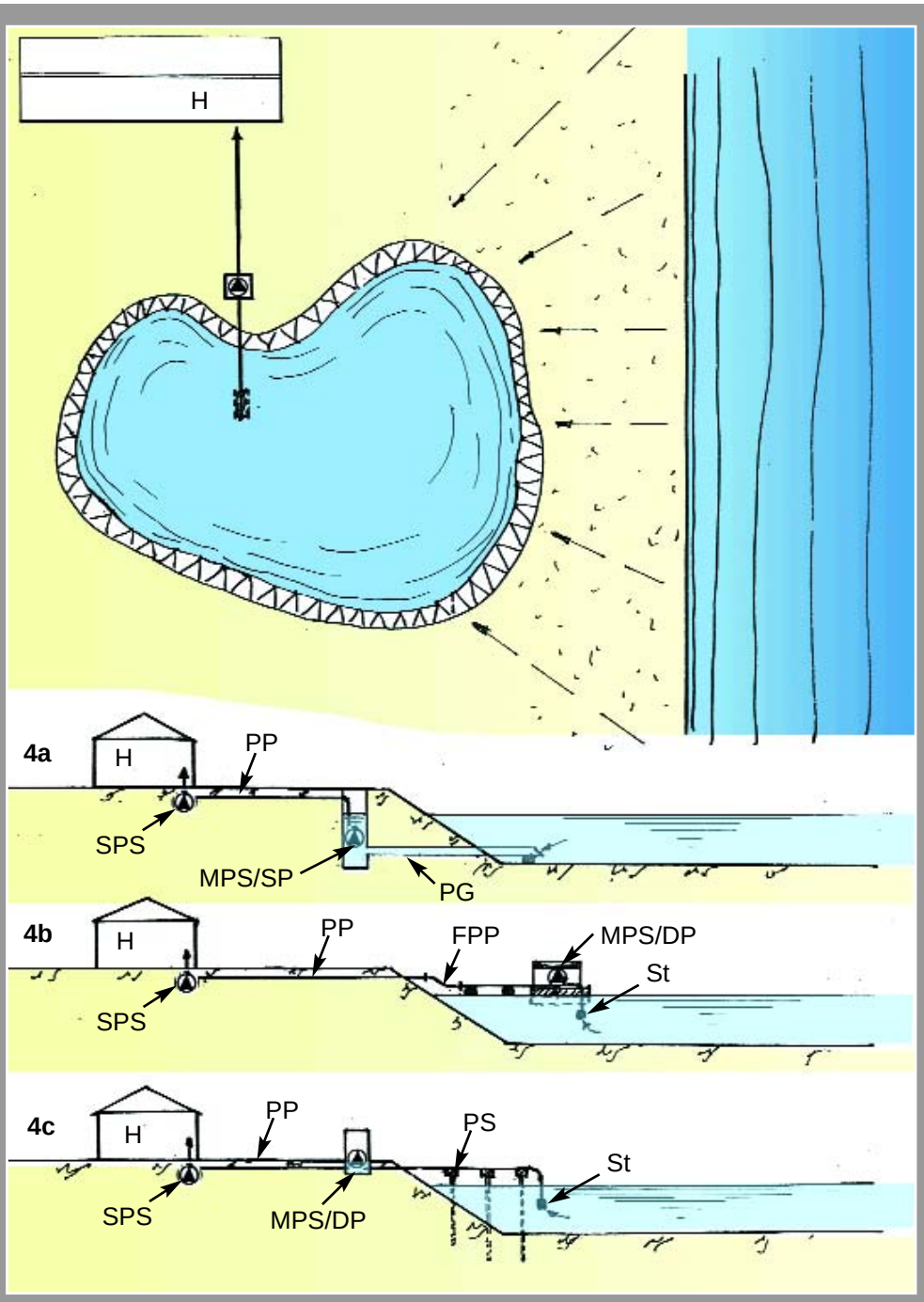


Fig. 37

- **type 4a**: an intake pipeline brings the water to the pump by gravity;
- **type 4b**: a floating pumping station and a delivery pipeline partially floating;
- **type 4c**: an intake pipeline supported above water level.

LEGEND

MPS = main pumping station
SPS = secondary pumping station
H = hatchery
C = canal
St = strainer
PD = principal device
FPP = floating pressurized pipeline
DP = dry pump
SP = submersible pump
PP = pipeline
- PP = pipeline under pressure
- PG = pipeline gravity
- PS = pipeline suction

2.4 DESIGNING WATER INTAKES

Geometry and structure of seawater intakes on a sandy coast

The design and construction of water intakes in this type of coastline are closely related to the study of existing littoral transport, which in turn depends on the nature and size of local sediments. This study, together with the structural study, has to be carefully analysed in order to prevent disastrous effects such as the complete and rapid silting of the water intake facilities.

Any study of the local littoral transport is based on the wave/swell spectrum, which gives for each direction the amplitude (range) frequency of the different swells. From this spectrum it is possible to draw the diffraction curves (or swell forecast) of the swells from different directions on the nautical map.

These curves provide estimates of the decrease/increase coefficients (c) of the swells with a significant amplitude as these swells progress toward the shore, and particularly when they reach the shallower water area and break over (the breaking area), at the edge of the shore area. This is where the works have to be built and where almost all the littoral drift takes place.

These curves in (Fig. 38 to 40) also allow estimate of the obliquity angle (α) of the swell in relation to the shore line. The solid flow (see below) along the shore is closely correlated to this angle. Figure 40 shows the variation of (α), the wave efficiency coefficient.

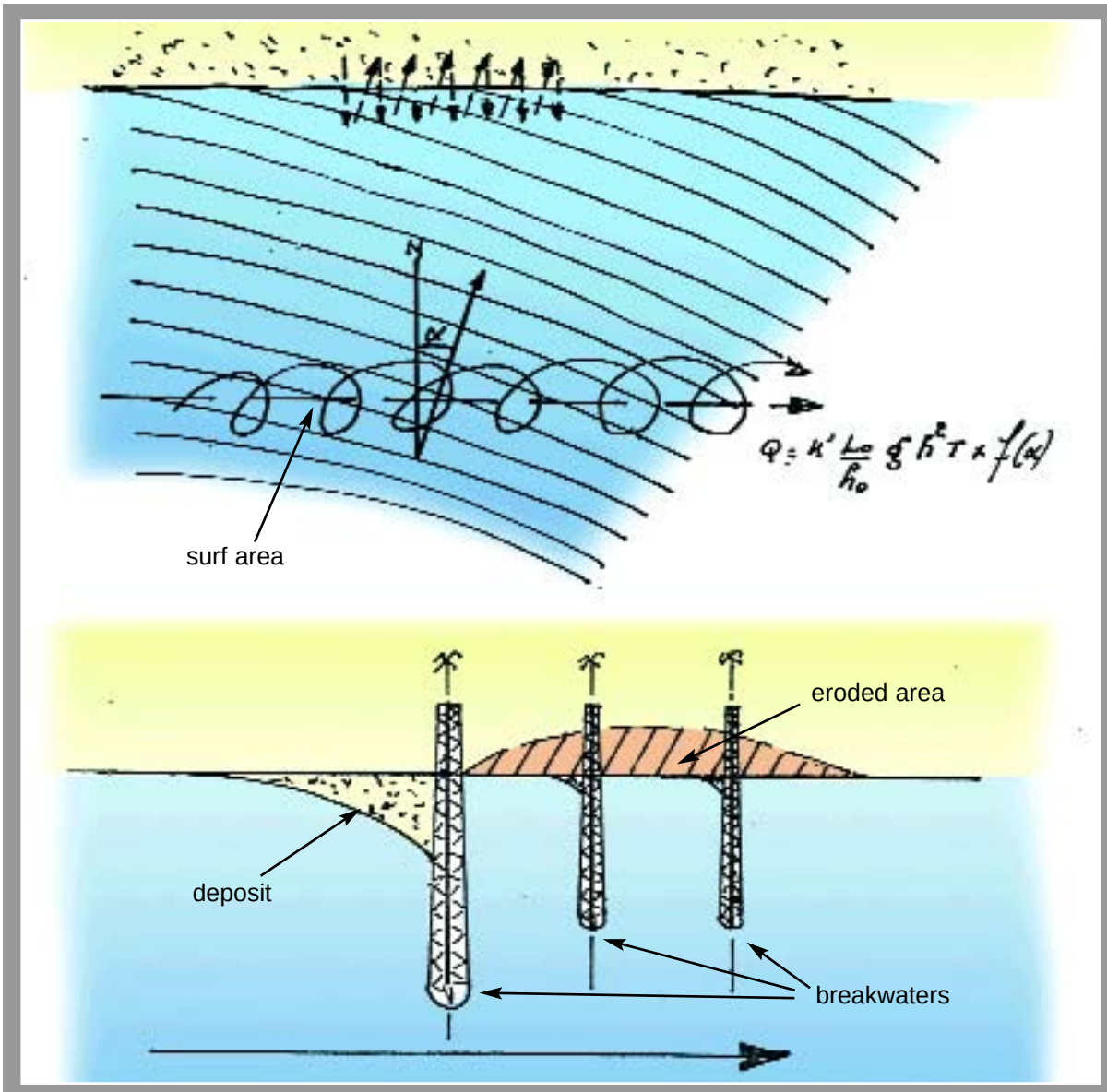


Fig. 38 - Sediment littoral transport by currents and waves. Effects of breakwaters on sediment transport

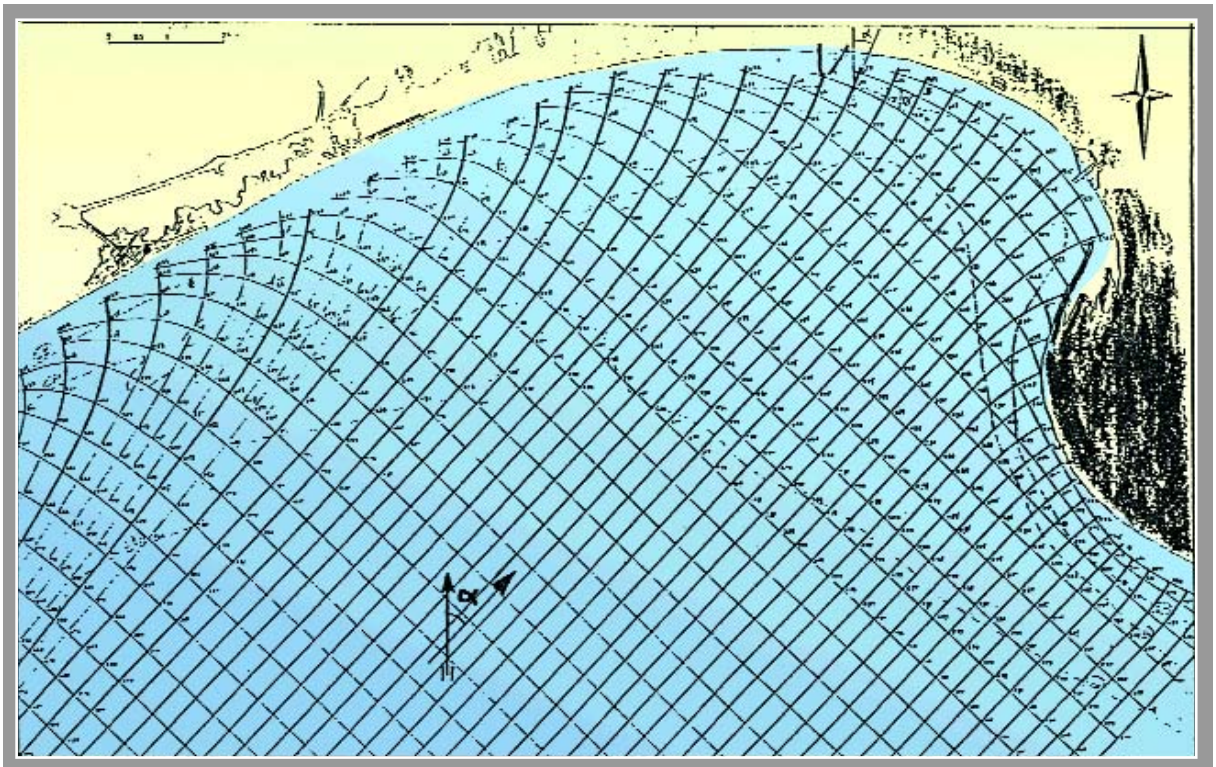


Fig. 39 - Wave spectrum and diffraction plans

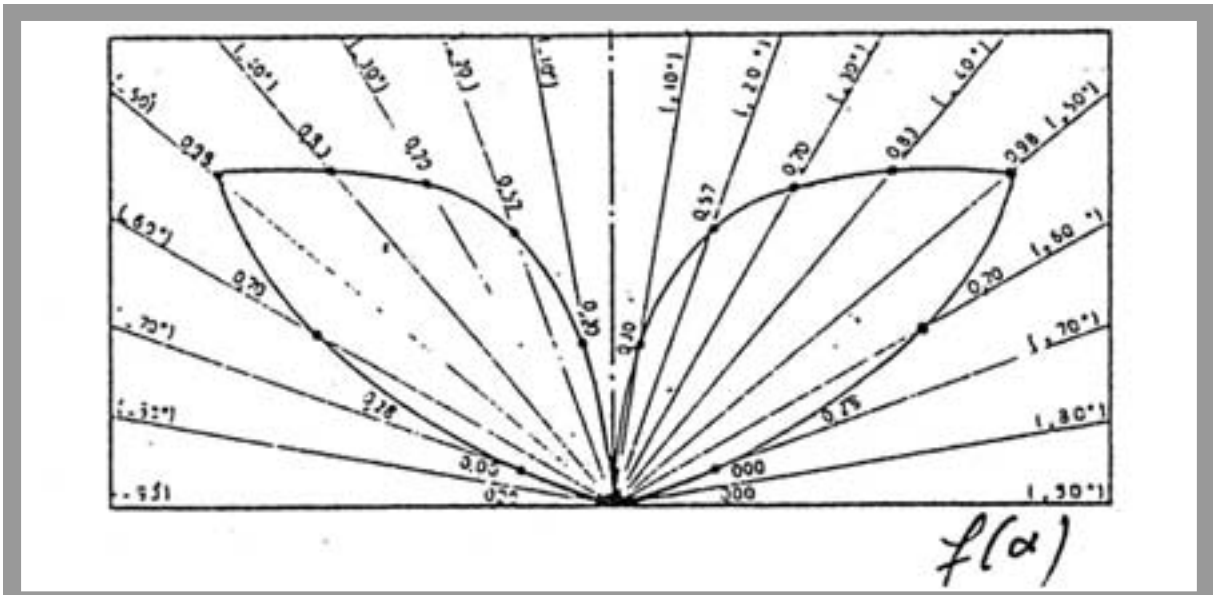


Fig. 40 - Curve of sediment transport in relation to wave obliquity angle (α)

The solid flow is defined as the quantity of solid material maintained in suspension in the water (by wave energy) and passing through the beach per unit of time. It is a flow of material going in and out the beach. To help define the water intake design, the formula of the solid flow produced in the wave breaking area along the shore, is as follows:

$$Q = K' (L_o + h_o) g h^2 T f(\alpha)$$

where:

- Q is the quantity of material transported
- K' is a coefficient function of the size of sand particles (d)
- L_o is equal to 1.56 T^2
- h_o is the swell amplitude in the open sea
- T is the period of the studied swell or wave period
- g is the gravity force acceleration, 9.81 m/s
- h is the amplitude at the first breaking swell or (h_o x c), with c being a coefficient taken from the "diffraction curves" of the swells when entering the breaking area
- α is the angle between the general direction of the waves and the the shore line at the entrance of the breaking area.

If Q_1 is the quantity of sand moved into one direction by all the oblique swells of quadrant (1) and Q_2 the sand quantity moved into the other direction by all the oblique swells of quadrant (2), then, the ratio Q_1/Q_2 (either greater or smaller than 1) will give the direction of the resultant littoral drift as follows:

$$\frac{Q_1}{Q_2} = \frac{\Sigma(Ki \frac{Lo}{ho} g h^2 T f(\alpha))}{\Sigma(Ki \frac{Li_o}{hi_o} g hi^2 T' f(\alpha))} = \frac{\Sigma(Lo \frac{h^2}{ho} T f(\alpha))}{\Sigma(Li_o \frac{hi^2}{hi_o} Ti f(\alpha))}$$

This is, of course, an estimate of the predominant sediment circulation.

Calculation and design of structures against sea storms

The calculation is based on the Hudson formula generally used to design the elements of the rock cover that should protect the structures from strong wave action. The formula is as follows:

$$P = \frac{d(H_c)^3 tg\alpha}{K\Delta(\frac{d}{d_o} - 1)^3}$$

where:

- P is the weight of the rocks in tonnes
- $K\Delta$ is a coefficient (equal to 3.2 for rocks)
- d is the specific density of the rocks, in t/m^3
- d_o is the water specific density or about 1 t/m^3
- $\propto$ is the angle with the horizontal of the external wall of the dyke
- H_c is the amplitude of the waves breaking on the structure

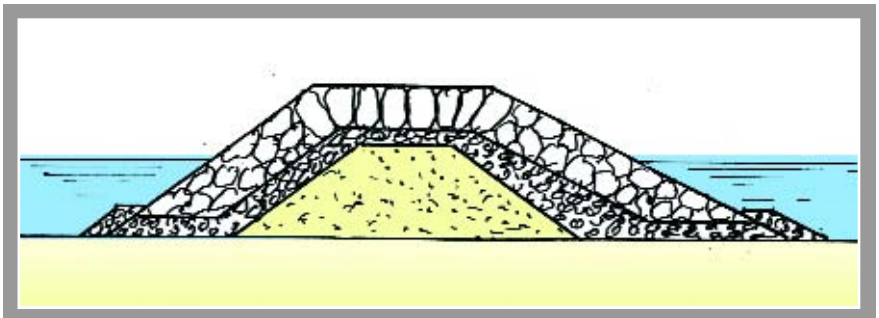


Fig. 41 - Cross-section of dyke built with rock in shallow water

Figure 41 shows the theoretical cross-section of a dyke made of rocks in shallow water. It is at a level higher than is usually considered for Mediterranean situations (3m). It is designed using the above formula.

Geometry and structure of seawater intakes on a rocky coast

In this case the intake structures, which when well-positioned do not interfere with the littoral transport, are designed taking into account only their resistance to the sea storms, and wave energy.

Hydraulic section of seawater intakes

(a) Open canal

It is a structure with a trapezoidal section (see Fig. 42).

However, it can also be built as a structure in reinforced concrete with a rectangular section (as indicated in Fig. 43).

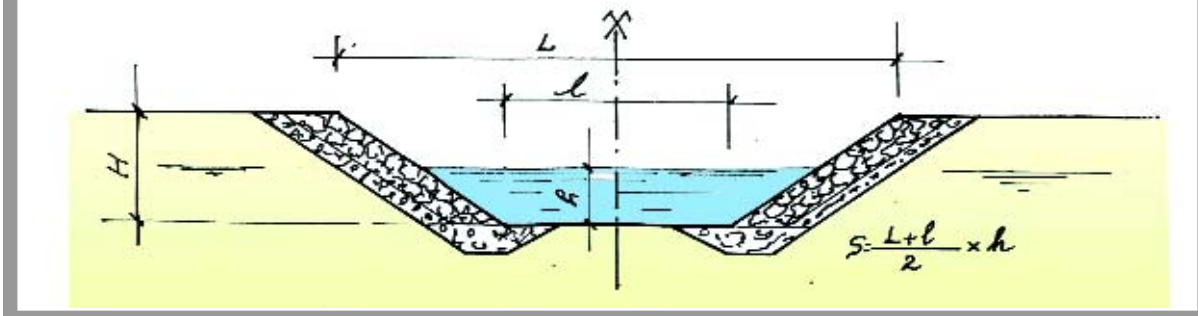


Fig. 42 - Open canal cross-section

The area of the cross-section to be used depends on the maximum water flow required, which is calculated by applying the **Bazin formula**:

$$Q = US \text{ and } U = C\sqrt{Ri} \text{ with } C = 87\sqrt{R} \div \gamma\sqrt{R}$$

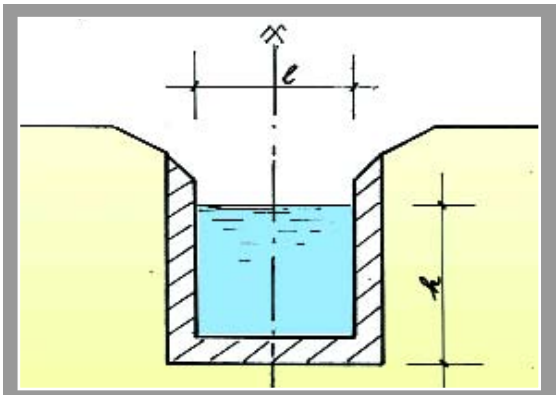


Fig. 43 - Square canal cross-section

where:

- Q is the water flow in m^3/s
- U is the water velocity in m/s
- S is the wet area of the canal cross-section, in m^2
- R is the hydraulic radius = S ÷ P, in m
- P is the wet perimeter, in m
- γ is the roughness coefficient of the internal dyke walls
- i is the hydraulic slope of the canal in m/m

Calculations are simplified by using the abacus that is usually found in the most important textbooks on hydraulics.

(b) Pipeline

In this case seawater is conveyed by pipeline to the pumping station either by gravity or by suction.

The size of the pipeline is calculated by applying the **Manning-Strickler** formula, as follows:

$$Q = US \text{ and } U = (1 \div n)\, R^{2/3}\, i^{1/2}$$

where:

Q is the water flow, in m^3/s
U is the water velocity, in m/s
S is the pipeline cross-section area, in m^2
n is the roughness coefficient of the pipe internal walls
R is the hydraulic radius = S ÷ P, in m
P is the wet perimeter, in m
i is the hydraulic slope of the pipeline, in m/m

The abacus for easier calculations and the data on head losses for pipes, elbows, ball valves and grating valves can be found in the most important hydraulic textbooks or are given directly by the PVC pipe and fitting producers.

2.5 CONSIDERATIONS ON THE CHOICE OF WATER INTAKE

When deciding on the construction of the seawater intake of a hatchery, two main groups of factors should be taken into account:

- the technical ones, which depend on site conditions and the required water flow;
- the economic ones, which are related to the cost of the structures to be built.

The final choice may be guided by the following considerations on water intakes and pumping stations:

- **Water intake through an open canal**

  An open canal supplying seawater by gravity directly to the main and secondary pumping stations and with water moving at low speed has the following advantages:

  - it carries little suspended sediments since it works as an effective settling basin,
  - it can be easily maintained without any interruption of water flow.

- **Water intake protected by converging dykes**

  From a technical standpoint, this is obviously the best solution. The littoral sediment transport is moderate and as the water intake is situated in a protected area (quiet water and low sediment load), the water can be fed to the main or secondary pumping station either through an open canal or a pipeline. However, because of the high construction costs, this solution can be considered only for very large hatcheries or, for those associated with large pond-based commercial farms.

- **Water intake in open sea with pipelines**

  From an economic point of view, this solution is certainly the most attractive. But, as it is built without any protection and within the wave breaking area, it may transport plenty of sand during swell periods, which means strong wear on the pumps. Moreover, before using water in the hatchery, coarse sediments and suspended solids should be removed through a set of filters.

- **Water intake with a screened pipe protected by a pile of rocks**

  This solution supplies water with less sediment at the pumping station. However, a set of filters to screen suspended solids is required.

- **Water intake working by suction or by gravity**

  It is always better, whenever possible, to have a water intake working by gravity. If properly designed and installed, a pipeline working by gravity does not affect the functioning of the pumps. On the contrary, a pipeline requiring suction is often a source of problems such as air intake, priming failure and mechanical wearing of the pumps.

2.6 MAIN PUMPING STATION

The pumping station is the structure where pumps are installed. When the hatchery is close to the sea or the difference between the hatchery level and the sea level does not exceed 2 meters, a single pumping unit is enough. In all other cases, it is better to bring seawater first to a reservoir close to the hatchery, from which it is pumped to the different units.

Wells are also used to supply water to the hatchery, but rather as a secondary pumping station, regardless of their type, number and dimensions.

Fig. 44 - An aerial view of farm showing the main pumping station (TIMAR, Portugal)

To bring seawater from the water intake to the hatchery, two types of pumping station exist:

- a "dry" pumping station, built as a room outside of the water or watertight in which the pumps are installed functioning in open air;
- a "flooded" or "wet" pumping station, built as a reservoir, in which submersible or vertical pumps are installed.

"Dry" pumping station

This type of pumping station is usually equipped with horizontal centrifugal pumps but sometimes vertical axial pumps are also employed. As these types of pumps work outside the water, the room where the pumps are to be installed should be located above the highest sea level. To eliminate the need for a priming cap on the pumps, which would be necessary when the suction pipeline is placed above water level, it would also be possible to install the pumps at a slightly lower level, close to sea level. This choice is, however, a risky solution and requires that the lower part of the premises of the pumping stations be watertight.

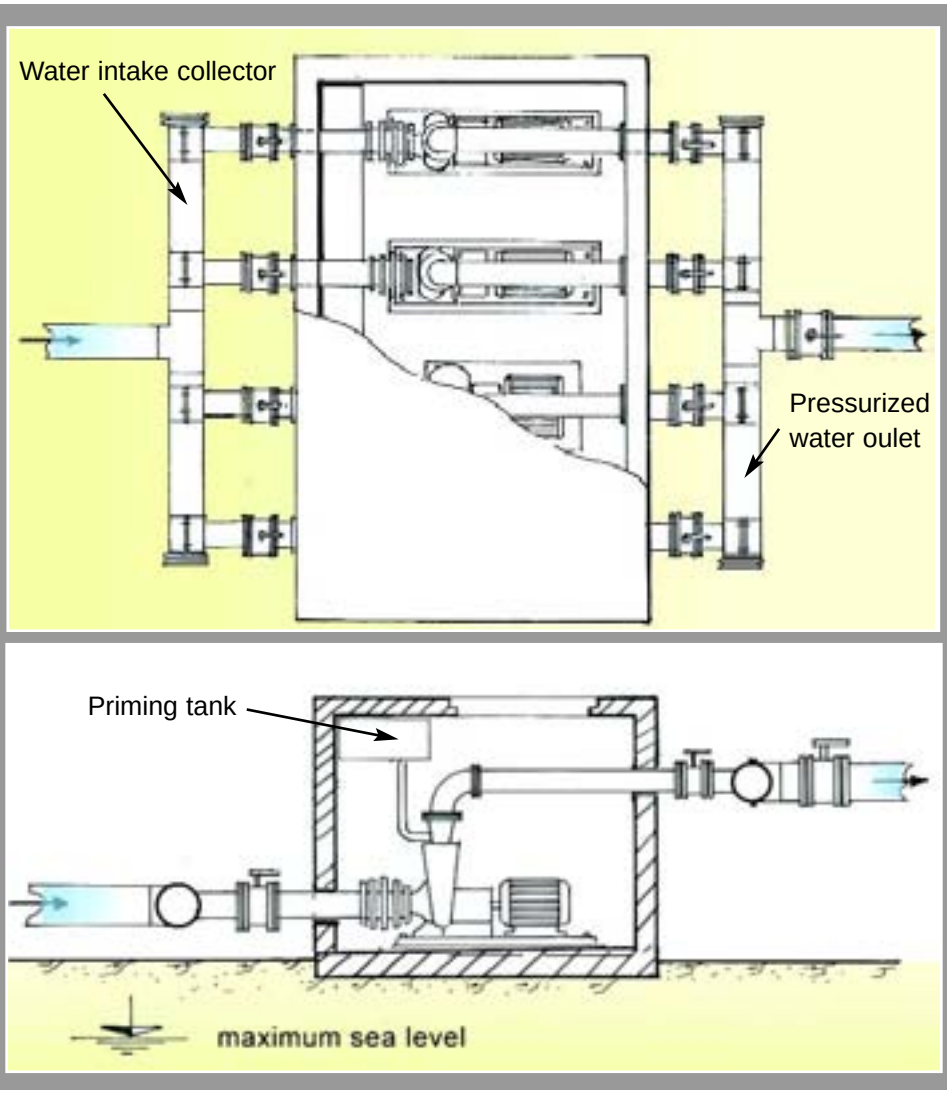


Fig. 45 - "Dry" pumping station. Top and lateral views

Seawater can be pumped in two ways:

- when an open canal brings sea water to the pumping stations, from a sump located at the end of the intake canal, or
- directly from the sea through a grating, which can be protected by a structure built of rocks, or else, installed in the open sea without protection.

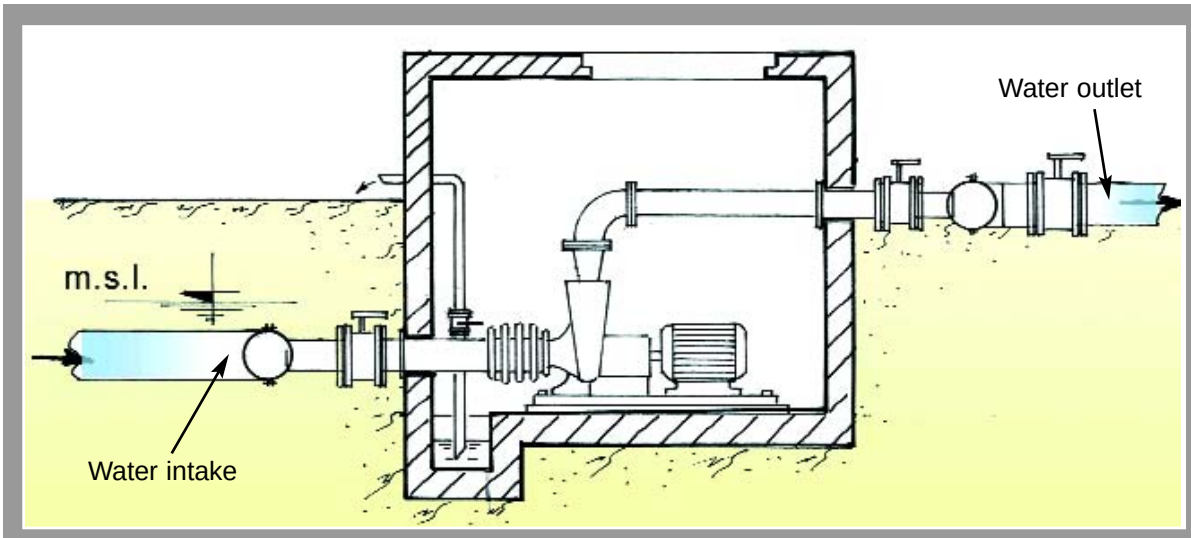


Fig . 46 - "Dry" pumping station below sea level

"Wet" pumping station

This type of main pumping station can be equipped with either submersible pump sets or vertical axial pumps. It consists of a sump communicating directly with the sea through an open canal or a pipeline feeding the sump by gravity. It is important to place the pipeline or the canal below the lowest sea level so that grating and suction line would never be empty. Submersible pumps are installed directly into this sump, together with their lifting and back-flow systems. Vertical axial pumps are installed above water level on a metal frame.

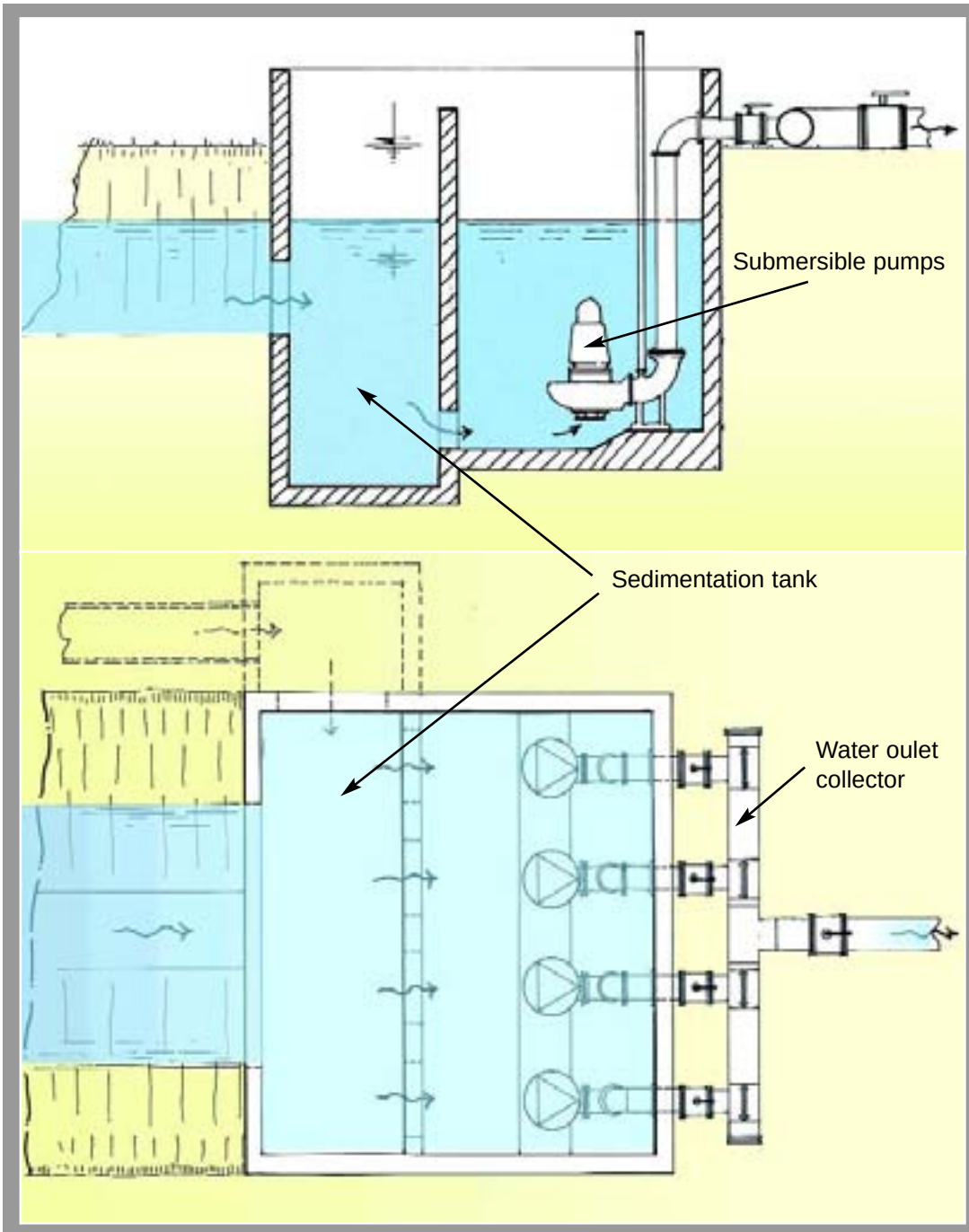


Fig. 47 - "Wet" pumping station. Section and top view

In a separate building, close to the pumping station, the following equipment is usually installed:

- the control panel of the pumps of the secondary station (main switch, controls, and protection circuits);
- the hatchery emergency generator set together with its control panel.

Sometimes, the pumping station can be equipped with a water tower, which should allow water distribution by gravity. This choice is very interesting in order to avoid nitrogen supersaturation, but it is much more complex to run as it requires frequent cleaning to maintain a maximum control of hygienic conditions. In any case, one separate reservoir per circuit has to be contemplated in the hydraulic design.

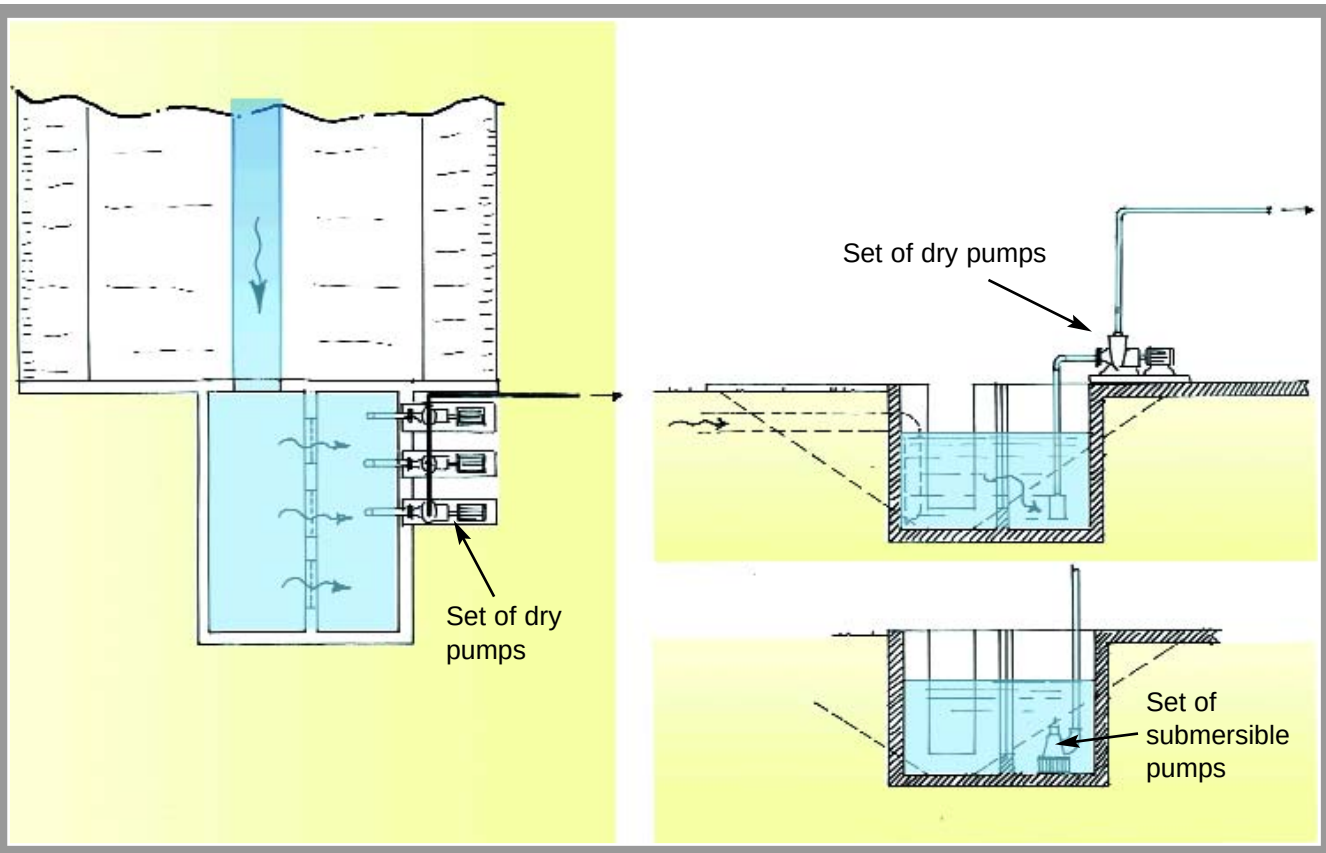


Fig. 48 - Secondary pumping station. Top view and section showing also alternative with submersible pump

2.7 DESIGN OF THE PUMPING STATIONS

The design of a pumping station should take into account the following parameters:

- type of pumps chosen (site conditions, design preference);
- maximum water flow required to supply the hatchery at any time;
- different water flows required during the annual production cycle;
- preferred schedule of utilization of the pumps; this helps in defining the number of pumps to be installed;
- hydraulic conditions under which the pumps operate, such as:
  - for the main station: lowest pumping level, i.e. the lowest sea level as recorded in front of the hatchery;
  - for the secondary station: partial flows to be distributed to the different hatchery sectors and necessary head for the equipment to function properly (which is a function of the hatchery design and type of equipment installed).

On the basis of these data, it is then possible to proceed with the design of the pumping stations by:

- determining the number of pump sets required and their characteristics;
- specifying the characteristics of the main and secondary pumping stations.

Design of the main pumping station

Generally the number of pump sets to be installed varies from two to four as a compromise between security (minimum two pumps) and economy (maximum of four pumps to cut running costs by fractioning the use) as follows:

- two sets with a unit flow Qu = Qmax and the installed flow Qi = 2 Qmax. This solution does not allow the adaptation of the flow to the changing needs in water supply of the hatchery, but reduces investments;
- three sets with a unit flow of Qu = 1/2Qmax and the installed total flow Qi = 1.5 Qmax. This solution allows a certain flexibility, but requires more investment;
- four sets with two sizes of unit flow: Qu = 1/2Qmax for two sets and Qu = 1/4Qmax for the two other sets. Then the total flow Qi = 1.5 Qmax, as in the previous case, but with a better possibility of adapting the flow to the real needs. Of course, this solution requires even more investment than the previous one.

(In which Qu is the unitary flow of one pump. Qmax is the maximum flow needed by the hatchery operations. Qi is the maximum flow capacity when all the installed pumps are running).

Design of the secondary pumping station

For each unit in the hatchery, at least two pumps should be installed, one to be in operation while the other is kept on stand-by. This is, of course, the minimal configuration acceptable. If more pumps are desired the same consideration on the balance between investment and running costs discussed in the paragraph above should be taken into account. Spare parts should be readily available for each type of pump, and should be regularly replaced when used.

2.8 CONSIDERATIONS FOR THE CHOICE OF THE PUMPING STATION

The final solution should be chosen taking into account factors like reliability of equipment and easy utilization, without neglecting the economic aspects related to investment and operational cost of the equipment. The following considerations can be of some assistance:

Type of pump set

Because of the type of liquid to be transported (seawater) and the salty environment in which the pumps operate, the pump type that gives best results are the submersible pumps treated against marine corrosion. The reliability of such pumps comes from the fact that they are built very carefully to work continuously underwater. Due to their easy installation and maintenance, submersible pumps offer real advantages due to the practical mechanisms used for their assembly and dismantling. The very reduced chance to produce nitrogen oversaturation in the water pumped is another positive characteristic of this type of pump. Vertical and horizontal pumps are also frequently used as they are cheaper and are also easy to maintain. These pumps are also suitable for work with seawater but some additional precautions have to be taken:

- the calculation of pump size and engines has to be very precise, in particular, for the total head. These pumps have a more limited range and working out of the optimal curve would affect their efficiency and can quickly destroy the impeller;

- materials have to be carefully chosen between marine bronze, stainless steel AISI 316, titanium and plastic (in case of pumps used for closed and semi-closed circuits, bronze should not be employed due to the risk of contamination with metallic ions);
- all joints have to be frequently checked in order to avoid nitrogen oversaturation in the water pumped.

2.9 SEAWATER WELLS

Well water of good quality, due to the stability of its physico-chemical characteristics, is an asset not to be missed by any hatchery. A well can be defined as a structure built in the ground, able to reach the water table and from where water can be pumped out. Its shape is usually cylindrical, developing along a vertical axis, and consists of two parts: an external wall, built from super-imposed cylindrical elements, in concrete, plastic or other materials forming the well-casing, and an internal filter.

The data required for a proper well design are divided in three main categories:

- topographic data,
- geo-technical data, and
- hydraulic data.

Topographic data are essential to have a correct idea of the land in terms of its elevation, and to evaluate the variations of the water table levels.

Geo-technical data are fundamental for the construction of the well and have an impact also on construction costs. In fact, as the well casing will penetrate up to the water table, it is necessary to know in advance the characteristics of the soil. In particular, it is necessary to know:

- the soil texture, to determine the size composition of the natural gravel filter;
- the permeability of the soil, which is characterized by the permeability coefficient, a fundamental element to determine the flow of the well.

The soil texture is determined in the laboratory on the basis of samples taken by means of augers at various depths of the water table.

The permeability coefficient is determined by percolation tests carried out on the spot at different depths of the water bearing layers. This is the only way to provide a correct value for this coefficient, as laboratory tests on samples taken from the spot are usually unreliable. This is due to the difficulty encountered in bringing sand samples from water-bearing layers to the laboratory, without affecting their characteristics.

Hydraulic data essential to calculate wells are:

- the well upper level, which is generally close to the average sea level in alluvial zones, with slight variations created by the sea level variations (alternated and out of phase);
- the strength of the water table, i.e. the thickness of the water-bearing sands, and the eventual position, if it exists, of:
  - the ceiling of the water table, formed by an impermeable layer;
  - the bottom of the water table, also formed by an impermeable layer;
- the level variation in the water table where pumping takes place.

To evaluate whether a well is feasible or not, two different types of analysis are required:

- the estimation of the well flow on the basis of geotechnical and hydraulic data collected;
- the calculation of the well structure in terms of civil works and filtering material.

Flow estimation

For this estimation the following formula is used:

$$Q = HK \frac{H_o^2 - H_p^2}{\ln\left(\frac{R_a}{r_p}\right)}$$

where:

- Q flow in m^3/sec
- K permeability coefficients in m/sec
- H_o height of the exploited water table
- H_p height of water in the well (stabilized level for a given Q)
- R_a external limit of the draw down curve
- r_p well radius
- ln neperian logarithm = 2.3 decimal logarithm

From this formula it can be deducted that the well flow is:

1. directly proportional to:
   - the coefficient K;
   - to a greater degree, to the variation of the water level in the well ($H_o^2 - H_p^2$);
   - to a lesser degree, to the radius of the well: rp (ln rp).

2. inversely proportional to:
   - the radius of the area where the well activity is felt (R_a) in the water table, this radius of activity being in itself inversely proportional to K, which increases still the importance of K in the flow calculation.

Finally, and to be able to appreciate the importance of the various parameters intervening in the calculation of the flow capacity of a well, two examples are given below:

Parameter	Example 1	Example 2
K (m/sec)	0.0001 or 10^{-4} (fine sand with limited permeability)	0.0001 or 10^{-3} (permeable sand)
Ho (m)	9.00 } Dh= 8.00	5.00 } Dh= 4.00
Hp (m)	1.00	1.00
Ra (m)	50.00	50.00
rp (m)	2.00	1.00
Q (m^3/sec)	$Hx \cdot 0.0001 \frac{(9^2 - 1^2)}{\ln\left(\frac{50}{2}\right)}$ $= \frac{0.025}{3.21} = 0.0078$ m^3/sec or 7.8l/sec	$Hx \cdot 0.001 \frac{(5^2 - 1^2)}{\ln\left(\frac{50}{2}\right)}$ $= \frac{0.075}{3.91} = 0.019$ m^3/sec or 19l/sec

The analysis of these two examples highlights the importance of the coefficient K, depending on whether we are dealing with fine sand with limited permeability or with more permeable coarser sand. Even with a hydraulic load and a well diameter reduced to half, the flow is considerably increased.

Q_2 = 19 l/sec with	K =	1×10^{-3}
	Dh_2 =	4 m
	rp_2 =	1 m
Q_1 = 7.8 l/sec with	K =	1×10^{-4}
	Dh_1 =	8 m
	rp_1 =	2 m

It may be possible to use seawater wells when a hatchery is to be established on sandy or non-homogeneous soils. They are easy to build and guarantee a constant water supply. Areas adequate for well construction are usually formed by sediments which go from fine sand to silt and for which the permeability coefficient K varies, in m/sec, from 1×10^{-3} for coarse sand to 1×10^{-9} for silt. In the case of rocky coastlines, apart from some very unusual locations, it is better to consider from the planning stages a standard pumping station, drawing water directly from the sea.

The strength of the littoral water tables is generally weak, usually only a few meters. This implies that the flow that could be obtained is modest, being in the order of a few litres per second rather than tens of litres per second.

As a final consideration, it is very important to bear in mind that in case of large wells we should avoid pumping more than 30 litres per second in order to reduce the movement of fine particles all around the well area and the resulting quick clogging. Moreover, it has to be borne in mind that wells are often temporary constructions with an expected life span of 5-10 years. Therefore locations for new wells should be found in due time.

2.10 PIPELINES AND CANALS

Pipelines and canals (open canals, gutters) are used to carry seawater to and from the hatchery. Different materials are used for pipelines, depending on their use and on the hatchery sectors where they will be installed. Materials used for the piping outdoors could be protected steel, concrete and fibreglass, while polyethylene (PE) and polyvinyl chloride (PVC) are used for piping inside the hatchery, where non-toxic materials are required. Canals and gutters are mostly made of reinforced concrete, prefabricated concrete, bricks, PVC and metal.

In general, for pipelines that have to work under pressure, PVC or PE are the materials used more frequently, while for hatchery systems in which liquids flow by gravity, open channels or PVC and PE pipes are common. Inside the hatchery all the water circuits are normally built using PVC piping, which is the more flexible and easy to use material in terms of installation and repairs, and also because of the variety of existing PVC fittings such as valves, elbows, fast joints, etc.

Feeding the main pumping station

Pipelines bringing water to the main pumping station, either using suction or gravity, are generally made of:

- coated steel pipes (inside and outside), with a special protection coat to limit corrosion;
- concrete pipes with a metal core;
- PE pipes covered with concrete or ballasted with concrete blocks to counter buoyancy.

The working pressure limit of the pipeline should be at least 6 bars, but it is better to use piping that could work at 10 or 12 bars pressure, although it may be slightly more expensive. It is preferable to use oversize pipes so that they can stand severe working conditions in the sea. All the sections and fittings of the pipeline are gathered on site; then they are welded/assembled after having prepared the trenches

in the sea bottom and on land. Immediately after, the pipeline is pushed into the sea on floats and is lowered into the trench. This work is often considered of secondary importance, but it is often a key element for the success of the hatchery and farm. Saving money on this installation, materials or studies could severely affect all farm sectors later.

Connecting the main and secondary pumping stations (when necessary)

This hydraulic connection is generally made using the following pipes:

- PE pipes of the series N.P. 6 (nominal pressure 6 bars) for service under low pressure or of the series N.P. 10 (nominal pressure 10 bars) for service under medium pressure;
- PVC pipes of series N.P. 6 or N.P.10. They are usually 6 m long and they are joined either by solvent welding, or by using flanges or adapter fittings; or
- concrete pipes, generally 5 m long and assembled by adapter fittings.

Distributing water in the hatchery

Water is distributed inside the hatchery by pipeline systems that are either suspended under the roof or running on the floor. The first solution is preferable to limit the risk of possible damage to the pipes and to facilitate movements in all areas, whilst the second option is frequently an easier and cheaper solution.

Pipelines for internal distribution of water are made of PVC and are usually of small diameter (31 to 200mm), assembled by solvent welding or threaded sockets, or fast joints. In the case of long pipelines, fast joints are preferable since a piping system that can be easily dismantled can also be thoroughly cleaned and disinfected. Standard pipes usually available are 6 m long.

Draining water from the hatchery

Water is drained from the hatchery through a network of secondary channels/gutters that convey the effluents from the various tanks to the main drainage canal. The internal gutter network is usually made of concrete, or of light PVC, and it can be covered with:

- removable reinforced concrete slabs, which are essential for PVC gutters;
- wooden boards, or metal slabs coated for protection against corrosion.

In summary, each pipe should be chosen and used according to specific needs. Stainless steel or concrete pipes should be used when a strong mechanical resistance is needed. PE pipes should be preferred when mechanical resistance is not the sole factor to consider, and the pipe is going to be exposed to atmospheric conditions. Finally, PVC pipes are generally used for internal pipelines as this material is not toxic and has a very small roughness coefficient, which allows the use of smaller pipes for accurate calibration of the water flow to the various outlets.

The final choice for materials should be based on an accurate survey to identify local manufacturers, to evaluate the quality and cost of available materials and to locate potential contractors with the know-how and equipment necessary to put together the hydraulic systems.

2.11 DESIGN OF PIPELINES, OUTLETS AND CANALS

Four types of information are essential for the correct sizing and design of a pipeline network:

1. the roughness coefficient of the material chosen;
2. the water flow required;
3. the internal water velocity;
4. the pre-defined head loss produced by the line lenght/fittings and by the equipment interposed.

Design of a pipeline working under pressure

The design of a closed pipeline is made using the Manning-Strickler formula, (also applicable for water transfer by gravity), which is as follows:

$$Q = US = U\,(K\,R^{2/3}\,i^{1/2})$$

where:

Q = water flow in m^3/s
U = water speed in m/s
S = wet section area in m^2
K = head loss coefficient = 1/n
n = roughness coefficient
R = average radius = S/P
P = wet perimeter in m
i = hydraulic slope in m per m

Using this formula it is easy to calculate any of its elements, for example:

- knowing section and flow, it is possible to determine the hydraulic slope;
- in case of a fixed slope, it is possible to determine how much water can pass through the pipe;
- vice-versa, knowing the flow it is possible to determine the dimension of the pipe.

Sometimes, to simplify calculations, an abacus or graphic methods can also be used.

The head loss coefficient generally considered for smooth pipes under pressure is K = 95 which corresponds to a roughness coefficient n = 0.0105. For PVC pipes, K is about 120 and n = 0.0083.

To calculate the total head charge H in m (the height necessary to transfer a given flow), we can use the formula: H = i L, where i is the hydraulic slope (in m/m) and L the length (in m) of the pipeline. To this the sum of head losses due to the pipeline fittings (grating, elbows, valves, etc.) should be added.

Pipe fittings are frequently expressed in equivalent length of pipe L_1. L_2, L_3, etc. The length of the pipeline L is lengthened by the sum of these equivalent lengths, so that finally the formula would be:

$$H = i\ (L + L_1 + L_2 + L_3 + ...)$$

Example:

- flow required: 0.3 m^3/s
- pipeline: diameter 400 mm; length 500 m (straight pipe without fittings)
- Hydraulic slope from the abacus as: i = 0.01175 m/m

Thus, the total head charge necessary: H = 0.012 x 500 = 6 m or 0.6 bar

In many cases, choosing the size of a small PVC/HDAD pipe is done by consulting a simple graphic abacus provided by the pipe manufacturer. This way it is easy to determine the pipe sections, and it also gives often the opportunity to choose the correct internal section and to evaluate head losses (in m/m).

It is very important to bear in mind that this way of calculating pipeline size is absolutely empirical and is easily applicable to pipes working under pressure. However, when the pressure applied consists of only gravity, a better evaluation is needed.

Overflow outlets

For overflow weirs with a free water fall, the flow calculations are based on the following formula:

$$q = m\ Hd\ \sqrt{2g}\ Hd = mHd\ \sqrt{19.62}\ Hd$$

where:

- q is the water flow *per meter of weir* (in m^3/s)
- m is a coefficient (close to 0.45)
- Hd is the water head above the crest of the weir (in m)
- g is the gravity (9.81 m/s)

For a weir that is L meters wide, total flow Q (m^3/s) = qL = mL Hd $\sqrt{19.62}$ Hd.
Knowing the weir width (L, in m) and the flow (Q, in m^3/s), it is possible to calculate the difference in level (Hd) between the weir crest and the water level upstream as:

$$Hd = \sqrt[3]{[Q \div 1.993\ L]^2}$$

Canals and gutters

The hatchery gutter network consists of rectangular canals of small size made usually of reinforced concrete, and either built on the spot or assembled using prefabricated sections.

Generally, the main drainage canal is a ditch of trapezoidal section, not covered, with a gentle slope and over-sized for the flow expected.

The flow capacity of any type of canal is obviously related to its section and can be calculated with the Bazin formula:

$$Q = C\ \sqrt{Ri} = US$$

where:

- Q is the water flow in m^3/sec
- U is the water velocity in m/sec
- C is the Bazin coefficient = $(87\ \sqrt{R}) \div (\gamma + \sqrt{R})$
- R is the hydraulic radius (in m) = S/P
- S is the wet section area in m^2
- P is the wet perimeter in m
- γ is the Bazin roughness coefficient
- i is the hydraulic slope in m/m

Note:
Bazin roughness coefficient varies as follows:

concrete smooth surface	= 0.06
surface in stones or bricks	= 0.16
surface in masonry	= 0.45
embankment	= 0.85
ordinary embankment	= 1.30
rock embankment	= 1.75

An abacus can be used to determine the hydraulic slope necessary for a given flow Q, with the cross-section selected and the roughness coefficient known. It also allows to determine the difference in level between the channel upstream and downstream (Δh).

2.12 DESIGN OF HATCHERY HYDRAULIC CIRCUITS: EXAMPLES OF CALCULATIONS

Referring to the above mentioned formulas and principles, this section gives some examples of practical calculations for pipe inlets and outlets in a marine finfish hatchery.

Example: Water inlet system

Description

Let's assume that the internal network is made of three different circuits: A, B and C.

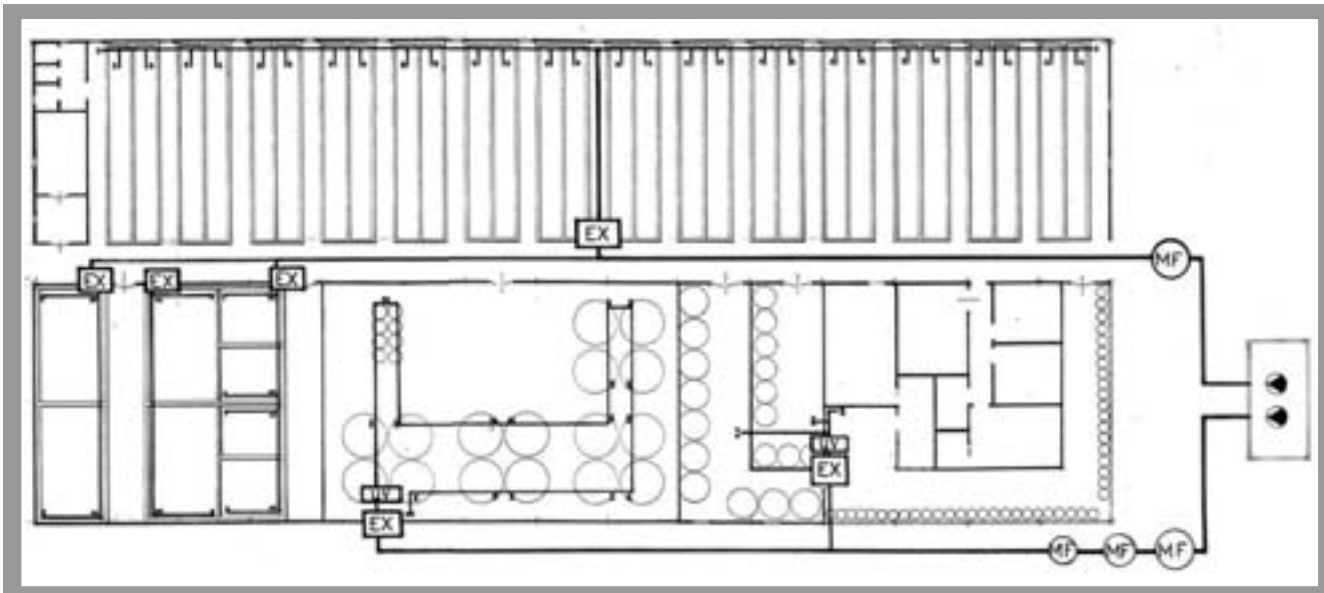


Fig. 49 - Hatchery circuits MF = mechanical filter EX = plate exchanger = pumping station

Circuit A

- Length: 210 m
- Equipped with a pump A: maximum flow Q_A = 10 l/s = 0.010 m³/s
- Water velocity: U = 1.20 m/s
- Pipeline: rigid PVC 10 bars

Thus the theoretical section is given as $S = Q_A \div U = 0.010 \div 1.20 = 0.008 m^2$

- Selected diameter: N.D. ∅ 100 mm, which means 98.8/110 mm

With a real section of 0.00785 m² [Calculated as $(98.8/2*1/1000)^2 \pi$] and the real velocity as $U = 0.010 \div 0.00785 = 1.275$ m/s

- Interposed circuit equipment: considering Q = 10 l/s
  - filter F1, which gives a head loss of 10m
  - filter F2, which gives a head loss of 20m
  - UV sterilizer, which gives a head loss of 5m
  - Secondary water distribution pipes to the tanks, with the following characteristics:
- Length: 50 m
- Equivalent flow (considering homogeneous water distribution to the tanks):
  $Q_e = Q_a \div \sqrt{3} = 10 \div 1.732 \approx 6$ l/s
- Water velocity: 1.0 m/s
- Pipe type: rigid PVC 10 bars
- Selected diameter: N.D. ø 80 mm which means 80.6/90 mm

With a real section: S = 0.0395 m² and the real velocity: $U = Q_e \div S = 0.006 \div 0.0395 \approx 1.05$ m/s

Circuit B

- Length: 210 m
- Circuit equipped with a pump B; maximum flow: Q_B = 50 l/s=0.050 m^3/s
- Water velocity: U = 1.20 m/s
- Pipeline: rigid PVC 10 bars

Thus the theoretical section is given as S = $Q_B \div U = 0.050 \div 1.20 \approx 0.04\ m^2$

- Selected diameter: N.D. ∅ 250 mm which means 224.2/250 mm
- Real section: S = 0.0395 m^2
- Real velocity: $U = Q_B \div S = 0.050 \div 0.0395 \approx 1.265$ m/s
- Interposed circuit equipment: considering Q = 50 l/s
  - filter F1, which gives a head loss of 15 m
  - secondary water distribution pipes to the tanks with the following characteristics:
- Length: 50 m
- Equivalent flow (considering an homogeneous water distribution to the tanks):
  $Q_e = Q_B \div \sqrt{3} = 50 \div 1.732 \approx 29$ l/s
- Theoretical velocity: 1.0 m/s
- Pipe type: rigid PVC 10 bars
- Selected diameter: N.D. ø 200mm, which means 179/200 mm

With a real section: S = 0.025 m^2 and the real velocity: $U = Q_e \div S = 0.029 \div 0.025 \approx 1.16$ m/s

Circuit C

Sea water reservoir feeding the tanks under the following conditions:

- Inlet flow coming from circuit B: 3 l/s = 0.003m^3/s
- Maximum flow to the tanks through circuit C: Q_C= 3 l/s = 0.003 m^3/s
- Capacity: half an hour of flow, which means: (3600 x 3)
- Length: 4 m
- Maximum flow: Q_C= 3 l/s
- Water velocity: U = 1.20 m/s
- Pipeline: rigid PVC 10 bars

Thus the theoretical section is given as S = $Q_C \div U = 0.003 \div 1.20 \approx 0.04\ m^2$

- Selected diameter: N.D. ø 75 mm which means 63.2/75 mm

With a real section: 0.0031 m^2 and a real velocity: $U = Q_C \div S = 0.003 \div 0.0031 \approx 1$ m/s

- Water distribution: considering Q = 3 l/s
- Length considered: 50 m
- Max. flow (considering an homogeneous water distribution to the tanks):
  $Q_e = Q_C \div \sqrt{3} = 3 \div 1.732 \approx 1.75$ l/s
- Theoretical velocity: 1.0 m/s
- Pipe type: rigid PVC 10 bars
- Selected diameter: N.D. ø 75 mm which means 63.2/75 mm

With a real section: S = 0.0031 m^2 and the real velocity: $U = Q_e \div S = 0.00175 \div 0.0031 \approx 0.565$ m/s

Calculation

To finalize the design of the water inlet system, it is necessary to determine the sum of the head losses due to the equipment installed on the circuit, the friction of the water in the pipelines and the energy lost to move the water to obtain the flow required.

The head losses i are calculated using the Manning-Strickler formula:

$Q = U\ S$ where

$U = K\ R^{2/3}\ i^{1/2}$ and therefore

$i = U2 \div K^2\ R^{4/3}$

Adding this hydraulic load of the pipeline system to the final load to deliver at the end of the circuit, allows the calculation of the necessary total head of the pump.

Use an abacus to determine easily “i” knowing U, K and R (or diam. ∅).

Circuit A

(a) Residual load necessary at the end of the distribution lines in the secondary circuits: 5 m, which means a line of load = (+4.00) + 5.00 = (+9.00) m

(b) Head losses into secondary distribution circuit with (see (a) above) where:

L = 50 m
Q_e = 6 l/s
U = 1.05 m/s
K = 100 (n = 0.01)
∅ internal ~ 80 mm or 0.08 m
R = ∅ ÷ 4 = 0.02 m

thus $i = (1.05)^2 \div (100)^2 \sqrt[3]{(0.02)^4} \approx 0.02$ m/m
and $\Delta h = 0.02 \times 50 = 1$ m
which means a load line in A3 = (+9.00) + 1.00 = (+10.00) m

(c) Head losses for primary internal circuit (see (a) above), where:

L = 60 m
Q = 10 l/s
U = 1.275 m/s
K = 100 (n = 0.01)
∅ internal ~ 100 mm or 0.10 m
R = 0.10 m ÷ 4 = 0.025 m

thus $i = (1.275)^2 \div (100)^2 \sqrt[3]{(0.25)^4} \approx 0.022$ m/m
and $\Delta h = 0.022 \times 60 = 1.34$ m

If local head losses are:

filter F1 = 10 m
filter F2 = 20 m
UV lamp = 5 m

for a total of 35 m, then total head losses = 1.34 m + 35 m = 36.34 m
which means a load line in A2 = (+10.00) + 36.34 = (+46.34) m

(d) Head losses for primary external circuit (see (a) above), where:

L = 150 m
Q = 10 l/s
U = 1.275 m/s
K = 100 (n = 0.01)
∅ internal ~ 100 mm or 0.10 m
R = 0.10 ÷ 4 = 0.025 m

thus $i = (1.275)^2 \div (100)^2 \sqrt[3]{(0.025)^4} \approx 0.022$ m/m
and $\Delta h = 0.022 \times 150 = 3.30$ m, which means a head loss at the outlet of the pump equal to (+46.34) + 3.30 = (+49.64) m

Circuit B

(a) Residual load necessary at the end of the distribution lines in the secondary circuit: 5m which means a line of load = (+4.00) + 5.00 = (+9.00) m

(b) Head losses into secondary distribution circuit (see (a) above), where:

L = 50 m
Q_e = 29 l/s
U = 1.16 m/s
K = 100 (n = 0.01)
∅ internal ~ 180 mm or 0.18 m
R = (0.18) ÷ 4 = 0.045 m

thus i = $(1.16)^2 \div (100)^2 \sqrt[3]{(0.045)^4} \approx 0.0084$ m/m
and $\Delta h = 0.0084 \times 50 = 0.42$ m
which means a loadline in B3 = (+9.00) + 0.42 = (+9.42) m

(c) Head losses for internal primary circuit (see (a) above), where:

L = 60 m
Q = 50 l/s
U = 1.265 m/s
K = 100 (n = 0.01)
∅ internal ~ 224 mm or 0.224 m
R = 0.224 ÷ 4 = 0.056 m

thus i = $(1.265)^2 \div (100)^2 \sqrt[3]{(0.056)^4} \approx 0.0075$ m/m
and $\Delta h = 0.0075 \times 60 = 0.45$ m
If local head losses for filter F1 = 15 m
then total head losses = 0.45 + 15 = 15.45 m
and the load line in B2 is (+9.42) + 15.45 = (+24.87) m

(d) Head losses in the external primary circuit (see (a) above), where:

L = 150 m
Q = 50 l/s
U = 1.265 m/s
K = 100 (n = 0.01)
∅ internal ~ 224 mm or 0.224 m
R = 0.224 ÷ 4 = 0.056 m

thus *i* = $(1.265)^2 \div (100)2\ 3 \div (0.056)^4 \approx 0.0075$ m/m
and $\Delta h = 0.0075 \times 150 = 1.125$ m
This means a load line in B1 at the outlet of the pump equal to (+24.87) + 1.125 = (+25.995) m.

Circuit C

(a) Feeding pipe to the reservoir:

- load at the pipe feeding the reservoir : (+9.42) m
- load at the top of the reservoir where the water is distributed: (+5.50) m
- head losses into the distribution pipe to the reservoir (see (a) above), where:
  L = 4 m
  Q = 3 l/s
  U = 1.0 m/s
  K = 100 (n = 0.01)
  ∅ internal ~ 53 mm or 0.053 m
  R = 0.053 ÷ 4 = 0.01325 m

thus i = $(1)^2 \div (100)^2 \sqrt[3]{(0.01325)^4} \approx 0.032$ m/m
and $\Delta h = 0.032 \times 4 = 0.13$ m
which means a load necessary to distribute 3 l/s at the top of the reservoir equal to
(+5.50) + 0.13 = (+5.63) m.

(b) Distribution pipe

- Minimal load at the starting point of the pipe at the reservoir (with the most unfavourable conditions): (+4.25) m
- Head losses into distribution pipe (see (a) above), where:

L = 50 m
Q_e = 1.75 l/s
U = 0.565 m/s
K = 100 (n = 0.01)
∅ internal ~ 63.2 mm or 0.0632 m
R = 0.0632 ÷ 4 = 0.0159 m

thus i = $(0.8)^2$ ÷ (100)2 3÷(0.0158)4 ≈ 0.008 m/m
and Δh = 0.008 x 50 = 0.40 m
which means a load line at the end of the distribution pipe equal to (+4.25) - 0.40 = (+3.85) m.

Thus, the load available at the end of this pipe situated at (+3.50 m) is:
(3.85) - (3.50) = 0.35 m, a very low load which will make use of large valves compulsory.

Example: Water outlet system

Description

There are several possible solutions to design the main outlet system. Three different ways are provided as example:

- dug as a ditch in the ground, of triangular section and with a slope ratio of 2:1;
- built in concrete or reinforced concrete, of rectangular section, open;
- buried, using a large diameter pipe in reinforced concrete or centrifuged concrete.

In all cases, let us assume that the main gutter should allow the drainage (in good hydraulic conditions) of around 60 l/s with a total length of 150 m.

Calculation

The calculation is based on various formulas according to the kind of system used (open or closed):

- For an open channel use the Bazin formula:

  Q = US where:
  U = C √Ri and
  C = (87 √R) ÷ (γ + √R)

  Note:
  Bazin roughness coefficienγ varies as follows:

concrete smooth surface	= 0.06
surface in stones or bricks	= 0.16
surface in masonry	= 0.45
embankment	= 0.85
ordinary embankment	= 1.30
rocks embankment	= 1.75

The different values for C are thus function of γ.

- For a closed pipeline: use the Manning-Strickler formula:

  Q = U S where
  U = K $R^{2/3}$ $i^{1/2}$

with K = 90 for a free flow in concrete or reinforced concrete pipelines and K = 95 for a flow under pressure in concrete or reinforced concrete pipelines.

These two formulas are applied in the following examples where the relevant calculations are shown. However, an abacus for each formula can also be used for faster approximate calculations.

Main gutter as a triangular ditch in the ground (Bazin formula)

γ = 1.30
Q = 60 l/s or 0.06 m^3/s
Section: type I
- length: 150 m
- bottom width: nil
- side slope: 2:1
- water height (downstream): 0.50 m
- wet section (downstream): S = 0.50 m^2

U = Q ÷ S = 0.06 ÷ 0.50 = 0.12 m/s
Wet perimeter P = 2.24 m
Therefore:
R = S ÷ P = 0.50 ÷ 2.24 ≈ 0.22 m
C = 23.1
i = $U^2 \div C^2$ R = $(0.12)^2 \div (23.1)^2$ (0.22) = 0.000123 m/m
Δh = 0.000123 m/m x 150 m ~ 0.02 m
which means, following the scheme, the following water levels:
- downstream: (+0.50 m)
- upstream: (+0.50) + 0.02 = (+0.52 m)

Fig. 50 - Aerial view of water circulation in hatchery and farm (TIMAR, Portugal)

Main gutter as a rectangular channel in concrete (Bazin formula)

γ = 0.06 m
Q = 60 l/s or 0.06 m^3/s
Section: type II
- length: 150 m
- width: 0.30 m
- water height (downstream): 0.30 m
- wet section (downstream): 0.09 m^2

U = Q ÷ S = 0.06 ÷ 0.09 = 0.67 m/s
Wet perimeter P = 0.90 m

Therefore:
$R = S \div P = 0.09 \div 0.90 \approx 0.10$ m
$C = 73.1$
$i = U^2 \div C^2 R = (0.67)^2 \div (73.1)^2 (0.10) \approx 0.00084$ m/m
$\Delta h = 0.00084$ m/m x 150 m ~ 0.125 m
which means, following the scheme, the following water levels:

- downstream: (+0.50 m)
- upstream: (+0.50) + 0.125 = (+0.625 m)

Main gutter as a round concrete pipe (Manning-Strickler formula)

K = 90, "free flow"
Q = 60 l/s or 0.06 m^3/s
Section: type III
$\varnothing$ D = 0.50 m
$S = \tau D^2 \div 4 = 3.14\ (0.50)^2 \div 4 = 0.196\ m^2$
$P = \tau D = 3.14 * 0.50 = 1.57$ m
$R = S/P = 0.196 \div 1.57$

Therefore:
$i = (0.30)^2 \div (90)^2\ \sqrt[3]{(0.125)^4} \approx 0.000178$ m/m
$\Delta h = 0.000178$ m x 150 m = 0.03 m
which means pipeline levels as follows:

- downstream: (+0.50 m)
- upstream: (+0.50) + 0.03 = (+0.53 m)

Fig. 51 - Water outlets

Fig. 52 - Main pumping station using axial propeller pump (source: ETEC catalogue)

2.13 PUMPS

For our purposes it is possible to define a pump as a device able to increase the mechanical energy of a liquid, or in more practical terms, a machine able to push a fluid from one point to another.

Pumps are frequently made of cast iron or 304 stainless steel. However, in marine hatcheries, because of corrosion problems linked to the use of seawater as pumped liquid, these two metals are not suitable and other materials like bronze, 316 stainless steel or plastic are preferable. When only cast iron or 304 stainless steel pumps are available, they have to be well protected outside and inside with an epoxy coating. For semi-closed circuits, in which pollution by metal ions should be avoided, plastic pumps are strongly recommended.

Pumps are generally driven by electric two/three-phase engines or, in sites where electricity is not available, by diesel engines. The latter are mostly employed in the case of low pumping heads and large water flows and are only used if the hatchery is linked to a land-based growout farm.

Types of electrical pumps

Although a large number of pumping systems exists, it is possible to group them into three categories as follows:

- **Turbine (regenerative) pumps**, where a rotating impeller equipped with paddles or blades transmits kinetic energy to the fluid. This is the type most commonly used in a hatchery.
- **Water lifts**, such as the Archimedes screw and air-lifts. These types of pumps are seldom used in a marine hatchery.
- **Displacement (volumetric) pumps**, where the fluid transport is done through successive variations of capacity, the pumping being done through the alternate filling and emptying of an enclosed volume. These volumetric pumps are used only in very large hatcheries and on-growing facilities for cleaning procedures or to transfer live food.

In view of the above, the following sections will only deal with electrical turbine pumps.

Turbine pumps

Turbine pumps are rotative and usually have a rigid connection to the engine. They are simple, relatively small, light and easy to maintain. According to the type of impeller used and the way it works, turbine pumps used in hatcheries and aquaculture farms can be of three types:

- centrifugal pumps;
- centrifugal-propeller pumps;
- propeller pumps.

Centrifugal pumps are designed for medium water flows and great heights, while propeller pumps raise very large flows at low heights (only a few meters).

Depending on construction criteria adopted, turbine pumps can also be classified in the following categories according to:

- **axis position**: horizontal, vertical or leaning axes;
- **number of impellers present**: mono- or multi-stage;
- **pressure produced**: low, medium or high pressure.

Fig. 53 - Centrifugal pump

As far as position of the turbine pump in relation to the water level in the sump, pumps can be classified as follows:

- **a surface pump**, when working completely outside the water;
- **immersed**, when the pump is underwater but the engine is outside the water;
- **submersed**, when both pump and engine are underwater.

Hatcheries are generally equipped with centrifugal turbine pumps, with a horizontal or a vertical axis. They are usually mono-stage and produce low or medium pressures. They can be surface, immersed or submersed pumps depending on the sites.

Information requirements for the design of a pumping system

Concerning fluids:

- type and origin of the fluid;
- maximum flows needed;
- working conditions;
- hydraulic conditions at water intake and delivery points.

Information concerning pumps:

- **The total head** (TH) of a pump is the pressure difference in meters of liquid column (MLC) between the suction and the discharge points. It is related to three elements:
  - geometric head (GH), according to the hydraulic conditions defined above;

- pressure losses at suction point (J SUC), equal to the pressure (in MLC) necessary to overcome pressure losses in the suction pipe;
- pressure losses at discharge point (J DIS), equal to the pressure (in MLC) necessary to overcome pressure losses in the discharge pipe; these also depend on the fluid velocity and on the different fittings installed in the circuit.

If suction and discharge take place under atmospheric pressure, total head is calculated as
TH (in MLC) = GH + J SUC + J DIS

If pressures (in kg/cm^2) at suction and discharge points are different, say P_1 at suction and P_2 at discharge, you can refer to a homogeneous system by using instead:

- at suction ($P_1 \div \gamma$) x 10 (in MLC), and
- at discharge ($P_2 \div \gamma$) x 10 (in MLC),

where γ is the density (in kg/dm^3) of the pumped liquid, which is close to 1 for sea water. The above formula then becomes:

$$TH \text{ (in MLC)} = GH + JSUC + J\,DIS + 10\,[(P_2 - P_1) \div \gamma\,]$$

- **Maximum suction height** for centrifugal pumps:

  In theory, if a vacuum is created inside a vertical tube immersed in water by eliminating the atmospheric pressure at its upper end, the water will reach a height in the tube equal to the atmospheric pressure at that location, in MLC. At sea water level, this means a height of 10.33 m. In general, for an altitude A (in m), the height reached by the water inside the tube is reduced to 10.33 m - 0.012 A.

  In practice, however, the water height obtained by suction using a centrifugal pump is lower because part of the available pressure is needed to overcome the pressure losses in the suction pipe and to give the desired velocity to the fluid. To avoid pump cavitation (the formation inside the fluid of vapour bubbles), the absolute pressure at the pump inlet should never drop below the value of the vapour pressure corresponding to the temperature of the fluid to be pumped. To ensure that the pump will run safely, the pressure at the pump inlet should remain well above the vapour pressure of the fluid. The vapour pressure (in MLC) for sea water at 20°C is around 0.20 m. But it can reach as much as 1.3 m at 50°C at sea level.

Fig. 54 - Section of submersible pump

The suction performance of a pump, taking into consideration its technical characteristics and the way it is installed, is determined by the net positive suction head (NPSH). Two types of NPSH exist:

1. the available NPSH, which is the value of the absolute pressure measured at the pump intake considering the type, materials and equipment used for construction of the intake, such as pipe diameter, type and other fittings;
2. the required NPSH, which is a set of values given by the manufacturer for each type of pump and for a given speed of rotation of the engine, and which is shown as a curve relating NPSH to pump outflow.

For a pumping installation to work properly, it is necessary that the available NPSH is greater than the required NPSH by a few decimetres. The value of the available NPSH for water supply under depression in a free water basin such as the sea, is equal to: 10 m - (GH + J SUC).

Figure 55 gives an example of available and required NPSH curves. The operating point of the pump must be situated to the left of the vertical line passing by the intersection of the two curves, so that available NPSH be greater than the required NPSH.

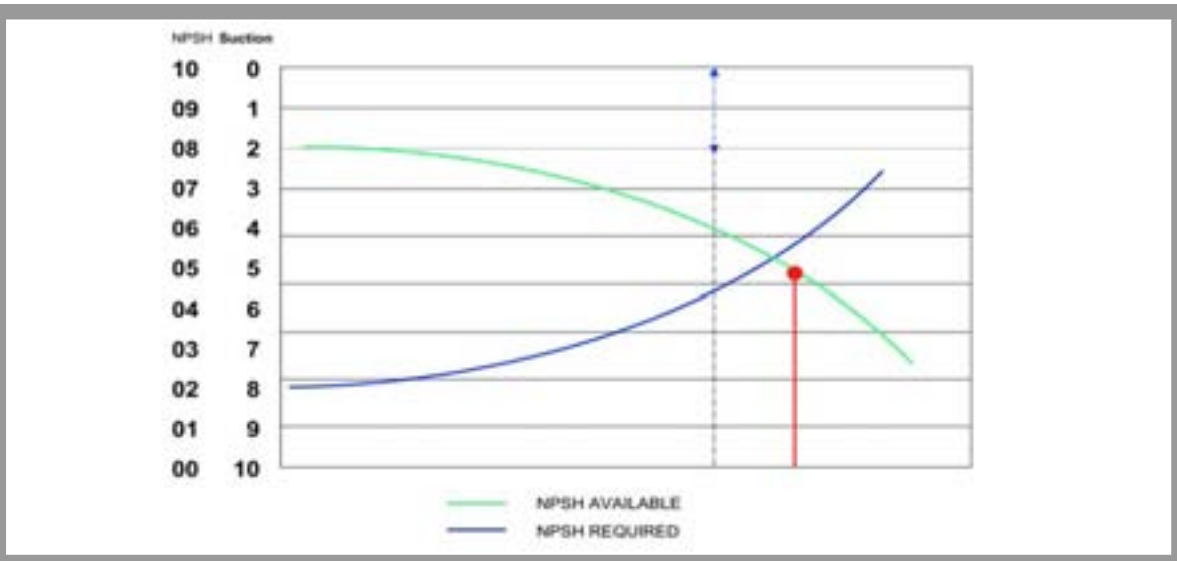


Fig. 55 - Example of available and required NPSH pump curves

- **Rotation speed of centrifugal pumps**:

  The rotation speed of a centrifugal pump affects potential water flow (Q), total head (TH), and consumption of energy (P). If this rotation speed varies from V_1 to V_2, the following three relationships exist:

  1. $(Q_2 \div Q_1) = (V_2 \div V_1)$
  2. $(TH_2 \div TH_1) = [(V_2)^2 \div (V_1)^2]$
  3. $(P_2 \div P_1) = [(V_2)^3 \div (V_1)^3]$

- **Operating point of a pump**

  The two main information elements needed for evaluating the operating point of a pump connected to a given system are flow (Q) and total head (TH) produced by the pump. To identify this operating point, you should superimpose on a graph the QH curve of the pump, and the characteristic curve of the pipeline, obtained by adding geometric head and total pressure losses.

  The intersection point (S) of these two curves determines the operating point of the pump.

  This clearly shows also that the operating point of the pump moves if the characteristic curve of the pipeline changes. For example, when the valve of the discharge pipe is partially closed, pressure losses increase. Similarly, if the pump is changed by a different one, there will be a new QH curve and thus a new position for the operating point S on the characteristic curve of the pipeline.

- **Pump curves**:

  There are three important and characteristic curves for a pump:

  1. The outflow to height curve or QH curve, which shows the relationship between total head (TH) produced by a pump in relation to the flow (Q);
  2. The efficiency curve, which relates efficiency of the pump to flow (Q). It always shows a peak value (optimum efficiency). It is best to use the pump around this peak value, which thus helps define the QH relationship to be respected. The efficiency of centrifugal pumps does not exceed 0.80, while for propeller pumps it can reach 0.90;
  3. The brake power curve or PQ curve, which relates brake power (P) to flow (Q).

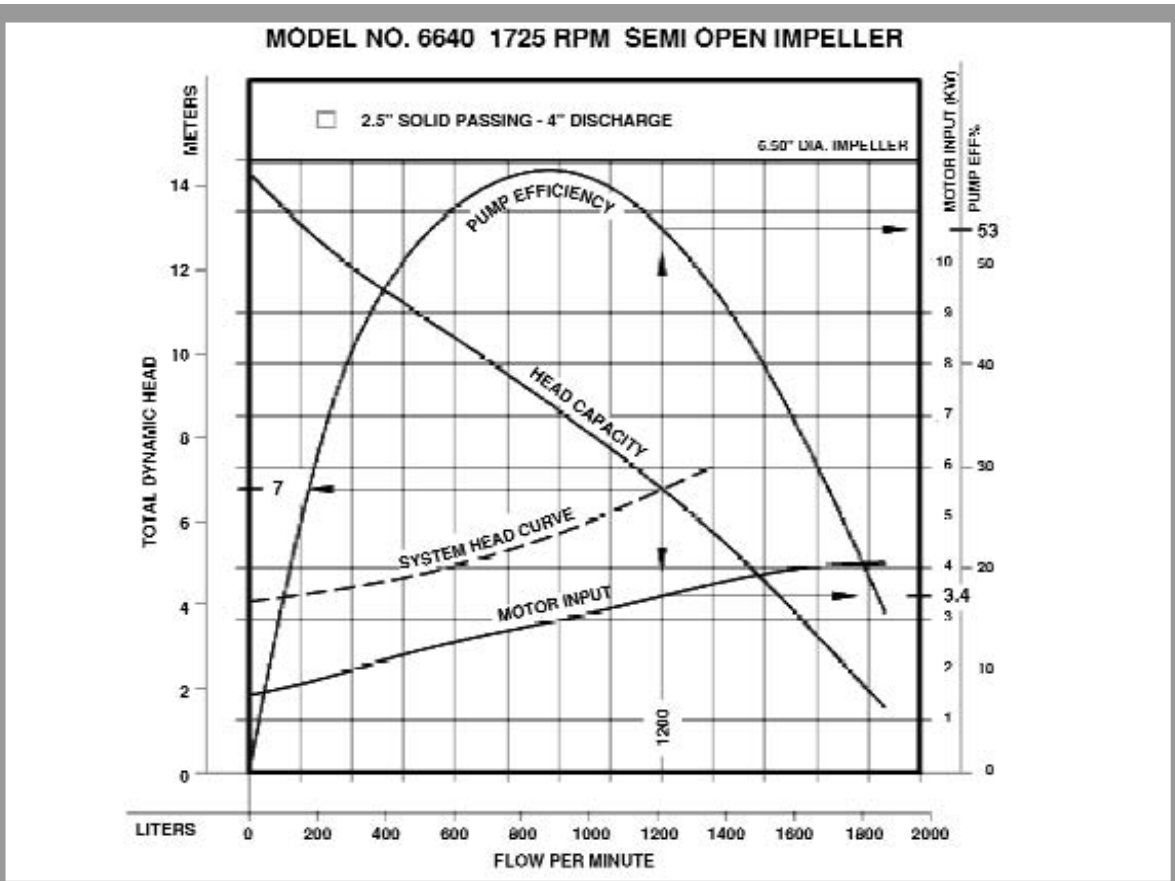


Fig. 56 - Typical pump curves (Source: J. Fletcher, Zoeller Company)

- **Grouping centrifugal pumps**

  The grouping of centrifugal pumps may be needed for two reasons: to increase the available flow or, to produce a greater head. In the first case, the pumps should be grouped in parallel. To obtain a greater head, group the pumps in series.

2.14 DESIGNING THE PUMPING SYSTEM

Calculation of the pumping system

The calculation of the pumping system can be carried out after the data mentioned in the previous sections on pipelines and pumps characteristics have been collected. The steps required are as follows:

1. Define the characteristics of the hydraulic system(s) and calculate the following:
   (a) geometric head (GH): the difference between the maximum level of discharge and the water level in the sump from where water is pumped.
   (b) total pressure losses (J TOT): consider the maximum flow necessary for the circuit. Include pipe losses, losses due to special fittings (elbows, T-junctions, valves, etc.), and losses due to all equipment installed in the hydraulic system. These partial pressure losses should be measured in metres of liquid column (MLC) and can be determined by using graphs or manufacturer's technical specifications. When water is pumped by suction it is very important to ascertain that the selected diameter of the suction pipeline fulfils the condition: (available NPSH) > (required NPSH), as described above.
2. Transfer the characteristic curve of the pipeline (defined by TH = GH + J TOT) onto a graph.
3. Transfer the three characteristic curves of the pump (QH, Rdt, PQ) explained above onto the same graph.
4. Finally, define the point S at the intersection of QH curve and characteristic curve of the pipeline. This gives the operating point of the pump, which should be located close to the maximum of the pump efficiency curve (Rdt).

The total flow necessary is obtained by increasing the number of pumps, as a multiple of the flow of a single pump. Any modification of the curves mentioned above will cause a change in the operating point at the expenses of pump efficiency.

Power absorbed

The power (P in CV) absorbed by a pump can be estimated by the following formula:

$$P = \frac{Q \times 3600 \times TH}{(270 \times Rdt)}$$

where :
Q is the flow in m^3/s
TH is the total head in m
Rdt is the pump efficiency as given in the technical specifications by the manufacturer.

2.15 CONSIDERATIONS FOR THE CHOICE OF A PUMPING SYSTEM

To make the correct choice when installing a pumping system, it is also very important to consider the three following points:

1. Use the equipment that best suits local conditions, and is the most reliable and easiest to maintain;
2. Choose the equipment necessary to guarantee a continuous supply of water to the hatchery, making sure that this supply is not under-sized as water availability is essential for hatchery security;
3. Evaluate the investment cost in relation to the two previous points. Beware of proposals that appear to be very convenient at first but can be very expensive.

Such a choice should be made for each installation but it can be guided in general by the following further considerations derived from experience.

Choice of pump category

For a hatchery with a flow requirement varying from a few litres per second to up to 100 l/s, and with a maximum total head of 40 m, the best choice appears to be a mono-stage turbine centrifugal pump.

Choice of pump type

When water is pumped directly from the sea by suction and without the use of a sump, the only pumps adapted to this job are the horizontal mono-stage centrifugal pumps.

When water is pumped from a sump, the choice has to be made between a dry, a semi-submersed and a submersed centrifugal pump. The final choice should be made according to the above considerations on service and cost rather than strictly from a technical point of view, even though the submersed pumps appear to be more suitable for this kind of installation. They are much easier and quicker to assemble and dismantle.

Choice of number of pump sets

Main pumping station: let us consider one main pumping station that should deliver a non-stop variable flow, reaching a maximum value Qmax:

1. the minimum equipment for this installation is two pump sets, each capable of delivering a flow equal to Qmax and working alternatively for 12 h each. Q installed is equal to 2 Qmax. This represents the cheapest solution in terms of investment, but it is the most uneconomical in terms of running costs, as it delivers too much water during a long period and the pumps are under-utilized as they can operate for 16 instead of 12 h;
2. it seems thus more interesting to equip this main station with three pump sets of unit flow equal to Qu = 0.5 Qmax, which means that total Q installed is equal to 1.5 Qmax;

3. still better, one could install a group of four pump sets as follows: 2 sets with a unit flow equal to main flow/2 (Qu = 0.5 Qmax); and another 2 sets with a unitary flow equal to main flow/4 (Qu = 0.25 Qmax). In such a case, the total Q installed is equal to 1.5 Qmax as in the case above. Running costs would be much more variable and therefore adapting better to the various situations for flow requirements.

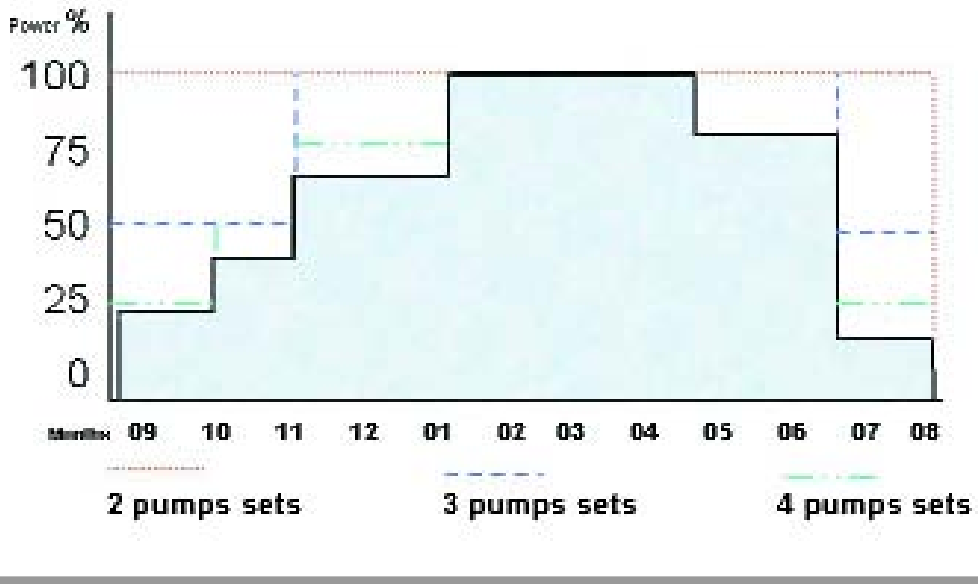


Fig. 57 - Operating diagram for three options of pump sets

These three possible solutions are further analysed in figure 57 where the operating diagrams of the pumping station equipped with two, three or four pump sets are shown.

Translating such calculations into operational costs, and particularly into annual electricity costs for pumping, is important before deciding which type of installation would be preferable.

Secondary pumping station: the equipment of the secondary pumping station consists generally of two to four types of pumps with different characteristics, which vary according to the service units to be supplied with water. The unit flow varies from a few litres per second to about 100 l/s, with a variable total head ranging from 10 to 40m.

A good choice in such cases is to install double sets of each type of pump. Obviously, it will be too costly to treble each pump set, all of them having a different QH. It would be more than reasonable to keep a good stock of spare parts available.

3.1 TANKS

Tanks are containers used in a hatchery for fish rearing or live-food production. Fibreglass or concrete are the more common materials used for tank construction. Fibreglass is mostly used for small (0.5 to 30 m^3) cylindrical or cylindro-conical tanks whereas concrete is frequently preferred for larger (over 20 m^3) square or rectangular tanks, which are mainly found in the nursery, pre-growing or broodstock sections.

Rectangular and square tanks are frequently preferred because they maximise the utilization of space and, in some countries, because they are cheaper to build. In rectangular tanks, the bottom should have a gentle slope (1 to 2 percent) towards the outlet. In square tanks, this slope should be from the sides to the centre. Such tanks are normally built in concrete. Floors and inside walls are either plastered or painted with epoxy resin.

Circular tanks are better for water circulation and self-cleaning. But they are usually more expensive and the ratio between occupied floor space and available volume is less advantageous. Their bottom is frequently slightly conical or rounded with a central outlet. They are mostly made of fibreglass with smooth gel-coated inside surfaces.

Fig. 58 - Plastic tanks

In both rectangular and circular tanks, a white or light coloured bottom is preferable to facilitate routine controls and cleaning, since larvae and sediments are easier to observe against such backgrounds.

Apart from materials and costs criteria, which mainly depend on local availability and technology, the two most important points to consider for a good choice of production tanks are the following:

- **Water circulation.** In the tanks, water quality should theoretically be as far as possible homogeneous, avoiding stratification or accumulation of sediments in corners or on the bottom. In this respect cylindrical tanks are preferable because internal circulation of the whole water mass is obtained by positioning the water inlet as shown in Figure 22. In rectangular tanks, on the contrary, a suitable water circulation pattern is more difficult to obtain, as water stratification cannot be avoided.

- **Maintenance.** Internal dimensions should allow easy maintenance and cleaning, while also maximizing rearing volume per square meter of floor space used. An expensive element of the investment cost is the building area, which is directly related to the surface occupied by the rearing tanks. From this angle the best solution would be to have tanks at least 2.5 m high but, unfortunately, this kind of tank cannot be properly cleaned or managed. An average height of 1.2 to 1.3 m seems to be the best compromise.

3.2 FILTERS

Filters are used to remove or to separate materials like suspended solids, ammonia, chemicals, etc., from liquids or gases. In marine hatcheries, three types of filters are used for treating seawater: mechanical, biological and chemical filters.

Mechanical filters

Mechanical filters are used to remove solids from water using a porous sept, a screen or a coarse layer of sand. To design mechanical filters, it is important to analyze:

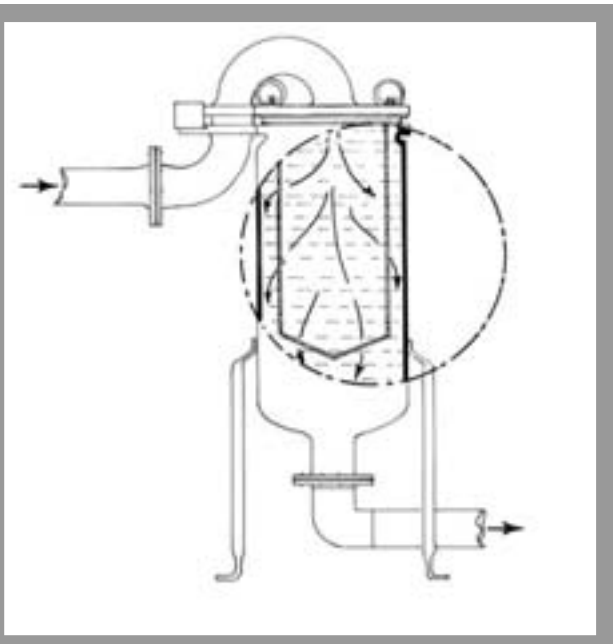


Fig. 59 - Mechanical filter

- **Type of solids:** the sort of suspended solids to be removed by the filter taking into account average particle dimension and type of material must be known. These parameters are important because they are decisive in the choice of the filtration system. They will be important to determine the type of material to be used for filtration and the type of cleaning routine to be adopted (backwashing, spray nozzles, mechanical or manual cleaning);

- **Quantity of solids:** their concentration is usually measured in milligrams per litre (mg/l). This parameter defines how much material to be filtered is present in one litre of water. Together with the type of solids, this is the main cause of filter-clogging;

- **Mesh or filtration size:** it is measured in microns (μm) and gives the real performance of the filter. It can be classified by the manufacturer in two types:
  - absolute, which means that all solids with dimensions equal to or greater than the size declared by the manufacturer are retained by the filter.
  - relative or nominal, followed by a percentage giving the average quantity (in percent) of filtration for a given size (in mm) of solids to be filtered.

- **Flow capacity:** measured in litres per second (l/s), defines the maximum water flow according to type of solid, quantity and dimension, and for a fixed mesh size. It is also a characteristic declared by the manufacturer.

- **Head loss:** measured in metres (m), it represents the energy required to pass the filter by a desired water flow. It is normally calculated at maximum acceptable clogging by the filter in operation.

Types of mechanical filters

Another classification, useful in understanding the way mechanical filters work, is that related to the energy needed for water to pass through the filter. There are two types:

(a) Gravity filters. When the only energy available to pass the filter is gravity, filters are usually open. They work with a reduced head and water frequently reaches the filter through an open channel. Such filters are frequently used when a large amount of water with an important quantity of suspended solids has to be filtered (with particles up to 20 mm).

This type of filter has typically a large area and a minimum head loss. It carries out an absolute filtration only and it is generally equipped with an automatic cleaning system starting automatically or manually, which is used to avoid filter clogging by solids.

Examples of such gravity filters are: screens or grids, drum filters, wheel filters, and disc filters.

- *Screens or grids*: the oldest and the simplest method, it is still in use to filter large volumes with very large meshes or gratings. They work only with mesh sizes larger than 2–3 mm and need, in any case, a mechanism to remove solids. This type of filter is used when large sediments are present in the water as a pre-filter unit, and it is placed before the farm inlet.

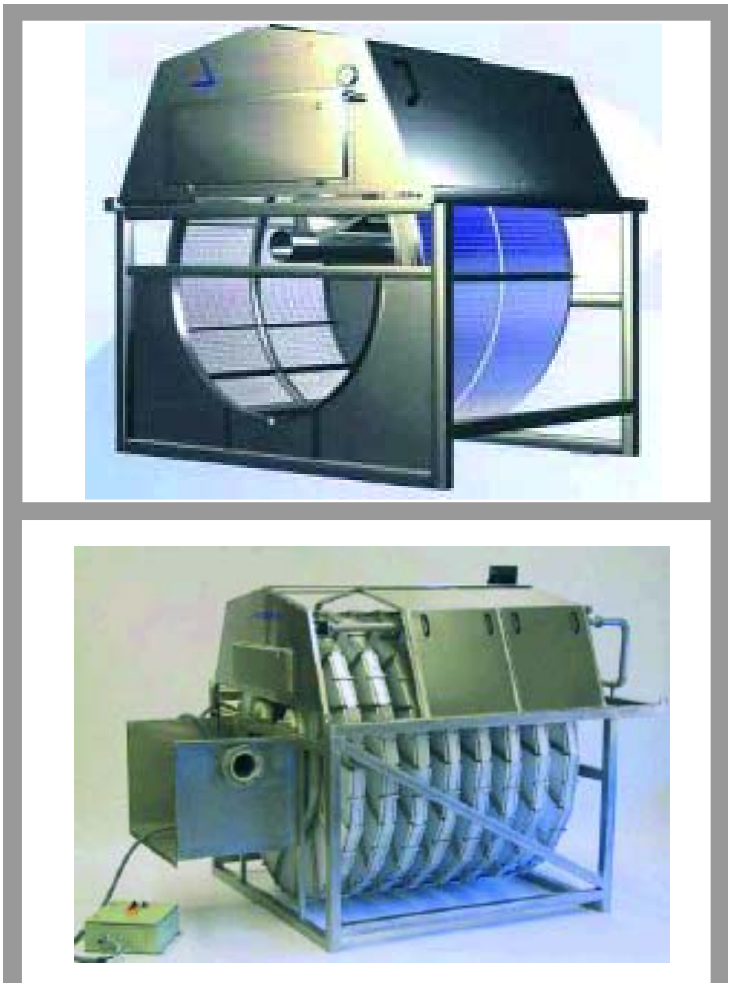


Fig. 60 - Drum filter and disc filter (Hydrotec catalogues)

- *Drum filters*: a good technical solution, is probably one of the most efficient and most used. In these filters, water passes through a stainless steel drum, its lateral wall being made of plastic or metal netting. The filter is either in constant movement or its rotation is activated by clogging sensors. Backwashing takes place routinely by means of a timer, using both fresh and salt water.

- *Wheel filters*: in these filters, water passes through two or more large wheels, where the filter net is placed. In order to avoid clogging, the two wheels rotate continuously with constant backwashing.

- *Disc filters*: these filters are a variation of the drum filter in which the surface is largely increased by the use of discs, so that a unit with similar characteristics in terms of water flow and solids contents requires less space. As the general construction of this equipment is more expensive than the previous ones, it is recommended only when the space available is limited.

These last three types of filter are used in the hatchery for:

- Filtering effluents at the outlet to reduce environmental impacts;
- In recirculation systems, to reduce organic matter content.

(b) Pressure filters. When a pump or a reservoir with a considerable head is placed before a filter, then the filter works under pressure. Such filters are totally enclosed in order to maintain water pressure. Head loss may be higher than with gravity filters (3 to 15 m at maximum clogging). They are used to treat small to medium quantities of water with medium loads of suspended solids. The size of the filter mesh varies (1 mm or more). For medium water quantities, such filters are frequently equipped with backwashing, whereas for small water quantities (the case of cartridge or small bag filters) they are manually cleaned. Filtration can be either absolute (normally for special cartridge filters or bag filters) or relative for all types of filters. In the case of absolute filtration, 100% of the particle equal or larger than the filter size will be stopped. In relative filtration, only a percentage of particles will be retained (normally more than 95%). All the rest will pass through the filter.

Examples of pressure filters are: cartridge, sand and bag filters.

- *Cartridge filters*: until now the most commonly used filters for very fine filtration (up to 1μm absolute) when the water flow is very small (maximum 1 to 2 l/s). This solution is quite expensive because a correct backwashing of the cartridge is impossible without altering the filtration characteristics.

- *Sand filters*: probably the most used and the most common type of filter when the water quantity to be treated is important and for relatively large size filtration (25 to 120 relative μm). They are mainly used for the first treatment of water. These filters are very economical for different reasons:
  - sand is a cheap and indestructible material;
  - with plastic replacing the stainless steel case, their cost has dropped;
  - maintenance is very easy.

Fig. 61 - Pressurized sand filter

- *Bag filters*: these filters are intermediate between cartridge filters and sand filters. They are very adaptable to various conditions such as high water flow and good filtration performances (up to 2 μm relative). The filter itself is made either of a single chamber or of several chambers where the filtration bags are housed. Bags are made of different materials ranging from plastic to stainless steel 316.

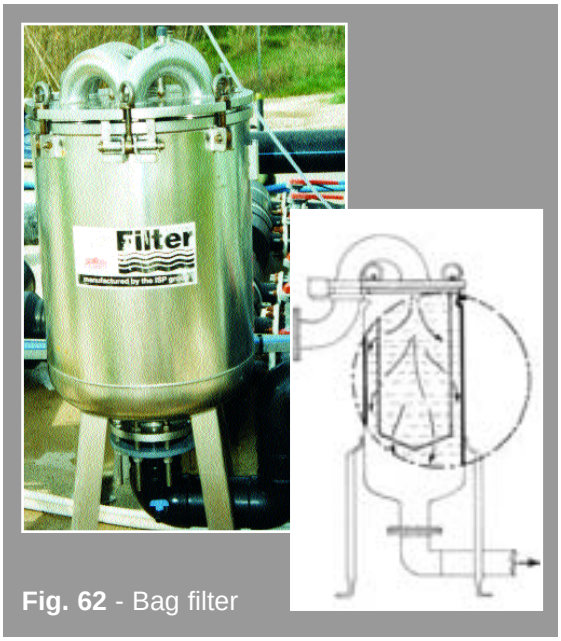


Fig. 62 - Bag filter

Pressure filters are frequently used for seawater filtration at the inlet. They are normally installed in series in order to avoid fast clogging of the finest ones. In fact, when water for rotifers is to be filtered at 5 μm, one should not install a single mechanical filter of this filtration size directly on the pipeline as it would clog too easily. Instead, a series of three filters of 100, 50 and 10 μm respectively, should be installed upstream of the 5 μm filter. The system will work better and the total need for filtering elements will be reduced. As price of the equipment decreases as filtration size increases, costs will also be reduced.

Biological filters

In intensive culture systems the fish biomass per unit flow rate is high. The main limiting factors are dissolved oxygen and ammonia content, the latter being the most dangerous part of the metabolic

wastes produced by fish. But water in theses systems contains also suspended solids (uneaten food, faeces), dissolved solids and other organic compounds.

Biological filters or diluters allow for the partial re-use of heated water because of their capacity to transform ammonia into less toxic nitrites and nitrates. Partial water recirculation presents several advantages, such as a reduced consumption of external water per unit of biomass stocked, reduced heating or cooling costs and a reduced impact on the environment.

The main differences between biofilters and diluters are in the quantity of new water introduced in the system in each cycle and/or the quantity of ammonia produced by the system. In the case of large stocked biomass and large productions, it is preferable to adopt biofilters while in the case of small biomass (i.e. larval rearing until day 35) it is preferable to dilute water and ammonia, instead of trying to start a biofilter that will never work properly.

Fig. 63 - Old fashioned biofilter

The biological filter is, within a re-circulation system, the more complex component, to the extent that it can be considered almost a living organism. As such it requires stable physical and chemical parameters, a permanent supply of food (ammonia) and adequate levels of oxygen.

But water recirculation tends to accumulate metabolic wastes and bacteria to an extent that can easily become dangerous. Recirculated water should be reconditioned by constant removal of metabolic wastes and bacteria from the system.

A biofilter usually consists of a coarse particle substratum, which is submersed in a separate container and is colonized by nitrifying bacteria on its relatively large surface. These microorganisms convert highly toxic ammonia to less toxic nitrites and nitrates.

The efficiency of bacterial nitrification is related to:

- water flow;
- relative filter surface (m^2/m^3 of substratum);
- residence time (contact time between water and nitrifying bacteria);
- dissolved oxygen content and pH (directly related to oxidation of ammonia);
- metabolic wastes (quality/quantity): total fish biomass, feed characteristics and feeding practices.

Fig 64 - Different kind of substrate: bio-rings and bio-sphere

The efficiency of a biological filter, defined as the ratio between the organic load produced by cultured fish and the organic load removed by the filter, is heavily influenced by values, or sudden variations in values of: temperature, salinity, pH, oxygen, alkalinity, hydraulic flow, light intensity and by the concentration of ammonia and nitrites. Moreover, it is extremely important to feed the filter in a regular way avoiding peaks of ammonia and to manage therefore the entire system in relation to the filter performance.

Fig. 65 - Pressure biofilter and plate heat exchanger

In essence, for any type of filter used, the functioning of a biological filter is based on creating favourable conditions for the development of autotrophic and aerobic bacterial colonies that could set a nitrifying process. This means to oxydize the ammonia to nitrites (*Nitrosomonas* sp., equation 1) and then to transform also by oxydation the nitrites into nitrates (*Nitrobacter* sp., equation 2).

$NH_4^- + 1.5\ O_2 \rightarrow NO_2^- + 2H^- + H_20$
(equation 1)

$NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$
(equation 2)

As nitrites are unstable and toxic for fish their concentration should not exceed 0.5mg/l. The haemoglobin in contact with nitrites forms a compound called meta-haemoglobin.

The nitrates, less toxic than ammonia and nitrites can be accumulated in the hydraulic system to concentrations two orders of magnitude higher (it should be also possible to reach concentrations of 100 mg/l). Then, they can be eliminated through a dilution process, or else through a denitrification process.[5]

The growth of nitrifying bacteria colonies depends, in addition to optimal environmental conditions, on the availability of surface on which to grow. This surface is defined as specific surface area, and it is usually indicated as m^2 (of surface) on m^3 (of volume of filtering material) and it is one of the fundamental parameters in the evaluation of the quality of a biological filter. The total surface of a filtering bed is also determined by the need to leave sufficient space between the particles of the substrate for an adequate water circulation and to reduce the risk of clogging. This void ratio in the substrate is generally related to the specific surface area desired. In practice an efficient filter has a void ratio of about 90%.

However, it should be borne in mind that in terms of surface the objective of the manager is to devote as much surface as possible to the rearing tanks. With this in mind the size of biological filters has been progressively reduced creating compact structures requiring less space.

The selection of substrates on which bacteria could form colonies has led to a reduction of the size of biological filters. From the initial substrates formed by gravel or shells, used in submerged or trickling filters, now inert fibre cushions, similar to those used in the filters or air conditioners, or small moulded pieces of plastic for packing purposes or else blocks of undulated PVC soldered sheets ("*structured packings*") are utilized. The continuous search for ideal substrates is oriented towards materials offering the highest surface/volume ratio, limited weight, strong mechanical resistance and limited clogging characteristics in addition to being cheap and easy to maintain.

5 Environmental and public health considerations have led to a limit of maximum permissible nitrate values (even if they are relatively less toxic) for effluents at 11.6mg/l. (EU directive).

Several typologies of biological filters exist. The ones more commonly utilized in aquaculture are:

- submerged filters
- trickling filters
- rotating biological contactors
- pressure filters

(a) Submerged filters

Submerged filters are so-called because the filtering substrate is constantly under water (Fig. 63). They are usually crossed by a vertical flow of water ("upflow" or "downflow" filters) or, more rarely by a horizontal flow. The main advantages of these filters consist in the possibility of modifying the duration of the contact between water and bacteria colonizing the substrate, simply by changing the speed of the water flow. A limit in this case is the fact that all the oxygen required by nitrifying bacteria is provided through the water. Too slow flows would lead to insufficient oxygen supply, limiting the nitrification process. Too slow flow could also favour clogging and the appearance of preferential directions inside the filter. In this case, this creates areas in the filter with a too fast water flow and also other areas where organic sediments accumulate and decompose in anaerobic conditions.

(b) Trickling filters

In a trickling filter, the water volume that crosses it is a fraction of the volume of the filter. The water is distributed on the substrate through water jets so that it can cover all the surface of the filter and thus favour the creation of a homogeneous layer of bacterial film. The bacterial film, which is not constantly submerged, is exposed to the air. In this type of filter, water is well oxygenated, thus favouring the process of oxidation of ammonia and nitrites, the removal of undesirable gases (CO_2, H_2S, N_2), and preventing risks of filter clogging.

Fig. 66 - Trickling filter

(c) Rotating biological contactors

The biodrum or biodiscs use the same principle of the trickling filters. The difference is that during the rotation of the filter, the bacterial film fixed on the drum or discs is submerged in water for half of the time of the rotation and also exposed to the air for the other half. The speed of rotation of the drum or discs is selected in such a way as to avoid oxygen depletion on the bacterial film while it is under water, and at the same time preventing excessive dehydration while it is exposed to the air. In these two types of filter (biodrum and biodisc) the main drawback is that the time of contact between water and bacterial film can be increased only by increasing the surface of the filter and thus its size.

(d) Pressure filters

These filters can be considered a special form of submerged filters (Fig. 65). The filter is made with a closed container, which is crossed from bottom to top by a flow of water under pressure. Inside the container you find packs of plastic on which the bacterial film grows. These plastic pieces are maintained in constant suspension by the water flow. In this way the bacterial film receives sufficient oxygen and the risk of filter clogging due to sediments in the water is minimized. A particular type of these filters is the fluidized bed, in which the filtering substrate is made with very small particles (e.g. sand) with a very large surface/volume ratio. The bed is maintained in constant suspension by the water flow which, however, has to be controlled to avoid the risk of draining the substrate that forms the fluidized bed. Also in this case the risk of clogging is minimal.

As for the submerged filter, the oxygen supply in pressure filters is provided through the water that passes through the filter. The water flow is usually enough to grant optimal conditions if the water that enters the filter has an oxygen level close to or above saturation.

Pressure filters are often used in combination with more traditional biological filters, such as trickling filters, as their main function is to reduce suspended solids given their efficiency in sedimenting organic matter ("bioflocs") in suspension.

It should also be borne in mind that clogging problems of biofilters are in large part resolved by adding mechanical filters upstream of the biological filter. An efficient reduction of particulated organic matter contributes to the reduction of heterotrophic bacteria which, having a faster growth rate than the nitrifying bacteria, could compete successfully both for oxygen and substrate.

How to calculate a biological filter

With submerged substrate and a specific inoculum of *Nitrosomonas* and *Nitrobacter*

- <u>Standard reduction</u>

J. Petit has established the following formula:

$$\blacktriangleright\ NH_4^+ = K \times \frac{H}{U} \times 1{,}08^{(Y-10)}$$

with ▸ NH_4^+ in g/m^3
K in $g/m^3/h$
U in m/h
H in m

- ▸ is the reduction without limiting factors
- 1.08 represents an average growth rate for bacteria. Theoretically the growth of *Nitrosomonas* is slower and sets the speed of the whole system.

This formula is valid when ▸ $NH_4^+ \geq 0.5\ g/m^3$. In fact this ammonia concentration would not represent a limiting factor

- <u>Definition of K</u>

$$K = -\frac{1{,}28}{Y} \times B \times \mu_1 \times \varepsilon \times a$$

with $\frac{1{,}28}{Y} \times B \times \mu_1$ which depends on the strain and

$\varepsilon \times a$ which depends on the type of substrate

- 1.28 Correction factor to obtain the results in mg/l
- Y(%) Cell performance g MVS/gN (bacteria rate/g of eliminated nitrogen) (according to the various authors, values range between 6 and 17%)

- B (g/m^2) bacteria per m^2 (average value: 0.6)
- μ_1 (mg/mg/h) growth rate at 10°C (mg of bacteria appearing/mg of bacteria/h) (average value: 11.10^{-3})
- ε (%) coefficient of emptiness of material (from 0.4 to 0.9)
- a (m^2/m^3) usable surface (from 100 to 500) a can be different from the data provided by the supplier as a function of the effective colonization of the surface)

The values found in the literature are based on studies on farms or pilot plants and provide the following K values:

- expanded clay: (a = 360) 10-20 in freshwater, 3-9 in seawater
- plastic (type bio-balls): (a = 225) 14 a 28

- Corrections

The Petit formula was derived for trout farms (fresh and cold water). Several parameters have an influence on the calculation of the filter:

- NH_4^+
- O_2
- pH
- Salinity

(a) Impact of the NH_4^+ concentration at the input

Real reduction = ▸ $NH_4^+ \times F_N$

$$F_N = \frac{N}{N + 10^{(0.05Y - 1.158)}}$$

with N = concentration at the input

Y = temperature °C

The concentration of dissolved ammonia has an influence on bacterial growth. When this concentration is low, the bacterial growth will also be low and the correction factor will also lower the effective reduction. On the contrary if the concentration is high, the correction factor will have a minimal impact.

(b) Impact of the oxygen levels

Real reduction = ▸ $NH_4^+ \times F_{O_2}$

$$F_{O_2} = \frac{DO}{K_{O_2} + DO}$$

DO is the oxygen concentration in the center of the filter

It has to be borne in mind that for the nitrification reaction 4.3mg O_2 per 1 mg of $N\text{-}NH_4^+$ are required.

K_{O_2} is the oxygen saturation coefficient that corresponds to a reaction speed equal to half of the maximum speed of bacterial growth. According to various authors this values ranges from 0.3 to 0.5.

Therefore,

$$F_{O_2} = \frac{DO}{0.5 + DO}$$

The Petit general formula applies with non limiting oxygen levels. With the correction factor, it would be possible to utilize the formula when the oxygen levels are not at saturation. However, it is important to bear in mind that nitrification:

- Decreases when the O_2 concentration is less than 60% of saturation level, and
- It stops when O_2 concentration is less than 45% of saturation level,
- Is endangered if O_2 concentration is over 15mg/l.

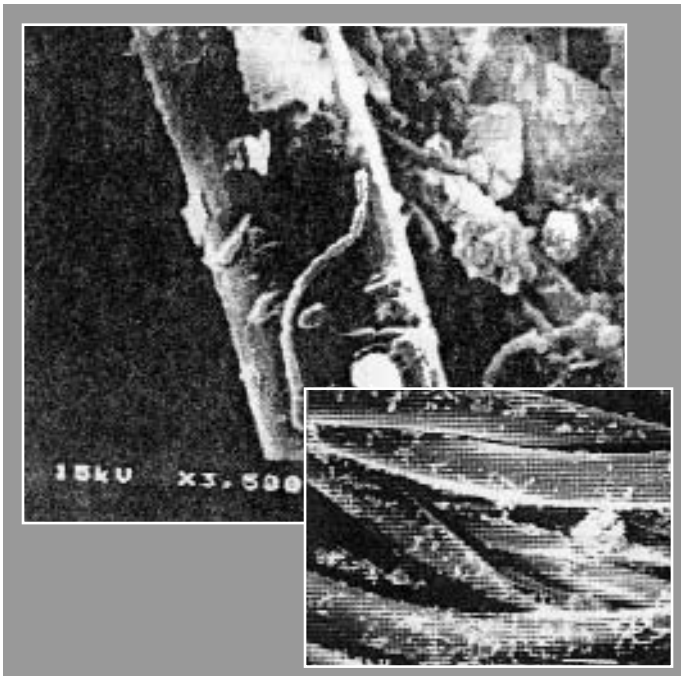


Fig 67 - Bacteria on filaments

(c) pH impact

The pH variation has some influence on the kinetics of nitrification. In the literature several pH levels are reported. The optimal pH is not the same for *Nitrosomonas* and *Nitrobacter*. The optimal values range from 7.5 to 8.3. Nitrification also reduces alkalinity in the water and this process of acidification is mainly due to:

- The CO_2 production
- The HNO_3 production.

Until water has sufficient buffer capacity pH remains relatively stable. Otherwise the H^+ ions do accumulate according to the nitrification equation:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

The ion H^+ is neutralized by bicarbonates present in the water according to the following equation:

$$H^+ + HCO_3^- \rightarrow CO_2 + H_2O$$

This decrease in the level of bicarbonate ions which are transformed in carbon dioxide results in a reduction of the pH level.

To neutralize 1 mg of NH_3-N a total of 7.13 mg of HCO_3^- are required

Real reduction = $\blacktriangleright NH_4^+ \times F_{pH}$

With $F_{pH} = 1 - 0.83\ (7.2 - pH)$

(d) Salinity impact

Salinity can inhibit nitrification. In fact, in seawater the quantity of nitrites and nitrates produced is higher than in freshwater and their oxidation is slower. Moreover, oxygen saturation also decreases when salinity increases (with similar temperature and pressure). The literature indicates a difference of 15% between freshwater and seawater $F_s = 1 - 0.15 = 0.85$

(e) Final reduction

$$\blacktriangleright NH_4^+ = \blacktriangleright NH_4^+ \times F_N \times F_{O_2} \times F_{pH} \times F_s$$

Chemical filters

Chemical filters are seldom used in aquaculture, except for scientific work or test. These filters require reagents and are used with small quantities of water. However, and with increased frequency, due to

the expansion of closed circuits, chemical or biological additives are used to correct water parameters, mainly pH. These additives (in powder or liquid form) area added to the circuits with the help of industrial dosing dispensers, driven by a probe.

3.3 SETTLEMENT TANKS AND OTHER SETTLEMENT DEVICES

Another way to separate suspended solids from water consists in the physical separation of the solids on the basis of the difference in specific weight. Therefore, with this method, it is very difficult to separate solids with a specific weight similar to that of water and separation is impossible for floating solids.

Settlement tanks

The simplest settlement tank is just a large reservoir through which the outlet channel flows. As the water enters the reservoir its speed is drastically reduced and the solid's energy decreases. Every kind of solid (faeces, wasted pellets, etc.) has its own sedimentation speed; the higher the speed, the more effective is the separation of the solid from effluent water.

Settlement devices use the same basic principle but they increase the efficiency by adding various kinds of obstacles in order to decrease the solid's energy as quickly as possible.

Settlement is actually used for two main purposes:

- separation of large sediments such as sand before the main pumping station, and
- settlement of organic wastes at marine hatchery outlets when simple engineering is all that is needed and a large outdoor area is available.

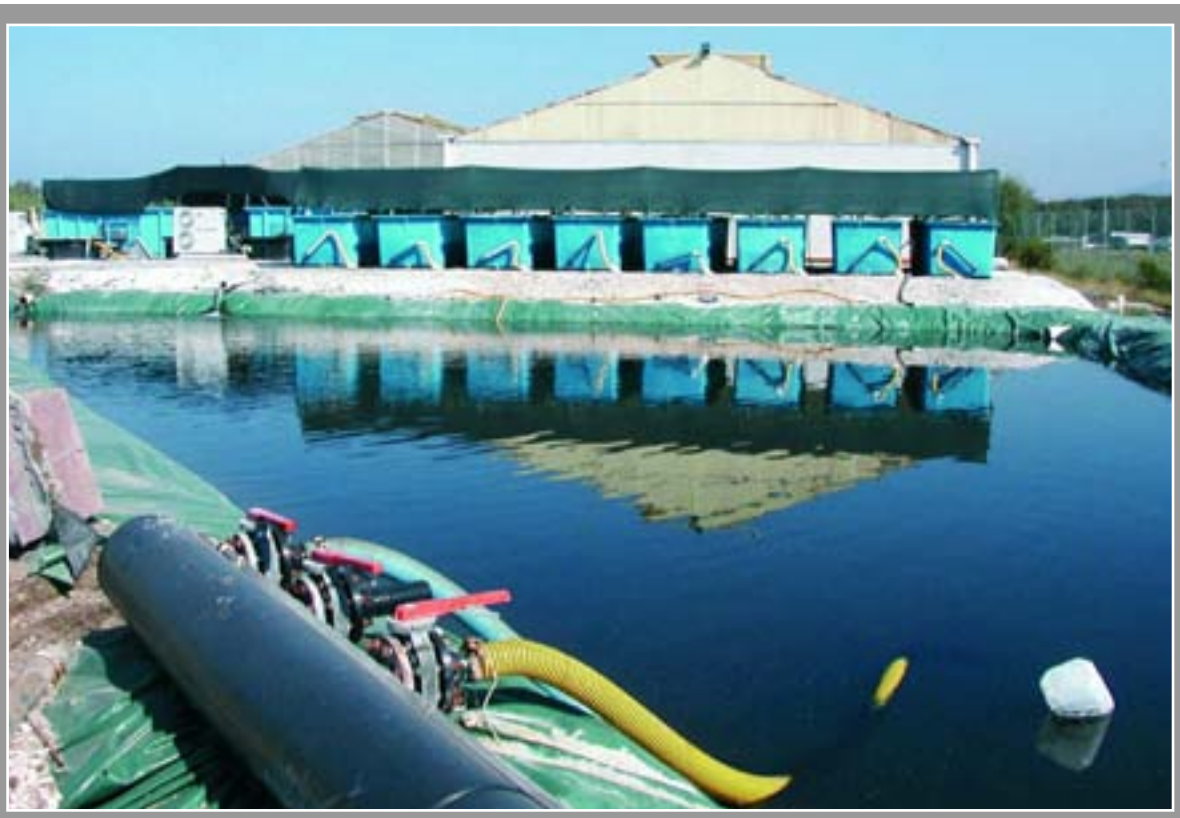


Fig. 68 - Settlement pond

When a decision is taken to use sedimentation to separate solids, the sedimentation process takes place usually in specific ponds in which the water circulation must be slow and possibly laminar, avoiding the creation of turbulences. In the sedimentation tank, four different areas can be recognized;

1) The area when the effluents enter, usually with high turbulence.
2) The sedimentation tank, with slow and laminar flow, where particles sediment.
3) The area where mud is deposited.
4) The outflow area, which is a transition area between the sedimentation tank and the outlet where the flow speed and turbulence increase again.

The general formula for the sedimentation process for particles in a static liquid, with F as the acceleration force determining the sedimentation speed, is:

$F_1 = (\rho_p - \rho_f)\, gV$ where: F_1 = acceleration force

ρ_p = particle density

ρ_f = liquid density

g = gravity acceleration

V = particle volume

The factors involved are therefore; the difference in density between particle and liquid, the force of gravity and the volume of the particle. In a laminar horizontal flow, the sedimentation speed of a particle is found by adding the vectors representing the vertical sedimentation speed (v_s) and the velocity of the horizontal flow (v_h).

Fig. 69 - Concrete settlement tank

The F_1 acceleration becomes small when the volume of the particle decreases and when the difference between its density and that of the fluid in which it moves is small. The permanence in water of organic particles favours also their hydration, thus reducing the difference $\rho_p - \rho_f$. In these conditions, the sedimentation efficiency can be increased by reducing the velocity of the horizontal flow, which for a given quantity of water to be treated, will be achieved only by increasing the sedimentation surface. This is the main limitation for the utilization of sedimentation basins in circuits which have to treat large quantities of water.

Cyclonic and laminar sedimentation chambers

Different models of sedimentation chambers have been designed in order to reduce the sedimentation time and therefore the size of the sedimentation basins. The cylindro-conical decanters were designed to make better use of the force of gravity, by reducing to zero the horizontal flow. Water enters from the bottom and exits by overflow. The suspended particles sediment vertically, in the opposite direction to

the water flow. Obviously, to maintain a low speed of the mounting water and to limit their size, cylindro-conical decanters can be utilized only for situations in which modest flows have to be treated.

The laminar sedimentation tanks base their better efficiency on the presence of obstacles (baffles) inside the sedimentation tanks, which are placed to absorb part of the energy of the moving solids allowing a faster sedimentation. The laminar sedimentation tanks require, however, complex cleaning procedures which are not always justified by the limited reduction in the size of the sedimentation tank.

Another example is the cyclonic sedimentation chamber (Hydroclone). These are circular tanks with conical bottom that utilize the centrifugal force to separate the sediment from the fluid. The rotation of the entire volume of water to be treated is induced by the tangential entrance of the water in the tank. The spiral flow in the tank forms a depression in the water, like a cylinder full of air, at about two thirds of the diameter of the tank. Clean water goes upwards in the inner part of the spiral and drains in the upper part of the tank. The solids which sediment against the wall and part of the water leave the tank through the bottom. The efficiency of these sedimentation tanks improves when the diameter increases. They are, however, seldom used due to their high cost, the need to operate a pump continuously to maintain the circular water flow, their limited flexibility and their size, which is large when large volumes of water have to be treated.

The use of sedimentation tanks in aquaculture is limited by the large areas required for the treatment of large amounts of water. Other disadvantages are the variability in their efficiency and the need to stop the operation periodically to clean the tanks. Where possible sedimentation has been replaced by mechanical filters.

3.4 WATER STERILIZERS

The most common treatments for water sterilization are UV and ozone. Treating the water with chemicals such as formaldehide or hypochlorite is normally avoided in close circuits to avoid damaging fish, algae or rotifers.

Blowing air or pure oxygen between two electrodes with a high voltage current produces ozone. The spark generates ozone, which is an allotropic form of oxygen. This gas must be produced locally and used immediately since it is highly unstable and reverts to normal oxygen molecules quickly. Ozone is a powerful oxidant, whose efficiency depends on the dosage and on the time in which it is in contact with the substances or organisms it has to oxidise. Mixed with water, it oxidizes organic matter and interacts with bacteria and viruses. Ozone also works as an oxidant on compounds and inorganic elements such as iron or manganese, and generates insoluble oxides.

Its use as a sterilizer has to be carefully evaluated because of the high toxicity for workers. Its residues, even in low concentration, can be dangerous for farmed fish. The presence of ozone, even in small quantities in the rearing tanks must be avoided. Although theoretically very interesting, ozone treatment is expensive because sophisticated equipment is required to measure the residual levels in out flowing water. As it is dangerous for the workers due to its oxidative characteristics, UV treatment for sterilization of water in the hatcheries is much more common. This section will deal only with UV treatment.

UV lamps

One of the most effective ways to drastically reduce bacterial growth inside a semi-closed system or to eliminate pathogens from raw seawater is to use UV sterilizers.

UV light can be divided according to its wavelength in three types:

extreme UV	100 – 190 nm
far UV	190 – 300 nm
near UV	300 – 380 nm

UV is high energy radiation and it affects marine micro-organisms starting from 190nm up to 380nm. The most important effect on bacteria or viruses consists in the modification of nucleic acids of those micro-organisms thanks to the absorption of energy by the nucleotides and the consequent modification. Very effective DNA damage produced by the UV radiation is the production of thymine dimers occurring by linking two adjacent thymine molecules. This stops DNA replication and therefore the reproduction of the micro-organism.

Sometimes micro-organisms are able to repair some of the damage caused by UV. This capacity is called reactivation and can happen in a dark environment and/or in presence of light. This is why the choice of UV is critical for the engineers who have to choose the proper lamp with the correct energy.

UV equipment consists of a pipe or a cylindrical chamber containing one or more quartz tubes (permeable to UV), producing ultra-violet radiation. Water flowing through the pipe/chamber is exposed to UV-C radiation produced by special lamps. The most effective UV radiations are UV-C and UV-B with a wavelength range of 200 to 300nm. The highest bactericidal efficiency is obtained at 240 to 275nm.

Fig. 70 - UV lamp

UV-sterilizer chambers are made of different materials such as specific plastic or stainless steel. The most convenient solution in terms of maintenance and cost is the use of plastic chambers, which are usually cheaper than stainless steel, but as mechanical performance and safety are far from those of stainless steel, many hatchery technicians still prefer the latter.

UV chambers should be equipped with: a UV meter to indicate UV radiation intensity (in percentage), a UV alarm for low intensities, a water sensor to indicate the presence of water and to protect the lamps from overheating, as well as a counter to record time when the UV-lamp is being used, as the lamps have to be changed periodically.

In order to damage the DNA of micro-organisms present in the water through the action of high-energy UV-C radiation, two types of UV lamps are used; low/medium and high-intensity lamps. The former contains mercury vapours at low pressure (max. 3 millibars) while in the latter the pressure of the mercury vapours reaches 1 to 3 bars.

Which type of UV lamps to choose

Low-intensity lamps range from 20 to 80 watts and the major output wavelength is 253.7nm, giving maximum efficiency at 15°C. High-intensity lamps range from 1.5 to 4 kW. Their output spectrum is broader but their UV-C efficiency is lower. In terms of electrical consumption, low-intensity lamps are much more cost effective than high-intensity lamps, but there are certain advantages in choosing equipment with high-intensity lamps:

- the number of lamps required is less, which means that cleaning routines and maintenance are easier and cheaper;
- the cost per lamp is lower if one compares one high-intensity lamp with the equivalent number of low-intensity lamps;
- the space requirements are considerably less and installation is easier.

The best solution seems to be low/medium-intensity equipment for small flow systems (with less than 30 to 100 m^3/h) or for intermittent use. On the contrary, medium high-intensity equipment should be preferred for large water flows or for dirty water.

Since quite often the water circulating in the system is not perfectly clean, (semi-closed system, reduced filtration of suspended solids, presence of colloids, etc.), it would be very useful to have inside the sterilizer some device to clean the external walls of the quartz lamps when they are switched on. This would avoid wasting time and interrupting the treatment and would increase the effectiveness of the lamps. However, manual cleaning often remains the most effective and common solution.

Radiation intensity or dosage is expressed in millijoule/cm^2; one millijoule (mJ) corresponding to one milliwatt (mW) per second. If lamp output is 10 mW/cm^2 and residence time of water inside the sterilization chamber is three seconds, total UV-C dosage applied equals 30 mJ/cm^2.

The dosage of UV-C radiation needed to kill at least 90 percent (log 1) of the population present in water, is well known for many organisms. This dosage is called the D10 for the organism considered because its survival will be at the most 10 percent. D10 (in mJ/cm^2) values for various organisms are listed in Annex 10.

For example, the D10 of *Escherichia coli* (wild isolate) ranges from 3 to 10 mJ/cm^2. To find the theoretical energy necessary to kill 99.9 percent (log 4) of its population, multiply the D10 (example 6) by the log requested (6 x 4 = 24 mJ/cm^2). As a general rule, an output of 40 mJ/cm^2, at the end of the UV lamp life span, is considered safe.

The purpose of using a UV sterilizer is not always to exterminate all bacteria present in the water, as the energy required to achieve this would be excessive. In fact, UV equipment is used mostly in closed recirculation systems to maintain bacterial populations below dangerous levels.

In addition to the power of a UV lamp, it is also necessary to know the useful life span (usually 2 500-10 000 hours). During this period the UV dosage of the lamp will progressively decrease until it reaches a value close to 50-60% of the original dosage which is considered the end of its life span. Usually the manufacturers indicate this as a value in milliJoule/cm^2 at the end of the lamp life span.

It must be remembered that the dosage is defined as intensity by the time of irradiation:

$D = E \times t$

where: D = dosage (milliJoule/cm^2)
E = radiation intensity (milliWatt/cm^2)
t = radiation time

The efficiency of the sterilization using UV radiation is strongly conditioned by the way in which this radiation is transmitted in the water (transmittance). The transmittance can be drastically reduced by the presence of suspended solids.

Considering as 1 the maximum value of transmittance (meaning that the dosage of the lamp passes through the liquid and reaches the opposite side of the radiation chamber unaltered), in normal conditions in recirculation water in a hatchery this index decreases to 0.75-0.80. For this reason all UV equipment should have a filtration system upstream to reduce suspended solids.

The efficacy of the radiation is also closely related to the thickness of the water mass that has to the radiated. Sterilizers are, in fact, built with a radiation chamber that contain the lamps inside one or more quartz tubes. In this way, water circulates around the lamp with a predetermined thickness. The number of lamps and tubes determines the volume of water than can be treated by the sterilizer.

The UV dosage is also influenced by other factors such as the variation of the water flow inside the radiation chamber or the temperature of the water to be treated.

Selection of UV sterilizers

For proper selection of UV sterilizers, the following parameters should be given to the UV supplier:

- water temperature;
- species and average number of micro-organisms to be controlled;
- transmission coefficient of water (measured with a photometer);
- maximum water flow;
- level of sterilization desired compared with D10.

The size of each sterilizer should be calculated separately.

3.5 OXYGENATORS AND AERATORS

Increasing dissolved oxygen content of water

Fish metabolism is based on respiration; a physiological process in which the energy required by the organism is produced through oxidation of organic matter. Fish obtain the oxygen required for this process from the water.

Thus the oxygen dissolved in the rearing tank water is constantly being used by fish. As modern hatchery practices are characterised by high fish densities in confined water volumes, oxygen content in water has to be kept under close control and as far as possible be regulated. Since water temperature in a hatchery is usually fairly stable, oxygen regulation is needed due to the demand created by fish metabolism.

Oxygen consumption in fish is related to many factors, such as the species, the body size, activity (rest, forced swimming, feeding), temperature, feeding and water quality. In general, oxygen consumption for a given fish species reaches a peak during feeding or full activity (swimming), and when dissolved oxygen is high and when temperature increases. When size is small (larvae, fry) oxygen consumption is higher in relation to the biomass. For example, a 4 g seabass has an oxygen consumption of 863 mg O^2/h/kg during feeding.

In general, there are three ways to match the increasing oxygen needs of fish:

a) by renewing water more often and thus introducing more dissolved oxygen. To a certain extent, increasing water renewal is the most common method of adding oxygen to the rearing tanks. The growth of larvae and fry is associated with a regular increase of water exchange in the rearing tanks. This increase not only provides more oxygen to the fish, but it also helps to eliminate feed residues and metabolic by-products. The limiting factor remains the cost of supplying a large quantity of water (intake facilities, pumps, pumping station, electricity generator set, distribution facilities, etc.) compared with the cost of introducing oxygen by other means.

b) by adding atmospheric oxygen to the water (aeration). Before the introduction of liquid oxygen this was the most common method of adding oxygen to water. But the oxygen content of atmospheric air is low (21 percent) and a relatively high volume of air

Fig. 71 - Pump set

is needed to add a small quantity of oxygen to the water. There is also a limit to the quantity of oxygen that can be dissolved in seawater. Temperature and atmospheric pressure determine the saturation threshold. On the basis of normal temperature and salinity ranges in hatcheries, and at atmospheric pressure, the quantity of additional oxygen that can be added by aeration is limited and cannot go above saturation values.

c) by adding pure oxygen to the water (oxygenation).This method brings rearing water into contact with pure gaseous oxygen. Since the oxygen content is higher in the gaseous phase than in water, there is a tendency for oxygen to dissolve following this concentration gradient. If the entire process takes place under a pressure level higher than atmospheric pressure and if pure oxygen is used, the result is an even higher and quicker dissolution of oxygen, into the rearing water. If instead of pure oxygen, air under pressure was used, we would have a problem due to the supersaturation of nitrogen, which would become dangerous. This is why only pure oxygen is used to oxygenate water under pressure.

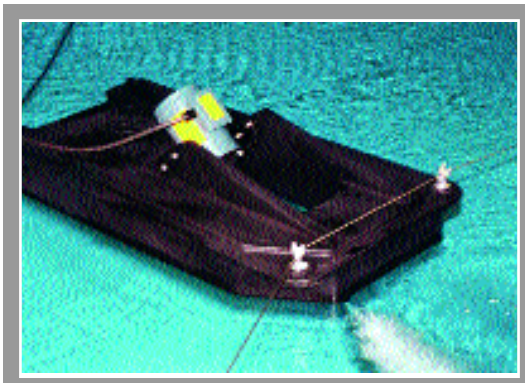


Fig. 72 - Air injector

Fig. 73 - Liquid oxygen reservoir and oxygen bottles

These three ways can normally be found in marine hatcheries, either separately or in combination.

Improving oxygen transfer into water

Gas transfer into water is regulated by the difference between the partial gas pressures in the atmosphere and in the water. If a pressure gradient is present, the gas will follow this gradient.Therefore if the partial pressure of oxygen in the air is higher than that in the water, oxygen will dissolve into the latter. Since this process tends to reach an equilibrium, it is of great importance to keep this difference of pressure positive, to transfer oxygen continuously to the water. To achieve this, both the liquid phase (water flow) and the gaseous phase (gas flow) should be renewed continuously. Therefore it is necessary to keep a continuous flow of water in the proximity of the source of oxygen.

Apart from water temperature and salinity that we will consider constant, three main factors control oxygen dissolution into water: pressure, exchange surface, and contact time.

- **Pressure**. Under atmospheric pressure and average hatchery water parameters (20°C and 30 ppt salinity), the maximum quantity of oxygen that can be dissolved into water (saturation value) is 7.6 g/m^3. This value can be

Fig. 74 - Oxygen generator

greatly increased since the dissolution power of each gas rises as the pressure increases. But when using air under pressure, this also results in a very dangerous (for the fish) increase in nitrogen concentration in the water. However, when using pure oxygen, this problem will not arise since it would be the only gas benefiting from a higher partial pressure (i.e. higher concentration, Henry's Law) and then dissolve into water.

- **Exchange surface.** Gas diffusion into water is also a function of the amount of contact surface between the two phases. For a certain water volume, the larger this exchange surface, the higher and the quicker would be the gas transfer. For example, a large gas bubble has a smaller surface than a number of fine bubbles containing the same gas volume. Devices which maximize exchange surface between air/oxygen and water should be preferred, such as diffusers producing very fine bubbles and jets or nozzles spraying evenly fine water droplets into an atmosphere of pure oxygen.

- **Contact time.** Transfer of a gas into water is also a function of time. It takes a certain time to achieve total transfer. Methods and devices which maximize contact time are to be preferred, such as counter-current mixers and mixers with water velocity lower than that of rising bubbles. Shape of tanks may also influence oxygen diffusion as fine bubbles of oxygen take more time to reach the surface in deeper than in shallower tanks.

Air and oxygen diffusers

Diffusers are devices to mix air or pure oxygen, as bubbles of various sizes, with the rearing water. Diffusers can be made with simple perforated PVC pipes, with a series of holes of suitable diameter (typically pipes of $^3/_4$, 1 and $1^1/_4$ inches diameter and holes of 2 to 5 mm diameter), or with any porous material having coarse to very fine holes (porous stones, porous rubber hoses, porous steel tubes, porous soft wood).

The porous material or the perforated pipe is connected to a source of compressed air or pure oxygen, and they are placed in the tank to be aerated/oxygenated. Since, as indicated above, the transfer of a gas into water is also a function of the exchange surface and contact time, the more efficient diffusers will be those producing the finest bubbles rising slowly into the water.

Fig. 75 - Air diffusers

Porous stones connected to a compressed air line are usually placed into various culture tanks for live-food production, egg incubation, larval rearing and fry weaning. The bubbles they produce help in maintaining the still passive yolk-sac larvae and the first-feeding larvae afloat, and in homogenizing the rearing medium (rotifers, microalgae). When an additional quantity of oxygen is required (for example, when there is a temporary failure of the water supply system or when there is a temporary high density in the rearing tanks), one or more porous stones can be placed in the rearing tanks, connected to a separate compressed oxygen line. The porous material of the diffusers should be periodically cleaned, since small particles (algae, food residues, faeces) in the rearing water can easily clog the pores and reduce (or even block) the air/oxygen flow.

Injection of pure oxygen using a submersible pump

To dissolve pure oxygen in rearing water, an easy and quickly assembled device would be an oxygen supply pipe placed under the intake of a submersible pump.

The pump propeller generates and mixes a great number of very fine gas bubbles and the higher pressure created during the suction allows for a quick and abundant dissolution of oxygen in the water. When these systems are used, the pump should be made of plastic material, since oxygen can cause corrosion in the propeller chamber of cast-iron pumps. Cavitation should not be a problem when using this device, since the oxygen micro-bubbles in the propeller chamber do not implode, as air bubbles would do. This system has been tested to have an efficiency of 60 to 80 percent for oxygen transfer.

This device can be easily assembled in situations in which a pump is continuously working to supply rearing water (for example, in recirculation or flow-through systems) or in the compensation line going to the biofilter. Advantages of this system are that the whole mass of flowing water is enriched with oxygen, that no modification of the water distribution system is needed (at least if the inlet pipe in the tank is lower than the water surface) and that the response time is very short (only a few minutes are required to oversaturate 2 to 4 m^3 of water).

Injection of oxygen into a pipeline

As a simplification of the system described above, oxygen injection can take place directly into the water distribution pipeline, after any priming device, such as a pump or header tank.

However, this system creates relatively coarse bubbles in the water pipes. These bubbles, even when using a porous diffuser, tend to be unstable and to become larger, thus reducing exchange surface and contact time. Complete dissolution of oxygen is also hampered if the injection point is too close to the water inlet of a tank, since the gas will not have enough time to dissolve.

This system can be used with pipelines distributing water by gravity (taking advantage of the pressure provided by an elevated distribution reservoir), as well as with a pressurized water distribution line. Since each tank can be supplied with oxygen individually, by having different injection points, this system increases the flexibility of the oxygenation system. For further refinement of the system, oxygen injection for the individual tanks can be automated using a solenoid valve at injection point.

Pressurized mixers

In this system a mixing barrel, with the shape of a cylinder or a double cone, is connected to the water distribution line, after the priming pump. Part of the rearing water is pumped into the barrel and is mixed with pure oxygen. The gas is injected just below a special perforated plate through which water must pass or is injected in the lower part of the bi-conical barrel. An almost complete dissolution of oxygen can be achieved with this equipment.

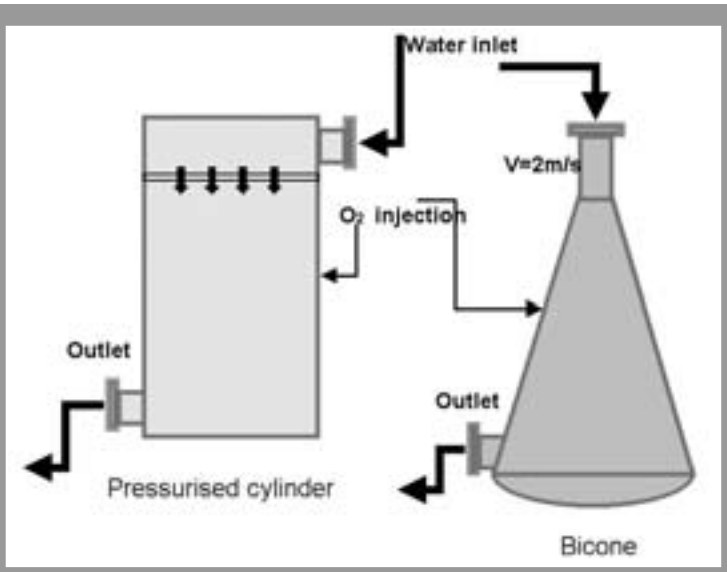


Fig. 76 - Mixing chambers

This device needs to be supplied with water under pressure (best from 1 to 2 bars) and it is connected to a compressed oxygen line. A thin oxygen-filled chamber is formed under a perforated plate. Since the diameter of the barrel is greater than that of the distribution line, the water entering the barrel loses velocity, stabilizing its gaseous phase. Water under pressure is forced through the perforated plate and through the oxygen chamber in the form of multiple jets. These jets suck the oxygen bubbles from the gas chamber into the water under it, forming a cloud of fine bubbles. As these bubbles have a rising velocity greater than the water velocity in the

mixing barrel, they remain trapped inside it long enough to complete the oxygen transfer into the water. In salt water, a few very fine bubbles may leave the barrel with the outgoing water, but owing to their small size they become almost completely dissolved in the water distribution line (due to the long contact time and great exchange surface).

The efficiency of an aeration/oxygenation device is measured as the quantity of oxygen dissolved in relation to the quantity of oxygen utilized. Pressure mixers of this kind have an efficiency greater than 80 percent under the operating conditions encountered in a hatchery.

Fig. 77 - Bicone oxygenator

This type of device is used to hyper-oxygenate part of the rearing water or the make-up water of the bio-filters. Dissolved oxygen content can reach as much as four to five times the saturation level. This hyper-oxygenated water is then mixed with the rest of the rearing water, either in the main distribution line (centralized oxygenation) or at each tank inlet (individual oxygenation). The system can be automated by using a solenoid valve linked to a remote oxygen monitoring probe.

Estimating oxygen requirements in tanks

In the larval rearing section, dissolved oxygen content is always kept at saturation level, but this would not be sufficient in the weaning and pre-growing sections in which the higher biomass and the distribution of compounded feeds (crumbs or pellets) will increase the oxygen demand.

A widely-used formula can be used to calculate the hourly oxygen requirements (DOn) for each tank or for the entire system. It relates the oxygen required to metabolize one kilogram of feed (Iox) to the maximum fish biomass present and to its daily feeding rate as follows:

B x DFR = DTF

where:

- B is the maximum fish biomass to be present in tank/system, in kg
- DFR is the daily feeding rate, in percent
- DTF is the daily total feed quantity distributed, in kg

and therefore

DOn = (DTF x Iox) ÷ 24

where:

- Iox is the oxidation index equal to 0.4 kg O_2 per kg feed
- 24 is the number of hours per day
- DOn is the hourly oxygen consumption for a certain fish biomass, in kg O_2

Of course, this formula will give only the theoretical amount of oxygen consumption per hour as an average during the day and without considering the way it dissolves in water. The real oxygen needs in fact will have to cope also with the efficiency of dissolution and the metabolic phase (rest or feeding phase) of the fish population during the specific time.

Example

If we consider a daily consumption of 10 kg of feed and a system efficiency of around 40% the total consumption of gas (O_2) will be:

10 x 0.4 = 4 Kg of dissolved oxygen

and thus the requirements on the base of the efficiency of dissolution would be 4 /0.4 = 10 Kg of oxygen consumed per day. As indicated above, this oxygen consumption will not be regular and constant during the day but will be maximal after each feeding period and minimal during the night.

3.6 OXYGEN MONITORING AND REGULATING SYSTEM

Control systems

As already mentioned, dissolved oxygen values can vary rapidly and dangerously in a hatchery. The high stocking densities found in hatcheries and the need to adopt sometimes close-circuit systems to better manage water quality, require the constant monitoring of a number of rearing parameters. Oxygen level is the most important.

In hatcheries using oxygen injection in tanks and pipeline systems, maintaining optimal oxygen levels by regulating oxygen supply is important to avoid unnecessarily high costs of operation.

Considerable progress has been made in the last twenty years in oxygen monitoring systems and in the automation of aeration and use of oxygen. This progress has allowed an improvement in the reliability of systems as well as in the economy of the operation.

Fig. 78 - Fry biomass

Measuring dissolved oxygen

Oxygen level measurements in farms and hatcheries is carried out using highly reliable instruments that work as potentiometers, measuring the difference of potential between two electrodes. This difference is affected by the quantity of dissolved oxygen present in the water.

The probe has usually two electrodes, a silver one (normally the anode) and the other made of platinum, rhodium or other valuable metal that normally works as a cathode. A difference of potential is created between the two electrodes, usually with a battery. The chamber in which the two electrodes are placed is filled with an electrolyte and is closed at one end by a Teflon or polypropylene membrane which is oxygen permeable. The oxygen dissolved in water passes through the membrane and reacts with the electrolyte, creating a current with a voltage in the order of 500-800 millivolts which is proportional to the oxygen concentration. This current is read by a micro-voltmeter and it is displayed directly as oxygen concentration in mg/l.

Fig. 79 - Oxygen probe

The more recent oxygen meters can also compensate automatically for measurement variations in the oxygen concentration due to temperature variations, and can be calibrated for readings at different salinities and altitude. The oxygen readings are normally indicated as mg/l and as a percentage of saturation levels. In recent years the manufacturers have evolved from oxygen meters for laboratory use to field probes which are protected against possible damage, are impermeable and have limited maintenance requirements.

Oxygen supply management

The placement of probes in critical points of the hatchery (individual tanks, collection points, etc.) allows a continuous control in real time of oxygen values. With such a configuration of the oxygen control system, it is possible to automatize oxygen management.

The probes can be connected to analogical management systems. After determining minimum and maximum values, thresholds which should not be trespassed and optimal values to be maintained, the system, can, on the basis of the readings of the probes, switch on and off aerators and oxygenators.

Fig. 80 - Oxygen monitoring system

The use of a digital system operating the monitoring systems as well as the various switches regulating oxygen supply, allows additional possibilities. The probes are read by a central controller and the readings are transferred to a PC which, in addition to storing this information, is programmed to manage the system on the basis of several variables. As an example, oxygen levels and supply can be correlated to temperature variations or to the stocking densities in the tanks.

The computer could manage at the same time programmes for automatic feeders which will be related to the oxygen values. Thus the system will be able to control dissolved oxygen values before, during and after feed distribution, and through the control of the oxygen supply solenoids, will be able to keep optimal rearing conditions.

In case of anomalous situations in the oxygen supply, the automatic management system, in addition to warning the operator with sound or light alarms, will be able to decide autonomously on suspending feed distribution.

3.7 WATER TEMPERATURE CONDITIONING

Hatchery water temperature normally does not follow the natural cycle outside the hatchery because temperature is one of the main important factors conditioning larval rearing periods. When most of the work concentrates in the winter period, temperature conditioning means heating the water in the tanks or in the hatchery as a whole. Generally the systems employed are adaptation of heating devices used for central heating or air heating. When individual tanks are heated electrical resistances and temperature sensors are employed to reach the desired temperature in the tanks. The following figures show examples of heat exchangers, heat pumps and resistances and sensors utilized for temperature increase and control in hatcheries.

Fig. 81 - Heat exchanger

Fig 82 - Heat pumps

Fig. 83 - Tanks equipped with titanium heaters and thermostats

Fig. 84 - Internal view of tanks in Fig. 83: the heater and the thermostat probe

3.8 AUXILIARY EQUIPMENT FOR FRY MANAGEMENT

For large and medium size hatcheries, in order to maintain properly large numbers of fry and at the same time to reduce the personnel requirements, some auxiliary equipment can be installed: for example feeding systems and fish graders.

Fig. 85 - Air-driven feeding bins

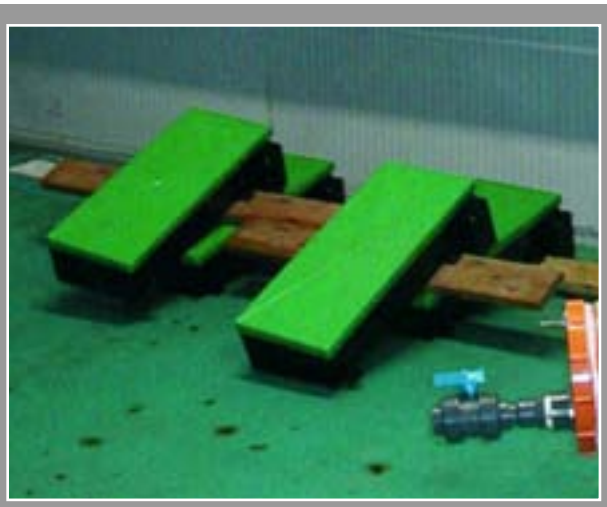


Fig. 86 - Traditional belt feeder

Feeding equipment has developed rapidly during the last ten years, evolving from the small belt feeders to the more sophisticated automatic feeding systems that are PC driven.

The figures below show new and old feeding equipment used for larval rearing.

Another problem encountered mainly in the nursery stages in many hatcheries is the difference in growth performance between larvae and fry which, in the case of larvae of the marine species reared, leads to mortality due to cannibalism. It is the old adage; "big fish eat small fish", which is totally undesirable in a hatchery. In addition, large differences in size imply different consumption patterns and an additional competition for food in which the winners are the larger fish. The solution is to reduce losses due to cannibalism. It is best to grade the fish as often as possible to reduce competition for food wich, in turn, leads to greater size differences.

Procedures for grading have been explained in the first volume and figures of traditional and manual fry graders have been provided. Below the reader can find figures showing automatic grading and sorting machines which facilitate considerably the work of the hatchery operators while at the same time minimizing handling of fry. This is always undesirable when dealing with large quantities of fry. There is also an illustration of a manual grader.

Fig. 87 - Fry grader under working conditions

Fig. 88 - Manual grading for very small fry

PART 4 FINANCIAL ASPECTS

4.1. INVESTING IN A HATCHERY

It is to be assumed that when deciding on investing in the construction and operation of a Mediterranean fish hatchery a potential entrepreneur has some interest in the subject and some knowledge of what a hatchery is in terms of facilities and how it operates. Essentially before investing in the construction and operation of a hatchery there are some basic questions that the future hatchery owner should ask himself as a sort of check list in order to make a decision. Typical questions, assuming that he does not own a site, would be:

a. Where can I establish the hatchery?
b. Where could I sell the fingerlings?
c. At what cost can the fingerlings been sold?
d. How should I produce to have an acceptable margin?
e. Are technology, technicians and equipment locally available?
f. Are there any schemes to assist funding these type of relatively new technologies?
g. Is the banking system willing to finance hatchery construction and operation? Or are they penalizing the funding by increasing the interest rates on this type of business?

The previous questions mean dealing with aspects of: existing legislation and regulations for use of sites (a), marketing considerations (b and c), technology choices (d and e) and, financing and financial analysis (f and g). They have been listed here because all of them interact and have a bearing on the final decision of the investor and should be dealt with simultaneously. Also, it has to be remembered that the answers to the various questions will vary considerably from place to place in the Mediterranean making this sort of check list analysis compulsory for the investor before deciding to embark on hatchery construction and operation.

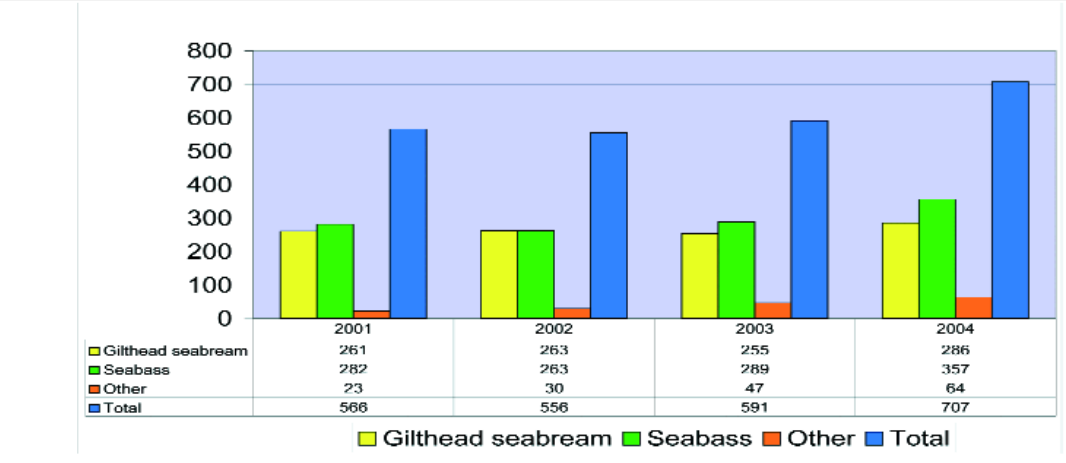


Fig. 89 - Mediterranean fry production (in millions) from 2001 to 2004

The section that follows will give the potential investor some guidance on the various choices to be made. Regarding financial analysis and calculation of financial indicators on the investment, such as IRR or NPV, hatchery construction and operation is no different from any other agro-industry. Therefore economists should have no problems applying the same reasoning to evaluate fixed, variable and financial costs, as well as profits. Specific models are not discussed here because the methodology is not specific to Mediterranean hatcheries. The variability that characterizes investment in the Mediterranean countries, in terms of cost of land, construction costs, energy, manpower, cost of money etc, would invalidate any attempt to provide an example which could be applied to the entire region. In

addition, the changes in technology are rapid and impacting on the economics so that a single model, even if the conditions in the region were more homogeneous, would become obsolete very rapidly.

Therefore, it has been decided to write about considerations that the manager or investor should take into account on the various elements of cost that have to be considered when selecting a design for a new hatchery.

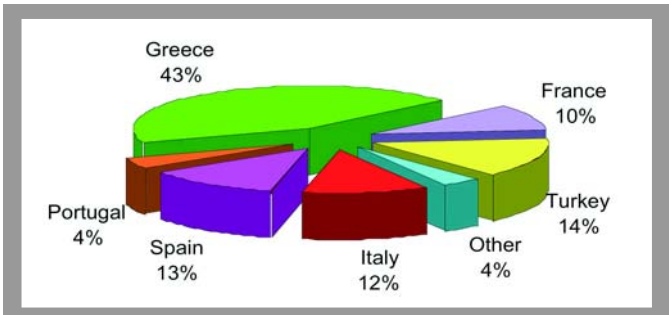


Fig. 90 - Mediterranean production by countries

Project design

The choices implicit in the construction of a hatchery, and therefore in the design of the project, depend not only on zootechnical choices but they are also linked to managerial choices with impacts on the investment. These design choices will affect the economic capacity of the hatchery.

Putting aside on purpose the consideration related to infrastructure typologies (greenhouses or workshop, water intake open or in pipelines, etc.) which are usually affected by local or technical reasons, and putting aside the elements of cost, there are two typical choices characterizing the project and management of the hatchery:

a. High automation of procedures and controls with limited use of personnel;
b. Low automation of procedures and controls with greater use of personnel.

Both choices have advantages and constraints. The first choice requires additional funding, favorable conditions as far as the availability of personnel, and infrastructure that can support the high automation.

Before entering into the pros and cons of high or low automation two fundamental concepts should be borne in mind:

Staff are always a key factor in production and may represent a fundamental bottleneck. As much as the investor may wish to install sophisticated equipment for monitoring, management and automation of procedures, nothing will replace the interface between staff and animals in a farming operation. The risk involved in a hi-tech investment which does not properly consider the choice of staff is very high. It might even fail.

Fig. 91 - Low technology versus high technology choices for sediment removal

Any structure built to work with a low level of automation whilst considering the possibility of using automatic devices, can be easily transformed into an infrastructure with high automation. Therefore, one choice does not preclude the other. A possible upgrading could be planned at the time of project design. This is particularly true in cases not requiring programmed investments such as the case of public funding to be implemented in a short period of time.

PROS AND CONS OF HIGH AUTOMATION SYSTEMS;

Pros	Cons
Optimization of management fees	High investment cost in infrastructure
Optimization in staff use	Requires qualified personnel
High ratio product/staff time	Requires maintenance and adequate external services
Good control of management parameters	

PROS AND CONS OF LOW AUTOMATION SYSTEMS;

Pros	Cons
Low investment	Low ratio product/staff time
Requires medium level staff	Low control level
Management and maintenance simplified	Difficult to insert in a highly competitive market
Low risk level	

The best approach would be to plan a very modern and extremely flexible facility, reaching its maximum level or automation about three to five years after its construction. This would be a facility with an initial higher cost, but will be able to grow in efficiency as it becomes progressively a high automation facility.

Structure and construction typologies

Once the level of automation and the time span to achieve it has been decided, construction typologies and related technology have to be decided. A hatchery can be built as a greenhouse, as a prefabricated building or even as a reinforced concrete building.

These decisions obviously have to be related to the work which is going to take place inside the building, (for example it would be difficult to create a properly insulated facility to work on photo and thermoperiod controls in a non-insulated greenhouse intended for agricultural production). Moreover these decisions have to be linked to the economic and financial plans related to the investment planned by the entrepreneur, as well as to the depreciationof the various possible choices

In fact, from the initial steps of the project there is a close link between funding or financial aspects and the implementation of the project in terms of design and technology. To underestimate this link leads often to unachieved dreams or to projects which have to be drastically reviewed in the course of their implementation.

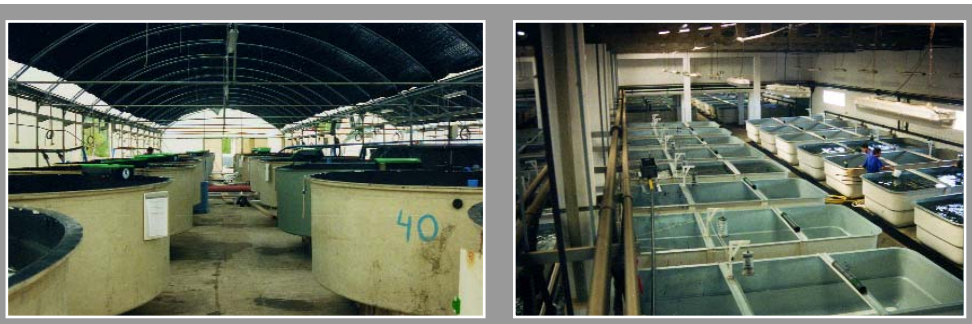


Fig. 92 - Costruction typologies: greenhouses versus concrete

Timing and production

As in many other production related activities where the cost of money has a big influence on the economic feasibility of the enterprise, so in the case of hatcheries, timing of construction has an important role in the implementation strategy to be adopted. Entrepreneurs approach this matter in two different ways:

1. Completing the construction of the entire facility, testing it, before starting any production;
2. Completing the construction in sections could be operative even if what follows in the production process would not be yet ready.

The first option could be implemented only in cases where the impact of payment of interest would be very low, which is rare. In all the other situations, it is clear that the second option will be the preferred choice. However, in this second case due to the higher risk incurred (e.g. larval rearing units could be producing 35 day old postlarvae with the risk that the weaning section would not be ready in time and the entire production would have to be discarded), a few but important precautionary considerations are necessary to limit the risks:

1. To include a specific delivery schedule with clearly established penalties for delays in the construction contract to be signed;
2. All common civil works must be built at the same time in order to save on their construction;
3. All the services and systems should be completed (pumping stations, PVC piping, generator, monitoring and alarm systems) before starting any production;
4. Then follow with the building of the production units maintaining the same order as in the production procedures (e.g. algae, rotifers, *Artemia*…) leaving last the broodstock unit (because it is most likely, with rare exceptions, that breeders will not produce eggs the first year). Some time for troubleshooting should also be allowed.

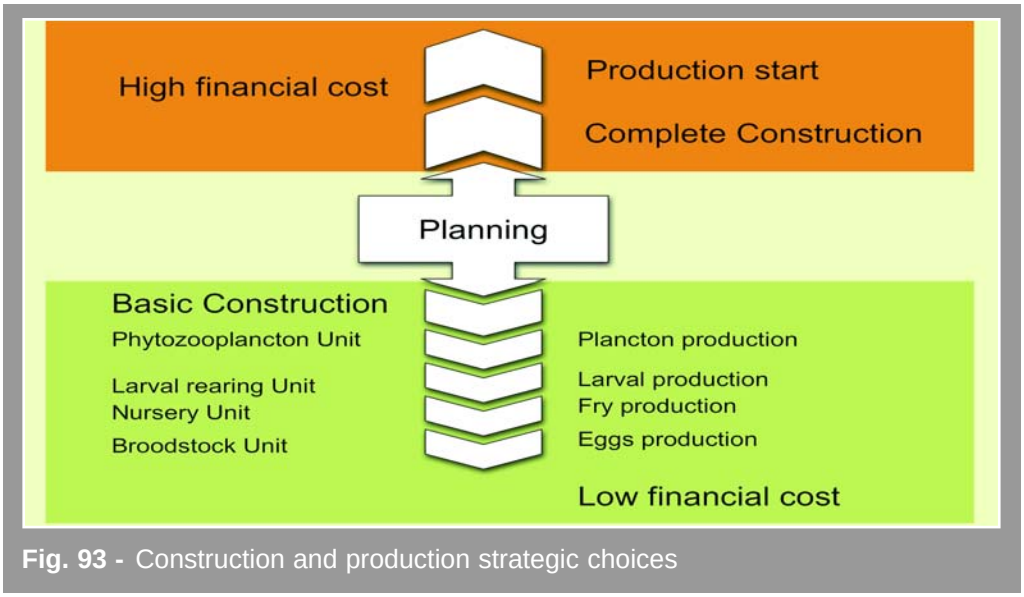


Fig. 93 - Construction and production strategic choices

Economies of scale and modular design

When dealing with the construction of a hatchery that has to produce profits, particular attention should be paid to economies of scale. This could also be related to the minimum number of fry to be produced and sold to obtain an acceptable return, and profit margin, in relation to the capital invested. In this context, the direct involvement or not of the owners in the production activities would also have a bearing on the results of the economic performance of the hatchery. A small hatchery managed by a family could be apparently penalized by limited resources. But it could coexist in the market with larger facilities thanks especially to the flexibility it offers on personnel costs and to the direct involvement of the same people in the economic results and distribution of profits. Therefore, the size of the facility would not be the only thing that counts on the economies of scale but also how the personnel costs and profits are distributed.

On the other hand, a decision in favour of investing in an industrial facility to be managed by external staff can also be extremely valid. In this case the lesser flexibility and lack of direct involvement of the owners in production should be compensated by production numbers that could absorb occasional scenarios of price drops and/or small difficulties with production.

In fact, the most difficult choice for a production model is something in-between. For example, a hatchery of average size (and the concept of average size should be adjusted to the prevailing local technologies) will have to face the high production numbers and the marketing capabilities of large hatcheries. It will also be unable to compete with small family hatcheries in terms of flexibility and personnel costs.

The construction of a hatchery in modules is strictly related to the design phase and can be a valid alternative for the future development of the hatchery in order to adjust to variable market and price conditions. A modular design has higher initial investment costs (some investments will have to be calculated for the expected final size of the hatchery), but also allow an easier adjustment between production capacity and growing objectives. Indeed, a correct modular design may be the key to success for many hatcheries.

Depreciation

Apart from purely administrative regulations, which obviously vary from one country to another, the choice of the project construction typology has a strong influence on the depreciation of the investment made by the company.

The choice of “light” infrastructures (such as greenhouses) combined with simple project typologies (such as open circuit) and species which are simple to rear (such as seabass), will result in moderate investment that, however, will have to be repaid quickly as the infrastructure will have a short life span and will deteriorate rapidly. On the other hand, hatcheries designed with heavier infrastructure (such as brick buildings), more sophisticated systems (closed circuits for example) and producing several species, will require higher initial investment that can be repaid over a much longer period. Both choices, with the continuum of intermediate situations, pose a decision problem which has to be studied carefully by the entrepreneur. It is nevertheless important to point out that a hatchery is a very hostile environment for most materials due to the location of the facilities and the utilization of seawater. The duration of materials is considerably reduced compared with similar uses for other activities in dry or freshwater environments.

Points to consider for financing of a hatchery

In addition to considering the markets where the production of the hatchery will be sold, there are three other important points which influence financing aspects in a hatchery. First is the relative simplicity of the facility. Second is the relatively rapid turnover generated by production (when compared with the growout phases). Third is the fact that there will be a natural and gradual improvement in the production corresponding to a learning curve which should take about five years to reach the plateau of production of the facility.

One more aspect should be considered. If the hatchery is going to operate to supply fingerlings for a growout farm in the same company, then its construction costs can be integrated in the overall financing of the company. Otherwise, if the hatchery is going to operate as a separate company selling fingerlings to other farms, then the financing of its construction can follow the normal channels through banks.

Investment and maintenance

Investors must bear in mind that aspects of maintenance of facilities and equipment have to be taken into account. Since the hatchery environment is particularly aggressive for materials and equipment, maintenance represents an important element of expenditure, both in terms of requirements of manpower and spare parts. It is thus recommended to select products and equipment which value quality over low cost. Equipment should be easily serviced locally. Spare parts should be available quickly: otherwise the investor will need to purchase a large amount of spare parts in advance.

4.2. EVALUATION OF FINANCIAL REQUIREMENTS FOR HATCHERY OPERATION

Before entering into the analysis of the various items involved in the operational costs of a Mediterranean hatchery, it would be opportune to highlight some aspects that characterize the operational cost of this activity and have a considerable influence on the various elements of a budget.

The first aspect to be considered is that this is an extremely variable activity, as it is a relatively new one and is subject to important changes in a short period of time. The technology, the markets, the farmed species, the credit for the sector, the productivity of the facilities, are all very sensitive variables, and even today are subject to oscillations that suggest a very cautious approach in the analysis of operational costs. Too much optimism is certainly a serious danger and this is perhaps quite often the first risk factor for the entire sector.

A cautious approach to the analysis of operational costs would involve several steps which would progressively transform the base cost into something more similar to the real situation the entrepreneur will face:

1. Base cost, which is the list of standard cost items, but not adjusted to the local production situation of the company
2. Average cost for the last five years, or costs which are derived from production experience. Even if this average is not representative for a specific financial year, it will, give the entrepreneur a better idea of how the company operates.
3. Costs including the risk or loss elements of the last 5 years, which are the costs indicated in the point above augmented by the risk factor, which is derived from the risk/losses experience of the company in the last five years.
4. The above plus the financial cost incurred would provide a more real picture of what the operational costs are going to be.

In the sections that follow only the cost items to be considered for the operating base costs (step 1 above) will be discussed.

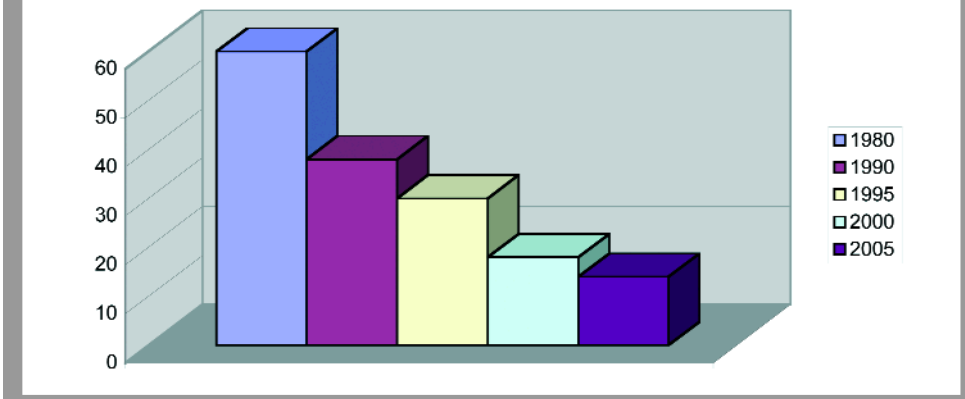


Fig. 94 - Evolution of manpower needs (man/year) to produce 10 million fry

4.3 BASE COST ELEMENTS

The base operating costs elements are composed of two main groups of cost items: fixed and variable costs.

FIXED COST

Fixed costs are cost items the entrepreneur will have to incur and which are not directly linked to the amount of production of the hatchery.

A. Permanent technical staff

For many Mediterranean hatcheries the cost of permanent technical staff is the highest item of the base cost elements. Therefore, the managers, in many cases, tend to reduce it as much as possible, transferring this cost to variable costs, recruiting temporary technical staff. In the case of a hatchery this approach would not be correct as well-trained permanent staff represent perhaps the best asset of the company. Success in production is not only related to the utilization of equipment, but is rather related to the combination of management and equipment.

Therefore this approach must be avoided as far as possible or, eventually, the use of temporary staff must be limited to less than 30% of the total staff time. Permanent staff should also be estimated in terms of total number of hours of work or of staff per quantities of product. This obviously should be related to the total size of the company.

B. Administrative staff

The cost of administrative staff is usually separated from that of the permanent technical staff. This is due to the fact that, being in many cases rather small companies, it is not always convenient to recruit administrative staff on a full-time basis. In many cases, managers make use of external personnel or services. Even if the cost of the administrative staff is not directly linked to production, it can impact substantially on the balance of the company, especially in the more developed countries of the Mediterranean where the existing bureaucracy requires a considerable amount of work.

C. Leasing

With leasing becoming more common in many countries it would be possible to transfer part of the cost of equipment as rapid amortization costs. When this arrangement is possible, it is rather convenient for hatchery operations because of the continuous technical progress and the rapid deterioration of materials and equipment in a marine hatchery. However, in countries where investment is subsidized or supported by the state, leasing arrangements cannot always be used. They may not be compatible with the public funding provided.

D. Services

Depending on the country and on the level of automation, service costs can be very different. Telephone, water (which would have also an element as variable costs), and sewage, are all costs which have lower limits which cannot be reduced and which are linked to the registration of the company as a user of these services.

E. Tax, licenses

Tax costs are strictly related to the regulations of the country in which the hatchery will operate. They are an important element to take into consideration when preparing a feasibility study. License costs could be related to the use of consultants and, in this case, are directly related to negotiation between the company and the consultant. Quite often, license costs are linked to the number of fish produced. This approach which, in principle, could appear to be interesting for the manager, can be tricky in a market the size of which is not entirely known and which could vary substantially from year to year. In fact, the consultant may tend to increase hatchery production to the maximum possible and, in the case of a crisis in the markets, the company would be forced to pay royalties without selling the product. The best solution would be to set a minimum production fee that could be increased by the addition of a variable royalty.

VARIABLE COSTS

Variable costs are those directly linked to the production plans and therefore are the costs elements which can be changed in relation to the production targets of the year. Nevertheless, variable costs are not always directly related to production. Electricity is a classic example of a variable cost with some, although usually limited variations in relation to the quantity used. Feeds and oxygen are typical variable

costs which are not related to tariff/consumption brackets, but their costs are related to negotiation with the suppliers and therefore to consumption levels. Nobody would pay the same prize per kg of feed if he had to consume in a year 100 kg or 10 tons.

A. Energy

In a modern hatchery, energy is surely one of the highest variable costs. This is because a lot of complex equipment is used. Managers should pay attention to this cost item since it could be optimized easily, both in terms of direct consumption, but also in relation to the contracts to the signed with the companies. Quite often energy costs are considered unavoidable and managers may tend to pay limited attention to the optimization of this cost item. On the contrary, an analysis of the various production activities and the energy consumption involved in each of them could lead to substantial savings of 20-30% of the annual costs without affecting the operation of the hatchery.

B. Feeds

Feed costs are surely an important cost element, but in order to carry out a rigorous analysis, up to four different cost categories can be identified:

1. Cost of products required for algal culture and for rotifer rearing. This is directly proportional to the amount of fry planned for production and is also a function of the type of technology adopted. For instance, if for rotifer culture the hatchery uses commercial diets the quality of the final product will be more uniform and indexes of production will be higher. In the case of utilization of yeast only, we will get lower production/volume ratios and lower production costs.
2. Cost of *Artemia* cyst. This is now an international commodity. Large market price variations, which can reach 700%, influence heavily this element of cost. With the rapidly increasing cost of *Artemia* cysts in the last years, many operators would think, wrongly, that this cost element could influence heavily and directly the final cost of production of fry. Luckily this is no longer true since, in recent years, the use of *Artemia* has been reduced substantially. There are now also feeds replacing it. In fact, often an increase in the cost of *Artemia* of US$20/kg has a reduced impact on the final sale price of the fingerlings.
3. Cost of enrichment products. This is also a cost directly proportional to the production, but strictly related to the technological choice. It is not easily replaceable if the operator is interested in production of high quality fingerlings.
4. Cost of dry feeds. This has been going up recently as dry feeds replace a large part of the *Artemia* biomass previously utilized. Dry feed should be sub-divided into two categories: larval feeds and feeds for post-larval stages of high quality and relative high cost, but used in limited quantities than those employed in the nursery and pre-fattening stages with a much lower unit cost (up to ten times less than the first group). Therefore, from the above it is evident that considerable attention should be given to the optimization of the use of the last category as it has a considerable impact on the cost of the fingerlings.

C. Oxygen

Oxygen is a relatively new cost item for hatcheries as, only in the last decade or so, has this product become of common use for production of fingerlings. Because of this, even today, it is relatively difficult to give an estimate of the impact of oxygen on the final cost of the fingerlings. Although poor use of oxygen will continue, a process of optimization in its use will start in the hatcheries, although at present it is not very common. Oxygen supply systems dilute oxygen in water and therefore increase the availability of oxygen as gas for farmed fish. At present, an average efficiency does not exceed 25-30% which means that in the best of cases 70% of oxygen is wasted. In addition, extra energy costs are needed to dissolve oxygen efficiently. The operator should find a compromise between the use of energy and efficiency of oxygen transfer to optimize costs.

D. Eggs

This cost element is a recurring one for small hatcheries which do not have a breeder section, or else should be calculated for medium and large size hatcheries as the annual cost to maintain and reproduce the broodstock.

The increasing attention given to the quality of the eggs has resulted in a progressive increase of this cost in recent years.

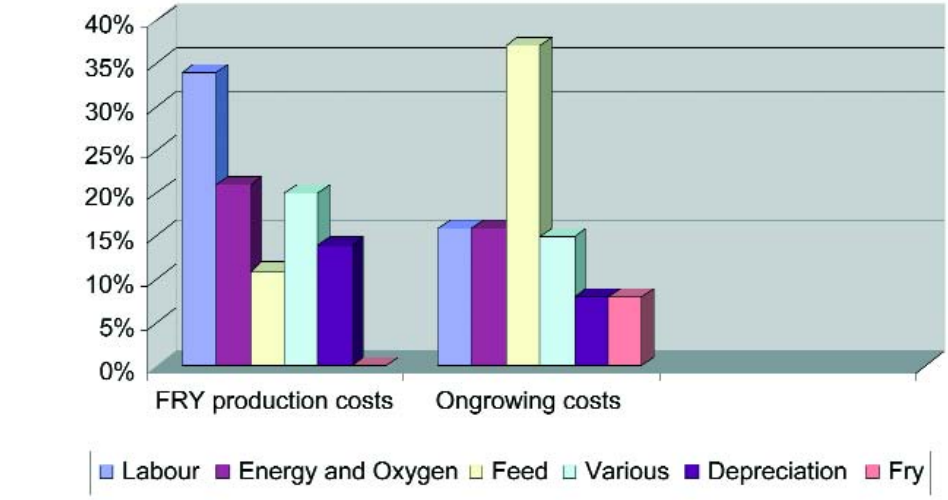


Fig. 95 - Example of relative weight of cost categories between hatchery production and an intensive growout facility (concrete tanks)

E. Temporary staff

As previously indicated the use of temporary staff is a strategic choice of the entrepreneur, as this type of personnel should only cover routine duties which are seasonal in nature and should have limited technical capacity (grading, extra-ordinary cleaning and maintenance activities). We would insist on the fact that personnel is one of the most important assets in a hatchery and therefore it should be used in a continuous manner all year round, avoiding the recruitment of temporary staff as much as possible, except for activities such as the ones indicated above. Moreover it is important to note that this is a personal view of the authors and one of the various strategies adopted on the use of personnel. In many hatcheries the owners maintain a constant rotation between staff involved in routine and non-routine duties.

F. Sales and distribution

Sales and distribution cost are essentially irrelevant in the case of hatcheries except for the case of transport between hatcheries and growout facilities. This is not a real production cost but an additional service that could be provided by the hatchery. Sales costs are minor since the number of clients and the frequency of contacts is relatively limited. In fact, with the exception of a few very large Mediterranean hatcheries, only a few have a full-time commercial section, and often this function is covered by the production manager together with the administrator.

4.4. FINANCIAL COST AND CASH FLOW REQUIREMENTS

Financial costs are closely related, as in any other agro-business, to the way the hatchery has been financed and to the wealth of the investor. It would thus seem unnecessary to mention them if it was not for the slow and progressive annual increase in the production that modifies the cash flows and the

related financial costs. In other types of activities, once the production facilities are built and the staff is trained, the planned production capacity is rapidly reached and maintained with the exception of catastrophic events.

On the contrary, in a hatchery one often finds a slow increase in production capacity. Due to the seasonality of the production cycle this can last three, four or even five years. This phenomenon which is seldom considered during the project preparation is often the cause of financial crisis of the hatchery and of the related increase in the financial costs. Cash flow requirements follow the process mentioned above and very often in the first years of operation are considerably higher than expected.

Moreover, because of the seasonality of production, the cash flow requirements tend to vary with a peak that, in Italy for example, coincides with the May-June period. In Italy, this is a period of maximum financial exposure. Outgoings are high but income is low. Payment for fingerlings produced in autumn and sold in February-March has not yet arrived because very often they are paid for up to 120 days after collection from the hatchery. Obviously the months in which cash-flow requirement peaks appear may differ in other Mediterranean countries according to the calendar of production and the sales agreements. Payment for fingerlings is an essential element of cash-flows. With the exception of the initial years, when the hatchery reaches its regular production target, they can be the main source of worry due to the frequent and unforeseen delays in payments, complaints or, in the worst case, bankruptcies.

4.5 HATCHERIES TURNOVER COMPARED WITH GROWOUT FARMS

Altough hatcheries and growout farms are two sides of the same coin, hatcheries are in a better financial position. This is due to the shorter production period. It takes 4-5 months to produce fingerlings of 2 g against the 14-20 months that a growout operator will take to bring the fingerling to a marketable size of 350-400g. That is why payment for fingerlings may take from six months to a year.

4.6 HOW AND WHAT TO PRODUCE

To answer this question is foresee the future. Unfortunately this is not yet possible but nevertheless some rules of thumb can help in providing a partial answer.

How to produce. Taking into account the company economic set-up and its position on the market and local area. Avoid a static view of the production as final goal and rather trying to sell profitably the hatchery production and therefore adapting to the dynamics of the markets. Quite often, in fact, production targets have taken the upper hand against the optimization of the economics of the hatchery, leading to large and unjustified economic losses which could have been avoided with a more careful analysis of the dynamics of the markets.

What to produce. What the market demands in terms of species and quality of product (which is a key factor in the long term). At the same time being aware of innovations, not only new species, but also better services, improved quality, different sizes of product and different time to sell the product in the market.

As for other topics dealt with in this manual, they have to be regarded as subjective views based on the experiences of the authors.

4.7 RISKS

From what has been discussed so far, it is evident that hatchery operation and in general aquaculture as well is still a sector in which risks are high compared to other industrial activities, and again not fully understood as in the case of pathologies, deformities, markets, etc.

As with other zootechnologies it is impossible to exclude all the possible risks. But, to a certain extent, the hatchery manager should try to prevent what it is possible. The sector is usually divided in two categories of operators; the optimist and the pessimist. Belonging more to the second than to the first category, we believe that it will be impossible to avoid problems (Murphy's Law…) but to foresee the problem and to limit the impact is the duty of the hatchery manager.

Apart from the general risks typical of any entrepreneurial activity the main specific risks of the hatcheries are:

- Market risks,
- Disease risks, and
- Risks related to non-foreseeable natural events.

4.8 INSURANCE

To insure a hatchery is at present a rather complex business, but it is becoming something possible and a duty of the management. In the previous paragraphs on risks, it has been indicated that the duty of the hatchery manager is not to ignore them, but to prevent them and to create mechanisms to reduce the impact. Insurance is an instrument of the collectivity, which, if well structured, will permit losses that the single operator would not be able to absorb alone without high costs in terms of money and personnel. Good insurance, in fact, is nothing more than a collective cost paid to a third party by several participants who are aware that in the collectivity someone could have problems.

The main concept is therefore that the insurance should cover mainly for losses of medium and serious importance and not for the small losses.This limits annual losses and enables the hatchery to confront a serious situation which could otherwise lead to bankruptcy.

ANNEXES

LIST OF ANNEXES

These annexes are selected tables taken from the book Aquaculture Desk Reference by R. LeRoy Creswell published in 1993 by AVI Books, New York. We are grateful for permission to reprint them.

ANNEX 1

Conversion tables

TABLE 1-1: TEMPERATURE EQUIVALENTS - CENTIGRADE TO FARENHEIT

Temperature in °C. is expressed in the left column and top row with the corresponding temperature in °F. in the body of the table.

°C.	0	1	2	3	4	5	6	7	8	9
0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2

TABLE 1-2: TEMPERATURE EQUIVALENTS - FARENHEIT TO CENTIGRADE

Temperature in °F. is expressed in the left column and top row with the corresponding temperature in °C. in the body of the table.

°F.	0	1	2	3	4	5	6	7	8	9
30		-0.6	0.0	0.6	1.1	1.7	2.2	2.8	3.3	3.9
40	4.4	5.0	5.6	6.1	6.7	7.7	7.8	8.3	8.9	9.4
50	10.0	10.6	11.1	11.7	12.2	12.8	13.3	13.9	14.4	15.0
60	15.6	16.1	16.7	17.2	17.8	18.3	18.9	19.4	20.0	20.6
70	21.1	21.7	22.2	22.8	23.3	23.9	24.4	25.0	25.6	26.1
80	26.7	27.2	27.8	28.3	28.9	29.4	30.0	30.6	31.1	31.7
90	32.2	32.8	33.3	33.9	34.4	35.0	35.6	36.1	36.7	37.2
100	37.7	38.3	38.9	39.4	40.0	40.6	41.1	41.7	42 2	42.8

For intermediate temperatures or those exceeding the range of the tables, the following formulas may be used:

$$°F = 1.8 \times °C + 32$$

$$C = \frac{F - 32}{1.8}$$

TABLE 1-3: CONVERSIONS FOR UNITS OF WEIGHT

FROM \ TO	GRAM	KILOGRAM	GRAIN	OUNCE	POUND
GRAM	1	.001	15.43	0.0353	0.0022
KILOGRAM	1000	1	1.54×10^{4}	35.027	2.205
GRAIN	0.0648	6.48×10^{-5}	1	0.0023	1.43×10^{-4}
OUNCE	28.35	0.0284	437.5	1	0.0625
POUND	453.6	0.4536	7000	16	1

TABLE 1-4: CONVERSIONS FOR UNITS OF LENGTH

FROM	TO CENTIMETER	METER	INCHES	FEET	YARDS
CENTIMETER	1.0	0.01	0.3937	0.0328	0.0109
METER	100	1.0	39.37	32.81	1.0936
INCHES	2.540	0.0254	1.0	0.0833	0.0278
FEET	30.48	0.3048	12.0	1.0	0.3333
YARDS	91.44	0.9144	36.0	3.0	1.0

TABLE 1-5: CONVERSIONS FOR UNITS OF VOLUME

FROM	TO CM^3	LITER	$METER^3$	$INCHES^3$	$FEET^3$	FL. OZ.	FL. PT.	FL. QT.	GAL.
CM^3	1.0	0.001	$1x10^{-6}$	0.061	$3.53x10^{-5}$	0.0338	0.00211	0.00106	$2.64x10^{-4}$
LITER	1000	1.0	0.001	60.98	0.0353	33.81	2.113	1.057	0.2624
$METER^3$	$1 x 10^6$	1000	1.0	$6.1x10^4$	5.31	$3.38x10^4$	2113	1057	264.2
$INCHES^3$	16.39	0.0164	$1.64x10^{-5}$	1.0	$5.79x10^{-4}$	0.5541	0.0346	0.0173	0.0043
$FEET^3$	$2.83 x10^4$	28.32	0.0283	1728	1.0	957.5	59.84	29.92	7.481
FL. OZ.	29.75	0.0296	$2..96x10^{-5}$	1.805	0.00104	1.0	0.0625	0.0313	0.0078
FL. PT.	473.2	0.4732	$4.73x10^{-4}$	28.88	0.0167	16.0	1.0	0.5000	0.1250
FL. QT.	946.4	0.9436	$9.46x10^{-4}$	57.75	0.0334	32.0	2.0	1.0	0.2500
GALLON	3785	3.785	0.0038	231.0	0.1337	128.0	8.0	4.0	1.0

TABLE 1-6: CONVERSIONS FOR UNITS OF VELOCITY

FROM	TO FT/MIN	M/S	M/MIN	M/HR	MPH	KNOTS
FEET/MIN	1.0	0.00508	0.30480	180288	0.01130	0.00987
METER/SEC	196.85	1.0	60.00	3600.0	2.2369	1.9425
METER/MIN	3.2808	0.01667	1.0	60.00	0.03728	0.03238
METER/HR	0.05468	0.00028	0.01667	1.0	0.00062	0.00054
MPH	88.0	0.44704	26.822	1609.4	1.0	0.86839
KNOTS	101.34	0.51479	30.887	1853.2	1.1516	1.0

TABLE 1-7: CONVERSIONS FOR UNITS OF ENERGY

FROM	TO BTU	JOULE (J)	FOOT POUND
BTU	1	1055	778
JOULE (J)	0.0009478	1	0.7376
FOOT POUND	0.001285	1.3558	1

BTU = British Thermal Unit, a unit of heat equal to 252 calories, or the quantity of heat required to raise the temperature of one pound of water from 62 °F to 63 °F

JOULE = a unit of electrical energy or work equivalent to the work done to raise one coulomb of electricity one volt, or in maintaining for one second a current of one ampere against a resistance of one ohm

FOOT POUND = a unit of work equal to the amount of energy required to raise a weight of one pound a distance of one foot

TABLE 1-8: CONVERSIONS FOR UNITS OF POWER

FROM	HORSEPOWER	TO WATT (W)	FT. LB/S	BTU/S
HORSEPOWER	1	746	550	0.7068
WATT (W)	0.001341	1	0.7376	0.00095
FT. LB./S	0.00182	1.356	1	0.001285
BTU/S	1.415	1055	778	1

HORSEPOWER = a unit of power equal to a rate of 33,000 foot-pounds per minute (the force required to raise 33,000 pounds at the rate of one foot per minute)

WATT = a unit of electrical power equal to one ampere under one volt of pressure, or one joule per second

TABLE 1-9: CONVERSION FACTORS OF RADIANT ENERGY, POWER, AND INTENSITY UNITS
(from Hollaender, 1956)

FROM	TO				
	ENERGY				
	ERG	JOULE	G-CAL	WATT HOUR	KG-CAL
ERG (DYNE-CM)	1	10^{-7}	0.239×10^{-7}	0.278×10^{-10}	0.239×10^{-10}
JOULE (WATT-SEC)	10^{7}	1	0.239	0.278×10^{-3}	0.239×10^{-3}
GRAM-CALORIE	4.19×10^{7}	4.19	1	1.163×10^{-3}	10-3
WATT HOUR	3.60×10^{10}	3,600	860	1	0.860
KILOGRAM-CALORIE	4.19×10^{10}	4,190	1,000	1.16	1
	POWER				
	ERG/SEC	µWATT	CAL/MIN	WATTS	CAL/SEC
ERG/SEC	1	0.1	1.43×10^{-6}	10^{-7}	0.239×10^{-7}
µWATTS	10	1	1.43×10^{-5}	10^{-6}	0.239×10^{-6}
CALORIE/MIN	6.98×10^{5}	6.98×10^{4}	1	0.0698	0.0166
WATT	10^{7}	10^{6}	14.3	1	0.239
CALORIE/SEC	4.19 x 107	4.19×10^{6}	60	4.19	1
	INTENSITY				
	ERG/SEC/CM^2	µWATT/CM^2	µWATT/MM^2	WATT/M^2	CAL/MIN/CM^2
ERG/SEC/CM^2	1	0.1	0.001	0.001	1.43×10^{6}
µWATT/CM^2	10	1	0.01	0.01	1.43×10^{-5}
µWATT/MM^2	1000	100	1	1	1.43×10^{-3}
WATT/M^2	1000	100	1	1	1.43×10^{-3}
CAL/MIN/CM^2	6.98×10^{5}	6.98×10^{4}	698	698	1

ERG = a unit of work or energy in the metric system equal to the amount of work done by one dyne acting through a distance of one centimeter

DYNE = a unit of force which in one second can alter the velocity by one centimeter per second of a mass of one gram

CALORIE = the amount of heat needed to raise the temperature of one gram of water one degree Centigrade

TABLE 1-10: CONVERSION FACTORS FOR ILLUMINATION

FROM	TO			
	BRIGHTNESS			
	FOOT-LAMBERT	LAMBERT	CANDLES/CM2	CANDLES/MM2
FOOT-LAMBERT	1	1.08×10^{-3}	3.39×10^{-3}	3.39 x 10-5
LAMBERT	929	1	0.318	0.318×10^{-3}
CANDLES/CM^2	2920	3.14	1	0.01
CANDLES/MM^2	2.92×10^5	314	100	1
	ILLUMINANCE			
	LUX	FOOT-CANDLES	LUMEN/CM^2	
LUX	1	0.093	10^{-4}	
FOOT CANDLES	10.8	1	1.08×10^{-3}	
LUMEN/CM^2	10^4	929	1	

LAMBERT = the centimeter-gram-second unit of brightness, equal to the brightness of a perfectly diffusing surface that radiates or reflects light at the rate of one lumen per square centimeter

LUX = illumination equal to one lumen per square meter or the illumination of a surface uniformly one meter distant from a point source of one foot candle

FOOT-CANDLE = illumination equal to the amount of direct light thrown by one international candle on a surface one foot away

INTERNATIONAL CANDLE = a measure of the intensity of light, equal to the light given off by the flame of a sperm candle 7/8 inch in diameter burining at the rate of 7.776 grams per hour

LUMEN = a measure for the flow of light, equal to the amount of flow through a unit solid angle from a uniform point source of one international candle

(Source: E. Bickford and S. Dunn, *Lighting for Plant Growth*; 1972)

TABLE 1-11: CONVERSIONS FOR PRESSURE EQUIVALENTS

FROM	TO POUNDS/$IN.^2$	FEET WATER	INCHES MERCURY (in. Hg)	ATMOSPHERES (atm)
POUNDS/$IN.^2$	1.0	2.309	2.036	0.068
FEET WATER	0.433	1.0	0.882	0.0295
INCHES MERCURY .	0.491	1.134	1.0	0.033
ATMOSPHERES (atm)	14.7	33.9	29.92	1.0
KILOPASCALS (kPa)	0.145	0.335	0.295	0.010

INCHES MERCURY = a unit of pressure as measured by a manometer equal to the pressure balanced by the weight of a one-inch column of mercury in the instrument

ATMOSPHERE = the weight of the atmosphere per square inch of surface; the pressure of 14.69 pounds per square inch exerted in all directions at sea level by the atmosphere

KILOPASCAL = 1,000 pascals = a unit of force equal to one Newton per square meter (N/m^2); typically used as pascal second (Pa • s), or 10 poise designating absolute viscosity

BAR = a metric unit of measure often used, equal to 100 kilopascal (kPa) or 14.5 lb/in^2

TABLE 1-12: MULTIPLIERS FOR CONVERSION OF UNITS

TO GET FROM	MULTIPLY BY	TO OBTAIN
	LINEAR	
CENTIMETERS	3.2808×10^{-2}	FEET
	3.9370×10^{-1}	INCHES
	1.0000×10^{4}	MICRONS
	1.0000×10^{1}	MILLIMETERS
FEET	1.2000×10^{1}	INCHES
	3.0480×10^{-4}	KILOMETERS
	3.0480×10^{-1}	METERS
	1.8939×10^{-4}	MILES
	3.0480×10^{2}	MILLIMETERS
INCHES	2.5400×10^{-2}	METERS
	2.54	CENTIMETERS
	2.5400×10^{1}	MILLIMETERS
	0.08333	FEET
	0.027778	YARDS
	0.000'015783	MILES
KILOMETERS	1.0000×10^{3}	METERS
	6.2137×10^{-1}	MILES
METERS	6.2137×10^{-4}	MILES
	39.37	INCHES
	3.28	FEET
	1.0936	YARDS
	1.0000×10^{3}	MILLIMETERS
	100	CENTIMETERS
MICRONS	1.0000×10^{-3}	MILLIMETERS
	1.0000×10^{-6}	METERS
MILES	1.60935	KILOMETERS
	1,760	YARDS
	5,280	FEET
	63,360	INCHES
	1.6093	KILOMETERS
	1.6093×10^{3}	METERS
	AREA	
ACRES	43,560	SQUARE FEET
	4,840	SQUARE YARDS
	43,560	SQUARE FEET
	4,047	SQUARE METERS
	0.404687	HECTARES
	0.0015625	SQUARE MILES
	4,840	SQUARE YARDS
	4,047	SQUARE METERS
HECTARE	1.0000×10^{4}	SQUARE METERS
	2.47 ACRES	
SQUARE CENTIMETERS	1.0764×10^{-3}	SQUARE FEET
	1.5500×10^{-1}	SQUARE INCHES
	1.0000×10^{-4}	SQUARE METERS

TABLE 1-12 (cont):

TO GET FROM	MULTIPLY BY	TO OBTAIN
SQUARE FEET	1.4400×10^{2}	SQUARE INCHES
	9.2903×10^{-2}	SQUARE METERS
	0.000000003587	SQUARE MILES
	0.000022957	ACRES
	0.11111	SQUARE YARDS
SQUARE INCHES	0,0000000002491	SQUARE MILES
	6.4516×10^{-4}	SQUARE METERS
	6.45163	SQUARE CENTIMETERS
	0.0000001594	ACRES
	0.0007716	SQUARE YARDS
	0.006944	SQUARE FEET
SQUARE KILOMETERS	3.8610×10^{-1}	SQUARE MILES
SQUARE METERS	10.76	SQUARE FEET
SQUARE MILE	4,014,489,600	SQUARE INCHES
	27,878,400	SQUARE FEET
	3,097,600	SQUARE YARDS
	640	ACRES
	259	HECTARES
SQUARE YARDS	0.0000003228	SQUARE MILES
	0.0002066	ACRES
	9	SQUARE FEET
	1,296	SQUARE INCHES
GRAMS (FL)/GALLON	2.6455×10^{2}	MILLIGRAMS/LITER
	3.4392×10^{-2}	OUNCES (FL)/GALLON
	2.6455×10^{2}	PARTS PER MILLION
	2.6455×10^{-1}	PARTS PER THOUSAND
GRAINS PER GALLON	17.12	MILLIGRAMS PER LITER
	142.9	POUNDS PER MILLION GALLONS
MILLIGRAMS PER LITER	1	PARTS PER MILLION
	0.0584	GRAINS PER GALLON
	8.345	POUNDS PER MILLION GALLONS
	1.3000×10^{-4}	OUNCES (FL)/GALLON
	1.0000	PARTS PER MILLION
	1.0000×10^{-3}	PARTS PER THOUSAND
	3.7800×10^{-3}	GRAMS (FL)/GALLON
OUNCES (FL)/GALLON	7.6923×10^{3}	PARTS PER MILLION
	7.6923	PARTS PER THOUSAND
	2.9077×10^{1}	GRAMS (FL)/GALLON
	7.6923×10^{3}	MILLIGRAMS/LITRE
PARTS PER MILLION	1.0000×10^{-3}	PARTS PER THOUSAND
	3.7800×10^{-3}	GRAMS (FL)/GALLON
	1.0000	MILLIGRAMS/LITER
	1.3000×10^{-4}	OUNCES (FL)/GALLON
PARTS PER THOUSAND	1.3000×10^{-1}	OUNCES (FL)/GALLON
	1.0000×10^{3}	MILLIGRAMS/LITER
	1.0000×10^{3}	PARTS PER MILLION
	3.7800	MILLIGRAMS/LITER

TABLE 1-12 (cont):

TO GET FROM	MULTIPLY BY	TO OBTAIN
	DENSITY	
KILOGRAMS/CUBIC METER	1.0000×10^{3}	MILLIGRAMS/LITER
	6.2422×10^{-2}	POUNDS/CUBIC FOOT
MILLIGRAMS/LITER	6.2422×10^{-5}	POUNDS/CUBIC FOOT
	10000×10^{-3}	KILOGRAMS/CUBIC METER
POUNDS/CUBIC FOOT	1.6020×10^{1}	KILOGRAMS/CUBIC METER
	1.6020×10^{4}	MILLIGRAMS/LITER
	ENERGY	
BTU	1.0543×10^{3}	JOULES
	2.5200×10^{-1}	KG-CALORIES
	2.9285×10^{-4}	KILOWATT-HRS
JOULES	2.3903×10^{-4}	KG-CALORIES
	9.4852×10^{-4}	BTU
KG-CALORIES	1.1621×10^{-3}	KILOWATT-HRS
	3.9683	BTU
	4.1836×10^{3}	JOULES
KILOWATT-HRS	3.4147×10^{3}	BTU
	8.6050×10^{2}	KG-CALORIES
	FLOW	
CUBIC CENTIMETERS/SEC	3.5315×10^{-5}	CUBIC FEET/SEC
	1.0000×10^{-6}	CUBIC METERS/SEC
	1.5848×10^{-2}	GALLONS/MIN
	2.6413×10^{-4}	GALLONS/SEC
	6.0000×10^{-2}	LITERS/MIN
CUBIC FEET/SEC	2.8317×10^{-2}	CUBIC METERS/SEC
	4.4876×10^{2}	GALLONS/MIN
	7.4794	GALLONS/SEC
	1.6990×10^{3}	LITERS/MIN
	2.8317×10^{4}	CUBIC CENTIMETERS/SEC
CUBIC METERS/SEC	1.5848×10^{4}	GALLONS/MIN
	2.6413×10^{2}	GALLONS/SEC
	1.0000×10^{6}	CUBIC CENTIMETERS/SEC
	6.0000×10^{4}	LITERS/MIN
	3.5315×10^{1}	CUBIC FEET/SEC
GALLONS/MIN	1.6667×10^{4}	GALLONS/SEC
	3.7860	LITERS/MIN
	6.3100×10^{1}	CUBIC CENTIMETERS/SEC
	2.2283×10^{-3}	CUBIC FEET/SEC
	6.3100×10^{-5}	CUBIC METERS/SEC
	8.021	CUBIC FEET PER HOUR
GALLONS/SEC	3.7860×10^{-3}	CUBIC METERS/SEC
	1.3370×10^{-1}	CUBIC FEET/SEC
	2.2716×10^{2}	LITERS/MIN
	3.7860×10^{3}	CUBIC CENTIMETERS/SEC
	6.0000×10^{1}	GALLONS/MIN

TABLE 1-12 (cont):

TO GET FROM	MULTIPLY BY	TO OBTAIN
LITERS/MIN	1.6667×10^{1}	CUBIC CENTIMETERS/SEC
	5.8858×10^{-4}	CUBIC FEET/SEC
	1.6667×10^{-5}	CUBIC METERS/SEC
	2.6413×10^{-1}	GALLONS/MIN
	4.4022×10^{-3}	GALLONS/SEC
LITERS/SEC	15.85	GALLONS PER MINUTE
	MASS	
GRAMS	1.0000×10^{-3}	KILOGRAMS
	1.0000×10^{3}	MILLIGRAMS
	3.5327×10^{-2}	OUNCES
	2.2050×10^{-3}	POUNDS
	1.0000×10^{-6}	TONNES
KILOGRAMS	1.0000×10^{6}	MILLIGRAMS
	3.527×10^{-5}	OUNCES
	2.2050	POUNDS
	1.0000×10^{-3}	TONNES
	9.8438×10^{-4}	TONS (LONG)
	1.1025×10^{-3}	TONS (SHORT)
MILLIGRAMS	2.2050×10^{-6}	POUNDS
OUNCES	7.7778×10^{-2}	POUNDS
	4.5351×10^{-4}	TONNES
	4.4643×10^{-4}	TONS (LONG)
	5.0000×10^{-4}	TONS (SHORT)
	7,000	GRAINS
	453.6	GRAMS
TONNES	1.1025	TONS (SHORT)
TONS (LONG)	1.1200	TONS (SHORT)
	VELOCITY	
CENTIMETERS/SEC	1.9685	FEET/MIN
	1.0000×10^{-5}	KILOMETERS/SEC
	1.0000×10^{-2}	METERS/SEC
	2.2369 X 10-2	MILES/HR
FEET/MIN	1.8288×10^{-2}	KILOMETERS/HR
	5.0800×10^{-3}	METERS/SEC
	1.1364×10^{-2}	MILES/HR
KILOMETERS/HR	6.2137×10^{-1}	MILES/HR
	1.0000×10^{3}	METERS/SEC
METERS/SEC	2.2369	MILES/HR
	3.281	FEET PER SECOND
	VOLUME	
ACRE-FOOT	4.3573×10^{4}	CUBIC FEET
	1.2338×10^{3}	CUBIC METERS
	1.6138×10^{3}	CUBIC YARDS
	2.7137×10^{5}	GALLONS (IMP)
	3.2590×10^{5}	GALLONS (US)

TABLE 1-12 (cont):

TO GET FROM	MULTIPLY BY	TO OBTAIN
CUBIC CENTIMETER	0.06102	CUBIC INCHES
CUBIC FEET	1 728	CUBIC INCHES
	7.481	GALLONS
	28.32	LITERS
	1 728	CUBIC INCHES
	7.4805	U. S. GALLONS
	28.317	LITERS
	0.037037	CUBIC YARDS
	0.00022957	ACRE-FEET
CUBIC METERS	35.31	CUBIC FEET
	264.2	GALLONS
	1 000	LITERS
CUBIC YARDS	21	CUBIC FEET
	46,656	CUBIC INCHES
	0.00061983	ACRE-FEET
	0.76456	CUBIC METERS
GALLONS	3785	CUBIC CENTIMETERS
	0.1337	CUBIC FEET
	231	CUBIC INCHES
	3.785	LITERS
GALLONS OF WATER	8.345	POUNDS OF WATER
LITERS	1,000	CUBIC CENTIMETERS
	0.03531	CUBIC FEET
	0.2642	GALLONS
PRESSURE		
ATMOSPHERES	14.7	PSI
	33.9	FEET OF WATER
	29.9	INCHES OF MERCURY
	76.0	CENTIMETERS OF MERCURY
BAR	1.0197	KILOGRAM/SQUARE CENTIMETER
	14.504	PSI
FEET OF WATER	0.4335	POUNDS/SQUARE INCH
	0.0295	ATMOSPHERES
	0.433	PSI
	0.883	INCHES OF MERCURY
INCHES OF MERCURY	1.133	FEET OF WATER
	0.49	PSI
	0.0334	ATMOSPHERES
INCHES OF WATER	0.074	INCHES OF MERCURY
	0.0.036	PSI
PSI	2.31	FEET OF WATER
	2.04	INCHES OF MERCURY
	0.068	ATMOSPHERES
	0.0685	BAR

TABLE 1-13: TREATMENT CONVERSION CHART

(Amounts listed are for active ingredients or a trade name preparation, depending on the recommendations)

PARTS PER MILLION (PPM)	DILUTION	% SOLUTION	MG/L	GM/L	MG/GAL	OZ/GAL	OZ/1,000 GAL	GM/FT^3	OZ/1,000 FT^3	LBS/ACRE FOOT
0.1	1:10,000,000	0.00001	0.1	0.0001	0.38	0.000013	0.013	0.0028	0.1	0.27
1	1:1,000,000	0.0001	1	0.001	3.8	0.00013	0.134	0.0285	1	2.7
2	1:500,000	0.0002	2	0.002	7.6	0.00029	0.268	0.0567	2	5.
3	1:333,333	0.0003	3	0.003	11.3	0.00040	0.402	0.0851	3	8.1
4	1:250,000	0.0004	4	0.004	15.2	0.00053	0.536	0.1134	3.99	10.8
5	1:200,000	0.0005	5	0.005	19.0	0.00067	0.670	0.1418	4.99	13.5
6	1:161,600	0.0006	6	0.006	22.8	0.00080	0.804	0.1701	5.99	16.2
7	1:142,900	0.0007	7	0.007	26.6	0.00093	0.938	0.1985	6.99	18.9
8	1:125,000	0.0008	8	0.008	30,4	0.00117	1.072	0.2268	7.99	21.6
9	1:111,000	0.0009	9	0.009	34.1	0.00120	1.206	0.2552	8.98	24.3
10	1:100,000	0.0010	10	0.010	38.0	0.0013	1.340	0.2835	9.98	27.0
11	1:90,909	0.0011	11	0.011	41.8	0.0014	1.474	0.3118	10.98	29.7
12	1:83,333	0.0012	12	0.012	45.6	0.0016	1.608	0.3301	11.98	32.4
13	1:76,923	0.0013	13	0.013	49.4	0.0017	1.742	0.3684	12.97	35.1
14	1:71,429	0.0014	14	0.014	53.2	0.0018	1.876	0.3367	13.97	37.8
15	1:66,667	0.0015	15	0.015	57.0	0.00195	2.010	0.4250	14.98	40 5
16	1:62,500	0.0016	16	0.016	60.8	0.0021	2.144	0.4533	15.97	432
17	1:59.235	0.0017	17	0.017	64.6	0.0022	2.278	0.4816	16,97	45.9
18	1:55,555	0.0018	18	0.018	68.4	0.0023	2.412	0.5099	17.96	48.6
19	1:52,632	0.0019	19	0.019	72.2	0.0025	2.546	0.5382	18.96	51.3
20	1:50,000	0.0020	20	0.020	76.0	0.0026	2.680	0.5620	19.97	54.0
100	1:10,000	0.0100	100	0.100	380.0	0.013	13.400	2.8350	99.84	270.0
125	1:8,000	0.0125	125	0.125	475.0	0.016	16.750	3.5338	134.80	337.5
250	1:4,000	0.025	250	0.25	950.0	0.03	33.500	7.0875	249.60	675.0
500	1:2,000	0.05	500	0.5	1,900.0	0.07	67.000	14.1750	49920	1,350.0
750	1:333	0.075	750	0.75	2,950.0	0.10	100.500	21.2625	748.80	2,025.0
1,000	1:1000	0.1	1,000	1	3,800.0	0.13	134.000	28.3500	998.4	2,700.0
2,000	1:500	02	2,000	2	7,600.0	027	268.000	56.7000	2,000.0	5,400.0
3,000	1:333	0.3	3,000	3	11,400	0.40	402.000	85.1000	3,000.0	8,100.0
4,000	1:250	0.4	4,000	4	15.200.0	053	536.000	113.4000	3,990.0	10,800.0
5,000	1:200	0.5	5,000	5	19,000.0	0.67	670.000	141.8000	4,990.0	13,500.0
6,000	1:166.6	0.6	6,000	6	22,800.0	0.80	804.000	170.1000	5,990.0	16,200.0
7,000	1:142.9	0.7	7,000	7	26.600.0	0.93	938.000	198.5000	6,990.0	18,900.0
8,000	1:125	0.8	8,000	8	30,400	1.07	1,072	226.8	7,990	21,600
9,000	1:111	0.9	9,000	9	34,100	1 20	1,206	255.2	8,980	24,300
10,000	1:100	I	10,000	10	38,000	1.34	1,340	283.5	9,984	27,000
20,000	1:50	2	20,000	20	76,000	2.67	2,680	567.0	20,000	54,000
25,000	1:40	2.5	25,000	25	95,000	3.34	3,350	709.0	25,000	67,500
30,000	1:33.33	3	30,000	30	114,000	4.01	4,020	851.0	30,000	81,000
40,000	1:25	4	40,000	40	152,000	5.34	5,360	1,134.0	39,900	108,000
50,000	1:20	5	50,000	50	190,000	6.68	6,700	1,418.0	49,900	135,000
60,000	1:16.16	6	60,000	60	228,000	8.01	8,040	1,701.0	59,900	162,000
70,000	1:14.29	7	70,000	70	266,000	9.35	9,380	1,985.0	69,900	189,000
75.000	1:13.33	7.5	75,000	75	295,000	10.01	10,500	2,127.0	74,900	202,500
80,000	1:12.50	8	80,000	80	304,000	10.68	10,720	2,268.0	79,900	216,000
90,000	1:111.1	9	90,000	90	341,000	12.02	12,060	2.552.0	89,800	243,000
100,000	1:10	10	100,000	100	380,000	13.35	13,400	2,835.0	99,840	270,000

(Source: N. Herwig, *Handbook of Drugs and Chemicals used in the Treatment of Fish Diseases*; 1979))

ANNEX 2

Geometric formulas

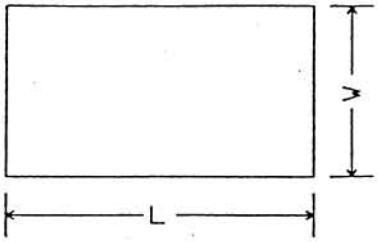
TABLE 2-1 : GEOMETRIC FORMULAS

WHERE:

A = AREA	**A1** = SURFACE AREA OF SOLIDS,
C = CIRCUMFERENCE	**P** = PERIMETER
H = HEIGHT	**D** = DIAMETER
R = RADIUS (1/2 DIAMETER)	$\pi = 3.142$
L = LENGTH	**V** = VOLUME

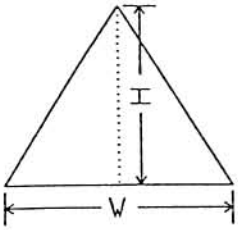
RECTANGLE

$$A = W \times L$$



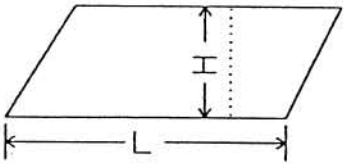
TRIANGLE

$$A = \frac{W \times H}{2}$$



PARALLELOGRAM

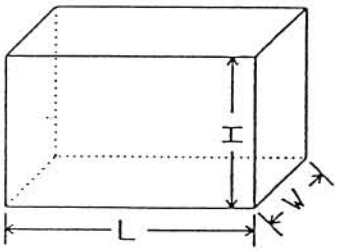
$$A = H \times L$$



RECTANGULAR SOLID

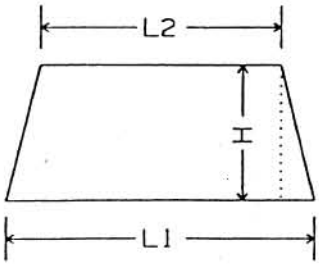
$$A_1 = 2\,[\,(W \times L) + (L \times H) + (H \times W)\,]$$

$$V = W \times L \times H$$



TRAPEZOID

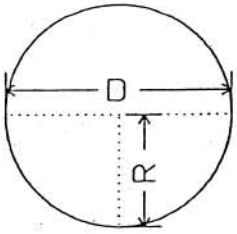
$$A = H \times \frac{L_1 + L_2}{2}$$



CIRCLE

$$A = \pi \times R^2$$

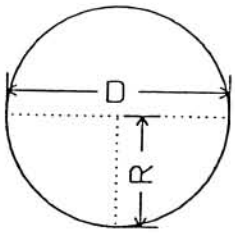
$$C = 2\,\pi \times D$$



Annex 2 continued

(continued from page 13)

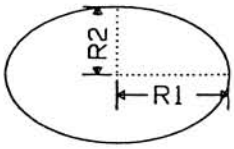
$$R = \frac{D}{2}$$



ELLIPSE

$$A = \pi R_1 \, x \, R_2$$

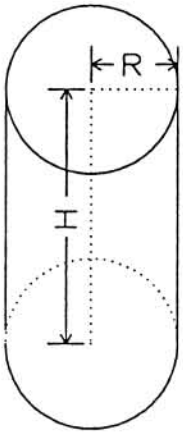
$$C = 2\pi \sqrt{\frac{R_1^{\,2} + R_2^{\,2}}{2}}$$



CYLINDER

$$A_1 = 2\pi (R \, x \, H) + 2\pi R^2$$

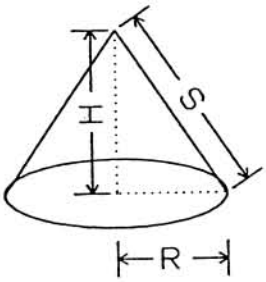
$$V = \pi R^2 \, x \, H$$



CONE

$$A_1 = \pi (R \, x \, S) + \pi R^2$$

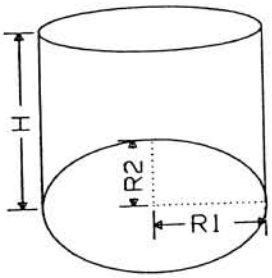
$$V = \frac{1}{3}\pi R^2 \, x \, H$$



ELLIPTICAL TANKS

$$V = \pi (R_1 \, x \, R_2 \, x \, H)$$

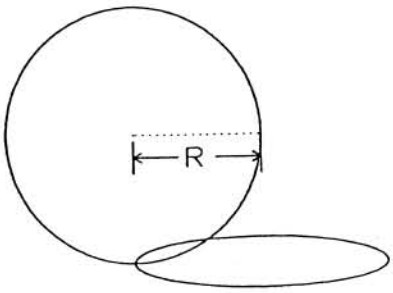
$$A_1 = 2\pi \sqrt{\frac{R_1^{\,2} + R_2^{\,2}}{2}}$$



SPHERE

$$A_1 = 4\pi \, x \, R^2$$

$$V = \frac{4}{3}\pi \, x \, R^3$$



ANNEX 3

Oxygen solubility

TABLE 3-1: AIR SOLUBILITY OF OXYGEN (mg/l) IN SEAWATER (0-40 g/kg, ‰)

TEMPERATURE (°C)	SALINITY (g/kg) 0	5	10	15	20	25	30	35	40
0	14.621	14.120	13.636	13.167	12.714	12.277	11.854	11.445	11.051
1	14.216	13.733	13.266	12.815	12.378	11.956	11.548	11.154	10.773
2	13.829	13.364	12.914	12.478	12.057	11.650	11.256	10.875	10.507
3	13.460	13.011	12.577	12.156	11.750	11.356	10.976	10.608	10.252
4	13.107	12.674	12.255	11.849	11.456	11.076	10.708	10.352	10.008
5	12.770	12.352	11.947	11.554	11.175	10.807	10.451	10.107	9.774
6	12.447	12.043	11.652	11.272	10.905	10.550	10.206	9.872	9.550
7	12.139	11.748	11.369	11.002	10.647	10.303	9.970	9.647	9.335
8	11.843	11.465	11.098	10.743	10.399	10.066	9.744	9.431	9.128
9	11.559	11.194	10.839	10.495	10.162	9.839	9.526	9.223	8.930
10	11.288	10.933	10.590	10.257	9.934	9.621	9.318	9.024	8.739
11	11.027	10.684	10.351	10.028	9.715	9.412	9.117	8.832	8.556
12	10.777	10.444	10.121	9.808	9.505	9.210	8.925	8.648	8.379
13	10.537	10.214	9.901	9.597	9.302	9.017	8.739	8.470	8.210
14	10.306	9.993	9.689	9.394	9.108	8.830	8.561	8.300	8.046
15	10.084	9.780	9.485	9.198	8.921	8.651	8.389	8.135	7.888
16	9.870	9.575	9.289	9.010	8.740	8.478	8.223	7.976	7.737
17	9.665	9.378	9.099	8.829	8.566	8.311	8.064	7.823	7.590
18	9.467	9.188	8.917	8.654	8.399	8.151	7.910	7.676	7.449
19	9.276	9.005	8.742	8.486	8.237	7.995	7.761	7.533	7.312
20	9.092	8.828	8.572	8.323	8.081	7.846	7.617	7.395	7.180
21	8.914	8.658	8.408	8.166	7.930	7.701	7.479	7.262	7.052
22	8.743	8.493	8.250	8.014	7.785	7.561	7.344	7.134	6.929
23	8.578	8.334	8.098	7.867	7.644	7.426	7.214	7.009	6.809
24	8.418	8.181	7.950	7.725	7.507	7.295	7.089	6.888	6.693
25	8.263	8.032	7.807	7.588	7.375	7.168	6.967	6.771	6.581
26	8.113	7.888	7.668	7.455	7.247	7.045	6.849	6.658	6.472
27	7.968	7.748	7.534	7.326	7.123	6.926	6.734	6.548	6.366
28	7.827	7.613	7.404	7.201	7.003	6.810	6.623	6.441	6.263
29	7.691	7.482	7.278	7.079	6.886	6.698	6.515	6.337	6.164
30	7.558	7.354	7.155	6.961	6.772	6.589	6.410	6.236	6.066
31	7.430	7.230	7.036	6.846	6.662	6.483	6.308	6.137	5.972
32	7.305	7.110	6.920	6.735	6.555	6.379	6.208	6.042	5.880
33	7.183	6.993	6.807	6.626	6.450	6.278	6.111	5.948	5.790
34	7.065	6.879	6.697	6.520	6.348	6.180	6.017	5.857	5.702
35	6.949	6.767	6.590	6.417	6.248	6.084	5.924	5.768	5.617
36	6.837	6.659	6.485	6.316	6.151	5.991	5.834	5.681	5.533
37	6.727	6.553	6.383	6.218	6.056	5.899	5.746	5.597	5.451
38	6.619	6.449	6.283	6.121	5.963	5.810	5.660	5.513	5.371
39	6.514	6.348	6.186	6.027	5.873	5.722	5.575	5.432	5.292
40	6.412	6.249	6.090	5.935	5.783	5.636	5.492	5.352	5.215

Based on Benson and Krause. 1984.

(Source: J. Huguenin and J. Colt, *Design and Operating Guide for Aquaculture Seawater Systems*; 1989)

ANNEX 4

Dissociation tables for ammonia in seawater

TABLE 4-1 : MOLE FRACTION OF UN-IONIZED AMMONIA: 0-5 g/kg SALINITY (Emerson *et al.*, 1975)

TEMPERATURE (°C)	pH							
	7.0	7.8	7.9	8.0	8.1	8.2	8.3	9.0
5	0.0012	0.0078	0.0098	0.0123	0.0154	0.0193	0.0242	0.1107
10	0.0019	0.0116	0.0145	0.0182	0.0229	0.0286	0.0357	0.1567
15	0.0027	0.0169	0.0212	0.0266	0.0332	0.0415	0.0516	0.2144
20	0.0039	0.0243	0.0304	0.0380	0.0474	0.0590	0.0731	0.2833
25	0.0056	0.0346	0.0431	0.0537	0.0667	0.0825	0.1017	0.3621
30	0.0080	0.0483	0.0600	0.0744	0.0919	0.1130	0.1382	0.4455
35	0.0111	0.0663	0.0820	0.1011	0.1240	0.1513	0.1833	0.5293
40	0.0153	0.0894	0.1100	0.1345	0.1638	0.1978	0.2367	0.6088

Based on freshwater equilibrium constants (Emerson *et al.*, 1975).

TABLE 4-2 : MOLE FRACTION OF UN-IONIZED AMMONIA: 5-40 g/kg SALINITY (Emerson *et al.*, 1975)

TEMPERATURE (°C)	pH							
	7.0	7.8	7.9	8.0	8.1	8.2	8.3	9.0
5	0.0007	0.0043	0.0054	0.0068	0.0085	0.0107	0.0135	0.06410
10	0.0010	0.0064	0.0081	0.0101	0.0127	0.0160	0.0200	0.0928
20	0.0022	0.0136	0.0171	0.0215	0.0269	0.0336	0.0419	0.1798
25	0.0031	0.0195	0.0244	0.0305	0.0381	0.0475	0.0591	0.2394
30	0.0044	0.0274	0.0343	0.0428	0.0532	0.0661	0.0818	0.3088
35	0.0062	0.0381	0.0475	0.0591	0.0733	0.0905	0.1114	0.3858
40	0.0086	0.0521	0.0647	0.0801	0.0988	0.1213	0.1481	0.4665

Saltwater data from Khoo *et al.*(1977), salinity and the equation for the computation of ionic strength (Whitfield, 1974). Converted to the NBS pH scale by addition of 0.149 to freshwater negative logarithm of the equilibrium constants (Bates, 1975).

DETERMINATION OF NH_3-N CONCENTRATION FROM TOTAL AMMONIA NITROGEN (TAN)

$$NH3\text{-}N = (a)\ (TAN)$$

WHERE:,

a = Mole Fraction of Un-ionized Ammonia

TAN = Total Ammonia Nitrogen

EXAMPLE:

A tank of seawater (35ppt) at a temperature of 25°C has a pH of 8.2 and a Total Ammonia Nitrogen level of 0.4 mg/l. Calculate the concentration of un-ionized ammonia in the tank.

NH_3-N = (a) TAN where a = 0.475 (taken from the table above at 25°C, pH = 8.2)

NH_3-N = (0.0475) (0.4) = 0.0190 mg/l = 19 µg/l or ppb

(Source: J. Huegenin and J. Colt, *Design and Operating Guide for Seawater Aquaculture Systems;* 1989)

TABLE 5-1: SALT CONCENTRATIONS FOR THE MODIFIED SEGEDI-KELLEY MEDIUM FORMULA (S = 35.3 ‰)
(Segedi and Kelley, 1964)

ADDITIVE	CONCENTRATION
NaCl	27.60 g/l
$MgSO_4 \cdot 7H_2O$	6.89 g/l
$MgCl_2 \cdot 6H_2O$	5.40 g/l
$CaCl_2 \cdot 2H_2O$	1.38 g/l
KCl	0.60 g/l
$NaHCO_3$	0.21 g/l
KBr	26.90 mg/l
$SrCl_2 \cdot 6H_2O$	19.84 mg/l
$MnSO_4 \cdot H_2O$	3.97 mg/l
$NaH_2PO_4 \cdot 7H_2O$	3.97 mg/l
LiCl	0.99 mg/l
$Na_2MoO_4 \cdot 2H_2O$	0.99 mg/l
$Na_2S_2O_3 \cdot 5H_2O$	0.99 mg/l
$Al_2(SO_4)_3 \cdot 18H_2O$	0.85 mg/l
RbCl	149.00 µg/l
$ZnSO_4 \cdot 7H_2O$	95.90 µg/l
$CoSO_4 \cdot 7H_2O$	89.30 µg/l
KI	89.30 µg/l
$CuSO_4 \cdot 5H_2O$	9.90 µg/l

(Source: S. Spotte, *Seawater Aquaria: The Captive Environment;* 1979)

TABLE 5-2: OTT'S (1965) ARTIFICIAL SEAWATER

ADDITIVE	CONCENTRATION
SALTS	MAKE UP TO 1 LITER DISTILLED H_2O
NaCl	21 g/l
$MgSO_4 \cdot 7H_2O$	6 g/l
$MgCl_2 \cdot 6H_2O$	5 g/l
$CaCl_2 \cdot 2H_2O$	1 g/l
KCl	0.8 g/l
NaBr	0.1 g/l
$NaNO_3$	0.2 g/l
NaHCO3	0.2 g/l
H_3BO_3	0.06 g/l
$Na_2SiO_3 \cdot 9H_2O$	0.01 g/l
$Sr(NO_3)_2$	0.03 g/l
Na_2HPO_4	0.02 g/l

To the above, add 1 ml each of the micronutrients listed under the formula for BOLD'S BASAL MEDIA (Table 3-7). This artificial seawater may be used in preparing Erdschreiber or von Stosch's enrichment media.

(Source: H. C. Bold and M. J. Wynne, *Introduction to the Algae; 1978*)

TABLE 5-3: INSTANT OCEAN™ ARTIFICIAL SEAWATER MIXTURE (1)

ADDITIVE	CONCENTRATION (µm/l)	ADDITIVE	CONCENTRATION (µm/l)
Cl	5.19×10^5	MoO_4	4.40
Na	4.44×10^5	S_2O_3	3.60
SO_4	2.60×10^4	Li	28.80
Mg	4.94×10^4	Rb	1.20
K	9.50×10^3	I	0.55
Ca	9.20×10^3	EDTA	0.13
HCO_3	2.30×10^3	Al	1.50
H_3BO_3	4.04×10^2	Zn	0.31
Br	2.50×10^2	V	0.39
Sr	91.30	Co	0.17
PO_4	10.50	Fe	0.18
Mn	18.00	Cu	0.05

(1) Aquarium Systems, Inc. Twinbrook, Mentor, Ohio 44060

(Source: J.P. McVey, *CRC Handbook of Mariculture: Volume I - Crustacean Aquaculture;* copyright ©1983 - reprinted with permission of CRC Press, Boca Raton, FL)

TABLE 5-4: SALT CONCENTRATIONS FOR THE GP MEDIUM FORMULA (S = 33.1 ‰, ppt)

SALT	SOLUTION	CONCENTRATION
NaCl	A	26.00 g/l
$MgSO_4 \cdot 7H_2O$	A	6.58 g/l
$MgCl_2 \cdot 6H_2O$	A	4.88 g/l
$CaCl_2 \cdot 2H_2O$	A	1.46 g/l
KCl	A	0.675 g/l
$NaHCO_3$	A	0.184 g/l
KBr	B	95.3 mg/l
$SrCl_2 \cdot 6H_2O$	B	24.2 mg/l
$NaH_2PO_4 \cdot 7H_2O$	B	4.0 mg/l
LiCl	B	1.04 mg/l
$Al_2(SO_4)_3 \cdot 18H_2O$	B	0.0235 mg/l
H_3BO_3	C	24,2000.0 µg/l
Na_2EDTA	C	9,440.0 µg/l
Fe citrate H_2O	C	3,830.0 µg/l
$Na_2MoO_4 \cdot 2H_2O$	C	2,220.0 µγ/l
$MnSO_4 \cdot H_2O$	C	1,610.0 µg/l
$ZnSO_4 \cdot 7H_2O$	C	1,425.0 µg/l
$CuSO_4 \cdot 5H_2O$	C	97.7 µg/l
KI	C	79.1 µg/l
$CoSO_4 \cdot 7H_2O$	C	13.4 µg/l
$Na_2VO_4 \cdot 4H_2O$	C	9.24 µg/l
Thiamine HCl	D	1,953.0 µg/l
Cyanocobalamin	D	0.977 µg/l

SOLUTION A: Dissolve salts separately; dilute to approximately 75% by volume; cover and aerate.

SOLUTION B: Dissolve in distilled water; add to Solution A on second day

SOLUTION C: Dissolve each salt in distilled water with 2 molar equiv. of Na_2EDTA; boil and dilute to volume; add to solutions A and B on third day.

SOLUTION D: Requires no special preparation; dissolve in distilled water

(Source: S. Spotte, *Seawater Aquaria: The Captive Environment;* copyright ©1979 - reprinted by permission of John Wiley &Sons, Inc.)

TABLE 5-5: GATES AND WILSON'S NH ARTIFICIAL SEAWATER MEDIUM

ADDITIVE	CONCENTRATION
NaCl	24.0 g/l
KCl	0.6 g/l
$MgCl_2 \cdot 6H_2O$	4.5 g/l
$MgSO_4 \cdot 7H_2O$	6.0 g/l
$CaCl_2$	0.7 g/l
K_2HPO_4	10.0 mg/l
Vitamin B_{12}	1.0 µg/l
Thiamin HCl	10.0 mg/l
Biotin	0.5 ug/l
SULPHIDES[1]	1.0 ml/l
VITAMIN MIX [2]	0.1 ml/l
TRACE METALS MIX[3]	5.0 ml/l
Adenine sulphate	1.0 mg/l
Tris buffer	0.1 g/l
NaEDTA	10.0 mg/l
NUTRIENT MIXES	
[1] SULPHIDES	MAKE UP TO ONE LITER DISTILLED WATER
NH_4Cl	0.2 g
KH_2PO_4	0.1 g
$MgCl_2 \cdot 6H_2O$	0.04 g
$NaHCO_3$	0.2 g
$Na_2SiO_3 \cdot 9H_2O$	0.15 g
[2] VITAMIN MIX	MAKE UP TO 100 ML DISTILLED WATER
Thiamin-HCl	20 mg
Biotin	50 µg
Vitamin B_{12}	5 µg
Folic acid	0.25 mg
PABA	1.0 mg
Nicotine acid	10 mg
Thymine	80 mg
Choline	50 mg
Inositol	100 mg
Patrescine	0.8 mg
Riboflavin	0.5 mg
Pyridoxine	4.0 mg
Orotic acid	26 mg
Fe Tartrate	2.5 ml (5 mg Fe)
[3] TRACE METAL MIX (1 % SOLUTION)	MAKE UP TO 100 ML DISTILLED WATER
H_3BO_3	3.0 ml (5.1 mg B)
H_2SeO_3	0.1 ml (1.0 mg Se)
NH_4VO_3	0.12 ml (0.5 mg V)
K_2CrO_4	0.11 ml (0.2 mg Cr)
$MnCl_2$	0.37 ml (1.0 mg Mn)
TlO_2	0.11 ml (5.0 mg Ti)
Na_2SiO_3	5.0 ml (5.0 mg Si)
$ZrOCl_2$	0.4 ml (2.0 mg Zr)
$BaCl_2$	0.15 ml (1.0 mg Ba)

(Source: T.V.R. Pillay, *Aquaculture Principles and Practices;* 1990)

TABLE 5-6: BOLDS BASAL MEDIUM (BBM) (Bischoff and Bold, 1963)

BBM is a medium useful for culturing Chlorophyceae, Chrysophyceae, Cyanophyceae and Rhodophyceae.

Six macronutrient and four trace metal stock solutions are prepared.

ADDITIVE	CONCENTRATION
MACRONUTRIENT (STOCK)	ADD 10 ML / 940 ML DISTILLED H_2O
$NaNO_3$	10.0 g/400 ml
$CaCl_2 \cdot 2H_2O$	1.0 g/400 ml
$MgSO_4 \cdot 7H_2O$	3.0 g/400 ml
K_2HPO_4	3.0 g/400 ml
KH_2PO_4	7.0 g/400 ml
NaCl	1.0 g/400 ml

To 940 ml distilled water, add 1.0 ml of each of the stock trace-element solutions prepared as follows:

1. 50 g EDTA and 31 g KOH dissolved in 1 liter distilled H_2O (or 50 g $Na_2 \cdot$ EDTA)
2. 4.98 g $FeSO_4 \cdot 7H_2O$ dissolved in 1 liter of acidified water (acidified H_2O :1.0 ml H_2SO_4 dissolved in 1 liter distilled H_2O).
3. 11.42 g H_3BO_3 dissolved in 1 liter distilled H_2O.
4. Trace Element Stock Solution (below)

TABLE 5-7: BBM TRACE METAL STOCK SOLUTION

ADDITIVE	CONCENTRATION
TRACE ELEMENT (STOCK)	MAKE UP TO ONE LITER H_2O
$ZnSO_4 \cdot 7H_2O$	8.82 g/l
$MnCl_2 \cdot 4H_2O$	1.44 g/l
MoO_3	0.71 g/l
$CuSO_4 \cdot 5H_2O$	1.57 g/l
$Co(NO_3)_2 \cdot 6H_2O$	0.49 g/l

This may be enriched by substituting 30 ml of stock $NaNO_3$ per liter to the definitive solution (3 x Nitrogen BBM). Alternately, many algae thrive when urea is substituted as the nitrogen source; it may be provided at the level of 3 x or 6 x the level of nitrogen in BBM.

Vitamins, most frequently B_1, B_6, and B_{12}, may enhance the growth of algae in BBM. These may be added to a liter of BBM as 5 ml of Eagle's mixture [1] and B_2 (cyanocobalamine) at concentrations of 0.1 ml of a 1.0 mg/ml solution (equivalent to 100 mg/liter).

[1] "TC-Vitamins Minimal Eagle, 100 x " (Difco Laboratories, Detroit, Mich.).

(Source: H. C. Bold and M. J. Wynne, *Introduction to the Algae*; 1978)

ANNEX 6

Tables of enriched seawater media

TABLE 6-1: PROVASOLI'S ENRICHED SEAWATER (ES) (Provasoli, 1963, 1968; McLachlan, 1973)

Seawater is sterilized by filtration or autoclaving, enrichments assembled into a single solution, and added aseptically to the medium.

ADDITIVE	CONCENTRATION
$NaNO_3$ (STOCK A)	35 g/100 ml
Na_2glycerophosphate (STOCK B)	5 g/100 ml
Vitamin B_{12} (STOCK C)	1 mg/100 ml
Thiamine (STOCK D)	50 mg/100 ml
Biotin (STOCK E)	0.5 mg/ 100 ml
Fe (as EDTA 1:1 molar) (STOCK F)	
$Fe(NH_4)_2(SO_4) \cdot 6H_2O$	351 mg/100 ml
Na_2EDTA	300 mg/500 ml
P 11 TRACE METALS (STOCK G)	
H_3BO_3	1.14 g/l
$FeCl_3 \cdot 6H_2O$	49 mg/l
$MnSO_4 \cdot 4H_2O$	164 mg/l
$ZnSO_4 \cdot 7H_2O$	22 mg/l
$CoSO_4 \cdot 7H_2O$	4.8 mg/l
Na_2EDTA	1 g/l

Mix 10 ml of each stock solution A - E and 250 ml of each stock solution F and G and bring total volume to 1250 ml with distilled or deionized water. Add 20 ml of the above stock solution mixture to 1000 ml of filtered seawater to prepare full-strength medium.

(Source: H.C. Bold and M. J. Wynne, *Introduction to the Algae*; 1978)

TABLE 6-2: "f" ENRICHED SEAWATER MEDIA (Guillard and Ryther, 1962)
COMPOSITION PER LITER OF SEAWATER FOR "f/2"

This medium is widely used to culture a variety of marine phytoplankton. Pre-mixed modification of this formulation are available commercially.

ADDITIVE	CONCENTRATION
MAJOR NUTRIENTS	
$NaNO_3$	75 mg/l
$NaH_2PO_4 \cdot H_2O$	5 mg/l
$Na_2SiO_3 \cdot 9H_2O$	30 mg/l
TRACE METALS	
Na_2 EDTA	4.36 mg/l
$FeCl_3 \cdot 6H_2O$	3.15 mg/l
$CuSO_4 \cdot 5H_2O$	0.01 mg/l
$ZnSO_4 \cdot 7H_2O$	0.022 mg/l
$CoCl_2 \cdot 6H_2O$	0.01 mg/l
$MnCl_2 \cdot 4H_2O$	0.18 mg/l
$Na_2MoO_4 \cdot 2H_2O$	0.0006 mg/l
VITAMINS	
Thiamin HCl	0.1 mg/l
Biotin	0.5 mg/l
B-12	0.5 mg/l

TABLE 6-2 (cont.): PREPARATION OF STOCK SOLUTIONS

ADDITIVE	CONCENTRATION
MAJOR NUTRIENTS STOCKS	
$NaNO_3$	7.5 g/100 ml
$NaH_2PO_4 \cdot H_2O$	0.5 g/100 ml
NH_4Cl	2.65 g/100 ml
$Na_2SiO_3 \cdot 9H_2O$	3.0 g/100 ml (heat to dissolve if necessary)
TRACE METAL PRIMARY STOCKS	
$CuSO_4 \cdot 5H_2O$	0.98 g/100 ml
$ZnSO_4 \cdot 7H_2O$	2.2 g/100 ml
OR $ZnCl_2$	1.05 g/100 ml
$CoCl_2 \cdot 6H_2O$	1.0 g/100 ml
$MnCl_2 \cdot 4H_2O$	1.8 g/100 ml
$Na_2MoO4 \cdot 2H_2O$	0.63 g/100 ml
VITAMIN PRIMARY STOCKS	
Biotin	10 mg/96 ml distilled H_2O
Vitamin B_{12}	10 mg/ 10 ml distilled H_2O

MAJOR NUTRIENT STOCKS are 10^3 more concentrated than in the final medium. Use 1 ml/liter of seawater to obtain medium "f/2", "h/2", or "f/2-beta".

TRACE METAL WORKING STOCK SOLUTIONS, EDTA CHELATED

Use 1 ml/l of **TRACE METAL WORKING STOCK** to make final "f/2" or "h/2" media.

1. "Ferric Sequestrene" as iron and chelator source.
Dissolve 5 g ferric sequestrene in 900 ml of distilled water, add 1 ml of each TRACE METAL PRIMARY STOCK, and bring to 1 liter. pH is @ 4.5.

2. Trace metal stock solution, using ferric chloride and di-sodium EDTA. Dissolve 3.15 g $FeCl_2 \cdot 6H_2O$ and 4.36 g Na_2 EDTA in 900 ml of distilled water; add 1 ml of each **TRACE METAL PRIMARY STOCK** and bring to one liter. pH is @ 2.0. The solution remains clear if left at pH 2.0. If titrated to @ pH 4.5 (taking ca. 7 ml of N_2NaOH), a precipitate will form, resembling that in the solution made with ferric sequestrene.

VITAMIN WORKING STOCK SOLUTION

Use 0.5 ml/l of **VITAMIN WORKING STOCK SOLUTION** for final "f/2" or "h/2" media.

Add 1.0 ml of **BIOTIN PRIMARY STOCK** and 0.1 ml of **B_{12} PRIMARY STOCK** to 100 ml distilled H_2O and add 20 mg of thiamine HCl (no primary stock of thiamine is needed).

(Source: R. Guillard, In: W.L. Smith and M.H. Chanley, *Culture of Marine Invertebrate Animals*; copyright ©1975 - with permission Plenum Publishers)

TABLE 6-3: MODIFIED F MEDIUM [1](Guillard & Ryther, 1962)

ADDITIVE	CONCENTRATION
N-P (STOCK A -500X)	MAKE UP TO ONE LITER DISTILLED H_2O
$NaNO_3$	42.07 g
$NaH_2PO_4 \cdot H_2O$	5.0 g
SODIUM METASILICATE (STOCK B -500X)	MAKE UP TO ONE LITER DISTILLED H_2O
$Na_2SiO_3 \cdot 9H_2O$	15.0 g
FERRIC CHLORIDE (STOCK C-500X)	MAKE UP TO ONE LITER DISTILLED H_2O
$FeCl_3 \cdot 6H_2O$	1.45 g

TABLE 6-3 (cont.):

ADDITIVE	CONCENTRATION
EDTA STOCK (STOCK D -1000X)	MAKE UP TO ONE LITER DISTILLED H_2O
Na_2 • EDTA	10.0 g
VITAMIN (STOCK E)	MAKE UP TO ONE LITER DISTILLED H_2O
Biotin	0.2 g
B12 primary stock (0.1 g/liter)	10 ml
Biotin primary stock (0.1 g/liter)	10 ml
TRACE METAL (STOCK F-1000X)	MAKE UP TO ONE LITER DISTILLED H_2O
TM primary stock A*	1 ml
TM primary stock B**	1 ml
TM primary stock C***	1 ml
TM primary stock D****	1 ml
Distilled water (to make)	1000 ml
***TM PRIMARY STOCK A**	MAKE UP TO 100 ML DISTILLED H_2O
$CuSO_4 \cdot 5H_2O$	1.96 g
$ZnSO_4 \cdot 7H_2O$	4.4 g
****TM PRIMARY STOCK B**	MAKE UP TO 100 ML DISTILLED H_2O
$Na_2MoO_4 \cdot 2H_2O$	1.26 g
$(NH_4)_6Mo_7O_{24} \cdot 2H_2O$	0.9 g
*****TM PRIMARY STOCK C**	MAKE UP TO 100 ML DISTILLED H_2O
$MnCl_2 \cdot 4H_2O$	36.0 g
******TM PRIMARY STOCK D**	MAKE UP TO 100 ML DISTILLED H_2O
$CoCl_2 \cdot 6H_2O$	2.0 g

(1) 2 ml each of solutions **A, B,** and **C** plus 1 ml each of solutions **D, E,** and **F** per liter of seawater

(Source: Kongkeo, In: W. Fulks and K. L. Main, *Rotifer and Microalgal Culture Systems*; 1991 - reprinted with permission of Argent Laboratories)

TABLE 6-4: FORMULA OF WALNE MEDIUM FOR ALGAE CULTURE (Walne, 1974)

ADDITIVE	CONCENTRATION
STOCK A(1)	MAKE UP TO ONE LITER DISTILLED H_2O
$FeCl_3 \cdot 6H_2O$	1.30 g
$MnCl_2 \cdot 4H_2O$	0.36 g
H_3BO_3	33.60 g
EDTA (Na salt)	45.00 g
$NaH_2PO_4 \cdot 2H_2O$	20.00 g
$NaNO_3$	100.00 g
TRACE METAL SOLUTION	1.0 ml
STOCK B(2)	MAKE UP TO 100 ML DISTILLED H_2O
Vitamin B_{12} (Cyanocobalamin)	10 mg
Vitamin B_1 (Thiamin)	200 mg
STOCK C(3)	MAKE UP TO 100 ML DISTILLED H_2O
$Na_2SiO_3 \cdot 5H_2O$	4.9 g
TRACE METAL SOLUTION(4)	MAKE UP TO 100 ML DISTILLED H_2O
$ZnCl_2$	2.1 g
$CoCl_2 \cdot 6H_2O$	2.0 g
$(NH_4)_6Mo_7O_2 \cdot 4H_2O$	0.9 g
$CuSO_4 \cdot 5H_2O$	2.0 g

TABLE 6-5: ENRICHED SEAWATER MEDIA (Guillard, 1975)

ADDITIVE	CONCENTRATION (µm/l) f/2	h/2	f/2 beta	ES	SWM
INORGANIC MACRONUTRIENTS					
$NaNO_3$	880	-	880	660	500 - 2,000
NH_4Cl	-	500	-	-	-
NaH_2PO_4	36.3	36.3	36.3	=	50 - 100
Na2glycerophosphate	-	-	-	25.0	-
$Na_2SiO_3 \cdot 9H_2O$	54 - 107	54 - 107	54 - 107	-	200
INORGANIC MICRONUTRIENTS					
Fe EDTA	-	-	-	7,200	2.0
$FeCl \cdot 4H_2O$	11.7	11.7	11.7	1.8	-
Na_2EDTA	11.7	11.7	11.7	26.9	48.0
$CUSO_4 \cdot 5H_2O$	0.04	0.04	0.04	-	0.3
$ZnSO_4 \cdot 5H_2O$	0.08	0.08	0.08	0.80	35.0
$CoCl_2 \cdot 4H_2O$	0.05	0.05	0.05	0.17	0.30
$MnCl_2 \cdot 4H_2O$	0.90	0.90	0.90	7.30	10.0
$Na_2MoO_4 \cdot 2H_2O$	0.03	0.03	0.03	-	5.0
Boron	-	-	-	185	400
ORGANIC MICRONUTRIENTS					
Thiamine HCl (B_1)	100 µg	100 µg	100 µg	20 µg	-
Nicotinic acid	-	-	-	-	0.1 mg/l
Ca. pantothenate	-	-	-	-	0.1 mg/l
p-Aminobenzoic acid	-	-	-	-	10 µg/l
Biotin	0.5 µg	0.05 µg	0.5 µg	0.8 µg	1.0 µg/l
i-Inositol	-	-	-	-	5.0 mg/l
Folic acid	-	-	-	-	2.0 µg/l
Cyanocobalamin	0.5 µg	0.5 µg	0.5 µg	1.6 µg	1.0 µg/l
Thymine	-	-	-	-	3.0 µg/l
Tris	-	-	"	0.66	0 - 5000
Glycylglycine	-	-	-	-	5000
Soil extract	-	-	-	-	50 ml/l
Liver extract	-	-	-	-	10 mg/l

"h/2" media adds 26.5 mg (0.5 mM) NH_4Cl to the "f/2" Major Nutrient Stock for culturing those species which cannot grow well on nitrate. If NH_4Cl is added to seawater and autoclaved,25 - 30 % of the ammonium is lost. NH_4Cl Stock, because of its low pH, can be autoclaved, and should be added aseptically to medium autoclaved separately.

"f/2-beta" differs from "f/2" in that citrate is used as the chelator. Dissolve 16.8 g citric acid ($C_6H_8O_7 \cdot H_2O$) in 900 ml distilled water. Add 3.0 g ferric citrate ($FeC_6H_5O_7 \cdot 5H_2O$) and 1 ml of each "f/2" TRACE METAL PRIMARY STOCK. Bring to one liter and autoclave (pH @ 2.3)

ES media = Provasoli Enriched Seawater (Provasoli, 1968)

SWM media (McLachlan 1964; Chen, Edelstein and McLachlan, 1969) has several variations, depending on the species under cultivation. The original reference should be consulted.

ANNEX 7

Specific growth rates of algae

TABLE 7-1: SPECIFIC GROWTH RATES [1] OF ALGAE CULTURED AT LOW AND HIGH TEMPERATURES

Marine Strain: Salinity = 33 ‰, Light:Dark = 24:0, f/2 Medium
Freshwater Strain: Salinity = O ppt, Light:Dark = 24:0, Complesal medium

	LOW TEMPERATURE (°C)				HIGH TEMPERATURE (°C)			
	5		10		25		30	
LIGHT INTENSITY (lux)	5000	2500	5000	2500	5000	2500	5000	2500
Caloneis schroderi	-0.01	-0.50	-0.10	0.25	0.28	0.30	0.38	0.29
Chaetoceros gracilis	-0.01	-0.05	0.16	0.07	0.52	0.39	0.62	0.73
Chaetoceros simplex	-0.06	-0.01	0.27	0.55	0.47	0.52	0.54	0.63
Cyclotella sp.[1]	0.16	0.08	0.00	-0.10	0.00	0.00	-0.18	-0.19
Cyclotella sp.[2]	-0.06	-0.20	0.12	0.16	0.57	0.58	0.42	0.26
Hanzchia marina	-0.36	-0.07	-0.68	-0.21	0.21	0.15	0.11	0.06
Navicula incerta	0.16	0.20	0.37	0.22	0.39	0.37	0.48	0.35
Navicula sp.	0.08	0.02	0.31	-0.01	0.29	0.26	0.30	0.43
Nitzschia sp.	-0.10	0.12	0.20	0.23	0.23	0.29	0.46	0.40
Phaeodactylum tricornutum[3]	0.37	0.39	0.71	0.63	0.85	0.84	-0.53	-0.53
Phaeodactylum tricornutum[4]	0.22	0.26	0.66	0.51	-0.03	-0.43	-0.45	-0.46
Skeletonema costatum	0.29	0.34	0.66	0.61	0.60	0.67	0.48	0.43
Thalassiosira fluviatilis	0.03	0.06	0.10	0.11	-0.03	0.10	0.28	0.23
Thalassiosira sp.	-0.29	-0.17	-0.04	-0.12	0.13	0.15	0.40	0.41
Boekelovia sp.	0.04	0.01	0.18	0.27	0.67	0.62	0.01	0.27
Isochrysis galbana	-0.57	-0.07	0.42	0.25	0.55	0.55	0.52	0.51
Isochrysis aff. galbana	-0.62	-0.67	0.06	-0.14	0.78	0.81	0.76	0.74
Nannochloris oculata	0.01	-0.03	0.01	0.04	0.85	0.92	1.09	1.14
Nannochloropsis salina	0.06	0.07	0.04	0.54	-0.32	-0.34	0.46	0.06
Chlorella ellipsoidea	0.03	0.02	0.58	0.53	0.88	0.85	0.98	0.94
Chlorella stigmatophora	0.01	0.24	0.36	0.24	0.78	0.56	0.66	0.39
Chlorella vulgaris *	-0.25	0.00	0.21	0.17	0.68	0.67	-0.29	-0.20
Dunaliella tertiolecta	0.28	0.17	0.43	0.42	0.60	0.64	0.60	0.45
Eudorina elegans	-0.24	-0.23	0.15	0.13	0.28	0.35	0.05	0.05
Gloeocystis sp.	-0.20	0.01	0.14	0.25	-0.19	0.09	0.03	0.20
Heterosigma sp.	0.02	0.00	0.43	0.38	0.92	0.78	1.02	0.60
Oocystis pusilla	0.14	0.14	0.21	0.19	0.16	0.15	0.17	0.27
Palmella mucosa	-0.01	0.02	0.76	0.57	0.93	1.10	0.93	1.05
Scenedesmus sp.*	-0.18	-0.45	-0.26	-0.36	-0.25	-0.18	-0.16	-0.13
Tetraselmis suecica	0.04	-0.02	0.42	0.28	0.46	0.44	0.55	0.51
Platymonas subcordiformis	0.04	0.11	0.38	0.39	0.30	0.30	0.23	0.28
Microcystis aeruginosa	0.08	0.04	0.10	0.03	0.94	0.87	0.91	0.59
Protogonyaulax sp.	-0.03	0.07	0.37	0.39	0.74	0.57	0.70	0.78
Euglena sp.	-0.24	-0.61	0.51	0.38	0.65	0.51	0.52	0.55

[1] $k\ (\text{divisions/day}) = 3.322 \dfrac{\log \frac{N_1}{N_0}}{t_2 - t_1}$ (Guillard 1973)

* Freshwater strains, [1] NFUP-9, [2] NFUP-13, [3] NFUP-2, [4] NFUP-10

(Source: S.B. Hur, In: W. Fulks and K.L. Main, *Rotifer and Microalgae Culture Systems*; copyright © 1991 - Argent Laboratories)

ANNEX 8

Technical data on light sources

TABLE 8-1: TECHNICAL DATA ON LIGHT BULBS (Weast,1987; Lundegaard, 1985; Osborne, 1983)

BULB TYPE	WATTS	INITIAL LUMENS	INITIAL EFFIENCY	COLOR TEMP (°K)	HOURS OF LIFE	CRI (1)	LENGTH INCHES
INCANDESCENT							
60 INCAN	60	870	14.5	3000	1000	99	N/A
100 INCAN	100	1750	17.5	3000	750	99	N/A
200 INCAN	200	4010	20.0	3000	750	99	N/A
1000 INCAN	1000	23740	23.7	3000	1000	99	N/A
FLUORESCENT							
COOL WHITE	40	3150	78.8	4150	20000	62	48
WARM WHITE	40	3200	80.0	3000	20000	52	48
DAYLIGHT	40	2600	65.0	6250	20000	75	48
COOL WHITE HO	60	4300	62.0	4160	20000	62	48
VITA-LITE~ FS	40	2400	60.0	5500	20000	91	48
CHRONA 50~) FS	40	2210	55.3	5000	20000	90	48
CHRONA 75(~) FS	40	2000	50.0	7500	20000	92	48
COLORTONE 503 FS	40	2200	55.0	5000	20000	92	48
VERILUX(~ FS	40	2168	54.2	6200	20000	93	48
SP30	40	3325	83.1	3000	15000	70	48
SP35	40	3325	83.1	3500	15000	73	48
SP41	40	3265	81.6	4100	15000	70	48
GREEN							
COOL GREEN	40	2850	71.3	6450	20000	68	48
SEALUX	40	1600	40.0	5326	20000	G	48
AQUARILUX	40	880	22.0	10500	20000	F	48
ACTINIC 03	40		-	-	-	-	48
PLANT LIGHT	40	850	21.3	6750	20000	2	48
PLANT WS	40	1950	48.8	3050	20000	90	48
COOLWHITE	75	6300	84.0	4150	12000	62	60
WARM WHITE	75	6500	86.7	3000	12000	52	60
DAYLIGHT	75	5450	72.7	6250	12000	75	60
COOL WHITE	110	9200	83.6	4150	12000	62	96
WARM WHITE	110	9200	83.6	3050	12000	52	96
DAYLIGHT	110	7800	71.0	6250	12000	75	96
DAYLIGHT	215	13300	61.8	6250	12000	75	
HIGH INTENSITY DISCHARGE - MERCURY VAPOR							
CLEAR	400	21000	52.5	N/A	24000	G	N/A
DELUXE WHITE	400	22500	56.3	N/A	24000	G	N/A
WARM WHITE	400	19500	48.8	N/A	24000	G	N/A
CLEAR	1000	57000	57.0	N/A	24000	G	N/A
DELUXE WHITE	1000	63000	63.0	N/A	24000	G	N/A
WARM WHITE	1000	58000	58.0	N/A	24000	G	N/A
HIGH INTENSITY DISHARGE - METAL HALIDE (2)							
CLEAR E-23 1/2	175	16600	94.9	N/A	10000	E	N/A
DIFFUSE E-23 1/2	175	15750	90.0	N/A	10000	E	N/A
PHOSPHOR E-28	175	14000	80.0	N/A	10000	E	N/A
CLEAR E-28	250	20500	82.0	N/A	10000	E	N/A
PHOSPHOR E-28	250	20500	82.0	N/A	10000	E	N/A
CLEAR E-37	400	36000	90.0	N/A	20000	E	N/A
PHOSPHOR E-37	400	36000	90.0	N/A	20000	E	N/A
CLEAR BT-56	1000	110000	111.0	N/A	12000	E	N/A
PHOSPHOR BT-56	1000	105000	105.0	N/A	12000	E	N/A

(1) CRI (Color Rendering Index) Signifies the spectral distribution of light sources. The CRI of sunlight, as a standard, is 100. The higher the CRI of a bulb, the more all colors appear natural to the human eye.

ANNEX 9

Use of haemocytometer to determine phytoplankton density

The hemocytometer was originally developed as a medical tool for counting blood cells, but it is widely used in aquaculture to determine phytoplankton cell counts. It consists of two parts; a) a base which is a thick slide of thermal and shock resisting glass with an H-shaped trough cut into it. Two precisely measured shoulders rise 0.1 millimeter above each side of the trough, b) the second component is a thick cover glass (0.4 millimeters) which rests on top of the shoulders forming the top of the counting chamber.

Upon the base glass is fused a thin metallic film which is precisely etched into a pattern of nine squares, each one millimeter on the side. These are divided into 16 smaller squares, and the center square is further subdivided into 4 other squares each measuring 0.05 millimeters on a side. As hemacytometers may vary in dimensions, consult the manufacturers instructions to determine the depth of the counting chamber and the precise area of the counting grids before calculating phytoplankton density.

PREPARING A SAMPLE FOR COUNTING

1) Thoroughly clean the base slide and cover slip with distilled water and and lens paper.

2) Collect a sample of the algae culture and make serial dilutions if required. Addition of Lugol's stain may be added to kill and immobilize the cells.

3) Introduce a single drop of solution to the V-groove on the side of the hemocytometer, allowing the solution to spread through the counting chamber by capillary action. Avoid overfilling the counting chamber and allowing the cover slip to float, as this will result in high cell counts.

4) Place the hemocytometer on the stage of a compound microscope and at the lowest power of magnification focus onto the center grid.

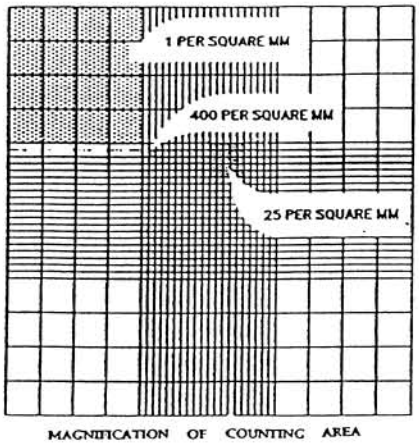
5) Beginning at the upper righthand corner count all cells within the grid. It is suggested to count only cells on the upper line of the grid; cells intersecting the lower lines of the grid should be counted on the next lower grid. This method avoids duplicating counts.

CALCULATING CELL COUNTS

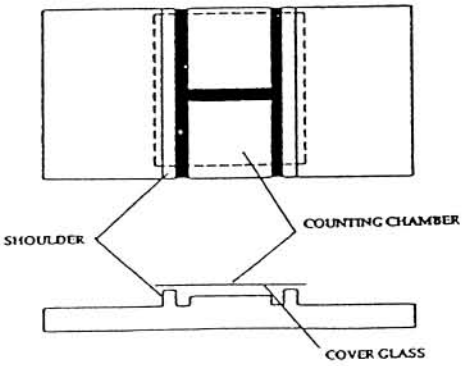
$$\text{CELLS/mm}^3 = \text{CELLS/mm}^2 \times 10 \times \text{DILUTION}$$

WHERE:

$$\text{CELLS/mm}^2 = \text{AVERAGE CELLS COUNTED/ AREA COUNTED (mm}^2\text{)}$$



MAGNIFICATION OF COUNTING AREA



ANNEX 10

UV energy requirements to prevent bacterial colonies formation

TABLE 10-1: ULTRAVIOLET ENERGY OF 2537 A WAVE-LENGTH TO INHIBIT COLONY FORMATION IN 90 AND 100 PERCENT OF TEST ORGANISMS ($\mu W/s/cm^2$) (Phillips and Hanel, 1960)

ORGANISM	UV ENERGY ($\mu W/s/cm^2$) 90%	100%
BACTERIA		
Bacillus anthracis	4,250	8,700
S. enteritidis	4,000	7,600
B. megaterium sp. (veg)	1,300	2,500
B. megaterium sp. (spores)	2,730	5,200
B . paratyphosus	3	200
B. subtilis	5,800	11,000
B. subtilis spores	11,600	22,000
Corynebacterium diphtheria	3,370	6,500
Eberthella typhosa	2,140	4,100
Escherichia coli	3,000	6,600
Micrococcus candidus	6,050	12,300
Micrococcus sphaeroides	10,000	15,400
Neisseria catarrhalis	4,400	8,500
Phytomonas tumefaciens	4,400	8,500
Proteus vulgaris	3,000	6,600
Pseudomonas aeruginosa	5,500	10,500
Pseudomonas fluorescens	3,500	6,600
S. typhimurium	8,000	15,200
Sarcina lutea	19,700	26,400
Serratia marcescens	2,420	6,160
Dysentery bacilli	2,200	4,200
Shigella paradysenteriae	1,680	3,400
Spirillum rubrum	4,400	6,160
Staphylococcus albus	1,840	5,720
Staphylococcus aureus	2,600	6,600
Streptococcus hemolyticus	2,160	5,500
Streptococcus lactis	6,150	8,800
Streptococcus viridans	2,000	3,800
YEAST		
Saccharomyces ellipsoideus	6,000	13,200
Saccharomyces sp.	8,000	17,600
Saccharomyces cerevisiae	6,000	13,200
BREWER'S YEAST	3,300	6,600
BAKER'S YEAST	3,900	8,800
COMMON YEAST CAKE	6,000	13,200
MOLD SPORES		
Penicillium roqueforti (green)	13,000	26,400
Penicillium expansum (olive)	13,000	22,000
Penicillium digitatum (olive)	44,000	88,000
Aspergillus glaucus (bluish green)	44,000	88,000
Aspergillus flavus (yellowish-green)	60,000	99,000
Aspergillus niger (black)	132,000	330,000
Rhizopus nigricans (black)	111,000	220,000
Mucor racemosus A (white-gray)	17,000	35,200
Mucor racemosus B (white)	5,000	11,000
Oospora lactis (white)	5,000	11,000

Consult manufacturers of UV sterilizing lights for energy output at specified flow rates.

(Source: F.W. Wheaton, *Aquacultural Engineering*; copyright © 1985 - with permission of John Wiley & Sons, Inc.)

TABLE 10-2: ULTRAVIOLET ENERGY FOR 100 PERCENT KILL ($\mu W\ s/cm^2$) (Kelly, 1974)

ORGANISM	UV ENERGY ($\mu W\ s/cm^2$)
MOLD SPORES	
Penicillium roqueforti	26,400
Aspergillus niger	330,000
YEASTS	
BREWER'S YEAST	6,600
BAKER'S YEAST	8,800
COMMON YEAST CAKE	13,200
BACTERIA	
Streptococcus hemolyticus	5,500
Staphylococcus aureus	6,600
Escherichia coli	7,000
Proteus vulgaris	7,500
Bacillus subtillis	11,000
Bacillus subtillus spores	22,000
VIRUS	
BACTERIOPHAGE (*E. coli*)	6,600
INFLUENZA VIRUS	3,400
NEMATODE EGGS	40,000

Consult manufacturers of UV sterilizing lights for energy output at specified flow rates.

(Source: F. W. Wheaton, *Aquacultural Engineering;* copyright © 1985 - with permission of John Wiley & Sons, Inc.)

TABLE 10-3: SIZES AND MLD OF UV RADIATION FOR SOME MICROORGANISMS FREE-LIVING OR PARASITIC IN AQUARIUM OR HATCHERY WATER. (from Hoffman, 1974)

MICROORGANISM	LIFE STAGE	SIZE (μm)	MLD ($\mu W\ sec/cm^2$)
Trichodina sp.	-	16 x 20	35,000
Trichodina nigra	-	22 x 70	159,000
Saprolegnia sp.	ZOOSPORE	4 x 12	35,000
Saprolegnia sp.	HYPHA	8 x 24	10,000
Oodinium ocellatum (1)	DINOSPORE	8 x 12	
Sarcina lutea	-	1.5	26,400
Ichthyophthirius sp.	TOMITE	20 x 35	336,000
Ichthyophthirius sp.	TOMITE	20 x 35	100,000
Cryptocaryon irritans (2)	TOMITE	35 x 56.5	
Chilodonella cyprini	-	35 x 70	1,008,400
Paramecium sp.	-	70 x 80	200,000

(1) From data in Nigrelli (1936).

(2) From data in Nigrelli and Ruggieri (1966).

(Source: S. Spotte, *Fish and Invertebrate Culture;* copyright © 1979 - with permission of John Wiley & Sons, Inc.)

ANNEX 11

Biological activity of antibiotics

TABLE 11-1: BIOLOGICAL ACTIVITY OF ANTIBIOTICS COMMONLY USED IN AQUACULTURE

ANTIBIOTIC	SPECTRA [1] - RANGE [2] µg/ml				
	G+	G-	BACTERIA	FUNGI	PROTOZOA
CHLORTETRACYCLINE [3]	1	1	0.002-50		25-1000
BACITRACIN	1	2	0.002-125	-	-
CARBOMYCIN	1	2	0.01-12		32-250
CHLORAMPHENICOL [3]	1	1	0.06-50		125-2000
COLISTIN	3	1	0.5-50	20	125
CANDICIDIN	-	-	-	0.5-50	-
ERYTHROMYCIN	1	2	0.003-200	-	-
KANAMYCIN	1	1	0.3-500	-	-
NYSTATIN	-	-	-	1-13	250
NEOMYCIN	1	1	0.2-100	-	43-3000
NOVOBIOCIN	1	2	0.02-200	10-1000	125
OLEANDOMYCIN	1	1	0.08-50	-	-
PENICILLIN	1	2	1-5000	-	-
POLYMIXIN B	3	1	0.02-50	125-250	125
STREPTOMYCIN [3]	1	1	0.5-300	-	-
TETRACYCLINE [3]	1	1	0.05-7.5	-	62-250
OXYTETRACYCLINE [3]	1	1	0.002-50	-	31-250
TRICHOMYCIN	-	-	-	0.6-10	250

[1] Effectiveness of antibiotic against gram-positive (G+) and gram-negative (G-) bacteria; (3) no activity; (2) little activity, effective against a few representative species; (1) activity, effective against most representative species.

[2] Range in ug/ml of antibiotic which inhibits microbial growth.

[3] Known as broad-spectrum antibiotic because active against gram-negative, gram-positive and other microorganisms.

(Source: W.L. Smith and M.H. Chanley, *Culture of Marine Invertebrate Animals*; copyright © 1975 - with permission of Plenum Publishing)

TABLE 11-2: STABILITY AND ACTIVITY OF ANTIBIOTICS COMMONLY USED IN AQUACULTURE

ANTIBIOTICS	pH[1]	STABILITY IN AQUEOUS SOLUTIONS			DEVELOP RESIST.[2]	CROSS RESIST.[3]
		DAYS	pH	°C		
1. CHLORTETRACYCLIN	6.0-6.6	14	2.5-3	25	slow	4;16;17
2. BACITRACIN	6.0-6.6	14	5-7	35-37	slow	none
3. CARBOMYCIN		11	5-7	25	yes	7;12
4. CHLORAMPHENICOL	7.4-8.0	30	6-8	30	slow	1;14;16;17
5. COLISTIN	7.0-8.0	16	7-7.8	20	slow	-
6. CANTICIDIN		7	7	4	-	-
7. ERYTHROMYCIN	7.4-8.0	1	7-8	25	rapid	3;12
8. KANAMYCIN	7.4-8.0	30	7.8	4	rapid	10
9. NYSTATIN	-	-	-	-	-	-
10. NEOMYCIN	7.4-8.0	30	2-9	25	slow	8;15
11. NOVOBIOCIN	6.0-6.6	60	7-10	24	rapid	none
12. OLEANDOMYCIN	6.0-6.6	1	5-7	25	rapid	3;7
13. PENICILLIN	6.0-6.6	3	6-7	25	yes	-
14. POLYMIXIN		365	6-7	37	slow	5
15. STREPTOMYCIN	7.4-8.0	90	3-7	25	rapid	8;10
16. TETRACYCLINE	6.0-6.6	3	7	37	slow	1;14;16;17
17. OXYTETRACYCLINE	6.0-6.6	7	7	25	slow	1;16
18. TRICHOMYCIN	-	-	-	-		none

[1] pH range for maximal antimicrobial activity.

[2] Bacterial strains develop resistance to the antibiotic.

[3] Microorganisms which have become resistant to an antibiotic numbered in column one also acquire resistance to antibiotics whose numbers are listed in this column.

Antibiotics with long half-lives include streptomycin, chloramphenicol, kanamycin and neomycin.

Effective antibiotics with short half-lives include chlortetracycline, oxytetracycline, bacitracin and carbomycin are most active at pH 6.0-6.6, and are much less effective in seawater. Colistin remains effective in seawater.

Antibiotics with very short half-lives include oleandomycin, wide-spectrum tetracycline, erythromycin and penicillin. Although effective against sensitive organisms, they are less effective for long-term control in cultures.

ANNEX 12

Oxygen consumption

TABLE 12-1: SOME OXYGEN CONSUMPTION VALUES FOR FARMED FISH.

SPECIES	SIZE (g)	TEMP. (°C)	FEED RATE	OXYGEN CONSUMED (g O_2 / kg fish / hr)	SOURCE
Salmo gairdneri	100	15	?	0.3	Liao (1971)
	100 1	15	production levels	0.3	Muller-Fuega *et al* (1978)
O. nerka	28.J	15	unfed	0.23	Brett and Zala (1975)
	28.6	15	3% body wt day^{-1}	0.28	
Ictalurus punctatus	100	30	unfed	0.56	Andrews and Matsuda (1975)
	100	30	satiation	0.81	Andrews and Matsuda (1975)
Cyprinus carpio	100	10	fed	0.17	Beamish (1964)
		20	fed	0.48	Beamish (1964)
		25	fed	0.70	Beamish (1964)
Hypohthalmichthys molitrix	15	20	-	0.20	Muhamedova (1977)[1]
	240	23	fed	0.25	Vetskanov (1975)[1]
0reochromis niloticus	50	25	unfed	0.16	Ross and Ross (1984)
	50	30	unfed	0.24	Ross and Ross (1984)
	50	35	unfed	0.40	Ross and Ross (1984)
Macrobrachium rosenbergii	0.5g	24	unfed	36.0	Nelson *et al* (1977)
	0.5	24	satiation [2]	43.0	Nelson *et al*. (1977)

[1] From ADCP, 1984. [2] Fed Purina marine ration #2

(Source: M.C.M. Beveridge, *Cage Aquaculture;* 1987)

TABLE 12-2: TYPICAL OXYGEN TRANSFER RATES OF VARIOUS DEVICES USED IN FISH CULTURE SYSTEMS (modified from Colt and Tchobanoglous, 1981).

AERATION SYSTEM	TRANSFER RATE kg O_2 kW / h STANDARD[a]	6 mg l^{-1} O_2[b]
DIFFUSED AIR SYSTEM		
A: FINE BUBBLE	1.2-2.0	0.25-0.42
B: MEDIUM BUBBLE	1.0-1.6	0.21-0.34
C: COARSE BUBBLE	0.6-1.2	0.13-0.25
SURFACE AERATOR (low speed)	1.2-2.4	0.25-0.80
SURFACE AERATOR (high speed)	1.2-2.5	0.25-0.50
VENTURI AERATOR	1.2-2.4	0.25-0.50
FLOATING ROTOR AERATOR	1.2-2.4	0.25-0.5
U-TUBE AERATOR		
A: ZERO HEAD	4.5	0.95
B: 1-FOOT HEAD	45.6	9.58
GRAVITY AERATOR	1.2-1.8	0.25-0.38
PURE OXYGEN SYSTEM		
A: FINE BUBBLE	-	1.2-1.80
B: MECHAN. SURF. AERATION		1.0-1.2
C: TURBIN-SPARGER		1.2-1.5

[a] 20°C, tapwater, D.O. = 0 mg/l [b] 20°C, D.O. = 6 mg/l

Note: kg/kW•h x 1.6440 = lbO_2/hp•h

(Source: J. Colt and W. Tchobanoglous, In: *Proceedings of the Bio-Engineering Symposium for Fish Culture;* copyright © 1981 - with permission of American Fisheries Society)

ANNEX 13

Concentration of selected fish tranquillizers

TABLE 13-1: CONCENTRATIONS OF SOME DRUGS USED TO TRANQUILIZE FISH FOR TRANSPORT

DRUG	CONCENTRATION
SODIUM BICARBONATE	642 mg/l
TERTIARY AMYL ALCOHOL	2 ml/gallon
METHYLPARAFYNOL (Dormison)	1-2 ml gallon
CHLORAL HYDRATE	3.0-3.5 g/gallon
SODIUM BARBITAL	6.7-7.7 micrograms/l
URETHANE	1-4 g/l
METHANE TRICAINESULFONATE (MS-222)	40-150 mg/l
QUINALDINE	2-20 mg/l
MIXTURE OF MS-222 AND QUINALDINE	20-30 mg/l MS-222 and 5 mg/l of quinaldine

(Source: Courtesy of Dr. William McLarney, *The Freshwater Aquaculture Book;* copyright © 1984 - with permission of Hartley & Marks, Inc.)

ANNEX 14

Average proximate composition of food organisms

TABLE 14-1: AVERAGE PROXIMATE COMPOSITION OF SELECTED INVERTEBRATE FOOD ORGANISMS

All Values Are Expressed As % By Weight On An As-fed Basis: Water-H_2O; Crude Protein-CP, Lipid Or Ether Extract-EE; Crude Fiber-CF; Nitrogen Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P [1]

INVERTEBRATE	AVERAGE COMPOSITION (% by weight)								NO. REF.
	H_2O	CP	EE	CF	NFE	Ash	Ca	P	(1)
ROTIFERS [2]									
Brachionus plicatilis (wet basis)									
Cultured on bakers yeast	90.7	6.2	1.8	-	-	0.7	0.015	0.127	(1)
Cultured on bakers yeast + marine chlorella	88.7	7.7	2.4	-	-	0.5	0.016	0.138	(1)
Cultured on marine chlorella	86.9	7.9	3.9	-	-	0.7	0.016	0.142	(1)
Cultured on marine oil enriched bakers yeast	86.8	7.2	4.6	-	-	0.5	0.015	0.130	(1)
BRINE SHRIMP [2]									
Artemia salina									
Eggs (dry basis)	-	51.1	7.2	-	-	11.5	0.24	0.74	(1)
Larvae (nauplii); Just after hatching (wet basis)	89.0	6.7	2.1	-	-	1.1	0.03	0.14	(1)
Larvae (nauplii); Just after hatching (dry basis) [3]	-	52.2	18.9	14.8		9.7	-	-	(1)
Juveniles and adults; cultured (dry basis)	-	54.6	13.2	-	-	16.6	-	-	(1)
Adults; wild (dry basis) [3]	-	58.4	11.1	12.1		17.8	-	-	(1)
Brine shrimp meal; Adults (dried)	18.7	44.3	4.0	17.5		15.6	-	-	(1)
MARINE COPEPODS [2]									
Tigriopus japonicus (wet basis)									
Cultured under natural conditions	88.6	8.1	2.6	-	-	0.5	0.01	0.09	(1)
Cultured on bakers yeast	87.2	8.9	2.6	-	-	0.6	0.02	0.12	(1)
Cultured on bakers yeast + marine Chlorella	86.6	9.0	3.2	-	-	0.5	0.02	0.13	(1)
Cultured on bakers + dry prawn diet	86.3	9.8	3.1	-	-	0.5	0.02	0.14	(1)
Cultured on marine oil enriched bakers yeast	87.2	8.7	2.6	-	-	0.6	0.04	0.14	(1)
Cultured on soy sauce cake	86.3	9.4	2.3	-	-	0.6	0.04	0.14	(1)
Acartia clausi	87.6	8.8	1.3	-	-	2.1	0.05	0.15	(1)
FRESHWATER COPEPODS [4]									
Moina spp. (wet basis)									
Cultured on bakers yeast	87.2	8.8	2.9	-	-	-	0.01	0.18	(1)
Cultured on bakers yeast + poultry manure	89.0	8.6	1.3	-	-	-	0.01	0.12	(1)
Cultured on poultry manure	87.9	8.2	3.3	-	-	-	0.02	0.16	(1)
Daphnia pulex (wet basis)	94.0	3.0	1.0	0.4	-	1.2	-	-	(1)
Daphnia spp. (wet basis)	89.3	7.5	1.4	-	-	0.7	0.02	0.15	(1)
Diaptomus spp. (wet basis)	92.4	4.4	1.9	0.5	-	0.4	-	-	(1)
MISCELLANEOUS FRESHWATER INVERTEBRATES (wet basis)									
Amphipod (*Gammarus lacustris*)	85.9	5.7	1.5	1.0	-	4.0	-	-	(2)
Damselfly nymph (*Enallagma* spp.)	86.5	7.9	1.8	1.3	-	0.8	-	-	(1)
Dragonfly nymph (*Aeshna* spp.)	86.4	4.7	2.9	1.0	-	0.6	-	-	(1)
Water boatmen (Corixidae)	78.9	12.2	5.7	2.5	-	0.7	-	-	(1)
Chironomid larvae (*Chironomidae* spp.)	83.9	9.1	13.6	-	-	7.1	-	-	(1)
Blood worm (*Tubifex* tubifex)	87.1	8.1	2.0	-	1.9	0.9	-	-	(1)
Riversnail (*Lymnea* spp.)									
Whole snall	36.8	5.7	0.7	-	2.0	54.8	-	-	(1)
Snail meat	78.4	12.2	1.4	-	4.3	3.7	-	-	(1)
Freshwater mussel	79.6	18.4	0.8	-	-	1.2	-	-	(1)
MISCELLANEOUS MARINE INVERTEBRATES									
Short necked clam (*Venerupis phillippinarum*) (flesh)	81.8	12.6	0.6	-	-	2.5	-	-	(1)
Squid (*Ommastrephes pacifica*) (meal; dried)	8.1	74.8	8.8	0.0	4.9	3.4	-	-	(1)

TABLE 14-1 (cont.):

INVERTEBRATE	AVERAGE COMPOSITION (% by weight)								NO. REF.
	H_2O	CP	EE	CF	NFE	Ash	Ca	P	(1)
KRILL (*Euphausia pacifica*) (whole;dried)	82.0	6.0	5.0	-	-	5.0	0.46	0.29	(1)
CRAB (*Cancer/Carcinus/Callinectes* spp.)									
Process residue (meal; dried)	6.5	31.0	2.1	10.6	13.7	36.1	16.28	1.54	(2)
Protein concentrate (dried)	10.0	60.5	0.4	-	-	6.8	0.09	0.60	(1)
Mysid shrimp meal (dried)	10 4	68.2	2.4	5.0		14.0	-	-	(1)
Sergestid shrimp (*Acetes* spp.) (whole; sun dried)	14.0	46.9	3.2	4.2	-	13.1	2.96	1.07	(1)
CRAWFISH (*Procambarus clarkii*) (by-product meal)	-	36.0	3.7	13.6	-	42.2	15.80	0.95	(1)
Shrimp meal (process residue; dehydrated)	10.0	40.6	2.6	14.2	2.6	30.0	9.70	1.57	(6)
Shrimp heads (dried) [5]	-	58.2	8.9	11.1	-	22.6	7.20	1.68	(1)
Shrimp shells (exoskeleton/hull; dried) [5]	-	45.9	0.4	27.2	-	31.7	11.10	3.16	(1)
Shrimp head silage (fresh)	81.0	14.1	1.4	-	-	3.5	1.08	0.30	(1)
Shrimp head silage (dried)	7.0	69.0	6.8	-	-	17.1	5.29	1.47	(1)
TERRESTRIAL INVERTEBRATES									
AFRICAN GIANT SNAIL (*Achatina fulica*)									
Snail meat meal (dried)	11.1	45.6	2.4	-	-	7.0	0.73	0.48	(1)
Snail meal (without shell; dry matter basis)	0.0	60.9	6.1	4.5	18.9	9.6	2.0	0.84	(1)
Snail shell (dry matter basis)	0.0	2.8	1.0	-	-	54.5	36.1	0.14	(1)
Whole snall (Includlng shell; dry matter basis)	0.0	16.1	2.0	-	-	46.0	31.1	0.32	(1)
EUROPEAN SNAIL (*Helix* spp.)									
Snail meat (*H. aspersa*) (fresh)	78.5	14.6	0.7	-	-	1.4	-	-	(1)
Snail meat (*H. lucorum*) (fresh)	80.3	12.9	0.6	-	-	1.8	-	-	(1)
Snail meat (*Helix* spp.) (dried)	5.7	62.7	7.5	-	-	7.8	-	-	(1)
SILKWORM (*Bombyx mori/Antheraea mylittapaphia*)									
Pupae (fresh)	74.9	13.7	8.3	1.1	0.9	1.1	0.03	0.18	(3)
Pupae (dry)	10.0	55.9	24.5	-	-	1.9	-	-	(1)
Pupae (solvent extracted; dried)	7.9	72.0	1.2	6.7	6.0	6.2	0.14	1.06	(3)
LOCUST (*Schistocerca gregaria*)									
Whole fresh	68.2	22.1	3.0	4.0	0.3	2.4	-	-	(2)
Whole dried	10.5	46.2	9.7	12.0	-	-	-	-	(1)
SOLDLER FLY (Hermetia illucens)									
Larvae meal (dried) [6]	7.9	42.1	34.8	7.0	-	14.6	5.0	1.5	(1)
TERRESTRIAL OLIGOCHAETE WORMS									
Eisenia foetida (fresh)	83.3	9.8	1.5	-	-	2.9	-	-	(1)
Eisenia foetida (meal; dried)	7.4	56.4	7.8	1.6	18.0	8.8	0.48	0.87	(1)
Eudrilus eugenige (fresh)	85.3	8.9	1.8	-	-	1.5	0.22	0.13	(1)
Eudrilus eugenige (dry matter basis)	0.0	60.4	12.0	-	-	10.5	1.49	0.89	(1)
Dendrodrilus subrubicundus (dried)	9.1	65.1	9.6	-	-	13.0	0.18	-	(1)
Allolobophora longa (fresh)	78.3	10.9	0.3	-	-	7.6	-	-	(1)
Lumbricus terrestris (fresh)	81.1	10.6	0.4	-	-	5.4	-	-	(1)

[1] The data presented represents the mean values from various sources, Including: Allen (1984); Choubert and Luquet (1983); Creswell and Kompiang (1981); Deshimaru and Shigeno (1972); Deshimaru *et.al.*, (1985); Elmslie (1982); Gallagher and Brown (1975); Gohl (1981); Hilton (1983); Imada *et.al.*, (1979); Ling (1967); Mathias *et.al.*, (1982); Meyers (1986, 1987); Newton *et.al.*, (1977), NRC (1983); Seidel et.al., (1980); Simpson, Klein-MacPhee and Beck (1982); Stafford and Tacon (1984, 1985); Tacon (1986a); Tacon, Stafford and Edwards (1983); Watanabe, Kitajima and Fujita (1983); Yoshida and Hoshii (1978), Yurkowski and Tabachek (1978), and Leger *et.al*, (1986).

[2] Data obtained from Watanabe, Kitajima and Fujita (1983).

[3] Data obtained from Leger *et.al*., (1986); no information provided on moisture, crude fiber or NFE content - the carbohydrate content being represented by a single value.

[4] Data compiled from Watanabe, Kltajima and Fujita (1983) and Yurkowski and Tabachek (1978).

[5] Data obtained from Meyers (1986); crude protein (N x 6.25) values do not correspond to the corrected true protein value of 53.5% and 22.8% for shrimp heads and shrimp hulls respectively (ie. values corrected for chitin content)

[6] Data obtained from Newton *et.al*., (1977); no value is presented in this table for NFE, as the existing values reported by these authors total 106.4%.

(Source: A.G.J. Tacon, *Standard Methods for the Nutrition of Farmed Fish and Shrimp;* 1990 - with permission of Argent Laboratories, Inc.)

TABLE 14-2: AVERAGE ESSENTIAL AMINO ACID (EAA) COMPOSITION OF SELECTED INVERTEBRATE FOODS
All values are expressed as % by weight on a as-fed basis: Arginine-ARG; Cystine-CYT; Methionine-MET; Threonine-THR; Isoleucine-ISO; Leucine-LEU; Lysine-LYS; Valine-VAL; Tyrosine-TYR; Tryptophan-TRY; Phenylalanine-PHE; Histidine-HIS [1]

INVERTEBRATE	AVERAGE EAA COMPOSITION (% dry meal or % total recovered amino acids) ARG	CYT	MET	THR	ISO	LEU	LYS	VAL	TYR	TRY	PHE	HIS	NO. REF. (1)
Rotifer (*B. plicatilis*)[2] (% total AA)	6.3	1.1	1.2	4.7	4.8	8.2	8.2	5.5	4.2	1.6	5.3	2.1	(1)
Brine shrimp (*A. salina*)													
Nauplii (newly hatched) (% total AA)	7.3	0.6	1.3	2.5	3.8	8.9	8.9	4.7	5.4	1.5	4.7	1.9	(1)
Nauplii (3-day old) (% total AA)	6.5	1.1	2.3	4.8	4.8	7.6	8.0	5.1	7.8	-	5.7	3.6	(1)
Adults (wild) (% total AA)	6.5	2.2	2.7	4.6	5.3	8.0	7.6	5.4	4.5	1.0	4.7	1.8	(1)
Brine shrimp meal [3] (% total AA)	6.8	1.3	2.3	4.9	5.1	8.6	7.4	5.3	4.6	-	5.3	2.2	(1)
Copepod (*A. clausi*) (% total AA)	5.6	1.0	2.0	5.5	4.6	7.2	7.1	5.9	4.7	1.4	4.8	2.5	(1)
Copepod (*T. japonicus*) (% total AA)	6.9	0.9	1.5	5.0	3.3	6.6	7.5	4.3	5.3	1.5	4.6	2.1	(1)
Copepod (*Moina* spp.) (% total AA)	7.0	0.8	1.4	5.2	3.4	8.3	8.0	4.4	4.5	1.6	4.9	2.2	(1)
Amphipod(*G. lacustris*) (% dry matter)	2.5	0.4	0.8	2.0	1.7	3.0	2.8	2.2	3.2	-	1.9	1.1	(1)
Soldier fly (*H.illucens*) (larvae) (% dry matter)	2.2	<0.1	0.9	0.5	2.0	3.5	3.4	3.4	2.5	0.2	2.2	1.9	(1)
Snail (*A. fulica*) (meal) (% dry matter)	4.9	0.6	1.0	2.8	2.6	4.6	4.3	3.1	2.4	-	2.6	1.4	(1)
Crab process residue (meal) (% by weight as fed)	1.7	0.2	0.5	1.1	1.2	1.6	1.4	1.5	1.2	0.3	1.2	0.5	(2)
Crab protein concentrate (meal) (by wt. as fed)	5.5	<0.1	0.8	3.5	3.4	5.3	3.6	5.0	4.8	-	5.1	2.3	(1)
Squid (*0. pacifica*) (meal) (% total AA)	7.2	0.7	2.9	5.1	4.9	7.7	8.0	4.4	3.8	-	5.6	2.1	(1)
Mysid shrimp meal (% total AA)	6.5	1.2	3.1	5.6	0.5	7.3	8.6	5.3	4.5	-	5.0	2.5	(1)
Short-necked clam (*V. phillippinarum*) (%tot. AA flesh)	7.7	1.3	2.6	4.8	3.4	6.9	7.3	4.2	3.9	1.3	3.8	2.2	(1)
Shrimp meal (processing residue; dehyd.) (% by wt.as fed)	2.5	0.6	0.8	1.4	1.7	2.7	2.2	1.8	1.3	0.4	1.6	1.0	(1)
Shrimp meal (sun dried) (% total AA)	6.9	1.7	3.1	4.7	3.6	8.3	6.7	4.8	4.0	1.4	5.0	2.1	(1)
Shrimp head meal (% total AA)	6.8	2.4	1.7	4.3	6.3	6.8	9.3	6.9	3.7	0.6	4.7	2.3	(1)
Shrimp (*Acetes* spp.)[4] (whole; dried; % by wt. as fed)	4.6	0.2	1.6	2.3	2.5	4.9	4.4	2.7	2.0	-	2.5	1.0	(1)
Shrimp (*Acetes* spp.) [4] (whole; dried; % total AA)	8.2	0.4	3.0	4.1	4.5	8.8	8.0	4.8	3.6	-	4.6	1.8	(1)
TERRESTRIAL OLIGOCHAETE WORMS													+
E. eugenige (% dry matter basis)	1.73	0.23	0.77	1.37	0.99	-	1.83	1.15	1.01	-	1.19	0.40	(1)
E. foetida (% dry meal)	2.73	0.34	1.36	2.72	2.01	4.03	3.17	2.26	1.68	0.35	1.93	1.44	(1)
A. longa (% dry meal)	3.15	0.30	0.50	2.11	2.24	3.57	3.43	2.46	1.99	-	2.65	1.01	(1)
D. subricunda (% dry meal)	3.39	0.35	1.29	2.50	1.72	3.86	3.25	1.89	1.79	0.57	2.15	1.39	(1)
L. rubellus (% dry meal)	3.68	0.39	1.31	2.77	1.97	4.17	3.86	2.26	1.95	0.46	1.88	1.29	(1)
L. terrestris (% dry meal)	3.17	0.32	1.11	2.48	2.20	4.11	3.52	2.30	1.78	0.44	2.02	1.38	(1)

[1] The data presented represence the mean values from various sources, including: Allen (1984); Cresswell and Komplang(1981); Deshimaru and Shigeno (1972); Deshimaru *et al.*, (1985); Gallagher and Brown (1975); Hilton (1983), Mathias *et al.* (1982); Meyers (1986); Newton *et al.*, (1977); NRC (1983); Seidel *et al.*, (1980); Stafford (1984); Tacon, Stafford and Edwards (1983); and Watanabe, Kitajima and Fujita (1983).

[2] Mean of the eight amino acid analyses presented by Watanabe, Kitajima and Fujita (1983)

[3] 0rigin of meal not specified (Deshimaru and Shigeno, 1972).

ANNEX 15

Nitrogen and CO_2 solubility

TABLE 15-1: SOLUBILITY OF NITROGEN (mg/liter) IN WATER AT DIFFERENT TEMPERATURES AND SALINITIES FROM MOIST AIR WITH PRESSURE OF 760 MM HG. (Colt, 1984)

TEMPERATURE (°C)	SALINITY (ppt)								
	0	5	10	15	20	25	30	35	40
0	23.04	22.19	21.38	20.60	19.85	19.12	18.42	17.75	170
5	20.33	19.61	18.92	18.26	17.61	16.99	16.40	15.82	15.26
0	18.14	17.53	16.93	16.36	15.81	15.27	14.75	14.25	13.77
15	16.36	15.82	15.31	14.81	14.32	13.86	13.40	12.97	12.54
20	14.88	14.41	13.96	13.52	13.09	12.68	12.28	11.89	11.52
25	13.64	13.22	12.82	12.43	12.05	11.69	11.33	10.99	10.65
30	12.58	12.21	11.85	11.50	11.17	10.84	10.52	10.21	9.91
35	11.68	11.34	11.02	10.71	10.40	10.10	9.82	9.54	9.26
40	10.89	10.59	10.29	11.01	9.73	9.46	9.20	8.94	8.70

(Source: C. E. Boyd, *Water Quality in Ponds for Aquaculture;* 1990)

TABLE 15-2: SOLUBILITY OF CARBON DIOXIDE (mg/liter) IN WATER AT DIFFERENT TEMPERATURES AND SALINITIES FROM MOIST AIR WITH PRESSURE OF 760 MM Hg (Colt, 1984)

TEMPERATURE (°C)	SALINITY (ppt)								
	0	5	10	15	20	25	30	35	40
0	1.09	1.06	1.03	1.00	0.98	0.95	0.93	0.90	0.88
5	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.75	0.73
10	0.75	0.73	0.71	0.69	0.68	0.66	0.64	0.63	0.61
15	0.63	0.62	0.60	0.59	0.57	0.56	0.54	0.53	0.52
20	0.54	0.53	0.51	0.50	0.49	0.48	0.47	0.46	0.45
25	0.46	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.39
30	0.40	0.39	0.39	0.38	0.37	0.36	0.35	0.35	0.34
35	0.35	0.35	0.34	0.33	0.33	0.32	0.31	0.31	0.30
40	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.27	0.27

(Source: C. E. Boyd, *Water Quality in Ponds for Aquaculture;* 1990)

ANNEX 16

Nitrobacter and *Nitrosomonas* parameters

TABLE 16-1: TEMPERATURE OPTIMA FOR *NITROSOMONAS* (NS) AND *NITROBACTER* (NB).

SPECIES	TEMPERATURE (°C) RANGE	OPTIMUM	INHIBITORY	SOURCE
NS	30-36	30-36	-	Buswell *et al.* (1953)
NS	10-40	30-35	-	Kawai *et al.* (1965)
NS	-	-	< 5	Buswell *et al.* (1953)
NB	8-24	28	-	Nelson (1931)
NB	4-45	34-35	-	Deppe & Engle (1960)
NB	-	42	-	Laudelout *et al.* (1960)
NB	10-40	30-35	-	Kawaietal. (1965)
NB	-	-	< 4	Depp & Engle (1960)
NB	-	-	>45	Depp & Engle (1960)

(Source: Wheaton, Hochheimer and Kaiser, In: D.E. Brune and J.R. Tomasso (Eds.), *Aquaculture and Water Quality;* 1991)

TABLE 16-2: THE pH RANGES GIVING THE BEST NITRIFICATION RATES FOR *NITROSOMONAS* (NS) AND *NITROBACTER* (NB).

SPECIES	RANGE TESTED	pH OPTIMA	SOURCE
NS		8.0 - 9.0	Hofman & Lees (1952)
NS	7.0 - 9.0	8.0	Engle & Alexander (1958)
NS		6.0 - 9.0	Winogradsky & Winogradsky (1933)
NS	5.0-10.0	9.0	Kawai *et al.* (1965)
NS		7.2 - 7.8	Loveless & Painter (1969)
NB		8.3 - 9.3	Mererhof (1917)
NB	7.0 - 8.6	7.8	Boon & Laudelout (1962)
NB		6.3 - 9.4	Winogradsky & Winogradsky (1933)
NB	5.0-10.0	9.0	Kawa *et al.* (1965)
BOTH	7.0 - 9.5	8.5	Kholdenbarin & Oertli (1977)

(Source: Wheaton, Hochheimer and Kaiser, In: D.E. Brune and J.R. Tomasso (Eds.), *Aquaculture and Water Quality;* 1991)

TABLE 16-3: GROWTH REQUIREMENTS AND TOXICITY OF VARIOUS COMPOUNDS TO *NITROBACTER* (NB) AND *NITROSOMONAS* (NS).

SPECIES	COMPOUNDS	CONCENTRATIONS	INHIBITION	SOURCES
NS	Ni	0.25 mg/l	mod	1
NS	Cr	0.25 mg/l	mod	1
NS	Cu	0.1 mg/l	slight	1

TABLE 16-3 (cont.):

SPECIES	COMPOUNDS	CONCENTRATIONS	INHIBITION	SOURCES
NS	Cu	0.5 mg/1	complete	1
NS	Stainless EN58B	presence	none	1
NS	Fe	< 0.5 mg/1	limits growth	1
NS	L-Arginine	5×10^{-3}M	slight	2
NS	L-Histidine	5×10^{-3}M	complete	2
NS	L-Phenylalanine	5×10^{-3}M	slight	2
NS	L-Tyrosine	5 x 10-3M	slight	2
NS	DL-Methinoninesulphoxide	5×10^{-3}M	slight	2
NS	Creatinine	5×10^{-3}M	slight	2
NS	Glycocyamine	5×10^{-3}M	slight	2
NS	2,4 Dinitophenol	5×10^{-3}M	none	2
NS	Ethylurethane	5×10^{-3}M	moderate	2
NS	Calcium	50 mg/1	stimulated	
NB	Iron	7 mg/1	stimulated	3
NB & NS	Phosphate	310 mg/1-P	stimulated	4
NB	Magnesium	5 mgll	stimulated	3
NB	Phosphorus	5 mg/1	stimulated	3
NB	Molybdenum	1 mg/1	stimulated	3
NB	Zinc	1 mg/1	stimulated	3
NB	Molybdenum	0.1 - 1 mg/1	stimulated	5
NS	Magnesium	5.0 mg/1	stimulated	1
NS	Phosphate	0.28 mg/1	stimulated	1
NS	Iron	2 mg/1	stimulated	1
NS	Ni	0.1 mg/1	stimulated	1
NS	Cr	0.1 mg/1	stimulated	1
NS	Co	1.0 mg/1	stimulated	1
NS	Mn	1.0 mg/1	stimulated	1
NS	Zn	1.0 mg/1	stimulated	1

SOURCES:

(1) Skinner and Walker (1961)

(2) Lees (1952)

(3) Aleem (1959)

(4) Laudelout *et al.* (1967) (not referenced in source)

(5) Finstein and Delwiche (1965)

(Source: Wheaton, Hochheimer and Kaiser, In: D.E. Brune and J.R. Tomasso (Eds.), *Aquaculture and Water Quality*; 1991)

TABLE 16-4: EFFECTS OF COMMONLY USED ANTIBACTERIAL AGENTS AND PARASITICIDES ON NITRIFICATION IN FRESHWATER AQUARIUMS AT THERAPEUTIC LEVELS. (from Collins et al. 1975; 1976 and Levine and Meade 1976)

COMPOUND	CONCENTRATION (mg/l)	% INHIBITION	SOURCE
CHLORAMPHENICOL	50	0	B
	50	84	C
OXYTETRACYCLINE	50	0	B
SULFAMERAZINE	50	0	B
SULFANILAMIDE	25	65	C

TABLE 16-3 (cont.):

SPECIES	COMPOUNDS	CONCENTRATIONS	INHIBITION	SOURCES
NS	Cu	0.5 mg/1	complete	1
NS	Stainless EN58B	presence	none	1
NS	Fe	< 0.5 mg/l	limits growth	1
NS	L-Arginine	5×10^{-3}M	slight	2
NS	L-Histidine	5×10^{-3}M	complete	2
NS	L-Phenylalanine	5×10^{-3}M	slight	2
NS	L-Tyrosine	5 x 10-3M	slight	2
NS	DL-Methinoninesulphoxide	5×10^{-3}M	slight	2
NS	Creatinine	5×10^{-3}M	slight	2
NS	Glycocyamine	5×10^{-3}M	slight	2
NS	2,4 Dinitophenol	5×10^{-3}M	none	2
NS	Ethylurethane	5×10^{-3}M	moderate	2
NS	Calcium	50 mg/l	stimulated	
NB	Iron	7 mg/l	stimulated	3
NB & NS	Phosphate	310 mg/1-P	stimulated	4
NB	Magnesium	5 mgll	stimulated	3
NB	Phosphorus	5 mg/l	stimulated	3
NB	Molybdenum	1 mg/l	stimulated	3
NB	Zinc	1 mg/l	stimulated	3
NB	Molybdenum	0.1 - 1 mg/l	stimulated	5
NS	Magnesium	5.0 mg/l	stimulated	1
NS	Phosphate	0.28 mg/l	stimulated	1
NS	Iron	2 mg/l	stimulated	1
NS	Ni	0.1 mg/l	stimulated	1
NS	Cr	0.1 mg/l	stimulated	1
NS	Co	1.0 mg/l	stimulated	1
NS	Mn	1.0 mg/l	stimulated	1
NS	Zn	1.0 mg/l	stimulated	1

SOURCES:

(1) Skinner and Walker (1961)

(2) Lees (1952)

(3) Aleem (1959)

(4) Laudelout *et al.* (1967) (not referenced in source)

(5) Finstein and Delwiche (1965)

(Source: Wheaton, Hochheimer and Kaiser, In: D.E. Brune and J.R. Tomasso (Eds.), *Aquaculture and Water Quality*; 1991)

TABLE 16-4: EFFECTS OF COMMONLY USED ANTIBACTERIAL AGENTS AND PARASITICIDES ON NITRIFICATION IN FRESHWATER AQUARIUMS AT THERAPEUTIC LEVELS. (from Collins et al. 1975; 1976 and Levine and Meade 1976)

COMPOUND	CONCENTRATION (mg/l)	% INHIBITION	SOURCE
CHLORAMPHENICOL	50	0	B
	50	84	C
OXYTETRACYCLINE	50	0	B
SULFAMERAZINE	50	0	B
SULFANILAMIDE	25	65	C

GLOSSARY

TERM	DEFINITION
abacus	A calculating table provided by manufactures to select equipment
abiotic	Physical factor which affects the development and/or survival of an organism
aeration	In aquaculture systems: the mechanical mixing of air and water; this generally refers to a process by which gases contained in air are transferred across the air-liquid interface (in contrast with the transfer of oxygen alone)
agar	A gelatinous colloidal extractive of a red alga (as of the genera Gelidium, Gracilaria, and Eucheuma) used especially in culture media or as a gelling and stabilizing agent in foods
air blower	A device that pumps large quantities of ambient air at low pressure, through an air distribution network to aerate water by air stones or air diffusers
airstones	Stone-like porous structure used as an air diffuser in water to promote the transfer of oxygen and the removal of carbon dioxide
algal inoculum	Algal cells belonging to a population in exponential growth phase used for incubation to launch new algal culture vessels
allotropic	Relates to the existence of a substance and especially an element in two or more different forms (as of crystals) usually in the same phase
anaerobic	Referring to a condition or process where gaseous oxygen is not present or not necessary
anaesthetics	Loss of sensation with or without loss of consciousness
anamnesis	A preliminary case history of a medical patient (also applied for veterinary sciences)
anoxia	Deficiency or absence of oxygen in the blood and tissues
aseptic	Free or freed from pathogenic microorganisms (an aseptic operating room)
autoclave	An apparatus (as for sterilizing) using superheated steam under high pressure
axenic	Free from other living organisms
bacteriosis	Infection caused by bacteria
bar	In the context of the manual: a unit of pressure equal to a million dynes per square centimeter
beach seine	Net hauled by two or more people near the shore and made of four parts: float line, webbing lead line and poles
beaker	A deep widemouthed thin-walled vessel usually with a lip for pouring that is used especially in science laboratories
benthic organism	Organisms occurring at the bottom of a body of water
biofilter	The component of the treatment units of a culture system in which the removal of organic matter takes place and dissolved metabolic by-products are converted (mainly oxidized) as a result of micro-biological activity. The most important processes are the degradation of organics by heterotrophic bacteria and the oxidation of ammonia via nitrite to nitrate
biological filter	See biofilter
blastodisc	The embryo-forming portion of an egg with discoidal cleavage usually appearing as a small disc on the upper surface of the yolk mass
blastomer	A cell produced during cleavage of a fertilized egg
branchial arch	Related of, relating to, or supplying the gills or associated structures or their embryonic precursors
broodstock	In aquaculture: sexually mature specimens of both sexes kept for the purpose of controlled reproduction (independent of whether a first or subsequent generation is produced) as well as younger specimens destined to be used for the same purpose

Bunsen burner	A gas burner consisting typically of a straight tube with small holes at the bottom where air enters and mixes with the gas to produce an intensely hot blue flame
burette	A graduated glass tube with a small aperture and stopcock for delivering measured quantities of liquid or for measuring the liquid or gas received or discharged
calculi	A concretion usually of mineral salts around organic material found especially in hollow organs or ducts
carboy	A large container for liquids
cavitation	The formation of partial vacuums in a liquid by a swiftly moving solid body (as a propeller) or by high-intensity sound waves
centrifugation	To subject to centrifugal action especially in a centrifuge
chelating agents	To combine with (a metal) so as to form a chelate ring
ciliates	Any of a phylum or subphylum (Ciliophora) of ciliated protozoans (as paramecia)
colorimeter	An instrument or device for determining and specifying colors; specifically: one used for chemical analysis by comparison of a liquid's color with standard colors
ctenoid scales	Having the margin toothed (ctenoid scale); also: having or consisting of ctenoid scales (ctenoid fishes)
cycloid scales	Smooth scales with concentric lines of growth
cyst	A capsule formed about a minute organism going into a resting or spore stage
DO	Dissolved oxygen
dead corners	Referred to area in tanks where there is no circulation of water and debris and waste accumulates
deionized water	To remove ions from (deionize water by ion exchange)
demersal	Living near, deposited on, or sinking to the bottom of the sea (demersal fish eggs)
dimmer	Emitting a limited or insufficient amount of light
diploid	Having the basic chromosome number doubled
dry resting eggs	See cyst
electrolyte	A substance that when dissolved in a suitable solvent or when fused becomes an ionic conductor
Erlenmayer flask	Conical gas flask named after him
essential fatty acids	Fatty acid which cannot be synthesized by an organism and must be supplied in the diet to avoid a dietary deficiency
etiological agent	The primary organism responsible for changes in host animal, leading to disease
eukaryotic	An organism composed of one or more cells containing visibly evident nuclei and organelles
euryhaline	Able to live in waters of a wide range of salinity
eurythermal	Tolerating a wide range of temperature (eurythermal animals)
extensive farming (aquaculture)	Any culture system that does not require supplemental feeding or direct energy input to support growth of the species under consideration
fingerling	Finger size young fish
fish larvae	A fish from the beginning of the exogenous feeding to metamorphosis into juvenile. At a larval stage a fish differs greatly in appearance and behavior from a juvenile or an adult
flask	A vial or a round long necked vessel for laboratory use
flow-through water system	Indicates hydraulic system in the hatchery in which water passes only once from inlet to outlet, without partial or total recirculation
FRP	Fibre Reinforced Polymer
fry	Recently hatched fish which weighs less than 1 g or measures less than 2.5 cm total length

fungi	Any of a group of primitive plants lacking chlorophyll, reproducing through the production of spores, comprising single-celled or multinucleated organisms that live by decomposing and absorbing the organic material in which they grow, including moulds, rusts, mildews, smuts and mushrooms. Some kinds are parasitic on fishes
gametogenesis	The process by which gametes are produced
gastrula	The embryonic stage of development consisting of two layers of cells enclosing a sac-like central cavity with a pore at one end
gill raker	Bony, finger-like projections variously arranged along the anterior and often the posterior edges of the gill arches. They vary in number and shape, and are useful taxonomic characteristics
gonochoric	Refers to species with separate male and female sexes
grading	A means of separating larger fish from smaller ones
Gram stain	A method for the differential staining of bacteria by treatment with a watery solution of iodine and the iodide of potassium after staining with a triphenylmethane dye (as crystal violet) -- called also Gram's method
green water	In hatcheries it refers to water with a high content of microscopic algae employed in larval rearing tanks
hatchery	Place for artificial breeding, hatching and rearing through the early life stages of animals, finfish and shellfish in particular. Generally, in pisciculture, hatchery and nursery are closely associated. On the contrary, in conchyliculture, specific nurseries are common, where larvae produced in hatcheries are grown until ready for stocking in fattening areas
head loss	The loss of pressure in a flow system measured using a length parameter (i.e. inches of water, inches of mercury)
hermaphrodite	Having both male and female sexual characteristics and or/ organs
hosha (= howash)	Low-lying areas from 2 to 6 ha in size enclosed by small dykes, in the Nile delta, in coastal regions and in coastal lakes of Egypt; following the increase of the drainage discharge from the Nile irrigation systems, the water table rises, fills the howash and natural stocking takes place; artificial stocking and supplementary feeding are optional; harvesting by complete drainage takes place in winter when water discharge rates are reduced
HUFA	Highly Unsaturated Fatty Acids
hydraulic slope	Difference in hydraulic head over some flow path length
induced spawning	Egg-laying brought about by manipulation of the environment or treatment of the animal, for example, temperature and fertility cycle, osmotic shock, UV irradiation of water, hormone injections
intensive rearing	Production systems which are dependent on nutritionally complete diets added to the system, either in the form of fresh or frozen fish (freshwater or marine) or formulated diets, usually in dry pellet form
kyphosis	abnormal backward curvature of the spine
latency period	The time that elapses between a stimulus and the response to it
lateral line	Sense organs of fish and amphibians; believed to detect pressure changes in the water
live feeds	The term live feed can be used to describe either naturally occurring animals (although this is usually referred to within the broad band of productivity) or animals which are produced (usually under artificial, controlled conditions) for feeding larval stages of farmed fish, crustaceans and bivalves. The types of live feed used include rotifers, *Artemia*, algae and copepods
log-phase	Referred to bacterial or algal growth introduced in fresh media. It is the population growth phase in which binary division occurs. This phase of growth is called logarithmic or exponential because the rate of increase in cell number is a multiplicative function of cell number. This can be seen in a graph of cell number versus time where cell numbers increase at ever increasing rates with time or generation; that is, the rate of increase is a function of absolute cell number such that the more cells present, the faster the population of cells increases in size (at least, during log phase)
longlines	Rope suspended by buoys from which are attached ropes which hang down (drop line) to hold cages, clusters, baskets or lantern nets of shellfish. May be held at the water surface or at a deeper depth (subsurface or bottom longline)

lordosis	abnormal curvature of the spine forward
lorica	In the Rotifers a hard protective case or shell
Lugol solution	Solution based on potassium iodide and iodine. See Annex 7 (Vol 1) for preparation
lux	Unit of illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter
mastax	The pharynx of a rotifer. It usually contains four horny pieces. The two central ones form the incus,against which the mallei, or lateral ones work so as to crush the food
meiotic divisions	Reductive division (two successive divisions) of a nucleus following one single replication of the chromosomes, so that the resulting four nuclei are haploid. In animals, it occurs during gamete formation
melanophores	Chromatophores (large pigment cells of fish, amphibia, reptiles and many invertebrates) which contain melanin. Short term color changes are brought about by an active redistribution of the melanophores pigment containing organelles (melanosomes)
metanauplii	Late nauplius stage of crustaceans, with more than three pairs of limbs present but no functional thoracic limbs
metazoan	Any of a group (Metazoa) that comprises all animals having the body composed of cells differentiated into tissues and organs and usually a digestive cavity lined with specialized cells
microalgae	Microscopic photosynthetic (chlorophyll-containing) organisms that are usually single cells, these aquatic forms are often referred to as phytoplankton, but they can also be benthic microalgae present in the bottom sediment
molting	Periodic shedding of the cuticle in arthropods
morphometric	measurement of external form
morula	A globular solid mass of blastomeres formed by cleavage of a zygote that typically precedes the blastula
nauplius	Earliest larval stage of a crustacean; it exhibits the simplest type of head region with three pairs of appendages, uniramous first antennae, biramous second antennae and mandibles. Although the nauplius larva is typical, it does not appear in all crustaceans. It is common in lower forms, but in many of the higher forms it occurs during development in the egg, and the young are hatched as differentiated and more advanced larvae
nematodes	Elongated, cylindrical, unsegmented worm; includes a number of plant and human parasites
nutritional boosters	Feed additives intended to provide additional energy to feed or to optimize the balance of ingredients to adjust the feed to the nutritional requirements of the species farmed.
oocyte	Cell which develops into an ovum
oogenesis	Cellular development that leads to the formation of an ovum
oogonia	A descendant of a primordial germ cell that gives rise to oocytes
operculum	the covering of the gills of a fish
osmotic regulation	movement of a solvent through a semi permeable membrane (as of a living cell) into a solution of higher solute concentration that tends to equalize the concentrations of solute on the two sides of the membrane
osteogenesis	development and formation of bone
ovarian atresia	Absence or disappearance of an anatomical part (as an ovarian follicle) by degeneration
oviparous	Producing eggs that are fertilized, develop, and hatch outside the female body
ovoviparous	Producing eggs, usually with much yolk, that are fertilized internally. Little or no nourishment is furnished by the mother during development; hatching may occur before or after expulsion
palatine bones	Bones forming the roof of the mouth separating the mouth from the nasal cavity
parapophisis	The ventral transverse, or capitular, process of a vertebra
Pasteur pipette	A small piece of apparatus which typically consists of a narrow tube into which fluid is drawn by suction (as for dispensing or measurement) and retained by closing the upper end

pasteurellosis	Infection caused by the bacteria genus *Pasteurella*
pelletized dry feed	Compounded feed formed by pressing and forcing feed ingredients through die openings by a mechanical process
peptidase	An enzyme that hydrolyzes simple peptides or their derivatives
Petri dish	A small shallow dish of thin glass or plastic with a loose cover used especially for cultures in bacteriology
pH	A term used to describe the hydrogen ion activity of a solution. The pH of pure water is 7 and is referred to as neutral. A solution of pH less than 7 is said to be acid whereas a solution of pH above 7 is said to be alkaline
photoperiod control	Technique used to anticipate or retard breeding based on the control of the duration of time in a given day during which the culture organisms are exposed to light and dark. The light source can be natural or artificial
photosyntesis	Synthesis by plant cells of organic compounds (mainly carbohydrates), in the presence of light, from carbon dioxide and water, with simultaneous production of oxygen. Conversion of light energy into chemical energy
physoclist	Type of fish species having the gas bladder closed, with no connection to the gut
phytoplankton	Minute plants suspended in water with little or no capability of controlling their position in the water mass; frequently referred to as microalgae (the plant component of plankton
pipette	Measuring instrument consisting of a graduated glass tube used to measure or transfer precise volumes of a liquid by drawing the liquid up into the tube
ppm	Parts per million
ppt	Parts per thousand
preoperculum	A boomerang-shaped bone whose edges form the posterior and lower margins of the cheek region; the most anterior of the bones comprising the gill cover
PUFA	Poly Unsaturated Fatty Acids
purse seine	A large seine designed to be set by two boats around a school of fish and so arranged that after the ends have been brought together the bottom can be closed
PVC	Polyvinil Chloride
refractometer	An instrument to measure indices of refraction (directly related to salinity levels)
repletion	The condition of being filled up or overcrowded
roughness coefficient	Designated by "N" in Manning's flow equation, the roughness coefficient is an expression of the resistance to flow of a surface such as the bed or bank of a stream
salinity	In aquaculture: an expression for the concentration of soluble minerals (often restricted to salts of the alkali metals or of magnesium) and chlorides in water; usually expressed as parts per thousand (ppt)
schooling	A group of fish swimming together
scoliosis	a lateral curvature of the spine
screw clamp	A device designed to bind or constrict or to press two or more parts together so as to hold them firmly
skimmers	Floating device where air is blown at low pressure tangentially to the water surface to trap and continuously remove floating debris and oily surface layer from the air/water interface in larval rearing tanks of industrial hatcheries. The fish larvae may thus easily gulp air and inflate their swimbladder
solenoid (valve)	A coil of wire usually in cylindrical form that when carrying a current acts like a magnet so that a movable core is drawn into the coil when a current flows and that is used especially as a switch or control for a mechanical device (as a valve)
stoichiometric	The quantitative relationship between two or more substances especially in processes involving physical or chemical change
swimbladder	Organ (bladder) containing gas, present in the roof of the abdominal cavity in bony fish. It allows the specific gravity of the fish to vary in order to match the depth at which the fish is swimming or resting
tank meniscus	The curved upper surface of a column of liquid

teleost	Any of a major taxon (class Osteichthyes or superclass Teleostomi) comprising fishes (as a sturgeon, salmon, marlin, or ocean sunfish) with a bony rather than a cartilaginous skeleton
thermoperiod	Refers to the daily temperature cycle to which a species is subject
trace minerals	Nutrient elements essential for the life and growth of an organism, but needed in only very small quantities or amounts
trawl net	A large conical net dragged along the sea bottom in gathering fish or other marine life
vallicultura	Italian term referring to fish farming in embanked or fenced lagoons found principally on the northwestern Adriatic coast of Italy, which are subject to a considerable control of water levels, salinity and temperature
vibriosis	Infection caused by *Vibrio* genus bacteria
vitamins	An organic compound occurring in minute amounts in foods and essential for numerous metabolic reactions
vitellogenesis	Yolk formation
vitellus	Total nutritive reserves incorporated into the egg cytoplasm
vomerine teeth	Teeth on a bone of the skull of most vertebrates that is situated below the ethmoid region
zona radiata	A thickened, rather complex egg membrane of teleost fishes, which often has a radiate appearance. It is formed at the surface of the egg by the ooplasm, or the ooplasm and the follicle cells and hence should be regarded as a true vitelline membrane. May be overlain by the chorion
zooplankton	The animal component of plankton

Seabass and gilthead seabream are the two marine fish species that have characterized the development of marine aquaculture in the Mediterranean basin over the last three decades. The substantial increase in production levels of these two species that used to be high-level value ones and now are considerably cheaper was made possible by the progressive improvement of technologies for fry production in hatcheries. As a result, more than 100 hatcheries have been built in the Mediterranean basin, working on these and other similar species. At present the farmed production of these two species derived from hatchery produced fry is far greater than the supply coming from capture fisheries. This second and final volume of the manual deals with the design and construction of the hatchery and its various sections, engineering aspects of water supply, hydraulic circuits, and equipment used in the hatcheries. And it also includes guidance on financial aspects that could be useful for the project design, and operation of hatcheries.