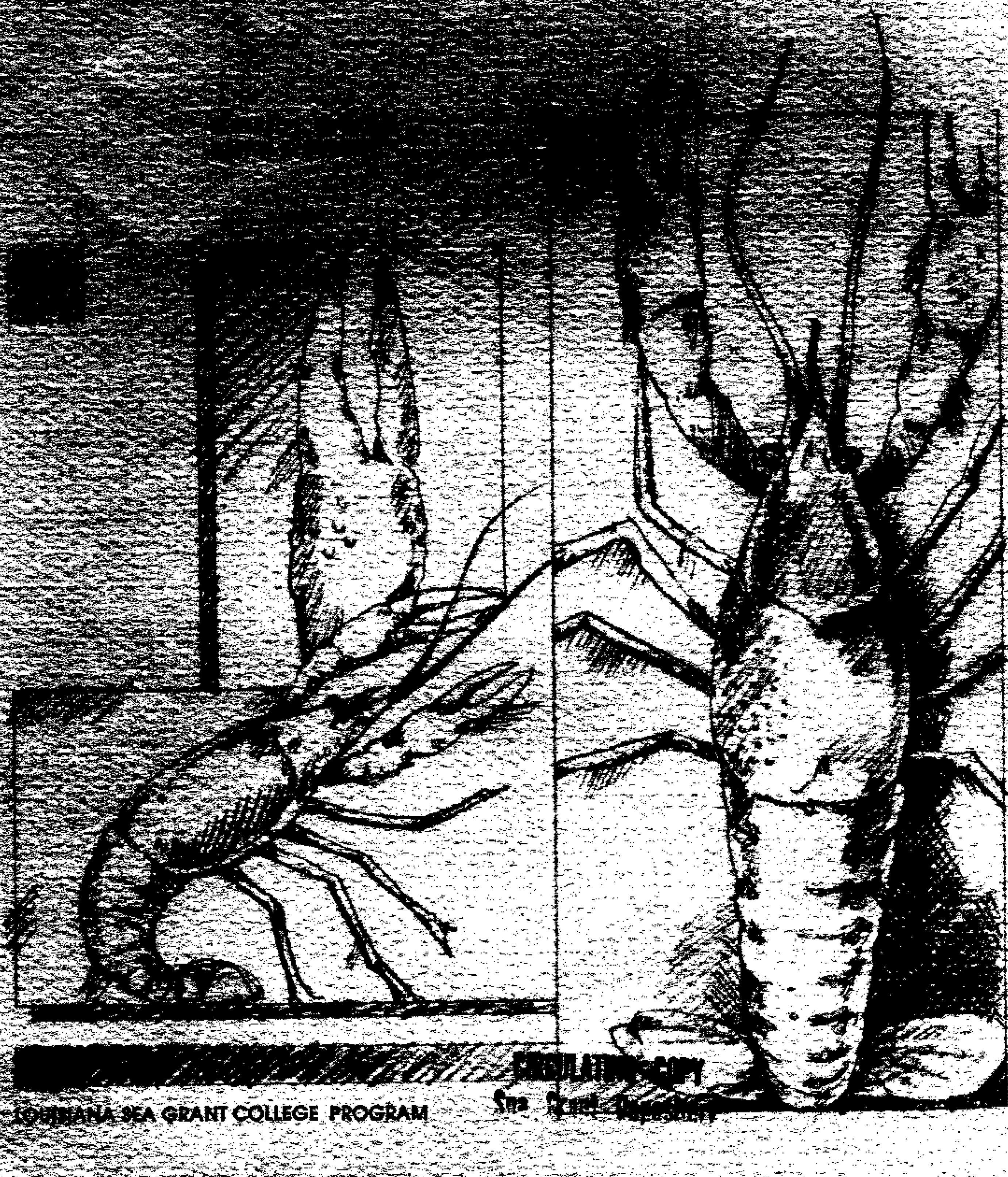
Design of Recirculating SOFT CRAWFISH SHEDDING SYSTEMS



LOUISIANA SEA GRANT COLLEGE PROGRAM

DESIGN OF RECIRCULATING
SOFT CRAWFISH
SHEDDING SYSTEMS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Overview

Crustaceans, like the red swamp crawfish (Procambarus clarkii), undergo a growth process in which they periodically replace their hard exoskeletons. This growth process, known as "ecdysis" or molting (as it is more commonly referred to), occurs quite frequently with young, immature crawfish. During the molting process the crawfish expands and forms a flexible new, inner shell, while dissolving and cracking the old shell from which it works free. After the animal emerges from the old shell, the new, larger shell begins to harden. Molting periods range from a couple of days for very small crawfish to over a month for animals approaching maturity. The new exoskeleton remains soft and pliable for a few hours unless the animal is refrigerated. During that period, the soft crawfish is considered a seafood delicacy although availability has been severely limited in the past by lack of production. However, recent technical developments now permit the production of soft crawfish for commercial markets.

The commercial production of these animals depends on capturing juvenile crawfish, holding these animals until they molt, and finally harvesting them as soft crawfish when they emerge from their hard exoskeletons. This process can be described as a series of separate steps: capture, transport, acclimation, sorting, shedding, processing, and sale. Each step is briefly described in Table 1.1. This manual focuses on the shedding aspect of commercial production with specific emphasis on designing recirculating shedding systems which are used to hold premolt crawfish while waiting for them to molt.

1.2 Evolution of Criteria

Chidester (1912) thought he could predict the approximate molting time of crawfish based on his observation that the premolt crawfish partially exposed its carapace, thus allowing its exoskeleton to dry out (an observation that has not been supported by later work). Brown and Cunningham (1939) went further to note that the approximate molting period became visibly apparent by a separation between the carapace and the abdomen. Penn (1943) noted that molting signs were reasonably predictable within one to three days as indicated by the appearance of a white "waist" between the cephalothorax (the head and carapace) and the abdomen. Since these initial observations, a number of authors have reported additional findings on the molting patterns of crawfish (Scudamore, 1948; Stephens, 1955; Bittner and Kopanda, 1973; Huner, 1980). More recent information explaining the identification of premolt crawfish and the molting cycle are found in reports by Huner and Barr (1984) and Culley et al. (1985a).

Many authors have also centered their attention on identifying factors which directly influence the crawfish molting pattern. Penn (1943) noted an acceleration in molting rate during the months of February, March, and April when moderate, yet increasingly warmer, temperatures occurred and when food supplies were readily available. Furthermore, molting rates appeared to correspond to periods before water temperatures reached a maximum. Huner and Avault (1976a) noted that crawfish in ponds tend to delay or completely cease molting during the summer months when low water levels and high temperatures force the animals to burrow regardless of maturity. Furthermore, the authors noted that adverse pond conditions can also delay molting no matter what the time of year. Huner (1980) later noted that young crawfish that were kept indoors in relatively warm

Table 1.1 Critical steps in the commercial production of soft crawfish.

Step	Function
Capture	Capture of undamaged crawfish from ponds/traps
Transport	Minimizing stress and damage of immature crawfish while transporting to shedding system
Acclimation	Adaptation period necessary for wild or pond-raised crawfish when brought to a commercial facility
Sorting	Identification and separation of immature crawfish
Shedding	Maintaining crawfish in an environment suitable for molting
Processing	Separating, wrapping, and freezing of soft crawfish
Sales	Development of product market

water (70°-75° F) generally molted within 10 days whereas crawfish reaching maturity took much longer.

Since small soft crawfish (one to three inches) are extremely attractive to predators, particularly bass and catfish, the species rapidly became widely used as bait by a large number of fishermen (Huner and Avault, 1976b). Prior to 1980, handpicking was the only method available for obtaining soft crawfish. Because of the intensive labor requirements, steps were initiated so that individuals could produce their own soft crawfish. These steps included (1) obtaining premolts, (2) holding the premolts in trays through which aerated water flowed with an exchange rate of twice a day, and (3) removing the animals immediately after molting (Huner, 1980). These early flow-through systems maintained a crawfish density of 10 crawfish/ft^2 (approximately 0.25 lbs/ft^2) with a tray water depth of three inches or less. Water temperatures were kept constant between 70° and 75° F. Crawfish harvested from colder waters (more than a 5° F temperature difference) required an acclimatization period that allowed the crawfish to warm up to the desired temperature. Daily feeding was based on 3 to 5 percent of crawfish body weight. After each feeding, the holding system was flushed to maintain suitable water quality. Huner (1980) also reported methods for holding and preserving the soft crawfish after removing them from the molting trays.

In the early 1980s the soft crawfish began to acheive recognition as a seafood product in Louisiana. Consequently, a much larger scale shedding system was successfully developed at Louisiana State University in 1982 (Culley et al. 1985b). This system was based on feeding intermolts until ready to molt rather than using only premolt crawfish as Huner (1980) did with his initial experiments. Following additional testing and refinement, the first commercial systems were developed. These first shedding operations employed flow-through systems for holding and separating soft crawfish. As consumer demand for the seafood product increased, additional commercial flow-through facilities were built.

Several methods for direct harvesting of soft crawfish have been developed. Pond harvesting was conducted using a boat-mounted electric trawl (Cain and Avault, 1983). The trawling method did not discriminate between soft- and hard-shelled crawfish, therefore requiring additional labor for separation. The method has been reported to cause damage to the soft crawfish that makes the product less desirable in appearance (Culley et al. 1985a). Another method developed for raising soft crawfish uses a patented tank apparatus which allows feeding, separating, and harvesting crawfish from one molt cycle to the next (Bodker, 1984). However, only limited use of this apparatus has been observed in the commercial sector.

Wholesale market prices for soft crawfish reached $11 per pound in 1986, with a predominant price of $8 per pound. Total production for this growing industry rose from an estimated 6,500 pounds in the 1985-1986 season to over 15,000 pounds during the 1986-1987 season. Current projections indicate that between 50,000 and 75,000 pounds will be produced during the 1987-1988 season. Production levels exceeding one million pounds annually are expected within a few years.

Operators using flow-through systems have indicated recurring problems with maintaining adequate water quality as well as increasing energy costs required for heating water. Flow-through systems require fresh water, usually drawn from wells or municipal water systems, at a continuous flushing rate ranging from 0.025-0.1 gpm/lb of crawfish. According to projections that the industry could produce one million pounds per year, there would be a demand for 9-35 billion gallons of fresh water during a normal eight-month season if flow-through technology were to become the norm.

Recirculating systems provide an alternative to the current flow-through technology, which conserves neither water nor heat. These systems, characterized by their reuse of water, contain filtration components which process animal wastes, in the form of ammonia and nitrite, to a relatively harmless state. In 1985, a research effort was initiated to develop efficient filtration systems for recirculating shedding systems. The research team selected two filter types for testing: fluidized bed and upflow sand filters. The fluidized bed filter proved superior in its ability to remove toxic ammonia and nitrite while the the upflow sand filter displayed excellent ability to capture solid wastes in the system (Malone and Burden, 1987). Laboratory findings and initial commercial applications indicate that recirculating systems using this filtration technology provide excellent water quality and are relatively inexpensive to operate. Furthermore, the recirculating systems offer substantial savings in water and heating costs when compared with the flow-through technology.

1.3 Objectives

This manual presents interim design recommendations for recirculating shedding systems to use for the commercial production of soft crawfish. These recommendations are based on the research team's experience with prototype systems using fluidized bed and upflow sand filters during the past three years. The authors believe that the system configurations and recommendations presented in this manual will assist commercial operators in adopting this new filter technology. These recommendations, however, are termed "interim recommendations" since they are subject to revision as the research team receives a more complete evaluation from the few commercial operators currently testing this new technology.

CHAPTER 2

RECIRCULATING SYSTEMS

2.1 Historic Development

Shedding facilities operated under management strategies developed by Culley et al. (1985a) were originally based upon flow-through systems (Figure 2.1). In a flow-through system, clean water is continually flushed through the trays to limit the build-up of excretion products that may be harmful to the crawfish. The water, used only once, remains in the system for only five to ten minutes. Crawfish continuously excrete ammonia while in the culture and molting trays (Hartenstein, 1970). Until recently, mortalities resulting from ammonia toxicity and low dissolved oxygen levels hindered the growth of the soft crawfish industry. The mortality problems stemmed, in part, from operators flushing too little fresh water through the system, thus allowing lethal ammonia concentrations to build up and dissolved oxygen levels to fall. These problems can be alleviated by increasing the flowrates through the system; however, costs associated with water supplies, pumping, and heating can severely affect profitability. Consequently, many operators have chosen to adopt the recirculating technology.

A recirculating system consists of six distinct functional elements: culture and molting trays, a biological filter, screen boxes, a reservoir, a sump, and a pump (Figure 2.2). In an open recirculating system, the water is recirculated, filtered, and reused for about a month. The culture trays are used to hold immature crawfish until the crawfish approach molting while molting trays are used to hold the premolts through the shedding process. The filters, screens, and reservoirs maintain suitable water quality in the system while the sump and pump provide circulation and reaeration of the system's water (Table 2.1). The rate of water consumption and the heating requirements are dramatically reduced when compared with a conventional flow-through system.

Table 2.2 compares the two types of water-flow systems. The flow-through system is easy to understand and operate. Capital costs are relatively low if a water source is readily available. The overwhelming reason for using the recirculating technology results from the excessively high cost of heating water in the cooler winter and spring months for flow-through options. The cost of heating water in a flow-through system is 15 to 30 times that of a well-designed recirculating system. Annual heating costs for a 1,000-pound flow-through system using well water at 70° F can range from $20,000 to $30,000 per year, compared with $1,000 to $2,000 for an insulated recirculating system. Furthermore, many operators have found their water source is neither ideal in quality nor unlimited. Many groundwater wells have high iron or ammonia concentrations that make them unsuitable for crawfish systems. A number of the pond-based systems have also failed to provide suitable water quality during the changing seasons of the year, particularly during the warm summer months when algal populations become increasingly abundant. River waters are subject to man-made pollution and the influence of storms which can impose high sediment loads on a flow-through system. A limited water supply also makes the flow-through technology unfeasble since a system requires from 2,000 to 4,000 gallons of heated water to produce each pound of crawfish.

The recirculating system offers an alternative which depends very little on conditions outside the facility and reduces the water demand to about 10 gallons per pound of product. The recirculating system is completely controlled by the operator. The operator can readily test innovative approaches to enhance molting such as controlling calcium levels (which influence the rate of shell hardening) or manipulating temperature. Furthermore, the

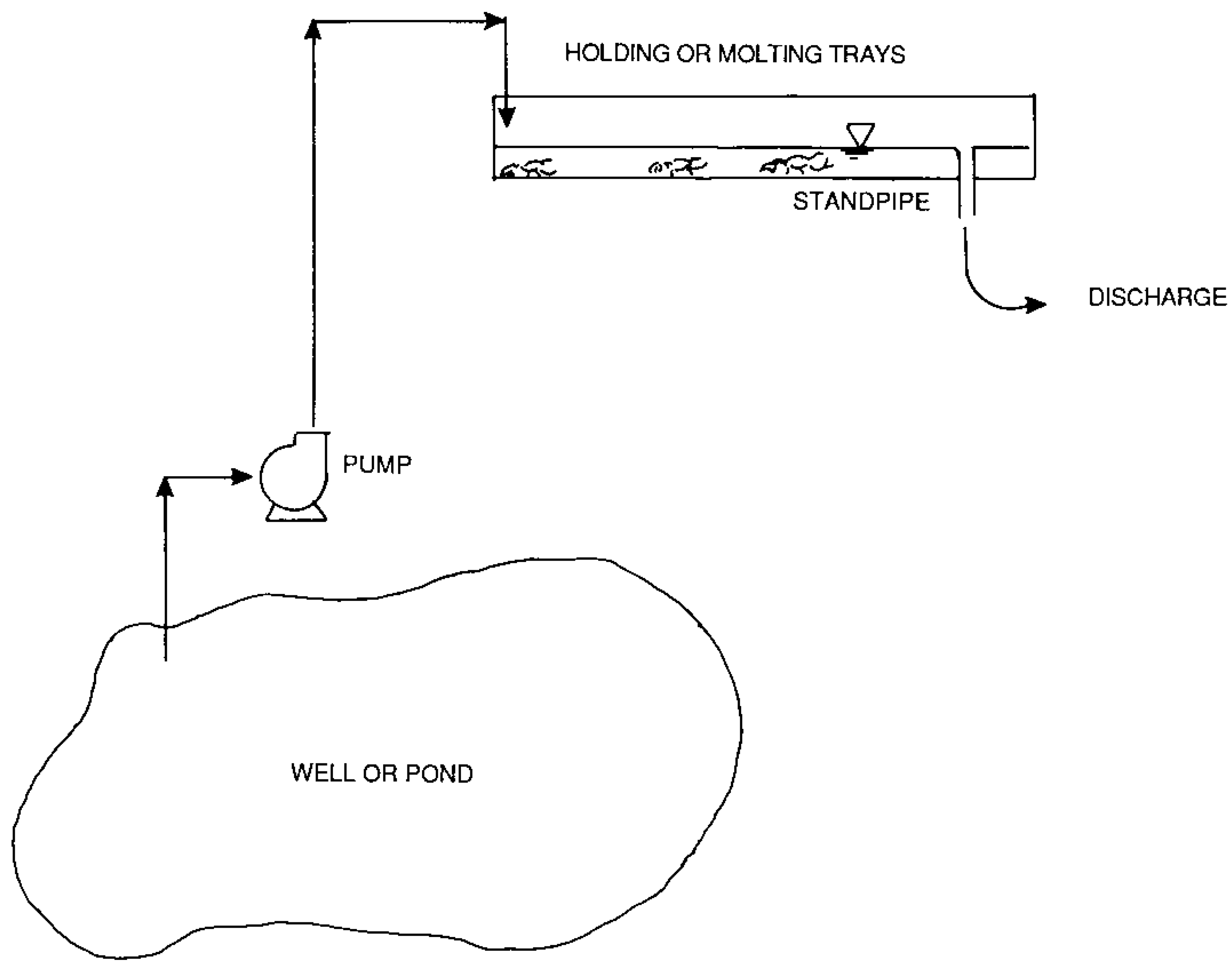

Figure 2.1 In a flow-through system the water is flushed through the trays once and discharged. The water is in the system for only five to ten minutes.

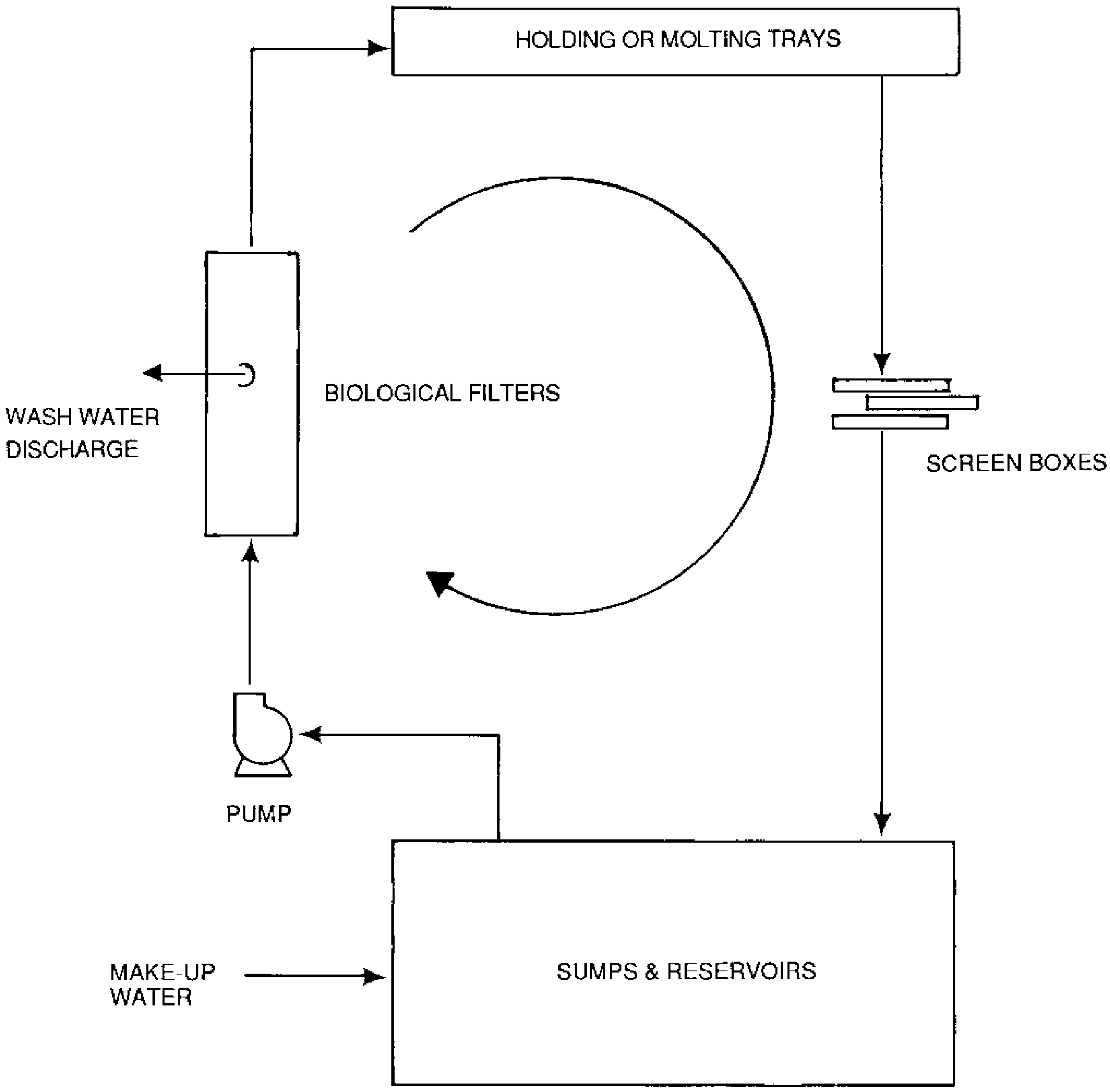

Figure 2.2 In an open recirculating system the water is filtered and reused for 20 to 30 days.

Table 2.1 Major components of a recirculating shedding systems.

Function	Design Factors
Culture and Molting Tanks Provide easily reached space for holding, separating, and molting of crawfish	Tank surface area, aeration rates, water circulation, lighting, access
Biological Filters Capture solids, degrade dissolved wastes, remove ammonia and nitrite	Volume, media composition, media surface area, aeration, water flowrate
Screens Capture debris, prevent clogging of spray heads	Mesh size, box size, placement
Reservoirs Provide dilution volume to stabilize the system	Volume, circulation rate
Sumps Provide water for pump intake and control system water levels	Volume, turbulence, circulation rate
Pumps Provide circulation and aeration of system water	Pump type, flowrate, pressure

Table 2.2 Advantages and disadvantages of flow-through and recirculating shedding systems.

Description	Advantages	Disadvantages
Flow-Through System		
Tap, pond, or well water is continually flushed through the shedding system	Low capital cost Simple operation	Large quantities of water required Sensitive to water quality changes Discharge permit may be required High heating costs High-quality source water required
Recirculating System		
Water is filtered and reused for about a month	Under complete control of operator Water quality reliable Low heating costs Low water use Little or no discharge	Moderate capital costs Water management expertise required

recirculating system does not contribute to environmental pollution since the wastes produced by the crawfish are degraded within the system or captured as solids. Because of this feature and the small quantities of discharge water involved, recirculating systems are not normally subject to environmental regulations governing discharge permits. These advantages tend to outweigh the principal disadvantages of recirculating systems which include the need for managing crawfish densities and training management personnel in the area of water quality. However, the recirculating system can have higher initial capital cost and imposes an additional management burden on the operator.

2.2 Carrying Capacity

The concept of a "carrying capacity" is fundamental when designing and operating a recirculating shedding system. Simply stated, the carrying capacity is the maximum poundage of crawfish that the system can safely support for an extended period of time. The poundage of crawfish in the system must match the capacity of the system's filtration components to process wastes produced by the animals. So long as the poundage of crawfish in the system is less than the design carrying capacity, mortality problems caused by over-crowding or water quality deterioration should not exist. By exceeding the carrying capacity, detrimental water quality conditions result and consequently molting success rapidly decreases.

The design criteria presented here are based upon the concept of carrying capacity expressed as the number of pounds of fed red swamp crawfish (Procambarus clarkii) a system can safely support. The criteria are not sensitive to the size of the crawfish or the type of food. However, all recirculating systems are sensitive to overfeeding. All uneaten food rapidly breaks down to wastes that must be reduced by the filtration systems. The design criteria presented in this manual include safety factors that compensate for some mismanagement; however, overfeeding is the most common problem with novice operators of recirculating systems.

The design criteria presented must be used in their entirety. Each component in a recirculating system has a specific function. For example, pumping rates to the trays are designed to flush ammonia from a specified poundage of crawfish. All components are sized to support animals of approximately the same weight. This approach assures that the system's carrying capacity can be met without inducing a failure in a specific component. All the critical components must be included and properly sized for the same number of animals or the system will fail.

CHAPTER 3

CRITICAL WATER QUALITY PARAMETERS

The following sections discuss the major water quality parameters affecting crawfish and the recirculating system. Many of the parameters are interrelated and, therefore, complex in their interactions. The reader is directed to the references section for more in-depth information on the chemistry of recirculated water. Methods used for monitoring these parameters are presented are Chapter 6. The following sections briefly review the most important water quality parameters.

3.1 Dissolved Oxygen

Dissolved oxygen (D.O.) is defined as the amount of oxygen in the water. Dissolved oxygen concentrations are very important since crawfish and the beneficial bacteria living in the biological filter need it to live. Oxygen (O_2) concentrations are measured in units of oxygen by weight (milligrams) per volume of water (in liters). Thus, water with 5 mg-O_2/l contains 5 milligrams of dissolved O_2 gas in every liter of water. Oxygen levels may also be expressed in "parts per million," or ppm. One ppm is equivalent to 1mg/l.

The maximum amount of O_2 that water can hold is called the "saturation level". The saturation level changes with temperature (Table 3.1). In general, as the water temperature increases, the saturation level decreases. Water that contains O_2 at its saturation level contains sufficient amounts of oxygen to support aquatic life. But this available oxygen can be rapidly consumed when crawfish are placed at high densities in a shedding system. In addition to crawfish consumption, O_2 is also consumed in large quantities by the bacteria in the biological filters. Low dissolved oxygen levels weaken the crawfish and can prevent bacteria from converting wastes. Table 3.2 presents the effects of oxygen levels on the operation of a crawfish shedding system.

A number of individuals have done research on crawfish mortality and its relationship to low dissolved oxygen concentrations. Melancon and Avault (1976) indicated significant mortalities in young (9-12 mm long) and juvenile (31-35 mm long) crawfish when exposed to dissolved oxygen concentrations from 0.75 to 1.1 mg/l and less than 0.49 mg/l, respectively. The authors also noted that crawfish in molt were more susceptible to low dissolved oxygen. This period of increased sensitivity results when crawfish are unable to breathe for a brief period during the molting process. Crawfish must, therefore, be exposed to reasonably high oxygen levels prior to molting if they are to survive the stress of shedding their shells. Molting crawfish in holding trays without sufficient oxygen are often observed lying on their carapace exposing the gills to the atmosphere. Molting crawfish exposed to low oxygen levels often die when backing out of their hard exoskeletons. Romaire (1983) states that dissolved oxygen concentrations should remain above 2.0 mg/l for optimum crawfish production in ponds. Culley et al. (1985b) recommended a minimum dissolved oxygen of 3.0 mg/l. Based on experience, the authors feel that 5.0 mg/l should be maintained to avoid stress in the holding trays although the crawfish can tolerate lower concentrations. This minimum level of O_2 remains within the range of saturation levels corresponding to normal shedding temperatures.

Since the biological filters are submerged, the oxygen source for the bacteria is the water flowing through the filters. If this oxygen supply is exhausted before the bacteria consume

Table 3.1 Oxygen holding capacity at various water temperatures (in mg-O_2/l).

Temperature (°C)	Temperature (°F)	Dissolved Oxygen (mg-O_2/l)
16	60.8	9.86
18	64.4	9.45
20	68.0	9.08
22	71.6	8.73
24	75.2	8.40
26	78.8	8.09
28	82.4	7.81
30	86.0	7.54
32	89.6	7.29

Table 3.2 The effect of oxygen on a crawfish shedding system.

Oxygen Concentration[1] (mg-O_2/l)	Impact
> 5.0	Oxygen levels safely support all system operations
4.0-5.0	Molting crawfish not affected Premolt crawfish not affected Bacteria in filters not affected
3.0-4.0	Molting success may be adversely affected Premolt crawfish not visibly affected Bacterial performance below optimum
2.0-3.0	Premolt crawfish may show signs of stress and seek water surface to expose gills to air Molting mortalities will increase with loss of weakened animals Bacterial rates of waste conversion decline
1.0-2.0	Molting rates decline Mortality generally increase Bacteria shut down, nitrites rapidly accumulate

[1]oxygen measured in holding tray for crawfish, coming out of the biological filter for bacteria

all the crawfish-excreted wastes, the water purification processes cease and wastes accumulate in the system. Water flowing from the biological filters must always have at least 2.0 mg-O_2/l to avoid inhibition of the nitrifying bacteria which consume the crawfish-excreted wastes. Although oxygen deficiency in the filters does not directly affect the crawfish in the trays, dissolved oxygen eventually becomes critical when wastes accumulating in the system reach toxic levels.

3.2 Nitrogen

Nitrogen dissolved in a recirculating system is found in five major forms: nitrogen gas, organic nitrogen, ammonia, nitrite, and nitrate (Table 3.3). Dissolved nitrogen gas (N_2), continually diffuses in and out of a recirculating system. Nitrogen gas behaves like oxygen except that there is no demand for nitrogen in a typical recirculating system; thus, the system's water is almost always at saturation. Nitrogen gas is almost totally inert and is of no consequence to a normal shedding operation. The forms of principal concern are organic nitrogen, ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). The term "organic nitrogen" refers to the amount of nitrogen in organic matter found dissolved or suspended in the system. All plants and animals contain organic nitrogen, so solid wastes in recirculating systems contain large amounts of organic nitrogen. Ammonia, nitrite, and nitrate are chemicals produced by organisms and bacteria as they process organic nitrogen taken in as food. Ammonia and nitrite are considered highly toxic forms of nitrogen, while nitrate is considered relatively safe. Concentrations of all dissolved nitrogen forms are expressed in terms of nitrogen weight (in milligrams) found in the compound per unit volume (liters). Thus, 3.0 mg NO_3^--N/l, indicates that the nitrate level is equivalent to 3.0 milligrams of nitrogen per liter.

Crawfish continuously excrete dissolved ammonia directly into a system's recirculating waters. Additional ammonia loading (in the form of organic nitrogen) results from the food decay when premolt crawfish are fed in a shedding system. Figure 3.1 illustrates how the bacteria in a biological filter use nitrogen wastes as a food source and in the process convert the nitrogen from one form to another. Organic wastes containing nitrogen are decomposed by a wide variety of bacteria which produce ammonia as a byproduct (Spotte, 1979; Wheaton, 1977). The ammonia produced by the decomposing processes, plus that directly excreted by the crawfish, is utilized by a highly specialized bacteria of the Nitrosomonas genus as an energy source. The Nitrosomonas bacteria convert ammonia to nitrite which, in turn is converted to nitrate by a second group of specialized bacteria of the Nitrobacter genus.

The two groups of specialized bacteria responsible for the conversion of ammonia and nitrite are collectively called "nitrifying bacteria" and this conversion process is referred to as "nitrification". The nitrification process is important because a successful shedding operation depends on avoiding the accumulation of the toxic nitrogen forms, ammonia and nitrite. In an improperly designed or mismanaged system, the rate at which ammonia or nitrite is produced can exceed the rate of conversion by the nitrifying bacteria causing accumulation of these toxins in the system. Under most conditions, high concentrations of ammonia or nitrite result in crawfish mortalities.

Table 3.3 The major forms of nitrogen in a recirculating system.

Form	Abbreviation	Importance
Nitrogen Gas	N_2	Inert gas; no significance
Organic Nitrogen	Org-N	Decays to release ammonia
Un-ionized Ammonia	NH_3	Highly toxic form; predominates at high pH values
Ammonium ion	NH_4^+	Moderately toxic form; predominates at low pH values
Total Ammonia	$NH_3 + NH_4^+$	Sum of un-ionized ammonia and ammonium ions found in water; converted to nitrite; typically measured in the ammonia test
Nitrite	NO_2^-	Highly toxic nitrogen form; decays to nitrate
Nitrate	NO_3^-	Stable, nontoxic form of nitrogen

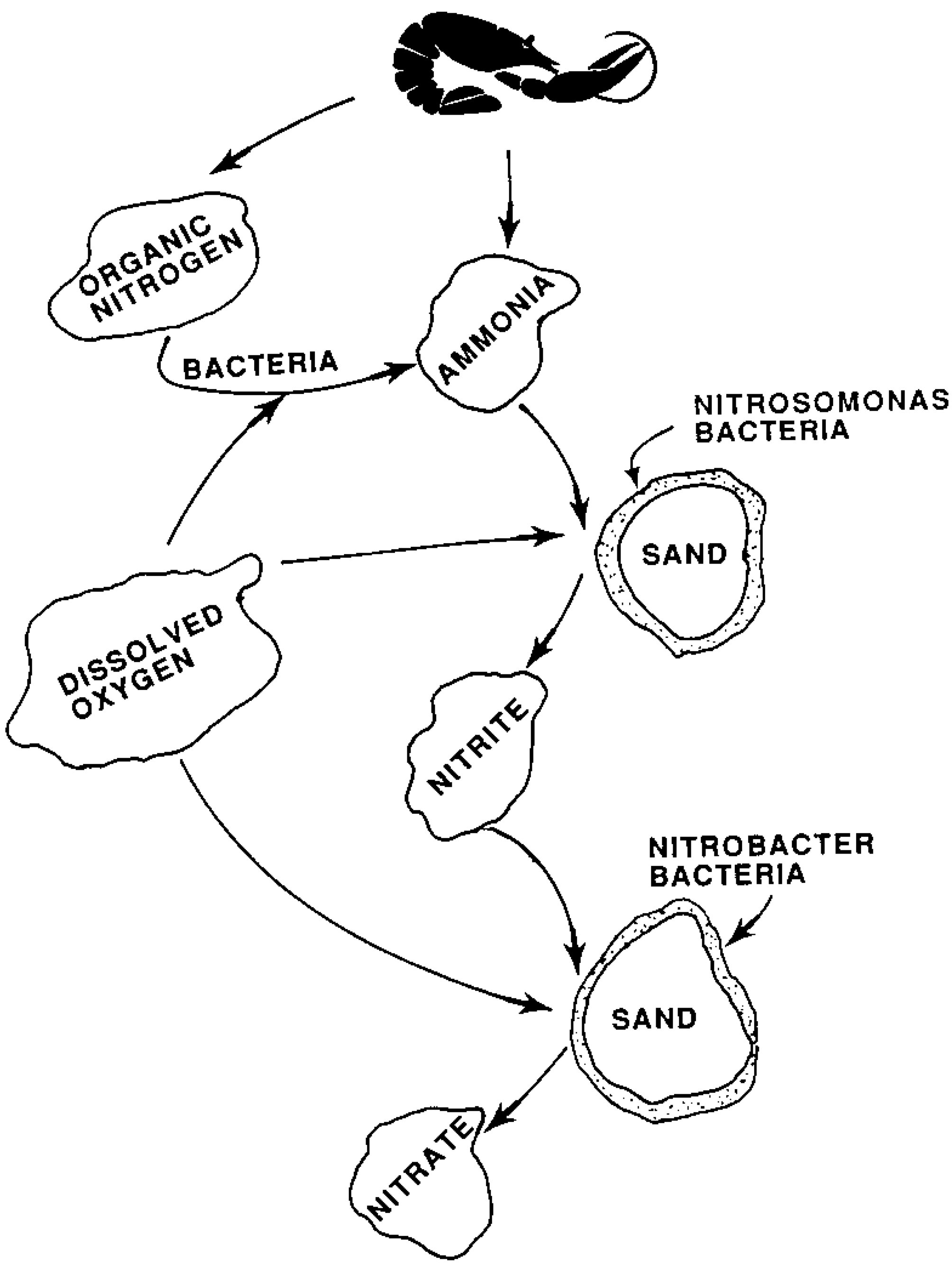

Figure 3.1 Nitrogen is processed through a series of forms by different groups of bacteria.

3.3 Ammonia Toxicity

Ammonia actually exists in water as the molecular form of un-ionized ammonia (NH_3) or as the ammonium ion (NH_4^+). The only difference between these two forms is a single hydrogen ion (H^+). Yet, NH_3 is highly toxic to aquatic organisms, including crawfish, and NH_4^+ is only moderately toxic. Reported values of total ammonia include both NH_3 and NH_4^+.

Very little information is available on the toxic effects of ammonia on crawfish. Hymel (1985) reported a mean total ammonia toxicity level of 2.64 mg-N/l (pH=8.6) for juvenile intermolt red swamp crawfish although animals of edible size were not considered. No mortalities were observed when juvenile, intermolt crawfish were exposed to ammonia levels as high as 1 mg/L for 96 hours. Johnson (1982) demonstrated that adult white river crawfish (Procambarus acutus acutus) survived ammonia concentrations as high as 4.9 mg/l NH_3-N but newly hatched crawfish suffered complete mortalities at levels as low as 2.0 mg/L NH_3-N. Hymel (1985) also demonstrated that crawfish ponds with total ammonia concentrations (pH=7.5) ranging from 0.05 mg/l (from November through January) to a high of 0.34 mg/l (in late May) had no significant effect on intermolt populations. However, the authors of this manual have observed that molting crawfish appear sensitive to ammonia levels as low as 1.0 mg NH_3+NH_4-N/l at a pH of 8.0. For a safe shedding operation, the authors currently recommend maintaining ammonia levels under 0.5 mg NH_3+NH_4-N/l.

The ammonia form depends entirely on the concentrations of hydrogen ions in the water (pH). Waters with low pH have high concentrations of hydrogen ions and, thus, NH_4^+ dominates. Conversely, at higher pH values (pH>8), very few hydrogen ions are found in solution; therefore, NH_3, the most toxic form of ammonia, dominates. Thus, systems with high pH values are more prone to ammonia toxicity. Shedding operations tend to have pH values in the range of 7.0 to 8.0, which appear to protect the intermolt crawfish from short-term exposures of total ammonia as high as 5 mg NH_3+NH_4-N/l.

3.4 Nitrite Toxicity

Although very little information is available on the nitrite toxicity limits of crawfish, high nitrite concentrations decrease the crawfish's ability to transport oxygen in the bloodstream. Crawfish, like other arthropods suffering from nitrite toxicity, essentially suffocate. Furthermore, molting crawfish are particularly sensitive to nitrite since they require an increased supply of oxygen to molt. If toxic nitrite concentrations are present during molting, crawfish often die halfway out of their old shells, as they do when the oxygen levels are low. Loss of molting crawfish is one of the first indications of nitrite toxicity.

Hymel (1985) is the only author who has reported lethal toxicity levels on crawfish. Mean toxic nitrite levels on juvenile crawfish were equal to 5.94 mg/l while no mortalities were observed with nitrite concentrations of 1 mg/l over a 96-hour period. However, molting crawfish are undoubtedly more sensitive to nitrite. The authors recommend maintaining nitrite concentrations below 0.5 mg-N/l, as a result of their experience with recirculating systems. Table 3.4 presents toxicity levels derived from the observation of both commercial and experimental systems.

Table 3.4 The impact of nitrite concentrations on the shedding operation.

Concentration Range (mg/l)	Shedding System Impact
0.0-0.5	Safe operational range
0.5-3.0	Marginal operational range; moderate molting mortalities
3.0-10.0	Chronic mortality in molts; moderate premolt losses
> 10.0	Acute mortality; few successful molts; massive losses of premolts

3.5 Nitrate

Nitrate is the stable end product of the decompositional and nitrifying processes in a recirculating system. Virtually all the nitrogen added to the system, except the inert nitrogen gas, ends up as nitrate. As long as the biological filter remains well aerated, nitrate accumulates in the recirculating system without any detrimental effect.

3.6 Water Temperature

The water temperature in unheated recirculating shedding systems is controlled by ambient air temperatures. The shallow holding trays and the rapid water circulation promote the transfer of heat in or out of the system's waters. Thus, the system's water temperature is typically within one or two degrees Fahrenheit (°F) of the air temperature.

Water temperature is an important factor in the recirculating system because it controls the metabolic rate of all organisms in the system and the maximum amount of dissolved gases, such as oxygen, that water can hold (Table 3.1). As temperature increases, the amount of dissolved oxygen in the water decreases while the rate that oxygen is consumed by the crawfish and the bacteria increases. Thus, as temperature goes up, the dissolved oxygen level typically go down.

A large amount of literature exists on the optimum temperatures for raising crawfish in both ponds and shedding systems. Johnson (1982) indicated that the optimum temperature for pond-raised crawfish ranged from 72 to 82° F (22 to 27° C). In his experiments on ammonia and nitrite toxicity levels, Hymel (1985) used temperatures ranging from 75 to 77° F (24 to 25° C). Huner (1980) reports that induced molting occurs with young crawfish maintained in water temperatures ranging from 70 to 75° F (21 to 24° C).

More recent observations on temperature and molting rates have been presented by Culley and Duobinis-Gray (1988a). These authors report that the optimum temperature range for shedding systems should lie between 72 to 82° F (22 to 28° C, respectively), although temperatures as high as 94° F (34° C) have been reported. Within this temperature range, crawfish rapidly molt with a high degree of success because the temperature is near their metabolic optimum while being cool enough to insure adequate oxygen supplies. Below the minimum temperature (72° F), the molting rate slows, production decreases, and the economic profitability of the system declines. Above 82° F, crawfish molt more rapidly but molting success declines as the temperature rises above their metabolic optimum and physiological stress occurs. Additionally, the crawfish's shell hardens faster, requiring that the shedding tanks be checked more frequently.

Although the optimum temperature for each shedding system may differ slightly because of differences in the temperatures of harvesting waters, temperature is a major factor when controlling the success and profitability of a shedding systems. Commercial operators in Louisiana are concerned with raising the system's water temperature in the early spring to accelerate the molting process. Thus, systems maintained near 80° F have high rates of production and potentially increased profitability.

3.7 pH

pH is the measure of the concentration of hydrogen ion (H^+) in water. A pH of 7.0 is considered neutral while water with a pH below 7.0 is considered acidic. Alkaline waters

Table 3.5 The relationship between pH and aquatic systems.

pH Range	Comment
9.0-10.0	Associated with algae blooms in natural waters; un-ionized ammonia ion predominates; ammonia highly toxic; nitrifying bacteria inhibited; calcium bicarbonates and metals precipitate
8.0-9.0	Normal range for ocean waters; ammonia toxicity can be a problem; optimum range for nitrifying bacteria
7.0-8.0	Normal range for marsh and estuary systems; optimum range for recirculating system operation; ammonium ion (NH_4^+) predominates; ammonia toxicity rare; nitrification process mildly inhibited
6.0-7.0	Associated with swamp backwater areas; ammonium ion (NH_4^+) predominates; ammonia toxicity rare; nitrifying bacteria severely inhibited; nitrite toxicity common; calcareous media and metals dissolve

have pH values above 7.0. Table 3.5 identifies the significance of various pH ranges. Backwater swamp areas frequently have pH values less than 7.0 reflecting the decay of organic matter. Ponds with algae blooms often display pH values of over 9.0. Thus, the pH values of harvesting waters can vary significantly from location to location.

Healthy populations of crawfish have been observed in waters with pH as low as 5.8 and as high as 10.0 (Huner and Barr, 1984). Hymel (1985) reported pH levels in ponds ranged between 6.5 to 9.0 over a seven-month season. Hymel (1985) also found the optimum pH ranged between 4.0 and 9.0 and no mortalities were observed over a 96-hour period upon exposure to waters within this pH range.

The pH range, however, in a recirculating system is very important because of the adverse impact low pH values have on the bacteria's consumption rate in the biological filter. Low pH values can also increase the dissolved metal concentrations in a recirculating system. Even moderate levels of dissolved metals in the water can inhibit the critical nitrifying bacteria, inactivating the biological filter.

The water purifying processes and respiration of animals in a recirculating system always tend to cause a decline in pH below 8.0. To prevent adverse impact from low pH values, recirculating systems should be designed and managed to maintain pH values above 7.5 and below 8.0. Above a pH of 8.0, moderate accumulations of ammonia can cause problems with molting crawfish. Below a pH of 7.0, the nitrifying bacteria in the biological filters can be inhibited and metal solubility from pump impellers can pose problems.

3.8 Alkalinity

Alkalinity measures the buffering ability of a water to resist a drop in pH as a result of acid addition (Sawyer and McCarty, 1978). Alkalinity is determined by the amount of acid needed to reduce the pH of a water sample to 4.5. If large amounts of acid must be added, the alkalinity is high. Conversely, if the pH drops rapidly upon the addition of a small amount of acid, then the sample's alkalinity is low. A wide variety of chemicals in a water can contribute to alkalinity, therefore alkalinity is expressed as equivalents of calcium carbonate ($CaCO_3$). Thus, a sample with an alkalinity of 150 mg-$CaCO_3$/l can resist a pH change as well as 150 milligrams of calcium carbonate per liter. However, the sample's alkalinity may result from a wide variety of chemicals.

The principal chemical contributing to the alkalinity of a recirculating system with a maximum pH range of between 6.0 and 8.3 is normally the bicarbonate ion (HCO_3^-). The bicarbonate ion interacts with dissolved carbon dioxide (CO_2) and carbonate ions (CO_3^-) through the carbonate alkalinity system to control the pH of a water (Sawyer and McCarty, 1978). The carbonate ions dominate when the pH is high (>9.5), but in the presence of acid, carbonate ions absorb free hydrogen ions (H^+) to form the bicarbonate ion. The removal of these hydrogen ions controls the pH. Similarly the bicarbonate ion can absorb a hydrogen ion when the pH drops below 8.0, as bicarbonate is converted to dissolved carbon dioxide gas. The pH can be controlled by manipulating the levels of carbonate ions, bicarbonate ions, and carbon dioxide gas in a recirculating system.

A few authors have reported alkalinity levels necessary for maintaining crawfish in a productive environment. In her work at Louisiana State University's Ben Hur farm in Baton Rouge, Louisiana, Jaspers (1969) reported total alkalinity values of approximately

200 mg/l as $CaCO_3$ for crawfish burrows in banks adjacent to ponds. Boyd (1982) indicates that alkalinity levels of at least 20 mg/l as $CaCO_3$ are necessary for good fish production. Paz (1984) more recently observed that waters with alkalinities less than 40 mg/l as $CaCO_3$ severely affect the nitrification process regardless of pH. Based on these observations, the authors recommend maintaining alkalinity above 100 mg/l as $CaCO_3$ to assure adequate nitrification.

The pH can be controlled by adding sodium bicarbonate ($NaHCO_3$) to the system. More commonly known as baking soda, sodium bicarbonate can be used to raise the pH to as high as 8.3. The baking soda readily adds bicarbonate ions to the water, leaving only sodium (Na^+) as a cation residual, thus avoiding potential problems with calcium accumulation. This method of pH control may be required with the new sand filters since they typically contain noncalcareous sands as media.

3.9 Carbon Dioxide

Carbon dioxide (CO_2) occurs naturally in water as a dissolved gas. Carbon dioxide's saturation level under normal atmospheric conditions is only 0.5 mg/l. Carbon dioxide reacts with water molecules to form carbonic acid (H_2CO_3) which affects the pH and alkalinity of the system. As the crawfish and bacteria respire in the system they consume oxygen gas and release carbon dioxide. If the carbon dioxide gas is not removed from the water by air stripping (removing a soluble gas from water by air contact), CO_2 levels in the system increase. Furthermore, CO_2 can become toxic to aquatic species when dissolved oxygen levels fall below 2.0 mg/l (Boyd, 1982). CO_2 concentrations as high as 60 mg/L have been reported to have no impact on fish in cases where dissolved oxygen levels are high. Hymel (1985), however, reports that reliable information regarding toxicity effects of CO_2 on crawfish does not currently exist. Water quality data collected on crawfish burrows (Jasper, 1969) indicated high CO_2 concentrations ranging from 24 to 372 mg/l. Crawfish ponds, however, displayed very small concentrations of CO_2 (< 6.0 mg/l). Carbon dioxide does not appear toxic to the crawfish so long as dissolved oxygen levels are held high.

The accumulation of dissolved carbon dioxide (CO_2) gas tends to lower the pH of a recirculating system, particularly if the alkalinity is low. In many cases, significant increases in pH can be achieved by simply increasing rates of aeration in the system. The depression of pH by CO_2 accumulation most likely occurs when a system is heavily loaded since both the crawfish and nitrifying bacteria release CO_2 when they respire. The pH drop inhibits the nitrifying bacteria, particularly Nitrobacter, and ammonia/nitrite accumulations result. The removal of the carbon dioxide from the water by aeration permits the bicarbonate ions to react more readily with the hydrogen ions in the system, thus raising the pH. The authors recommend that CO_2 levels be maintained below 5 mg/l to avoid problems with pH depression.

3.10 Total Hardness

Total hardness can be defined as the concentration of polyvalent metallic cations (i.e., calcium, magnesium, iron, manganese) contained in water and is expressed as mg/l of calcium carbonate ($CaCO_3$). Waters are usually classified with respect to the degree of hardness (Table 3.6).

Calcium levels in a recirculating system are important to the crawfish since the principal mineral in a crawfish shell is calcium carbonate. High calcium levels may accelerate the rate at which a soft crawfish hardens its shell (Freeman et al. 1986) and substantial increases may interfere with the molting process. However, there have been no documented cases of difficulties in shedding systems that were attributed to to calcium accumulation.

Very few authors report levels of hardness for maintaining aquatic species in an optimum environment. Boyd (1982) indicates that waters used for production of aquatic species should contain a total hardness of at least 20 mg/l. De la Bretonne et al. (1969) report that the total hardness should exceed 100 mg/l as $CaCO_3$ for optimum crawfish production in ponds while 50 mg/l as $CaCO_3$ is good. Lacking any detailed information, the authors feel that the desirable range for ponds, above 50 mg-$CaCO_3$/l, should be maintained in shedding systems.

3.11 Water Quality Guidelines

Table 3.7 presents safe operational ranges for selected water quality parameters used to monitor the basic operation of a recirculating system. These values were developed from the observation of both experimental and commercial operations over the past few years. If all the parameters are within the specified ranges, the system will operate properly and there should be no difficulty in shedding crawfish. Systems with water quality parameters falling outside the safe operational ranges may still operate successfully. The values presented in Table 3.7 merely reflect a safe range for conditions of actual operation.

If problems persist even though all the water quality parameters in Table 3.7 are within the specified limits, then the problem cannot be attributed to the basic operation of the recirculating system. Mishandling crawfish prior to their introduction to the system, for example, is unrelated to water quality, and yet will cause poor molting success. Transferring premolt crawfish in tightly packed sacks usually results in crushing their exoskeletons thereby leading to mortality in the shedding system. Additionally, problems may also be caused by failures to observe a water quality parameter not discussed here. For example, inexperienced operators frequently fail to properly flush freshly fiberglassed components prior to use. Chemicals released as fiberglass cures are highly toxic to crawfish and the nitrifying bacteria. Even small residual amounts of these chemicals cause molting losses. If the water quality parameters are within the proper ranges, look elsewhere for the problem.

Table 3.6 Classification of waters according to the degree of hardness (taken from Sawyer and McCarty, 1978).

Total Hardness (mg/l as $CaCO_3$)	Degree of Hardness
0 - 75	Soft
75 - 150	Moderately Hard
150 - 300	Hard
> 300	Very Hard

Table 3.7 Water quality guidelines for recirculating systems.

Parameter	Recommended Range
Dissolved oxygen	Above 5.0 mg O_2/l in holding trays; Above 6.0 mg O_2/l in sump; Waters leaving filters must contain above 2.0 mg O_2/l
Total Ammonia	Below 0.5 mg NH_3+NH_4-N/l in holding trays
Nitrite	Below 0.5 mg NO_2-N/l in holding trays
Nitrate	Below 500 mg NO_3^--N/l in sump
Temperature	72-82° F (22-28° C) in holding trays
pH	Between 7.5 and 8.0
Alkalinity	Above 100 mg/l as $CaCO_3$
Total Hardness	Above 50 mg/l as $CaCO_3$ (desirable)

CHAPTER 4

MAJOR COMPONENTS OF A RECIRCULATING SYSTEM

The major components required for a recirculating system include holding trays, filters, a sump, a reservoir, screen boxes, and pumps. This section identifies each component, discusses the design rationale, and presents a variety of ways to configure a successful recirculating system.

4.1 Holding Trays

The holding trays are designed to meet three objectives: (1) to hold a large number of crawfish, (2) to prevent escape of the crawfish, and (3) to provide easy access and viewing for the operator. The specific tray dimensions are not critical as long as these criteria are met.

The overall dimensions of a typical crawfish holding tray are 3 x 8 feet (Figure 4.1). At the recommended density of 1 lb/ft^2 (Culley and Duobinis-Gray, 1988c), this tray holds up to 24 pounds of crawfish and is the size commonly used in the commercial industry. The 3-foot width permits the operator to reach easily across the tray and remove crawfish. Trays should be placed at a convenient height for working and should also be well lighted to facilitate identification of premolts. If space is limited, a double-stacked system can be used with walkways between stacks to access the upper trays. The tray sidewalls should be smooth and at least 6 inches high to prevent the crawfish from escaping. The tray corners are removed or blocked off since these areas create "dead zones" in the circulation pattern. These areas typically exhibit depleted dissolved oxygen supplies and can eventually cause mortalities if crawfish are held in large numbers. Molded fiberglass trays appear to be the most durable. Fiberglass-coated wood trays are relatively inexpensive to construct and can be used for a few years before requiring replacement.

The tank drainage system consists of a 1-inch-high 1.5-inch (interior diameter) PVC stand pipe. This shallow water depth allows the crawfish to remain wet and use atmospheric oxygen if dissolved oxygen supplies in the tray becomes limited. The inside diameter of each standpipe should be fitted with a small piece of plastic louvering (or something similar) to prevent crawfish from clogging drain lines. The standpipe can be removed to facilitate tray drainage during the off-season. A PVC female fitting which can be cast directly into the tank bottom may be used to support a short piece of 1.5-inch PVC pipe (standpipe) that controls the water depth. The standpipe may be surrounded by a 4-inch collar protecting the overflow from clogging while removing solids from the tray floor.

The flushing rate through the tray should provide (1) sufficient aeration to keep dissolved oxygen levels near 5.0 mg/l, (2) sufficient flushing to keep ammonia levels below 0.5 mg-N/l and (3) sufficient flow to remove solid wastes from the tray. There have been no formal studies conducted to determine the flowrates required for flushing wastes or aeration, but Cange (1988) determined that flowrates for a typical 3 x 8-foot tray in the range of 1.7 to 2.4 gpm (0.070 to 0.10 gpm/lb) were required to control ammonia in systems fed low protein foods (20-30 percent) and high protein foods (>30 percent), respectively.

Low oxygen levels in trays with shallow water will not directly cause mortality because the crawfish can lift wetted gills above the water level and obtain oxygen directly from the air.

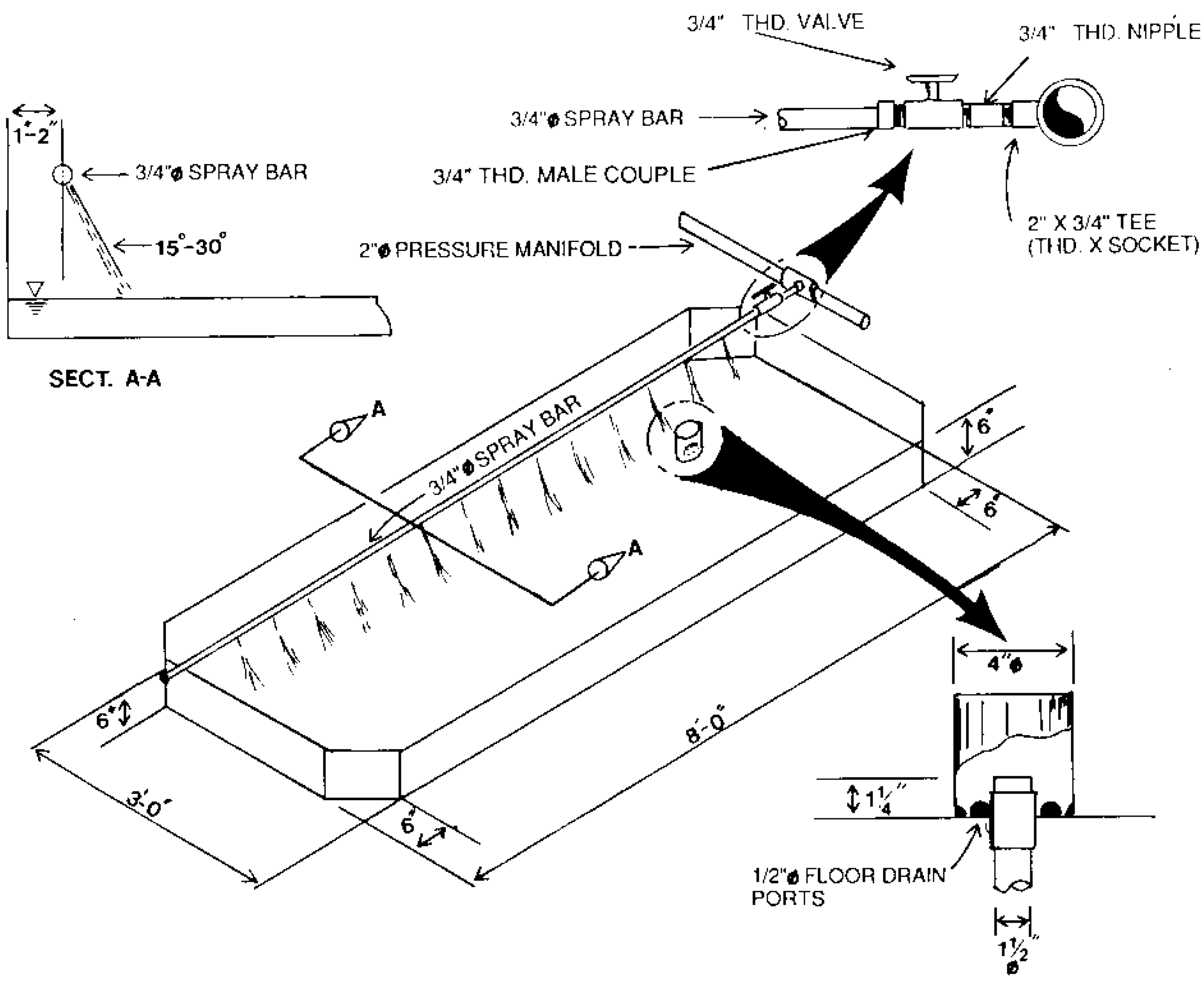

Figure 4.1 A typical shedding tray is designed to assure good circulation of water to control ammonia levels and assure adequate oxygen levels at all points in the tank.

However, the authors believe that this process weakens the crawfish and in combination with other stress factors, such as elevated ammonia, can increase mortalities. The spray head configuration strongly influences the oxygen levels in a tray. Water should be sprayed into the tray so that it is exposed to the air in a manner that assures a moderate circulation in the the tray. Unfortunately, crawfish prefer slowly moving water and do not respond well to strong currents. Figure 4.1 illustrates a spray bar that runs the length of the tray providing aeration. The water is sprayed in at a slight angle (15-30 degrees off the side wall) to induce a mild current across the tray. The strength of the circulation currents is controlled by the angle of impact, and can be adjusted independently of the flowrate. Unfortunately, the holes (1/8 to 1/4-inch) in these spray bars have a tendency to clog intermittently. This forces the operator to periodically clear the holes by using a small nail or similar object. However, the tray is protected from oxygen depletion by the large number of holes placed in the spray bar and clogging problems can be minimized by a good screening system.

4.2 Biological Filters

This section presents two biological filters (upflow sand and fluidized bed) that may be used to process wastes in the recirculating system. Both filters are designed to cultivate populations of waste-consuming bacteria on the surface of the sand grains (Figure 4.2). Since the bacteria remain attached or "fixed" on the substrate surface, these filters are technically known as "fixed film" biological filters. Bacteria living in the thin film draw dissolved wastes, oxygen, and other required nutrients from the passing water (Spotte, 1979; Wheaton, 1977). The rate at which bacteria consume waste is controlled by a wide variety of factors (Table 4.1). Filters are designed and managed to encourage the growth of bacterial films which continually purify the recirculating waters. These bacterial films contain hundreds of bacterial types. One particular population, the nitrifying bacteria, require special attention since they remove (or oxidize) the toxic forms of nitrogen from the system.

The importance of nitrogen in recirculating systems was previously discussed in Section 3.2 and illustrated in Figure 3.1. Two specific types (or genera) of bacteria required to process nitrogen through its toxic decay stages are Nitrosomonas and Nitrobacter . The Nitrosomonas bacteria live by converting toxic ammonia to toxic nitrite, while the Nitrobacter bacteria live by converting toxic nitrite to nontoxic nitrate. Both genera of bacteria prefer to live in a fixed-film mode (attached to a substrate) removing ammonia and nitrite from the water as it passes through the filter. The bacteria are strictly "aerobes," meaning they must have oxygen present to function. Furthermore, the bacteria are sensitive to both pH and temperature (Table 4.2).

Nitrifying bacteria have a slow growth rate. Consequently, 30 to 40 days may be required to establish a population of nitrifying bacteria in a biological filter. When a sudden increase in crawfish weight (typically 20 percent or greater) occurs within the system, an additional two or three days are necessary for the established bacterial population to expand and accommodate the sudden increase in waste load. Fortunately, once the nitrifying bacteria are established they prove durable, occasionally slowing down when starved or abused, but rapidly recovering when the adverse conditions are corrected.

The upflow sand and fluidized bed filter designs presented in the following sections provide a physical environment that favors growth of nitrifying bacteria. Proper system management (Chapter 6) is required if the bacterial populations within the filters are to remain healthy. A well maintained biological filter will purify the water so that the water quality does not interfere with the sensitive molting crawfish.

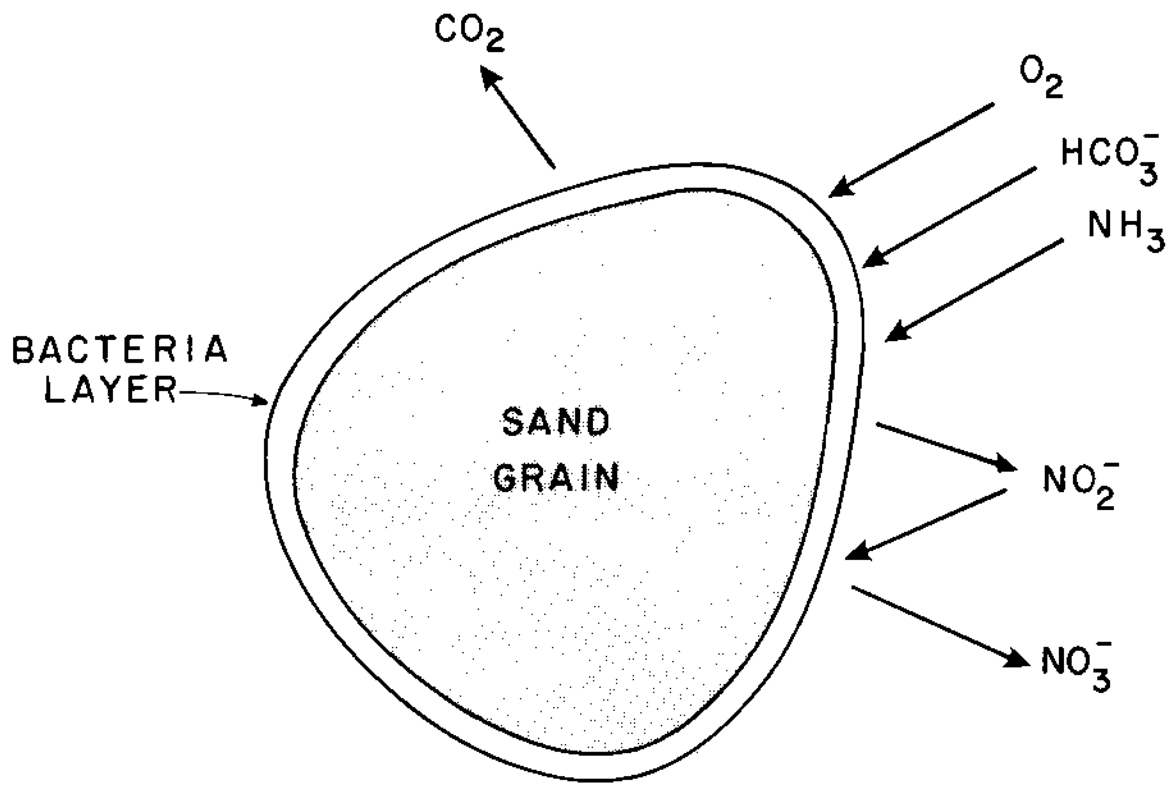

Figure 4.2 The sand grains in the biological filters are coated with a living bacterial film that consumes or converts the dissolved wastes produced by the crawfish.

Table 4.1 Factors affecting the rate of waste consumption by fixed-film biological filters.

Factor	Importance
Waste Concentration	Higher waste levels permit more rapid uptake of wastes into the film layer
Dissolved Oxygen Concentration	The bacteria require oxygen to function, waste degradation is reduced if dissolved oxygen levels fall below 3.0 mg-O_2/l
pH	Bacterial action is inhibited by low pH, sensitive populations are adversely affected by pH values below 8.0; general inhibition occurs below 7.0
Flowrate	Wastes must be continually transported to the bacterial film, rapid flowrates provide for rapid transport of wastes, assure good waste distribution within the filter bed, and induce turbulence which accelerates the uptake process
Media Size	Smaller substrates such as sand have more surface area to support bacterial films
Temperature	Bacterial activity increases with temperature

Table 4.2 The effect of various water quality parameters on nitrifying bacteria.

Factor	Importance
Temperature	Optimum temperature is 25-30° C, growth slows at lower temperatures, inhibited by temperatures below 20° C
pH	Optimum pH at 8.3, severely inhibited by pH values below 7.0
Dissolved Oxygen	Maximum efficiency reported for dissolved oxygen concentrations above 3.0 mg-O2/l,severe inhibition when concentrations fall below 3.0 mg-O_2/l
Alkalinity	Inhibition has been demonstrated when bicarbonate alkalinity falls below 100 mg-$CaCO_3$/l
Miscellaneous	Sensitive to a wide variety of antibiotics and metal ions

4.3 Upflow Sand Filters

The upflow sand filter discussed in this section consists of a coarse sand bed through which water passes upward at a slow rate. The sand grains have a large surface area for supporting the nitrifying bacteria and are very effective at capturing suspended solids entering the filter. However, these sand beds contain little void space for the storage of solids and must be periodically cleaned by expanding the bed to release the solids or otherwise the sand bed will clog. The sand volume and the amount of oxygen supplied by the water flowing through the filter bed control the carrying capacity of an upflow sand filter. The bed shape is not critical as long as the water passes evenly through the bed. Most beds, however, are between 12 and 15 inches deep since oxygen penetration is limited during periods of heavy loading.

Operation. Figure 4.3 illustrates a pressurized upflow sand filter constructed from 4-inch (interior diameter) clear acrylic pipe and common PVC fittings. Water flows into the bottom of the column, up through the underdrain, a 3-inch support bed of gravel, and a bed of sand. The rate at which the water flows through the sand bed controls the filter operation. During normal operation the sand bed remains packed, resting on the gravel bed. Solids entering the bed are captured, and dissolved wastes are consumed by the nitrifying bacteria attached to the sand grains. The water leaving the filter surface is clear, free of suspended solids, and contains low concentrations of dissolved waste. This clean water is discharged into the sump for recirculation through the holding trays.

As the filter operates, solids accumulate within the sand bed and the bacterial film thickens, gradually restricting flow through sections of the bed. This flow restriction causes a pressure buildup under the bed. Eventually, this pressure increase results in sand boil formations which occur within a small section of the bed, allowing the water to rapidly bypass the sand, thereby ending the filter's effective mode of operation. To re-establish normal operation, the accumulation of waste solids and excess bacterial films must be removed. This removal of wastes is accomplished by expanding the bed and effectively "cleaning" the filter.

During the cleaning operation, the flowrate is increased through the bed so the individual sand particles are lifted and suspended in the water column by the high water velocity. Careful setting of the cleaning flowrate will lift the sand bed without washing the sand out of the column. The abrasive action of the sand particles hitting each other as the sand bed expands shears the excessively thick bacterial films and the accumulated solid wastes. The abraded bacterial biomass and solid wastes have a lower density than the sand and are washed out the filter. The water leaving the filter during the cleaning operation is very dirty with a high solids content. These waters are directed away from the sump by means of a bypass line to prevent reentry of wastes to the recirculation system.

The physical capture of solids and their removal with the upflow expansion wash eliminates over 75 percent of the wastes produced in the recirculating system. In addition, the upflow sand filter serves as an effective biological filter supporting a large population of nitrifying bacteria. The filter's efficiency is limited only by the the frequency of cleaning and the rate at which wastes (and oxygen) are transported into the filter bed. The filter design guidelines presented here are intended to maximize the upflow sand filter's effectiveness.

Filter Design. Designing an upflow sand filter requires knowing the expansion characteristics of the sand used in the filter bed. Flowrates for expansion studies are referred to as "fluxrates" and expressed as gallons of flow per unit area of filter cross-

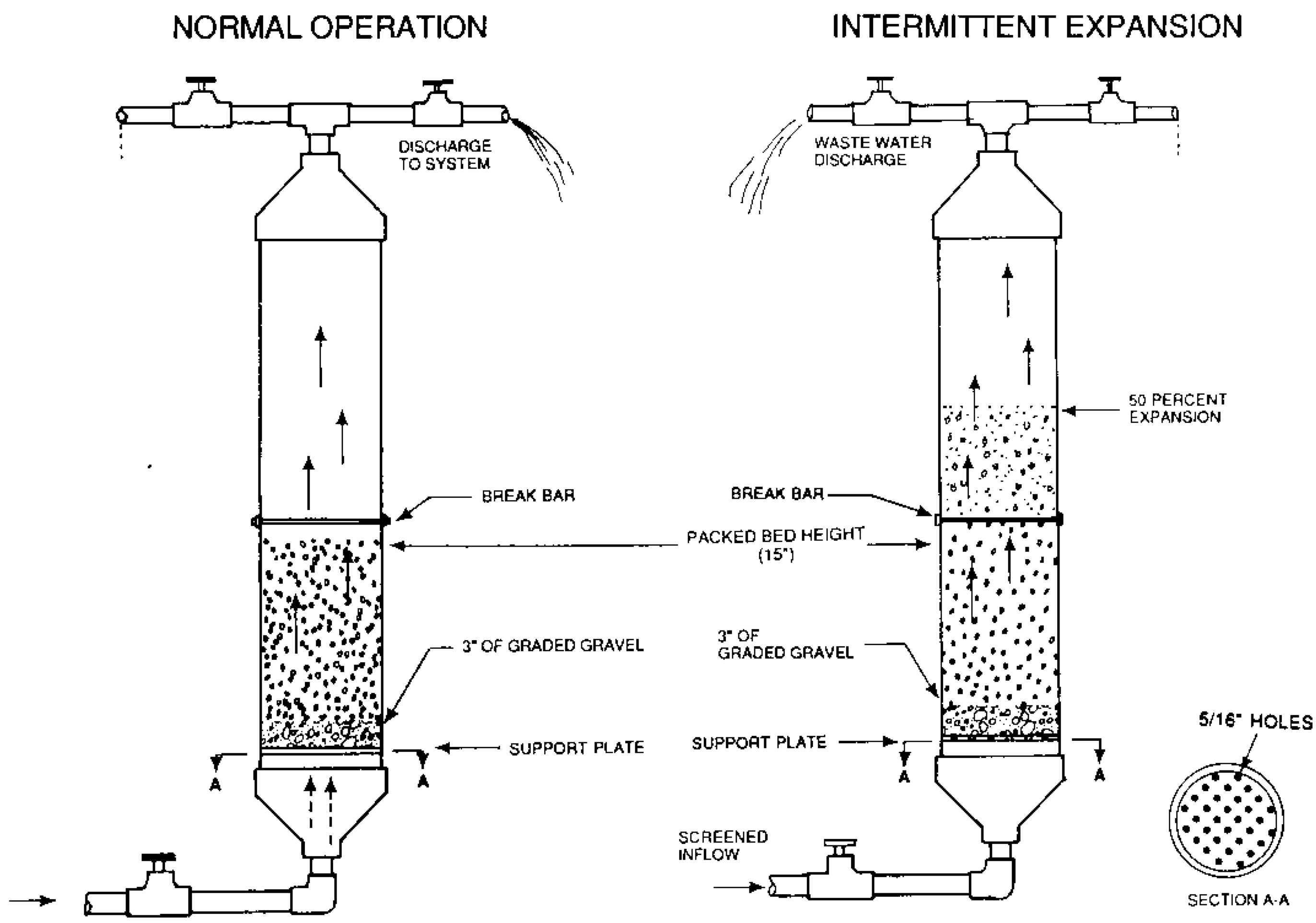

Figure 4.3 The two modes of operation for a pressurized upflow sand filter constructed from common PVC pipe and fittings.

sectional surface area (gpm/ft^2). Thus, a fluxrate of 3 gpm/ft^2 is equivalent to a flow of 3 gallons per minute flowing through a square filter that has sides of 1 foot (height is not considered).

At low fluxrates, the sand's weight exceeds the ability of the water to lift the bed and thus the filter sand remains packed. As the fluxrate increases, the water lifts the sand particles causing the filter bed to expand. The amount of bed expansion is expressed as a percent of the original bed height. Thus, a 12-inch sand bed at 50 percent expansion has increased in height to 18 inches.

Table 4.3 presents the relationship between fluxrates and expansion for three commercially available sands. Several factors affect the relationship between fluxrates and percent expansion (Table 4.4). Fluxrates must be determined experimentally for each type of sand. Coarse sands are recommended for use in upflow sand filters since they tolerate higher fluxrates than fine sands without expanding. These higher fluxrates allow a higher rate of solids removal and increase the filter's maximum nitrification capacity by increasing the oxygen supply. However, the coarse sands also demand a greater fluxrate for back-washing, thus possibly increasing the pumping requirements.

The design of upflow sand filters requires a quantitative appreciation of the hydraulic behavior of sands subject to expansion and biological film development. Although upflow sand filters can be configured in a wide variety of shapes and with a wide variety of sands, the individual operator cannot anticipate the problems that can occur with an innovative configuration. Operators who wish to use these filters for commercial production are advised to follow the design recommendations in this manual precisely, copy a working upflow sand filter, or obtain a commercially produced upflow sand filter for use. Changes that appear small can severely affect the operational behavior of an upflow sand filter.

Figure 4.4 presents a generic design for an upflow sand filter compatible with the requirements of small commercial operators. Filters in this configuration have undergone limited commercial testing by the authors and they seem to function quite well. This filter box has a dual diffuser system on the bottom. A 2-inch input line feeds water into a similar sized diffuser pipe (perforated on the bottom side only) which forces inflowing waters toward the filter bottom. This design prevents the momentum of the inflowing waters from creating a zone of high pressure on the wall opposite the input line. Secondly, the support plate (Figure 4.4, Section A-A) contains equally spaced holes to assure even distribution of the upflowing waters through the sand bed.

A 3-inch gravel bed placed over the support plate prevents the sand from falling through the holes when the flow is stopped. This gravel bed should contain a gravel mixture ranging from 1/2 to 1/8 inch in diameter. A 15-inch bed of coarse (8/16) filter sand rests on the gravel bed surface. During normal operation, the valve on the 2-inch discharge line is left open. Water passing through the sand bed and through this discharge line is directed back to the reservoir or sump. During the cleaning cycle the valve on the 2-inch discharge line must be closed and the fluxrate through the bed increased to induce 50 percent expansion.

The sand grains in the filter bed have a tendency to stick together during the initial stages of cleaning. Brass "break" bars, installed in the filter column, assure that the lower bed section breaks up so it will not be forced in a piston-like manner into the overdrain pipe. All wash water is discharged through the 4-inch overflow pipe out of the system for further treatment or discharge. Care must be taken to assure that the discharge line is not restricted causing water to back up into the filter box during the cleaning cycle. The 4-inch overflow pipe, extended across the filter, has the top inch sliced off forming a weir to assure even

Table 4.3 The relationship between fluxrates and percent expansion for three commercially available sand grades for clean, washed, 15-inch-deep filter beds.

Percent Expansion	Fluxrate (gpm/ft^2) Medium River Sand[1]	Coarse River Sand[2]	Crushed Dolomite[3]
0[4]	9	14	25
25	34	44	75
50	49	65	99
75	62	79	119
100	78	96	133

[1]0.84-1.68 mm filter sand graded to pass a #12 mesh and retain on a #40 mesh screen, often used for sand blasting

[2]1.19-2.38 mm filter sand, graded to pass a #8 mesh and retain on a #16 mesh screen, often used for sand blasting

[3]4.76-7.93 crushed dolomitic limestone, graded to pass a 5/16-inch mesh and retain on a #4 mesh screen, often used for gravel in saltwater aquariums

[4]maximum flow without bed expansion

Table 4.4 Factors affecting the relationship between fluxrate and percent expansion of sand beds.

Factor	Impact
Grain Size	Fluxrates required to expand beds decrease with decreasing sand size
Shape	Rounded sands expand more readily than crushed angular sands
Density	Sands of heavier minerals require higher flux rates to expand than those of lighter minerals
Bed Depth	Deeper beds require less flux but higher pressures to achieve expansion
Bacterial Growth	Growth of bacterial film on sand particles increases their effective size without increasing their weight and thus they expand more readily

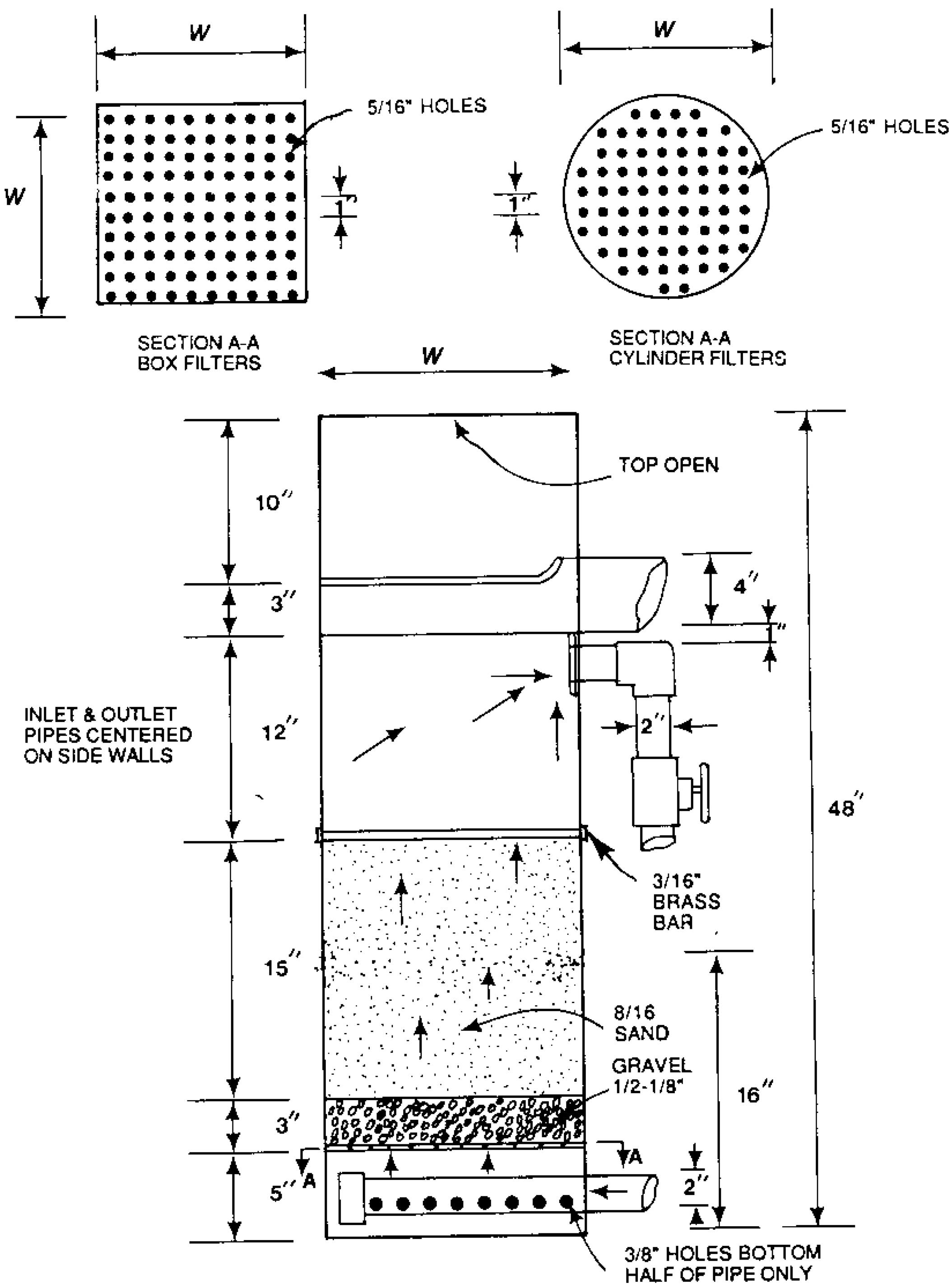

Figure 4.4 Generalized diagram of an open-top upflow sand filter for widths, W, ranging from 10 to 20 inches. Open top filters are easy to inspect and clean.

flow distribution during expansion. The filter top is generally left open providing the operator with access to the sand bed. Expansion can be verified visually or by probing the bed with a pole. The frequency of cleaning can be determined by checking for sand boils and the duration by directly observing the wash water.

The upflow sand filter can be constructed as a square box or a cylinder without altering the specified dimensions. The carrying capacity and flow requirements, however, do vary. Tables 4.5 and 4.6 present the critical operational parameters for the square and cylindrical filters, respectively. Experimental results indicate that an upflow sand filter with a bed of coarse (8/16) filter sand will support approximately 150 pounds of crawfish per cubic foot of sand. Thus, the carrying capacity is based on the volume of sand held in each filter.

Design flowrates for upflow sand filters must consider the bacterial film which develops and grows on the sand media. Experimental observations, based on the coarse (8/16) filter sand, indicate that these design flowrates are approximately two-thirds that observed with clean sand. Thus, the normal required flowrate is computed as 67 percent of the maximum fluxrate without expansion (Table 4.3) times the surface area of support plate. The flowrate required for 50 percent expansion is computed without correction since biological film development does not significantly affect the expansion characteristics of the coarse (8/16) filter sand once the filter bed has been expanded.

The coarse (8/16) filter sand was selected for design purposes in this manual because the sand permits a relatively high fluxrate without expansion and effectively abrades biological film accumulations during the cleaning cycle. The sizing of inflow pipes and discharge lines, as well as space provided for expansion in the generic upflow filter design, were specifically selected for this sand. Using filter sands other than 8/16 size will alter the hydraulic requirements for normal operation and expansion, thereby invalidating the design assumptions. Thus, the dimensions presented in Figure 4.4 are recommended only for use with the specified 8/16 filter sand.

Rationale. The upflow sand filter is the best general purpose filter tested by the authors in over five years of research on recirculating systems. The filter is robust, rapidly adjusting to changes in loading, while water clarity remains consistently superb. The nitrification power of the upflow sand filter reflects several factors. First, the intermittent removal of bacteria and trapped solids from the filter bed significantly reduces the amount of decaying material in the recirculating system. This means that a major portion of the wastes, either excreted by the crawfish as solids, released from uneaten food, or created by the bacterial growth, are physically removed from the system. Wastes flushed from the system place no short-term or long-term demands on the system. The oxygen demand in the upflow sand filter is significantly reduced. Consequently, aeration requirements on a per-pound basis for the filter are significantly reduced. Likewise, competition between bacterial populations for substrate space is reduced. Finally, the buildup of dissolved waste products (nitrate) is significantly slowed on a per-pound basis.

The major disadvantage of the upflow sand filter is the requirement for active management. The filter must be cleaned (expanded) at least once a day to prevent caking of the bed (as the bacterial slime layers from different sand particles tend to grow together). Management operations also include pH monitoring and sodium bicarbonate addition. Failure to perform these routine operations quickly leads to filter failure. The design of upflow sand filters is more complicated than most conventional filters. Flowrates, both for normal operation and cleaning, must be compatible with the sand selected for the filter bed. In addition, filter dimensions must be carefully selected to assure oxygen demands are met under normal operation and to guarantee the required flowrates are compatible with the recirculation pump.

Table 4.5 Carrying capacities and operational flowrates required for a square upflow sand or fluidized bed filter with 15-inch beds of 8/16 filter sand.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (lbs)	Operational* Flowrate (gpm)	Expansion** Flowrate (gpm)
4	0.14	21	1	7
6	0.31	47	2	16
8	0.55	83	4	29
10	0.87	30	7	45
12	1.3	188	9	65
14	1.7	255	13	88
16	2.2	333	17	116
18	2.8	422	21	146
20	3.5	521	26	181
22	4.2	630	32	218
24	5.0	750	38	260
26	5.9	880	44	305
28	6.8	1021	51	354

*flowrates required for normal upflow sand filter operation

**flowrates required for normal fluidized bed operation and for cleaning the upflow sand filters

Table 4.6 Carrying capacities and operational flowrates required for a cylindrical upflow sand or fluidized bed filter with 15-inch beds of 8/16 filter sand.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (lbs)	Operational* Flowrate (gpm)	Expansion** Flowrate (gpm)
4	0.11	16	1	6
6	0.25	37	2	13
8	0.44	65	4	23
10	0.68	102	7	35
12	0.98	147	9	51
14	1.3	200	10	69
16	1.7	260	13	91
18	2.2	330	17	115
20	2.7	410	21	142
22	3.3	495	25	172
24	3.9	590	30	204
26	4.6	690	35	240
28	5.3	800	41	278
30	6.1	920	47	319
32	7.0	1050	53	363

*flowrates required for normal upflow sand filter operation

**flowrates required for normal fluidized bed operation and for cleaning the upflow sand filters

4.4 Fluidized Bed Filters

Operation. The fluidized bed filter (Figure 4.5), the second type of sand filter, consists of a sand bed which is continuously expanded (fluidized) by a constant upflow of water. Typically, fluidized bed filters maintain between 25 and 100 percent expansion. The turbulent environment and rapid transport of oxygen and dissolved wastes through the filter favor bacterial growth. Waste conversion rates and bacterial growth are very rapid. The sand particles increase in diameter and the bacterial layer around the sand particles thickens, while the dynamic rolling of the sands assures full utilization of the bed. During expansion, the particles bounce around in the bed, continuously striking the filter walls or other sand particles. This mildly abrasive environment continuously wears off the bacterial slime layer around the sand particles, thereby eliminating any clogging problems. The fluidized bed cannot hold solids finer or lighter than the sand particles, so sheared biomass and solids from the shedding system pass out of the filter. The bed is self-cleaning and requires no routine maintenance.

Because the fluidized bed operates in a turbulent environment, the filter cannot remove suspended solids from the recirculating system. In fact, solids are continually generated since the growing bacterial biomass eventually passes through the filter bed as a result of abrasive action. Consequently, the fluidized bed must be complemented by a filter capable of capturing and/or removing solids in recirculating systems. Thus, in most applications, the fluidized bed is accompanied by an upflow sand filter to assure complete water treatment. The bed can also be used to upgrade the nitrification capabilities of existing treatment systems.

Filter Design. Figure 4.6 presents a generic drawing for the design of an unpressurized fluidized bed. An unpressurized (or open) fluidized bed closely resembles the design of an upflow sand filter (Figure 4.4). The fluidized beds, however, use only the expanded mode of operation and thus require only one large drain line. A brass "break" bar placed at the bed's surface alleviates packing in the event of a pump shutdown. The carrying capacity of a fluidized bed (150 lbs/ft^3) is equal to an upflow sand filter of equal size. The normal operational flowrates required by fluidized bed filters are equivalent to the expansion flowrates required by the upflow sand filters as presented in Tables 4.5 and 4.6. Flowrate requirements for square-shaped filters are greater than for the cylindrical filters of the same width since they have more surface area.

Although the open, unpressurized configuration presents the operator with the advantages of easy access to the sand bed, pumping costs associated with keeping a large bed expanded continuously are high. Recognizing that only a small pressure drop occurs across a bed, pressurized fluidized beds (Figure 4.7) can be placed in series with the distribution manifold for the spray heads in the holding trays (see Figure 5.3). This configuration substantially reduces the overall flow requirements for the recirculating system.

Pressurized filters must be designed to withstand the maximum (or shut off) pressure that can be produced by the recirculating system's pump. By using a pressure relief valve on the distribution manifold (which feeds the fluidized sand filter), this maximum pressure can be limited. The generic filters presented in Figure 4.7 should be fabricated from PVC, clear PVC, or acrylic piping with known pressure ratings. The translucent or clear piping allows the operator to easily set flowrates and observe the degree of biological film development within the filters. Square box filters are not recommended since they will not resist pressurization forces.

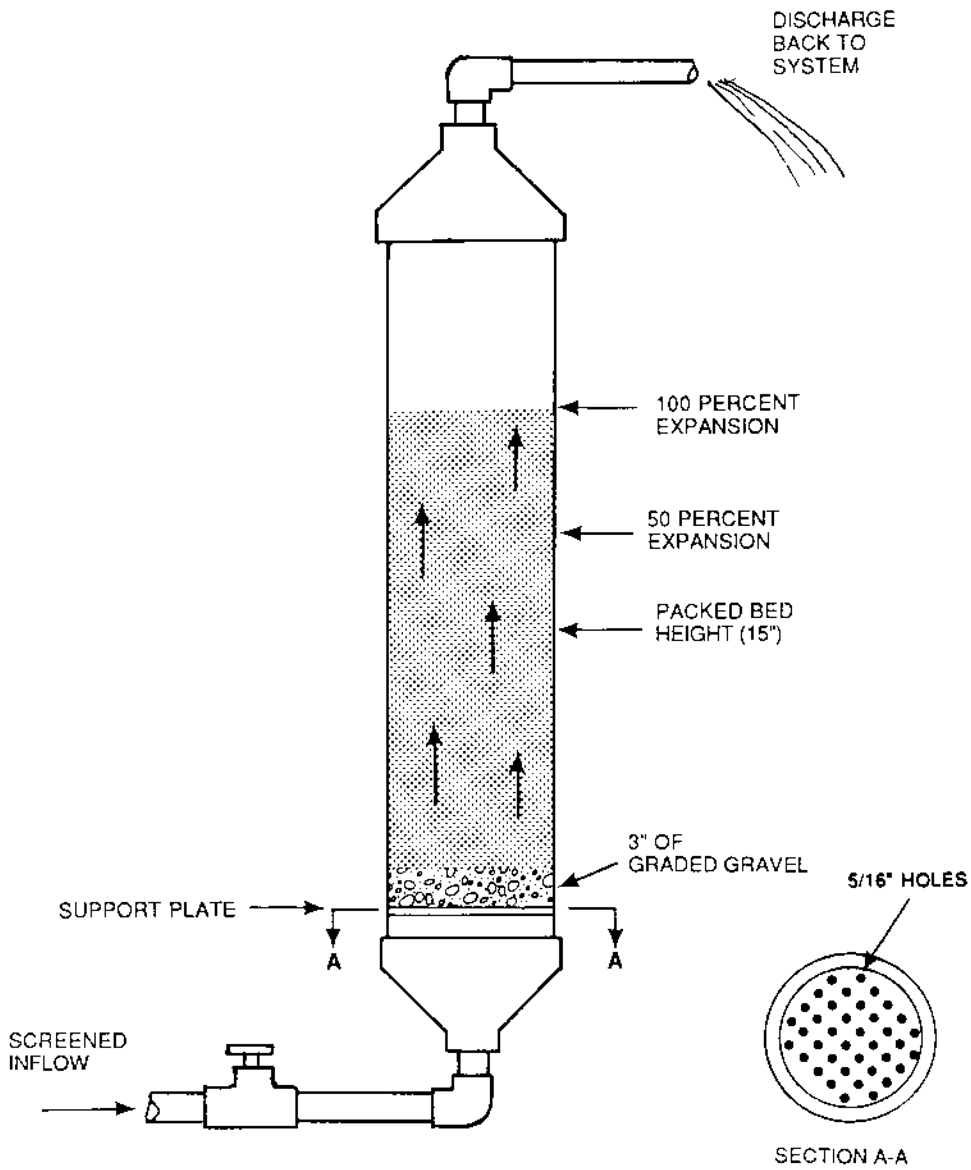

Figure 4.5 A fluidized sand filter is continually operated at 50 to 100 percent expansion to assure suspension of the entire filter bed. The filter provides an optimum environment for the nitrifying bacteria but does not capture solids.

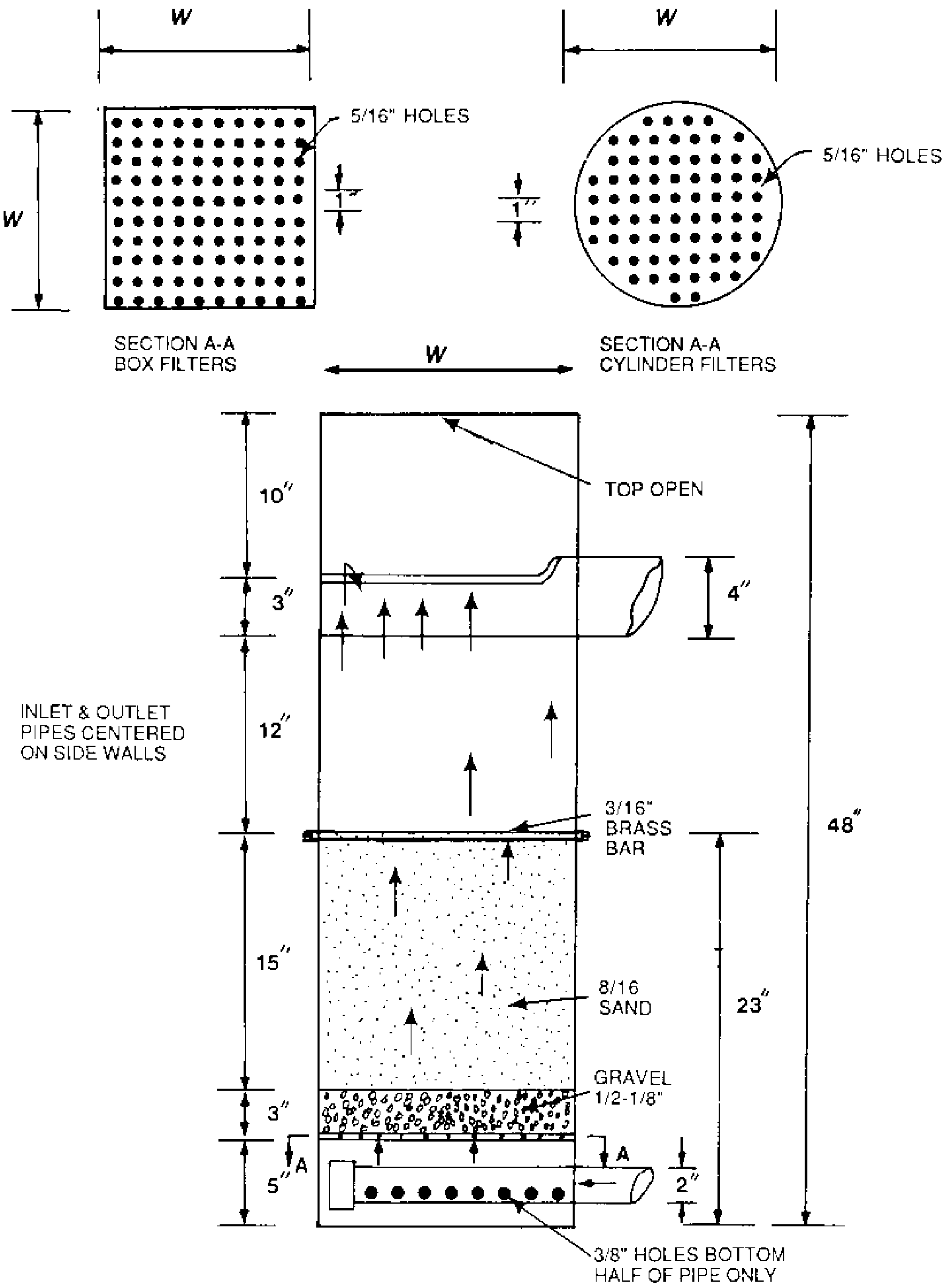

Figure 4.6 A general design for the open-top fluidized bed filter, with widths (W) ranging from 10 to 20 inches, that can be used when pressurization is not required. Expansion of the bed can easily be verified by probing with a pole through the open top.

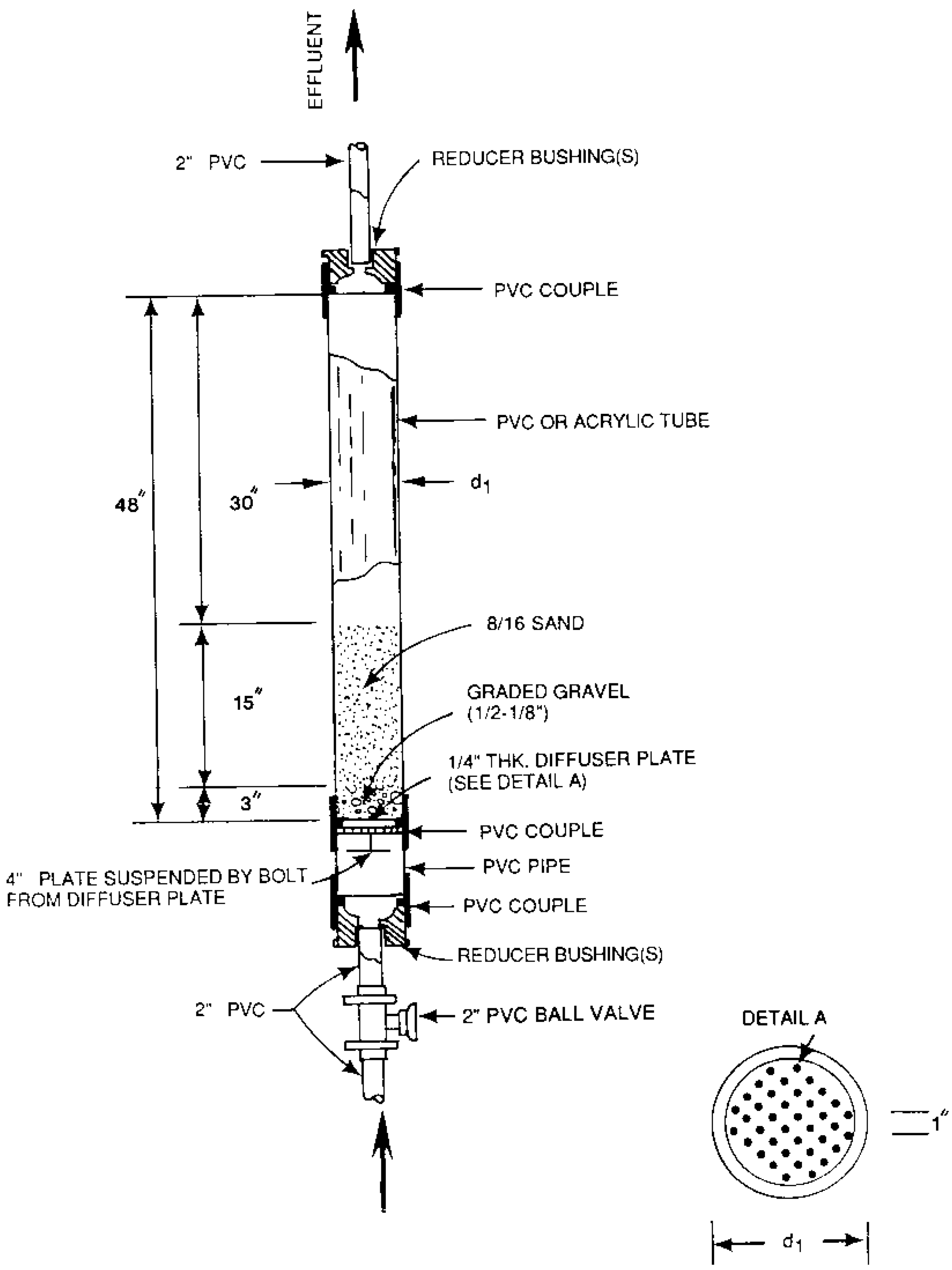

Figure 4.7 A pressurized fluidized bed, constructed from clear PVC pipe and standard fittings, can be used to reduce pumping costs.

Rationale. The fluidized sand filter is very compact, easy to construct, and virtually maintenance-free. The filter provides excellent control of nitrite and ammonia in a recirculating system and rapidly responds to shock loadings. The filter's ability to reduce nitrite levels exceeds the upflow sand filter although the recommended carrying capacity for the fluidized bed (150 lbs/ft^3) equals that of the upflow sand filter. The filter's condition can be easily determined since the sand increases in size and turns light brown with a bacterial increase.

Fluidized sand beds perform reliably up to the point of failure. Failure points are very predictable since the operator can observe the filter as it "gels up" or clogs under excessive loading. Fluidized beds are self-cleaning and can even recover within a few days after reaching a failure point. Fluidized beds can be configured with a wide variety of sands, provided the principles of design are understood. Minor flowrate fluctuations do not appear to adversely affect performance.

Three main disadvantages occur when using the fluidized bed filter in a recirculating system. The first involves the filter's inability to capture solids. The fluidized bed is a specialty filter, meaning that the filter is best used when complementing a filter that can remove solids. The filter does not have the "stand alone capabilities" of the upflow sand filter. The second disadvantage involves the filter's inability to maintain adequate pH levels. Fluidized sand beds require addition of sodium bicarbonate to assure that bicarbonate and pH levels are compatible with the needs of the nitrifying bacteria. And finally, the fluidized bed filter requires high flowrates to maintain its continuous mode of operation. For example, the fluidized bed requires almost seven times as much flow as the upflow sand filter to support an equivalent poundage of crawfish.

A very effective filtration system can be configured if an upflow sand filter (for solids removal) and a fluidized sand filter (for nitrification) are combined. The most apparent advantage of utilizing these new filters is their small size, which has become an apparent need for most operators. More importantly, shock loading has less impact on these systems, and peak nitrite levels associated with such disturbances are greatly reduced. The fluidized bed and upflow sand filters also appear ideal for nitrification control where calcium-free systems have been proposed to extend the hardening time for soft crawfish. If a noncalcareous sand is used as a medium, the sand filters will neither contribute or consume calcium. Consequently, calcium levels in the system can be precisely controlled by using chemical addition.

4.5 Sumps and Reservoirs

Sumps and reservoirs hold the bulk of the water in a recirculating shedding system. Operators should understand the conceptual functions of sumps and reservoirs even though many systems employ a single tank to perform both functions.

Sumps. The sump (Figure 4.8) serves as a collection point for waters returning from the holding trays and filters and provides a source of water for the pump intake. The sump must be sized to permit water fluctuations associated with daily operation of the facility without allowing the pump to run dry. The sump should have a sufficient volume to permit pump operation for about five minutes without any return flow. The sumps used with the upflow sand and fluidized bed filters must be properly sized to assure that turbulence from the return and reaeration lines prevents solids from settling. The sump should be only partially filled during normal operation to permit short-term storage of water drained from the system.

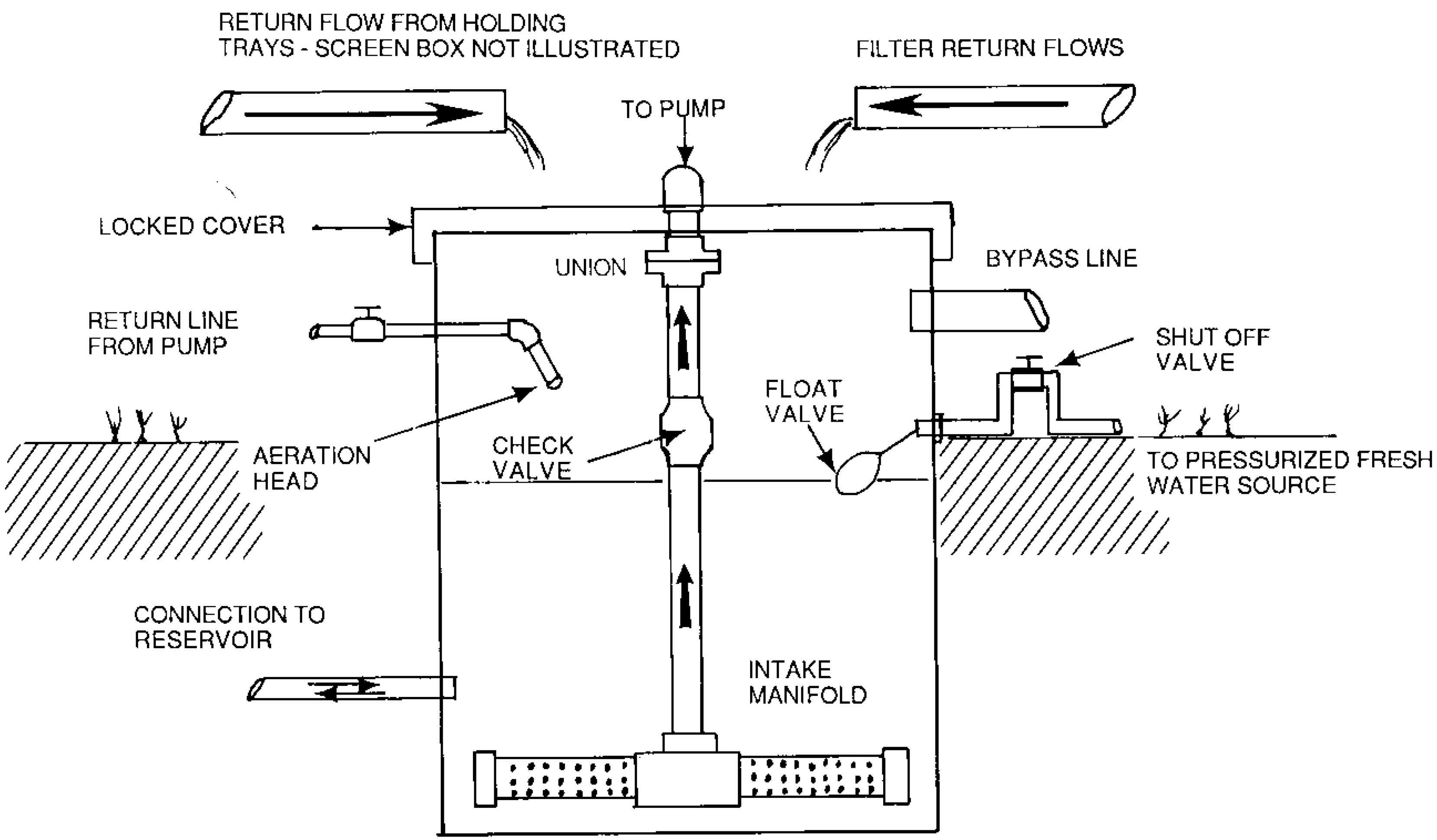

Figure 4.8 The sump provides clean, aerated water for the pump intake manifold.

Water levels are best controlled by a float valve connected to a pressurized freshwater source. This float valve will release water slowly to compensate for evaporation in the recirculating system. In most cases, the float valve is simply connected to the nearest tap water source, which can be conveniently closed when draining the system. Since fresh water enters the system slowly, chlorine is neutralized in the system before it can adversely affect the animals. Most systems can absorb a 20 percent water addition of chlorinated tap water within a day without any adverse impact. Systems requiring more than this amount should employ an activated carbon filter on the tap water line to remove chlorine.

The sump should be equipped with a bypass pipe unless the sump design, in combination with the reservoir, permits complete drainage of the holding trays and filters in the recirculating system. This bypass pipe should direct excess water to an external ditch or drain to avoid water damage during power failures.

The intake manifold for the recirculating pump is a critical component of the system. Besides the obvious need for intake water, the manifold must exclude debris that could clog spray heads or underdrain plates within the recirculating system. The performance of a centrifugal pump, typically used with recirculating systems, is adversely affected by constrictions on the intake line. Thus, the intake line must be protected without causing a significant head loss. In a typical sump, the intake line (2-inch inside diameter) is connected to a perforated manifold (4-inch inside diameter) near the bottom of the sump. The perforations (1/4-3/8 inch) in the manifold are often protected by a loose wrap of screening material. The intake manifold should also include a check valve that will prevent water backflow when the pump is turned off. The check valve will aid pump priming and prevent backflow of sand particles in systems using the upflow sand or fluidized bed filters in the event of system shutdown. Finally, the entire manifold unit should be connected to the pump with a removable union, permitting periodic cleaning of the manifold.

Sumps placed outside should be buried so that the water level is below the ground. Since soil is an effective insulator, burying the sump will help stabilize temperatures in the recirculating system. Outdoor sumps should be covered to prevent foreign matter, particularly leaves, from falling in the system. Covers should be locked and the sump fenced, if necessary, to prevent entry of children and animals.

Reservoirs. The reservoir's primary function is stabilizing water quality in the recirculating system. The design of recirculating systems is based on the concept of balancing the bacterial population with the crawfish population in the shedding system. When this balance is achieved, the wastes are removed or consumed by the bacteria as quickly as they are produced and the water remains free of ammonia and nitrite. In a commercial setting, however, the crawfish supply fluctuates from day to day. The bacteria slowly respond to changes in the crawfish population, and thus a dynamic imbalance exists. The bacteria require a day or so to adjust to an increase in the crawfish population. During this adjustment period, the rate of waste production exceeds the rate of consumption by the bacteria, leading to a short-term accumulation of ammonia and nitrite in the system. The reservoir provides additional water volume to dilute these wastes so that concentrations will remain below toxic levels.

As a secondary and optional function, the reservoir provides storage for the recirculating waters when the system is drained. This becomes a virtual requirement in areas that are subject to periodic power failures. If the reservoir/sump combination does not provide sufficient volume, water will be lost out the bypass line during pump shutdown, requiring the addition of water when operation resumes. The capital costs of constructing and installing a large reservoir must be balanced against the frequency and cost associated with periodic power failures.

The authors anticipate that systems using upflow sand and/or fluidized bed filters can safely operate at a volume ratio of 5 gallons/lb of crawfish. The upflow sand filters remove solids in the washing cycle that account for over 75 percent of the total waste load to the system. The removal mechanism, solids entrapment, responds instantaneously to increases in crawfish population. Since the upflow sand filter reduces the rate of waste accumulation during the imbalance period, the required volume of dilution water is also reduced. The interim recommendation for minimum water volume for systems using upflow sand filters is also 5 gallons/lb. However, volume ratios as low as 3 gallons/lb have been used in some cases where a water supply such as a pond is readily available in emergency cases. Thus a 1,000-pound crawfish system with draindown compatibility requires a total capacity of 5,000 gallons.

Reservoirs are normally buried in the ground at the same level as the sump. Reservoirs can be built by constructing plastic-lined pits covered with opaque plastic to conserve energy while preventing growth of plants (Figure 4.9). The reservoirs should be locked and fenced to assure that small children or animals cannot become trapped. Interconnections between the reservoir and sump should be below the operational water level in the sump (Figure 4.10). A small reaeration line or upflow filter discharge line should feed water into the reservoir to assure a slow mixing of water into the sump.

4.6 Screen Boxes

Screen boxes are used to prevent debris from entering the distribution system where it might clog openings in the spray heads and underdrain plates. The screens also remove solid wastes from the system. Screen boxes are mandatory since the sand filters do not provide protection and their underdrains are sometimes subject to clogging. Thus, systems employing sand filters must have the intake waters filtered through at least one screen. Failure to provide screening for the recirculation system will eventually lead to clogging problems with aeration heads and failure of the sand filters.

Figure 4.11 illustrates the placement and configuration of a screening box arrangement. These two boxes are placed such that all return flows from the holding trays must pass through at least one screen. The leading (or top) screen box is designed with a notched end so that water will divert to the second screen box when the top screen clogs. The lower box is similarly notched to prohibit water loss from the system should it clog. Most screen boxes are at least 2 x 3 feet in size. Boxes should be sized such that the leading box will not clog in a 24-hour period. The leading box should be cleaned each day.

In addition to the screen boxes, many operators wrap the intake manifold loosely with screening material. Plastic 1/8-inch mesh screen, typically used for this purpose, does not clog and provides a second line of defense should both the screening boxes be bypassed. Additional protection can be provided by inline screens that, for example, are frequently used to filter the intake line on swimming pool pumps.

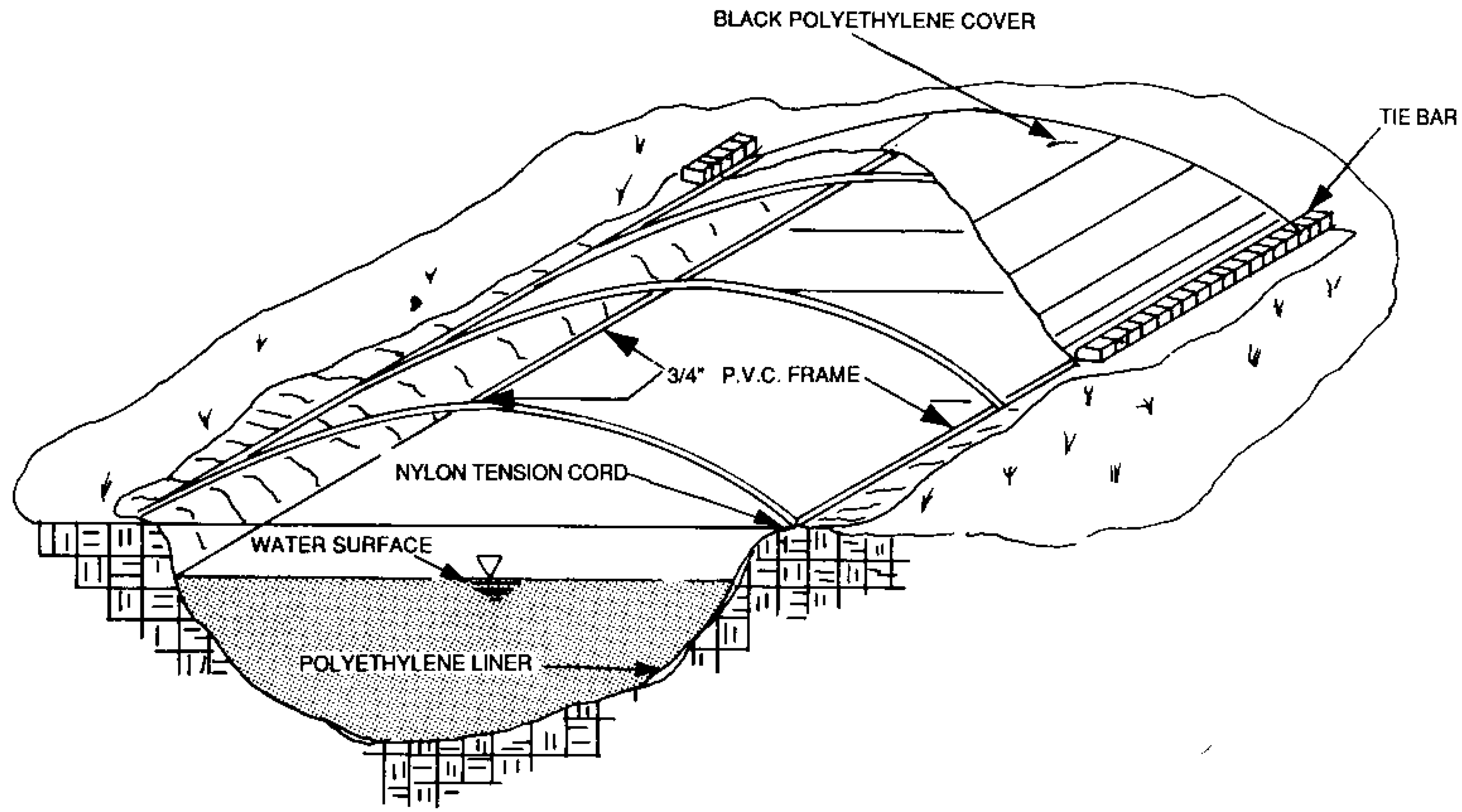

Figure 4.9 The reservoir may be as simple as a plastic lined pit covered with black plastic to prevent plant growth and conserve heat.

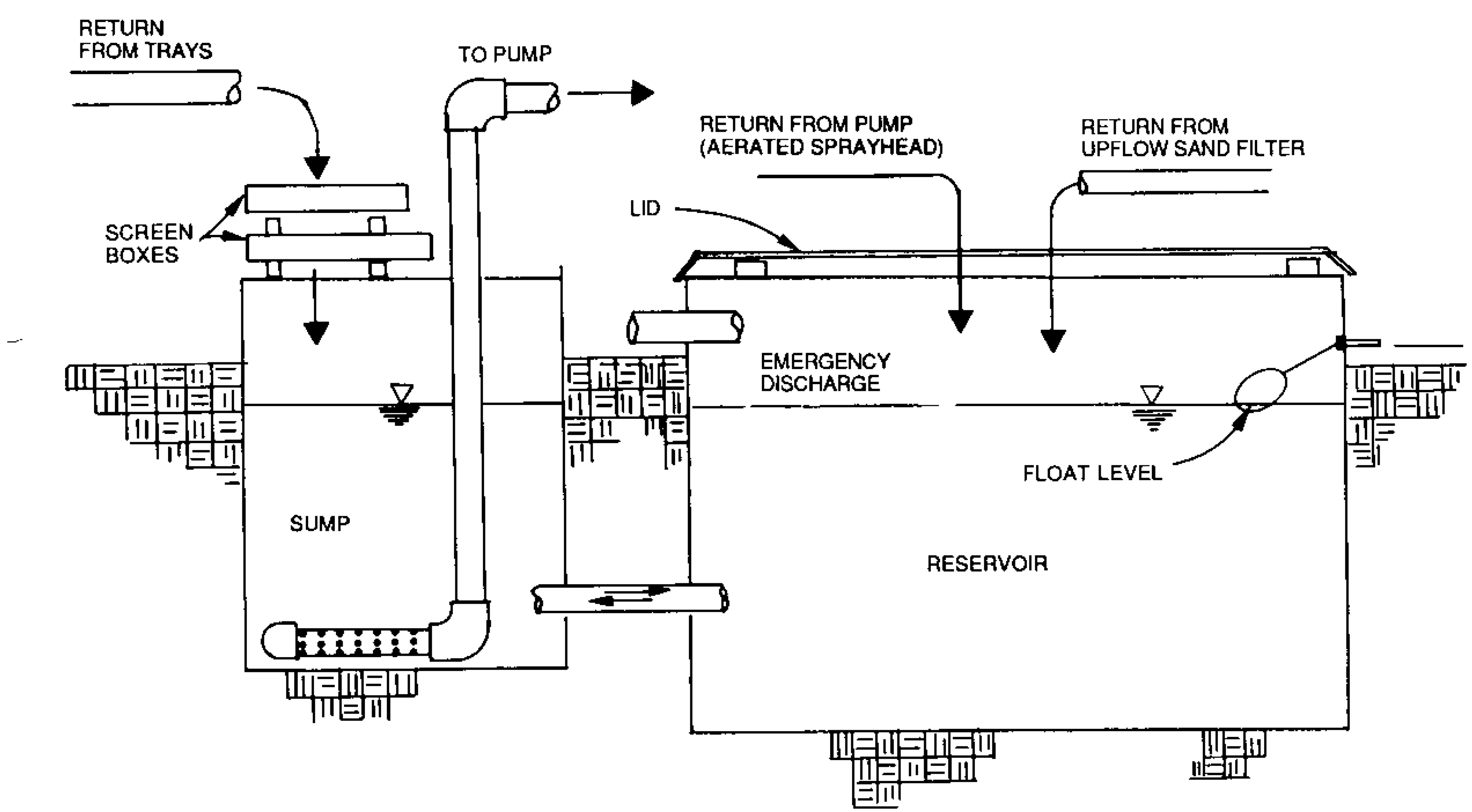

Figure 4.10 The sump and reservoir should be interconnected below the water level so that water levels will fluctuate together. Only solids-free water from the upflow sand filter is discharged into the reservoir to prevent solids accumulation.

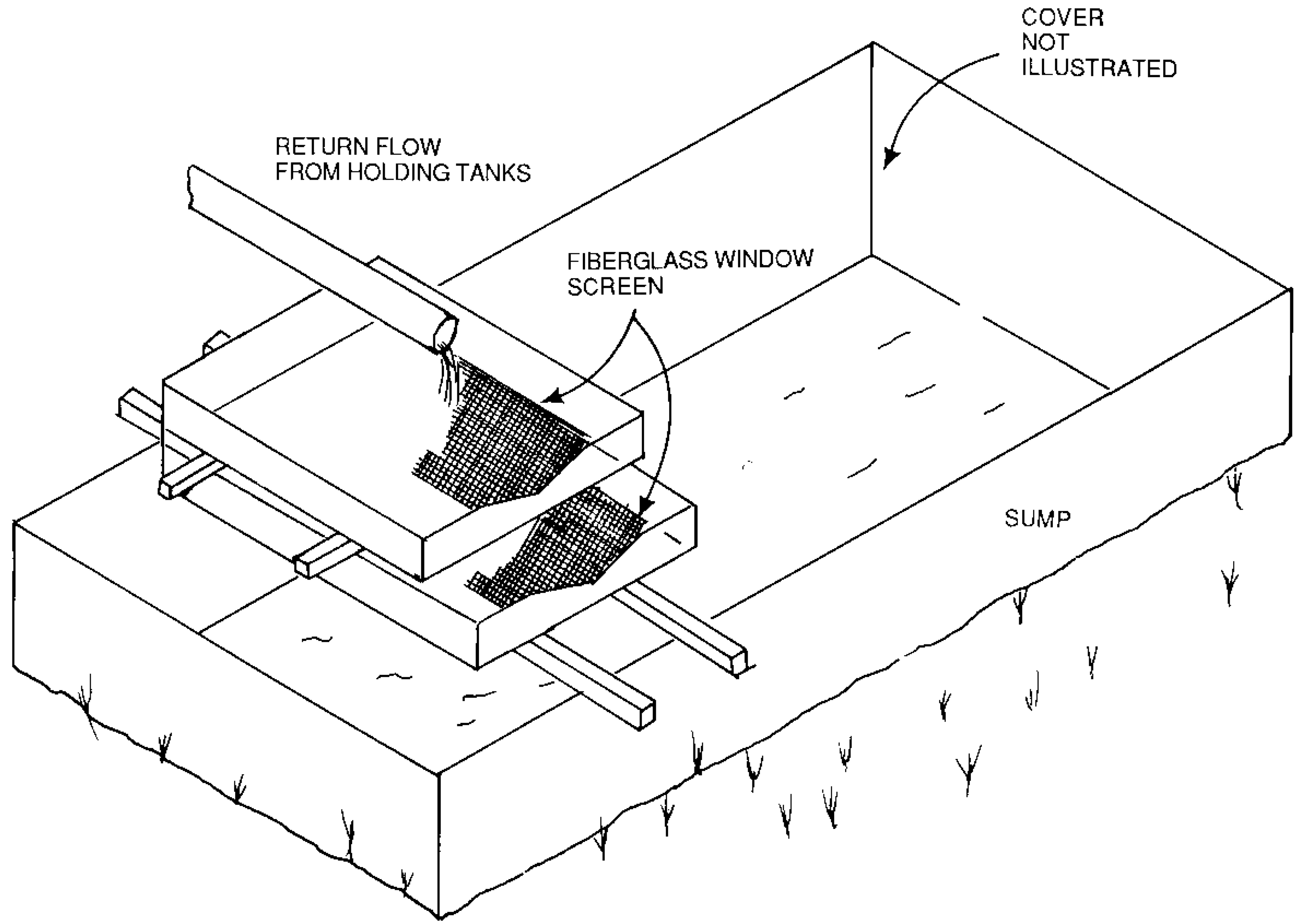

Figure 4.11 Screen boxes protect the recirculation system from debris that could clog the holes in the filter underdrains or spray bars.

4.7 Pumps

Low-head centrifugal pumps are most commonly used for water recirculation in shedding systems. Pumps for recirculating systems must be designed for continuous operation and should be constructed of corrosion-resistant materials. Impellers and housings that come in contact with the water should be plastic, brass or stainless steel. Self-priming pumps designed to run dry for short periods of time are recommended for use. There are a number of swimming pool and sauna pumps that meet these criteria.

The output (gpm) of pumps varies with the operational pressure of the system. Each pump model has a performance curve which specifies flowrates with increasing pressure. The pumps must be selected to deliver the desired flow at the normal operational pressures of a recirculation system. Observation of typical installations indicates that most recirculation systems following these criteria have operational pressures of about 30 feet (or roughly 15 psi) on the discharge end of the pump. This discharge pressure, however, depends upon the configuration of the distribution system. Generally, smaller or longer piping lines, as well as nonessential elbows and T's, increase operational pressures and consequently decrease flowrates.

Pumps that provide excessive flowrates increase the operator's flexibility to operate a shedding system. For example, aeration lines can be added at critical points within the system during periods of peak loading to enhance performance. Thus, obtaining a pump that has a flowrate capacity over the minimum rates specified generally makes sense.

Backup pumps are recommended for commercial operations. Although the animals in the trays can withstand a loss of circulation waters for several hours, major losses will occur if water flow is not quickly restored (usually within a day). Rapid temperature drops will occur in systems that depend upon water heaters for heating the water. Backup pumps can also serve to boost maximum pump output during the cleaning cycle for upflow sand filters. Commercial facilities located in areas where power failures are quite frequent should purchase a small generator for short-term use.

CHAPTER 5

RECIRCULATING SHEDDING SYSTEM CONFIGURATIONS

The system elements presented in Chapter 4 can be combined in a variety of ways to form a recirculating shedding system. This section presents design criteria that should be followed to assure that suitable water quality is maintained in a shedding operation. A series of configurations that have advantages, such as ease of operation or minimized pumping costs, are presented to illustrate design strategies that can be developed under the "umbrella" of the generalized design criteria.

Generalized design criteria for systems that utilize sand filtration systems are presented in Table 5.1. These criteria require the use of sand that is graded to pass a standard 8-mesh screen and be retained on a 16-mesh screen. At least, 50 percent of the sand media must be allocated to the upflow sand filters to assure that solids will be removed from the system. Fifteen-inch filter bed depths, based on using an 8/16 filter sand, are recommended for the generalized design. The hydraulic behavior of sands in expansion or near expansion is complex. Other sand grades are not compatible with the flow values presented in this table. System configurations differ primarily in their pumping requirements, although all comply with the generalized criteria outlined in Table 5.1.

5.1 Upflow Sand Filter Only

Figure 5.1 illustrates a system flow diagram with a reservoir and a single upflow sand filter for water treatment. This configuration consists of two parallel circulation loops: the first loop provides aeration and circulation to the trays, while the second loop circulates water from the reservoir to the upflow sand filter and back to the reservoir. This design permits the use of an open-top upflow sand filter of either the square (Table 5.2) or cylinder (Table 5.3) shape. Component sizes were derived from Tables 4.5 (square filters), 4.6 (cylindrical filters), and 5.1 (system designs). The use of a large upflow sand filter maximizes the ability to remove solids, permitting the combination of the sump and reservoir into a single tank.

This system is equipped with two pumps. The circulation pump provides continuous circulation through both the tray and filter loops. The second pump is switched on intermittently to clean the upflow sand filter once or twice a day. Since the expansion pump is much larger than the circulation pump, it could serve as a backup pump under emergency conditions but only for short periods of time. A single filter and a large expansion pump facilitate using timing switches for the cleaning cycle. The reservoir/sump should be constructed in a manner that does not allow solids to settle within the tank. Input and discharge lines should be placed to prevent settling of the solids before they reach the upflow sand filters.

5.2 Upflow Sand Filter and Unpressurized Fluidized Bed

Figure 5.2 illustrates a system configuration that employs one fluidized bed and two upflow sand filters. Based on this design, component sizes for systems ranging from 240 to 960 pounds (20 to 40 trays) are presented in Tables 5.4 and 5.5. All three filters are of identical size and operate in an unpressurized mode (open-top) to facilitate operator inspection and filter access. This configuration assures almost trouble-free operation and is

Table 5.1 Summary of interim design criteria for shedding systems employing sand filtration systems.

Parameter	Value	Comment
Tray Area	1 lb/ft^2	Normal loading density for trays
Water Depth	1 inch	Recommended water depth in trays
Sand Size	1.2-2.4 mm	Diameter of 8/16 filter sand
Bed Depth	15 inch	Assumed bed depth in sand filters
Sand Volume	0.0067 ft^3/lb	For portion of capacity supported by fluidized bed
	0.0067 ft^3/lb	For portion of capacity supported by upflow filter, at least 50 percent of sand volume must be in the upflow sand filter
Total Volume	5 gallons/lb	Total operational volume of all components
Flowrates	0.07 gpm/lb	Minimum flowrate to trays
	65 gpm/ft^2	Normal operational flux rate for fluidized bed
	9.4 gpm/ft^2	Normal operational flux rate to upflow sand filter
	65 gpm/ft^2	Expansion flux rate for upflow sand filter

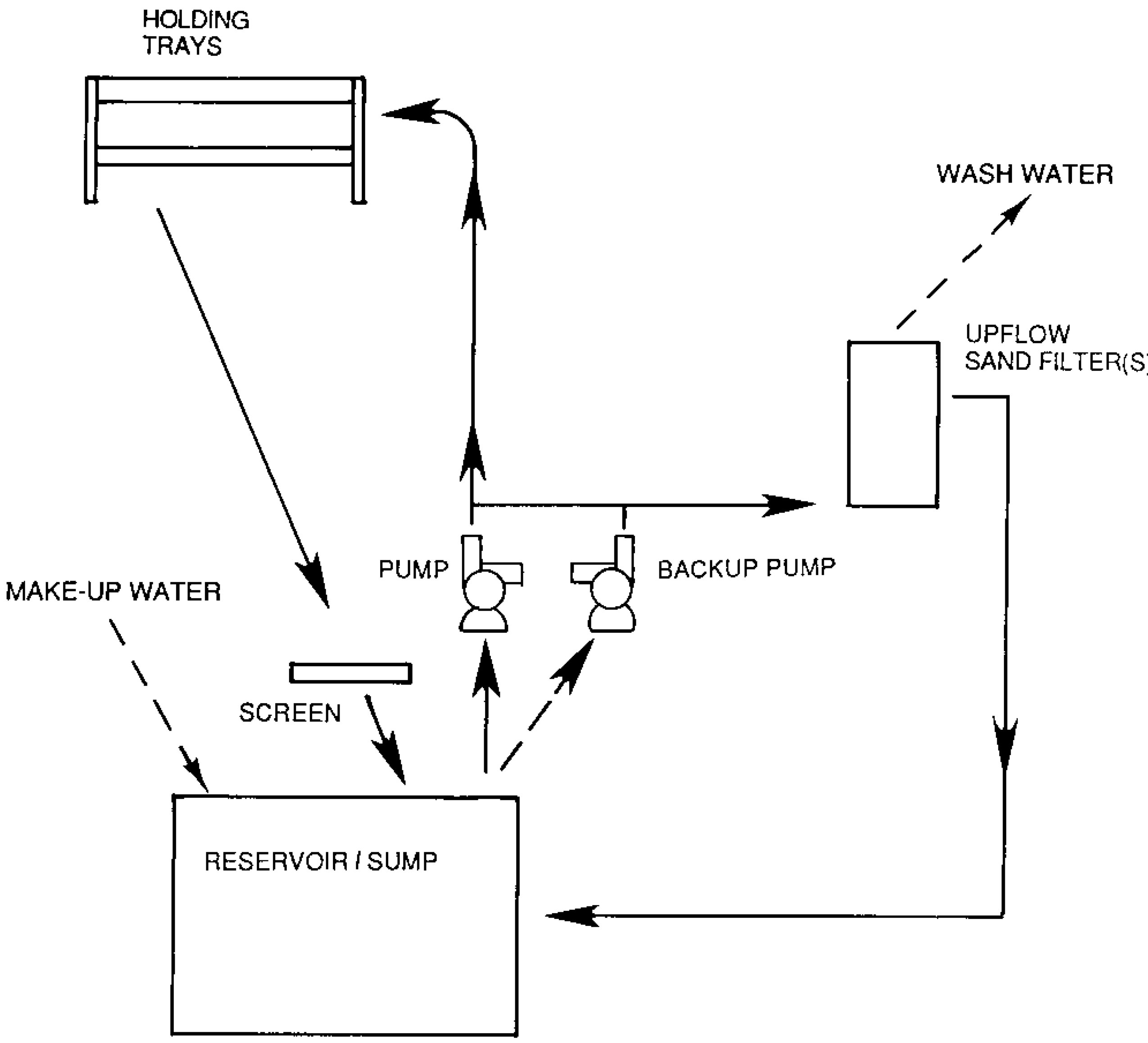

Figure 5.1 Flow diagram for systems using a combined sump/reservoir and a single upflow filter for filtration.

Table 5.2 System designs based on a single square upflow sand filter.

	Number of Trays			
Parameter	10	20	30	40
Pounds of Crawfish	240	480	720	960
Sump Volume (gallons)	1200	2400	3600	4800
Filter Width (inches)	14	20	24	28
Filter Volume (ft^3)	1.7	3.5	5.0	6.8
Flow to Trays (gpm)	17	34	50	67
Upflow Sand Filter Flowrate (gpm)	13	26	38	52
Circulation Pump Flowrate (gpm)	30	60	88	119
Expansion Pump Flowrate (gpm)	88	181	260	354

Table 5.3 System designs based on a single cylindrical upflow sand filter.

	Number of Trays			
Parameter	10	20	30	40
Pounds of Crawfish	240	480	720	960
Sump Volume (gallons)	1200	2400	3600	4800
Filter Diameter (inches)	16	22	27	32
Filter Volume (ft^3)	1.7	3.3	5.0	7.0
Flow to Trays (gpm)	17	34	50	67
Upflow Sand Filter Flowrate (gpm)	13	25	37	52
Circulation Pump Flowrate (gpm)	30	59	88	120
Expansion Pump Flowrate (gpm)	91	172	258	363

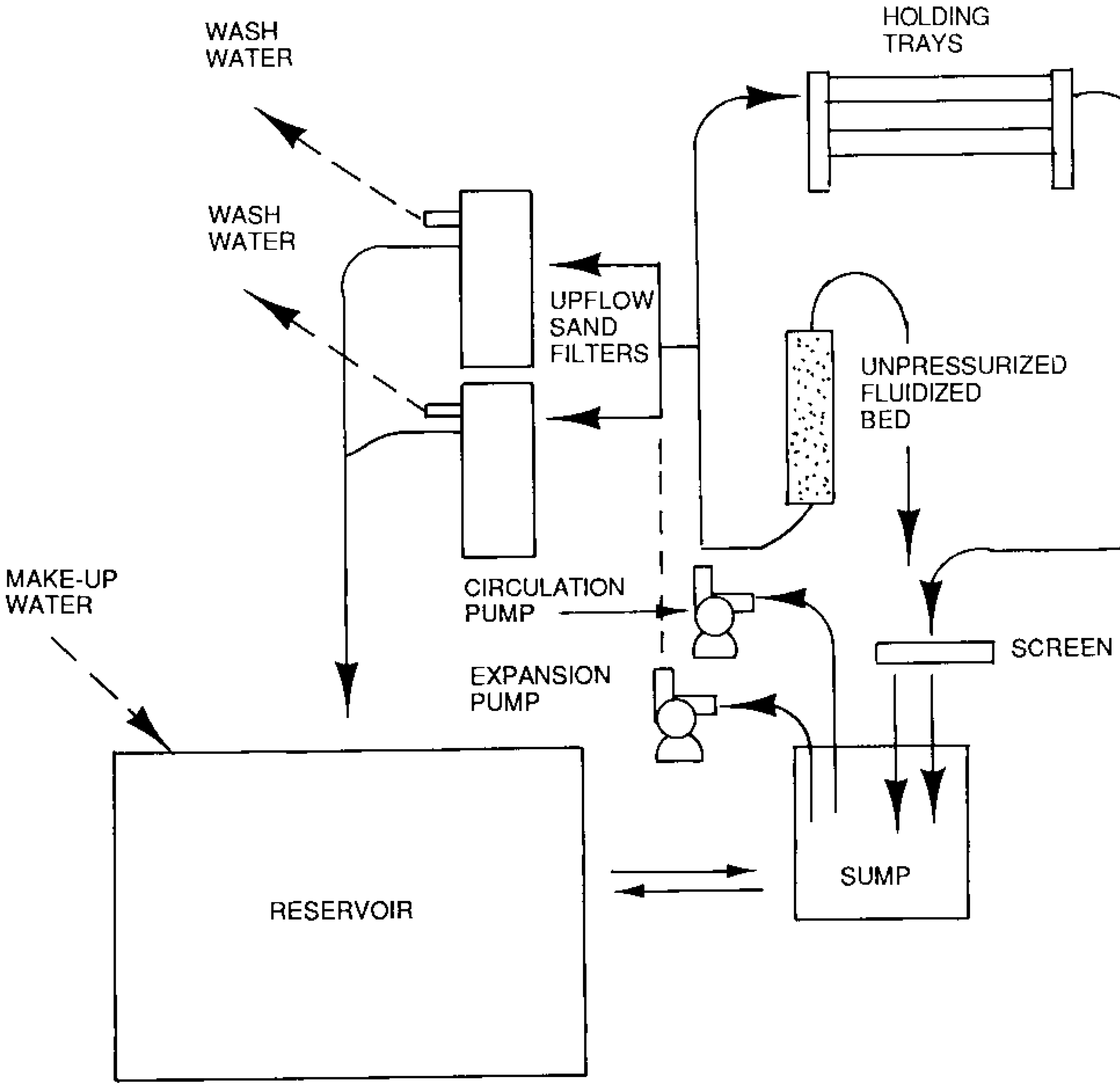

Figure 5.2 Flow diagram for a recirculating system using an unpressurized fluidized bed and two upflow sand filters.

Table 5.4 System designs using an unpressurized square fluidized bed and two square upflow sand filters to simplify operation.

Parameter	Number of Trays 10	20	30	40
Pounds of Crawfish	240	480	720	960
Flowrate to Trays (gpm)	17	34	50	67
Fluidized Bed Filters (#)	1	1	1	1
Width (in)	8	12	14	16
Sand Volume (ft^3)	0.6	1.3	1.7	2.2
Carrying Capacity (lbs)	83	188	255	333
Fluidized Bed Flow (gpm)	29	65	88	116
Upflow Sand Filters (#)	2	2	2	2
Width (in)	8	12	14	16
*Sand Volume (ft^3)	0.6	1.3	1.7	2.2
*Carrying Capacity (lbs)	83	188	255	333
*Normal Flowrate (gpm)	4	9	13	17
*Expansion Flowrate (gpm)	29	65	88	116
Circulation Pump (gpm)	37	117	164	217
Backup Pump (gpm)	37	117	164	217
Sump Volume (gallons)	300	650	900	1150
Reservoir Volume (gallons)	900	1750	2700	3650

*values given for a single filter

Table 5.5 System designs using a cylindrical, unpressurized fluidized bed and two cylindrical upflow sand filters to simplify operation.

Parameter	Number of Trays 10	20	30	40
Pounds of Crawfish	240	480	720	960
Flowrate to Trays (gpm)	17	34	50	67
Fluidized Bed Filters (#)	1	1	1	1
Diameter (in)	10	14	16	18
Sand Volume (ft^3)	0.7	1.3	1.7	2.2
Carrying Capacity (lbs)	102	200	262	331
Fluidized Bed Flow (gpm)	35	69	91	115
Upflow Sand Filters (#)	2	2	2	2
Diameter (in)	10	14	16	18
*Sand Volume (ft^3)	0.7	1.3	1.7	2.2
*Carrying Capacity (lbs)	102	200	262	331
*Normal Flowrate (gpm)	5	10	13	17
*Expansion Flowrate (gpm)	35	69	91	115
Circulation Pump (gpm)	62	123	167	216
Backup Pump (gpm)	62	123	167	216
Sump Volume (gallons)	350	700	900	1150
Reservoir Volume (gallons)	850	1700	2700	3650

*values given for a single filter

a good choice for those using sand filters for the first time. Filter condition can be easily verified by observation or by probing with a rod.

Separate tanks are recommended for the sump and reservoir since the solids capture rate is reduced in this configuration. Water containing solids from the fluidized bed and trays is directed back through the screen and into the sump where turbulence from the returning water assures that the solids stay in suspension. Solids-free water from the upflow sand filters slowly mixes with the reservoir water as it is pumped back into the main system. The circulation pump supports the trays, the fluidized bed, and the two upflow sand filters during most of the day. Intermittently, the expansion pump is turned on to clean the two upflow sand filters. The flowrates required for expansion and normal operation are nearly identical, so the system can be operated for extended periods with a single pump in case of a pump failure.

The main disadvantage of this system configuration is the high flowrate required by the circulation pump. Circulation rates for the 20-tray system are twice those required for a system equipped with a single upflow sand filter. Thus, electrical costs for pumping will double.

5.3 Upflow Sand and Pressurized Fluidized Bed Combination

Figure 5.3 illustrates the flow diagram for a system that employs both the upflow sand and fluidized bed filters for controlling water quality. This system is configured to operate with a single circulation pump. Filter designs (Table 5.6) are based on cylindrical components.

A pressurized fluidized bed, placed in series with the holding tanks in the aeration loop, takes advantage of the filter's low head loss to eliminate pumping costs associated with maintaining bed expansion. The circulation pump may be used to clean the two upflow sand filters, one at a time, thereby eliminating the need for a large expansion pump. Filter cleaning can be accomplished by momentarily shutting down the flow to the fluidized bed and holding tanks and diverting the flow to the upflow sand filters, one at a time. Alternatively, the backup pump (identical in size to the circulation pump) can also be used for filter cleaning, thus avoiding interruption of flows to the holding tanks.

The sump design (volume) assures that the waste solids remain in suspension until caught by the filters. Only return flows from the upflow sand filters (free of waste solids) are permitted to enter the larger reservoir, thereby preventing solids accumulation in this large tank. The fluidized bed treats the total volume of system water every hour providing rapid control of ammonia and nitrite. The combination of the upflow sand and fluidized bed filter provides better protection against shock loading because of the great nitrifying power of the fluidized bed.

This configuration has received little commercial testing. There are concerns that the fluidized bed may generate solids large enough to block the spray bar holes during periods of peak loading. This problem, however, has not been dobserved with laboratory units maintained for extended periods under moderate loading conditions. Pressurized fluidized beds must be constructed to withstand the shut-off pressure of the pump; thus, construction costs for the fluidized bed may be higher than those for the open-top units.

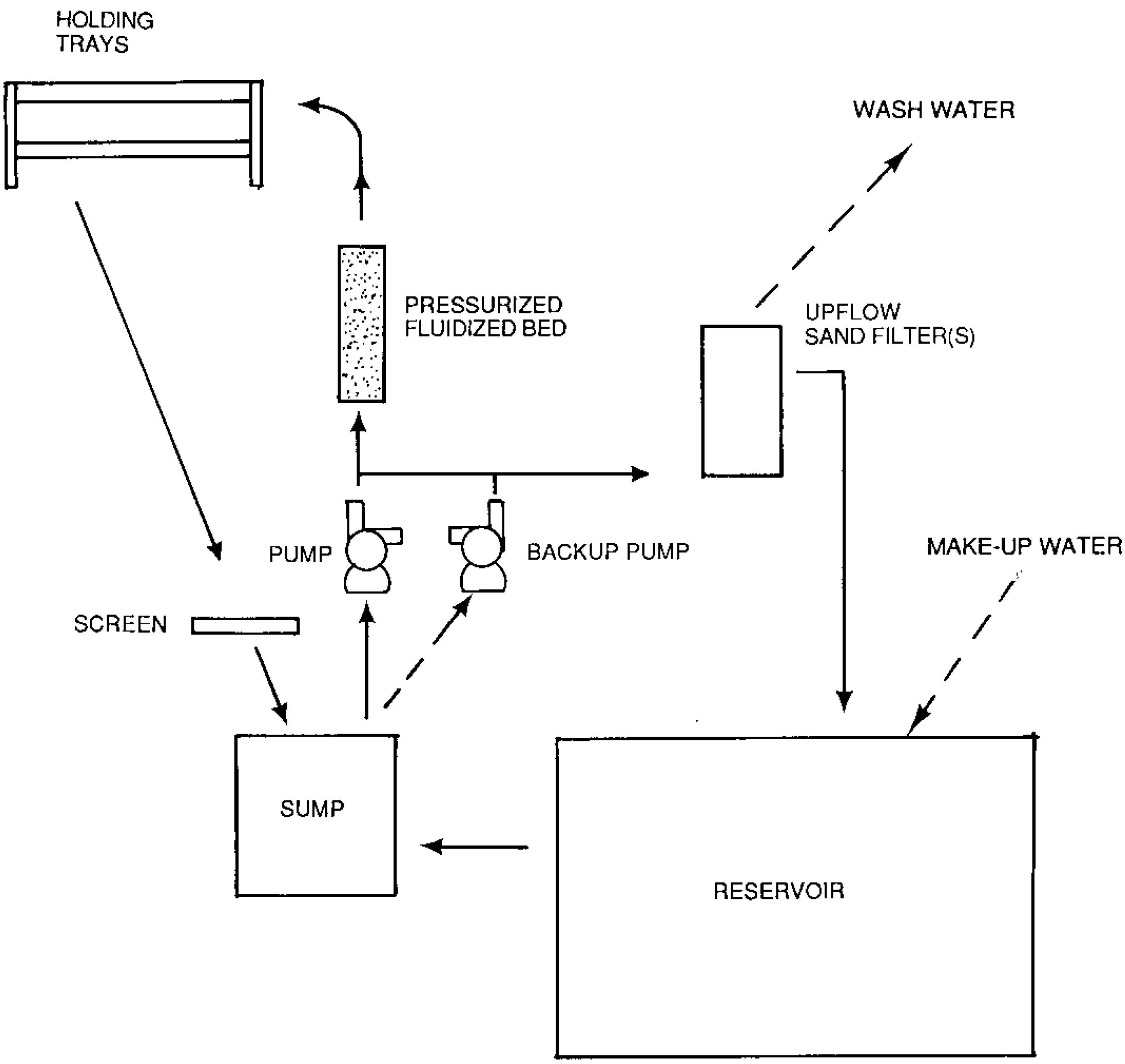

Figure 5.3 Flow diagram for systems using a cylindrical, pressurized fluidized bed and two upflow sand filters to minimize pumping requirements.

Table 5.6 System designs using a pressurized fluidized bed and two upflow sand filters to minimize pumping requirements.

Parameter	Number of Trays 10	20	30	40
Pounds of Crawfish	240	480	720	960
Fluidized Bed Filters (#)	1	1	1	1
Diameter (in)	8	10	12	14
Sand Volume (ft^3)	0.4	0.7	1.0	1.3
Carrying Capacity (lbs)	65	102	147	200
Flowrate to Trays (gpm)	17	34	50	67
Upflow Sand Filters (#)	2	2	2	2
Diameter (in)	10	14	18	20
*Sand Volume (ft^3)	0.68	1.34	2.2	2.7
*Carrying Capacity (lbs)	102	200	330	409
*Normal Flowrate (gpm)	5	10	17	21
*Expansion Flowrate (gpm)	35	70	114	142
Circulation Pump (gpm)	35	70	114	142
Backup Pump (gpm)	35	70	114	142
Sump Volume (gallons)	200	300	400	500
Reservoir Volume (gallons)	1000	2000	3000	4000

* values given for single filter

CHAPTER 6

SYSTEM MANAGEMENT

Once construction is completed, maintaining adequate water quality in a recirculating system is almost entirely under the operator's control. Understanding the behavior of the system and water quality are essential requirements for system management over an extended period of time. The following issues identify the management problems that may not be immediately apparent to the operator of a newly constructed system.

6.1 Flushing New Systems

The fiberglass used with system components (trays, filters, sumps, etc.) and the cements used to join the PVC piping system release highly toxic compounds when cured. Newly constructed systems must be flushed at least once prior to the introduction of animals. Flushing is accomplished by filling the system with fresh water, turning on the circulation pumps, and letting the system run for about 24 hours. All this water should then be drained and replaced. If time permits, repeat the process. The process should also be undertaken when new components are added to the system. Failure to flush a newly constructed system will almost certainly lead to animal mortality.

6.2 Filter Acclimation

The biological filters will only function effectively after a bacteria population is well established in the filter media. These bacteria must be grown in the filter. Filter acclimation is the process by which the initial bacteria population is cultivated.

Biological filter acclimation is simply accomplished by adding a small number of animals to the system. These animals will excrete ammonia which encourages the establishment of Nitrosomonas bacteria in the filter. As the Nitrosomonas bacteria become established they produce nitrite which, in turn, encourages the growth of the Nitrobacter bacteria which consume the nitrite. Depending on the temperature, this acclimation process takes between 20 and 40 days. The acclimation method has a distinct disadvantage since the Nitrobacter bacteria are not fed until the Nitrosomonas bacteria population becomes established. Thus, the acclimation is accomplished serially, first the Nitrosonomas population grows then the Nitrobacter population. The time for acclimation is therefore lengthened. Figure 6.1 illustrates the way the ammonia and nitrite will accumulate then decline as the acclimation process proceeds.

Filter acclimation can be accomplished faster by chemical addition, with a total cost under \$20. Ammonium chloride (NH_4Cl) is added to feed the Nitrosonomas population while, simultaneously, sodium nitrite ($NaNO_2$) is added to initiate growth of the Nitrobacter bacteria. Both populations become established simultaneously, reducing the startup time by at least 30 percent (Manthe and Malone, 1987). With this method, a bacterial population in the sand filter can become established in as little as two weeks if the system is kept warm (80° F).

Figure 6.2 illustrates the simultaneous reduction in nitrite and ammonia from a chemically dosed system. Both the ammonium chloride and the sodium nitrite should be added at a concentration level of about 10 mg/l (about four grams for each hundred gallons of water)

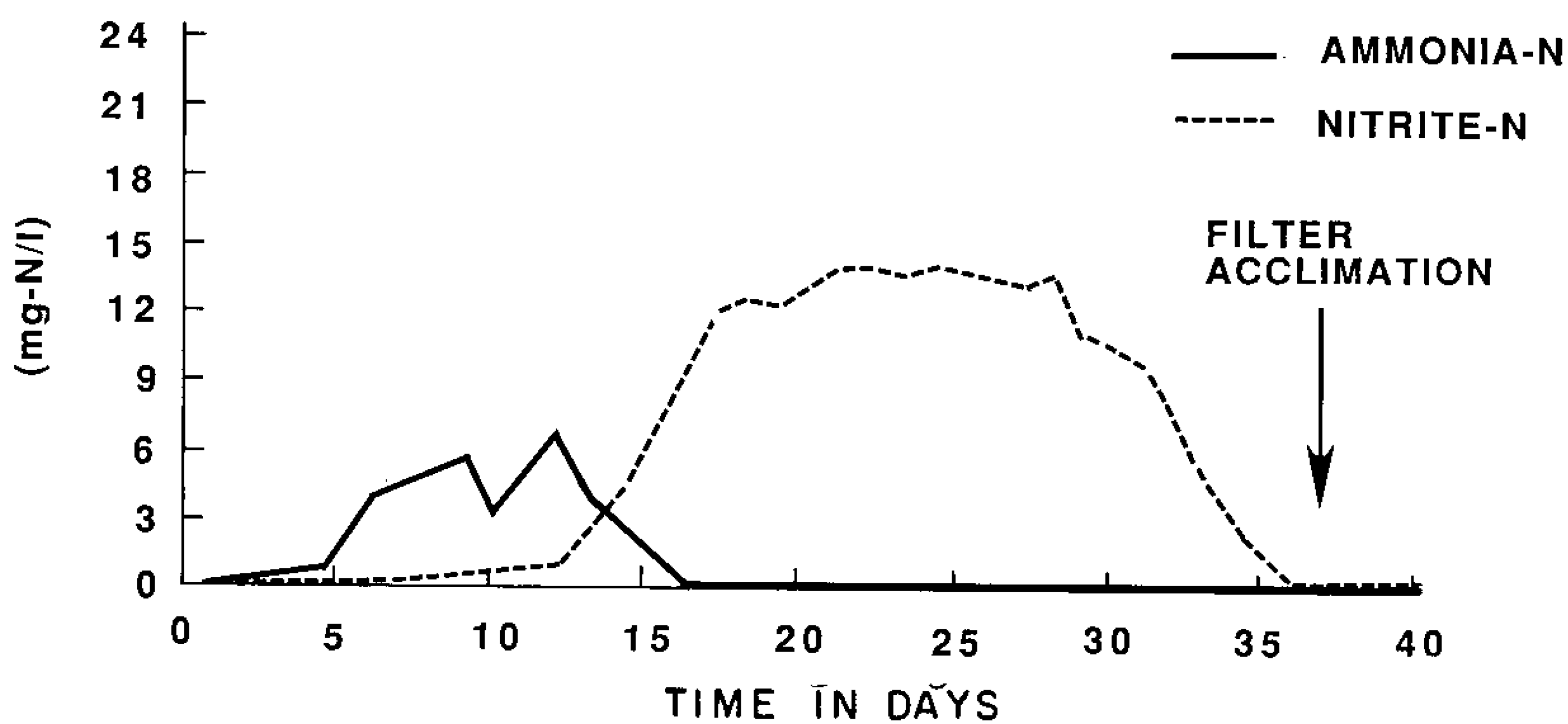

Figure 6.1 The ammonia and nitrite curves that result from acclimation of a biological filter with animals.

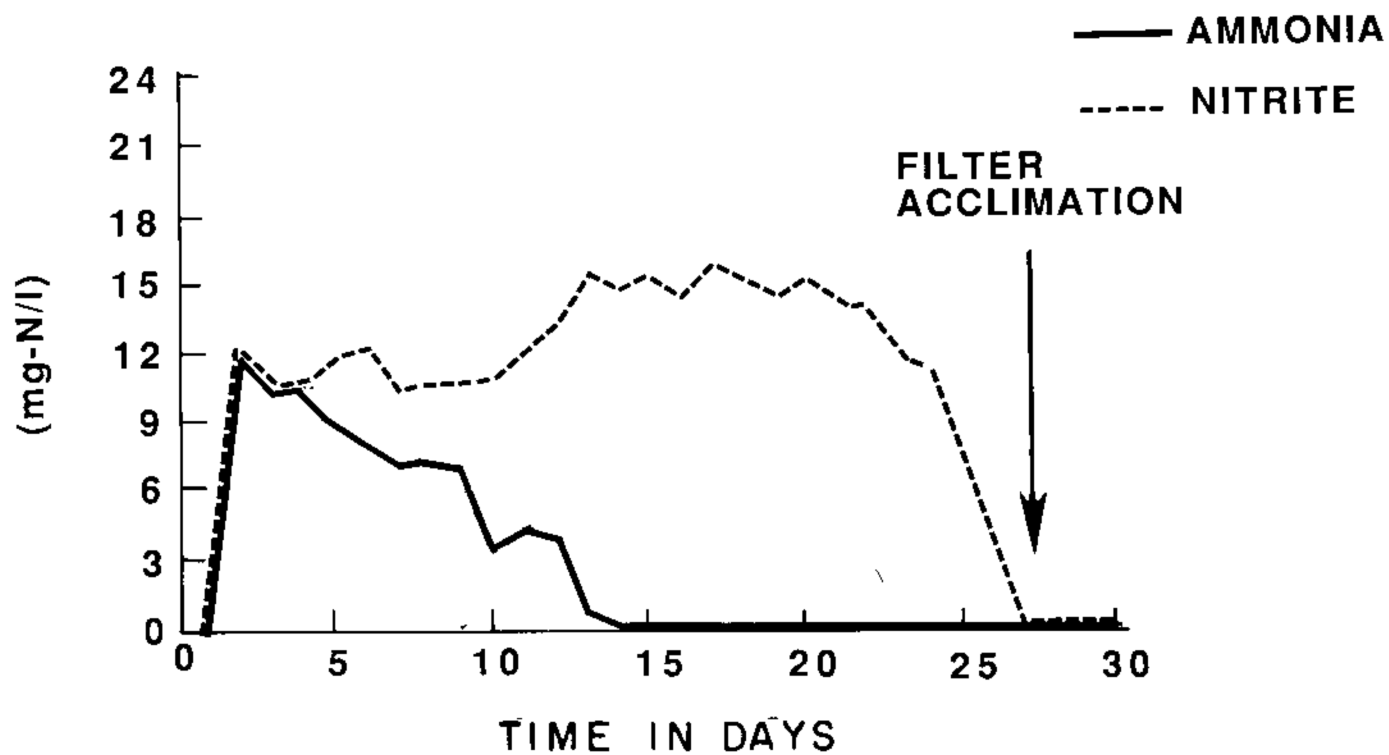

Figure 6.2 The acclimation with chemical addition is faster than acclimation with animals because nitrite is immediately available to stimulate the growth of the Nitrobacter species of bacteria.

to initiate the acclimation process. Upon completion of the acclimation, only a small amount of salt (NaCl) and nitrate (NO_3^-) remain as a residual in the system.

Acclimation of a filter will proceed faster if the bacteria are maintained under ideal conditions. The major factors controlling the growth rate of nitrifying bacteria were previously identified in Table 4.2. Temperature and pH are the most important controlling factors. If acclimation speed is critical, the biological filter should be kept warm and the pH should be raised to at least 8.0. Once the bacterial populations are established, all filters will perform similarly, regardless of the acclimation method.

6.3 Avoiding Shock Loading

All biological filters operate best when maintained with a constant population of animals. Shock loading is the most common cause of minor water quality disruptions. Sudden jumps in animal numbers in a system should be avoided. Short-term increases in ammonia (followed by a short-term increase in nitrite) will occur anytime the system population increases by more than approximately 10 percent per day. These transitional peaks of ammonia and nitrite take about three days to disappear. The larger the population increase, the higher the resulting peak. The reservoirs are added to the shedding system to neutralize this shock effect; however, each system has its limits. The operator must observe the effects of shock loading and then avoid excessive shocks thereafter.

6.4 pH Control

pH has a large impact on the rate at which the bacteria in the system function. Maintaining the pH in the range of 7.5 to 8.0 will assure that the bacteria operate effectively without seriously exposing the animals to ammonia toxicity. Systems equipped with sand filtration systems are subject to rapid pH drops, thus pH levels must be observed daily to assure maximum operational efficiency. The pH in all recirculating systems will drop since the nitrifying bacteria produce acids as part of the nitrifying process.

pH levels in a shedding system can be increased by one of two methods: mechanically or chemically. When mechanically raising the system's pH, first check for carbon dioxide accumulation. To do this remove a sample of water and promptly measure its pH. Next, place a small aquarium airstone in the sample and aerate the sample for about 30 minutes. Check the pH again. If the pH increases significantly, more than one-half a pH unit, then the system has accumulated carbon dioxide and its presence contributes to the pH decline. To raise the pH in the shedding system you must increase the rate of aeration in the reservoir or sump. This approach is effective only if the alkalinity (or bicarbonate levels) in the system remain high.

If aeration fails to raise the pH of the water then the alkalinity in the system probably has been exhausted and chemical addition must be implemented. Sodium bicarbonate ($NaHCO_3$ or baking soda) can be added to correct this situation. Addition of baking soda will raise the pH toward, but not over, 8.3. The authors estimate that for each 100 pounds of crawfish in a recirculating system, approximately 50 grams (1/9 lb) of baking soda are consumed by the nitrifying bacteria each day. Thus, a 1,000-pound shedding system requires approximately 1 pound of baking soda if the make-up water does not have high alkalinity. If this alkalinity is not replaced by intermittent water additions that compensate for evaporation, spillage, and loss of expansion waters, then alkalinity must be appropriately restored by chemical addition. Most systems filtered with sand filters require periodic addition of sodium bicarbonate to maintain alkalinity levels. Total alkalinity in a well-buffered system should be between 100 and 500 mg-$CaCO_3$/l. Do not add sodium bicarbonate if the pH in the sump is above 8.0.

6.5 Feeding

Feeding is an important requirement in any soft crawfish operation. Crawfish are normally fed twice a day using a low protein (25 to 35 percent) sinking food pellet. High-protein feeds should be avoided to eliminate unnecessary ammonia loading resulting from uneaten food. Furthermore commercial feeds which have the ability to break apart easily when placed in tanks should also be avoided since any food not eaten by the crawfish must be processed by the filters.

Overfeeding by operators is a major cause of the water quality problems (i.e., high ammonia and nitrite levels) observed in a commercial shedding system. Overall, the problems associated with overfeeding grossly outweigh those associated with underfeeding. The most accurate feeding method is based on crawfish weight. Five hundred pounds of crawfish should be fed less than five pounds of commercial feed per day.

6.6 Mortalities and Cannibalism

Crawfish mortalities will occur with any shedding operation as a result of natural causes, handling, transport, and poor water quality. Dead crawfish should be removed as soon as possible and not be allowed to remain in the system for lengthy periods of time. Dead crawfish which remain in tanks are quickly cannibalized and consequently contribute to the waste load on the system. The authors estimate that every dead crawfish that becomes cannibalized is equivalent to an additional 20 live crawfish (0.5 to 0.8 pounds) in a shedding system. Thus, if an operator allows 100 dead crawfish to remain in a system overnight, the actual waste load on the system increases by an amount equal to 50 to 80 pounds of live crawfish.

6.7 Periodic Water Quality Monitoring

Since recirculating systems are dynamic in nature, periodic monitoring is required to insure adequate water quality in the shedding facility. Monitoring usually consists of testing ammonia, nitrite, pH, alkalinity, dissolved oxygen, and temperature. A guideline for water quality monitoring based on these parameters is presented in Table 6.1.

Ammonia and nitrite monitoring is virtually mandatory with any recirculating shedding system. Most operators continuously check both ammonia and nitrite levels, especially during initial startup periods and also during periods of shock loadings. When systems are running smoothly, ammonia and nitrite levels should be monitored daily in both the holding trays and at the point that the water leaves the filter (commonly referred to as the effluent). Ammonia and nitrite test kits are very inexpensive and can be purchased from an aquarium shop.

pH testing equipment actually depends on the degree of accuracy that the operator wants to achieve. Simple pH monitoring can be done by using inexpensive litmus paper purchased from an aquarium shop. However, using litmus paper does have its disadvantages, since

Table 6.1 Summary of essential water quality parameters to monitor in a recirculating shedding system.

Parameter	Location	Guideline	Frequency
Total Ammonia	Trays	< 0.5 mg/l	Daily
Nitrite	Trays	< 0.5 mg/l	Daily
pH	Trays Sump	7.0 - 8.0 7.5 - 8.0	Daily
Alkalinity	Filter Effluent Sump	> 100 mg/l as $CaCO_3$	Daily
Total Hardness	Trays	> 50 mg/l as $CaCO_3$	Monthly
Dissolved Oxygen	Trays Sump	> 5.0 mg/l > 6.0 mg/l	Daily
Temperature	Trays	72 - 82° F (22 - 28° C)	Daily

the method is somewhat limited in accuracy. More accurate pH measuring devices include simple portable meters that operate on a nine-volt battery. These meters cost approximately $200. Monitoring for pH should be conducted on a daily basis in the sump (or sump/reservior) and at the filter effluent. pH readings must be taken directly in the system, since CO_2 gas will dissipate from samples transported for analyses, resulting in inaccurate high pH values.

Shedding operations which employ the new sand filter designs must periodically check the alkalinity, in addition to pH, to maintain an adequate buffering capacity in the system water. Weekly monitoring of alkalinity is usually conducted at both the sump and filter effluent locations. Alkalinity test kits, similar to the ammonia and nitrite kits, can also be purchased at a local aquarium store.

As previously mentioned, dissolved oxygen is also a critical water quality parameter. Dissolved oxygen levels are generally monitored in the trays and in the effluent water from the filters. Measurements should be made at least once a day. Although oxygen meters are quite expensive (typically $750 to $1000), they do provide the operator with valuable information concerning water quality particularly filter performance. Operators without dissolved oxygen meters are unaware of potential problems which may exist with filters particularly during periods of heavy loading.

6.8 Annual Maintenance

Upflow sand filters and fluidized beds should be operated for about one week with the system empty prior to shutting the system down. This procedure allows the bacteria population to run down, decreasing the biomass in the system during shut-down. The filters should be drained and left sitting damp during the off-season. Cleaning the sand filters is not required.

Sumps and reservoirs should be drained and rinsed at the end of the season to eliminate any solids that may have accumulated. Tanks that have been placed below ground may have to be refilled to prevent rising ground water from floating the tanks out of the ground or collapsing the sidewalls. Inside the shedding facility, all piping above ground should be drained to prevent freeze damage. Pumps should be inspected and serviced as required by their operation manuals.

6.9 Record Keeping

Recorded observations on water quality are an important aspect of successfully managing a shedding operation. By maintaining updated files on water quality data, operators can accurately determine where problems may possibly occur within the system given the guidelines within this manual. Recording daily observations on water quality may also give the operator insight on methods that may increase the production rate of soft crawfish in the system. A typical log sheet used for recording water quality and other miscellaneous data is presented in Table 6.2.

Table 6.2 Typical Log Sheet for Recording Water Quality and System Data.

Date	# Crawfish	# Premolt Mortality	#Molting Mortality	# Soft-Shells	Total Ammonia	Nitrite	O_2	pH	Temperature	Hardness	Alkalinity

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