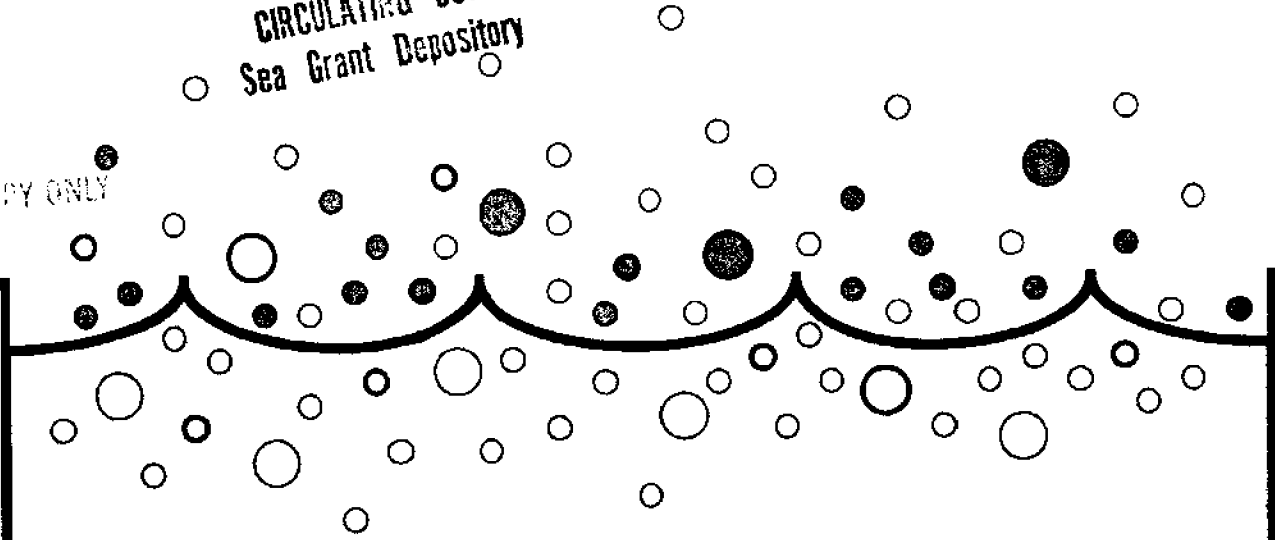


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**Guide to
Site Selection, Design,
and
Construction of
Dredged Material
Containment Areas
for
Aquaculture**

COOPERATIVE EXTENSION SERVICE • MISSISSIPPI STATE UNIVERSITY

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A Guide to Site Selection, Design, and Construction of Dredged Material Containment Areas for Aquaculture

U.S. Army Corps of Engineers (CE) has the responsibility to maintain, improve, and extend the navigable waterways of the United States. This gives the CE the regulatory responsibility for the dredging and disposal of over 450 million cubic yards of sediment annually from over 400 ports and 25,000 miles of coastal and inland waterways. Approximately 40 percent of dredged material generated from coastal dredging activities is placed into diked dredged material containment areas or DMCA (**confined, diked, or contained disposal sites/areas** are synonymous with DMCA).

An estimated 7,000 acres of new diked disposal areas are needed annually to replace those filled to capacity and to support new dredging projects. However, because suitable sites are often difficult and expensive to acquire, the CE and local dredging sponsors have an ongoing interest in programs that may help in making real estate available for DMCA construction. The adaptation of diked disposal areas for aquaculture is especially interesting because DMCA's and aquaculture ponds share many characteristics, including perimeter dikes, structures to regulate water levels, construction on impervious soils, and many similar permit requirements.

The construction of a confined disposal area that may also be used for aquaculture is a valuable commodity for the landowner. This increased value may provide an incentive for landowners to make more sites available for DMCA construction. This is the benefit to the CE of constructing a dual-use DMCA. The trade-offs are that alternative uses may affect site management and that additional construction and maintenance responsibilities may be incurred.

For the aquaculturist, the main advantage of containment area aquaculture is that capital costs may be significantly reduced. The main disadvantages are the interruption of production activities to accommodate disposal activity and sites may eventually become unusable as dredged material accumulates over time.

For landowners and local communities, the interaction of aquaculture with DMCA operations carries only benefits.

This report is part of a series of Extension documents and technical reports intended to make available to the public the technology developed for building and using DMCA for disposal and aquaculture. Most DMCA's are not generally suitable for aquaculture without substantial modification. This document provides a general overview of site selection, project planning, and construction needed to develop a DMCA for dual use as disposal sites and aquaculture ponds.

Dredging, Disposal, and DMCA

There are two important points to remember in planning for DMCA aquaculture. **First**, DMCA aquaculture can only take place in newly constructed facilities. This is the only way in which the benefit of making new disposal acreage available for DMCA construction can be realized. Unless an idle disposal area is brought back into use, refitting existing sites for aquaculture is not an option.

Second, the primary purpose of a diked containment area is to receive and retain dredged material. Aquaculture is the secondary or alternative use of any containment site. Site designs and operational requirements for aquaculture must allow for required dredged material disposal and site management without impediment.

For material disposal and aquaculture to be successful, the containment area site must be selected, designed, and constructed with primary- and alternative-use needs in mind. Those planning such multiple-use DMCA's must be familiar with current containment area siting, design, and construction requirements in order to incorporate compatible modifications for aquaculture.

Dredging and disposal operations under the authority of the CE are conducted according to specific guidelines. Criteria and procedures for the siting, design, construction, and operation of such facilities have been established (U.S. Army Corps of Engineers 1987). It is essential that these guidelines be consulted before considering aquaculture as an alternative use.

Confined disposal areas receive hydraulic dredge effluent, the combined mixture of dredged material solids and overlying water from the dredging site, retaining the solids while allowing the clarified water to be released. Containment areas are designed and operated to meet two objectives: a) to provide adequate material storage capacity for the dredging requirements of the project and b) to effectively retain solids in order to meet established effluent suspended sediment guidelines (Palermo 1988). These objectives are interrelated and dictate the design, operation, and management of the containment area from the CE viewpoint.

While project-specific characteristics make each confined disposal site unique, the main design components of a DMCA are shown in Figure 1. A tract of land is surrounded by dikes to form the containment area. The discharge pipe from a hydraulic dredge is positioned to provide the inflow of dredged sediments and water at one end of the structure. Coarse

material (greater than No. 200 sieve) rapidly falls out of suspension, forming a mound near the inlet pipe. While fine-grained materials remain in suspension for longer periods, they settle out as the discharge flows through the contain-

ment area. The clarified water is discharged from the containment area over a weir. The elevation of the weir crest controls the depth of water within the DMCA. Maintaining appropriate depths promotes the effective sedimentation of solids.

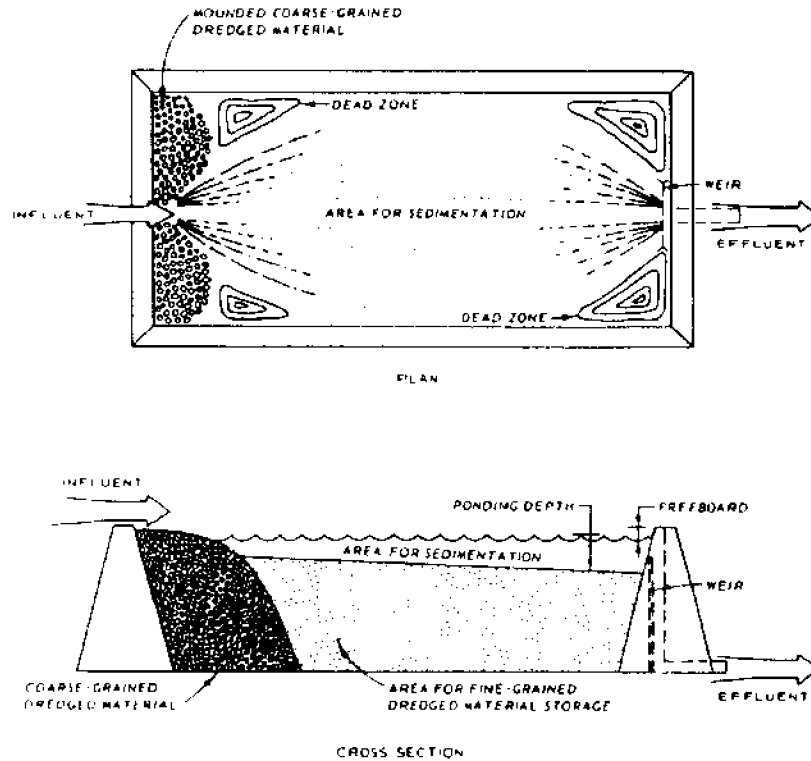


Figure 1 from U.S. Army Corps of Engineers 1987

Spur dikes, which extend into the disposal area, are common in a DMCA. They are often used to break up the flow of incoming water, preventing channelization and increasing sedimentation by reducing flow velocity and directing flow to hydraulically inactive "dead areas."

Long-term storage capacity is a major concern in the design and operation of a DMCA. In most cases, DMCA's are used for many years, storing material from repeated dredging cycles. Over time, the thickness of the deposited material increases, eventually filling the available volume. Sites are managed to consolidate the retained material. This increases storage capacity and extends the design life of a containment area. Natural drying and active measures, such as trenching, assist in the drying and consolidation processes. Once the sediments are properly consolidated, they can be reflooded without losing compaction. The incorporation of site management strategies affects the design and operation of a DMCA. They may also modify, or even preclude, use of the DMCA for aquaculture.

Selection and Evaluation

Selection and evaluation of an area for dual use (material disposal and aquaculture) can be viewed as a four-step process. The first two steps are closely related and may not be clearly distinguishable in all cases.

The first step is to determine concept feasibility. Dual-use (material disposal and aquaculture) structures can be feasible only where DMCA's are used or planned, where there is a need for additional DMCA acreage, and where there is interest in the concept by the CE. Next, compatibility of the proposed aquaculture operations with disposal requirements must be established. Aquaculture operations that do not substantially interfere with the use of the site for dredged material disposal will generally meet the compatibility requirement.

The selection and evaluation of candidate sites can proceed once feasibility and compatibility have been established. First, areas useful for confined disposal sites within the dredging project area are identified and their suitability for DMCA

construction is determined. Aquaculture suitability is then determined for those sites found suitable for DMCA construction.

Concept Feasibility

The evaluation of a DMCA aquaculture project feasibility requires close coordination with the responsible CE district. Four factors will determine initial feasibility:

1. There are active dredging projects that use DMCA for disposal.
2. Additional diked disposal acreage is needed.
3. Interest in developing a dual-use DMCA exists at the district.
4. Aquaculture allows consideration of sites otherwise unavailable.

A presentation of the project to responsible CE district personnel will determine feasibility for the first three points. The CE and the dredging sponsor can identify sites whose owners may be interested in developing a dual-use disposal area. Support from the CE district at this stage is essential.

Compatibility of Operations

Support from the CE and the local dredging sponsor is essential for determining the compatibility of aquaculture in a DMCA. Detailed information about the dredging project, for which confined disposal areas would be built, must be

assembled from the responsible CE district and port or waterway management agency. This information will serve to establish the compatibility of planned aquaculture activities with project disposal requirements and to identify potential DMCA sites.

At least the following project information will be needed:

- Project locations that would require additional confined disposal areas, along with potential sites for such areas.
- Project schedules, particularly the frequency and duration of dredging cycles.
- Restrictions, if any, on dredging to specific times of the year.
- Volume of material to be removed per dredging cycle and capacity/projected life of a given confined disposal area.
- Physico-chemical characteristics of the material to be dredged, including the presence (and amounts) of any contaminants of potential concern or a "reason to believe" that contaminants may be present (Tatem 1988).
- DMCA design specifications, including location of dredge discharge point, spur dikes.
- DMCA management strategies for increasing site capacity (dewatering, raising dikes).

Site Suitability for DMCA

Criteria and procedures for the siting, design, construction, and operation of diked disposal areas have been established. Table 1 summarizes the main points considered in evaluating a site for construction of a confined disposal area.

Table 1. Summary of dredged material containment area site selection factors.

Factor	Criteria
Land use	Material disposal should be compatible with adjacent land use.
Water quality/hydrology	No long-term effects on water quality.
Soil characteristics/geological conditions	No leachate migration to groundwater; good foundation soils.
Meteorological conditions	Sites not subject to flooding, runoff, extreme winds.
Access	Construction of access routes possible.
Environmental concerns	Environments and historical features of the area must be protected.
Social	Public input required for sites near populated areas.
Institutional	Regulations on material disposal and land use must be identified.
Economic	Costs of building and operating site, environmental protection, pumping/transportation acceptable.

Containment areas are designed and operated to meet two objectives: a) to provide adequate storage capacity for the requirements of the dredging project and b) to effectively retain solids in order to meet established effluent suspended sediment guidelines. These objectives are interrelated and dictate the design, operation, and management of the containment area. The U.S. Army Corps of Engineers (1987) reviews the DMCA design procedure in detail.

Site Suitability for Aquaculture

Site evaluation for aquaculture should be a part of the DMCA site selection process, requiring coordinated planning with the CE district. Data on soils, topography, and other important site characteristics will be available at the CE district office. The Soil Conservation Service (SCS) can frequently provide information on site soils, topography, local climate, and other valuable data. The SCS may also be able to evaluate the suitability of a site for pond construction, to assist in planning on-site surveys, and to provide valuable professional advice.

Site selection for aquaculture involves the assessment of numerous physical variables. In most cases, budget constraints preclude all but the most essential soil tests and engineering analyses. In DMCA aquaculture, however, data will have been generated by the CE in evaluating the site for construction of a confined disposal area. Use of this information will improve the quality of site engineering while significantly reducing time, effort, and cost to the aquaculturist.

While this report provides an overview of site selection, design, and construction, additional information is worth searching out. The CE technical reports on containment area aquaculture (especially Wilson and Homziak 1989, Tatem 1990, Homziak and Veal 1991) are valuable resources. Reviews in FAO/UNDP (1984), Huguenin and Colt (1989), and Wheaton (1977), among others, are excellent sources of aquaculture project design and engineering information. Species culture guides, published by state Cooperative Extension Services, the USDA Regional Aquaculture Centers, or Sea Grant programs, frequently cover commercial design and construction procedures. Local offices of the Soil Conservation Service also provide information on site selection, soil testing, pond design, and construction. The SCS has published a number of useful guides on pond design and construction (Soil Conservation Service 1969, 1971a, 1971b, 1982).

Where aquaculture is well established, such as in the Deep South catfish belt or the Louisiana crawfish region, both public (Cooperative Extension Service, Soil Conservation Service, University) and private sector expertise in planning, design, and construction is available. Where aquaculture is a novel industry, however, it is up to the individual to seek out expert assistance and to become familiar with the basic principles of site selection, pond design, and construction.

Aquaculture Evaluation Checklist

The following checklist was developed by Wilson and Homziak (1989) to assist with the aquaculture site selection

process. These are minimum, suggested requirements to be investigated. Additional site-specific or project-specific items may be required.

I. Background work

1. Determine feasibility of dual-use DMCA. Contact the CE and solicit their cooperation. Contact project sponsor to establish support.
2. Determine project locations that require additional DMCA.
3. Identify and secure all relevant documents and maps, and identify information resources.
 - a. Large-scale base maps.
 - b. Topographic maps.
 - c. Aerial photographs.
 - d. CE dredging project documents.
 - e. Port management plans.
 - Postdisposal evaluation report.
 - Environmental reports and assessments.
 - Project documents, including previous projects in area.
 - Construction and project specifications and invitations for bids.
 - f. Contacts and information sources.
 - Permit and review agencies.
 - Site owners and landowners along access routes.
 - Dredging contractors.
 - Local economic development assistance groups.
 - Other aquaculture operations in local area.
4. Review culture techniques and biology of the target species.
5. Develop preliminary production and business plans.

II. Preliminary survey

1. Locate all candidate sites in the area.
2. Determine dredging schedule, season, and length of time site will be used for disposal.
3. Determine access, power supply lines, and other services basic to site.
4. Determine characteristics and volume of material to be deposited at site.
 - a. Estimates of "in place" sediment volume.
 - b. "In place" void ratio or water content.
 - c. Specific gravity of material.
 - d. Degree of saturation.
 - e. Coarse-grained fraction (No. 200 sieve).
 - f. Settling behavior of the material.
 - g. Contaminant status (present, reason to believe, absent).
5. Evaluate current soil characteristics at site.
 - a. Soil classification.
 - b. Soil particle size and shape.

- c. Permeability/porosity of soil.
- d. Percent clay content.
- e. History of contamination (agricultural, industrial).
- 6. Evaluate hydrological properties of source water (monthly means, ranges, monthly and annual minima and maxima).
 - a. Temperature.
 - b. Salinity.
 - c. Tidal range (average and maximum).
 - d. Solutes.
 - e. Nutrients.
 - f. Dissolved gases.
 - g. Contaminants, agricultural runoff, sewage, wastewater.
 - h. National Shellfish Sanitation Program (NSSP) classification (for surface marine water sources only).

- a. Soil type.
- b. pH.
- c. Eh.
- d. Organic carbon.
- e. Cation exchange capacity.
- f. Engineering data.
- 6. Site-specific meteorology and climate.
 - a. Water budget (rainfall, evapotranspiration).
 - b. Wind data (direction, average speed, maxima).
 - c. Tidal data (cycle, maximum and minimum heights).
- 7. Site-specific management plans.
 - a. Proposed future site refurbishing plans.
 - b. Dewatering.
 - c. Future dike elevation methods.
 - d. Borrow area placement.
 - e. Other management requirements.

III. Evaluate disposal operations data

1. Frequency of disposal operations.
2. Duration of site closure.
3. Season(s) or months of year dredging scheduled (include regulated restrictions).
4. Discharge rate, net volume retained.
5. How long will site be used?
6. Determine if new work or maintenance work.
 - a. If new work, repeat evaluation of dredged materials and site design for maintenance work conditions.
7. Compatibility of site for disposal of dredged material and aquaculture based on dredging operations schedule.

IV. Evaluate disposal site data

1. Foundation conditions of base strata.
 - a. Depth.
 - b. Thickness.
 - c. Extent.
 - d. Composition.
2. Groundwater conditions.
 - a. Depth.
 - b. Hydraulic gradients.
 - c. Down gradient use.
3. Site location and topography.
4. Proposed disposal area design.
 - a. Dike dimensions.
 - b. Weirs (number and placement).
 - c. Spur dikes.
 - d. Intended ponding depth.
 - e. Average height (consolidated) of each lift of material.
 - f. Intended storage capacity of site.
 - g. Other features.
5. Soil properties (for new disposal site; repeat for material after disposal).

Project Planning and Design

Design considerations. The success of any production system in industry and agriculture relies heavily on good design and construction. On the other hand, even the best management techniques can do little to improve production in poorly designed and inadequately constructed systems. Aquaculture ponds are no different. Remember, avoidable mistakes in pond design and construction are the most common reasons for the failure of aquaculture ventures.

While the objectives of pond production systems vary widely, all depend on the same biological and technical bases. However, neither a good understanding of biology nor engineering alone is likely to result in a practical system. Success depends on a blend of expertise in these and other disciplines.

It is not uncommon in aquaculture projects for major design decisions to have been made and fixed before seeking engineering assistance. This can be a serious problem that may threaten project viability or add considerable cost to the operation. Professional advice in the site selection, design, and construction should be sought early. Coordinated decision making is even more important in containment area aquaculture where site selection, design, and construction inputs from the local CE district are essential to project success.

Planning outline. An outline of the planning process, adapted from Kovari (1984) and Huguenin and Colt (1989), is presented below. Project preparation and planning should include the following steps:

1. Identification of the project; a broad outline defining species cultured, culture system, and production target.
2. Feasibility plan.
3. Detailed production plan.
4. Preparation of cost estimates.
5. Preparation of contractual documents.

A simple flow chart (Figure 2) serves to illustrate the aquaculture design process. This chart serves as a summary of the processes detailed below.

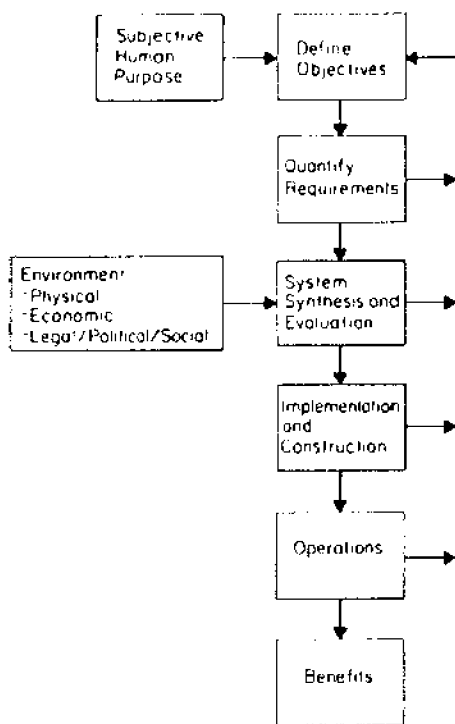


Figure 2 from Huguenin and Colt 1989

Identification of the project. The first steps in project planning are the definition of the project, identification of project objectives, and a broad concept of the design of the production facilities. This is an integral part of the site selection and evaluation processes for any project.

Decisions regarding project objectives are incorporated first into the feasibility plan and finalized in the production plan. While these decisions are subject to change as the project plan evolves, it is important they be carefully considered at each step of the process. It is these decisions that will progressively guide the project design.

Project preparation is usually considered to include all of the activities short of the decision to implement the project. A critical first design step is the definition of project objectives. Because all current and future project needs must be considered, all explicit and implied assumptions included in the project objectives must be clearly identified. Multiple use of a DMCA requires multiple goals. It is important to order priorities and resolve conflicts in order to arrive at design decisions. Since disposal of dredged sediments remains the primary focus of DMCA use, the aquaculturist must fit and adapt the aquaculture pond design and management process into this procedure in order for dual use to be possible. Other factors, such as successive disposal events, will alter the

DMCA site in ways that will affect long-term dual use. These modifications must be quantified and planned around.

Project objectives and physical data for a particular site are linked during the design process. Decisions (including future plans) regarding species to be cultured, site characteristics, farm size, water sources and anticipated demands, stocking densities, production cycles, management options, access and utilities provisions, equipment and supply needs and maintenance, reliability and replacement schedules, and others must be made early and in detail. As these project decisions are combined with information developed during the planning process, broad objectives will be refined into increasingly detailed statements that are successively incorporated into the plan. The apparent redundancy in the planning process outlined below reflects the progressively complex nature of the decision making.

Feasibility or outline plan. The purpose of the feasibility plan is twofold. The first function is to confirm that the project can be developed at the selected site. The second is to collect and provide all data, calculations, and plans needed for project approval and detailed planning.

Both the feasibility and the production plans are based on the number of steps in the production cycle, the amount of time required to complete these steps, and the survival and growth rates expected in each step. This information is used to calculate values for all of the major variables (e.g., water volumes, inflow and outflow, feed and other inputs, production level and timing, labor) employed in the planned production process. Other factors, including environmental conditions, technical variables, skills of personnel and others, will affect the estimates of these variables. Because all of these factors and variables are interdependent, tradeoffs will be necessary between production goals and water quality, stocking densities, operational procedures, feed requirements, equipment needs, economics, and levels of acceptable risk.

The following data and maps should be available for the selected site.

1. Maps

- a. Contour maps (1:25,000 to 1:50,000).
- b. Map showing legal ownership.
- c. Soil or geological map.
- d. Water resources map, including surface water sources, dry water courses, wells, water tables, and aquifer water characteristics and yield estimates.
- e. Climatological map showing nearest meteorological stations and mean monthly values of temperature and rainfall.

2. Meteorological data, mean monthly rainfall, evaporation humidity, wind speed and direction, and sunlight (solar radiant flux)

3. Hydrological data

- a. Measured well yields, flood and water elevations for existing water sources, including any data on restrictions or competing uses.
- b. Tidal data for marine/brackish water sites.

The feasibility or outline plan is usually the basis for permit applications and for securing external financing for the project. The plan should illustrate the technical feasibility of the project. Production calculations and design should be presented in sufficient details to allow for reliable cost estimates to be made. The main parts of the feasibility plan areas include:

1. **Report.** This should contain the most important information on the project, including a site description, soil characteristics (determined during the survey and assessment phase), water sources and results of water analysis, pond discharge estimates, and meteorological data used in planning. The report should provide the proposed operations plan with production calculations, planning considerations, site layout (with roads, buildings and other facilities), arrangements of the water supply, and drainage. An abstract of capital, operational and production costs, analysis of benefits, and the proposed construction program should be included. A list of legal documents acquired or applied for to allow the project to proceed should be appended as well.
2. **Maps and plans,** including:
 - a. General location map (unscaled);
 - b. Site map (scale 1:2000 to 1:5000, depending on project size), showing boundary lines, project site, existing features, contour lines, water source and drainage locations, and the locations of soil test pits;
 - c. Layout map (scale 1:1000 to 1:5000), showing arrangement of ponds, water supply and drainage systems, locations buildings and other works, proposed approach roads, and utility lines.
3. **Structures.** A list of all proposed buildings and their plinth areas and a list of equipment needed for the project.
4. **Soil and water tests.** Soil and water test results for engineering and production calculations, in tabular form.
5. **Cross-sections.** Typical outline cross sections of dikes and channels, showing slopes and dimensions.
6. **Cost estimates.** Cost estimates for civil works, showing major quantities and unit rates for each item (buildings, structures, earth work, utility supply, engineering, equipment, and physical contingencies. Estimates of operational costs and production costs should also be provided.
7. **Schedules.** A project schedule, based on project characteristics and quantity calculations, should show the time required for the activities required to complete the detailed plans.

Once the feasibility plan has been completed and approved, the data should be reviewed and any deficiencies should be corrected. Any modifications to the proposed operating schedule, water management needs and water calculations should be completed before detailed planning starts.

Detailed Plan

The detailed or final plan includes the modified and corrected version of the feasibility plan plus the production plan, final site plans and layout, cost and quantity estimates, completion schedules, and project organization and supervision.

Production Calculations

Project designs depend on the type of farm under development and the scale. Production calculations based on the production plan are the core of the planning process. These calculations usually contain the information presented below (taken from Kovari 1984), prepared for a planned fish farm.

1. **Production facility**
 - a. Production target.
 - b. Culture method.
 - c. Species cultured.
 - Stocking rate.
 - Initial weight.
 - Harvest weight.
 - Survival rate.
 - d. Requirements for broodstock, fry, fingerlings .
 - e. Seed stock sources.
 - Reliability.
 - Quantity.
 - Quality.
 - f. Feed requirements.
 - Types.
 - Storage and delivery.
 - Feed conversion.
 - g. Fertilizer.
 - h. Pond management.
 - Water quality standards.
 - Retreatment needs.
 - Aeration.
 - Treatment of effluent.
 - i. Pond specifications.
 - Types of ponds.
 - Size and number of ponds.
 - Water depths.
 - j. Harvesting specifications.
 - Methods.
 - Schedule.
 - Facilities.
 - k. Operations plan.
 - l. Marketing plan.
2. **Hatchery**
 - a. Production goals.
 - b. Proposed technology.
 - c. Operations plan.
 - d. Facility specifications.
 - e. Management requirements.

Plans and Drawings

The arrangement of an aquaculture facility has a major influence on construction and operating costs. The locations of ponds and other on-site facilities must be considered in the context of the production plan. The relative positions and orientation of various ponds will be determined by the management needs of the production system and by their relationship to water supply, drainage system, power supplies, and road connections. Topography and the location of wells, drains, or other water sources also influence layout.

There are other considerations that will also affect the arrangement of the facility. The farm center, which consists of operating buildings, storage, repair shop, and other structures, should have good all-weather road access. Facilities requiring frequent visits, such as feed storage, hatcheries, nursery ponds, holding ponds, or pumping and generating stations, should be located close to the farm center. Any facilities used for harvesting or storage of harvested fish should have all-weather access. Adequate lighting should be provided for security and to allow for night operations, if needed. Security considerations, including fences, watchman's quarters, etc., and communications should be included in any site design.

Once the data have been assembled and the necessary design computations have been completed, detailed drawings of the designs must be prepared. See Homziak and Veal (1990) for a complete listing of recommended data needed for planning a DMCA aquaculture facility. These drawings should include the following:

1. **Location, boundary, contour, and land maps.**
2. **Layout plan.** This should show all establishments on the site. It must also show all planned structures and their locations. Characteristic data of the structures must also be provided. Buildings' characteristics (with floor levels, measurements) should be located on a separate layout. The relationship of the buildings to internal roads and utility connections should also be shown.
3. **Setting out plan.** This plan includes all elevations, reference lines, measurements of all structures, and locations of all cross-sections to insure adequate marking of earthworks prior to construction. The plan should be adequate to peg out the center lines of the dikes and canals.
4. **Cross- and longitudinal sections.** See Homziak and Veal (1990) for requirements for cross- and longitudinal sections.
5. **Detailed structural drawings.** Drawings of all hydraulic structures, including water control and distribution, pumping station, predator filter, harvest basins, and other structures, should be prepared. This should show all measurements and elevations, connections, and materials. The reinforcement plan should provide all essential details (e.g., quality, shape, diameter, number) of the required reinforcement. Additional detailed plans should show the installation plans for the pumping station, predator screen, generating station, and other structures in similar detail.

6. **Hatchery and other buildings.** Detailed plans should include the layout, with details of equipment and facilities. Plumbing and Electrical plans for all buildings supplied with utilities should also be provided.

Cost and Quantity Estimates

Site data, combined with the production plan, form the basis for the final project design and bid estimates. Accurate collection, analysis, and interpretation of these sample data are critically important. Once the plans have been completed, the cost of the work must be evaluated. This requires the preparation of cost estimates from the plans and specifications discussed previously.

Estimating costs is a multistage process. First, a complete estimate of the quantities of materials that will be required is made from the plans and specifications. A detailed estimate of the cost of everything required to complete the work is then made. Finally, a complete estimate of all costs associated with the project is made; this includes all costs related to the project work, in addition to the detailed estimate of the actual project work; these may include items such as survey work, laboratory analyses, engineering support, preparation of plans and drawings, labor and supervision, land costs, permit fees, and other costs incurred in addition to the main contract.

For clarity, detailed estimates follow a general outline. An abstract of the cost includes the name of the project, the date of preparation, and the cost of the main subheadings (engineering costs, equipment, land and others, including contingencies). The estimated cost is prepared by multiplying the quantity estimate by the specified rate in a standard format or abstract form. Depending on circumstances, various percentage charges may be added to cover other associated costs, such as charges for tools.

Subheadings of categories are usually required to simplify preparation and inspection. Each subheading contains similar items of work. Common subheadings for aquaculture include:

1. Site clearing and preparation.
2. Earthwork (excavation, fill, dress).
3. Concrete and stone work (includes reinforcing work, forms).
4. Woodwork and carpentry.
5. Metalwork.
6. Roofing.
7. Water supply, plumbing, and sanitary work.
8. Electrical and lighting.
9. Finishing.
10. Miscellaneous.

Applicable rates must be established to determine costs of materials, labor, and equipment. The rate per unit of an item consists of the quantity of material and the cost, the labor cost, the cost of equipment and tools allocated to an item of work, overhead charges, and profit.

Measurement of all structures and buildings should be taken as per standard specifications to estimate quantities. Measurement of earthwork quantities can be calculated from cross- and longitudinal sections and other relevant drawings. The calculations follow the formulas given in Homziak and Veal (1990).

Organization and supervision. Because of the importance of completing construction on time and within budget, the work has to be organized. Adequate supervision must also be provided to insure that all the work is being performed in accordance with plans and specifications. Further, the duties and responsibilities of the supervisory engineer, owner or owner's representative, and various contractors need to be clearly defined. Because of the importance of this aspect of project development, it is strongly recommended that the procedure outlined by Homziak and Veal (1990) be reviewed.

Review of Pond Design Criteria

Physical Factors

Topography. Diked ponds are formed by building a dike to impound water. Most DMCA aquaculture ponds will be of this type. Land surfaces with a moderate slope in one or two directions are preferred. Areas with low slope, 1 to 5 percent, are suitable for pond construction, but slopes of 2 percent or less are preferred. Moderate slopes simplify delivery of water and gravity drainage of ponds. Topography around ponds should allow gravity drainage of the pond in any season. Water heights in external ditches and adjacent water bodies should be lower than the pond drain, even under expected high-water conditions.

Site surveys should be done by professional survey staff or in cooperation with the local Soil Conservation Service office. The survey should confirm the project boundaries and establish reference points for levelling operations and for the location of site facilities. It should also show all features and structures that exist on site.

Soil. An important consideration in designing aquaculture ponds is that the low earth dikes do not warrant expensive tests in soil laboratories. Soil properties for dike construction at DMCA sites will have been evaluated by qualified engineers. Soils that are adequate for the construction of containment dikes also will suffice for dikes modified for aquaculture. However, a qualified aquaculture engineer or a specialist from the Soil Conservation Service should review soil data. Soil data should be collected as early as possible in the initial site evaluation and selection process.

Sandy clays to clay loam soils are best for pond construction. Collect sufficient samples to determine that conditions are appropriate for pond construction. One or two sample stations for each 2 to 5 ha of site area are appropriate for homogenous soil conditions. More stations will be needed under variable soil conditions. The depth of the bore hole should be a minimum of 2.0 m below the deepest intended excavation in the project area. Advice on the appropriate num-

ber of samples for variable soils should be sought from the Soil Conservation Service or from a professional engineer.

Soil data should identify soil stratification throughout the pond area, under the dikes, along the routes of any canals, and at the site of any proposed structures. At a minimum, the data should be sufficient to estimate seepage losses (bottom and dike), foundation conditions for dikes and structures, risk of seepage and piping, degree of compaction, allowable flow velocities in canals and intake basins, and erosion potential.

In addition to soil information, the data should include information on chemical contaminants at the site. Tatem (1990) reviews procedures for evaluating contaminant levels at DMCA aquaculture sites. Information on groundwater conditions at the site may also be determined during the soil sampling.

Water. Planning an aquaculture system requires that adequate water be available for initial and future needs. Future needs include any planned expansion of the facility, changes in species cultured, or management intensity. Information on water supply and quality should be available from the initial site survey. Evaporation and precipitation rates may be estimated from local agricultural and aviation weather data.

Ponds must be sited and designed to protect them from excessive runoff and flooding. Access to the site may also be subject to runoff and flooding, influencing both site design and production options.

If surface water is to be used in filling the pond, the water quality of the intake water at the times that ponds would be filled should be known. The location and physical characteristics of the source body should also be known, especially with regard to fluctuations quality and quantity with season, rainfall, and other factors. Sufficient water for filling ponds must be available at the appropriate times. Variations in water quality and quantity influence the location and siting of intake pumps, water distribution systems, design of the predator control filters, and the need for storage reservoirs, sedimentation basins, and other structures.

If wells are the primary water source for the facility, information on aquifer depth, available volume and water quality of subsurface water sources is needed. This information will influence production plans and the facility design: the number and location of wells, power sources for pumps, design of water distribution systems, need for water storage or settling lagoons, aeration requirements, and other important components.

Legal aspects of water withdrawal and discharge must be known before the site design is finalized. Have in hand permits that specify the volumes of water that can be withdrawn and discharged before construction proceeds. Regulations governing entrainment of aquatic species may constrain pumping by requiring pumps to be screened or by limiting the volume, timing, or duration of water withdrawals. Similarly, regulations governing water quality of farm discharge must be taken into consideration before production plans and site designs are finalized.

Sites to be used for shellfish culture (oysters, clams) face additional water quality concerns. Ideally, the intake waters for a shellfish farm should meet National Shellfish Sanitation Program (NSSP) standards as approved waters for unrestricted harvesting of shellfish (U.S. Department of Health and Human Services 1989). The alternative, the use of conditionally approved waters for shellfish culture, opens the shellfish enterprise to the risk of periodic and unpredictable restrictions on the harvest of cultured shellfish. Similarly, the

occurrence of toxic algal blooms may force the closure of shellfish harvesting. Information on the occurrence of either situation is essential in siting a shellfish farm.

Domestic water and sewage requirements also need to be considered. Consult local building regulations in meeting sewage and waste disposal requirements.

Pond configuration. Figure 3 shows a general pond layout, while Figure 4 shows a more complex (and typical) design.

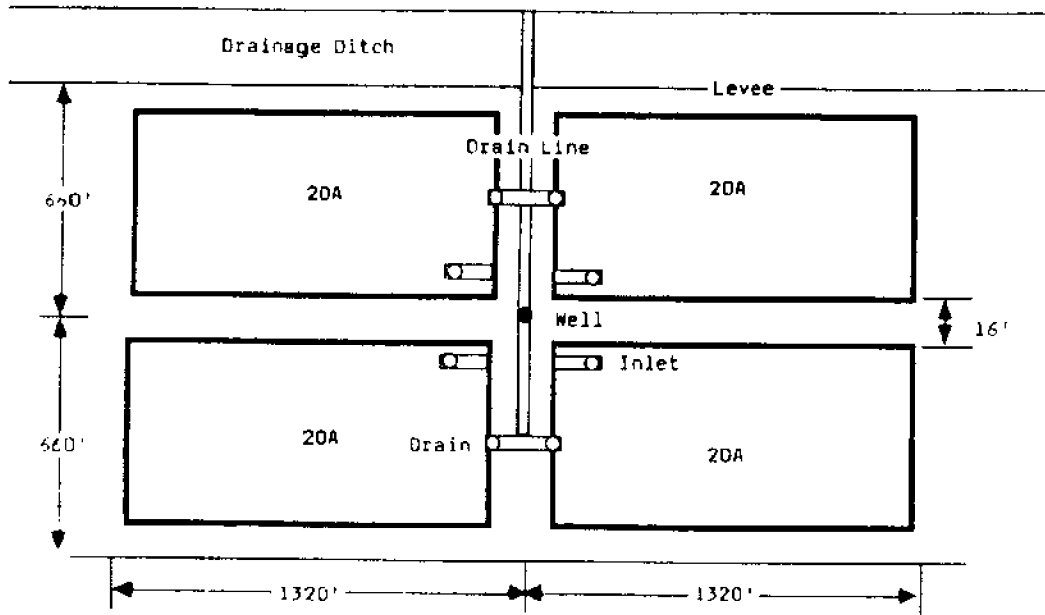


Figure 3 from Wellborn 1989b

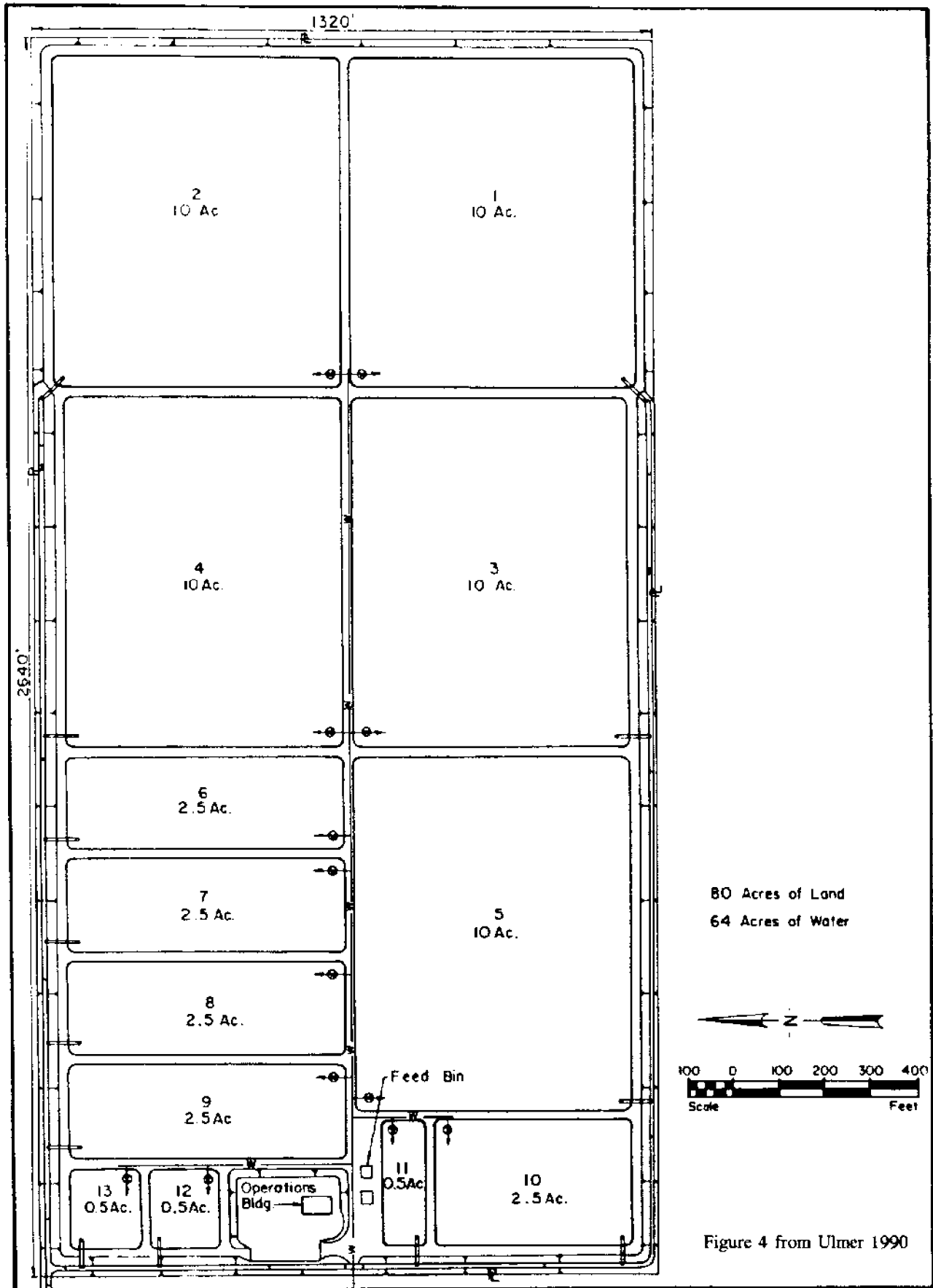


Figure 4 from Ulmer 1990

Aquaculture facilities may contain a number of ponds performing different functions. Depending on their function, ponds will be of different sizes and depths, as illustrated in Figure 4. Ponds may be for phased grow out, multistage production, holding brood stock/breeding, nurseries, water storage, or other uses. The relative positions and orientation of various ponds will be determined by the management needs of the production system and by their relationship to water supply, drainage system, power supplies, and road connections. Each pond should have separate drain and fill connections; drain and fill water should not be allowed to mix. These considerations will influence the general arrangement of the farm.

Pond bottoms should slope towards the drain with a minimum horizontal to vertical slope of 1000:1. Preferred slopes range from 1000:3 to 1000:6. A branching network of shallow ditches draining towards the outlet can facilitate drainage in large ponds that are difficult to grade. Avoid areas less than 1 m deep under normal operating conditions. Except for crawfish culture, the growth of rooted aquatic vegetation in fish ponds should be minimized.

Ponds can be designed for drain harvest or for harvest by seining or trapping. Drain-harvested ponds may incorporate an internal harvest basin near the pond drain. As the pond drains, fish will be collected in this basin, facilitating harvesting. Other designs incorporate an external harvest basin that will be discussed in the section on harvest structures.

Pond size. The main factors affecting size are dredging project requirements, species cultured, management requirements, and cost considerations. Size and shape of ponds can be defined by production purpose, management level, risk, marketing schedule, harvesting method, and cost considerations. The expected level of production levels is an important factor in determining pond size. Most production guidelines suggest completing the drain harvest of individual ponds in one day to reduce the possibility of deterioration or loss of the crop.

Construction cost per unit area declines with increasing pond size. This is because the area occupied by dikes and channels declines in proportion to pond area. Building five 10 ha ponds will require half the number of water control structures than ten 5 ha ponds. Both provide an effective 100 acres of pond surface. Construction costs also may be lowered by orienting the ponds so the long sides are parallel to the contour of the land, reducing cut and fill costs. While small ponds are relatively more costly to construct, they are more amenable to more intensive management efforts. Some culture systems (e.g., bait fish) require small ponds.

Dikes. The dikes of aquaculture ponds must be safe and stable during all phases of construction and operation. The design requirements for confined disposal area dikes (U.S. Army Corps of Engineers 1987) incorporate these considerations. Modification of DMCA dikes for aquaculture must not allow the dike design to be compromised. All modifications to earthworks or structures on the site must be coordinated with the Corps of Engineers office responsible for design and maintenance of the containment area.

Designing earth structures is a repetitive process. Working with data on dike height requirements, foundation conditions, construction material, and minimum top width, the problem is to design a dike cross-section that will be watertight and safe at minimum cost. Trial designs are proposed and evaluated until a solution that satisfies all requirements is found.

For dikes, do not use organic soils because they decompose with time, causing settlement and increasing the risk of leaks. Clear vegetated surfaces before construction. Clear organic soils and material from foundation surfaces to ensure a good bond between the dike and the foundation. A dike with an impervious core may be used to control seepage.

During construction, the soil should be at optimum moisture content to achieve maximum density. Embankment soils should be placed in layers, each compacted before the next layer is added. Even with compaction some settlement will occur. Allowance for settlement is calculated as a function of dike height. The allowance should be not less than 5 percent under normal conditions. A settlement allowance of 20 to 25 percent of dike height should be made where placement of material is by dragline or conveyor.

Dike top widths vary with the height of the dike. Minimum width for a dike 3 m high or less should be 2.5 m or more. If the dike top is to be used as a roadway, top width should be at least 3.7 m, and preferably 4.0 to 4.5 m. At least one side of each pond should be made wide enough for vehicles; it is best if all dikes can accommodate vehicles. The center line of the dike crest should be elevated about 15-20 cm higher than the shoulders to more effectively drain rainwater.

Dike side slopes are a function of the type of soil used. The most commonly used slope is 3:1 (horizontal to vertical). Highly stable soils can have slopes of 2.5:1 on the upstream side and 2:1 on the downstream side. Unstable soils may require slopes of 4:1 or flatter.

Ponds larger than 0.5 ha should incorporate erosion control in dike designs. Upstream slopes are exposed to the erosive forces of wave action; downstream slopes are exposed to erosion during heavy rains. In general, upstream slopes should be flatter than downstream slopes to better handle erosion in a saturated state.

Dike heights are primarily a function of design depths, although other factors play a role. Wave height, a function of pond size, must be considered in estimating dike height and freeboard. Freeboard is the vertical distance from the pond surface at its design depth to the top of the dike after settlement. Freeboard varies from 0.3 m to 0.6 m, depending on the length of the pond. The amount of traffic the dike is to bear and dike soil characteristics will modify this estimate. The dike crown must be well above the level of soil saturation under normal pond water levels to prevent sinking and damage to the dike from passing traffic.

Periodic use of dual use DMCA for material disposal will also raise the elevation of the pond bottom. Dikes will be raised as well, to accommodate the anticipated volume of dredged material and to provide adequate depths of water for

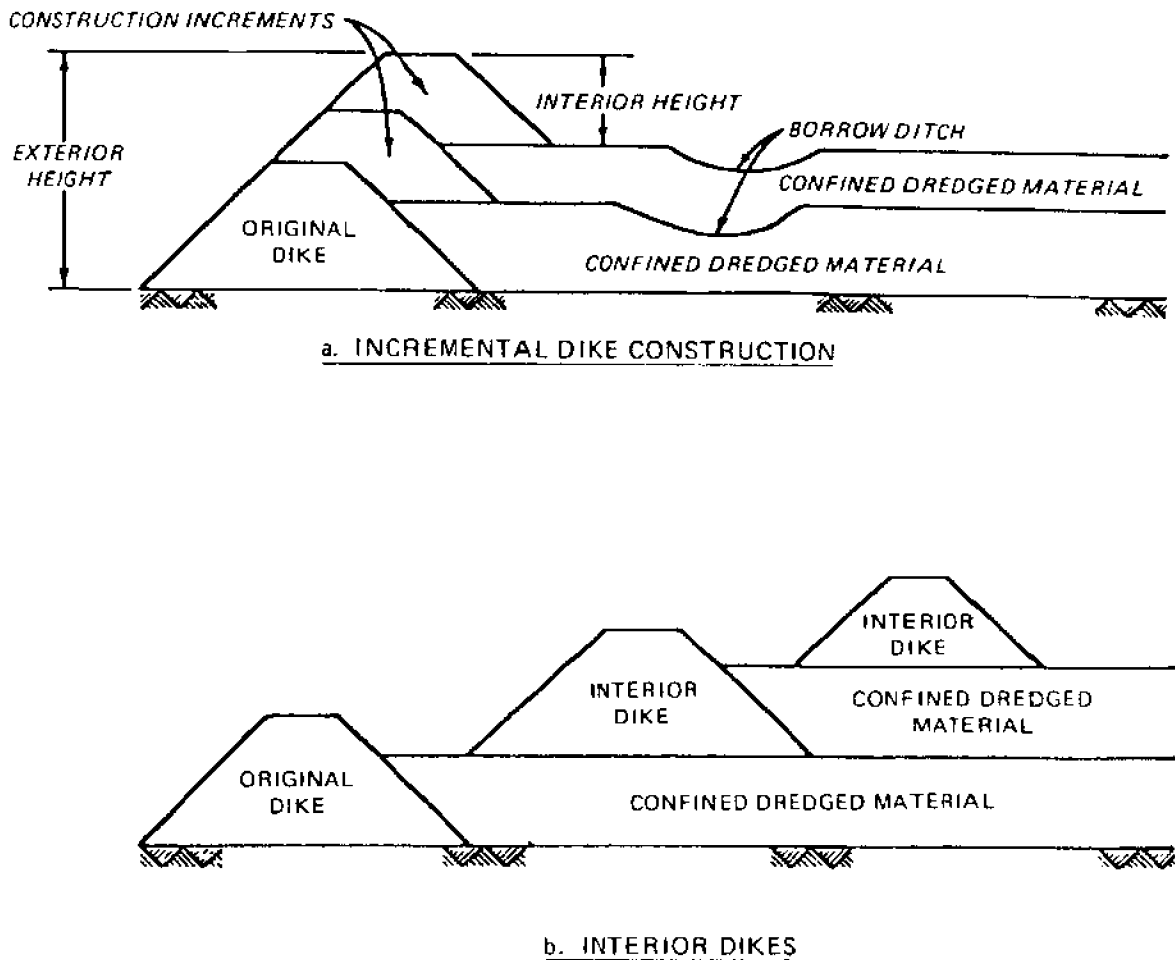


Figure 5 from U.S. Army Corps of Engineers 1987

subsequent aquaculture operations. Figure 5 illustrates the two ways in which dikes may be raised. Changes in pond size or bottom topography due to incremental dike construction should be anticipated in the design process.

A final consideration is the action of weather on the dike. The dike material may develop shrinkage cracks that allow rainwater into the embankment soil failure, liquefaction of sections of the dike, and tunnel or gully erosion can result. Soil down to the deepest frost penetration is subject to expansion and contraction forces due to freezing of the soil moisture; this can loosen and make dike soils unstable.

Water control structures. Design specifications of water control structure should anticipate future changes in dike height, height of pond bottom over initial levels, and changes in particle size of bottom soils. Coordination of design requirements needed for aquaculture with the project engineers at the CE district is essential.

Inlets and outlets must be separate and located to prevent any mixing of incoming and discharge. Locating the inlet and outlet far apart within the pond avoids "short circuiting" water flow within the pond and allows freshwater to be added to

the pond during harvest operations. The size of inlets and outlets is determined by the time needed to fill or drain the pond. This will depend on species cultured, pond dimensions, stocking density, management level, and other factors. While species production manuals often provide recommendations for pond sizes, drainage requirements, and other parameters, consult a professional engineer on these designs.

Two water control structure designs—a drop inlet structure and a movable standpipe or riser—are commonly encountered. Drop inlets can either replace a section of the dike (a weir, Figure 6) or can be a structure within the pond (commonly known as a monk). By locating the structures in a fill canal, both the monk and the standpipe can also be used to fill ponds.

In drop inlets, crest height maintains a constant water level in the pond. Incorporating adequate freeboard in weirs allows the structure to handle expected storm runoff. Spillways channel the water discharged over the weir crest. Figure 6 illustrates general spillway design features. The main consideration is that the spillway pass the projected harvest or overflow volumes without damage. Cost and pond manage-

ment requirements (especially spillway slope and the volume and velocity of discharge at harvest) will dictate spillway designs. The most common spillway type is lined for some distance upstream and downstream with reinforced concrete. The extent of concrete lining will be determined by local soil conditions, slope, and the depth of the flow over the sill at full discharge.

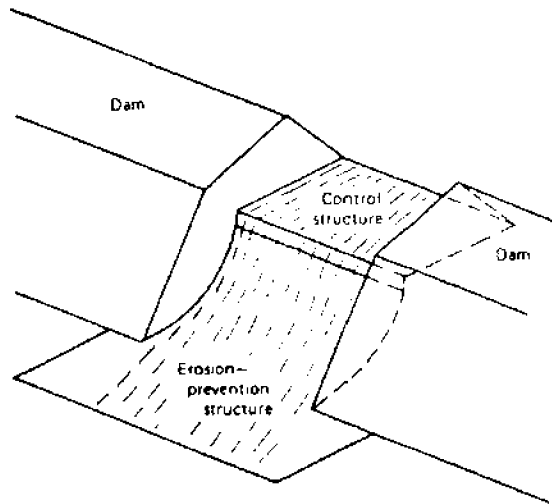


Figure 6 from Wheaton 1977

Monks are usually rectangular in cross-section and of poured concrete or concrete block construction. The opening of a monk designed to drain a pond usually faces into the pond, while inlet monks face the dike. Both weirs and monks use dam boards (of the appropriate quality and thickness), in conjunction with fish screens, to control water height and flow. The width of the weir opening should not exceed 1.5 m to prevent bowing of the lower dam boards.

The second type of water control structure consists of a horizontal conduit through the dike connected to a movable standpipe or riser within the pond. Figure 7 shows a typical outlet arrangement. Antiseep collars around the conduit will prevent leaks and possible dike failure. The height of the top of the riser controls water level. Swivelling the riser up or down controls water level. The hood over the top of the riser prevents fish or trash from entering the riser. Some designs join the pond drain, controlled by a valve, to the standpipe. The drain inlet, located at the lowest point in the pond, allows the pond to be drained dry.

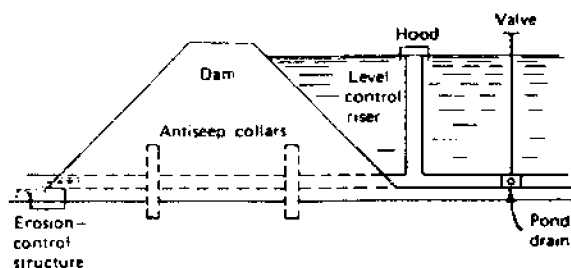


Figure 7 from Wheaton 1977

The downstream ends of any discharge pipes from monks or standpipes should incorporate an energy dissipator or some form of protection against scouring. The banks of drainage ditches opposite of discharge conduits are especially vulnerable to scour at full discharge flows.

Harvest basins. Fish and shrimp aquaculture crops are often harvested by draining the pond at the end of the crop cycle. Harvest basins are used to collect crops harvested by draining. These basins may be placed inside or outside the pond, in the vicinity of the pond outlet. Internal harvest basins serve only one pond, while two or more ponds may be connected to one external harvest basin.

External harvest basins may be located immediately outside the pond outlet or may be connected to the outlet by drainage canals of varying length. Nets placed within the basin are used to collect the crop. External harvest basins should be supplied with a source of water so the basin may be filled during harvest operations.

Water distribution and drainage canals. Feeder canals supply water to the ponds, and drainage canals carry discharge water away from the ponds. These must be sized to handle maximum projected flows, including storm water. Internal pond drains are sometimes used to carry water from undrained depressions to the pond outlet.

Water Supply

The annual water requirements of aquaculture ponds depend on soil conditions, environmental factors, species cultured, and the culture and harvest methods. All factors that influence water use need to be considered in the calculation of water requirements. Detailed methods of calculating water supply are presented in Homziak and Veal (1990).

Hydraulic computations. Overdesigning hydraulic structures is costly and inefficient. To insure that hydraulic structures are of the appropriate size and adequate for the intended operation, use hydraulic computations to determine size. Professional assistance may be necessary to complete hydraulic calculations.

Aeration needs also will have to be considered in planning water flow and exchange, pond design, and power needs on site. If supplemental or emergency mechanical aeration is being considered, Boyd (1982) and Jensen and Bankston (1988) provide information on oxygen transfer rates for various aerators, aeration effectiveness, power requirements, and aerator efficiency.

Quantity estimates. Stocking densities and biomass are generally given as number or weight per unit of pond area. Carrying capacity and exchange rate requirements are calculated in units of biomass per unit volume of water.

Sufficient quantity of water is probably the parameter most frequently underestimated by new aquaculturists. Meeting the needs to fill production ponds, make up for water losses (seepage, evaporation), and water exchange for managing water quality will determine the quantity of water needed. Monthly water budgets will indicate how demand for fill and makeup

water will vary seasonally. The amount of water that must be pumped (and pumping cost) to fill ponds will vary monthly.

Earth impoundments are relatively porous, and ponds and canals will lose water at rates that will vary with the porosity of the soil. Seepage is difficult to measure directly, and evaporation losses from fish ponds are significant and must be compensated for in determining total water needs. Adequate water depth and, in marine aquaculture, correct salinity levels must be maintained. Net evaporative water loss (allowing for precipitation) from fish ponds is a function of water temperature, air temperature, relative humidity, surface area of the water body, and wind velocity. In general, evaporation rates increase in warm months and decrease in cool months. Pan evaporation data may be obtained from the agricultural weather service in the region.

Fish farmers may partially drain ponds and refill with fresh water in an effort to improve water quality. This supplies oxygen-rich water to the ponds and flushes water laden with nutrients and organic matter from ponds. This positive displacement method has proved to be effective in improving water quality in small ponds but has not been verified for large ponds.

Pumps. Pumping costs may be a major cost item in production. Poor pump selection can increase pumping and maintenance costs. It also significantly increases the risk of pump failure, putting the crop at risk. McVey and Martin (1980) provide information on comparing costs among pumping systems. Aquaculture engineering texts or production handbooks (e.g., Baker 1987, Baker and Bankston 1988) can provide general information for selecting a pumping system. Detailed information on determining power requirements is available from numerous sources (e.g., Baker and Bankston 1988).

Water quality. Water quality criteria are essential in calculating water budgets, site design and layout, and production strategies. Wilson and Homziak (1990) discuss the use of water quality criteria in evaluating and selecting DMCA sites for aquaculture facilities.

Water quality is a relative term that depends on the use for which the water is intended. Water supply for aquaculture must possess several characteristics to be considered "good" quality water. Oxygen content, temperature, salinity, and hardness of the water supply should be at or near optimum levels for the type and number of aquatic organisms cultured. Pollutants, especially organic wastes, chemical compounds, and toxic or pathogenic organisms, should not be allowed to contaminate the water supply. Filters or provisions for water treatment should be made if the possibility of pollution of the water supply exists.

There are two ways to specify water quality criteria: screening criteria and production criteria. Screening criteria are applied when evaluating available water quality for aquaculture use. Production criteria define water quality within the production system. Huguenin and Coit (1989) presents established screening and production criteria for marine fish and crustaceans. Boyd (1982) reviews screening and production criteria for freshwater systems. It is important to remember that these criteria were formulated for a wide range of

species and life stages. They serve only as guidelines.

Water sources. There are two sources of water for aquacultural enterprises: surface water and groundwater. Each has advantages and disadvantages that must be considered. Groundwater sources are the most desirable as a water supply for aquaculture. Groundwater is usually free of pollutants, but some groundwater may contain toxic gases, with hydrogen sulfide and methane the most common. The cost of wells and pumping from deep wells and the deficiency of oxygen in groundwater are the most apparent disadvantages.

Wells draw water from aquifers located below the water table. The yield of a well depends on the thickness and permeability of the aquifer and the diameter of the well shaft. Generally, the greater the permeability and/or thickness of the aquifer the greater the potential yield. However, high-yield wells tend to be shallow and more susceptible to seasonal yield variations than deeper wells. Seek professional advice in locating wells. Groundwater sources normally have constant temperatures year-round. The temperature of groundwater from shallow sources approximates the mean atmospheric temperature of the area. As a rule of thumb, water temperature increases 1 °C for every 32 m depth below 15 m.

All surface waters suffer from the disadvantages of being exposed to pollution, seasonal or long-term changes in water quality characteristics, and are inhabited by potential predators, competitors, and disease organisms. However, most sources tend to be well oxygenated and are usually less expensive to develop than groundwater sources. Surface water sources include streams and rivers, lakes and reservoirs, and salt or brackish waters. Because of biological activity, alkalinity and hardness are not usually concerns.

The water quality characteristics of streams and rivers are influenced by the terrain through which they flow and are subject to wide variations with season. Flow rates, oxygen content, water temperature, nutrient levels, and suspended sediment loads are especially variable and influence production operations and site design. Water drawn from lakes and reservoirs has many similarities to water drawn from running water sources. Oxygen concentrations tend to be lower and temperatures tend to be more stable and more predictable than water drawn from streams. Other water quality parameters tend to be less variable in lakes and reservoirs than in flowing water as well. The larger the body of water the smaller the range and the less abrupt the change in water characteristics. Seasonal variations in water temperatures, the depth of the thermocline, and the possibility of freezing are important considerations influencing the design of aquaculture facilities.

Brackish water and seawater share the problems of lakes and reservoirs when used as water sources for aquaculture. Seasonal variations in salinity (influenced by freshwater input and evaporation) must be considered, along with other variable characteristics, in using these water sources. In addition, accelerated corrosion and biofouling are problems particular to marine surface water sources. More costly materials must be used in construction and more frequent servicing

and accelerated replacement requirements should be considered in designing the facility.

Pretreatment. Incoming water may require some treatment before use. The need to pretreat incoming water will affect site layout and design, especially the water distribution system. The three main water treatments are aeration and degassing, settling of suspended solids/precipitation of iron oxides, and the removal of unwanted organisms and debris. Site designs may need to incorporate holding ponds, aeration equipment or structures, and predator filters or similar features. Boyd (1982) and Huguenin and Colt (1989) review pretreatment methods used to improve the quality of incoming water.

Surface or groundwater sources low in dissolved oxygen can be aerated at the entry point to the farm, in holding ponds, or elsewhere in the water distribution system. Aeration also can be used to remove iron oxides and dissolved noxious gases such as hydrogen sulphide. The anticipated aeration system must be considered in the pond design, layout, assessment of power requirements, and water supply calculations. Aquaculture production manuals describe aeration needs and field tested solutions for commercial culture systems. At a minimum, all but the most extensive operations should include an emergency aeration capacity.

Filters. Aquaculture facilities using surface water sources generally filter the debris from incoming water. Removal of debris is essential to prevent damage to pumps, piping, and water distribution systems. Removal of eggs, larvae, or adult organisms, potential predators, and competitors from the incoming water is essential for efficient operations when using surface water sources. In some cases, state regulations may also require that discharge waters be filtered to prevent the introduction of exotic or controlled species into natural waters.

The choice of appropriate filter technique depends on performance, throughput (volume per unit time handled), economics, or some other important feature. Filters for pond-based fish or shellfish production systems are generally limited to techniques that mechanically separate liquids from solids. There are hundreds of designs available for these filters. Such filters retain suspended particles of a certain size or greater when a liquid passes through them. One common type uses screen mesh to remove particles. Screen mesh is available in a variety of materials, from stainless steel to cloth fabrics, and the cost of screens rises rapidly for the smaller-mesh sizes. As the diameter of the particles to be extracted declines, flow rates generally decline and cleaning and maintenance costs rise. Operating and cleaning costs can become prohibitive if suspended particle concentrations exceed reasonable values.

Pond effluent. The importance of aquaculture ponds as point sources of pollution is not known. Effluent from fish culture operations is considered a potential source of pollution. The primary restriction is that maximum instantaneous concentrations of solids could not exceed 3.3 ml/l. Properly designed settling basins will effectively reduce the suspended solids concentration of fish pond discharge water. Because little is known about effluent from fish and shrimp

ponds or about ways of treating effluent to improve their quality, the industry remains concerned about effluent limitations. Existing or proposed standards for settleable material, BOD, COD, total phosphorous, and total ammonia nitrogen will vary among states. Seek local professional advice in accommodating existing or planned regulatory restrictions on pond effluent.

Construction of Commercial Facilities: Examples

Practical information on design and construction of fish ponds primarily for freshwater fish production has been developed. Widely available manuals produced by extension services and federal agencies provide guidelines to the construction of typical pond production systems, based on the experience of commercial operations in a given area. These manuals should be referred to in determining pond dimensions, water requirements, culture methods, and other information, from hydraulic computations to cut and fill calculations. The following review is limited to construction only. Other details of site selection and water quality are available from the production manuals.

Catfish. There is a wealth of experience behind the recommended methods of construction for catfish ponds. A number of Extension documents and production guidelines (e.g., Jensen 1988, Ulmer 1987, Wellborn 1989a, 1989b) describe pond construction methods. Briefly, production ponds use well water, requiring 125 to 190 liters per second capacity for four 7-ha ponds. Water flow rates, fill times, pump sizes, and well casing diameters for efficient filling are provided by Jensen (1988) and Wellborn (1989b).

Average ponds are 7 ha on 8 ha of land and built in units of four ponds (size is variable). The bottom of the pond should be flat and slope 0.1 to 0.2 percent. Internal harvest basins are discouraged. Most operations seine harvest, making pond drains relatively simple turn down pipes. The end of the conduit through the dike should extend 1.5 to 3.0 m beyond the toe of the dike to control sloughing and erosion. Dikes should be at least 5 m wide; 6 m is preferred for dikes supporting vehicles. Slopes of 3:1 are acceptable. Flatter slopes tend to be more expensive to construct. A minimum freeboard of 0.3 m and a maximum of 0.6 m are suggested. Pond depth should not be less than 1 m at the toe of the dike at the shallow end and not more than 2 m at the deep end.

Pond shapes are usually rectangular, oriented according to contour and property lines. Orientation of the long axis with or at right angles to the wind has been debated. Both orientations may be found.

Crawfish. A number of excellent guidelines for crawfish pond construction are available (e.g., de la Brettonne 1987, La-Caze 1976). Crawfish are produced in rotation with forage crops, such as rice or sorghum, or in rotation with field crops, especially rice and soybeans. Ponds are drained in late spring to early summer (to allow planting of crops) and flooded in

the fall. Water requirements and dike heights take this cycle into consideration.

Water quality and quantity determine pond size. Pond sizes of 4 to 8 ha are common. Surface water, supplied by low lift irrigation pumps, is often used for large ponds, and wells are often used to provide water to smaller ponds. A well diameter of 20 to 25 cm is recommended for approximately 50 ha of ponds. Water requirements depend on flooding depth. Pond depths range from 30 to 90 cm, averaging 45 cm. Flooding the pond to a depth of 45 cm requires a water flow of 6 liters per second to complete filling in four days. Louisiana farmers average nine complete turnovers of pond water each season. Inlets should be matched to pump capacity and drains to pond size and predicted rainfall.

Pond bottoms should be flat, with slopes between 0.3 and 0.6 percent. Large ponds may have irregular bottoms. Ponds should be subdivided with cross dikes if bottom slopes are excessive. Dikes should be high enough to hold 45 to 55 cm of water when flooded. A dike 1 m high is usually sufficient. Dikes should be at least 2.5 to 3.0 m wide at the base to allow for the burrowing activity of the crawfish. Low baffle dikes (0.6 m), constructed using a levee plow, should be placed every 50 to 100 m across the ponds to improve circulation. Perimeter dikes should have a minimum crown width of 3.0 m to support vehicles and have a base width of at least 7.5 m.

Other freshwater fish. Production of freshwater food fish takes place in ponds similar to those used in the catfish industry. Information on production systems is available from general texts (Dupree and Huner 1984) or from your local Extension county agent.

Bait fish. Ponds for bait fish and mud or bull minnows (primarily for goldfish, golden shiners, fathead minnows) are constructed like catfish ponds. Giudice et al. (1981) provides information on pond construction for these species. Ponds 4 ha in size are considered ideal for fathead minnows and golden shiners; smaller ponds work best for goldfish.

The preferred pond shape is rectangular, oriented to take advantage of topography and to share water distribution lines, drain canals, and dikes. Dike crowns should be 2.5 to 3 m wide after settling, and have a freeboard of 0.6 m. Recommended dike slopes are 2.5:1. Pond bottoms should be smooth and without ditches. Harvest basins about 10 percent of the pond area are incorporated. Finished bottoms should slope 15 to 25 cm or more per 100 m towards the drain. A minimum water depth of 1 m is recommended; maximum depth is less important, usually kept at 2 to 2.5 m. A minimum of 2 liters per second water flow is required per hectare of pond surface; 4 to 8 liters per second recommended. Well or spring water is preferred, but good quality surface water is acceptable. Ponds are harvested by draining, so rapid draw down is required. Water levels are controlled by rotating drain pipes.

Marine/brackish water fish. Ulmer (1990) provides a description of marine fish farms for coastal areas. The designs are for proposed redfish farms, based on commercial catfish farms in Mississippi, but other marine fish species can also be produced in these facilities. Most marine fish

farms are new and many aspects of design and construction are not well known. However, the designs presented below will be generally appropriate for many coastal marine fish species, with variations in the design to accommodate individual culture requirements.

The design is based on units of four 6.9 ha ponds. Ponds are oriented with the long axis at right angles to the prevailing wind to minimize wave erosion, which is often more of a problem in coastal areas than in inland fish farming regions. Dikes should be 5 to 6 m wide. Side slopes of 4:1 to 5:1, combined with a wide 6 m crest, are recommended for dikes subject to erosion. Outside slopes are 3:1. All dikes are built to provide a minimum of 0.3 m freeboard above design pool level after settling. Pond depths range from 1 m at the shallow end to 1.7 m at the drain, graded to drain towards the outlet. Recommended bottom grades are 1 percent for fingerlings, 0.3-0.5 percent for yearling fish, and 0.1 percent for food fish. Multistage farms using different pond sizes may include harvest basins below the outlet drains for the fingerling and yearling ponds. Recommended sizes for these basins are 3 by 6 m and 15 m square, respectively. Water is supplied to the ponds by a 30-cm-diameter pipe.

Water requirements will be variable. For four 7 ha ponds, a discharge rate of 115 liters per second will be adequate to exchange 2.5 percent of the pond volume daily. Drain outlets are designed to carry the daily flush discharge. An outside perimeter drain canal handles all pond discharge.

Shrimp. The Texas Agricultural Extension Service (Chamberlain et al. 1985) has developed general guidelines for the construction of pond systems for shrimp culture. Marine shrimp are also amenable to extensive culture in impoundments. Wilson (1990) reviews facility design and operations for extensive culture.

Mollusks. Clams and oysters may be grown under pond conditions. Hard clams (*Mercenaria*) and oysters have been successfully grown in trials as supplemental crops on shrimp farms. Clams and oysters may also be cultivated together.

Ponds in New England tidal marshes have been historically managed for hard and soft (*Mya*) clams, suggesting that clam culture may be feasible under pond conditions. Hard, soft, and manila clams may also be grown in cages. Reference to clam farming manuals (e.g., Broadley et al. 1988, Castagna and Kraeuter 1984) will provide information on water quality and other variables needed to evaluate the feasibility of pond culture for clams.

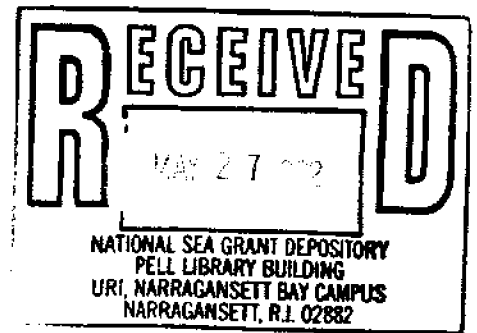
Oysters have been cultivated in suspended trays and in rack and bag culture, methods that can be adapted for use in pond culture. For cultivating shellfish, there are numerous methods that may be adaptable to pond conditions, especially along the Pacific Coast (e.g., Magoon and Vining 1980).

Extensive culture. Extensive culture of brackish water fish is particularly amenable for use in DMCA. Wilson (1990) reviews extensive fish culture in impoundments and describes designs for extensive pond systems. A low technology approach is often suitable for extensive fish or shrimp culture.

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