I. Introduction to Pond Construction

A. Definition of “pond”

A pond is an earthen container for storing water. The surface area of the stored water will normally vary from a fraction of an acre to tens of acres. The depth of the water will normally vary from two feet in the shallowest portion up to 25 feet in the deeper portions. Size range of Auburn ponds is from 0.05 to 25 acres, and depth from 2 Ft. to 20 Ft. (S-29).

With the construction of a pond a permanent or prolonged, and expanded water resource is created where the previously existing water resource was temporary or seasonal, and of more limited volume. The water to be stored may enter the pond from a variety of sources. For example it is commonly harvested from surface runoff following rainfall, or from the impoundment of small streams

B. Uses of Ponds

The possible uses of this new or improved water resource in meeting the needs of people are diverse, and commonly include aquaculture, stock watering, recreation, garden irrigation, and natural resource conservation, and less commonly small hydropower generation, household uses, and water table enhancement for wells.

With regard to natural resource conservation, harvesting water in ponds will aid restoration of watersheds that have been eroded, overgrazed or cut by reducing runoff and thus erosion, increasing soil moisture so that vegetative cover can be established, and sensitizing people to environmental concerns, e.g. soil loss problems in the U.S.

Pond construction is expensive. The cost is usually justified by intensive utilization (e.g. commercial catfish culture), or by multiple use which integrates several activities which maximize pond water utilization.

C. Water Supply for Ponds

1. Some Facts about water

Value of water is a prime consideration: If culture is of low intensity, (e.g. farm ponds for recreational fishing), pumping water may have an unacceptable cost. For intensively managed ponds, for example catfish ponds producing 3,000-3,500 lbs/acre, pumping costs are a relatively minor part of total production costs. Pumping costs may be about $0.03 per pound of fish compared to $.25 for feed and $0.07 for fingerlings.

Providing water to ponds by gravity, rather than pumping, is preferable for economic reasons. In some parts of the world aquaculture is not feasible unless water can be provided by gravity. The Auburn University experimental station is an example of a gravity-fed water supply system.

2. Water sources and their characteristics

Rainfall directly on pond surface
- more than 50 in. per year (1270 mm) in Alabama
- replaces evaporation losses (35”/yr.) plus about 1/4 of average seepage losses (70 “/yr.)

Overland and subsurface rainfall runoff
- Gravity flow
- Seasonal - pond must be deep to retain water all year
- Reduced flexibility with timing of filling and harvesting.
- Less control over water quantity management -- no flushing
- May need supplemental pumped water for aquaculture

Springs
- Gravity flow
- Water usually of high quality, and uncontaminated by wild fish
- Techniques available for exploiting springs and increasing their production of water
- May be subject to seasonal changes and fluctuations

Small streams and creeks
- Gravity flow
- Water often of high quality
- May or may not be subject to flooding
- Water flow often fluctuates seasonally
- Water rights may be a problem

Diversions from larger streams rivers or irrigation canals

- Gravity flow
- Limited sites available - usually requires large scale effort and multiple users
- Contamination (wildfish, chemical/biological pollutants, disease/parasites)
- An understanding of seasonal variation required

Reservoirs and lakes

- Gravity flow may be possible via irrigation schemes
- Limited availability - usually requires large scale effort and multiple users
- Expensive water control and delivery structure may be required
- Contamination w/ wildfish and pollutants is common

Wells

- Free of wildfish
- Relatively constant water quality
- Expensive (pumped often from deep sources) - roughly $100/acre
- Low DO, high concentrations of gases or other substances (e.g. CO_2 and iron which oxidizes and precipitates)

Pumping from lakes and rivers

- Usually less expensive than wells - less head to overcome
- Very common e.g. shrimp in Ecuador
- Contamination with wildfish, pesticide runoff, etc.

Water table

- No pumping
- Automatic compensation for evaporation
- Fluctuations in level during year
- Little control over water quality and quantity
- Difficulties with drainage, disinfection of pond bottom, etc.
- May be difficult to construct a pond.

Rainwater collected from roofs

- Appropriate for small scale aquaculture where rains are torrential but seasonal (monsoons), and land is flat (i.e. no runoff).

Tides

- Uses tidal energy
- Facilitate filling/draining of brackishwater ponds.
- Tidal influenced rivers may use tide to form a wedge to push back and lift freshwater for cheaper pumping , e.g. Guayas river with 2-3 m lift 50 miles upstream.

D. Principal Types of Ponds

1. Watershed pond: This name reflects the usual water source, i.e. rainfall runoff. This type of pond is characteristic of the upper portion of the Auburn University Fisheries Experiment Station.

Other names:

Hill Pond: Descriptive of the foothills, hilly uplands or rolling topography where this type of pond is usually built.

Embankment Pond or dammed impoundment: Describes how this type of pond is made by building an embankment or dam across a permanent, seasonal or temporary stream or watercourse, where the stream valley is sufficiently depressed to permit storing of two meters or more of water.

Contour Pond: Describes the waterline, which follows the natural contours of the land.

Other characteristics

Economics: Water-holding capacity can be very large relative to the amount of earth excavated. The only excavation is for the dam. Thus large volumes of water can be stored at relatively low cost. A very suitable type of pond where the water requirement is large.

In west Alabama a 10-acre watershed pond costs about $1,100 per acre of water compared to about $2,100 per acre for a typical 4-sided “excavated” pond. The cost of a watershed pond, however, depends upon the length of dam required to impound a given amount of water, which in turn depends upon the topography of the site.

Pond shape and dimensions: A substantial degree of control over pond shape and dimensions is difficult to achieve, because of the necessity of accepting the natural topographic features of the site. However, improved uniformity of pond shape and dimensions may be achieved in some cases through additional excavation of pond sides and filling of the valley floor/pond bottom.

Water supply:

- Direct rainfall
- Permanent streams or large springs - if the flow is too great excess water may have to be diverted around the pond.
- If there is no permanent water flow a watershed pond may receive water from overland runoff, groundwater inflow and/or intermittent stream flow.
- Water supply may be seasonal, in which case the pond must have enough storage capacity to last through the drier months.
- Pumping normally not used, with consequent loss of control over water supply, but gains in economy. Pumping generally costs about $100 per acre per crop of fish - i.e. $0.03-0.04 per pound of fish produced, thus savings are significant if little or no pumping is needed.

2. Excavated Pond: This type of pond is constructed where the topography is level or nearly level.

Other names:

Dug Pond: Same meaning as "excavated" pond

Levee Pond or Diked Pond: Refers to the dikes or levees which surround this type of pond.

Other characteristics

Excavation may be complete or partial

- May be completely excavated as is the case with ponds which are dug into the water table. Excess soil must be disposed.

- May be partially excavated so that cut (quantity of soil excavated) is balanced with fill (soil needed for dikes). In this case the pond bottom is below the original ground elevation, and the water level is above it.

Complete control of pond shape and size is usually possible with excavated ponds. They are thus well suited for experimental, demonstration and intensive production uses in which uniformity of size and shape of multiple units is important, and in which a high degree of control of water supply is desirable. Are protected from overland runoff and thus sedimentation and contamination.

Draining excavated ponds by gravity in some cases may not be possible, which has implications for water removal for purposes of harvesting fish, and draining completely for repair and renovation. This is especially the case for completely excavated ponds, and for ponds on lands with negligible slopes.

Water-holding capacity is directly proportional to the amount of earth excavated. Excavated ponds are thus expensive for water storage, and are best suited where the demand for water is small, and the use of the water is intensive. Cost is about twice that of watershed ponds of comparable surface area.

Water supply:

- Rainfall directly on the pond

- In the case of completely excavated ponds whose bottoms are cut below the water table, the usual water sources are ground water plus some overland runoff.

- In the case of partially excavated ponds, i.e. ponds without watersheds or ground water inflow, the usual water sources are diverted streams, irrigation canals, well water and reservoirs. Depending on the elevation of the water source, water may be provided by gravity or pumping.

3. Terrace Ponds: This type of pond is build on hillsides using techniques similar to those for building terraces.

Surface area and depth of water in terrace ponds may be very limited depending on the degree of slope of the hillside. Water surface area is inversely proportional to the slope of the valley sides. Also, the steeper the valley sides the more earth required for dikes to impound the same quantity of water.

Water sources for terrace ponds:

- Rainfall directly on the ponds

- Overland rainfall runoff and ground water flow are the most usual sources, though water may be conducted to terrace ponds from springs higher on the slopes.

4. Unexcavated, diked ponds: This type of pond is build above the original ground surface elevation.

A large quantity of earth must be brought in from outside the site to construct the pond bottom and dikes, thus cost is relatively high. The advantage is that it allows ponds to be built on seepage-prone sites with impermeable soil brought in from the outside. It also allows ponds to drain by gravity in situations where that might not otherwise be possible.

Otherwise similar to excavated ponds with regard to water holding capacity and best uses.

Water sources for unexcavated, diked ponds:

- Rainfall directly on the pond

- Reservoirs, diverted streams, canals and well water are usual sources. Similar to excavated ponds.

II. Feasibility criteria for site selection

Criteria for the selection of an appropriate site for pond construction fall into 3 categories. Evaluation of the criteria may require input from the requisite specialists.

Biological
Economic
Physical

We will spend little time discussing biological and economic criteria, as they are subject matter of other courses.

A. Biological criteria

1. Environmental requirements of culture species.

2. Definition of scale of operation: number and size of ponds: A clear understanding of the intended pond use, management practices to be applied, and the scale of operation are critical in order to estimate the total land area required for pond construction. The optimum size, depth and number of ponds required are a function of their intended use. The total land area required can be estimated once this information is available.

3. Source of contaminants: A biological understanding regarding the use of the pond is required to appreciate whether a substance in a potential water source is a harmful contaminant, a beneficial fertilizer or nutrient, or neutral in its impact.

B. Socio-economic criteria

1. Potential danger downstream

<u>Dam failure</u> and flooding downstream may be a significant danger with larger watershed ponds in danger of receiving heavy runoff.

<u>Deterioration of water quality</u> for downstream users of the water, is becoming an increasingly important criterion.

2. Demand for product and availability of marketing channels

Accessibility and proximity of processing and marketing infrastructure

3. Availability of personnel, labor and production inputs

A commonly underconsidered criterion

4. Security.

Respect for one's neighbor's property is not always observed, especially in the case of a pond with fish that are traditionally considered wild and for the taking! Where possible pond location should take this into consideration.

5. Economic feasibility and opportunity costs

Costs and returns and economics of alternative uses of the site.

Note: The above discussion on biological and socio-economic criteria in the selection of a pond site is not intended to be complete. It is subject matter for other courses. But it should be emphasized that failure to seriously consider these aspects often lead to well built, but nearly useless, ponds. The landscape is strewn with White elephants in the guise of ponds!

C. Physical criteria

1. Water supply

A. Quality

- Chemistry (pH, alkalinity, nutrients, contaminants)
- Temperature
- Transparency, sediment load.
- Stability (streams may change drastically from day to day)
- Pesticides/other toxicants - problems is they may be difficult to detect as the levels are highly variable.
- Flora and fauna of surface waters are good indicators of water quality.

B. Quantity

- General recommendations for pumping capacity for catfish ponds depending primarily on pumped water is <u>25 gpm per acre</u> of pond (4 liters/sec/ha) to permit filling in 10 days, and to permit management of water quality during the culture period by flushing, etc.

- If evaporation, seepage, and rainfall directly on the pond are considered, about 3 to 7 gpm (on a continuous basis) are needed to maintain water level in an Alabama fish pond.

- For <u>excavated ponds</u> analysis of water requirements and water availability is relatively simple because they are usually constructed to exclude rainwater runoff, and water supply is controlled. A typical water budget is illustrated below.

<u>Water loss/gain from excavated ponds in Alabama</u>

			<u>annual</u>	<u>monthly</u>
C	***Culture***:	Fill/exchange	?	
S	***Seepage***	Piedmont	95"	6-12"
		Black Belt	10"	<1 - 2"
E	***Evaporation***		46"	5 - 6"
P	***Rainfall*** *on pond*		53"	2 - 7"

Example: Alabama excavated pond

Conditions: Piedmont soils, no water exchange, pond depth 48", filled twice per year; no water exchange.

Annual requirements = C + S + E - P
= 2x48+95+46-53= 184"=15.3'

For 1-acre pond =15.3 acre-ft/year

For excavated ponds in other regions of the world:

- **Rainfall** statistics are usually available in most countries.

- **Evaporation** statistics may be available, or may be approximated by matching the climate of that country with a US region where evaporation statistics are available. In general, evaporation rates seldom exceed 1 cm/day in hot, dry regions and may be as low as 0.1 cm/day in cool, humid regions; evaporation rates of 0.5 cm/day are very common for tropical, subhumid countries.

- **Seepage** rates are site specific and highly variable. Test pits may be required.

•For **watershed** ponds water requirements are more difficult to evaluate as rainwater is a significant and highly variable source of water.

Water loss/gain from watershed ponds in Alabama

			annual	monthly
C	***Culture***: Fill/exchange		?	
S	***Seepage***	Piedmont	95"	6-12"
		Black Belt	10"	<1 - 2"
E	***Evaporation***		46" .	5 - 6"
P	***Rainfall on pond***		53"	2 - 7"
R	***Rainfall runoff***		20"*	0 - 4"

* expressed in inches per acre of watershed (not pond); quantity is highly variable depending on vegetative cover, soil texture, and slope.

Example: Alabama watershed pond

Conditions: 1-acre pond, 48" deep, filled twice per year, no water exchange; Piedmont soils; receiving runoff from 5 acres of watershed.

Annual requirements = C + S + E - P - R
= 2x48+95+46-53-(20x5) = 84" acre-in

• If "annual requirement" is negative, this means that no supplemental water would be required on an average annual basis. In reality, water budgets should be based on monthly gains and losses of water, especially for watershed ponds, as overflow from excessive runoff result from seasonal variations. Monthly water budgets will be prepared for Exercise 10.

(overhead on evaporation/rainfall in Auburn)

•Given the great variability in the quantity of runoff water from different watersheds, empirical estimates have been devised to evaluate the adequacy of watershed areas for filling ponds. (2 overheads)

•J. Lawrence, **for Alabama ponds 4 to 5 feet average depth**:

	Acres watershed per acre of pond	
	heavy clays	more porous clays
Pastured watershed	4	8
Wooded watershed	6	16

Example: a 3 acre pond with runoff from a wooded watershed in porous clays should have 3 x 8 = 24 acres of watershed

•The SCS has produced a guide that gives acres of watershed necessary **per acre-foot of stored water**. For Alabama it is 1.5 - 2 acre/ft, and for the Southwest US it is 60 - 140 acre/ft. The required watershed area is therefore a function of pond depth. Some considerations about pond depth are:

> If watershed ponds depend exclusively on rainwater runoff as a water supply, the water depth required to maintain year-round water depends on regional rainfall patterns (e.g. humid Vs semi-arid Vs arid). SCS provides a guide for different regions in the US. (overhead)
>
> For example: Alabama is in the humid zone, and 6 to 7 feet of water will be lost during the year through evaporation and seepage. Thus a watershed pond must be deep enough to meet intended use requirements, plus the 6 to 7 feet that will be lost. If a minimum depth of 4 ft is necessary for fish culture, then the pond must be initially filled 10 to 11 ft.

- These empirical data were developed for the U.S. What about other countries? A reasonable approximation can be derived by comparing the known rainfall pattern in another country with a similar region in the US. (overhead). Caution is required as many regions may have similar annual rainfall, but distribution during the year may vary greatly.

- After water requirements are determined, supplemental water may be needed for watershed ponds. It may be available by pumping from wells, rivers, lakes, reservoirs, or by diversion from springs and small streams

2. Topography

a. In general, the steeper the topography, the smaller the pond that may be constructed. The type of pond that may be constructed is also determined by the degree of slope. Excavated ponds are constructed on relatively flat land. As the relief becomes steeper, sites suitable for watershed ponds and terrace ponds may be found.

b. Valley types

- Type 1a valley: This is an Untruncated V-shaped valley: Valley side slopes form an acute, right or slightlyl obtuse angle. Usually of little practical interest for ponds, except perhaps very small ones.

- Type 1b valley: This is a slightly and obliquely truncated v-shaped valley. It is adaptable for ponds of limited surface area.

- Type 1c valley: This is a U-shaped valley. It is adaptable for ponds, the type depending in part upon the size of the water course.

- All of the above type 1 valleys are adaptable for construction of linear contour ponds, or terrace ponds along the valley sides. Small barrage or diversion ponds may also be possible, particularly for types 1b and 1c.

- Type 2 valley: These are slightly and horizontally truncated v-shaped valleys with the water course flowing at the foot of the valley slope. A supply canal can be built at the foot of the opposite slope and ponds situated between the two water courses.

- Type 3 valley: These are strongly truncated v-shaped valleys with the water course winding in the alluvial plain. This typevalley is excellent for ponds. Two series of ponds can be located at the foot of each valley slope supplied by water taken from the stream. The ponds can also be supplied with water by springs or lateral streams from secondary valleys.

- Type 4 valley: These are strongly or totally truncated (flat) v-shaped valleys. They are often characteristic of lower reaches of stream valleys. These valleys are adaptable for ponds as long as there is a slope. The absence of a slope makes water supply and drainage by gravity a problem, and pumping may become necessary.

- The above valley types are classified according to the slope of the valley sides as revealed in cross-section view. The slope of the valley floor as revealed in longitudinal section must also be considered in selecting pond sites. In general, the steeper the valley floor, the higher the dam must be to impound an equivalent volume of water.

- Experience is important in judging suitability of topography for contour pond construction. In the absence of experience the following ratios of water surface area (m^2) obtained with a given volume of excavation (m^3) provides a rough guide. Before the ratio can be determined it is necessary that a rough survey be conducted of the proposed site.

    - $M^2/M^3 < 3$ - In this case the slopes are too steep or the valley too wide, and consideration should not be given to pond construction unless alternative sites are not available, or the water is of high value.

    - $M^2/M^3 > 3$ - Site is satisfactory for pond construction.

    - $M^2/M^3 > 7$ - Site is ideal for pond construction.

3. Soils

The Unified Soil Classification System (USCS) is the system most useful for typing soils for pond construction.

a. The USCS is an international system

b. The USCS classifies soils according to their engineering properties.

c. The USCS has four major soil classes

- coarse-grained (gravel and sand)

  In the case of coarse-grained soils, texture (relative sizes and shapes of particles) has the greatest effect on engineering properties.

- fine-grained (silt and clay)

  For fine-grained soils presence of water has a greater effect on engineering properties than texture alone.

- organic

- peat

d. Atterberg's Limits describe the relationship between engineering behavior and water content of fine-grained soils. They are the water contents at which soil behavior changes. The results of the test to determine Atterberg's Limits for a given fine-grained soil are arbitrary and empirical, and correlate with physical properties of the soil, which depend upon the type of soil minerals present, pore water ions, etc. Parameters of Atterberg's Limits are:

- Liquid limit - the lower limit of viscous flow

- Plastic limit - the lower limit of the plastic state

- Shrinkage limit - the lower limit of volume change

- Plastic index - the range of water content over which a soil is plastic

- Shrinkage index - the range of water content over which a soil changes volume.

e. Potential problems in pond construction:

The lower the shrinkage limit, and the higher the liquid limit (i.e. the greater the distance between SL and LL), the higher the plasticity and volume change. The range of values for LL is 0 to 1000; the usual range is 0-100; beware if the liquid limit reported is higher than 50. Excessive cracking of dikes may occur, and damage to structures built on high LL soils.

f. Particle size distribution

This parameter may be determined by sieve and hydrometer analyses, and is reported as a "grain size curve."

Well-graded soils have particles of all sizes, and are generally good for pond construction.

Poorly- or uniformly-graded soils have a preponderance of a certain particle size group.

Gap- or skip-graded soils are missing certain size groups.

g. Summary of soil properties that affect their engineering behavior

INHERENT SOIL CHARACTERISTICS

Soil Grains

The size, distribution, and shape of soil grains are most important in coarse grained soils. Soil strength generally increases while permeability and compressibility generally decrease with increased size and better distribution.

Plasticity

Plasticity is most important in fine grained soils. Soils with higher plasticity generally have higher cohesion and resistance to piping, erosion, and settlement cracks than soils with lower plasticity.

Density

The density of a soil mass is probably the most important single determinant of the engineering behavior of soils. Soil strength generally increases while permeability and compressibility generally decrease with increased density. Density can be increased by compaction and by consolidation under static loads.

BEHAVIOR CHARACTERISTICS

Strength

Shear strength of soil is made up of two elements, friction and cohesion.

In its simplest form, friction is the resistance to sliding of one block of nonplastic soils against another. It is similar to, and can be assumed to have the same action as, the resistance of a block of wood sliding down a wooden plane. The friction in soil is complicated by such factors as the irregularity of the planes, interlocking of opposite particles, and size and shape of the soil gra-ins. The greater the weight placed on the sliding block the greater force is necessary to cause the block to slide.

Cohesion is the result of the magnetic-like attraction of particles that is noted in one form as the plasticity and stickiness of soils. It resists one block of 8011 sliding on another, but cohesion resistance does not increase with increased losd on the block.

Both friction flnd cohesion of soils increase with incressed density.

Erosion

Resistance to internal erosion or piping follows very closely the soils resistance to surface erosion. Soils with a high susceptibility to sheet erosion also have a high piping potential, and therefore are critical to earth structure safety. In contrast, soils with a low susceptibility to surface erosion such as the more plastic soils do not present an internsl erosion problem.

Cracking

Cracking of embankments may be caused by either of two physical actions or a combination of them.

Cracking may be caused by drying. As the soil drys, it shrinks and cracks form. The finest materials develop the highest cracking potential. Plasticity is only an indirect indicstor of cracking potential because higher plasticity means finer msterial. If nonplastic materials have the same grain size as plastic materials their cracking potentisl is essentially equal.

Cracking due to movement of embankments is a result of both the amount of movement and the deformability of the material. Deformability of embankments is a result of both the plasticity of the materifll and the water content at which the embankment is built. Generally the lower the water content when compacted the more brittle the embankment and the higher the cracking potential.

Permeability

Permeability depends on both the size and volume of pores in a soil; hence, it increases as grain size increases and decreases as density increases.

Compressibility

Compressibility of a soil deals with how readily and how much it will decrease in volume when subjected to load. Compressibility depends on the volume of voids in the soil, and increases with decreasing density. The amount of settlement that will occur in a soil depends on its compressibility and on the size of the load to be plsced on it. Because of grain to grain contacts, coarse grained soils may be nearly incompressible under static loads but may settle from shock or vibration. The finer grained soils are more susceptible to settlement.

Shrink - Swell

High swell potential occurs in highly plsstic soil and is related to increase of moisture contents under low loads. The swelling capacity may be estimated from the plasticity index of a soil. Soils with a plasticity index of more than 20 usually have a medium to high swell potential; those with more than 35 normally fall in the very high category. The strength of soils after swelling is greatly reduced.

Upon drying from saturation to the shrinkage limit, soils with a low shrinkage limit will shrink more than those with a high shrinkage limit.

If possible, the placement of soils with a high shrink-swell potential should be restricted to interior zones of embankments where little changes of moisture will occur, and where loads will be imposed which will tend to prevent swell.

Bearing Capacity

The ultimate bearing capacity of a soil is the average load per unit area required to produce failure by rupture of a supporting soil mass. Bearing capacity is important in evaluating the ability of soils to safely support semi-rigid structures through footings, piers, or piles.

h. USCS symbols for soil types - see attachment

I. Field identification - see attachment

j. Characteristics of USCS soil types - see attachments

k. Soil investigation of pond sites - see attachment

l. Soil sealing

- Compaction is the first and most important line of defense against leaky ponds. It is the process of artificially increasing the density of the soil for the purpose of stabilizing the soil and reducing porosity. Compaction is accomplished by mechanically pressing the soil particles together to expel air and water. A mixture of sand, silt, and clay compact well because the smaller particles will fill the pore spaces and bind the larger particles together.A uniform soil texture is undesirable for dam construction because it does not compact well, thus leaving pore spaces through which water may seep.

  Probably the most critical factor in compacting a soil is its moisture content. Every soil has an optimum moisture content for compaction purposes. A soil with too much or too little moisture will not compact well and result in an inferior structure. For the small dams used in aquaculture a simple test can be used to determine if the soil moisture content is satisfactory. Place a small sample of soil in the palm of your hand and roll it. If you can roll the material out to about the diameter of a pencil (8 mm) it is too moist and construction should be delayed. If the material crumbles it is too dry indicating that water should be sprinkled on the soil during compaction. If the material crumbles only slightly the moisture content is about right for good compaction. This simple test is only effective for cohesive materials with at least 5% clay content.

  A sheepsfoot roller is commonly used in compacting earth for dam construction. This type of roller works best if the soil is placed in layers of from 4 to 10 inches thick. If soil layers are too thick only the upper few inches will be compacted. Care should be taken so that each successive layer of soil is bonded to the preceding layer of soil. Soil compacted perfectly smooth as when a rubber tire roller is used will develop a weak laminated structure. The upper few inches of an earth layer compacted by rubber tired rollers must be scarified in order to bond it to a succeeding layer. A sheepsfoot roller leaves the upper few inches of the compacted layer in a loose state so the succeeding layers of soil are fused together in a continuous process.

- Organic matter - heavy organic fertilization will help seal leaking ponds. An Auburn project in Panama reduced seepage in ponds up to 75% by broadcasting on the pond surface 500-1000 kg/ha/wk of chicken litter for one month or more. Organic matter applied before the pond is filled with water should be disked into the bottom soil and compacted with a sheepsfoot roller.

- Soluble salts, which behave as "dispersing agents," may be added to ponds to break up soil aggregates, and "in effect" reduce grain size. This reduces soil pore size, and facilitates compaction. Tetrasodium pyrophosphate (TSPP) or sodium tripolyphosphate (STPP) may be applied at 1-2 tons/acre by disking into the bottom soil and compacting. NaCl may also be used at 4-6 tons/acre.

- Bentonite is is a highly plastic clay that is available commercially in granular form. It is disked and compacted into the pond bottom. The granules swell when wetted and fill soil voids. Application rates are 20-60 tons/acre, at a cost of $175-200/ton. Because of high cost its use may be limited to spot treatments in leaky ponds.

- Liners may be used to effectively seal leaky ponds. Liners are made from a variety of materials, including polyvinyl chloride, chlorinated polyethylene, polyester-reinforced PVC, etc. at thicknesses of 20-30 mils. Liner material is expensive and is used only where it can be economically justified.

- Clay blankets 6 inches to one-foot thick may be applied to ponds to obtain effective seals.

m. Wetlands - Before clearing or building on wetlands a permit is usually required from the Corps of Engineers and possibly other state agencies.

n. Flooding - Check with the U.S. Geological Survey Office or the Natural Resource Conservation Service about the probability of flooding.

o. Utility rights-of-way - If electrical, water, or other utility services are at the site check with the appropriate authorities to avoid problems.

II. Design of Ponds

A. Size and number of ponds

1. Watershed pond size is a function of:

   a. Availability of water, which is related directly to the size of the watershed. Water may be supplemented by pumping if economic requirements would permit. E.g. replacement of evaporation and seepage losses could require several hours of pumping per week.

   b. Topography and the height of the dam. There is a less direct relationship between the length of the dam and the size of the pond.

   c. Pond management - ponds larger than 20 acres or less than 5 acres may not be desireable. Weight of harvest, harvesting equipment, etc.

   d. Availability of inputs

   e. Cost of construction and capital availability

2. Excavated pond size shares some of the above limitations. Management strategy and marketing are dominant characteristics. In general, as pond size increases cost of construction decreases and cost of management increases.

   a. Example: Square ponds

Area	100	400	1600 m^2
Perimeter:	40m	80m	160m
Dike length per $100m^2$ of water surface area =	40m	20m	10m

   b. Economic implication:

   Pond construction cost, as affected by pond size, can make the difference between profit and loss in fish farming during lean years.

   AMORTIZATION COSTS AS FUNCTION OF POND CONSTRUCTION COSTS

   CONDITIONS: 10-YEAR LOAN AT 9% PER ANNUM
   3,500 LBS FISH/ACRE-YR

	CONSTRUCTION COST/ACRE	ANNUAL PAYMENT	$/LB
	$2,500	$390	$0.11
	$2,000	$312	$0.09
Difference:	$500	$ 78	$0.02

(Savings for 80-acre farm: $6,240/year)

B. Shape and arrangement

1. Excavated ponds: Construction cost is a function of length of dike.

a. Perimeter of 1-acre pond as a function of shape (overhead)

Shape		perimeter (ft)	% increase
Circular		740	standard
Square		835	13%
Length:width	2:1	885	20%
	3:1	964	30%
	4:1	1043	41%

1) Circular ponds are theoretically cheaper, but difficult to construct, manage and wasteful of land.

2) Square ponds are more economical than rectangular, but may be more difficult to manage (seine) and may be biologically less productive (eg *Machrobrachium* production is function of shore line length)

Difference between square and mildly rectangular is not much: eg a pond twice as long as wide has *only 6% greater* perimeter than square pond of equal area.

3) Shape (length:width) is often adjusted so a given number of ponds fit within a given distance eg 3 small ponds along 1 large pond so that dikes line up.

4) 5-acre shrimp ponds in Texas with 3:1 (L:W) shape required 33% more earth movement than square pond of same surface area (Overhead)

2. Watershed ponds: Like size, shape is largely determined by topography (contour lines). Some control is possible by additional excavation (at a cost).

Obtain fill for dike from within or outside of flooded area ?

Advantages of within	Disadvantages
Deepen edges	Decreased natural fertility
Increase volume	Danger of exposing permeable soil
Shaping for management	Earth movement possibly more difficult

3. Arrangement of ponds to each other and to watercourse - see handouts

C. Orientation to dominant winds

1. Scouring: put drain on leeward end of pond

2. Maximum *wave height* as a function of Fetch

Hw = 1.4   F meters

if F =	Hw =
20 m (about 0.1 acres)	6 cm
100 m (about 1-2 acres)	14 cm
500 m (about 25-30 acres)	31 cm
1000 m (about 100 acres)	44 cm
5000 m	99 cm

3. May be necessary to rip-rap on large ponds to protect dike.

4. The benefit/disadvantage of wave action is controversial: it introduces aeration but increases dike erosion. Criteria for decisions are pond size, consistancy, strength of dominant winds, and management intensity. It often happens that the days aeration is most needed are precisely the days you are least likely to get it from wind (cloudy, sultry days in late summer).

D. Depth of water and freeboard

1. Freeboard: (vertical distance between water at full pool and top of dam)

a) <u>1' freeboard ok for excavated ponds with controlled inflow of water</u>. Even with good water control, dikes with traffic should not have less than 1' freeboard because maintenance costs will be high as a result of erosion and reduced stability of soggy soil.

b) 2 to 3' freeboard for embankment ponds in small watershed receiving rainwater runoff.

c) Freeboard may be even greater if the size of the pond is sufficient to permit the generation of big waves (eg Fetch of 500 m or more).

2. Water depth

a) Watershed ponds:

- Depth sufficient to ensure a permanent, or extended, water supply as determined by:
    - Environmental factors
    - Rainfall amount and seasonal distribution
    - Evaporations rates
    - Seepage rates
    - Consumptive uses of pond water
    - Garden irrigation (most plants need 60 cm of water/crop)
    - Stock watering (generally considerably less than seepage+evaporation)

- Maximum depth for watershed ponds used for intensive culture (eg catfish) should be 10' at dike to permit fish harvest without draining.

- Minimum depth of 2-3 feet to prevent rooted aquatic weeds depending on fertility (turbidity) and culture species:
    - 2' sufficient in well fertilized ponds with herbivorous fish, such as tilapia or grass carp, or relatively high densities of common carp.
    - 3' recommended for lightly fertilized bass-bluegill farm ponds and catfish monoculture ponds.

    - Recommended minimum depth for US ponds filled with rainwater runoff to ensure year-round water (overhead):

climate	Minimum max-depth
humid	2 m

semi-arid	3.5 m
arid	4 to 5 m

Deeper if year-round water is *essential* or seepage exceeds 3"/mo.

In watershed ponds average depth is generally about 0.4 x maximum depth at dam.

- Watershed ponds with permanent supplemental water (e.g . well or spring) can be managed for optimum depths (usually 3-5 '). SCS recommends 10 gpm/ acre.(10 gpm continuous = 0.5 acre-inches/day) for supplemental water for watershed ponds.

b. Excavated ponds

- Minimum depth of 2-3 ' to control weeds (as above).

- Maximum depth: usually 4-5'. In well fertilized ponds net positive primary productivity does not occur below this level -- so there will likely be anaerobic water below that depth which is dangerous in case of turnover.

- Benefits of increasing water depth in very shallow ponds are great but as dike height (water depth) increases, the cost/benefit ratio works against deeper ponds:

Dike height	3'	4'
Water depth	2'	3'
% increase	-	**50%**
Dike X-section	48	72 ft^2
% increase	-	**50%**

	Water incr	x-section incr
4' dike vs. 3'	50%	50% (1:1)
5' dike vs. 4'	33%	39% (1.2:1)
6' dike vs. 5	25%	32% (1.3:1)

- The marginal costs of construction become progressively higher as depth increases, but (at least for aquaculture) the marginal benefits from deeper water increase at a decreasing rate, and even become negative (no biological benefit, but increasing water costs, difficulty in harvesting, DO problems with turnover, etc). However, if the goal is water storage for household use, the marginal benefit of being able to maintain water ALL year, instead of 9 months, may easily compensate the higher cost.

- Caution: increase in dike volume can not be compared directly against increased water volume. You must compare the additional cost against the additional benefits derived from deeper water. A direct measurement is to compare the additional amortization costs for construction against increased profits from fish sales. You really should work from enterprise budgets to incorporate all costs..

E. Bottom of pond

1. Slope

- Gentle enough so that soil on pond bottom is not eroded when pond is drained, and steep enough to permit adequate drainage.

- Maximum slope about 2% (2 ft. fall per 100 ft. of run). May be exceeded as necessary if bottom soils are tight and if pond is not drained often.

- Minimum slope 0.1% (1 ft. fall per 1000 ft. of run). Precision leveling required during construction.

- Recommended slope for 10- to 20-acre commercial catfish ponds: 0.1 to 0.2% along long axis.

- For relatively small excavated ponds, establish maximum and minimum water depths, and make sure resulting slope is within max-min tolerance.

2. Harvest basin (harvest sump, catch basin)

    - Especially important if fish are not easily seined and are to be kept alive for restocking or live marketing.

    - Usually about 1 to 1.5ft. deep, covering 2 to 3% of pond bottom, depending on fish biomass, harvest technique and requirements for maintaining good condition of the fish.

    - May be made partially or entirely of concrete, but usually earthern. In some cases may be located outside of the pond, as is case for B-ponds at Auburn.

F. Dike specifications

1. Most common causes of dam failure

    a) Overtopping (inadequate spillways and freeboard)

    b) Undermining (water flowing under dam)

    c) fissures and cracks in dam (poor compaction) and foundation

    d) percolation along tree roots and pipes

    e) dike erosion

    f) piping

2. Top width of dam

    a) Recommended minumum for driveable dams - 16 feet

    b) Practical minimum for dams built with heavy equipment - 10 feet

    c) Minimum of 3 ft. for small hand dug excavated ponds.

3. Side slopes of dam

a) Usual range for slopes - 2 to 4:1 (horizontal:vertical). Catfish ponds most commonly 3:1.

b) Factors that influence slope

- Soil stability: Clay, snady clay, silty clay slopes may be steeper; silt or clayey silt soils require flatter slopes.

- Wave Action: upstream slopes are often flatter than downstream slopes because they are more easily eroded by wave action, are often saturated and thus less stable.

- Maintenance: outer slopes should be 3.5:1 or flatter for maintennace by tractors.

- Construction cost and soil availability: approximately 25% more soil is required when slopes are 3.5:1 compared to 2.5:1.

Fill material	Upstream	Dowstream
clay, clayey sand, sandy clay, silty sand	3:1 - 3.5:1	2.5:1 - 3:1
silty clay, clayey gravel, silty gravel	3:1 - 3.5:1	2.5:1 - 3:1
silt or clayey silt	3.5:1 - 4:1	3:1 - 3.5:1

4. Dam height

a) As a rule-of-thumb earthern dams are seldom over 20 ft. Qualified technical advice is especially important for dams this high.

b) The design height of a dam will depend upon:

- desired water depth and surface area

- anticipated flood stage

- desired freeboard

- amount of expected soil settlement: expressed as percent of dam height, 20-25% settlement might be expected for poor soil materials or poor compaction. Peaty or highly organic soils have been known to settle up to 70%. 5% settlement is normal for well-compacted dams.

5. Dam foundation

a) Dam foundation soils must have two important qualities:

- <u>stability or strength</u> to bear the weight of the dam
- <u>impermeability to prevent undermining</u>

b) Good foundation soils are:

- sandy clay
- silty clay
- clays of low plasticity
- well-graded soils with at least 30% clay

c) Poor foundation soils are:

- poorly consolidated silts
- highly plastic clays
- sand and gravel
- limestone soils (dissolve at low pH)
- fissured rock

d) If foundation soils are “good,” only remove top soil and scarify to permit continuous bond with fill.

e) If foundation soils are permeable and/or unstable, a cutoff (foundation key or core) should be provided. This is common for watershed ponds since they are often built across a small, permanent or temporary stream with sandy or mucky soils.

f) The cutoff

- is made with impermeable soil
- penetrates at least 1.5 ft. into the naturally occuring, impermeable layer

- has a minimum width of four feet (usually wider to conform with width of construction equipment.

- importance increases as water depth (and pressure) increases

6. Emergency spillway

   a) The purpose of the emergency spillway is to discharge abnormal excess runoff water to prevent overtopping of the dam ("normal" excess is discharged through the drain structure).

   b) The emergency spillway should be located about one foot above full pool. The vertical distance between full pool and the crest of the emergency spillway is <u>flood storage depth.</u> This feature gives the overflow structure opportunity to discharge normal excesses, and keeps emergency spillway from being wetted by normal excesses.

   c) Spillway design:

   - <u>Inlet, or approach channel:</u>

     - slope should no be less than 2% to prevent choking of channel. If the slope is less than 2% excavation may be necessary to attain the desired slope.

     - entrance of channel should be 50% wider than the bottom width of the level section.

     - shaped with gentle, sweeping curves.

     - bottom width of channel should not exceed 35 times the design depth of flow - where this is exceeded the channel may be damaged by meandering flow and accumulated debris - where width is excessive 2 spillways at either end of dam might be used.

   - <u>Level portion/section:</u> at least 20 ft. long as measured in the direction of flow.

   - <u>Control section and crest:</u> the downstream border of the level portion - should be near the centerline of the dam.

   - <u>Exit section:</u> conducts water down and away from dike to prevent erosion on downstream side of dike. Wing dikes ("kicker levees") may be used to direct flow away from dam if needed). Minimun slope 1% to meet critical flow conditions;

maximum slope 2 to 12%, depending upon erodibility of soil and type of vegetation cover. Maximum velocity should not exceed 6 ft./sec. For ponds to be used for fish culture there should be sufficient vertical drop to prevent fish swimming upstream and entering the pond.

- Width of emergency spillway: Rough estimate for Alabama - Width in feet = 10ft. + 1/2 watershed area in acres. E.g. for a 30 acre watershed Width = 10 + 15 = 25 ft. For large watersheds this method overestimates the width of the spillway.

- SCS method uses the following factors to calculated width of spillway:

    - peak rainfall (25-year return period)
    - soil texture
    - vegetative ground cover
    - slope of watershed
    - area of watershed

d) Estimating peak storm runoff from watersheds

- See handouts for sample problem

G. Water diversion canals

1. Diversion canals are required when normal water flow through the pond is projected to be too great to be accommodated by ordinary overflow structures, and/or when longer retention time is desired for a fish pond receiving fertilizers.

2. The table below contains recommended limiting velocities of water for various soil types. If these velocities are exceeded scouring and erosion may take place.

Soil Texture	**Max. Velocity m/sec**
Sand and sandy loam (SP,SW,SM) (non-colloidal)	0.75
Silty loam (ML), also high lime clay	0.90
Sandy clay loam (SC)	1.05
Clay loam (CL)	1.20
Stiff clay, fine gravel, graded loam to gravel (CH,GP,GW)	1.50
Graded silt to cobbles (colloidal)	1.65

Shale, hardpan and coarse gravel	1.80

H. Water control structures

1. Location of water inlet

    a) Advantages of inlet at shallow end:

    - more complete mixing and flushing
    - good for production system requiring constant or frequent water exchange.

    b) Advantages of inlet at deep end:

    - fresh water can be added directly to deep end where fish concentrate during draining, especially important when fish must be kept alive after harvest.
    - During sudden oxygen depletion a refuge area of improved DO can be created at a point close to the drain, and in an area deep enough to accomodate large numbers of larger fish.

2. Water supply structures

    a) Open ditches: standpipe inlet with standpipe in ditch; gate inlet. Inexpensive to construct, but high maintenance requirements.

    b) Concrete channels: relatively expensive.

    c) PVC pipes with valves: relatively inexpensive; easy installation; low maintenance.

3. Structures for drain and normal overflow

    a) monks (box type with flashboard riser

    b) barrel with riser

    c) “Turndown” standpipe

4. Calculating pipe dimensions

a) Principal variables affecting water flow in pipes

- Whether pipe is flowing full
- friction loss (Manning Coefficient of Roughness)
- diameter of pipe
- length of pipe
- number and angle of bends
- head

b) Catfish ponds: install drain pipes that permit total drainage in no more than 5 to 7 days.

c) See handouts with Exercise 7c for additional detail.

5. Pond drain rate (hours per Acre-ft) = 12.1/rate of discharge (CFS). 12.1 is a constant (43,560 ft^3 per acre-ft/3,600 sec per hour). Total pond draining time is approximated by the two methods below:

a) $\sum$DRAIN TIMES OF ALL 1-FT LAYERS OF WATER

EXAMPLE: 0.25-acre pond; 3' (min) to 4' (max) water depth; 4" drain

Water depth (ft)		Discharge	Time	
Range	Aver	(cfs)	(hours)	
4 to 3	3.5	0.47	(12.1/0.47)(0.25) = 6.4	
3 to 2	2.5	0.39	(12.1/0.39)(0.25) = 7.8	
2 to 1	1.5	0.31	(12.1/0.31)(0.25) = 9.8	
1 to 0	0.5	0.18	(12.1/0.18)(0.12)* =8.4	
5 to 0			SUM	32.4

*at 0.5'depth surface water cover only 50% of pond

b) POND VOLUME (ACRE-FT) x DRAIN TIME/FT AT 40% MAX DEPTH

EXAMPLE: as above.40% of 4 = 1.6; discharge rate = 0.32 cfs

Drain time = (0.25 x 3 + 0.125 x 1)(12.1/0.32) = 33 hours