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Aquatic Plant Control Research Program

Outdoor Mesocosm System for Evaluating Aquatic Herbicides: Operating Manual

by Gary O. Dick, University of North Texas
Kurt D. Getsinger, R. Michael Smart, WES

Prepared for Headquarters, U.S. Army Corps of Engineers

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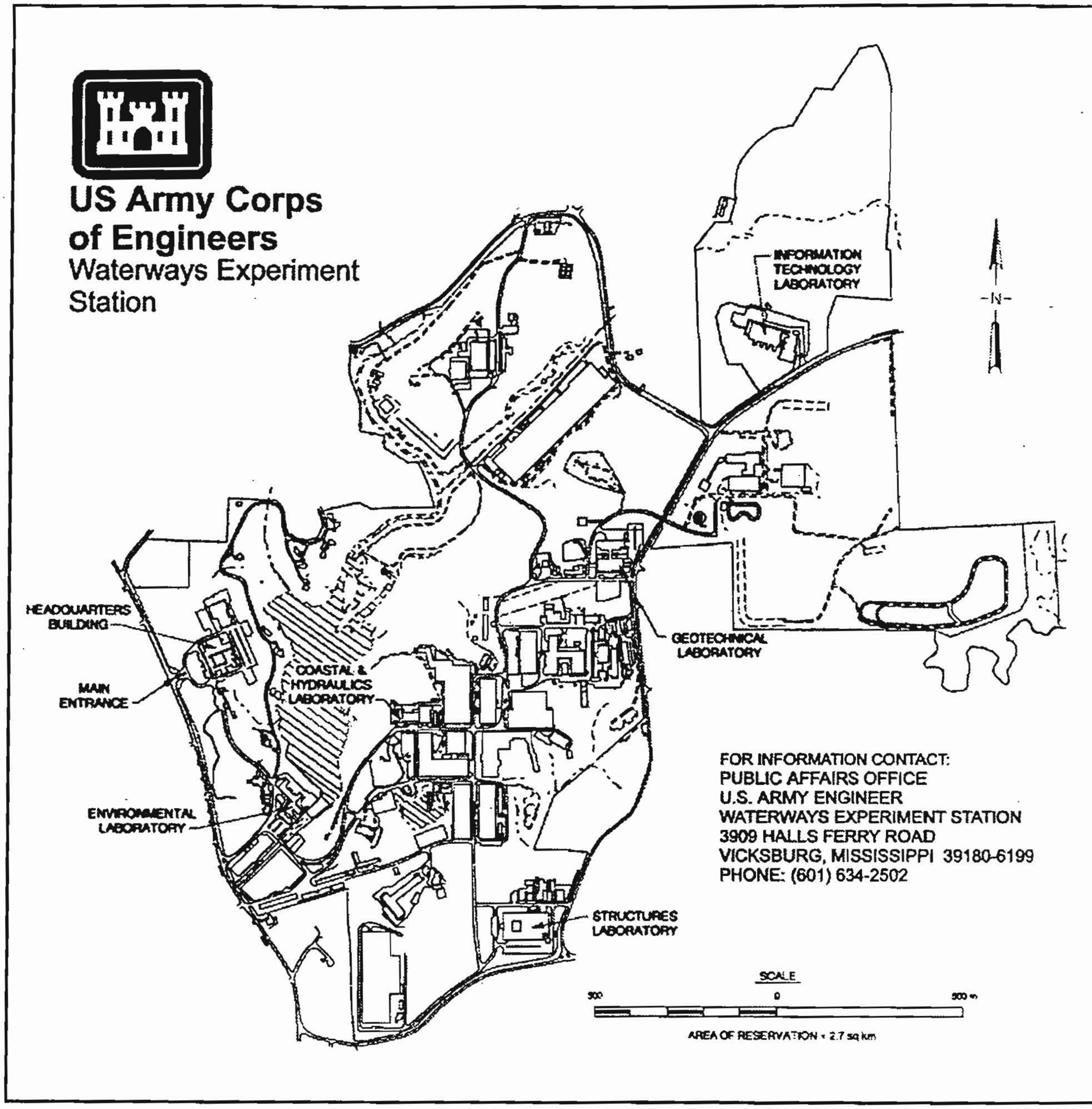

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32841, Species-Selective Use of Aquatic Herbicides and Plant Growth Regulators. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John W. Barko, Director. Mr. Robert C. Gunkel was Assistant Director for the CAPRT. Technical Monitor during this time was Ms. Denise White, HQUSACE.

Principal Investigator for this work was Dr. Kurt D. Getsinger, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. The report was written by Dr. Gary O. Dick, Institute of Applied Sciences, University of North Texas, Denton, TX; Dr. Getsinger; and Dr. R. Michael Smart, Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX. The report was reviewed by Dr. Robert Doyle and Mr. John Skogerboe, LAERF.

This work was performed under the general supervision of Dr. Richard E. Price, Chief, EPEB, and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

The U.S. Army Engineer Waterways Experiment Station's (WES) Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX, has expanded its research capabilities with the addition of several outdoor aquatic mesocosm systems. The principal function of the largest of these systems is to investigate the use of aquatic herbicides and plant growth regulators (PGRs) for achieving species-selective control of exotic nuisance aquatic plants, primarily Eurasian watermilfoil and hydrilla. This mesocosm system yields intermediate-scale verification of laboratory-derived aquatic herbicide and PGR-concentration/exposure-time (CET) relationships developed at WES. Prior to field evaluation, researchers recognize a need to verify laboratory results on a larger scale and under more natural conditions, and this system provides a combination of field (e.g., light and temperature) and controlled (e.g., water quality, sediment composition, plant communities) conditions for experimental purposes. Evaluations can accommodate flow-through as well as static chemical exposure conditions. The flow-through mode allows for field-simulation of herbicide degradation and dissipation, important processes in determining and predicting off-target movement, and nontarget consequences, of active ingredients. Static mode allows for the evaluation of worst-case scenarios per herbicide dissipation via water-exchange processes.

This report presents information on the design, operation, and maintenance of the LAERF mesocosm system and can be used as an operating manual for the system. In addition, a description of the system's construction, including materials and components, is documented. The system's design allows researchers to evaluate the effects of herbicides and PGRs on target and nontarget plants, providing operational guidance for restoring native plant communities in aquatic ecosystems.

2 Mesocosm System Design

Background

The mesocosm system is located at the LAERF, immediately south of the containment dam of Lewisville Lake, a Corps of Engineers reservoir that impounds the Elm Fork of the Trinity River. The LAERF is a 45-ha pond facility constructed in the early 1950s as a Texas Parks and Wildlife Department fish hatchery. The facility consists of 53 clay-lined, earthen ponds ranging from 0.16 to 0.81-ha surface area, each with an average depth of about 1 m. Water is supplied to the ponds from Lewisville Lake via a gravity-fed, 35-cm-diam cast iron piping system associated with the water release structure of the reservoir. Drainage water from ponds is returned to the Elm Fork of the Trinity River by way of an open, 1-m-wide by 0.75-m-deep concrete-lined drainage ditch. The LAERF and Lewisville Lake are found at the boundary of the cross timbers and blackland prairies in southern Denton County (Gould 1975). Average annual temperatures are 18.5 °C (LAERF records), with a 226-day freeze-free growing season from late March to early November (Ford and Pauls 1980). Average annual precipitation is 94.7 cm (Owenby and Ezell 1992), primarily as rainfall.

Lewisville Lake water entering LAERF ponds is generally alkaline, ranging between 100 and 150 μg/ℓ throughout most of the year (Smart et. al. 1995a). Water clarity typically ranges between 1 and 2 NTU turbidity, exhibits an average conductivity of about 300 μS/cm, and contains low to moderate levels of nutrients (ions), dependent upon time of year. Storms and turnovers that mix the Lewisville Lake water column may result in occasional increases in nutrient concentrations and suspended materials.

LAERF pond surface water temperatures vary widely during the year, ranging from 0 to 36 °C. Partial ice cover may occur on the ponds during winter, with complete cover (up to 10 cm thick) recorded three times since 1989. Subsurface (>0.3 m) water temperatures are generally cooler, and daily stratification/destratification patterns generally occur during warm weather. Dissolved oxygen and pH are greatly influenced by plant/algal communities within ponds and generally exhibit significant diel fluctuations. Concentrations of various ionic compounds are often lower in the ponds than in Lewisville Lake water, primarily as a result of uptake by aquatic vegetation and algae growing in the ponds (Smart et al. 1995a).

Components of Mesocosm System

The mesocosm system was built to allow researchers to test efficacy and species-selectivity of aquatic herbicides and PGRs for controlling exotic species aquatic plant communities. Operations required to carry out typical experiments include establishment of aquatic plants in sediment-filled containers, growth to desirable life stage, and placement in tanks under suitable environmental conditions. After a period of acclimation, plants are subjected to test conditions (e.g., aquatic herbicide treatment under static or flow-through modes), followed by harvesting and analyses. Major components of the mesocosm system, designed to facilitate experimental procedures, include the following: (a) tanks, (b) water supply reservoir, (c) fill system, (d) water circulation/aeration system, (e) drain system, (f) water-detention pond (g) wetland-retention cell, (h) support laboratory, (i) sediment preparation pad, (j) root washing station, (k) grow-out pond, and (l) shading canopy.

Mesocosm Site Selection and Preparation

An existing earthen pond (LAERF Pond 43) was selected as the principal site for the mesocosm system and is located at the mid-southern region of the LAERF (Figure 1). Several criteria were used in pond selection, including size (0.35 ha), pond-liner (clay) integrity, accessibility, and convenience to existing facilities.

Topsoil and organic debris were scraped and removed from the levees and bottom of Pond 43 to expose most of the clay liner. The southern levee was removed, with its clay and other fill material set aside for use elsewhere. The southern 75 percent of the pond bottom's original grade (2 percent south to north, 1.5 percent east and west to center) was reworked to produce a 1-percent drop from north to south (Figure 2a and b). These slopes were constructed to direct runoff of precipitation away from the site. The original deeper portion (northern 25 percent) was graded level, but with no fill removed.

Fill material from the pond bottom and its southern levee was used to construct a 2-m-high levee with center crown 30 m from the original northern levee crown (Figure 2b). The levee crown was constructed at a 3-m width for vehicular access, and slopes on both sides were graded to 3:1. The levee was compacted during and after construction. Original eastern and western levees of this area were left intact, with some surface reworking undertaken to restore the 3:1 slopes.

New levee construction resulted in a 60- by 30- by 1.5-m (mean depth) basin, which serves as the water supply reservoir (Figure 2b) for the mesocosm system. South of this basin is a 40- by 80-m level area with 1-percent southerly drainage slope, in which tanks and associated facilities are located (Figure 2b). A small area (12- by 15-m) was excavated to a depth of 1 m at the southwestern corner of the site to serve as a water-detention pond for herbicide-treated water (Figure 2b). A levee, measuring approximately

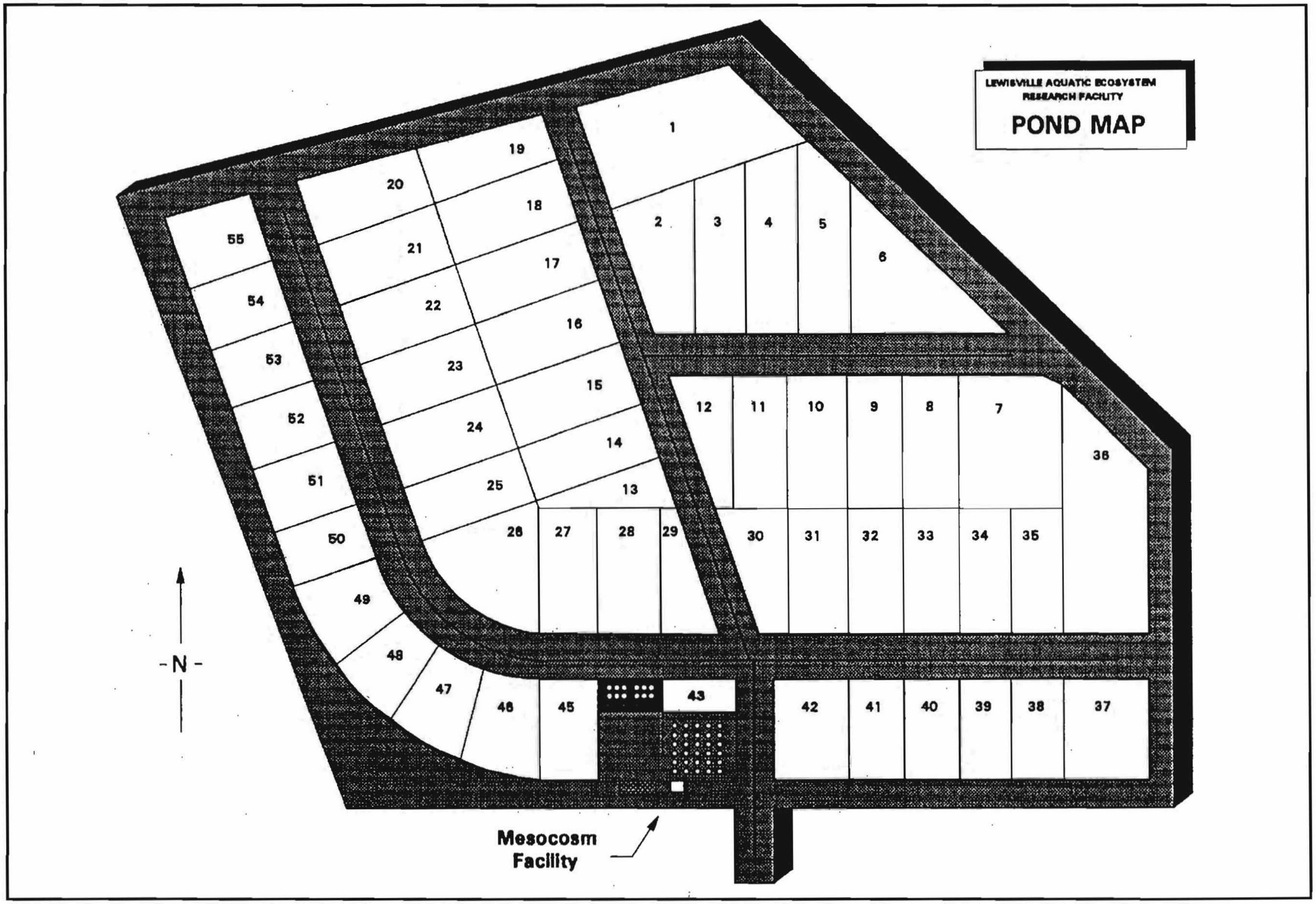

Figure 1. Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX, pond map

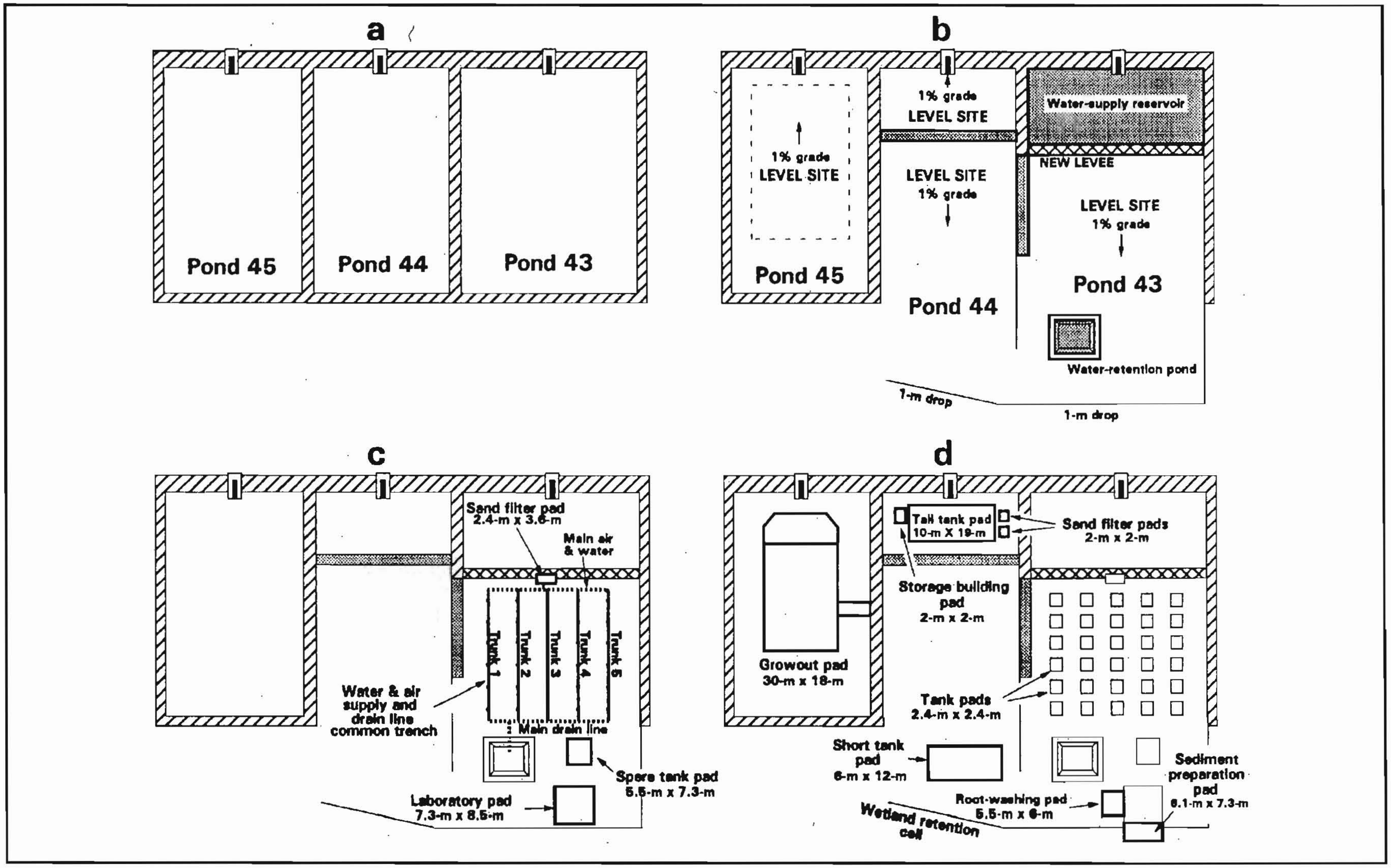

Figure 2. Progression of mesocosm system development: (a) original design of Ponds 43, 44, and 45; (b) reconstruction of levees and pond bottoms; (c) underground piping systems; and (d) structural (concrete pad) placement and mesocosm support facilities

0.3 m in height, was formed around the water-detention pond to increase its holding capacity and eliminate flooding from runoff from surrounding areas.

Trenches for the fill, drain, and recirculation/aeration systems were excavated and piping installed (Figure 2c). Excess fill materials were used to fill the area immediately south of the original pond, expanding the dimensions of the tank site (excluding the water supply reservoir) to approximately 40 by 100 m. This expansion provided space for construction of several facilities, including the support laboratory, sediment preparation pad, and root washing station (Figure 2d). A 1-m high berm was constructed immediately west of this area (southwest to the entire site) at lower elevation (approximately 1 m), producing the mesocosm system's wetland-retention cell (Figure 2d), designed to serve as an additional water-retention area.

Further excavations were made at the site to reduce seepage from the adjacent Pond 44 (west of the site) and to fill the eventual needs of other mesocosm systems (Figure 2b-d). The southern portion and a portion of the eastern levee were removed, and fill material was used to raise and reverse the grade of the southern 75 percent of that pond's bottom. This produced a southerly drainage slope similar to that of the first mesocosm site, but at about 1 m higher elevation, covering approximately 0.4 ha (40 by 100 m). Additional pond reconstruction was made on Pond 44 to facilitate the development of other tank systems, and Pond 45 was converted into an aquatic plant grow-out pond to serve all mesocosm systems at the LAERF. A detailed schematic of the major components of the mesocosm system is provided in Figure 3.

Tanks

The most conspicuous components of the mesocosm system are 32 prefabricated fiberglass tanks (Figure 4). Each tank measures 1.4 m tall and 2.6 m in diameter (2.4-m bottom diameter) and has a working volume of approximately 6,700 ℓ (maximum volume 7,000 ℓ). The tanks were constructed in standard fashion (Red-Ewald, Inc., Karnes City, TX) by laying fabric and resin over a mold to produce a 2-cm-thick single-piece, open-topped tank. Interiors are finished with a light blue fiberglass gel-coat, which discourages epiphyte attachment and simplifies cleaning. A 5.1-cm-diam slip by female-threaded schedule 40 polyvinyl chloride (PVC) fitting is molded into the fiberglass 15 cm from one side of the tank bottom for drainage. Tank exteriors are light gray in color, reducing heat absorption from sunlight, and tanks are numbered on outside walls with 15-cm-high white on black spray-painted stencil numbers for easy identification. Tank life expectancy is approximately 20 years.

Thirty of the tanks are arranged in a 5-column by 6-row pattern immediately south of the water supply reservoir, with sufficient space between them for vehicular access: 5 m between columns and 2.7 m between rows (Figure 3). Each tank is set on a 2.7- by 2.7-m reinforced, concrete pad (Figure 5). Three layers of roofing felt are placed beneath the tank to

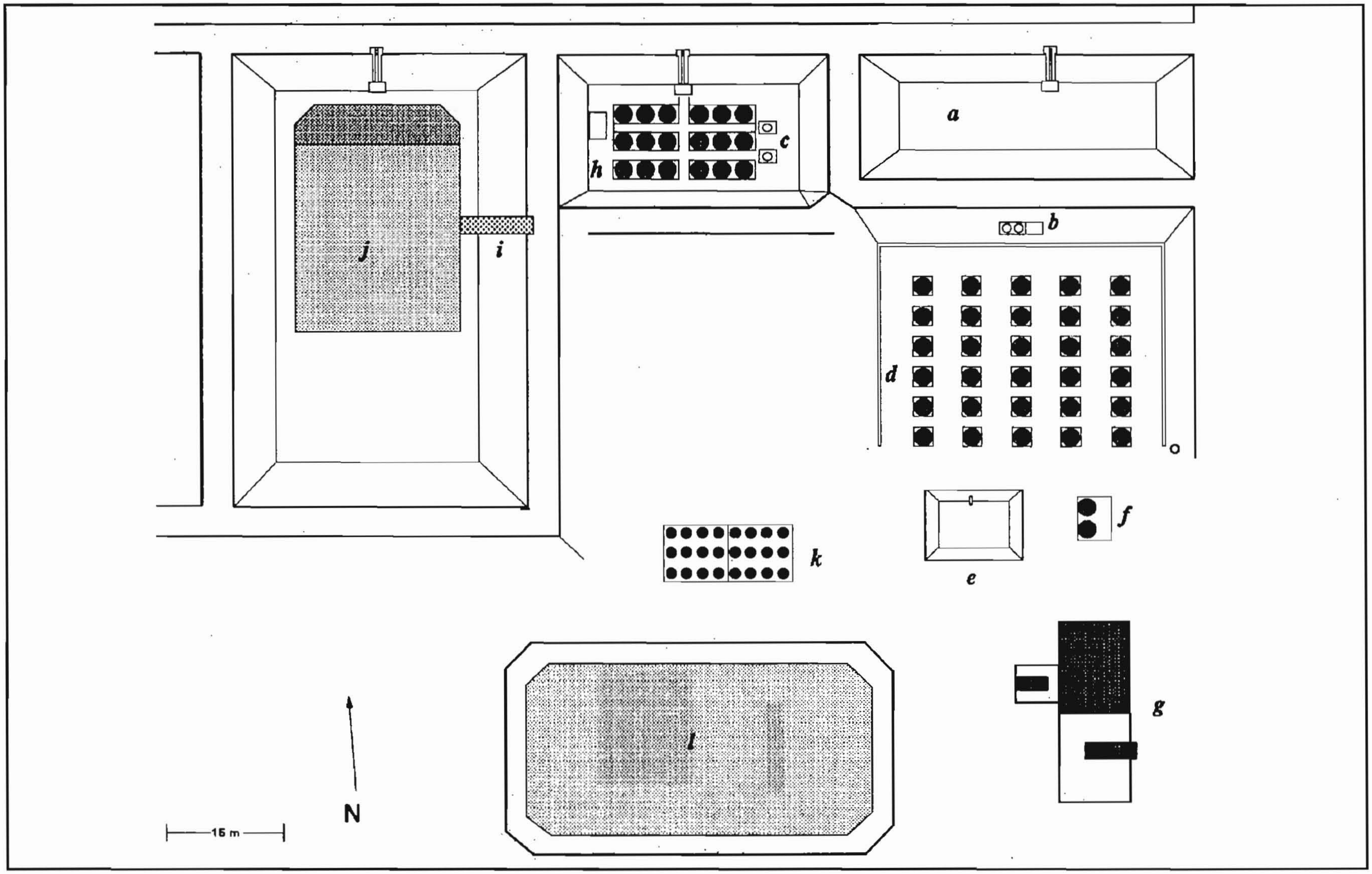

Figure 3. Mesocosm system and related facilities: (a) water supply reservoir, (b) sand filters and air supply station, (c) sand filters, (d) mesocosm tanks and pads, (e) water-retention pond, (f) spare mesocosm tanks and pad, (g) mesocosm laboratory, sediment preparation pad, and root washing station, (h) tall mesocosm tank facility, (i) access ramp, (j) grow-out pad, (k) short mesocosm tank facility, and (l) wetland retention cell

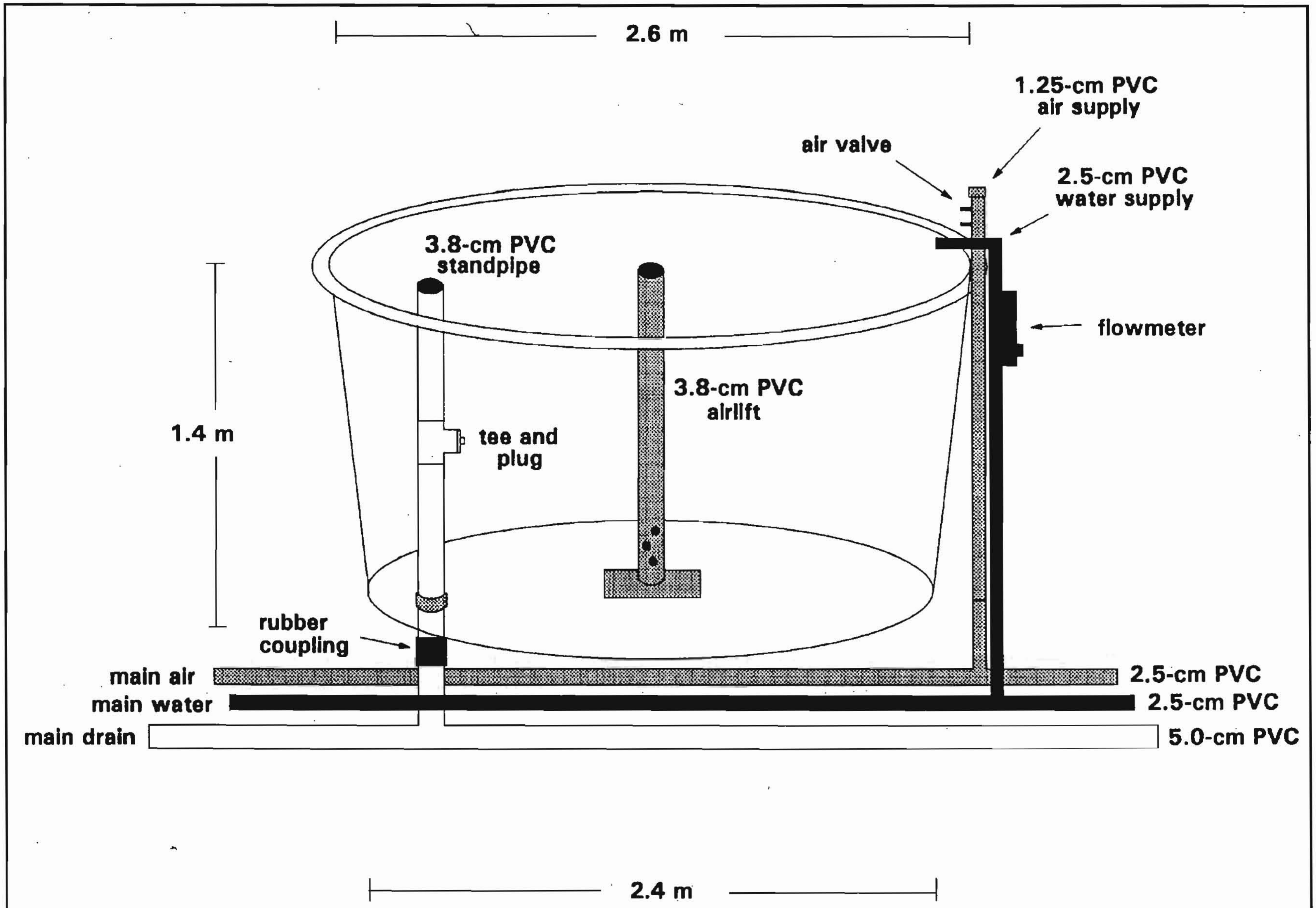

Figure 4. General diagram of mesocosm tank, water and air supply, and plumbing

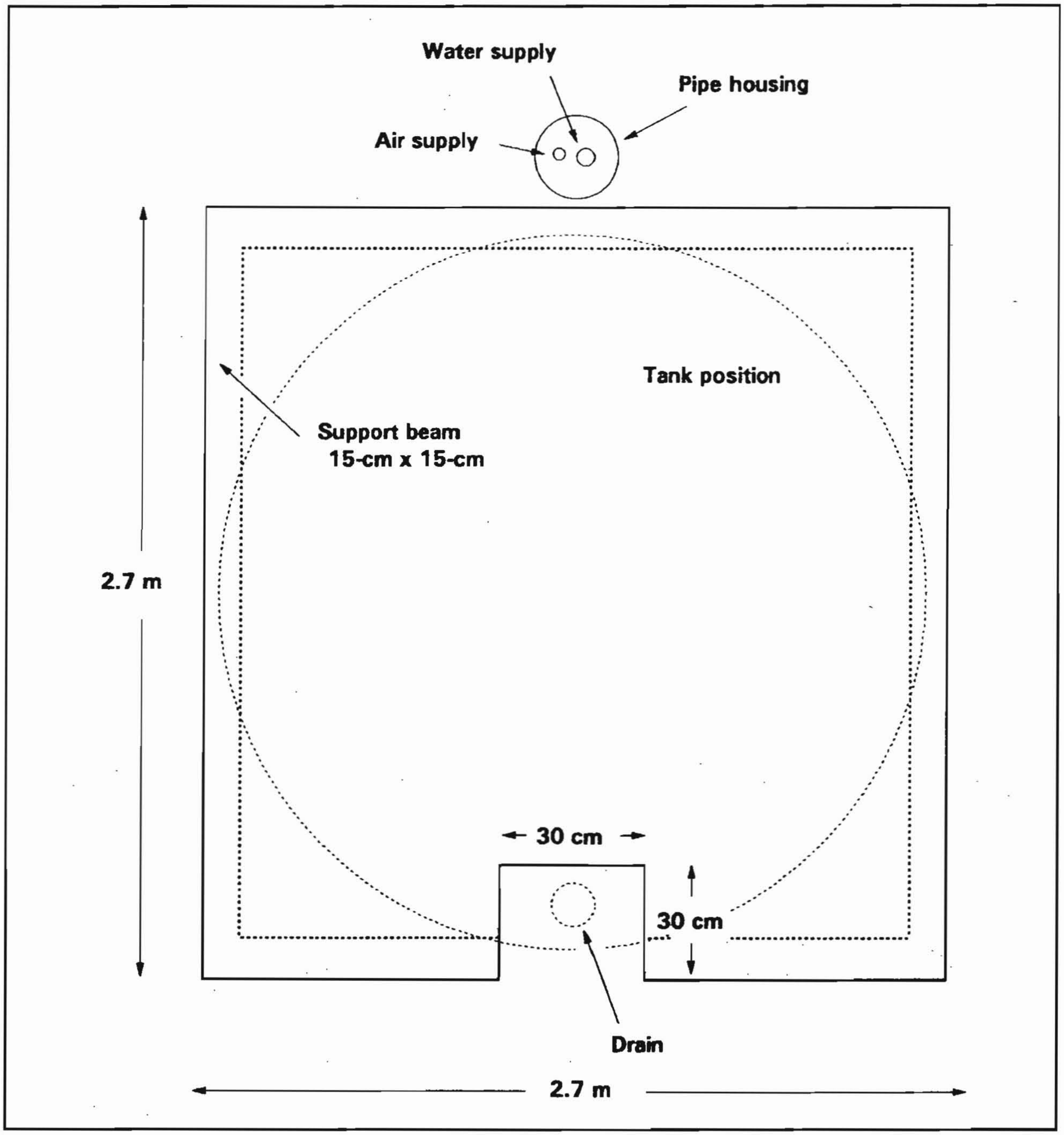

Figure 5. Mesocosm tank support pad

prevent damage to the tank bottom surface from small rocks and burrs on the pads.

Between concrete pads is a 15-cm-deep layer of flex road base, a hard substrate for easy tank access by pedestrian or vehicle. The immediate area is bordered by a 15- by 15-cm concrete curb to divert storm-water runoff from adjacent levees. Flex road base has also been laid throughout the system for access to support facilities.

Two additional tanks are set on a 6- by 4.5-m reinforced, concrete pad (Figure 4). These tanks are approximately 6 m south of the main tank area and serve as spares, culture tanks, and light attenuation references.

Water Supply Reservoir

The 1.4 million-liter water supply reservoir constructed during levee and bottom reconfiguration is lined with a 45-mil synthetic rubber liner (Hypalon, Staff Industries, Detroit, MI) (Figure 6). The liner lies on the surface of the reservoir bottom and inside levees and is held in place by the head of the water column. Perimeter anchoring is achieved by burying liner edges in a trench at the top inner edge of the levee crown. Aged railroad ties (3- by 0.25- by 0.25-m) are placed on top of the trench line for additional anchoring and to reduce storm-water runoff from surrounding areas.

The drain/fill structure of the original pond has been retained for use in the water supply reservoir, and aluminum battens attach the liner to the concrete steps of the structure. The reservoir can be drained completely through the original 15-cm cast iron double-gate valve at the bottom of the drainage trough. For maintaining constant water levels, a 10.2-cm PVC standpipe is inset and sealed into the drain valve (Figure 7). (Note: all PVC piping and fittings herein are given in nominal sizes and are schedule 40). Lewisville Lake water can be gravity fed to the pond at a rate of approximately 75,000 ℓph through a 15-cm cast iron double-gate valve. A rubber-reducing coupling is fitted to the cast iron fill-pipe, and the reduced piping is directed down to an overflow standpipe from above. The top of the standpipe is flared to house a PVC float and plug. Water is filtered as it is added to the water supply reservoir through 100-μm mesh aquacultural nylon netting to eliminate introduction of fish, plants, and other aquatic organisms.

Two sand filters (TD-100, PacFab, Sanford, NC) are positioned at the base of the water supply reservoir's southern levee: the easternmost of these is Sand Filter 1, and the westernmost is Sand Filter 2 (Figure 6). Two others are placed at the base of the western levee and are Sand Filter 3 (northernmost) and Sand Filter 4 (southernmost). Together, the filters recirculate water at a rate of about 1,600 ℓpm (1.6 turnovers of the water supply reservoir per day).

Each filter is driven by a 1,492 W, 110 V, 14 amp electric motor. The impeller pump head is self-priming, and pipes associated with pumps and filters are 5.1-cm PVC (Figure 8). Optimal operating pressure of the filters ranges between 100 and 200 kpa (15 and 30 psi), with a maximum of 330 kpa (50 psi). A six-way valve controls flow through a 530-ℓ filter tank, with valve settings including the following: (a) closed (no flow); (b) filter (unfiltered water from the water supply reservoir directed to the filter tank through filter medium, then back to the water supply reservoir); (c) backwash (unfiltered water from the water supply reservoir directed to the filter tank, but in the opposite flow direction of filter setting, then out a waste pipe to remove filtered materials from the filter medium);

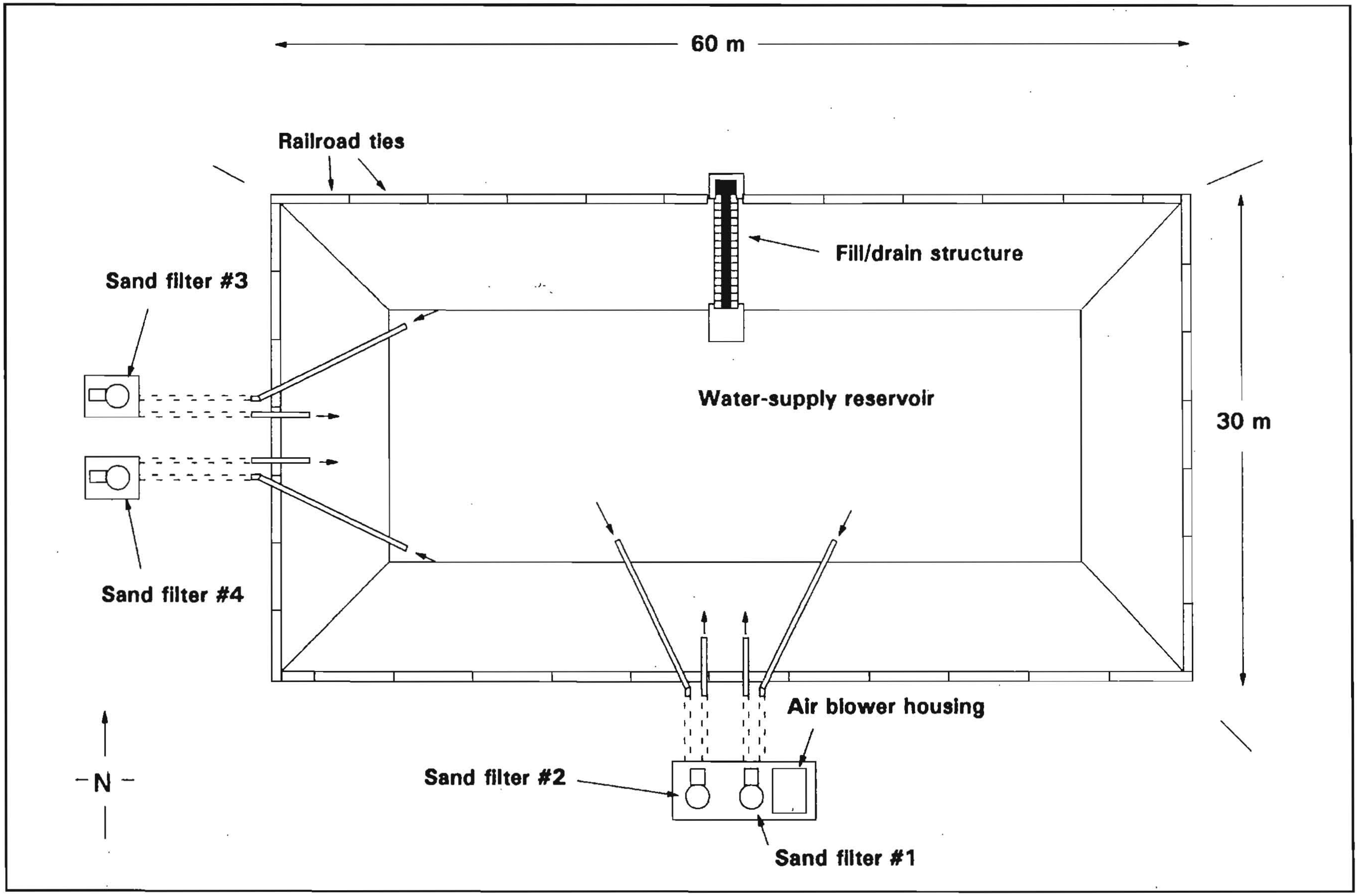

Figure 6. Water supply reservoir is synthetic rubber-lined and holds up to 1,400,000 ℓ of water (Sand filters continually remove suspended materials during normal operations)

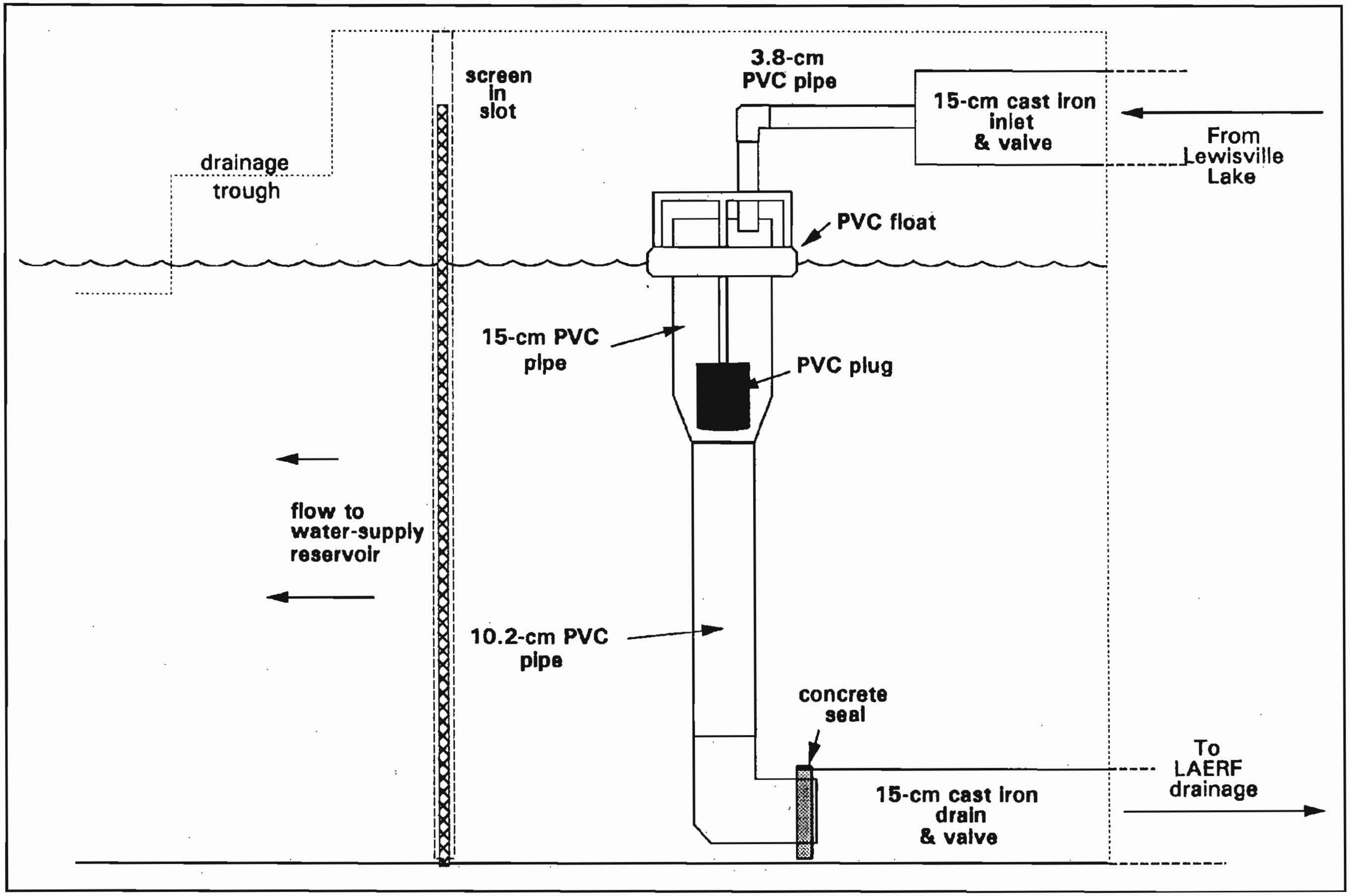

Figure 7. A float valve/standpipe allows automatic maintenance of water levels in water supply reservoir without diluting effects of sand filtrations and alum treatment

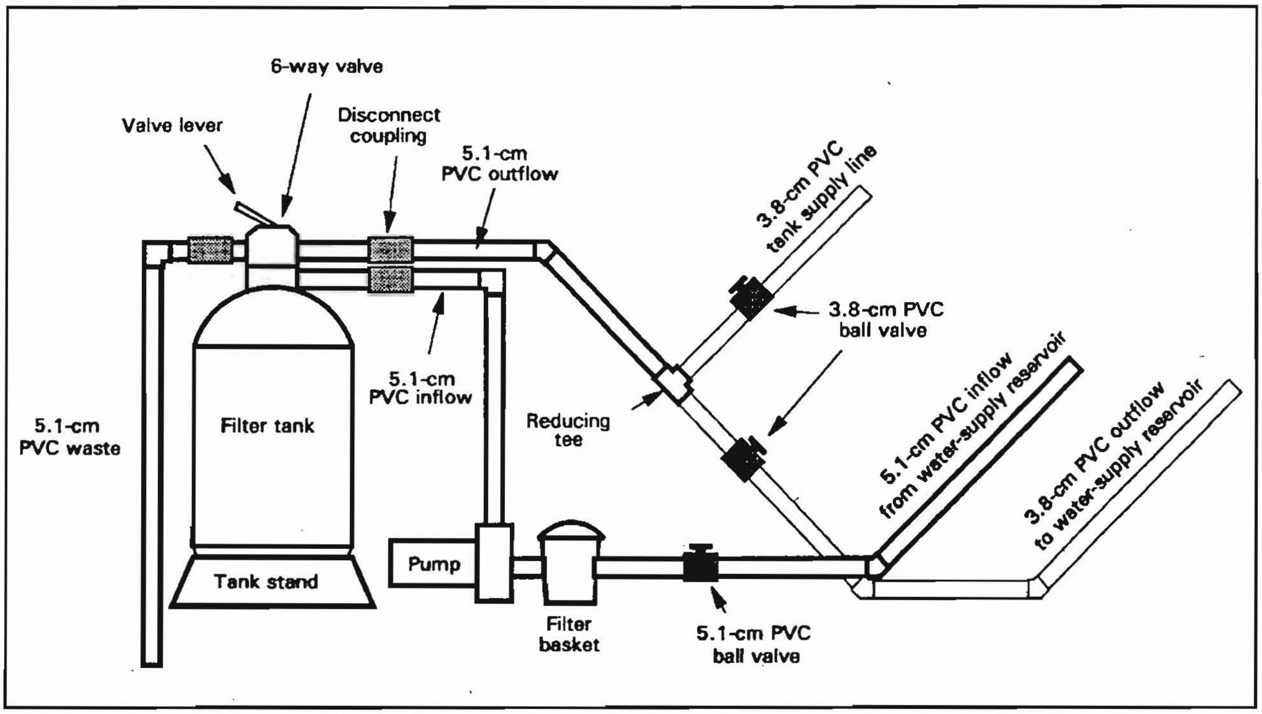

Figure 8. Four sand filters are plumbed similarly, filtering water supply reservoir and supplying water to various facilities associated with mesocosm system

(d) recirculate (unfiltered water from the water supply reservoir is returned without passing through filter medium); (e) waste (unfiltered water supply reservoir water is directed to the waste pipe, without passing through the filter medium); and (f) rinse (unfiltered water from the water supply reservoir is directed through the filtration medium, then flushes the valve for cleaning before returning to the water supply reservoir).

Each filter has independent inflow (from the water supply reservoir) and outflow (to the water supply reservoir) pipes buried along the slope of the levee. Both pipes emerge from the ground at the edge of, and run into, the water supply reservoir. Inflow pipes reach the bottom of the reservoir and have tee extensions to the middle of the water column as a precaution against clogging. If one opening is obstructed, the suction shifts to the second opening. Ball valves are installed on inflow pipes near the filters for stopping the flow. Outflow pipes end just above the water level, and filtered water cascades and aerates the surface waters as it returns to the water supply reservoir.

A common drain pipe allows backwashed waste from Sand Filters 1 and 2 to be pumped into the wetland-retention cell. Sand Filters 3 and 4 wastes are discharged through the original pond drainage valve and pipe of Pond 44 and into the LAERF drainage system.

Besides the general plumbing system, each sand filter has additional lines for supplying water to other LAERF mesocosm systems. A tee and reduction from the 5.1-cm PVC pipe to two 3.8-cm PVC pipes are installed in each outflow line, with ball valves installed distally to the tee on each smaller diameter pipe. One reduced pipe returns to the water supply reservoir, while the other serves as a water supply conduit for the mesocosm tanks or other facilities in the area. Sand Filter 1 supplies water to the mesocosm tanks. Sand Filter 2 supplies water to the support laboratory and outdoor facilities. Sand Filters 3 and 4 supply water to a tank system discussed in Stewart (1994). Sand Filter 3 is also used to pump and filter water from Pond 45 into the water supply reservoir.

The water supply reservoir can be filled from two sources: Lewisville Lake and a nearby pond, No. 45, which functions as the mesocosm system grow-out pond. When using Lewisville Lake water, full volume in the water supply reservoir is maintained automatically with a float valve/standpipe system. This system serves to replenish water lost to evaporation or operations, but does not dilute filtered (or treated) water with unnecessary flow-through (Figure 7). At normal levels, low-flow (<50 ℓpm) Lewisville Lake water is directed into the standpipe, which allows water to exit the drain pipe. A float valve positioned inside the standpipe plugs the drain when water supply reservoir levels drop, causing water to spill over and into the reservoir. Once the water level is adequate to lift the float and plug, water stops overflowing the standpipe and again flows out through the drain. This float valve/standpipe allows maintenance of a constant volume of water, replacing water lost to operations and evaporation, and prevents flooding during heavy rain events. Generally, this system is used when a high volume of water use is anticipated for large flow-through studies.

Lewisville Lake water quality is often not immediately suitable for mesocosm tank research, as it carries potentially high loads of suspended solids and dissolved ions (nutrients) that may interfere with operations and promote growth of nuisance algae. Filtration serves to remove particulate matter from the reservoir water, which clarifies the water and prevents clogging of needle valves associated with individual tank-filling systems. To address high nutrient loads, water quality is adjusted by adding agricultural-grade aluminum sulfate (alum), $Al_2(SO_4)_3$, at rates of 60-90 kg per full-volume treatment of the water supply reservoir. Alum treatment precipitates phosphorus and induces flocculation of organic and clay colloids suspended in the water column (Boyd 1979). These materials settle to the bottom of the reservoir and often support a flora of algae and bacteria that help in "curing" the water column further by removing additional nutrients. Floc materials that do not settle to the bottom are removed by the sand filters.

Access to the second water source (Pond 45) is dependent upon Sand Filter 3. This pond also serves as the mesocosm system's grow-out pond for culturing study plants and will be discussed later in this report. Sand Filter 3 includes plumbing that allows for water to be drawn from either the grow-out pond or water supply reservoir. A 5.1-cm tee splits the inflow line, and ball valve manipulations allow the filter to draw water from either (or both) source. Sand-filtered water from the grow-out pond can be pumped directly into the water supply reservoir. Because pond water exposed to macrophytes is often very low in suspended solids and phosphorus, this water does not require a long in-pond filtration period, and may not require alum treatment, as does Lewisville Lake water.

Alum is not added to the water supply reservoir when filling with grow-out pond water, unless excessive levels (>10 µg/ℓ) of phosphorus (SRP) occur. When in operation, several water quality parameters in the water supply reservoir are monitored by the analytical laboratory at the LAERF. These parameters include temperature, pH, conductivity, dissolved oxygen, total alkalinity, and phosphorus (SRP). Following alum treatment of water, excessively low alkalinities (<50 mg $CaCO_3$/ℓ) may disrupt the carbon cycle and therefore photosynthesis, limiting plant growth in the tanks. A low-end alkalinity range of 60-100 µg/ℓ is preferred for growth of plants, and alum treatments are limited to keep the water supply reservoir within this range. When phosphorus concentrations increase beyond acceptable levels (10 µg/ℓ), additional alum application is undertaken, with alkalinities closely monitored. The frequency of alum treatment varies, but usually precedes the initial filling and/or flow-through of mesocosm tanks during study preparations.

Drainage of the water supply reservoir is performed periodically to allow for cleanup of accumulated flocculent and other debris. This process also reduces the accumulation of ion concentrations in the water column. The standpipe is removed from the elbow sealed into the drainage gate valve to allow water to gravity-flow through the drainage pipe and into the concrete-lined drainage ditches of the LAERF. After draining, low-pressure trash pumps are used to spray-clean the liner. Debris is washed out through the drain, and remaining sediments are hand swept and removed.

Fill System

An underground plumbing system associated with Sand Filter 1 permits operators to divert filtered water from the water supply reservoir to the tanks. Under normal operations, the sand filter draws and returns water to and from the water supply reservoir through inflow and outflow pipes. The outflow pipe is split with a tee and reduced to 3.8-cm PVC pipe, with ball valves installed on both branches of this split. One branch leads back to the water supply reservoir, while the other leads to the tank filling system. Manipulation of these valves allows operators to vary the flow and pressure of water to the tanks.

A main tank supply line is buried approximately 0.5 m below ground and branches into five mesocosm tank trunk supply lines (Figure 2c). Each supply line has a cutoff valve at the base of the trunk and six branches positioned to supply individual tanks along the trunk. These branches each extend about 1.75 m vertically on the northern side of a tank, resulting in each of the 30 tanks having an independent water supply pipe (Figure 4).

A flowmeter with a flow-control needle valve is installed in-line just below the top of each tank, and an elbow and pipe directs water over the top and into a tank (Figure 9). Flowmeters are mounted on a 15-cm PVC "housing" pipe, which supports the upright piping and protects most of the aboveground plumbing associated with each tank. Housing pipes are attached to tanks with elastic straps for additional support.

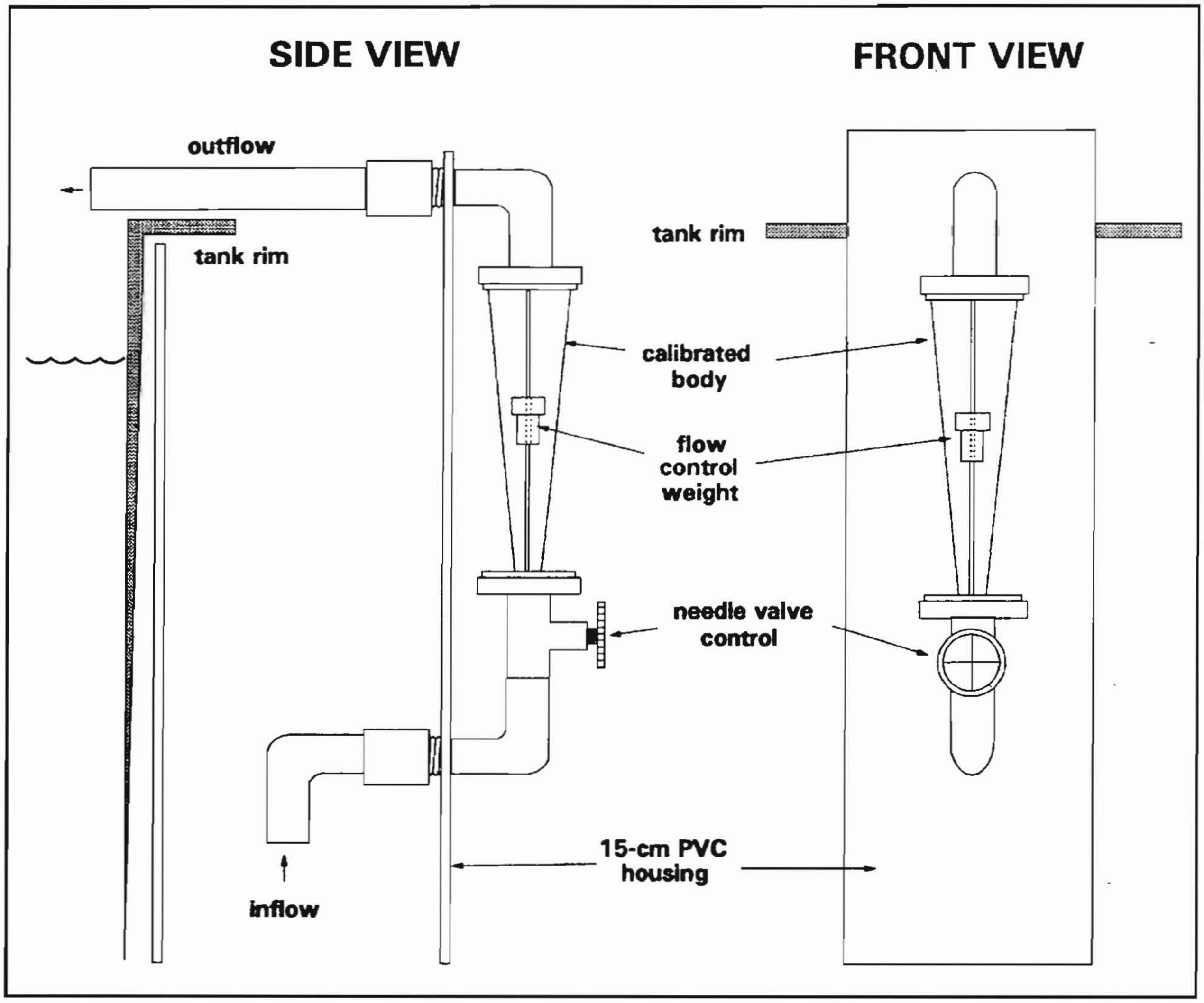

Figure 9. Flowmeters permit researchers to accurately (±5 percent) implement flow-through studies designed to assess relationships between aquatic herbicide species-selectivity and concentration exposure times

The two spare tanks are supplied water from an extension of Trunk 4, but flowmeters have not been installed. Instead, a double-headed brass faucet tap is used to fill these tanks through garden hoses. These tanks are not used in flow-through studies, although the plumbing is adaptable to include flowmeters if required.

As stated above, by manipulating the two 3.8-cm discharge valves, the tank supply lines can be pressurized incrementally. When pressurized to about 200 kpa (30 psi), water can be steadily supplied to tanks upon demand. All or some water passing through the filter can be diverted to the tanks, as when filling during study preparations or flowing water through tanks during a study. A portion of the flow is diverted back into the water supply reservoir to prevent overpressurization of the fill system. If flow is completely stopped, the pressure will exceed 330 kpa (50 psi), and the filter tank or plumbing system may be damaged. Flowmeters are activated by a needle valve control knob, which can be set to achieve a desired flow rate. Flowmeters and valves allow regulation of flow rates between 1 and 60 ℓpm (±0.5 ℓpm). At the higher rate, a tank requires about 2 hr to fill. Currently, using Sand Filter 1 a maximum 30 tanks can be filled simultaneously in about 5 hr (25 ℓpm).

During operation, sand filters require daily backwashing to remove trapped particles from the sand. Organic materials and associated bacterial flora build up in the filter sand over time, sometimes causing the filter sand to clog or clump. Channels develop in the clumped sand, which greatly reduce the efficiency of filtration. When clumping is noted, the filter is shut down and sand treated with 4 ℓ of household bleach to kill bacteria and oxidize organic matter. The sand is then stirred to break up clumps and the filter tank flushed before reactivation. When bleach treatment fails to clean the sand adequately, as noted when clumping recurs, filter sand is replaced.

During winterization, the fill system pipes are drained by opening a ball valve (installed on Trunk 4) that empties into the underground drainage system. All valves of the system are opened, and flowmeters are dismantled and stored. Sand filters are turned off, associated valves opened, and drain plugs on the sand filter tanks and pumps are removed.

The filling system is recharged in the spring, after the water supply reservoir has been filled. Sand filters are prepared by replacement of the filter medium, No. 20 silica sand (uniformity coefficient <1.75). Filters are started, with the self-priming pumps drawing water from the water supply reservoir. After flushing out piping systems, water is diverted to filter the water supply reservoir. Flowmeters are reinstalled, and various pressures are induced by valve manipulation to test the integrity of the piping and flowmeters.

Water Circulation/Aeration System

Air pressurized to approximately 30 kpa (5 psi) by a regenerative blower (746 W, 115 V, 12 amps) is supplied to tanks for water circulation and aeration. This blower is housed in a small wooden shed on the southern levee of the water supply reservoir, adjacent to Sand Filters 1 and 2 (Figure 3). The blower pushes air to a main air line (3.8-cm PVC pipe) buried in the same trench as the main filling and drainage water lines (Figure 2c). The basic design of the air and fill system plumbing is similar, except that individual air-supply lines (branches) are reduced to a 1.3-cm diam. This line is supported and protected by the housing pipe, and its end is capped, with a stainless steel airline valve fitted into the cap. A length of clear vinyl aquarium airline tubing is attached to the outlet of this valve.

An airlift pipe, constructed of a 1-m-long, 3.8-cm PVC pipe attached to a flat PVC base, is placed freestanding in the center of each tank (Figure 10). An air stone is attached to the vinyl tubing and placed inside the airlift pipe to a depth of about 0.3 m (the regenerative blower can supply air to about 160 air stones at this depth). Air stones are weighted by attaching four

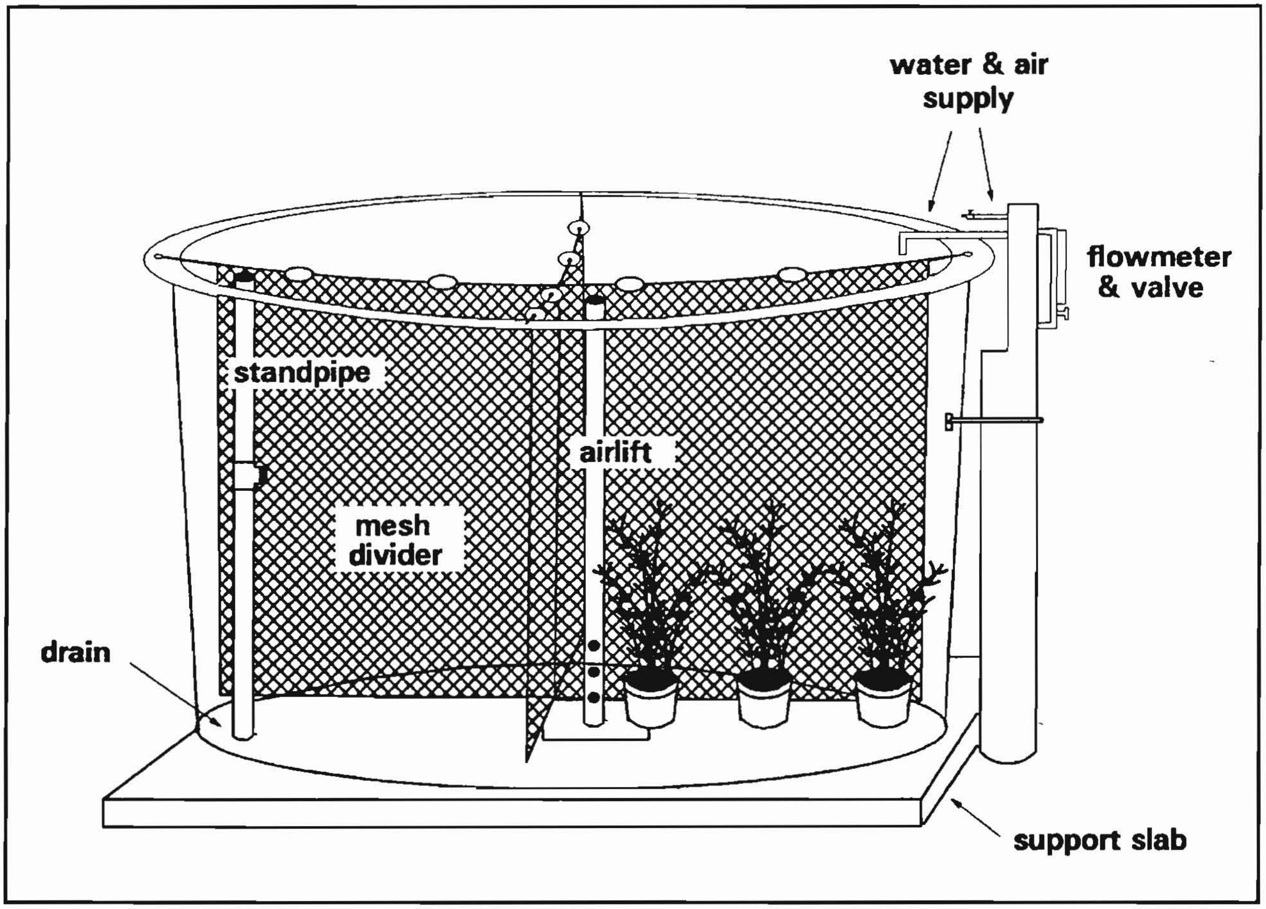

Figure 10. A typical setup of a mesocosm tank during a study (Mesh barriers can be installed to segregate plant species and reduce cross-contamination of plants)

stainless steel washers to counter buoyancy during operation. Four holes on the lower one-third of the airlift pipe serve as water intakes, and the top of the airlift is positioned approximately 10 cm below the water surface.

The water circulation/aeration system produces water movement sufficient to maintain an evenly mixed water column as demonstrated by isothermal conditions measured in the tanks (Table 1). Aeration also replenishes carbon dioxide (CO_2) lost to photosynthesis, increasing plant growth and moderating depletion of alkalinity by photosynthetic precipitation of $CaCO_3$.

Table 1
Water Temperatures (°C) in Static and Aerated Mesocosm Tanks (Ambient (air) temperature was 31 °C)

Depth	Static Tank	Aerated Tank
Surface (5 cm)	30	28.5
30 cm	29	28
60 cm	27	28
90 cm	26	28

The regenerative blower includes a 20-µm filtered intake that prevents clogging of airlines and valves in the system. Also, a bleed valve is present to vent excess air flow out of the system. Because this system currently uses only about 15 percent of the capacity of the pump, the bleed valve is usually left 80 percent opened. The blower operates under low pressure, with most excess air bled off, and air flow to individual tanks can be adjusted without interfering with the performance of the rest of the system.

Drain System

Individual tank drainage includes a female-threaded PVC pipe fitting molded into the bottom of the tank, with a 1.25-m-tall, 3.8-cm PVC standpipe installed as a drain plug (Figure 10). The base of the standpipe consists of a male-threaded adapter that screws into the female drain fitting. Standpipe construction includes a slip by slip by female threaded tee and plug in its middle. The remainder of the mesocosm system drainage is underground. Because of the weight of a filled tank (approximately 6,350 kg) and the nature of the soils at the facility (high clay content), aboveground tank drainage plumbing is attached to underground plumbing with a low-pressure rubber coupling. Flexibility provided by this coupling compensates for slight shifting of tanks or support pads during excessively wet or dry periods, preventing damage to tanks or the plumbing system. Each tank drain "trunk" consists of an underground drainpipe buried along with the fill and circulation/aeration piping. Trunks empty into a common drain line, which in turn empties at a lower elevation (~1 m) into the water-detention pond.

The standpipe maintains constant tank volume during flow-through studies, compensates for excess water addition (primarily from rainfall), and allows the tanks to be flushed without changing water levels. The plug in the middle of the standpipe permits half-drawdowns, which facilitates work in tanks when submersed plants are present (such as planting/harvesting operations). Complete tank drainage is achieved by removing the standpipe.

The elevation drop of the drainage system is approximately 1 m overall. A tank may require up to 30 min to drain, but can take longer when several tanks are drained simultaneously, or if the water-detention pond is full. When draining tanks along the same trunk, care must be taken to avoid backflow into empty tanks along that same trunk. A backflow head up to 20 cm above the tank bottoms can occur when all tanks along one trunk are drained simultaneously. Drainage backup into empty tanks is avoided by reinstalling the standpipe in a tank after it is drained.

Water-Detention Pond

The water-detention pond was constructed during the initial phases of site development and is located southwest of the tanks (Figure 3). The pond measures 16 by 16 m, has a maximum depth of 1.3 m, and has a capacity of 225,000 ℓ, sufficient to receive the entire volume of water held the 32 tanks (214,400 ℓ). Earthen levees (0.3-m height) surrounding the pond prevent storm-water runoff from adjacent areas. A 10-cm PVC drainage pipe in the southwest corner of the water-detention pond empties into the wetland-retention cell, which is located approximately 20 m to the southwest. The drainage pipe includes a 1-m-tall standpipe connected to a 90-deg slip by slip elbow inside the water-detention pond.

The function of this pond is to hold herbicide-treated water leaving the tanks during flow-through studies, or following static (no flow) studies. Because the water leaving the tanks is from variable treatments (concentrations), including untreated reference tanks, the concentrations of herbicides/PGRs in this pond are much lower than the maximum studied rates in tanks. Treated water can be held in this pond indefinitely for biological degration, chemical degradation, and photodegradation of residual herbicides. Water levels are regulated by angling the standpipe between vertical and horizontal, with its exact position dependent upon desired water level.

Emergent macrophytes, primarily cattail (*Typha angustifolia*) and spikerush (*Eleocharis* spp.), and some submersed macrophytes, southern naiad (*Najas guadalupensis*) and muskgrass (*Chara vulgaris*), have become established in this pond and serve as indicator species during herbicide-treated water release from the tanks. Considering the low concentrations used in experiments conducted in the mesocosm system, it is not surprising that few, if any, effects of herbicide treatments have been observed in this community of plants following release of experimental waters.

Wetland-Retention Cell

The wetland-retention cell encompasses approximately 0.2 ha and is contained by a 1-m-high by 3-m-wide earthen berm (Figure 4). The holding capacity of this cell is approximately 1.8 million liters. The bottom of the wetland-retention cell is about 2 m lower than the lowest point of the mesocosm tank area, and about 1 m lower than the bottom of the water-detention pond. Water enters the wetland-retention cell from several sources, including overflow from the water-detention pond, backwash from Sand Filters 1 and 2, and storm-water runoff. The water-detention pond drain pipe runs parallel with the northern levee of the wetland-retention cell for about 20 m, with reducing tees (to 2.5-cm diam) installed every 3 m, resulting in six discharge outlets. Also, Sand Filters 1 and 2 share a backwash line that discharges into the northeastern corner of the wetland-retention cell. The drainage system of the wetland-retention cell is found on the southern levee and consists of a 15-cm PVC drain and standpipe.

The water-detention pond is drained into the wetland-retention cell, which serves as a site for long-term retention of treated water. The cell is kept moist by periodic flooding from the water supply reservoir (backwashing sand filters), water-detention pond water, and runoff from precipitation. It also serves as overflow for the water-detention pond during flow-through studies. Multiple discharge sites from the water-detention pond drain line running along the northern levee of the wetland-retention cell provide an even distribution of incoming treated water. The wetland-retention cell supports a population of flood-tolerant species, primarily cattail and willows (*Salix* sp.). As in the water-detention pond, the plant community acts as an indicator of potential herbicide persistence.

The overflow from the wetland-retention cell is controlled by a standpipe, which is normally positioned vertically to hold water in the cell. By turning the elbow toward horizontal, the height of the standpipe is adjusted, regulating the depth of water in the wetland-retention cell. When water is released from this cell, as can occur during heavy rainfall, the water inundates a terrestrial system.

3 Associated Facilities

Support Laboratory

An insulated sheet metal building with a concrete floor is located south of the tanks and water-detention pond. The building consists of two sections: (a) an enclosed, insulated, and heated/cooled area, and (b) an open porch area for processing plant materials (Figure 11). Two access doors and two windows are included in this building. Built-in cabinets and counter tops line the southern wall, and a deep sink and adjacent counter spaces are installed on the western wall. Open, overhead storage shelves are constructed along the western and northern walls. A security system is present to alert the LAERF main security system when doors or windows are opened, or when electricity in the building fails.

Various equipment is installed or maintained in this laboratory. Two 0.5-m^3, 220-V convection drying ovens, two analytical balances, a fluorometer, four 0.6-m^3 locker-style freezers, and a 0.5-m^3 refrigerator are installed in the building.

The building functions as a working laboratory for most phases of mesocosm tank studies. Study preparation (plant propagule storage and chemical mixing), harvest processing (drying, weighing, and storing plant materials), and water-sample preparation and storage are routine functions of this lab. Additionally, equipment and laboratory support for dye studies (rhodamine WT) conducted in the mesocosm system are based in this building. The laboratory also serves as a storage site for maintenance supplies.

Sediment Preparation Pad

A 7.3- by 9-m reinforced, concrete pad sits on the south side of the support laboratory (Figure 11). The pad is partially covered by a 3- by 7.3-m aluminum lean-to. A vehicle ramp rising to 0.5 m above the slab is situated 3 m from the support laboratory. The uncovered portion of the slab (4- by 7.3-m) is edged with moveable, concrete-filled cinder blocks.

This area was constructed for large-scale sediment preparation and has a holding capacity of about 4 m^3 of sediment, enough to handle a 15-tank

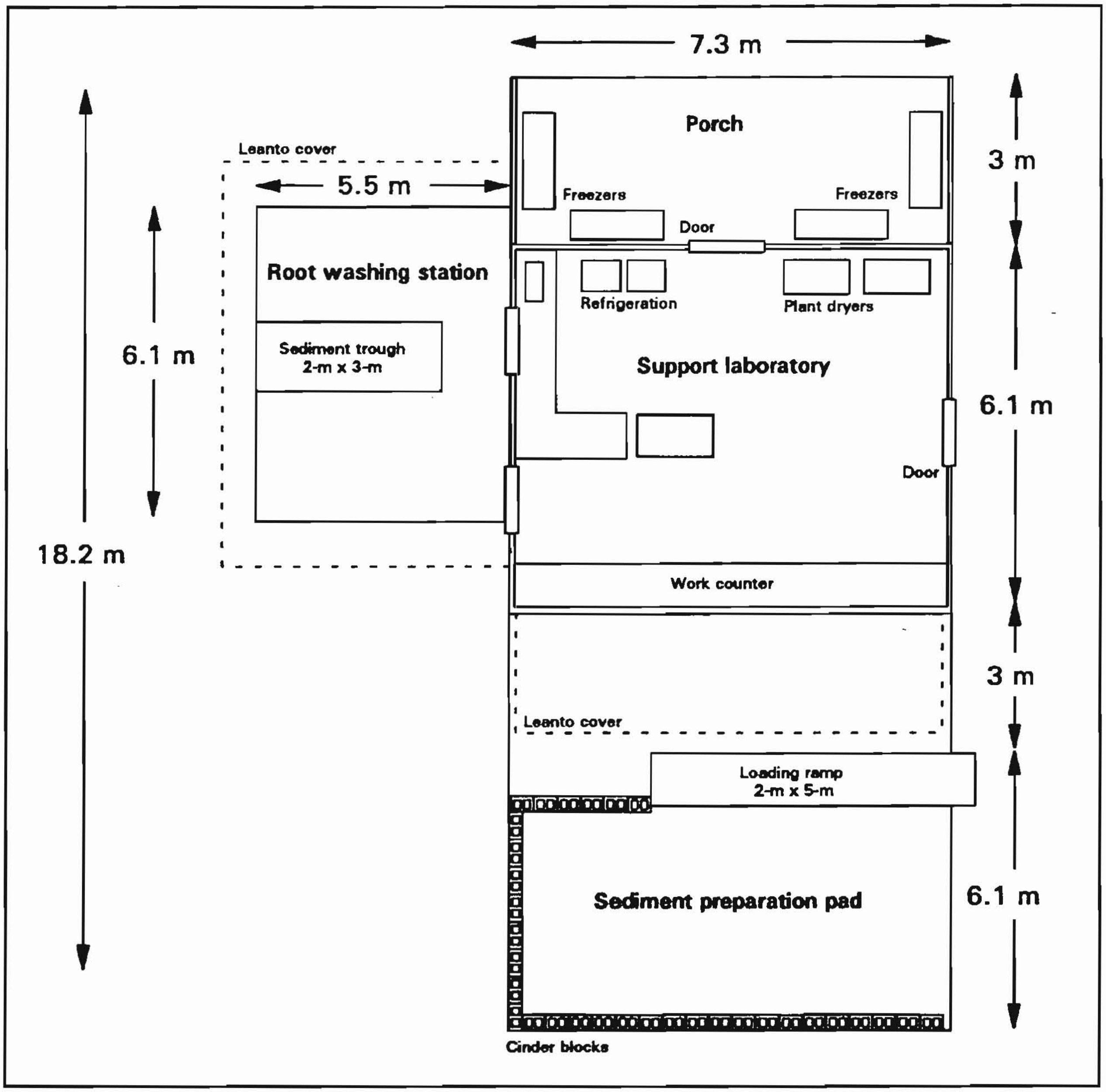

Figure 11. A support laboratory, sediment preparation slab, and root washing station are available for complete support of mesocosm-type studies

study. Generally, pond bottom or other sediment is transported to the slab with a front-end skid loader and placed on the south side of the ramp. Concrete-filled cinder blocks serve to contain the sediment at a depth of about 18 cm. Once on the pad, sediment is mixed with a tractor pto-driven rototiller. The sediment is then sterilized with sodium methyl dithiocarbamate (metam-sodium) at a rate of 1.5 ℓ/m^3 and covered with black polyvinyl sheeting. After 48 hr, the sediment is uncovered and mixed with a rototiller to induce escape of fumigant vapors. Sterilization is undertaken primarily to kill the seeds and spores of aquatic and emergent macrophytes, which may interfere with cultivation of research species.

After preparation, sediment is apportioned by hand into individual plastic, cylindrical containers, which are used to support the growth of aquatic macrophytes during studies. Filled containers are transported to the grow-out pond and positioned for curing and planting.

Root Washing Station

A 5.5- by 6.1-m concrete pad on the west side of the support laboratory serves as a site for collecting and washing roots of study plants (Figure 11). The slab slopes approximately 3 percent to facilitate drainage away from the building. Parallel with this slope, in the center and distal (from building) end of the slab, is a 2- by 4-m trough, which slopes from 15 to 30 cm below the remainder of the slab. Positioned in the deeper portion of the trough is a standpipe drain that empties into the wetland-retention cell. Slots on both sides of the trough allow for the positioning of dam boards. The entire pad is covered with an aluminum lean-to.

Water is supplied to this site from the water supply reservoir through an underground pipe associated with Sand Filter 2. This filter's outflow line is divided and reduced in diameter, with one branch returning to the water supply reservoir, and the other supplying water to the mesocosm laboratory, root washing station, and a nearby greenhouse. Ball valves allow operators to vary water pressure in this line, similar to those that allow the diversion of water to the tanks from Sand Filter 1.

During washing, plant roots are separated from sediment by rinsing over 0.6-cm mesh table tops. These tables are situated above the trough, which serves as a collection site for washed sediment. A standpipe inserted into the drain opening directs excess water to the wetland-retention cell, while sediment accumulates in the trough behind the dam boards. Following root washing operations, sediment is allowed to dry and is then removed with a front-end loader.

Grow-Out Pond

A 0.3-ha pond (No. 45) immediately west of the mesocosm system was modified for cultivation of study plants (Figures 2a-d, 3). This pond also serves as an alternate filling source for the water supply reservoir, holding approximately 3,000,000 ℓ at operational level. The deeper end of the pond bottom was graded to reduce the slope (from 1 to 0.1 percent).
A 30- by 18-m reinforced, concrete pad was constructed to serve as a stable surface for setting containers of sediment (Figure 12). The northern 6 m of this pad is approximately 25 cm deeper than the remainder of the pad. A concrete ramp from the eastern levee crown to the grow-out pad provides vehicular access.

A fence constructed of galvanized pipe and polypropylene shade fabric (30 percent) isolates the grow-out pad from the remainder of the pond.

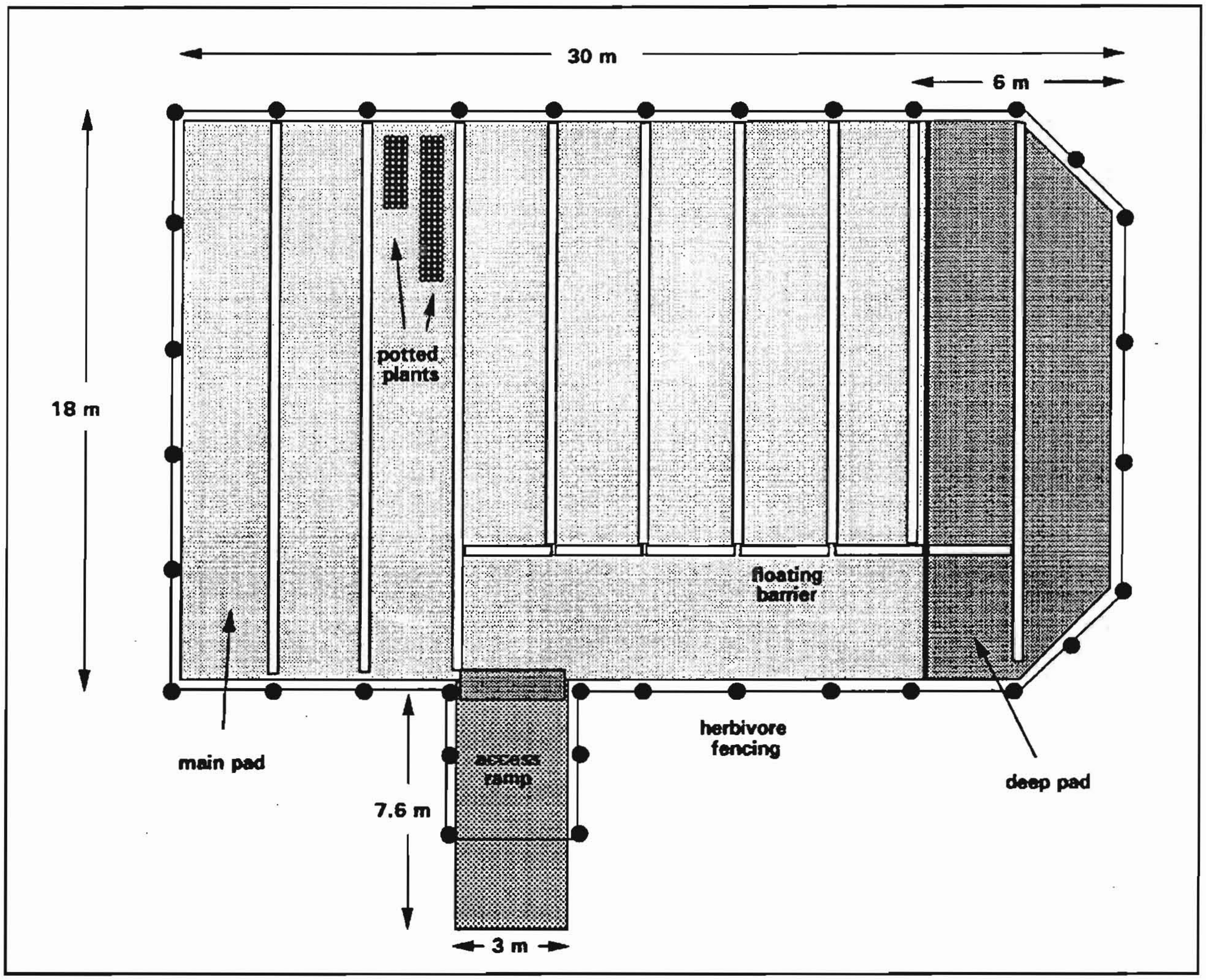

Figure 12. A large, concrete grow-out pad has been constructed in Pond 45 and serves as a cultivation site for study plants (After establishment in containers, plants are moved to tanks to begin studies. Barriers are present in grow-out pond to reduce herbivory and prevent cross-contamination of aquatic plant species)

The exclosure serves to exclude large herbivores, most notably aquatic turtles such as red-eared sliders (*Trachemys scripta elegans*). Inside the large enclosure, floating fences were constructed by attaching shade fabric to sealed 3.8-cm PVC pipe floats. Many aquatic macrophytes reproduce asexually by fragmentation, and this fencing system prevents cross-contamination between cultures.

After moving sediment-filled containers to the concrete pad, the grow-out pond is filled, and sediment is allowed to "cure." Because sediments used in mesocosm studies are from intermittently flooded ponds, the transition from oxic to anoxic chemical conditions occurs rapidly (days to weeks). The use of true terrestrial sediments would likely require a much longer "curing" time (months).

A jointed standpipe allows operators to vary the water level in increments: (a) empty, for transport of containers and maintenance of the pad; (b) planting level, about 15 cm over the top of containers; (c) cultivating level, about 30 cm over the top of containers; and (d) grow-out level, about 75 cm above the top of containers.

Propagules of study species are planted and cultured according to the experimental design, until they are ready to move into the study tanks. An example of plant preparation follows: the pond is filled and maintained by an overflow standpipe at the planting level. After a sediment curing period (generally 2 to 4 weeks), apical tips, tubers, winter buds, or other appropriate propagules are planted in the desired experimental arrangement. Water depth is maintained at this level, and containers are monitored to ensure sprouting (or germination) and growth of new plants. Replanting is undertaken where poor establishment is noted. Once plants are established, the water depth is increased to the grow-out level and plants allowed to grow. Occasionally, the water level is temporarily lowered to the cultivating level, and containers are inspected and weeded (if necessary). When the plants are ready for transport to the mesocosm tanks, generally about 2 weeks before the scheduled treatment date, the grow-out pond depth is lowered to the planting level, and containers are loaded and moved to the tanks. Plants are covered with a tarp to prevent desiccation when removed from the water.

The deeper portion of the grow-out pad serves as a permanently flooded site for long-term cultivation. Water can be lowered to provide vehicular access to the main pad before and after specific study operations, while maintaining levels adequate to avoid desiccation of aquatic plant species kept in the deeper portion.

As previously mentioned, the grow-out pond also serves as a water source for the water supply reservoir. When slow replenishment, no-alum treatment is required, Sand Filter 3 is adjusted to draw water from this pond. Water removed from the grow-out pond is replaced with continuous low-flow of Lewisville Lake water.

Shading Canopy

The support structure for the mesocosm system shading canopy consists primarily of galvanized steel posts welded to form a series of trusses and support beams. The top of the support structure is approximately 3.5 m above the ground, or about 2 m above the tops of tanks. Black polypropylene shade fabric is affixed to the top of this structure to provide 30-percent reduction of sunlight on tank water surface, tank sides, and the surrounding grounds.

Support posts are arranged in an approximate 6- by 9-m pattern (total 24) and are positioned to maximize accessibility to the tanks. The entire structure measures 35.2- by 37.8-m and covers an area to 1 m outside the runoff deflection curb surrounding the tanks. Shade cloth is cut and fashioned to fit each of these 24 "cells," with grommets installed along the sides for attachment to the frame with black polypropylene cable-ties.

Exceptionally clear waters of the mesocosm system can cause excessive light penetration into the water column, and plants respond by reducing elongation, remaining short and bushy. Additionally, during mid and late summer, direct sunlight heats the water surface, tank sides, and concrete pads, often causing water temperatures to exceed favorable levels. Partial shading reduces light intensity and lowers temperature, allowing plants to grow more similarly to those in ponds and other natural systems.

Shade fabric is used only during the hotter, brighter months. In the late fall, the fabric is removed to prolong its life and avoid possible damage to the cloth and frame due to ice/snow accumulation.

4 Mesocosm Function and Pilot Studies

Several studies have been conducted in the system for plant growth and system calibration purposes. Besides operations tests, some preliminary and full-scale herbicide/PGR evaluations have been completed, with information from these studies used to improve the operation of the system (Smart et al. 1995b; Getsinger et al. 1994; Getsinger and Smart 1994; Nelson 1994; Dick, Getsinger, and Smart 1993; Nelson 1993). This section addresses typical conditions and parameters required for conducting routine studies in the mesocosm system, including plant growth, water quality, flow-through, and light attenuation.

Plant Growth

A pilot study conducted in the mesocosm system evaluated various system functions and compared growth of plants in tanks with growth in LAERF ponds (Dick, Getsinger, and Smart 1993). In April 1992, the water supply reservoir was filled with lake water, amended with alum, and then sand filtered throughout the study period. Tank standpipes were installed, and tanks were filled to check for plumbing leaks. After inspections and minor repairs, tanks were drained to assess the reliability of the drainage system. Once satisfied with the performance of all plumbing systems, four tanks were refilled and divided into quarters with 1.2-m-deep, 0.64-cm mesh netting (Figure 10).

In early summer 1992, eight 4.7-ℓ plastic containers each of vallisneria (*Vallisneria americana*) and American pondweed (*Potamogeton nodosus*) and 16 containers of Eurasian watermilfoil (*Myriophyllum spicatum*) were placed in three tanks, separated in quarters by species. An additional six containers of each species (12 for Eurasian watermilfoil) were placed in 1.4-m-diam by 0.25-m-tall pools set in a pond maintained at a depth of 1.2 m. All plants had been established in sediment containers the previous fall.

After 6 weeks, the shoot materials of six containers of pond-grown Eurasian watermilfoil and one quadrant (eight containers) of Eurasian watermilfoil from each planted tank were harvested and dried in a convection oven at 60 °C for 48 hr to measure dry biomass accumulation. After 12 weeks, remaining containers of all species were harvested from tanks and the pond, and the biomass was similarly dried and weighed. Dunnett's t-tests (SAS Institute, 1988) performed on dry biomass of each species suggested no significant differences among tanks, or between tank- and pond-grown plants, except for *vallisneria*, which had accumulated greater biomass in the tanks (Figure 13).

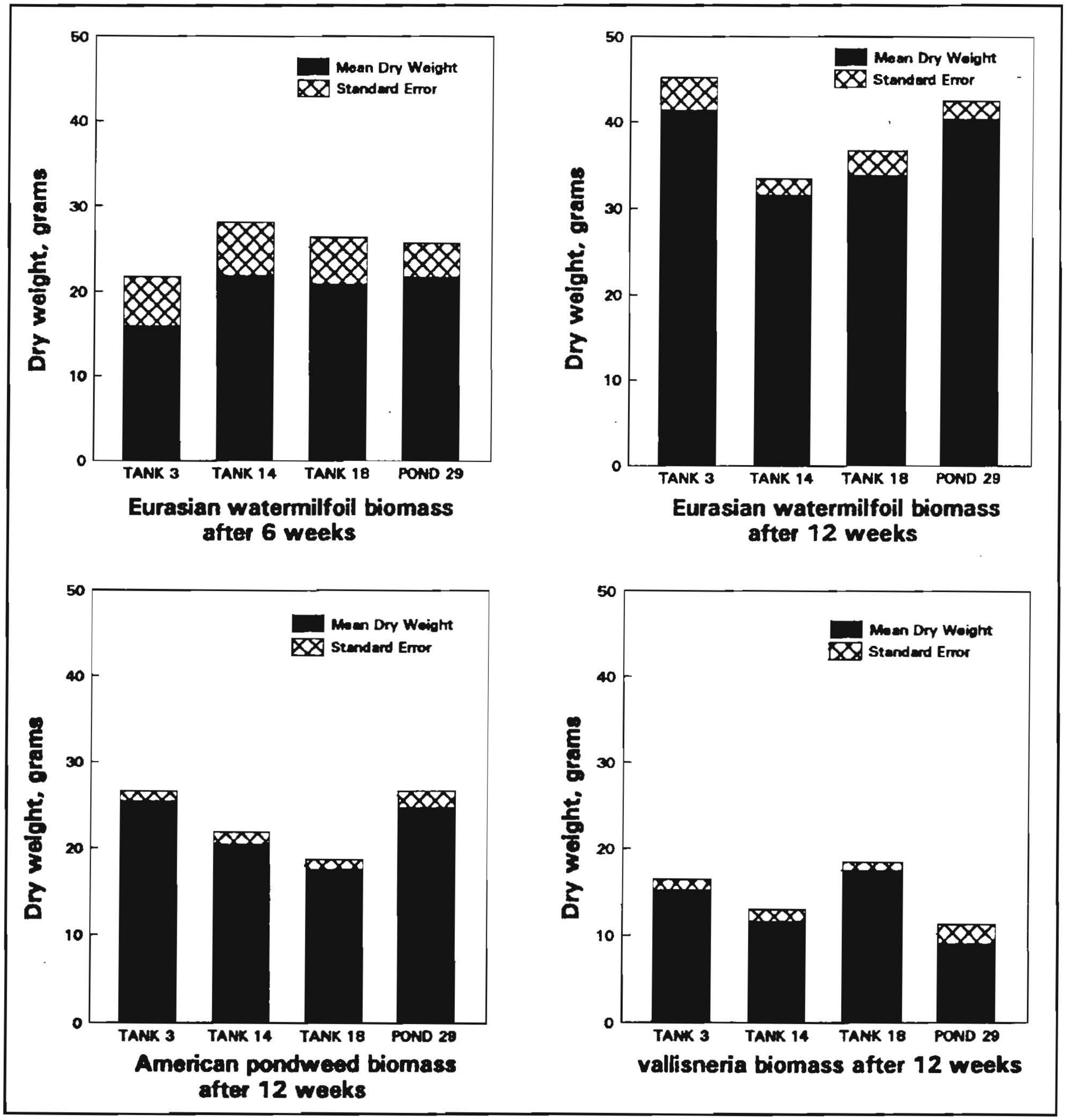

Figure 13. Comparison of growth of three submersed macrophyte species in mesocosm tanks and in LAERF pond after 6- and 12-week periods

These results showed that plant growth in mesocosm tanks and ponds was similar during the same period. In addition, the biomass produced in tanks and ponds per sediment surface area by the three species fell within the ranges reported under field conditions (Grace and Wetzel 1978; Titus and Stephens 1983; Korschgen and Green 1988). Furthermore, the onset of flowering occurring within 1 week between tank- and pond-grown plants suggested that conditions were met for normal seasonal growth.

Besides the plant communities established by the transfer of planted containers to the tanks, other nontarget organisms were observed to readily establish themselves. Several zooplankton groups, including cyclops and daphnia, have been abundant in planted tanks. Aquatic insect larvae (odonates) and adults (coleopterans, hemipterans) are common in planted tanks, and many larvae successfully emerge. Pond snails are also generally abundant in the plant communities.

The ability of mesocosm tanks to support such diverse communities may lead investigators to incorporate nontarget fauna into the research conducted in the tanks. Small invertebrates and vertebrates could be included to act as indicators of the health of a treated system, by direct toxicity of application rate response or by response to changes in plant communities. Additionally, tissue samples from nontarget species might be analyzed for more precise measurement of herbicide residues under tightly controlled water column concentrations.

Water Quality

In order to explain differences that may occur between tanks of the same treatment, and to support the contention that these represent experimental replicates, various water quality parameters are measured during mesocosm studies to document conditions under which plants grow. Sampling and analyses of water were undertaken during the plant growth study in the summer of 1992. This investigation was conducted to document and compare water quality in planted tanks, unplanted tanks, and the water supply reservoir. Additionally, water quality in tanks was compared with that of several LAERF ponds. The ponds, supporting native submersed macrophytes and filamentous algae, represented natural environmental conditions.

Three weeks after filling the tanks and positioning plant containers, Hydrolab data sondes were deployed in three planted tanks and an unplanted tank to measure mid-depth (0.5 m) water temperature, pH, dissolved oxygen, and conductivity. Simultaneously, data sondes were deployed at 0.5-m depths in several LAERF ponds for comparison with tanks. Data sondes were set to record continuously (every 5 min) over a 42-hr period.

Diel fluctuations in temperature were similar between tanks and ponds, but tank temperatures averaged about 2 °C lower than ponds (Figure 14). This may have been due to water circulation in the tanks (by the circulation/aeration system), which prevented temperature stratification and reduced higher temperatures at the surface and moderate depths. Tank water temperature changes were influenced to a greater (and more rapid) degree by ambient temperatures, with heat loss and gain most likely occurring through the fiberglass walls of the tank and the water surface.

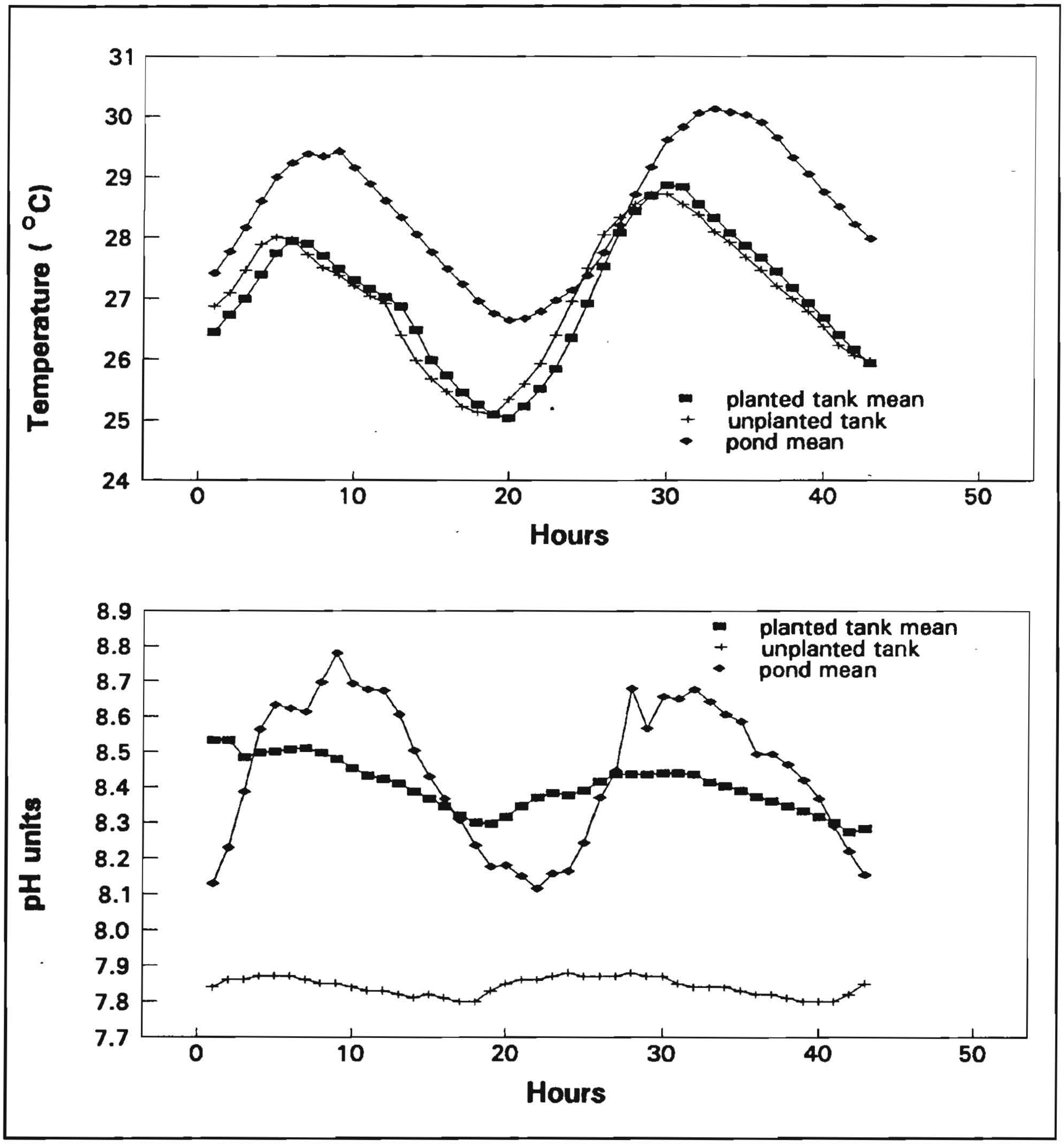

Figure 14. Hourly fluctuations in water temperature and pH in three planted tanks, an unplanted tank, and three ponds, beginning 0800, June 23, 1992

Diel fluctuations of pH were prominent in ponds, increasing during daylight and decreasing at night, coinciding with periods of photosynthetic and respiratory activity by the plants and other community components (Figure 14). Planted tanks also exhibited pH shifts, but these were less pronounced than shifts seen in ponds. The lower ratio of plant biomass and sediment to water volume may have contributed to this lower fluctuation. Ponds supported mature, nearly topped-out communities of southern naiad, muskgrass, and American pondweed, whereas plants in the tanks occurred in only about half the water column. Additionally, sediment containers covered about 60 percent of the tank bottom, limiting the surface area of sediment and its interaction with the water column. The unplanted tank exhibited only minor pH shifts, reflecting the absence of higher plants and limited activity by a small population of attached algae that had become established on the sides and bottom of the tank.

Dissolved oxygen (DO) concentrations were more stable in tanks than in ponds (Figure 15). This stability was due in part to lower metabolic activity in the artificial systems: less sediment surface area per unit volume water, lower diversity and density of organisms, and therefore a lower oxygen demand. Also, lower plant and algal biomass in tanks prevented DO from reaching the elevated concentrations seen in the ponds. Diurnal fluctuations did occur in tanks, suggesting some balance between photosynthesis and respiration. The unplanted tank exhibited the smallest variation in DO concentrations, indicating that DO in planted tanks was influenced by the plant communities. Air flow (from the circulation/aeration system) into the tanks likely diminished diel fluctuations of DO concentrations.

Conductivity was variable between planted tanks, the unplanted tank, and ponds and was not prone to diel fluctuations (Figure 15). The unplanted tank exhibited high conductivity (~300 μS/cm), suggesting a sustainment of dissolved ions in the water column. Conductivity in planted tanks was lower (~150 μS/cm), most likely caused by uptake of ions and $CaCO_3$ precipitation by plants (Smart et al. 1995a). Pond water conductivity ranges fell between planted and unplanted tanks.

Flow-Through Capabilities

Design parameters (high volume water supply, independent supply and drain systems for tanks, large tank volume, and adequate mixing/circulation systems) allow researchers to conduct chemical CET studies with a high degree of accuracy and confidence in the mesocosm system. CET studies frequently involve exposure of plants to herbicide or PGR concentrations for a known number of half-lives, or the time it takes the concentration to subside by one-half (by degradation or dissipation). This is achieved by adding untreated water to the system and removing a mixture of the untreated and treated water at known rates. When operated in a flow-through mode, the mesocosm system can simulate a herbicide application and dissipation in a flowing-water environment.

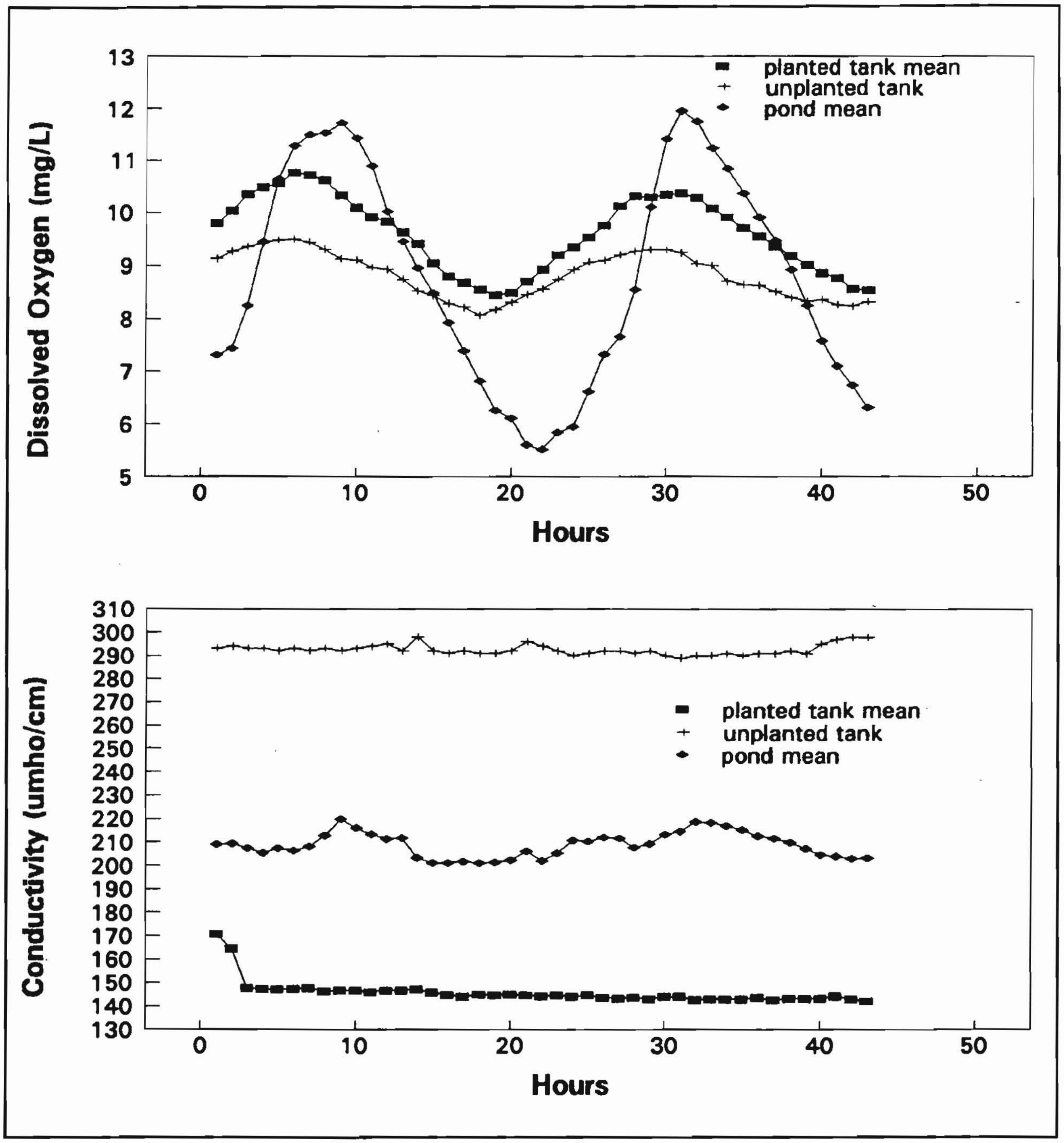

Figure 15. Hourly fluctuations in dissolved oxygen and conductivity in three planted tanks, an unplanted tank, and three ponds, beginning 0800, June 23, 1992

The ratio of flow-through volume to tank volume is critical in maintaining an acceptable (within 5 percent of a target half-life) decline in herbicide concentration. Water supply-line pressure changes and flowmeter/valve accuracy and dependability are factors requiring rigorous testing before starting a study. Removal of particulate matter by alum treatment and sand filtration and frequent backwashing of sand filters are critical in maintaining the reliability of the flow-through system.

Preliminary calculations for flow-through volume were based upon the following assumptions:

a. For each unit volume of water added, an equal unit volume was removed.

b. Untreated and treated water mixed immediately.

c. Dilution was incremental.

For example, a herbicide is added to a 10-ℓ tank to achieve a concentration of 10 mg/ℓ. One liter of untreated water is added, diluting the concentration to 9.18 mg/ℓ. Simultaneously, 1 ℓ is removed, leaving 10 ℓ of water with a herbicide concentration of 9.18 mg/ℓ. On a continuing basis, another liter of water is added (diluting the herbicide to 8.35 mg/ℓ), 1 ℓ of the mix removed, and so on.

Calculations based upon this model suggested that a tank volume turnover of about 75 percent would yield a reduction in concentration of one-half, or one half-life. This estimate assumes complete mixing occurred immediately as fresh water was added to the tank. Because this does not occur during the flow-through, a lag time occurs between addition of untreated water and removal of the treated water/untreated water mix. However, this lag time is small (perhaps several minutes) in comparison with dissipation/dilution rates planned for typical studies, which generally range from half-lives of 6, 12, 24 or more hours.

A dye (rhodamine WT) study was used to test the effectiveness of the system for flow-through studies. Flowmeters of nine tanks were tested at working pressure (1,500 g/cm²) and calibrated using a 2-ℓ volumetric flask and stopwatch. A second check at lower pressure (1,000 g/cm², simulating a clogged sand filter) showed the calibration held over expected ranges in the operating pressure. Volumes of the tanks were calculated based on standpipe heights and individual measurements using the frustum of a cone volumetric equation $\left(V = \frac{1}{3}\pi * h\left(r^2 + rR + R^2\right)\right)$, and flow rates were calculated for each tank. Three dilution rates (half-lives) were chosen for the test: 6, 12, and 24 hr, and a reference with no volume exchange (static) was included to separate potential dye degradation. Flow rates needed to achieve these half-lives were calculated to be 12 ℓpm for 6-hr half-lives, 6 ℓpm for 12-hr half-lives, and 3 ℓpm for 24-hr half-lives.

Appropriate quantities of dye were diluted from a concentrated (20 percent) stock solution and added to the tanks to achieve an initial target concentration of 12 µg/ℓ. The circulation/aeration system was engaged to induce mixing of the water column. After thorough mixing, the flow-through mode of each tank was begun. Two samples (from opposite sides, one near the fill pipe, and one near the standpipe) were taken hourly from each tank during the initial 6 hr, and then once every 3 hr for a 48-hr period. Samples were read immediately with a fluorometer, adjusted for temperature differences between sampling periods, and compared with estimated concentration decline rates during the test. Flowmeters were checked when samples were taken to ensure consistent settings.

Concentrations over time are given in Figure 16. Concentrations declined within 5 percent of estimated half-lives after the flow-through modes were begun, an accuracy level considered acceptable for CET research. This level is within ranges seen in smaller scale growth chamber experiments conducted at WES. Photodegradation of dye in the reference tanks was not evident (overcast, late winter light was low intensity); thus all reductions in dye concentration were due to dilution caused by the flow-through systems.

Subsequent flow-through studies have used rhodamine WT as a tracer to monitor volume turnover efficiency (Smart et al. 1995b). In these studies, dye concentrations in the water-detention pond and wetland-retention cell were also monitored. Concentration was lower in the water-detention pond than any treated tanks, but increased gradually as the study progressed. Maximum concentrations did not exceed minimum treatment levels, due to dilution from existing water in the system and the flow-through of untreated references. Concentrations began to decrease after several days, as water from treated tanks carried less and less dye. Dye concentrations in the wetland-retention cell were much lower, further diluted by filter backwashing operations and occasional rainfall.

Light Attenuation

The extremely clear, filtered water supply reservoir water coupled with the light blue interiors of the tanks can produce unnatural underwater lighting conditions. Also, excessive reflections of light off the sides and bottoms of the tanks (light blue gel-coat) causes a disruption of light extinction curves, which can interfere with plant growth.

Under these light conditions, plants initially grow in forms that are "stunted" or "bushy," due to inhibition of cell elongation. Plants growing at similar depths in ponds at the LAERF elongate at a greater rate and reach the surface weeks sooner than plants growing concurrently in tanks. This "bushy" growth is not desirable for mesocosm system research. Rapid growth to the surface and early surface canopy development by weedy plant species are more common in nature, and these are the conditions and growth patterns required to duplicate natural systems.

The shading canopy was constructed to reduce overall light reaching the tanks, bringing light intensities in the water columns closer in line with those seen in ponds. Although ponds are also exposed to full sunlight, light does not penetrate as deeply into the water column due to greater turbidities in ponds. Also, reflection of light is greatly reduced in ponds. An approximate 30 percent reduction in light was deemed adequate, and neutral-density shade fabric that produced this reduction was installed on the support structure covering the tanks.

Light intensity in ponds and in tanks (shaded and unshaded) are given in (Table 2). In tanks, plants grown under the shading canopy reach the surface more quickly than plants grown in full sunlight. Eurasian watermilfoil reached the surface in just 2 weeks under shade, compared with

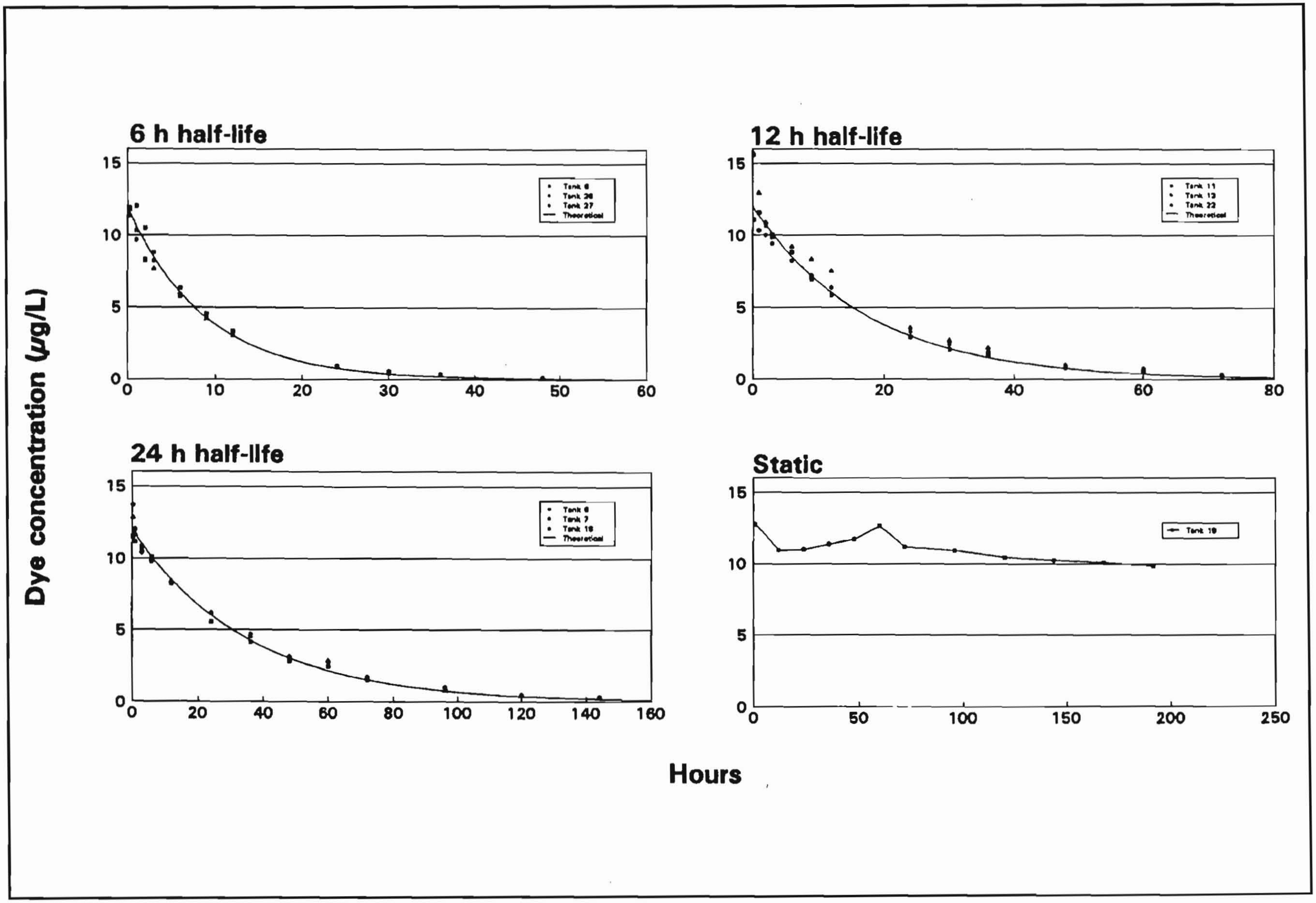

Figure 16. Theoretical and actual half-life concentrations of rhodamine WT dye during flow-through testing of mesocosm system

an average of 7 weeks for those grown under full sunlight. Hydrilla grown under the shading canopy reached the surface in about 4 weeks, compared with not reaching the surface after 16 weeks in tanks under full sun. The plants in those tanks grew to about 10 cm below the surface and then stopped vertical growth.

Table 2
Percent of Full Sunlight Penetrating Water Columns in an Unshaded Tank, a Shaded Tank, and and Unshaded Pond

Depth	Tank 31 (full sun)	Tank 14 (shaded)	Pond 26 (full sun)
Surface (5 cm)	58	44	48
30 cm	52	36	37
60 cm	48	34	31
90 cm	46	34	23

5 Summary and Conclusions

The mesocosm system was constructed to expand WES and LAERF capabilities for conducting aquatic herbicide evaluations. The system was designed to investigate community level species-selective control of aquatic weeds, and the results of studies in these tanks will prove useful in formulating strategies for management of freshwater ecosystems.

The system has been thoroughly tested and has proven acceptable for conducting aquatic plant studies on a large scale. Water quality can be managed to provide desired conditions for conducting research on plant communities under a variety of conditions. Water temperature and light intensity can be moderated to fine tune growth of plants in tanks, while retaining natural diel cycles. For example, when water temperatures are anticipated to exceed 30 °C, it is advised to install the shade fabric to prevent disruption of plant growth due to high temperatures. This is especially critical when cool-water species, such as Eurasian watermilfoil and common elodea (*Elodea canadensis*), are included in a study.

The abilities of the mesocosm system to accurately duplicate declining herbicide concentrations on a large, replicated scale makes it possible to combine CET and species-selectivity experiments, further simulating "real world" conditions. The system also functions well for conducting static experiments and will be useful as integrated management techniques are developed in the years to come.

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ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer Waterways Experiment Station's (WES) Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX, has expanded its research capabilities with the addition of a large, outdoor aquatic mesocosm system. This multi-tank system is used to evaluate aquatic herbicides and plant growth regulators (PGRs) for achieving species-selective control of exotic nuisance aquatic plants, particularly Eurasian watermilfoil and hydrilla. The mesocosm system provides intermediate-scale verification, under more natural conditions, of laboratory-derived aquatic herbicide and PGR-concentration/exposure-time relationships developed at WES. This information is critical prior to conducting many field evaluations. The mesocosm system provides a combination of field (e.g., light, temperature) and controlled (e.g., water and sediment composition, flow-through rates) conditions for experimental purposes.

The system consists of several primary components including 32, 6,700-ℓ aboveground fiberglass tanks, a 1.4 million-liter water supply reservoir, a water filtration, circulation, and aeration system, water drain and fill systems, a water detention pond, and a wetland retention cell. Various study-support facilities, including a small laboratory building, a large plant culture and grow-out pond, and a shading canopy are associated with the system.

(Continued)

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Information provided in this report on the design, operation, and maintenance of the LAERF mesocosm system can be used as an operating manual for the system. In addition, a description of the system's construction, including materials and components, is given. The design and function of the system allow researchers to evaluate the effects of herbicides and PGRs on target and nontarget plants, and to provide operational guidance for restoring native plant communities in aquatic ecosystems.