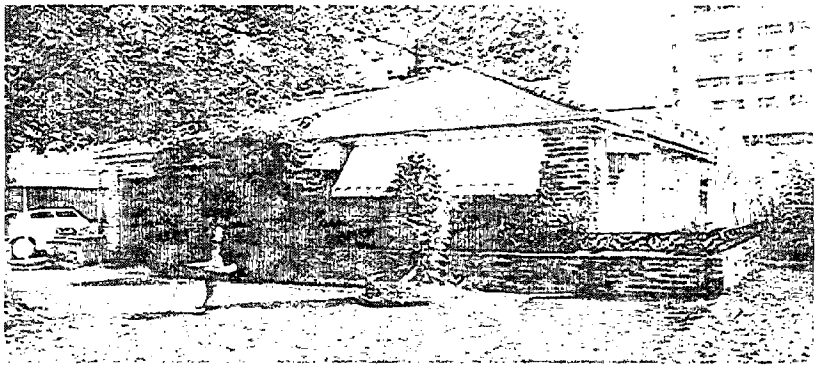

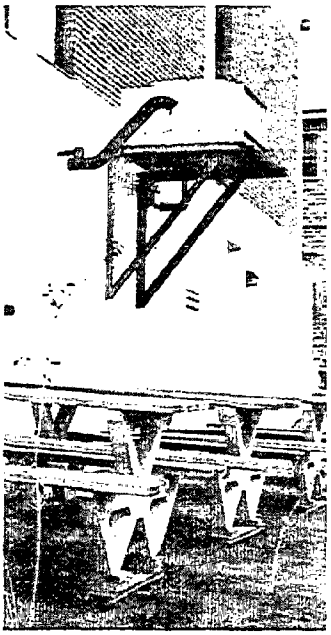

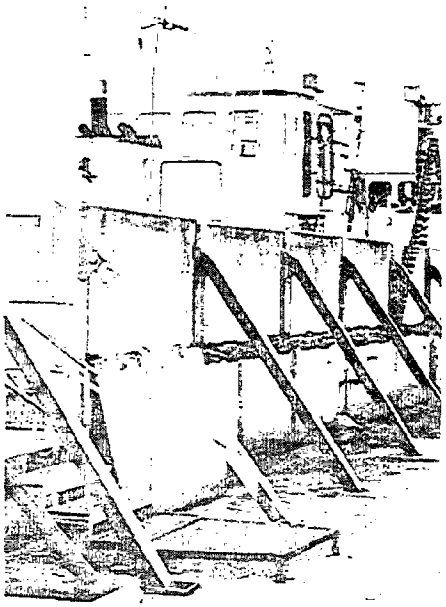

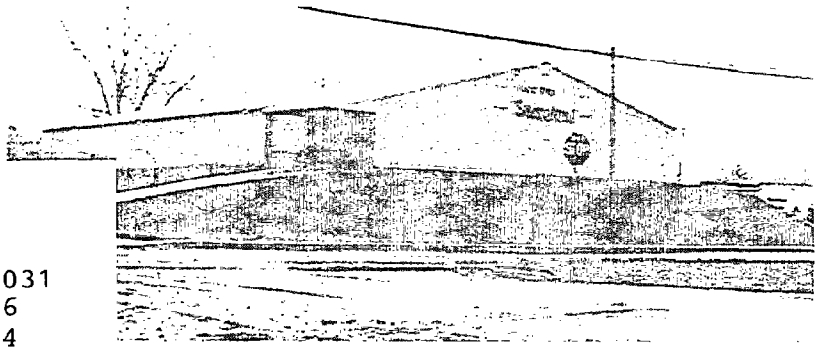

Flood Proofing Systems & Techniques

Examples of flood proofed structures in the United States

US Army Corps of Engineers

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Introduction

This report was prepared under the Corps of Engineers Flood Plain Management Services (FPMS) Program, authority for which is provided in Section 206 of the Flood Control Act of 1960, as amended. This program is the Corps' means of using its technical expertise in flood plain management matters to help those outside the Corps, both Federal and non-Federal, to deal with floods and flood plain related matters. Its objective is to support comprehensive flood plain management planning with technical services and planning guidance at all appropriate governmental levels, and thereby, to encourage and to guide them toward prudent use of the Nation's flood plains for the benefit of the national economy and welfare.

Most of the illustrations in this report were identified in a national survey of flood proofed structures. This survey was conducted in order to document the effectiveness of flood proofing techniques used in the United States by various occupants of flood hazard areas. The survey was based primarily on the personal knowledge of Corps officials and, in many cases, was augmented by information received from state and local governments, as well as other Federal agencies involved with water resources planning.

Flood proofing, as defined in this pamphlet, is "any combination of structural changes and/or adjustments incorporated in the design and/or construction and alteration of individual buildings, structures, or properties primarily for the reduction of flood damages." The results of the survey revealed pioneering flood proofing efforts by people in their struggle to reduce flood damages. Many commonplace efforts, such as elevating structures and building levees and floodwalls, were found. In addition, ingenious and complicated techniques, such as floatable houses and computer-controlled flood

proofing stations were noted. Examples of the various flood proofing techniques have been documented and are presented in this report. However, since the Corps of Engineers does not endorse development in flood hazard areas, this publication is not intended to encourage or support such development.

The majority of the structures identified were residential, with commercial establishments second in number. It is believed that the surveyed structures provide a representative cross section of flood proofed structures in the United States. Of the structures tested by actual flooding conditions, about 50 percent were judged to be effectively flood proofed.

This publication is intended primarily to illustrate the types of flood proofing techniques being used throughout the United States today. Additionally, it provides conceptual ideas for formulating individual flood proofing plans. It should be understood that careful planning, design, and construction are requirements for any successful flood proofing system. **NOTE: It should not be construed as a Corps endorsement of any of the examples, some of which may not function satisfactorily under actual flooding conditions.**

Special thanks are due to those individuals who provided valuable data on the flood proofing systems and techniques used to protect their homes, businesses, or industries. Without their assistance, the useful information provided in this publication would not be available for those who are contemplating flood proofing.

Before reading further, it is suggested that those readers unfamiliar with flood plain management and related terminology briefly review the technical definitions provided in the Glossary on page 11.

Flood characteristics, magnitude, and frequency

The concept behind flood proofing is to minimize flood damages by either keeping floodwaters away from damageable property or making the property less susceptible to damage when floodwaters get to it. To be successful, the flood proofing effort must consider local flood characteristics such as frequency, depth, duration, velocity, and perhaps water quality. These characteristics vary widely, from the slow-rising, long duration floods associated with most major rivers to fast-rising "flash floods" usually seen on small streams. Coastal floods, caused by hurricanes or other violent weather systems, have their own unique characteristics related to wind, wave action, and beach erosion. Regardless of the source of the flood, a successful flood proofing effort must be designed to withstand flood conditions that occur at the sites.

Flood frequency and elevation are the two most important characteristics that must be considered in designing any flood proofing project. Many of the flood proofing measures described in this pamphlet were designed to protect against the highest flood of record without determining the probability of that flood event. If the flood of record is a frequent event, the level of protection will be low and the structure will still be subject to flood damage. Fortunately, data needed for design of flood proofing projects are available in most urban areas.

The 100-year frequency flood was originally recognized by

both Federal and non-Federal interests as a reasonable minimum level of flooding on which to base protection plans. This flood level was later established by the National Flood Insurance Program (NFIP), which is administered by the Federal Emergency Management Agency (FEMA), as a national standard for regulating new building construction as well as any substantial improvement to existing structures. The limits and estimated levels of the 100-year flood are generally available in most urban areas through the Corps of Engineers' FPMS Program, FEMA, NFIP, or from local government agencies. There is nothing magical about the 100-year event; floods larger than this can and do occur. In cases in which flooding would result in substantial damages or loss of life, a more extreme flood should be considered. The Standard Project Flood and 500-year frequency flood have been used as reasonable upper limits of expected flooding to plan for and consider in planning critical structures (hospitals, schools, etc.) where flooding could result in catastrophic damages and/or loss of life. The examples presented in Appendix A cover a wide range of flooding conditions and geographic locations and are not necessarily based on any particular design flood. However, it is recommended that the level of protection provided be based on the potential of a life-threatening situation; economic considerations, including reduced flood insurance rates; and other factors dependent upon local conditions.

Flood proofing techniques

Selecting the best method of flood proofing for a given situation should be based on knowledge of local soil conditions, topography, flood characteristics, local building codes, the availability of materials, type of structure, and cost. The most common and often the best way to flood proof is to raise the structure above the flood hazard. The second most common way is through the use of levees and floodwalls.

Selected examples of flood proofing described in this report are categorized as follows:

Continuous wall or block foundation

Continuous concrete wall foundations are used for many different applications. Residential structures with above-ground basements are often constructed in this manner, as are many industrial and commercial establishments where docking facilities are incorporated into the design. Also, it is fairly common to find structures raised on concrete blocks to various heights depending upon the depth of flooding. Great care must be taken in this technique to prevent differential water pressure from damaging the foundation. If the foundation is not specifically designed to carry this loading, intentional flooding can be used to balance internal and external water pressures. Using potable water for this can minimize cleanup after the flood.

Fill

This is a fairly common method in subdivision development and siting of individual houses. Often, the shaping of areas to be developed in such a manner as to fill the house sites, in combination with use of a conventional foundation, will raise the first-floor level above the design flood level. Significant amounts of material hauled into a flood plain for this purpose may obstruct the natural flow of water or result in a loss of floodwater storage capacity. Either condition can cause higher and more frequent flooding. Before a structure is placed on fill, state and local land use regulations should be checked to determine if such action is permitted. The materials used for fill vary widely from one region to the next, but generally the material must be grassed or otherwise protected against erosion or slippage.

Elevating on piles or columns

This method is frequently used where the dynamic forces of wave action or floodwater velocity is severe, or where the water surface can vary considerably. Structures built on piles are often found in coastal areas and along river overbank areas and lakeshores. One advantage to this method is that the flow of floodwater is not restricted and impacts on flood storage capacity are minimized. Also, open areas under the structure can be used for parking or storage of materials that can be easily moved. Even though the best time to flood proof is obviously during initial construction, this method is often the most practical for flood proofing existing structures as well.

Levees and floodwalls

Levees considered in this report are those built around single homes, small subdivisions, and individual industrial complexes. These local levees, if adequately maintained, protect against more frequent lower level flood events; however, they are often overtopped during higher floods. Usually, pumps are required to handle interior drainage and seepage. Both floodgates and levees require periodic maintenance. Since local levees sometimes fail without being overtopped because of poor design, improper material and/or construction practices, poor maintenance, inadequate pumping facilities, and related reasons, it is strongly recommended that all levees, as well as floodwalls, be designed and constructed under the supervision of qualified professional engineers. Failure of levees protecting major urban and industrial areas can result in catastrophic losses.

Floodwalls are often added after a building or properties have experienced flooding one or more times and generally are used where space or other considerations preclude the use of levees. If designed properly, floodwalls are effective because they require little maintenance and can be easily inspected. The main problems with this method are keeping closure materials accessible and in good operating order and training personnel to assure timely closure. Generally, floodwalls are constructed from concrete or concrete blocks and have one or more

passageways that are closed by gates. Occasionally, a structure will have a floodwall incorporated into the architectural design. The use of levees and floodwalls will usually require a sump pump system to evacuate internal drainage along with underseepage that might occur. Excessive underseepage from improper design is a common problem.

Closures and sealants

Plastic, marine paints and water proofing compounds, and other sealants can be applied to structures, provided the structure can withstand the hydrostatic and hydrodynamic pressures. In addition, the foundation must be designed to withstand uplift forces caused by water pressure beneath the structure. A variety of bulkhead designs are used ranging from single plywood sheets to expensive steel stoplogs. It is extremely difficult to make closures completely watertight, and many systems using this technique employ pumps to evacuate leakage. No attempts should be made to seal a structure against floods deeper than 2 to 3 feet until the structure has been examined by a qualified professional engineer to determine that it can withstand the increased hydrostatic loads.

Other flood proofing efforts

A few other flood proofing techniques which do not fit the above categories have been developed. One of these is known as wet flood proofing. With this technique, the structure is built of materials that are not easily damaged by floodwaters and can be easily cleaned following a flood. Such materials include exterior or marine plywood. Often the structure is allowed to fill with clean water to minimize damage. This is also done to prevent the structure from collapsing from hydrostatic loading. In some areas, new construction behind low-frequency protection levees has utilized wet flood proofing on a large scale. The technique can be particularly useful to industries and businesses in reducing flood damages. Another technique that is rarely seen is to build the structure on pontoons or a barge-type foundation such that the structure floats during the flood. In this case, all land-based supporting facilities, utilities, etc., have flexible line connections. Other methods, such as wrapping the house in plastic or rubber sheeting, have also proven to be successful.

More detailed information on each of these flood proofing techniques is found in Appendix A.

Regulatory requirements

Individuals interested in flood proofing a structure or constructing a new structure in a flood-prone area should first contact their city or state government to determine what flood plain regulations, building codes, or other regulations are in effect for that particular area. Generally, these regulations will require new construction to be elevated to above the 100-year frequency flood level. For some locations there are no flood plain regulations and/or the 100-year flood elevations have not been determined. In these instances, it is recommended that the individual contact the Flood Plain Management Services Program representative at the appropriate Corps of Engineers District Office and request flood plain management information and guidance (refer to list of Corps offices in Appendix B).

Although the general policy of the Federal Government is to discourage development and construction in flood plains pursuant to Executive Order 11988, there are instances where this is unavoidable or impractical, and effective flood proofing techniques can be a viable alternative. The Corps, through its Regulatory Functions Program, regulates the placement of fill in designated wetland areas. An individual wishing to place fill in such a wetland area should file an application for intent to place fill with the District Engineer of his particular Corps District. Where permit applications are not necessary, it is still suggested that flood plain management information, when available, be used as a precautionary check of conditions.

Conclusions

The survey of flood proofed structures indicates that flood proofing is widely used, even though the chance of success historically has been only about 50 percent. To those individuals contemplating building in a flood-prone area or flood proofing an existing structure, these results should underline the need for careful planning and design. Improperly designed flood proofing schemes can result in increased flood damages from the large hydrostatic and/or uplift loads involved. There is also an inherent danger that a false sense of security provided by flood proofing will encourage people to remain in flood proofed buildings until rising floodwaters cover all escape routes. Regardless of the mixed success in the past and the dangers involved, it is evident that the use of flood proofing will continue. Therefore, it is important that the following factors be fully considered:

- New construction should be located outside the 100-year flood plain whenever possible. Before a decision is made to build in the flood plain, the owner should consult with Federal, State, and local authorities or private engineering firms to gather all pertinent information about the flooding potential.
- If a decision is made to build in the flood plain, a dependable flood proofing system should be included as an integral part of the design of the structure. Local flood characteristics, site conditions, and structure type should be considered in selecting a suitable flood proofing method.
- Elevation is the surest and generally the most dependable flood proofing scheme. However, many elevated structures have been damaged by floods that exceeded the design level. Elevated structures should not be occupied during flood events unless a safe means of exit is available at all times.
- Flood proofing projects should be designed by a qualified professional engineer. This is especially important if flood depths of greater than 2 to 3 feet are involved. High-velocity flow, wave action, and erosion are other factors indicating the need for professional assistance.
- All flood proofed structures must be properly anchored.
- Flood proofing seldom provides complete protection. Even the best project will not protect against floods that exceed the design elevation.
- An architect/engineering firm and/or qualified contractor should be employed for the design and implementation of flood proofing alterations to a structure.
- The Flood Plain Management Services Program representative in each Corps office can provide additional information (Appendix B).

Glossary

Building code—The regulations adopted by a local governing body setting forth standards for the construction, addition, modification, and repair of buildings and other structures for the purpose of protecting the health, safety, and general welfare of the public.

Design flood—Commonly used to mean the magnitude of flooding used for design and operation of flood control structures or other protective measures. It is sometimes used to denote the magnitude of flooding used in flood plain regulations.

Discharge or streamflows—A measurement of water quantity in relation to time, usually expressed in cubic feet per second (cfs).

Flash flood—A flood that reaches its peak flow in a short length of time (hours or minutes) after the storm or other event causing it. Often characterized by high-velocity flows.

Flood—An overflow of lands that are not normally covered by water and that are used or usable by man. Floods have two essential characteristics: the inundation of land is temporary; the land is adjacent to and inundated by overflow from a river or stream or an ocean, lake, or other body of standing water.

Normally a flood is considered as any temporary rise in streamflow or stage, but not the ponding of surface water, that results in significant adverse effects in the vicinity. Adverse effects may include damages from overflow of land areas, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions or other unfavorable situations by deposition of materials in stream channels during flood recessions, rise of ground water coincident with increased streamflow, and other problems.

Flood crest—The maximum stage or elevation reached by the waters of a flood at a given location.

Flood duration—The length of time a stream is above flood stage or overflowing its banks.

Flood fighting—Actions taken immediately before or during a flood to protect human life and reduce flood damages, such as evacuation, emergency sandbagging and diking, and assistance to flood victims.

Flood frequency—A statistical expression of the average time period between floods equaling or exceeding a given magnitude. For example, a 100-year flood has a magnitude expected to be equaled or exceeded on the average of once every 100 years; such a flood has a 1-percent chance of being equaled or exceeded in any given year. Often used interchangeably with "recurrence interval."

Flood plain—The relatively flat area or lowlands adjoining the channel of a river, stream, or watercourse or an ocean, lake, or other body of standing water that has been or may be covered by floodwater.

Flood proofing—Any combination of structural and nonstructural additions, changes, or adjustments to properties and structures which reduce or eliminate flood damage to lands, water and sanitary facilities, structures, and contents of buildings.

Flood stage—The stage or elevation at which overflow of the natural banks of a stream or body of water begins in the reach or area in which the elevation is measured.

Flood warning—The issuance and dissemination of information about an imminent or current flood.

Freeboard—A factor of safety expressed in feet above a design flood level for flood protective or control works. Freeboard is intended to compensate for the unknown factor which could increase design heights, such as wave action, floodway obstruction, or future changes in the watershed.

Hydrodynamic loads—Forces imposed on structures by floodwaters due to the impact of moving water on the upstream side of the structure, drag along its sides, and eddies or negative pressures on its downstream side.

Hydrostatic loads—Those loads or pressures resulting from the static mass of water at any point of floodwater contact with a structure. They are equal in all directions and always act perpendicular to the surface on which they are applied. Hydrostatic loads can act vertically on structural members such as floors, decks, and roofs and can act laterally on upright structural members such as walls, piers, and foundations.

Level of protection—The greatest flood level against which a protective measure is designed to be fully effective; often expressed as a recurrence interval (e.g., 100-year level of protection) or as an exceedance frequence (e.g., 1-percent chance of exceedance).

National Flood Insurance Program—The program under which communities may be eligible for federally subsidized flood insurance on the condition that the communities enact satisfactory flood plain management regulations.

100-year frequency flood—A flood having an average frequency of occurrence on the order of once in 100 years although the flood may occur in any year. It is based on statistical analyses of streamflow records available for the watershed and analyses of rainfall and runoff characteristics in the general region of the watershed.

Seepage—The passage of water or other fluid through a porous medium, such as the passage of water through an earthen embankment or masonry wall.

Standard Project Flood—The flood that may be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. Such floods, as used by the Corps of Engineers, are intended as practicable expressions of the degree of protection that should be sought in the design of flood control works, the failure of which might be disastrous.

Underseepage—Seepage along the bottom of a structure, floodwall, or levee or through the layer of earth beneath it.

Uplift—The upward pressure of water, as on the base of a structure. (See also the term "hydrostatic loads.")

Velocity—The rate or speed that water flows, usually expressed in feet per second. One foot per second is equivalent to about 0.7 mile per hour.

Appendix A: Flood proofing examples

Continuous walls or block foundations

Two-story, single-family, brick bungalow raised on concrete and concrete block foundation, Milton, Pennsylvania

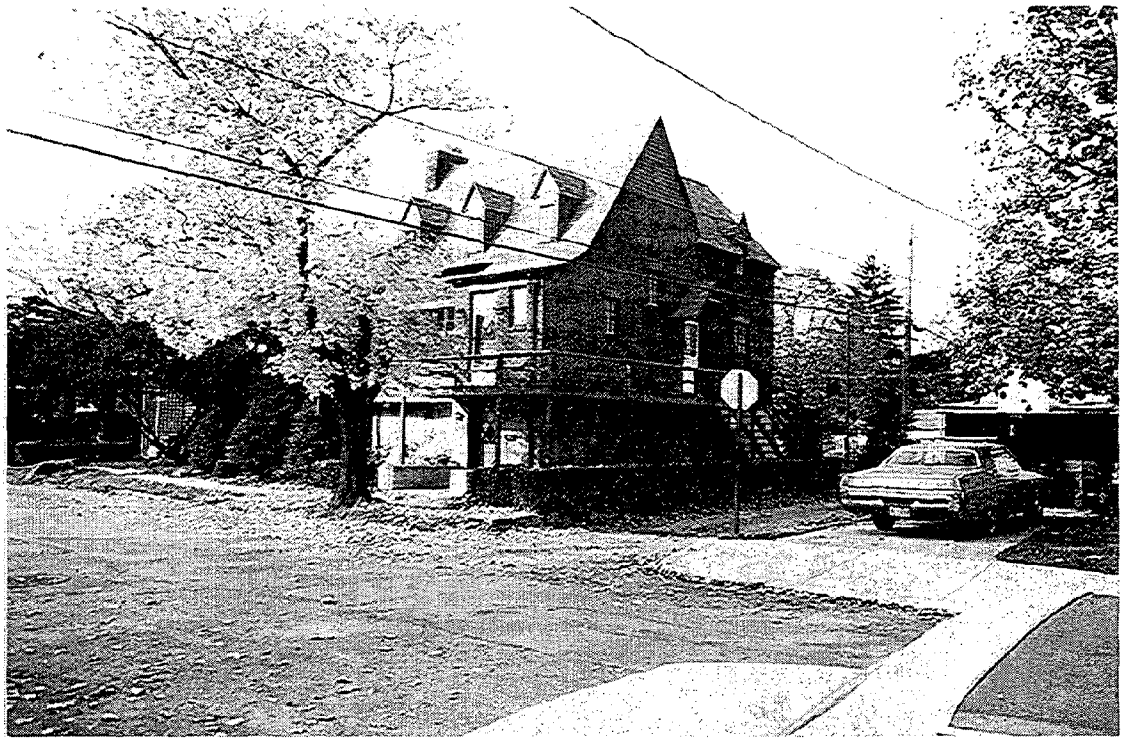
This structure was built in the 1940s in what was later determined to be the 100-year flood plain. The house originally had a basement below grade, with the first floor between 1 and 2 feet above ground level. Floors and walls of the upper two stories were wood frame with a brick-veneer exterior.

Flooding from the West Branch of the Susquehanna River put as much as 7 feet of water on the first floor of the house. In 1975, the owner made a decision to raise the entire structure and place it on concrete and concrete block foundation walls. The house was raised using beams and jacks, and then foundation walls were built atop the old walls to a height of 88 inches above ground level (approximately 4 inches above the flood of record for that area, which was Tropical Storm Agnes in 1972). Because of the brick-veneer exterior, jacking procedures had to be precisely controlled to prevent damage.

After the house was set on the walls, the old basement was backfilled to ground level and a floor slab was poured.

The heating system and hot-water heater are raised 2 feet to prevent damage from minor flooding. Flood-susceptible mechanical and electrical components of these systems are equipped with quick disconnects to facilitate removal prior to major flooding.

The raising of the house was completed in 1976 at an estimated cost of $11,300 for foundation work and materials. Much of the actual labor involved was performed by the owner, thus reducing costs below what a contractor would have charged. The ground level was designed for use as a two-car garage and for storage. An elevated wood deck at the new first-floor level surrounds the house on three sides. Two sets of stairs, one interior and one exterior, provide access to the first floor. The structure has not been tested since it was raised; however, excluding a flood greater than the flood of record, the first and second stories would remain dry. The owners are pleased with the outcome of their efforts. Photos of the structure are provided as Figure A1.



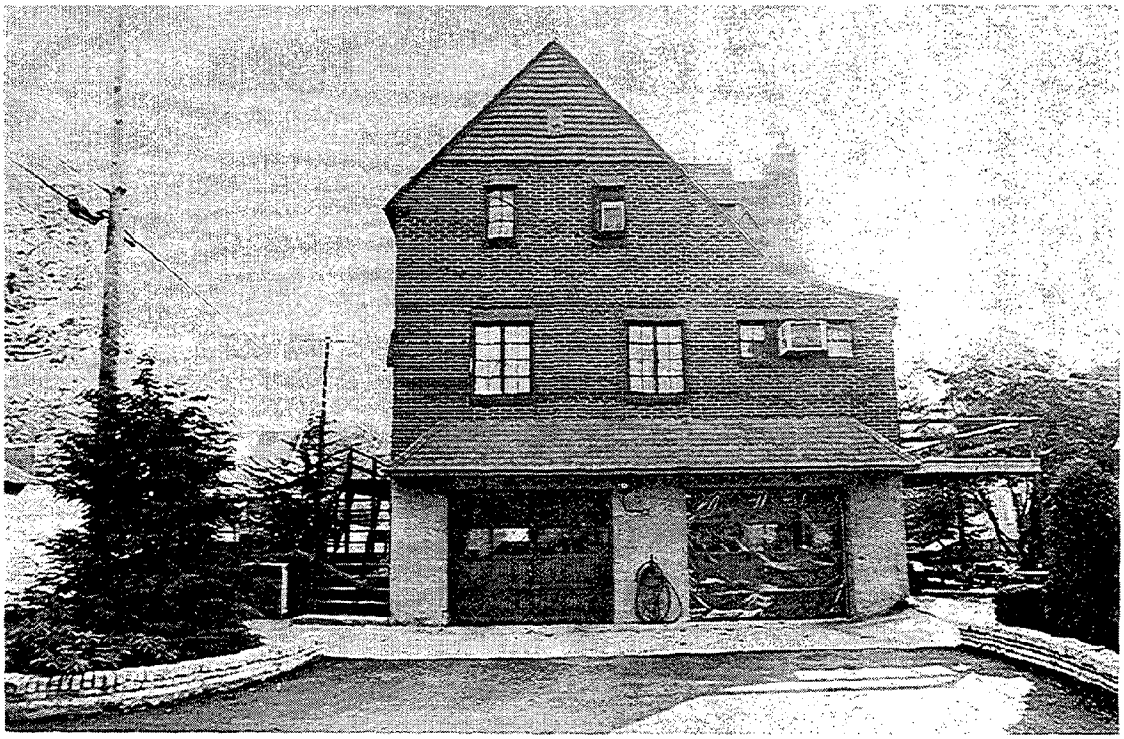


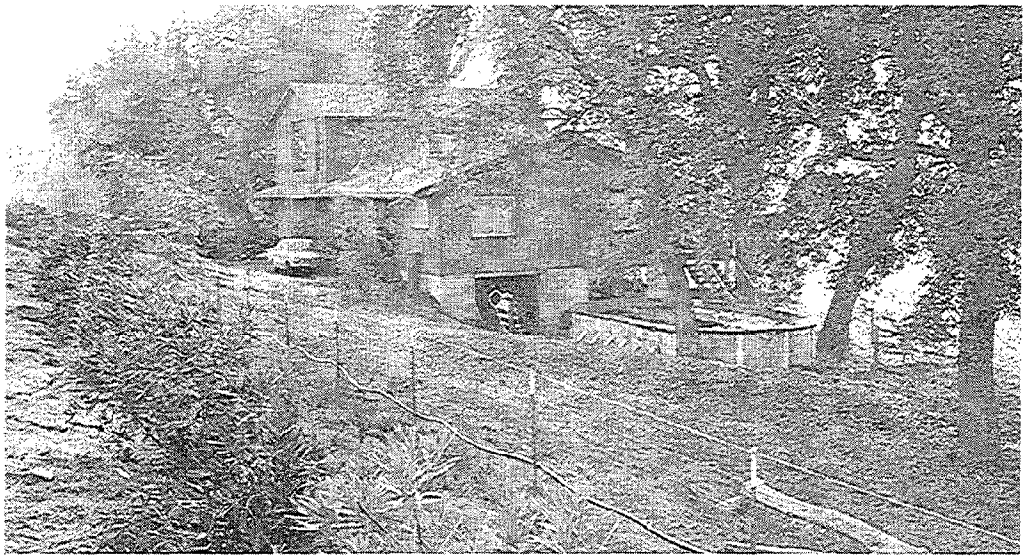
Figure A1. Brick house raised on concrete and concrete block foundation

Two-story wood frame house raised on concrete block foundation, Sacramento, California

This residence was built adjacent to the Sacramento River in an area that is frequently flooded. Depth of flooding may reach 6 to 7 feet. The house is of wood construction and was originally built upon a concrete block wall. The first floor has never flooded. Openings have been left in three of the four basement walls to allow floodwaters to enter the structure in order to equalize hydrostatic pressures. The grade of the lot is such that access to and from the house by way of the front can be accomplished at any time during flooding. Flood duration may be 1 to 2 weeks. Heating and air conditioning units are raised above ground level and are directly beneath the first floor. The brick wall on the river side of the house is also built to allow for the free flow of floodwater (Figure A2). The estimated cost of building the house above flood level is $15,000. The structure, as designed and constructed, is attractive as well as functional.

Raised air conditioning unit and openings for free flow.

Figure A2. Wood frame house raised on concrete block foundation



Without flooding.

With flooding.

Figure A2.

Multistory condominium on concrete wall foundation, Rochester, Minnesota

This 6-story, 20-unit condominium was constructed in 1978 on the bank of the Zumbro River in Rochester, Minnesota (Figure A3). Flooding from the Zumbro can be of a flash nature and has been known to reach depths of up to 4 feet in the vicinity of the condominium. The structure was designed and built with the structural walls aligned to allow for passage of floodflows. The building is set on concrete walls with concreted spread footings on bedrock. The ground floor, which was designed for parking, is a concrete slab on grade with reinforced concrete support columns. Stair towers and elevator shaft are made of poured concrete. The condominium units are elevated above the regional flood level. The electrical transformer and feed is of waterproof construction. The builder estimates the additional cost of raising the structure was only $15,000. This demonstrates the modest cost when included in the original design.

While the building is inaccessible during flooding, a door in the stair tower is located above flood level. This door leads to an embankment where residents can wait for evacuation. In addition, the elevator can be stopped at upper levels during floods to allow for evacuation from those floors.

The Zumbro River last flooded during the summer of 1978. At that time, the building was under construction and some damage occurred because the elevator cage had been inadvertently left at ground level. Damages could easily be avoided should another flood occur.

The design of this condominium is effective in two ways. First and most important, it reduces potential flood damages; second, it provides parking, which would otherwise be lacking due to property constraints.

First floor parking area, 3-ft depth of flooding in 1978.

BELOW:

Concrete columns aligned in direction of flow.

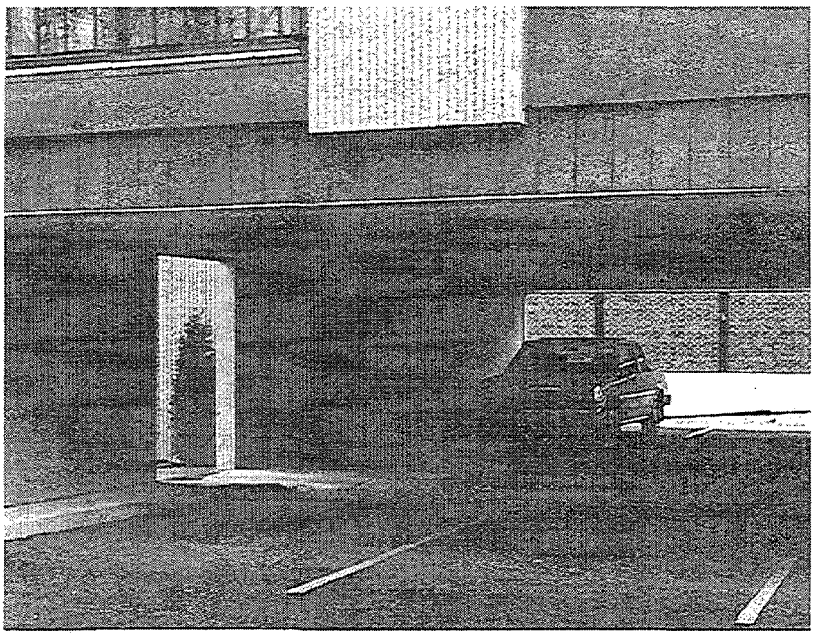


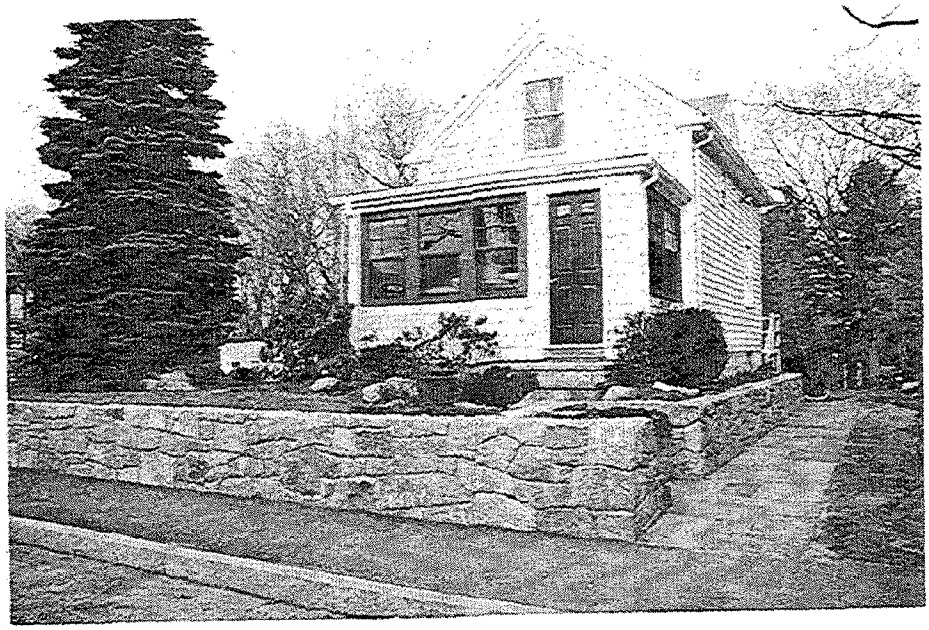
Figure A3. Condominium on concrete wall foundation

Two-story, single-family house raised on fill, South Natick, Massachusetts

This house contains 10 rooms on two floors, each floor of which is 2200 square feet. It is located approximately 150 feet from the Charles River, which within the past 40 years has flooded the area three times—March 1968, January 1979, and June 1982. During the floods of 1968 and 1979, floodwaters reached depths of approximately 3 feet in the vicinity of the house. The latest flood, in 1982, caused only minor flooding. Following the March 1968 flood, which caused substantial damage, a decision was made by the owner to flood proof the house. Waterproofing of the basement was too expensive considering there was no guarantee of its effectiveness. It was therefore decided to raise the house 4 feet on a concrete block foundation. This would place the structure above the 1968 flood level. The exterior walls were covered with plastic, and loam was filled in around the extended block foundation. A 3-foot-high stone wall was built around the front portion of the house (Figure A4). All utilities were subsequently moved to the first floor.

During January 1979 flood, neighbors on either side of this structure were forced to evacuate, while the owners of this house remained in their home for the duration of the flood. The only flooding was about 4 inches of water in the basement which was handled by a sump pump.

Although this method has proven to be effective, the house has no auxiliary power source. If the local electric utility were to discontinue service during a flood, the owners would be unable to keep the sump pump active and the water in the basement could rise to a level that would cause damage. Otherwise this flood proofing method appears to be thorough and effective. It should be noted that it is never advisable for occupants to remain in a flood proofed structure when it is surrounded by floodwater since it is always possible that a flood may exceed the design capacity of the flood proofing measure, thus endangering their lives.



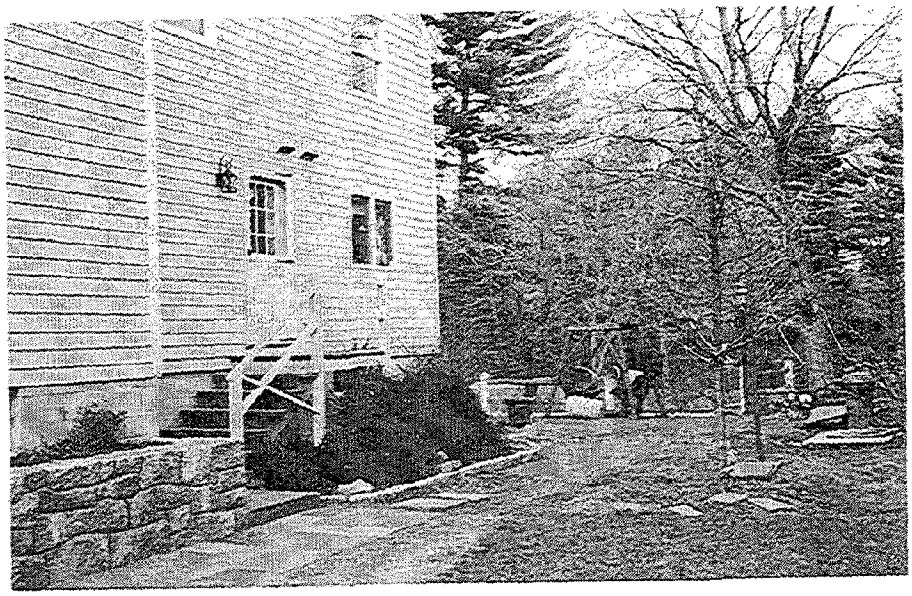


Figure A4. Two-story house raised on fill

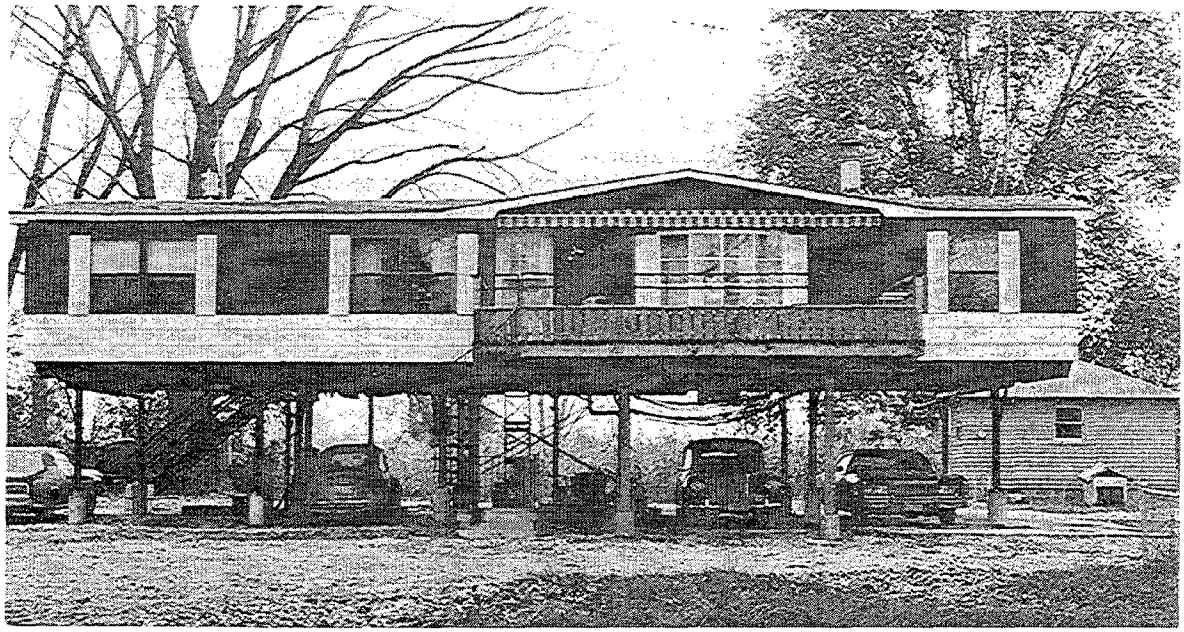
Columns and pilings

Mobile home raised on steel I-beams, Bellevue, Nebraska

This mobile home lies approximately 200 feet from the Missouri River, which has flooded the area frequently in the past. Although the last major flood was over 30 years ago, lesser flooding has occurred within the last 3 years. Completion of upstream main stem dams has reduced the frequency of major flooding. Past floods have been of long duration, lasting for as much as several weeks. The 100-year flood in the vicinity of the mobile home is estimated at 5 feet.

The mobile home is 12 feet wide and 60 feet long. In 1979, it was raised 8 feet above ground level by two cranes and is resting on 12 steel I-beams bolted to the top of concrete cylinders. Three longitudinal beams under the mobile home rest on six transverse beams joining the six pairs of I-beams and concrete cylinders (Figure A5). A deck and stairway were added to the east side of the home after it was raised. The owner has estimated the cost of raising his home at $1500.

The only structural problems with raising the trailer might result from high winds or ice from the Missouri River striking the I-beams if flooding should occur in winter or early spring. However, the many trees between the river and the mobile home should reduce the likelihood of ice hitting the structure.



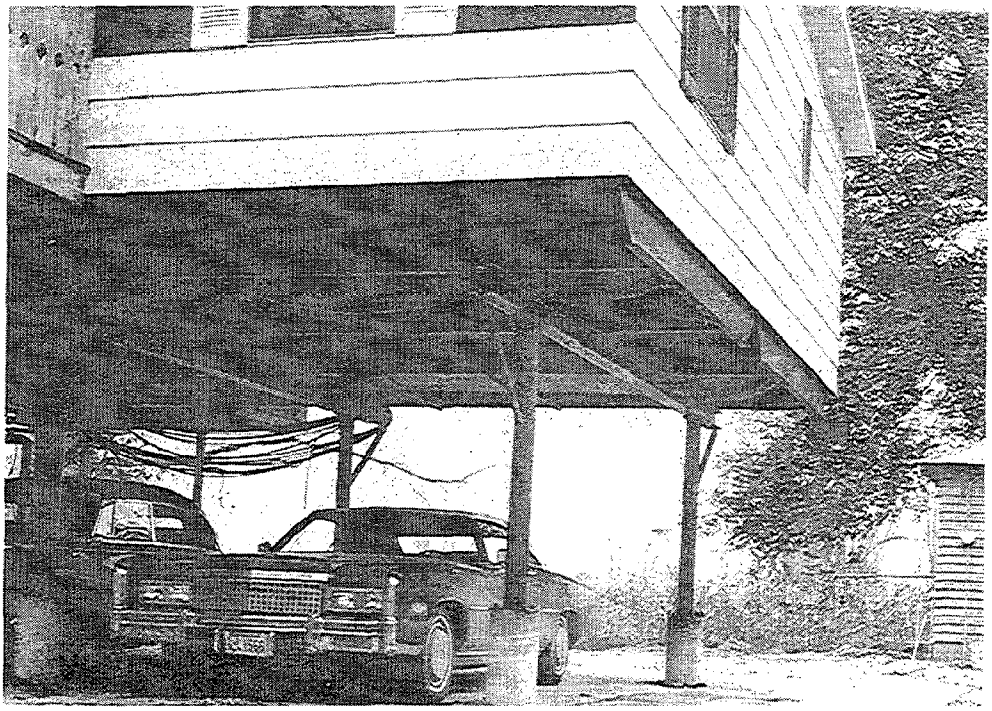


Figure A5. Mobile home raised on steel I-beams

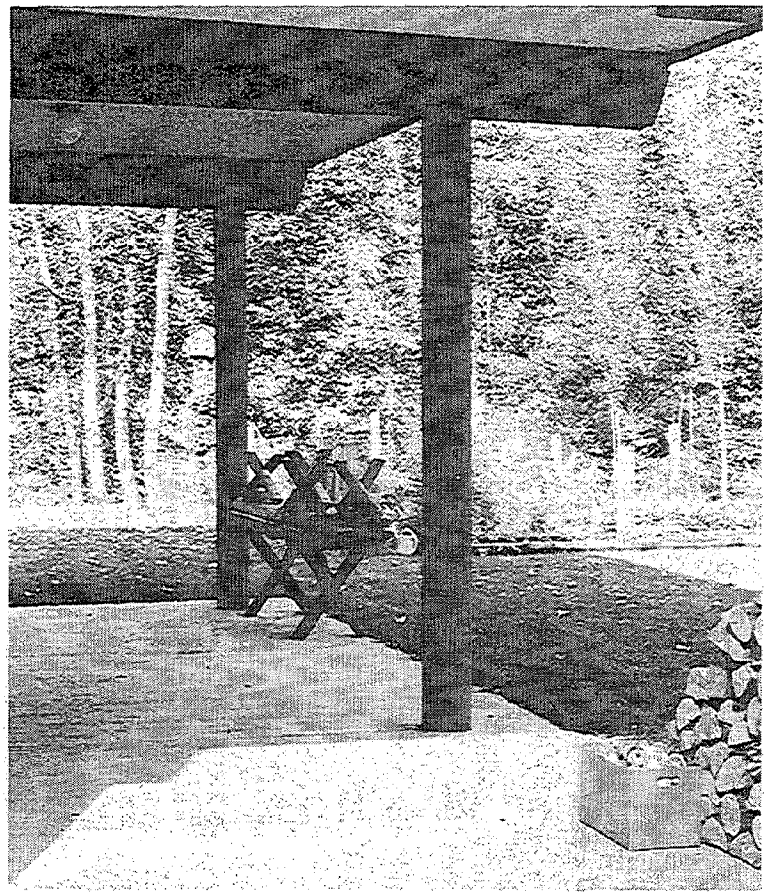
One-story, single-family house raised on concrete columns, Oregon City, Oregon

This residential structure was built in 1971 along the Clackamas River in Oregon. It sits 13 feet above a grade slab on 10-inch-diameter concrete columns (Figure A6). The house rests on timber beams that are secured to the top of the columns by steel straps embedded in and projecting from the columns. An inclosed "core area" at ground level connects with the upper main floor. It contains an access stairway and water and sewer connections. The house itself is of wood frame construction and contains approximately 1300 square feet of space. The owner estimates that the cost of raising the house was $5000. Under the floodway concept adopted by Clackamas County subsequent to construction of this dwelling, the "core area" would likely not be permitted, particularly since the wider dimension of the core area is oriented perpendicular to flow. Clackamas County also requires a 1-foot freeboard above the 100-year flood; however, this structure has approximately a 3-foot freeboard.

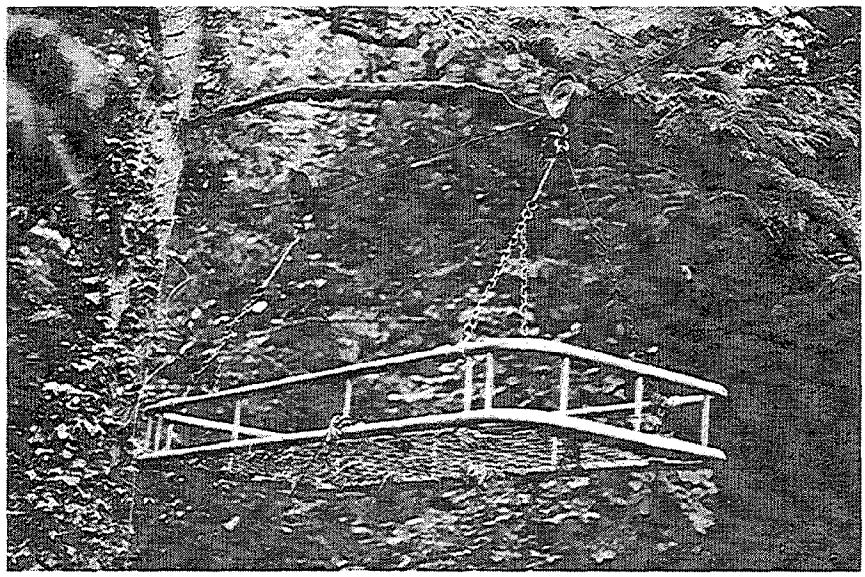
The last significant flood was in January 1972. It peaked at 70,800 cfs and was considered approximately a 20-year flood. The owner states that water was on three sides of the concrete ground slab but did not cover the parking area. The 100-year flood discharge is 110,000 cfs and its duration is about 6 days. Average overbank velocity is about 5 feet per second. The December 1964 flood peak was about 120,000 cfs. Of particular interest is the emergency exit provided by aerial cable tram (basket shown in the third photograph). In the event of major flooding, this provides access from the living level to nearby higher ground at the county road.

View from street, Clackamas River on other side.

Figure A6. One-story house raised on concrete columns



Closeup of columns and beams.

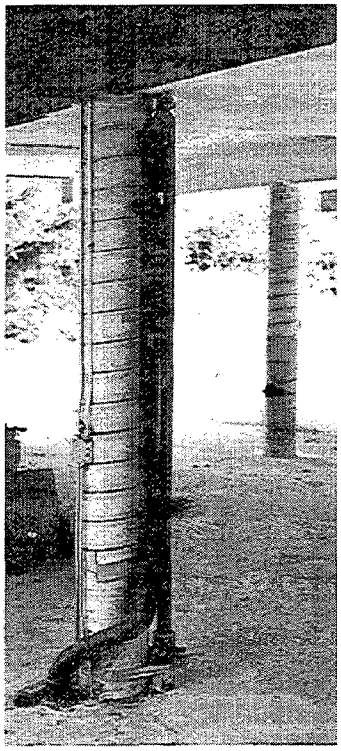


Aerial cable between structure and high ground.

Figure A6.

Newly constructed one-story dwelling on concrete columns, Oregon City, Oregon

This structure (Figure A7) lies adjacent to the dwelling previously described (shown in Figure A6). Flooding conditions are similar. This new construction includes an open stairway, to meet current county flood plain regulations. Such a stairway will permit free passage of floodflows. The dwelling was designed by a consulting engineer firm using design floodflow velocity of 8 feet per second. Reinforced 12-inch-diameter columns on 5-foot-square by 1-foot-deep spread footing support the house. The first-floor elevation is approximately 10 feet above the grade slab. Water and sewer lines are attached to the concrete columns and descend through the grade slab.



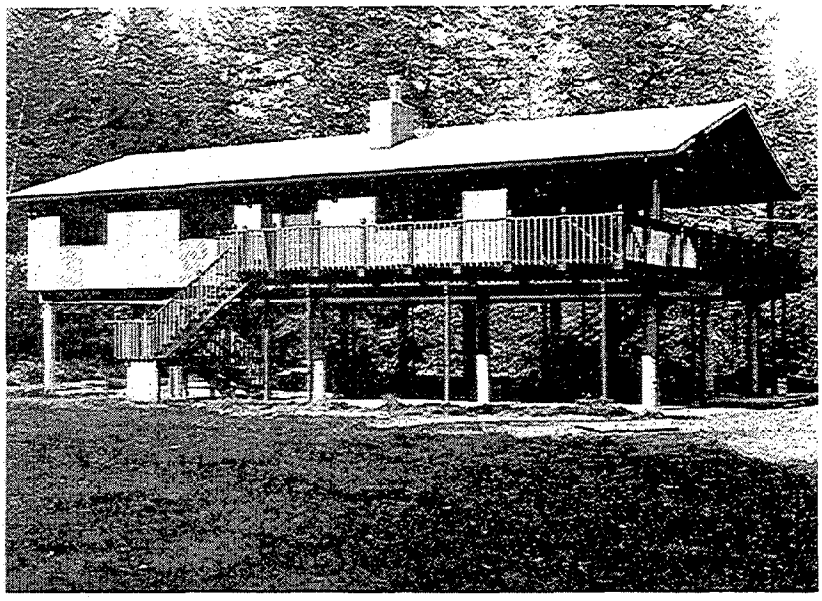


Figure A7. One-story dwelling constructed on columns

One-story dwelling raised on concrete pillars, Downers Grove, Illinois

This one-story rancher is located 10 feet away from St. Joseph's Creek in Downers Grove, Illinois. The structure was built in 1974 and complies with a village ordinance that existed at the time, requiring houses to be built 3 feet above the 100-year flood level. The house is constructed on an uphill slope which rises away from the creek. It is elevated about 10 feet above ground level on twelve 1-foot-thick poured concrete pillars (Figure A9). Each pillar rests upon a 4- by 4-foot poured concrete slab 2 feet thick. The garage is also raised on six pillars. As constructed, floodwaters are allowed to flow freely. Cost of flood proofing was not disclosed; however, the contractor indicated that it was less expensive to raise the house than it would have been to build a full basement.

The area was last flooded in spring 1979. At that time, floodwaters rose to the lowest step of the stairs leading to the raised deck. This was estimated to be a 10-year flood event.

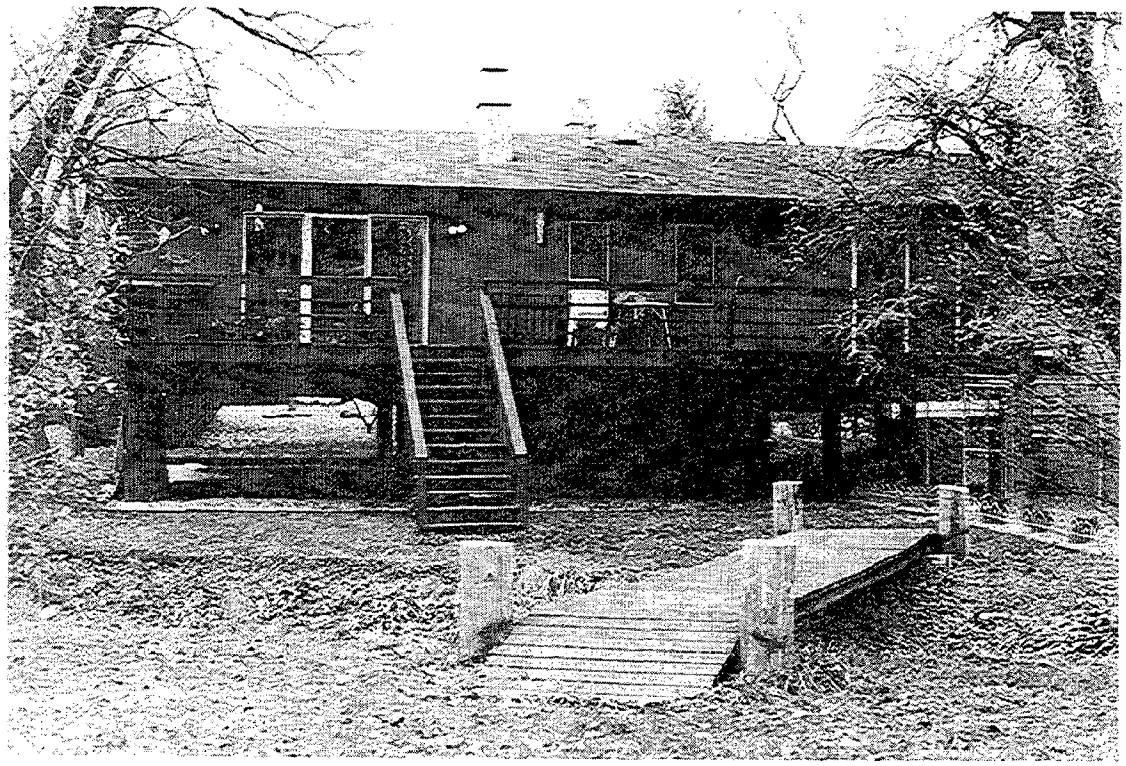


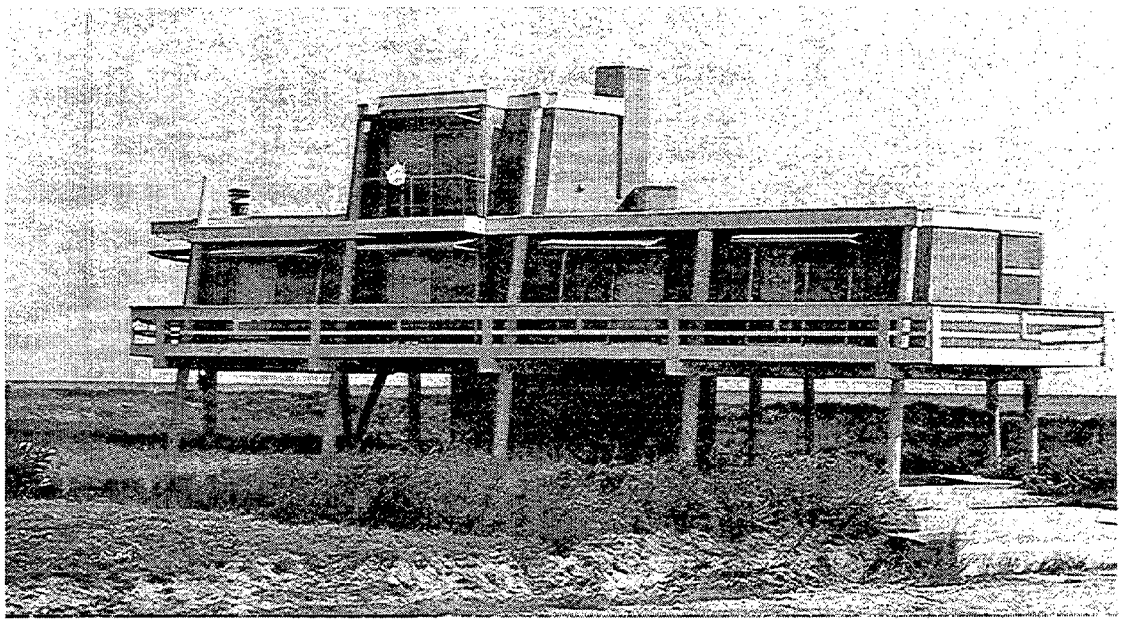
Figure A9. One-story dwelling raised on concrete pillars

Resort home on timber piles, Galveston Island, Texas

The resort home, shown in Figure A8, is located along the Texas Gulf Coast on Galveston Island. This and other structures along the coast are subject to hurricane tidal surges. The natural ground elevation is only about 5 feet, while the 100-year stillwater tidal surge is 12 feet above sea level. The house was built before the Federal Insurance Administration established wave-height requirements and therefore, if built today, would be required to have a higher elevation.

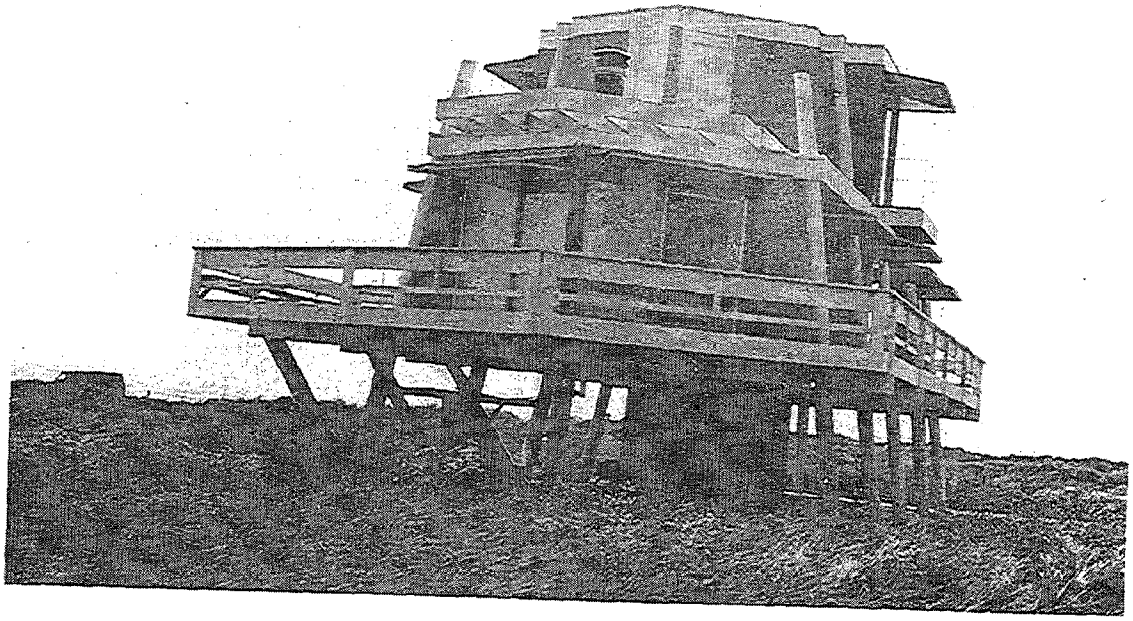
The house is of wood frame construction and is built within, and connected to, extended wood piles. These batter piles are not only aesthetically pleasing, but also provide greater resistance to the overturning forces of possible wind-driven waves. Window awnings are metal, and designed to fold down, thus serving as storm shutters. The first floor is elevated 8 feet above the ground level.

No severe flooding has been experienced by this structure. The only hurricane to strike after its construction was Alicia in August 1983. During that storm, winds were recorded at 130 m.p.h., and the still water surge elevation was 9.5 to 10 feet. It is not believed that wave action was significant at this site, and there was no apparent wind damage.

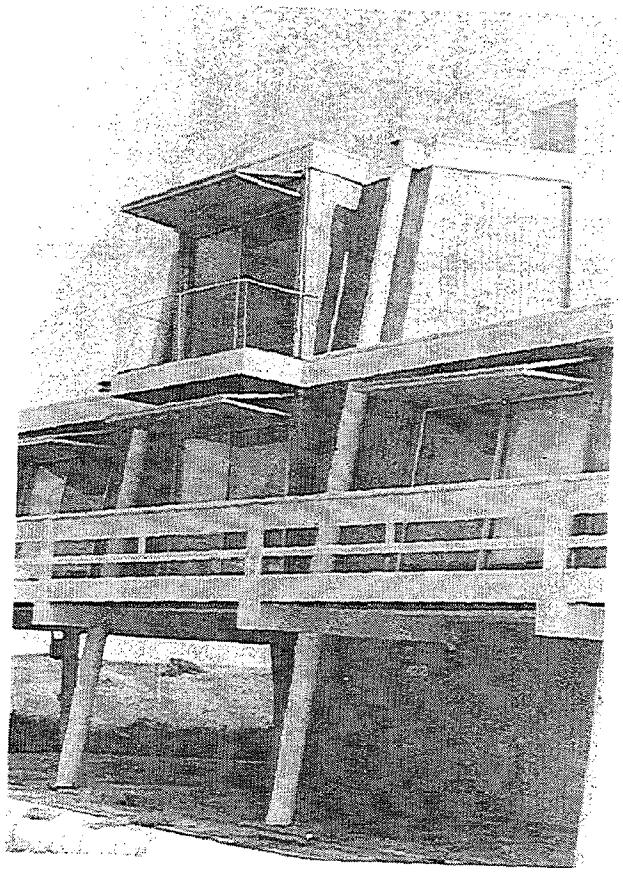


Front view.

Figure A8. Resort home on timber piling



ABOVE: Side view.

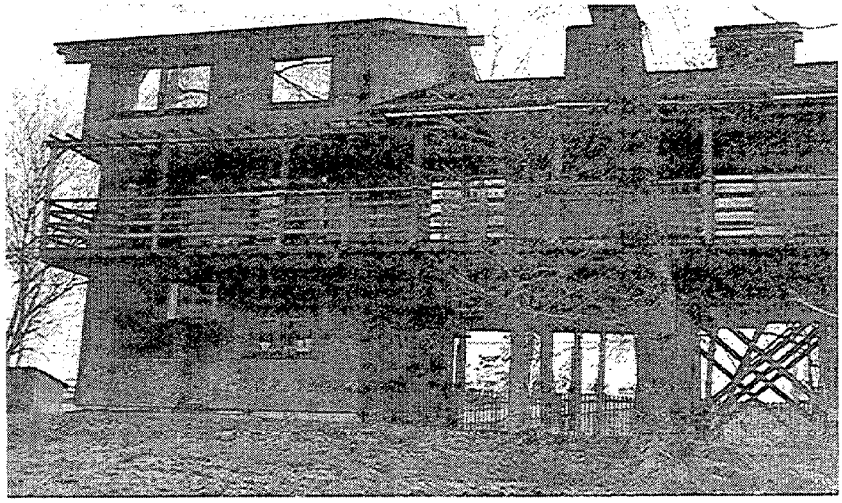


LEFT: Double 2×12 in. stringers through-bolted to timber piles. Piles protected by concrete slab. Note fold up storm shutters.

Figure A8.

Residential two-story wood frame structure on wooden posts, Sacramento, California

This house, shown in Figure A10, is elevated 11 feet above ground. It was built on nine wooden posts with 13.5-inch-diameter wooden piers set at 10-foot centers. The piers are set in concrete and bolted to the floor joists with steel plates. It is located about 40 to 50 feet away from the Sacramento River, which floods frequently. Depths of flooding may reach 6 to 7 feet in the vicinity of this house. In addition to the main house being raised, the air conditioning unit, shown in the first photograph, is also raised well above the flood plain. Cost of flood proofing the structure is estimated to be $8000.



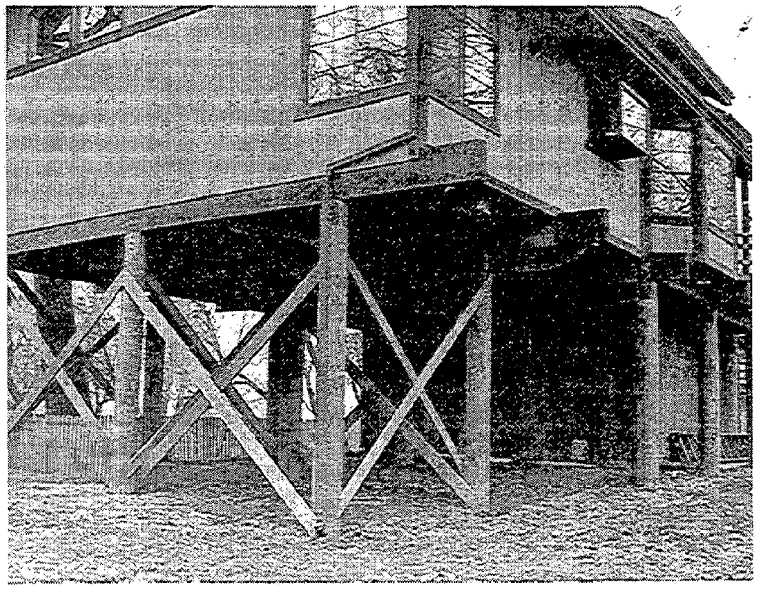


Figure A10. Wood frame structure on wooden posts

This structure is built in similar fashion to the one described previously. Located on the Sacramento River, this structure has nearly identical flooding characteristics also. A bridge leads to the first floor from the road (Figure A11). The wooden posts upon which the house rests are actually built into the house itself.

Residential two-story wood frame structure on wooden posts, Sacramento, California

Figure A11. Wood frame structure on wooden posts, with bridge

Two-story dwelling on steel posts, Sacramento, California

Located along the Sacramento River, this wooden frame house is raised 9.5 feet. Steel I-beams run the length of the house and are attached to 12 steel posts which are 6 inches in diameter. The posts are attached to the I-beams with bolts and are set in concrete. The wooden floor joists rest upon the I-beams (Figure A12).

Electrical circuit boxes and the heating/air conditioning unit are raised about 5 to 6 feet above the flood plain. The two-car garage is located beneath the first-floor ground level. A wooden bridge runs from the first floor to the road. Cost to flood proof the house is estimated at $5000.

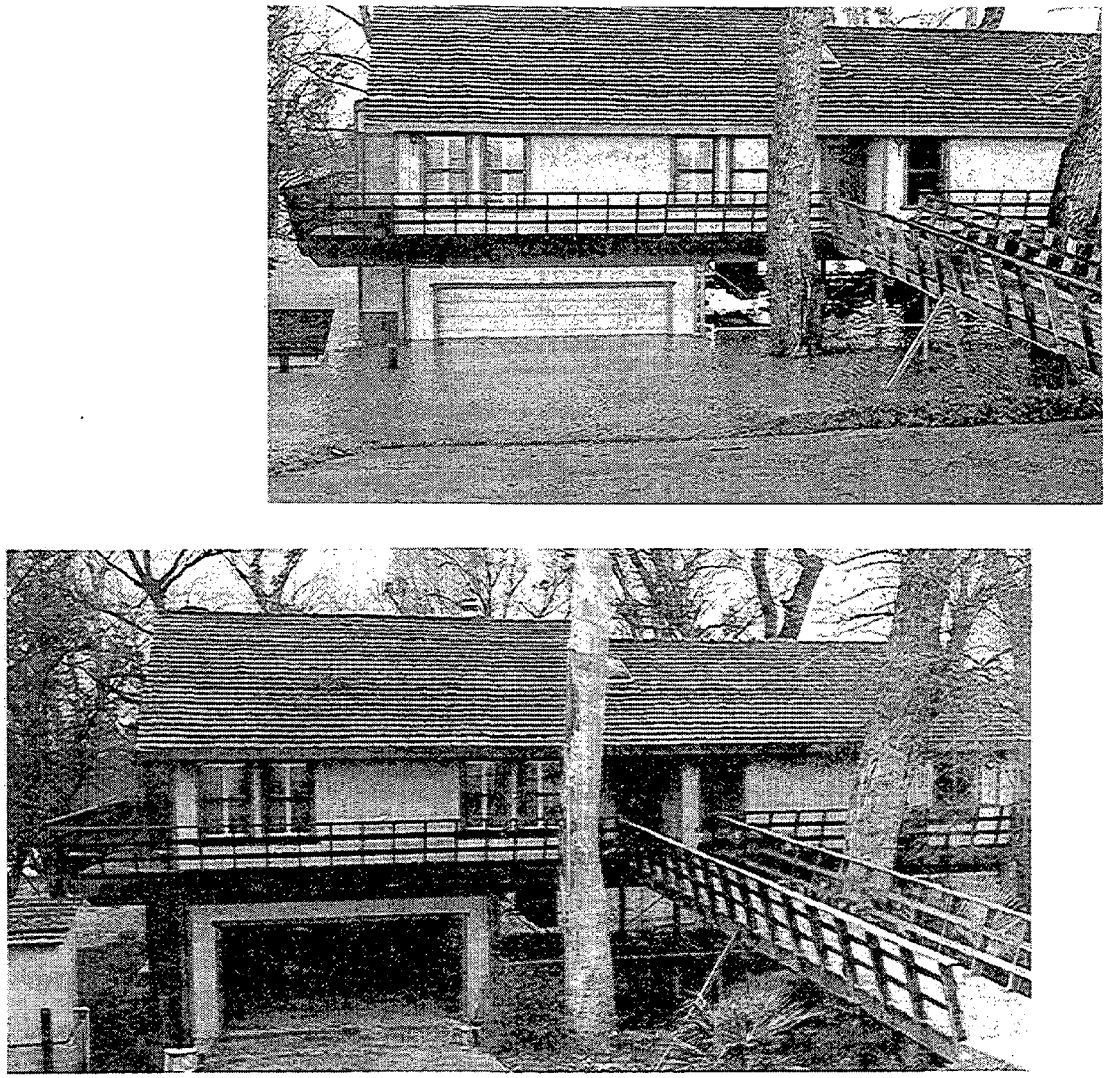


Figure A12. Two-story dwelling on steel posts

Wooden cube house raised using steel ribs and concrete pillars, Sacramento, California

This uniquely designed house (Figure A13) is of wooden frame construction and combines steel ribbing and 12-inch concrete pillars to raise it 12 feet above the Sacramento River flood plain. The pillars have No. 6 bars and No. 3 hoops at 12 inch center to center. The ribs are tied into the house with steel frame and bolted. All utilities, including electrical wires and plumbing, are contained in the large concrete pipes attached to the side of the dwelling. A steel stairway is the only access to the structure.

It should be noted that the owner has a second dwelling on the property, which is located at ground level. That structure has a concrete block wall surrounding it. Just prior to flooding, a gate is placed into the walkway opening to seal out floodwaters. The small amount of seepage through the wall and gate is pumped out by a sump pump operated during flooding.

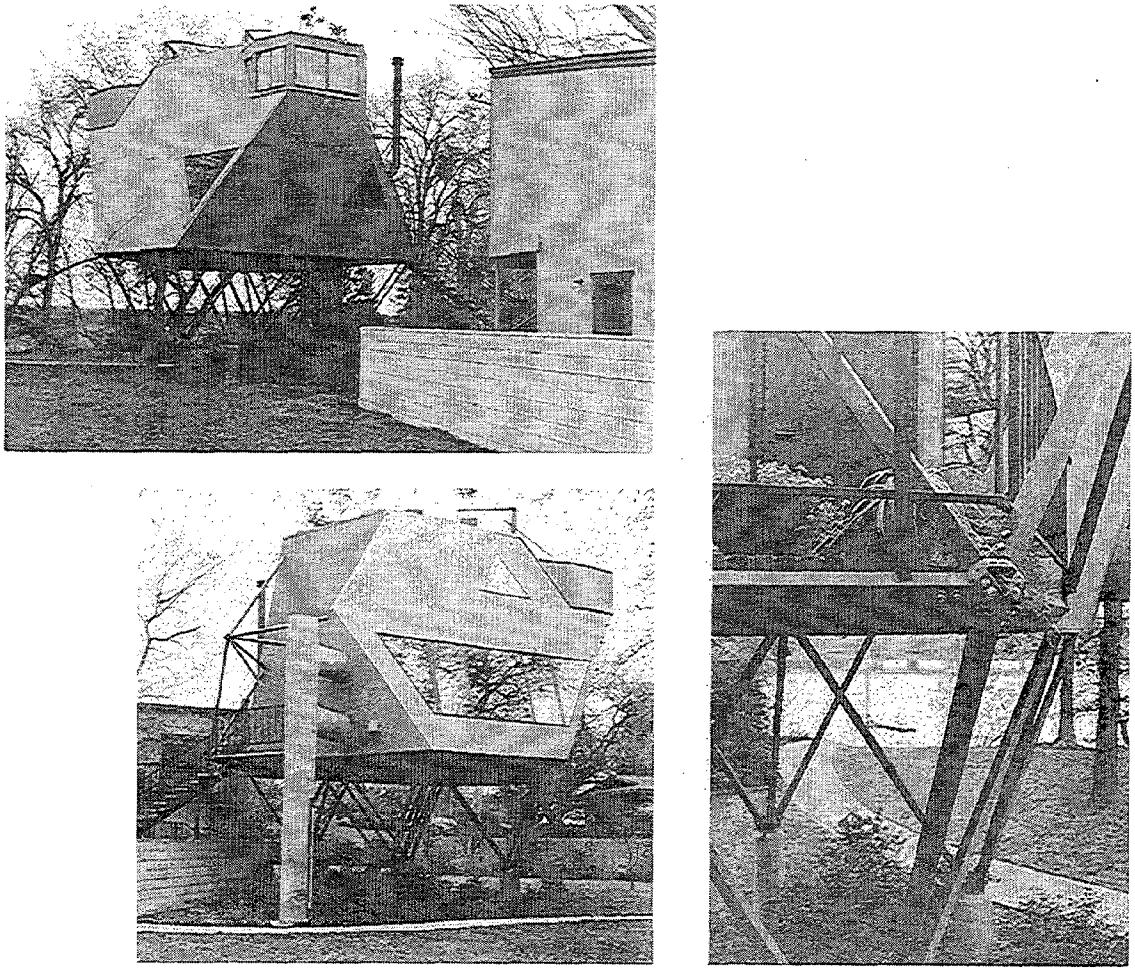
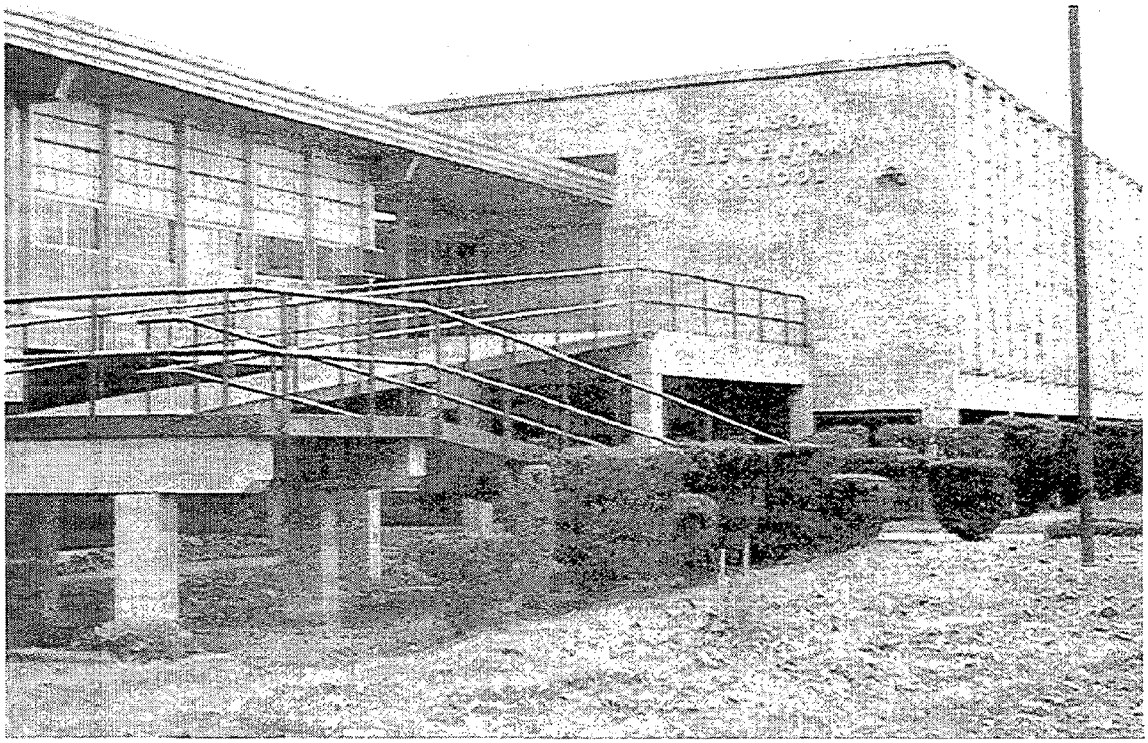


Figure A13. Wooden cube house raised with steel ribs and concrete pillars

Edison Elementary School elevated on concrete structural beams and columns, Jefferson County, Ohio

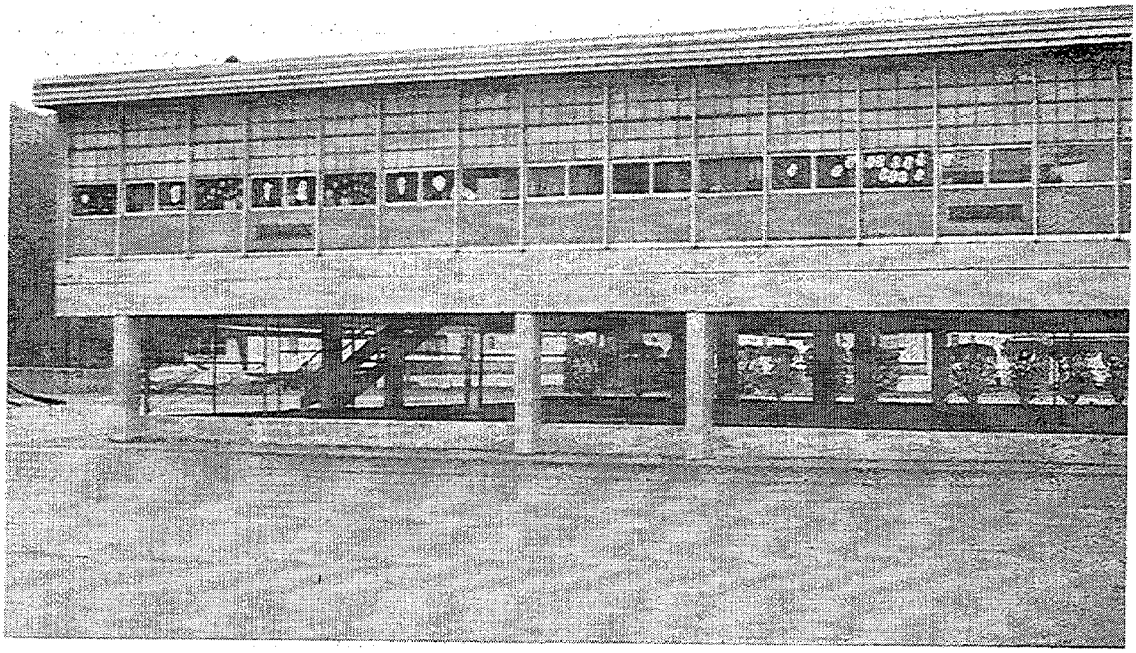
Edison Elementary School was constructed in 1961 on reinforced concrete piles, with the finished floor approximately 12 feet above ground level (Figure A14). The piles rest on concrete footings approximately 4 feet below ground level. The floor is constructed of prestressed concrete slabs.

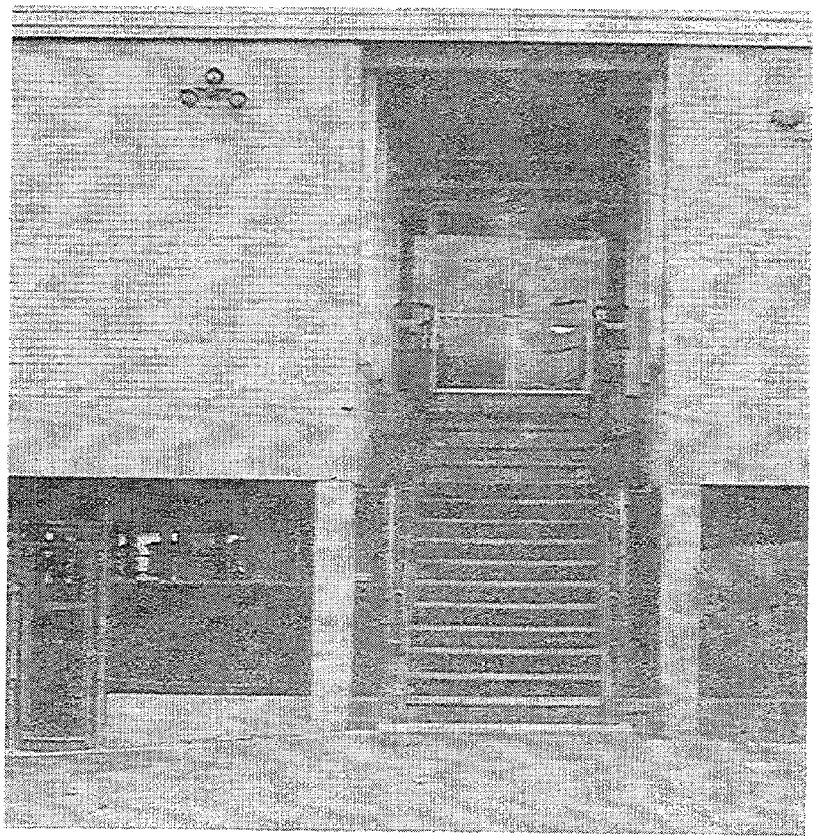
This area of Jefferson County is susceptible to backwater flooding from the Ohio River. The building's first floor is at the 500-year flood level, which approximates the March 1936 flood. The entire structure is raised, with the exception of a storage shed located below the finished floor. This shed is used to store maintenance equipment, such as lawn mowers, which could easily be removed prior to flooding. The school's heating and cooling are supplied by individual electric room units, all above the finished floor. A ramp leads from the ground level to the first floor. Outside stairways also permit access to and from the building. It is estimated that the school cost $500,000 to build, of which $75,000 was for design and construction in an elevated position. While the school property has flooded on several occasions, the school itself has remained dry and unthreatened.



Ramp leading to entrance.

Figure A14. School building elevated on concrete structural beams and columns





ABOVE: Flow-through area.

LEFT: Entrance and storage space.

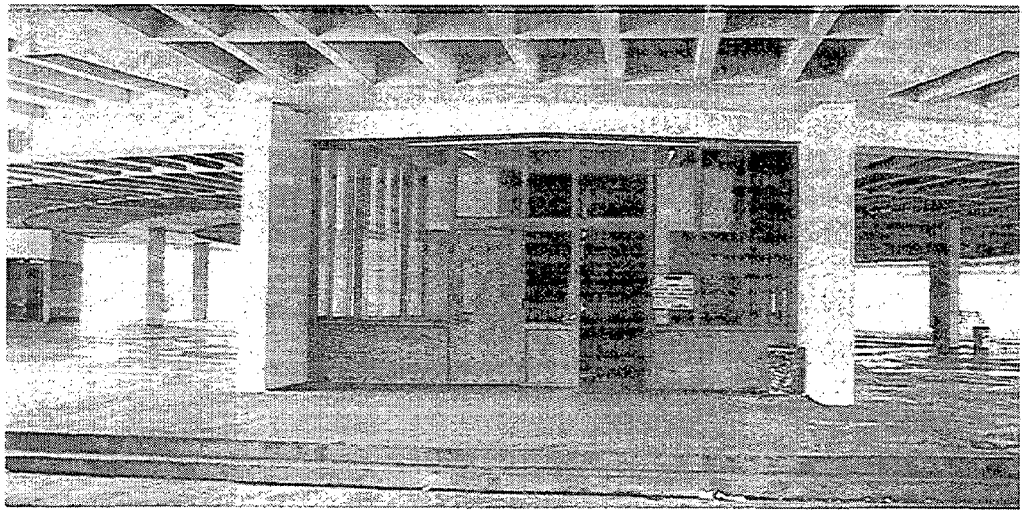
Figure A14.

Sebastian Roy Elementary School raised on concrete columns, Verret, Louisiana

The Sebastien Roy Elementary School in Verret, Louisiana, is subject to hurricane surges from both Lake Borgne and Breton Sound. Flooding has been known to reach depths of 7 feet (Hurricane Betsey, 1965) in the immediate area. The school is elevated approximately 10 feet above ground level by reinforced concrete columns. These columns rest on a reinforced concrete slab (Figure A15). The foundation characteristics are such that creosoted pilings were necessary to support the slab. Walls of the school itself are brick and concrete with metal panels for inside walls. The floor is also reinforced concrete.

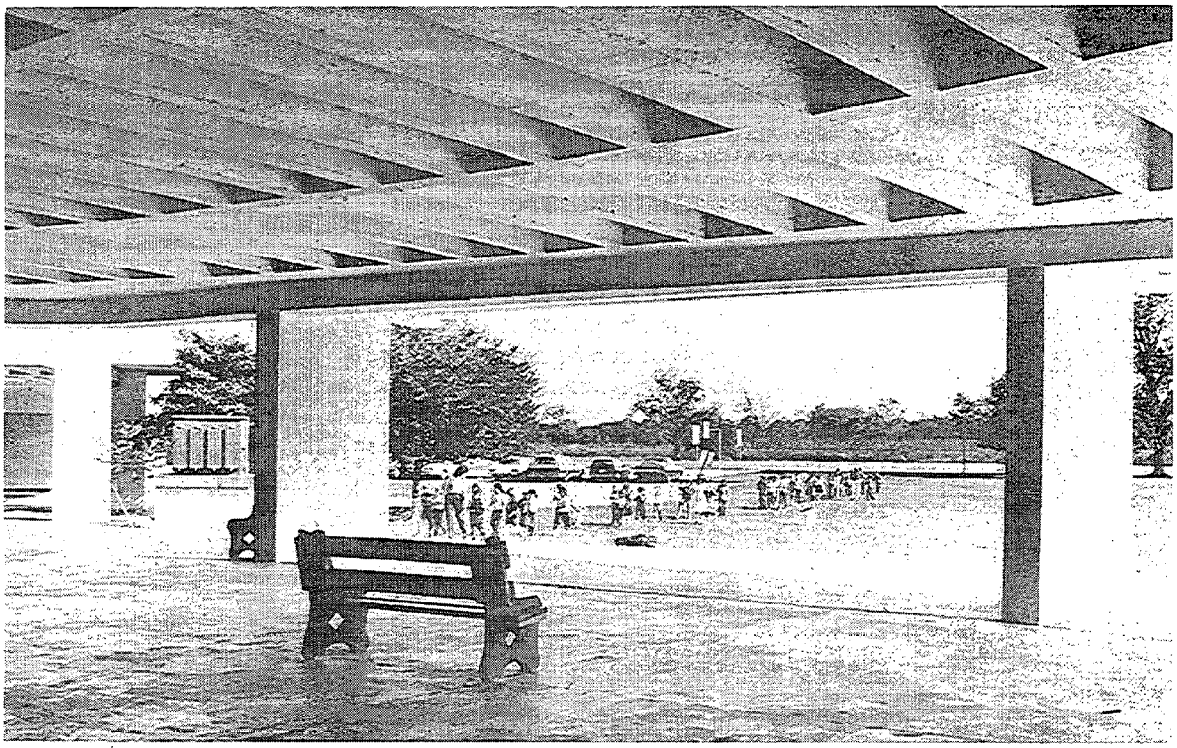
The school has an area of 59,760 square feet and was completed in 1968 at a cost of approximately $1.25 million. Heating and air conditioning units are located on the roof. The electric transformers are raised about 5 feet above ground on a concrete platform.

Full view looking north.

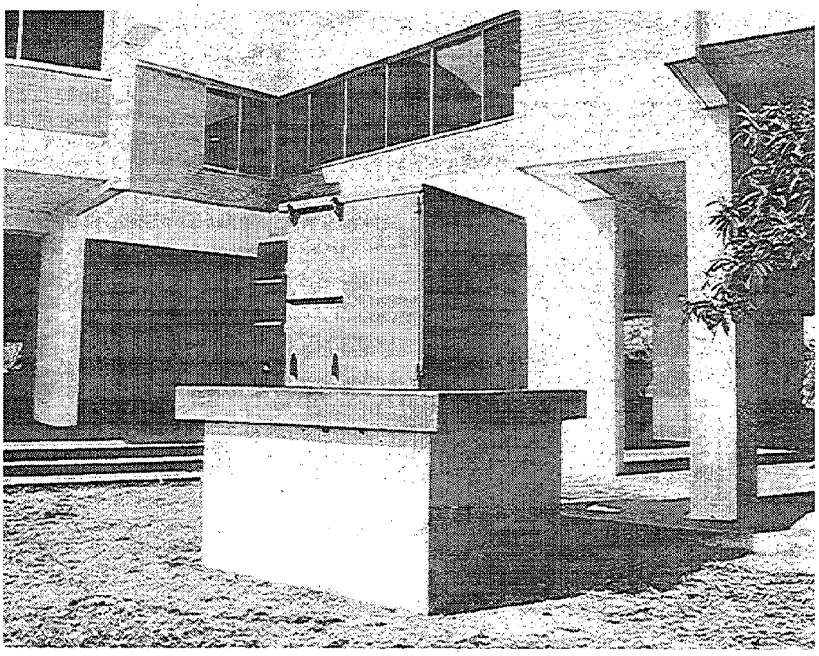


Main entrance to school.

Figure A15. School building raised on concrete columns.



Subfloor structure at school.



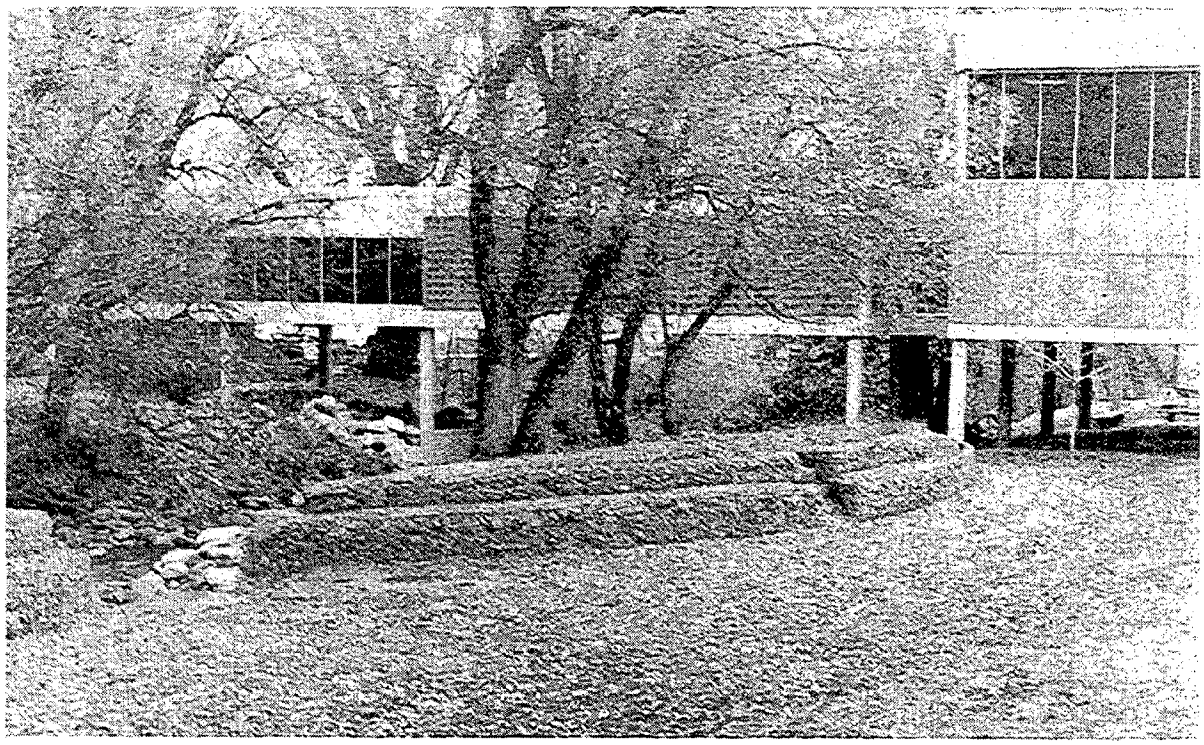
Elevated electrical main.

Figure A15.

City of Boulder library, raised on reinforced concrete piers, Boulder, Colorado

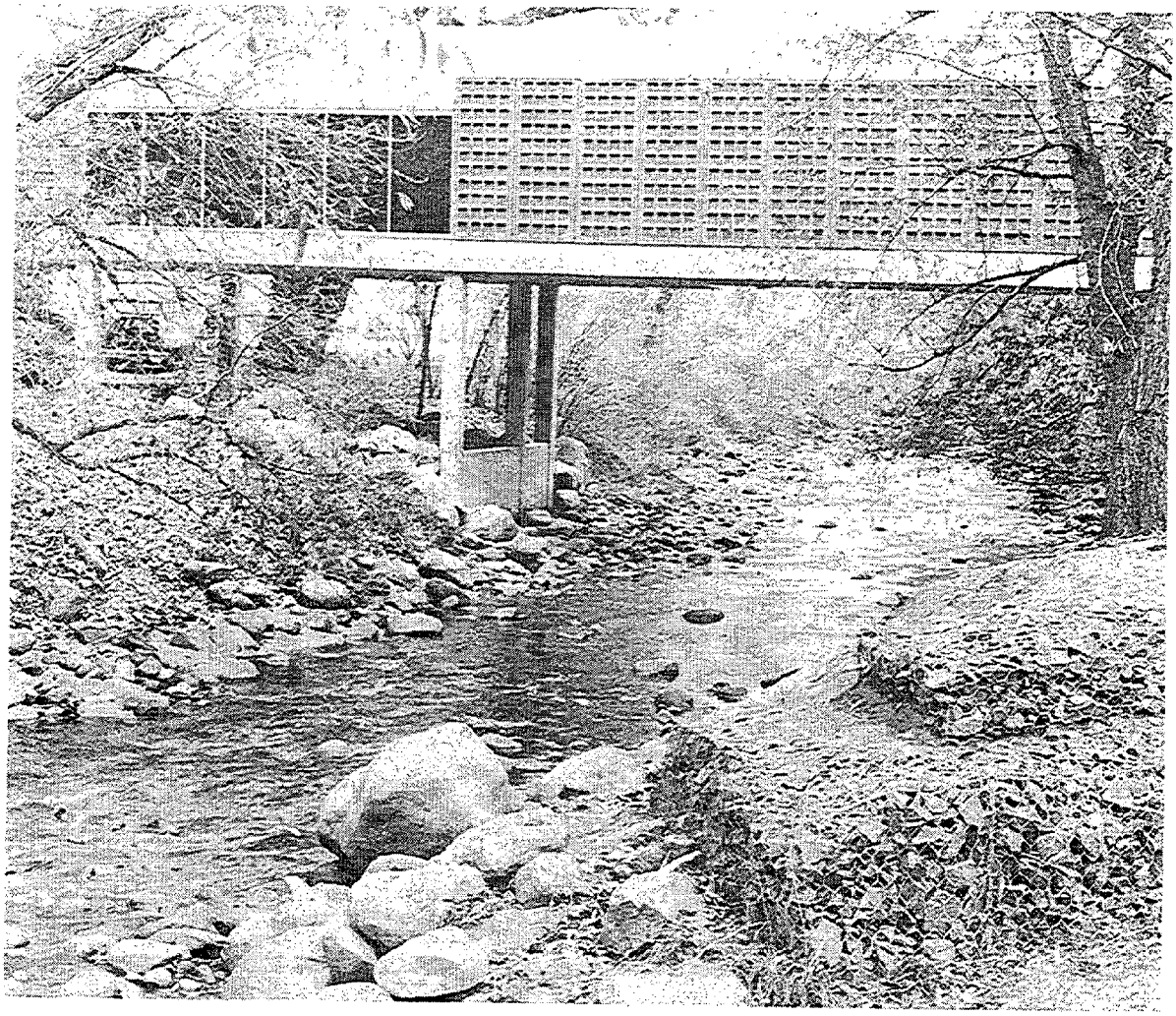
In 1974, the City of Boulder constructed a public library consisting of two buildings on opposite sides of Boulder Creek. The buildings are connected by a covered walkway (Figure A16). The terrain is such that the walkway and portions of the two buildings are raised 8 feet above the overbank on reinforced concrete piers. Photos of the structure indicate that the floor is made of reinforced concrete and the walls are precast.

The structure is both aesthetically pleasing and environmentally sound. The obstruction of the floodway is minimal. Flooding of Boulder Creek is of a flash nature, and very little can be done to prepare for a flood event. The design of the building requires literally no advance preparation. One possible problem with the location of the library is that column footings may be subject to erosion during severe floods due to the high velocities that are possible.



Good landscaping shows harmony with the building.

Figure A16. Two-building library raised on reinforced concrete piers



Boulder Creek flows under the building.

Figure A16.

Hager Hinge Company Hunting Lodge, raised on piers of concrete blocks, St. Charles County, Missouri

The Hager Hinge Company raised an existing hunting lodge in St. Charles County, Missouri, 8 feet above ground level following a Mississippi River flood in 1973. This represented an elevation higher than the 1973 flood. Since that time, the river, located about 1 mile from the lodge, has again flooded, putting as much as 2 feet of water on the property. While the building is elevated well above record flood heights, it is still 3 feet below the 100-year flood elevation. Duration of flooding for the area can be as long as a month or more.

The lodge itself is of wood frame construction. It was placed on a series of piers made of 16-inch-square by 8-inch-high concrete blocks; the piers rest on concrete footings (Figure A17). Cost to raise the structure (excluding cost of materials and labor to build the footings and piers) is estimated at $3000 to $4000.

It should be noted that an adjacent lodge was also raised. The lodge's fireplace and its foundation were raised, too.

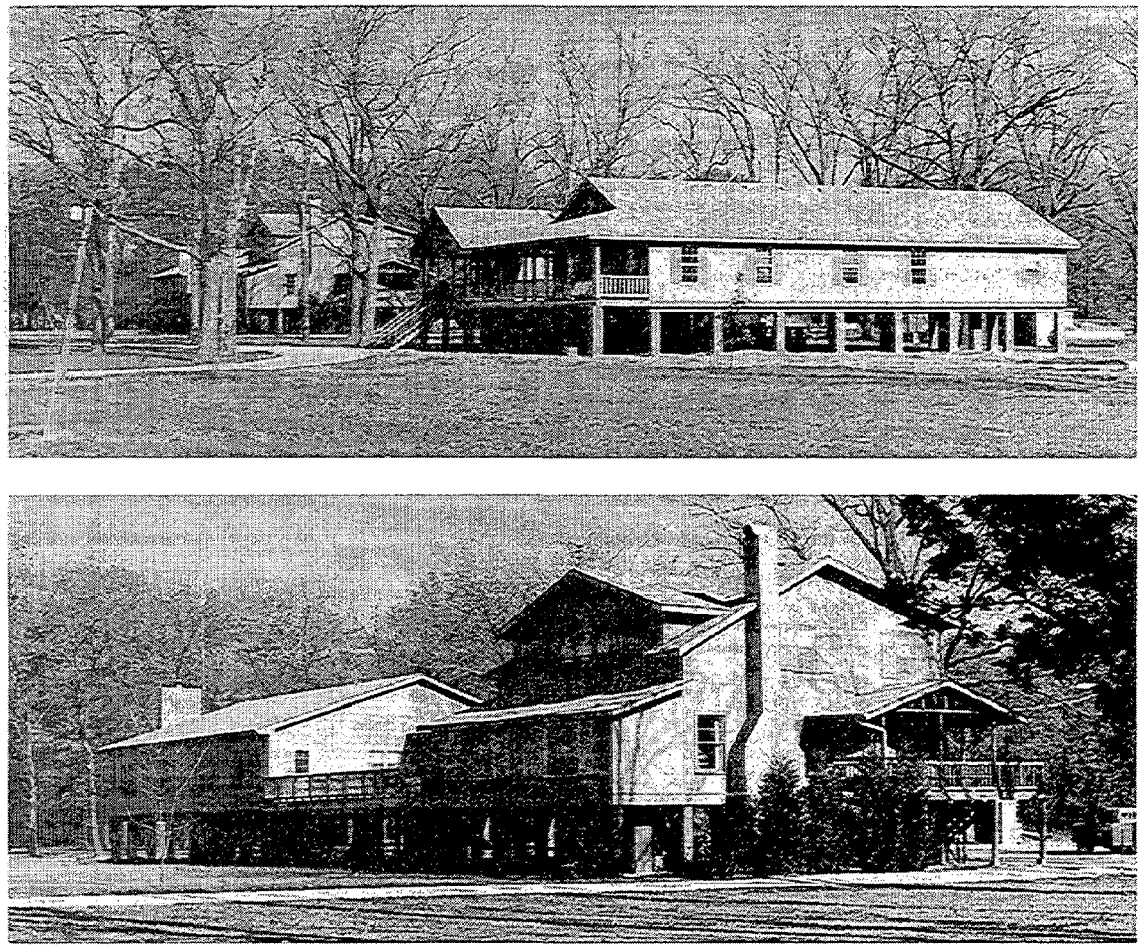


Figure A17. Hunting lodge raised on piers of concrete blocks

This commercial office building, completed in 1973, has a first-floor elevation of 63 feet, National Geodetic Vertical Datum (NGVD). It has a steel frame that is hung on four concrete columns. Exterior glass walls enclose the building, and a parking area exists beneath the raised building (Figure A18). Cost of construction was $274,000.

The 100-year flood elevation at this site is estimated to be 62 feet, NGVD. Since the building was completed, two 100-year floods on Little Bear Brook occurred, both in 1975 within 2 weeks of each other. The only damage sustained during the floods was an accumulation of mud on the parking lot. The owner indicated that, during the floods, floodwaters flowed freely beneath the building and no debris collected.

The Hillier Group office building raised on concrete corner columns, Princeton, New Jersey

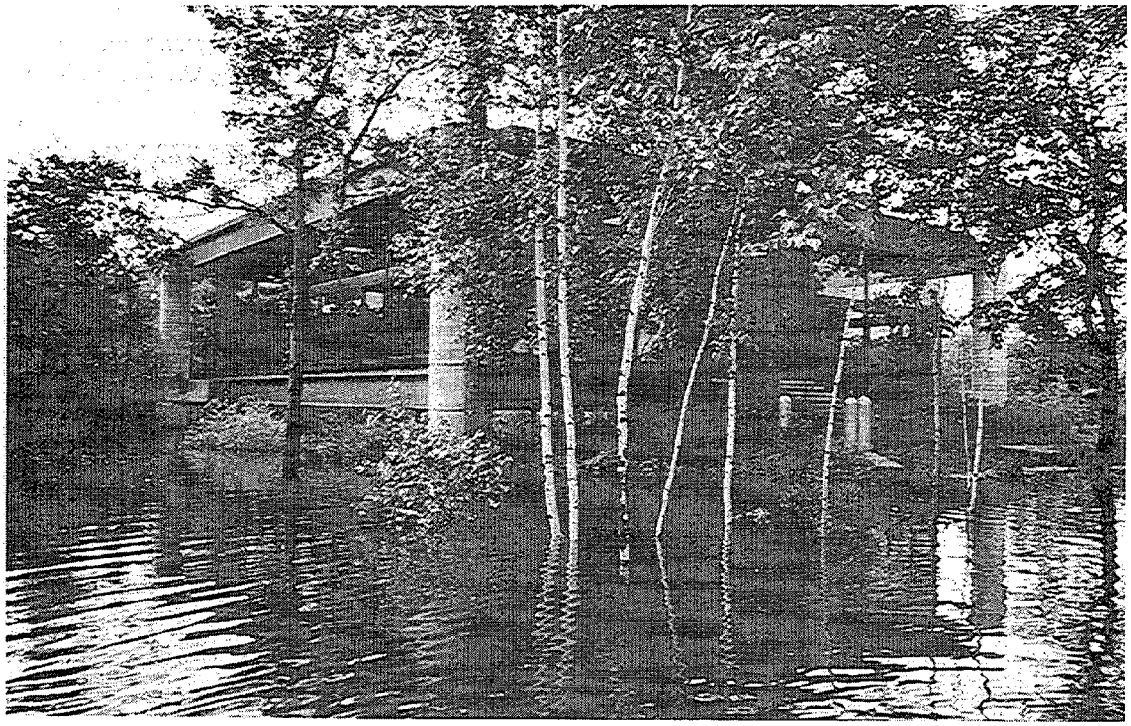


Figure A18. Office building raised on concrete corner columns

J. M. Huber Corporate Headquarters, raised on steel piles, Edison, New Jersey

This 11-story office building, shown under construction in 1983 (Figure A19), contains 200,000 square feet of space. Estimated cost of construction is $20 million. The structure has a steel frame with composite metal deck and is built directly over the South Branch Rahway River. Due to the poor bearing capacity of the soil and the location over the stream, the building's foundation is on steel piles that go down to bedrock. The first floor is supported 15 feet above the stream on steel columns encased between ground level and the first floor with concrete. Exterior walls are prefabricated tile panels with two-sided structural glazed windows.

In designing and constructing the office building, the client and the State of New Jersey required the following:

- Wetlands must be left virtually intact.
- Construction cannot substantially alter areas nor impede the stream.
- Parking for 800 vehicles must be provided in a flood-free area.
- Undisturbed views of the environment must be provided.

The design solution realigned the stream encroachment line by means of equal conveyance and not raising the stream height by more than 2.4 inches during flooding.

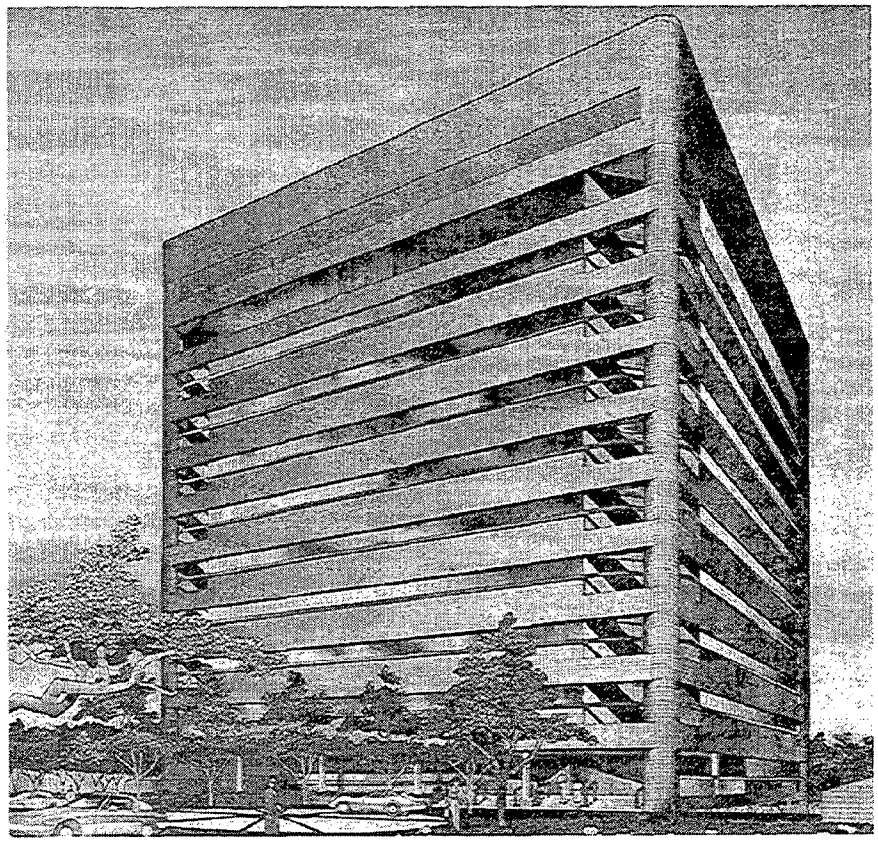


Figure A19. Artist's conception of office building raised on street piles.

The building's main entrance is on the north facade where a retaining wall was built. The retaining wall runs parallel and is on the stream encroachment line, with the rest of the facility supported on structural stilts over the floodway.

The underside of the first-floor structure allows for a 5-foot freeboard area between it and the 100-year flood height.

The parking deck on grade level was placed on fill by the equal conveyance method, with a final elevation of 41.0 feet. This allowed flood-free parking.

To protect the environmentally sensitive site, reduce time, and increase cost efficiency, the entire prefabricated tile facade was placed using helicopters.

The South Branch Rahway River, normally 8 feet wide, widens to more than 300 feet during flood stage, mainly due to the amount of flow into upstream areas and restriction of downstream flow. Flooding has averaged three to five times a year, and flood duration is for 1 to 2 days.

During construction the site was flooded several times south of the new stream encroachment line, but construction has not been hindered.

Building under construction.

Figure A19.

Fill

One-story single-family dwelling raised on fill, Kauai, Hawaii

This house, which is between 2000 and 2400 square feet in size, was built in 1979 on elevated fill. The photograph presented as Figure A20 shows the house under construction. It was built on a concrete slab. The fill that was used is a residual/tropical soil with a fill height ranging from 0.0 to 4.0 feet. One side of the lot ends with a vertical concrete block wall; the other side blends into the natural ground elevation. The fill was put into place prior to construction of the house. It is estimated that 540 cubic yards of material was used to elevate the house at a cost of $6500 (1982 dollars). The side slopes are covered with grass to prevent erosion or slippage.

Eight-story apartment buildings on fill with ground-level parking, Omaha, Nebraska

Four identical apartment buildings constructed in 1976 were placed on fill to raise them above the 500-year flood level. Each building measures 150 in length, 50 feet in width, and 80 feet in height and is made of prestressed concrete and steel. Exterior walls are brick. Each building is situated about 150 feet from Big Papillion Creek, which can flood simply from a heavy thunderstorm. The last major flood occurred in 1964 and lasted less than 1 day.

The ground level below each structure is used for open-ended parking stalls (Figure A21). Apartment units are 10 feet above ground, thus providing flood protection greater than the 500-year level. A small lobby is located on the ground level of each unit. On the opposite side of the buildings from Big Papillion Creek is an artificial lake. The ground floor on that side is below an embankment. Thus, the parking stalls extend only partway beneath the buildings.

The cost of including flood proofing in the design and construction of each building is estimated to be $150,000. This is relatively inexpensive considering each building is estimated to have a market value of $2 million.

Figure A20. One-story dwelling raised on fill

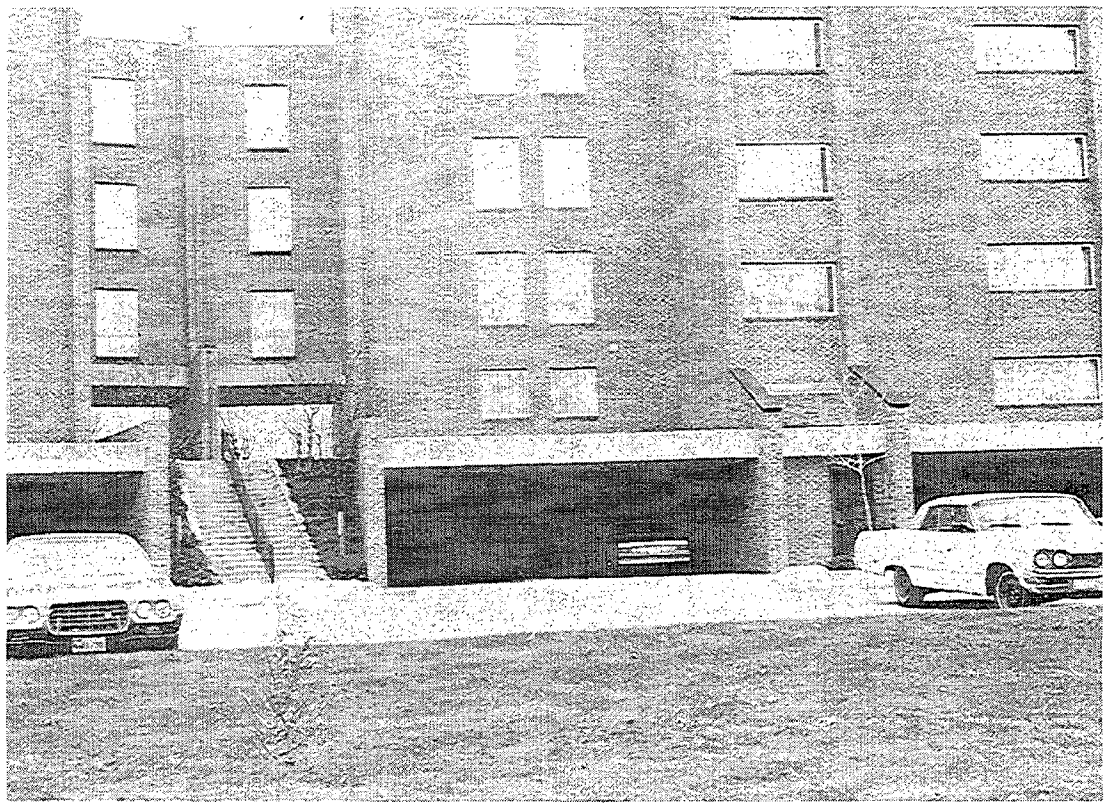


Figure A21. Multistory apartment buildings on fill with ground-level parking

Roller-skating rink raised on fill, Lock Haven, Pennsylvania

Built in 1978, this one-story roller-skating rink was constructed on compacted fill in order to raise it above the 100-year flood plain (Figure A22). Lock Haven is subject to periodic flooding from both the West Branch of the Susquehanna River and Bald Eagle Creek, a tributary to the West Branch. Earthfill was placed at the site in 8-inch lifts and compacted to 90 percent. Fill was placed to a maximum height of 10 feet above grade.

The foundation of the skating rink is a continuous concrete footer, 24 inches wide and 12 inches deep, enlarged to 5-foot by 5-inch pads under structural steel columns. Footers bear on the compacted earthfill. Foundation walls are 12-inch concrete block. The floor is a reinforced concrete slab on grade tied to the foundation walls by steel reinforcing bars. First-floor walls are sheet metal over a structural steel frame. Access to the structure is by way of a ramp. The cost to flood proof the structure is estimated to be $30,000, including the cost of the compacted fill and enlarged column pads.

Since the rink was constructed, no flooding has been experienced in the vicinity of the building. The owner, however, is satisfied with the structure and is confident it will remain dry during most floods.

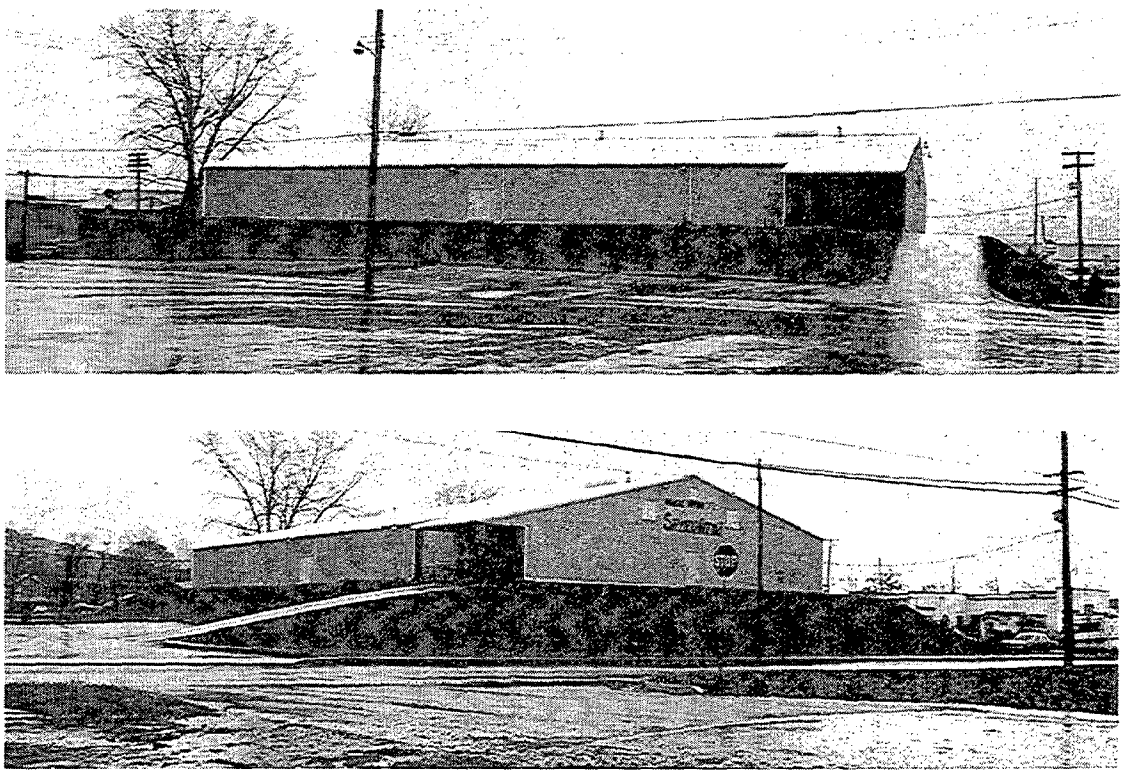


Figure A22. Roller-skating rink raised on fill

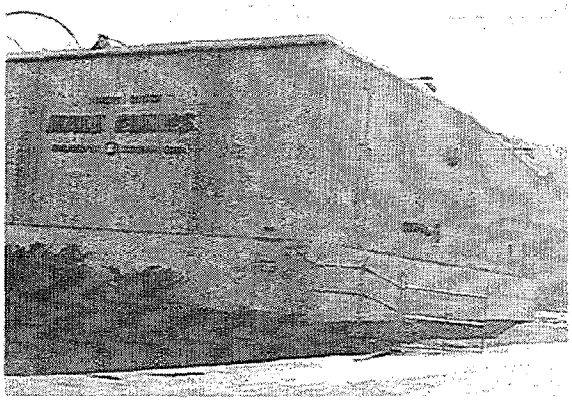
One-story industrial plant built on earthfill, Conshohocken, Pennsylvania

This one-story manufacturing plant, located outside of Philadelphia, houses a foundry operation and machinery used in the production of pump equipment. It was built in 1974 on 5 feet of fill. The steel frame structure is supported by concrete walls with perimeter pilings. A concrete slab serves as the floor, and corrugated metal panels constitute the walls of the building (Figure A23). No basement exists. Some manufacturing equipment within the structure, including drill presses and milling machines, have been raised as added protection from flooding. During floods, two exterior doorways are sealed from the inside by placing plastic sheets over the doors and piling sand from the foundry operation on top. This method of sealing the doors has not been tested by the company.

The 25,000-square-foot plant is located in the Schuylkill River flood plain. The last major flood occurred in June 1972, prior to construction of the plant. Since then the parking lot has been flooded several times to a depth of as much as 4 feet, for a duration of several hours.

The plant itself has never flooded, although floodwaters have come within inches of the door. Had the building not been raised, it would have flooded, and damage to the equipment would have been sustained.

It is estimated that the cost to raise the structure on fill was $10,000. The plant manager believes this cost has been recouped through savings in flood damage repairs to equipment and other contents.



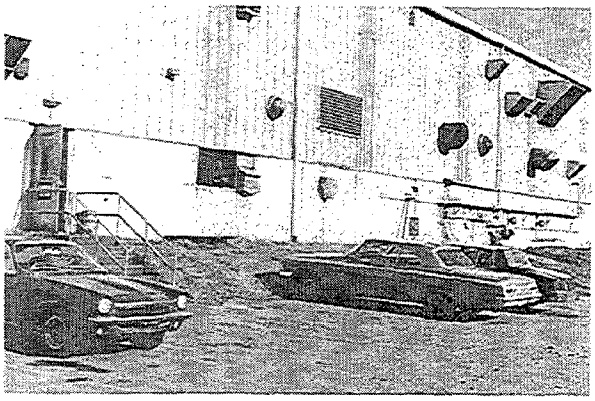


Figure A23. One-story industrial plant built on earthfill

Two-story high school elevated on columns and fill, Bloomsburg, Pennsylvania

The Bloomsburg High School, built in 1961 near the Susquehanna River, contains 45 classrooms, an auditorium, gymnasium, cafeteria, and offices. The structure is raised on fill approximately 10 feet above grade, with the exception of the auditorium, which is at ground level. The main floor of the school is a reinforced concrete slab bearing on a field of caissons (columns). These caissons were excavated, formed, and placed. Walls are masonry with a brick exterior. Earthfill was placed around the perimeter of the building and slopes off to low-lying areas that are used as parking lots and athletic fields (Figure A24).

The first-floor design elevation was based on the 1936 flood, which was the flood of record at the time of construction. Since 1961, two major floods have occurred—in June 1972 and September 1975. Neither flood reached the level of the first floor; however, the 1972 flood (Tropical Storm Agnes) came within 4 feet of the first floor. During that flood, hydrostatic pressure from saturation of the earthfill caused a wall to collapse, inundating the gymnasium. Future floods may continue to present a problem to the structure by saturating the apparently pervious earthfill. Thus, the auditorium may continue to be susceptible to inundation from seepage.

The school district estimates the cost of flood proofing the structure to be about $800,000. The technique has proven effective in keeping the first or main floor of the structure dry. The problem with the auditorium will likely persist, however. The steep-sloped berms on the sides and rear of the school also present a problem for both maintenance of the grounds and access to the school. The elevation of the front of the building is such that the school has never been isolated from high ground during a major flood event.

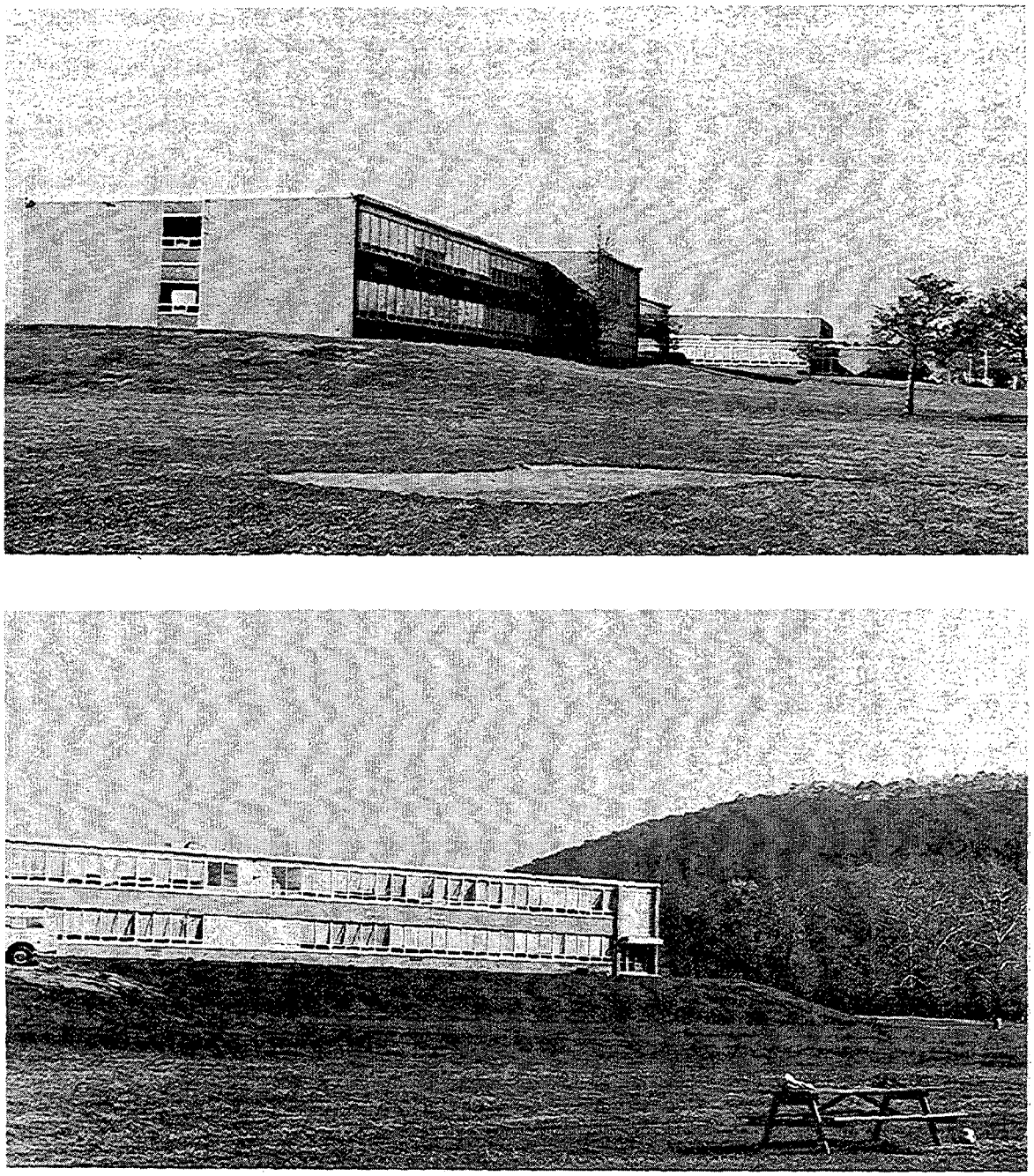


Figure A24. School building elevated on columns and fill

Commercial offices elevated on earthfill, Gresham, Oregon

Two one-story commercial office buildings were constructed on fill material to elevate them from flooding from Fairview Creek (Figure A25). Approximately 36,000 cubic yards of fill material, primarily gravel, was excavated from the adjacent flood plain and compacted to a depth of 3 to 4 feet. As a result, a pond was created between the creek and the buildings. Total area raised is approximately 4 acres, including the structures and parking areas. Access to the facility is from the main road, which remains flood free during flood events on Fairview Creek. Cost of raising the structure on fill is estimated to be $36,000.

Flooding on Fairview Creek results nearly every winter due to a constrictive culvert at a downstream road crossing. Flood heights are controlled by the weir effect of the road crest. Only "approximate area" coverage under the National Flood Insurance Program was available; consequently, the city permitted the development based on elevating floor levels above the controlling road crest.

The office buildings were completed about October 1979. The highest flood level since then occurred in January 1980, at which time water crested about 8 inches below the top of the fill and receded in a matter of hours. This flood represented about a 10-year event.

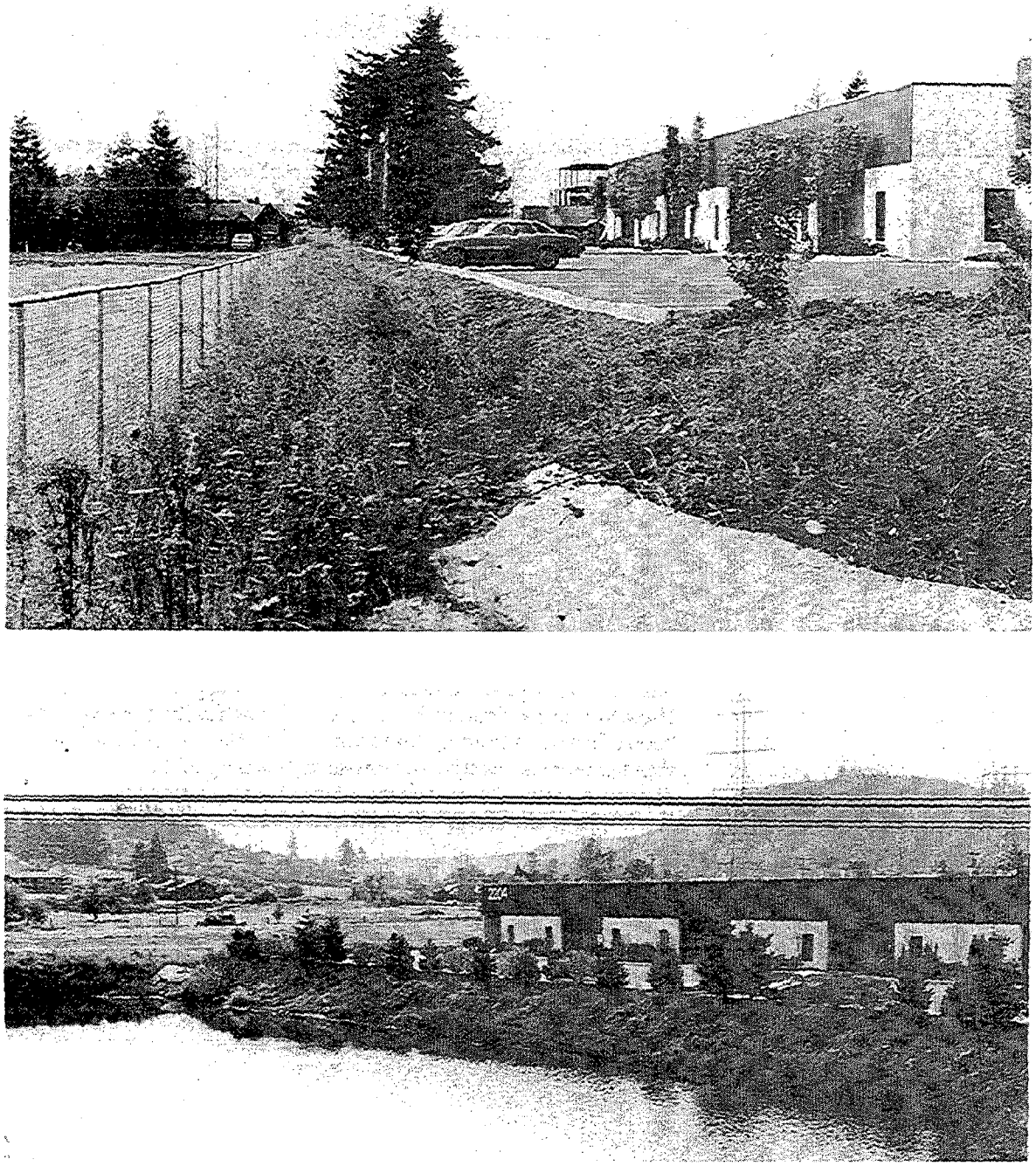


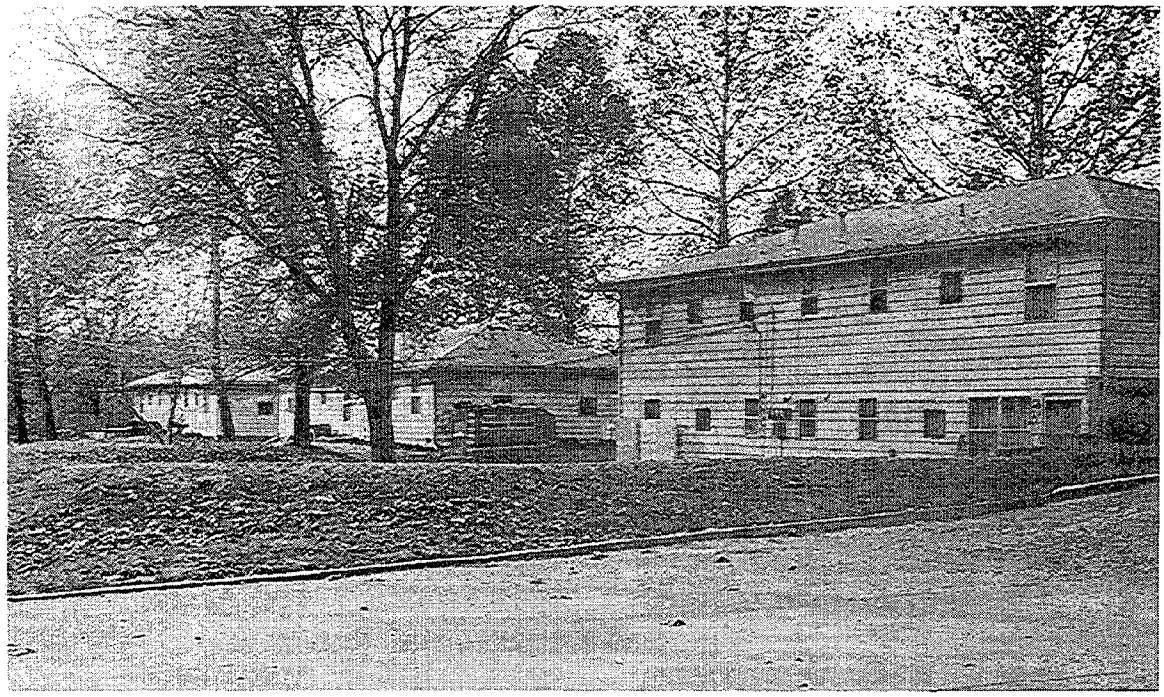
Figure A25. Commercial building elevated on earthfill

Levees and floodwalls

Small apartment building with ring levee, Kansas City, Missouri

This building, which was originally a single-family house but later converted to a multiunit apartment house, was built adjacent to similar structures along Line Creek, a small stream in Kansas City which floods frequently. The foundation of the structure is poured concrete, and the walls and floors are of wood-frame construction. The basement of the building serves as an apartment unit. When constructed during the 1970s, the building was unprotected from flooding. Later, an earthen levee was built on the streamside of the apartment house and tied into high ground near the front of the structure. The photographs shown in Figure A26 provide an idea of the height and slope of the levee. Height varies from 2 to 4 feet above the existing ground level. The levee is covered with grass to prevent erosion. A 6-inch pipe with a flap gate on the streamside serves as a gravity drain for interior ponded runoff. Flooding experience has shown this interior drainage system to work well.

Major floods occurred in 1974, 1975, 1977, and 1982. Duration of flooding is usually short, lasting from 2 to 4 hours, but depth can reach 15 to 20 feet above the channel flowline. During the 1982 flood, the levee was overtopped, resulting in the basement unit being inundated by about 4 feet of floodwater. However, during minor floods that occur annually, the levee has been effective in keeping floodwaters out. The owner believes that the levee is effective for low-level flooding up to approximately a 10-year event, before being overtopped. Estimates of the cost of construction of the levee were not available.



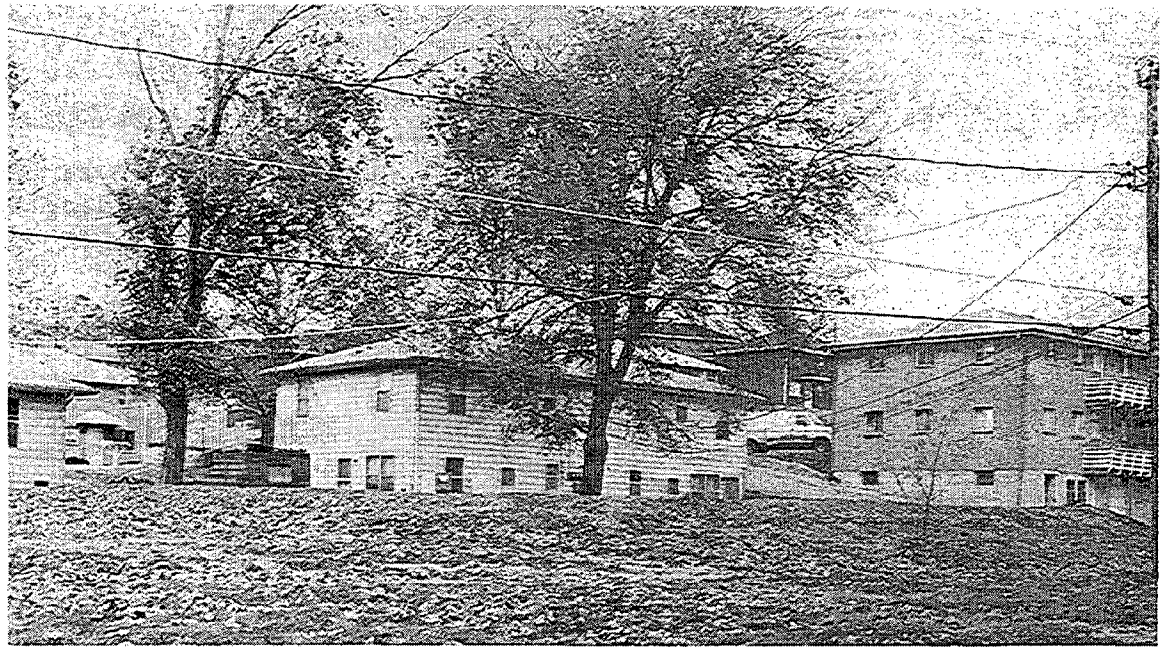
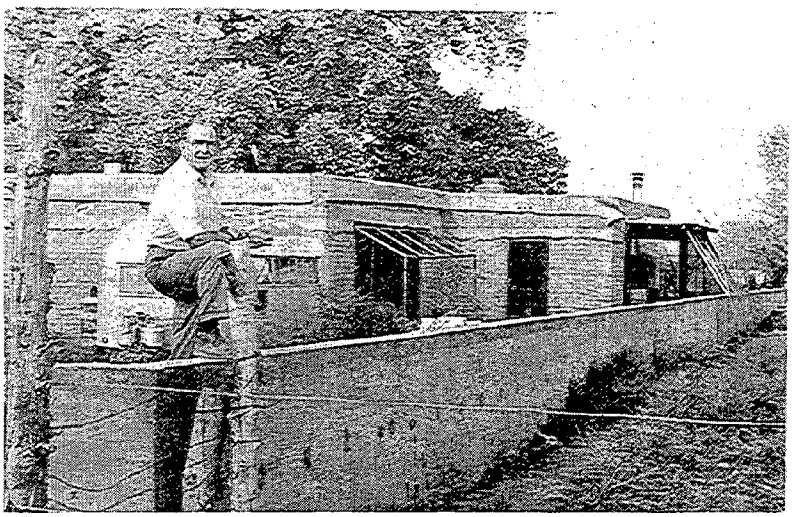


Figure A26. Apartment building with ring levee

Single-family house with concrete levee retaining wall, Corrales, New Mexico

The owners of this house had a reinforced concrete levee retaining wall (Figure A27) built around their house in 1978 to protect the structure from flooding from both the Rio Grande and Arroyo de las Montoyas. Cost of construction is estimated to be $11,000. The wall is rectangular in shape, approximately 120 feet wide and 200 feet long. Height varies from 1.5 feet to 3.5 feet, depending on ground elevation. Access to the house is by means of both an earthen ramp built over the wall for vehicles and by wooden steps. There are no provisions for handling interior drainage, although a gasoline-driven pump has been recommended by the Corps of Engineers.

While the levee retaining wall has never been tested, the owner estimates it will be effective against a 100-year flood depth of up to 2 feet.



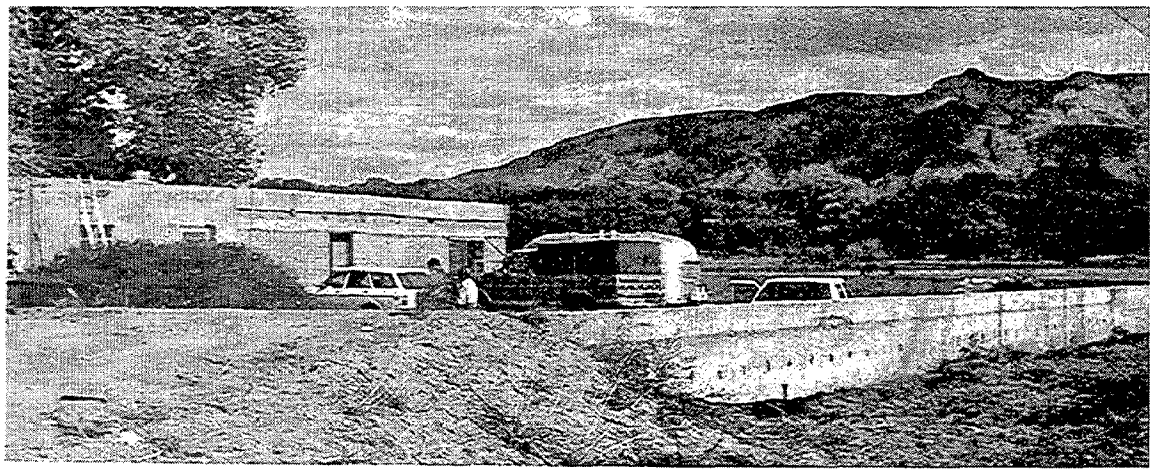


Figure A27. Single-family dwelling with concrete levee retaining wall

A concrete retaining wall encloses this house and yard on three sides to protect it from flooding from the Sacramento River. The wall is 5 feet high and 6 inches thick and approximately 300 feet long. The property is accessible from the levee road which is above flood level. The first floor of the house is approximately at the same level as the road. Cost of construction of the flood wall is estimated to be $10,000. The photographs presented in Figure A28 show the structure before and during flooding.

Residential two-story structure with concrete and concrete block retaining wall, Sacramento, California

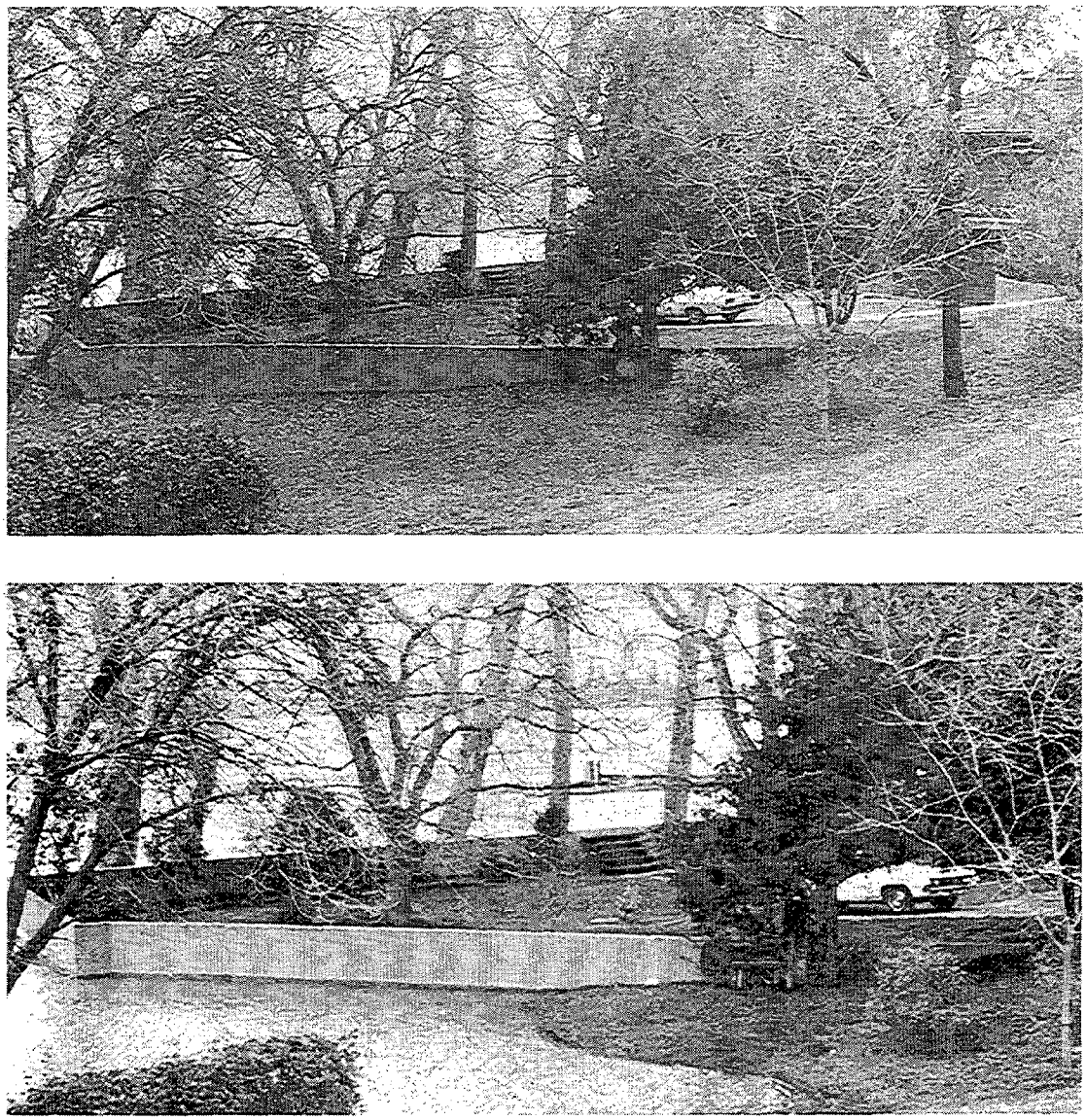


Figure A28 Two-story residence with concrete and concrete block retaining wall

Single-family structure with earthen levee, Yazoo River, Mississippi

This residential structure, built in 1968, is located in the Yazoo River backwater area of Mississippi where flooding can last up to 60 days and reach 6 feet in depth. Flood warning times, however, can range from 10-21 days in advance of flooding.

In 1973 the owner of the house and surrounding property built the first levee, which failed during the 1973 flood due to inadequate height. In 1974, a second, higher levee was constructed at an estimated cost of $6000. This levee surrounds the house on all sides, is 36 feet wide at the base, and 12 feet wide at the crown. The front levee is graded down to a height of about 4 feet during flood-free periods to allow access to the property. During flood periods, this front levee would require about 12 hours' construction time to rebuild.

The present levee was effective during both the 1974 and 1975 floods. Two gasoline-operated sump pumps handle interior drainage. An aerial photo of the house and surrounding levee is shown in Figure A29.

In an agricultural area where reliable crest information can be provided, where there is access to equipment for levee construction, and where sufficient area exists to build a permanent levee, this has proven to be an effective flood proofing technique.

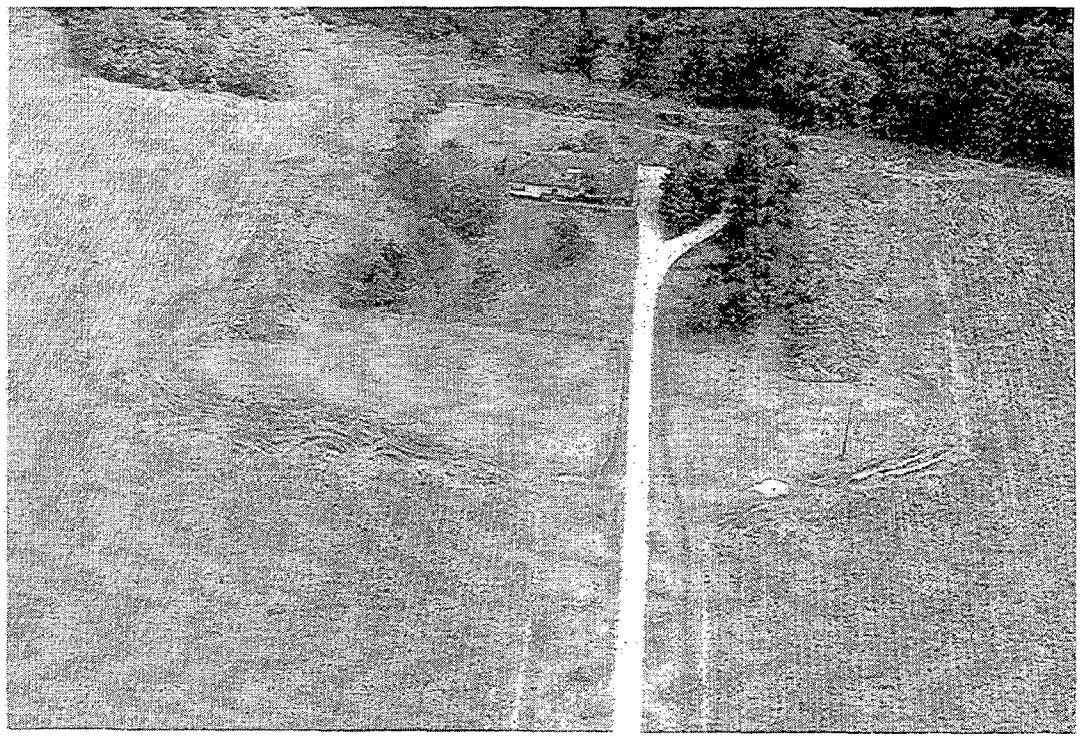


Figure A29. Residential structure with earthen levee

One story, single-family residence with reinforced concrete floodwall, Jefferson Parish, Louisiana

This one-story residence was built in 1950 on a reinforced concrete slab at an estimated elevation of 3.5 feet above National Geodetic Vertical Datum (NGVD). The structure is a three-bedroom, brick-veneer on wood frame house. The house is located in a flood plain in an area where the estimated 100-year flood elevation is 4.5 feet above NGVD. Thus, flooding is shallow. However, due to the ponding characteristics of the area, flooding is frequent, usually occurring anytime rainfall exceeds 1 inch.

The flood proofing system is a reinforced concrete floodwall that is 10 inches thick and rises 26 inches above ground (Figure A30). Eight inches of the floodwall is below ground. The wall completely surrounds both the residence and the backyard. It is 50.5 feet across the front and back, and 85 feet on either side. There is one opening in front of the garage that is 10.9 feet wide. Closure of this opening during a flood event is accomplished by the use of two self-cured pine 2- by 10-inch boards. The boards are rounded on the edges that fit into the slots in the wall and driveway. The mating edges of the boards have been milled so that the gap between them is very small. Three electric 1.5-inch-diameter discharge submersible electric pumps and one gasoline-driven pump discharge rainwater and seepage from the inside of the floodwalls. The primary pumps are the electric ones; the gasoline engine is used in the event of a power failure and to supplement the electric pumps. The gutter system on the house has been modified to discharge rainwater from the roof to the front lawn.

BELOW: Front of house and floodwall. Notice brick veneer on front of concrete floodwall. Side bricks are painted. Front bricks are real.

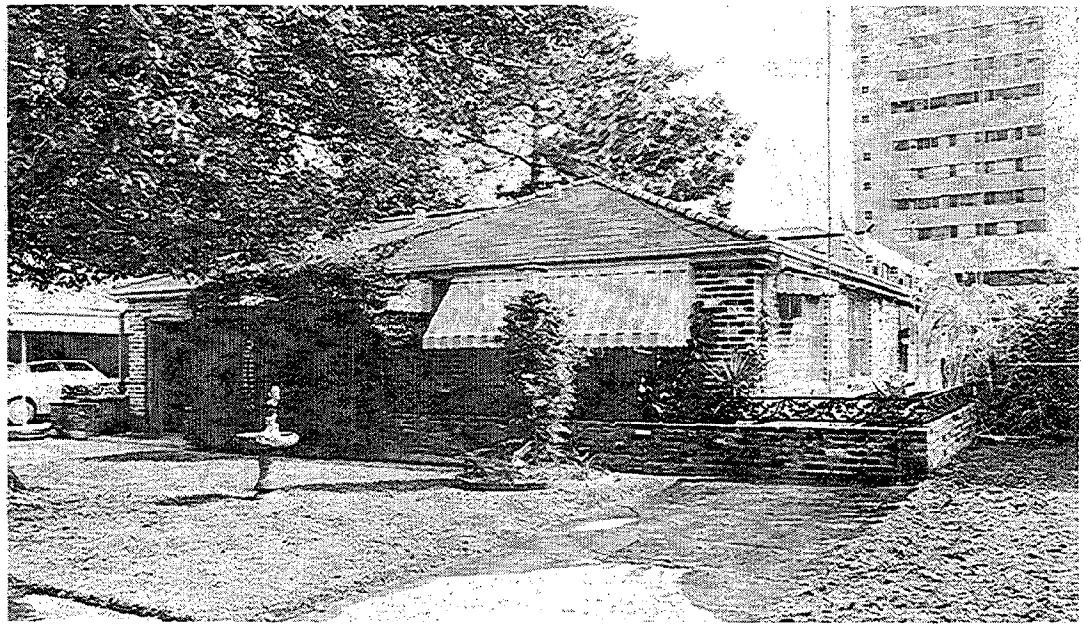
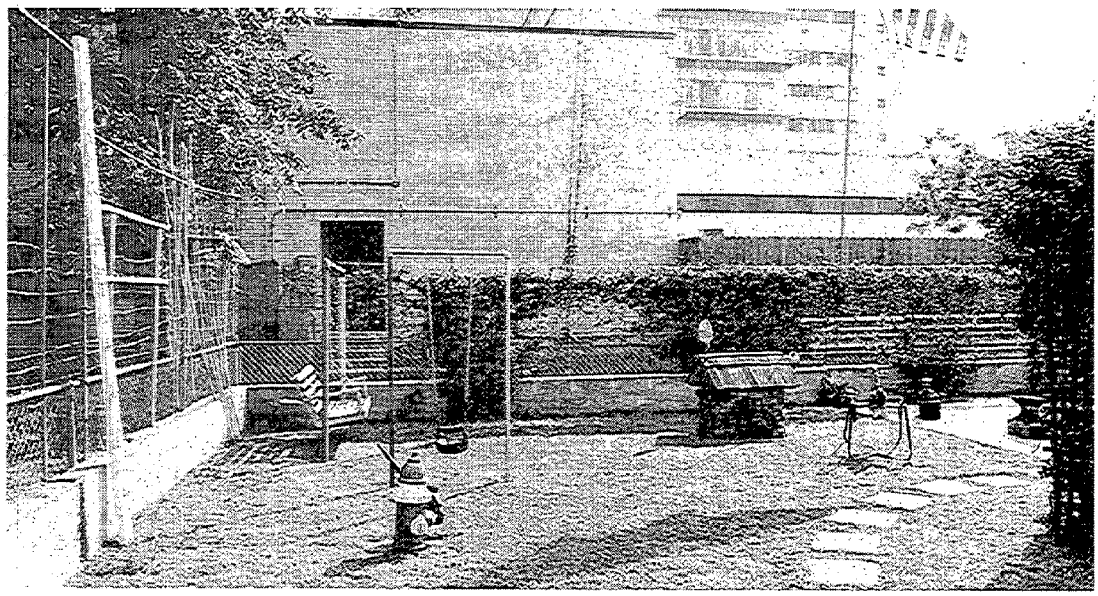
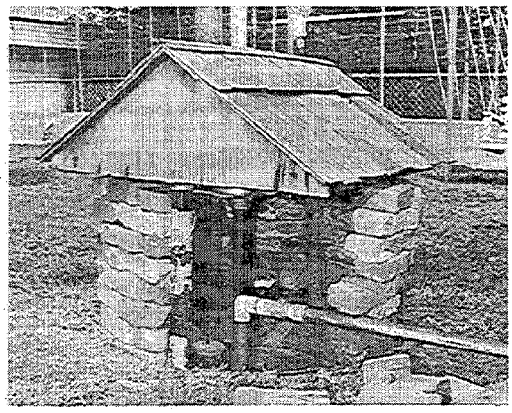


Figure A30. Residence with reinforced concrete floodwall





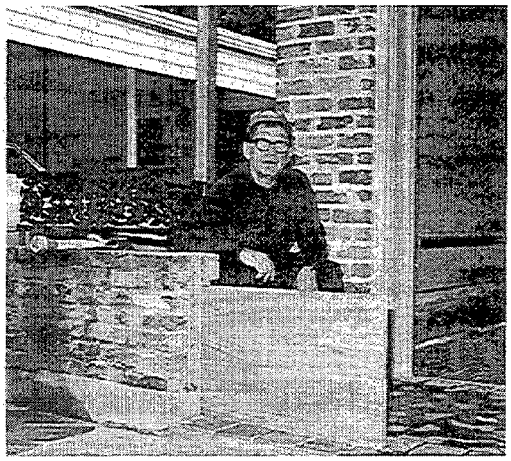


Figure A30.

ABOVE: Floodwall around back yard. Note pump house near flag.

LEFT: Rear view of pump house.

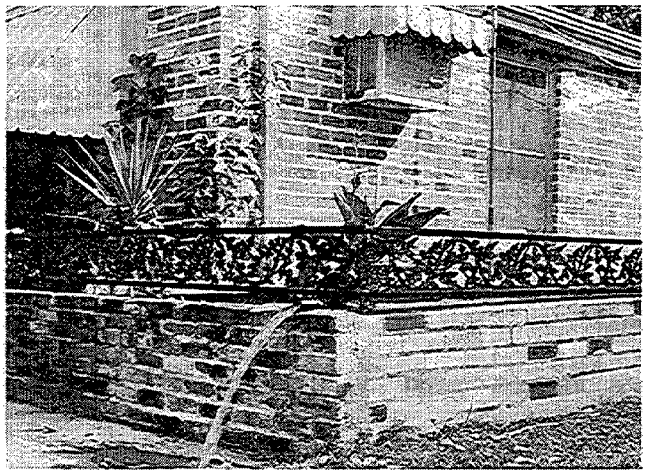
BELOW: Boards fit into slot. Actual boards are inside garage in background.

When street flooding occurs in this area, floodwaters enter the sewerage system. The sewerage system has a cleanout vent in the backyard. Therefore, when the street starts to flood, the owner inserts a rubber ball in the opening and forces it into place. The rubber ball is enough to stop floodwaters from entering the backyard through the cleanout vent. The owner has not installed a shutoff valve in the sewerage system because the floodwall would be overtopped before either the bathtub or commodes would be overtopped. Therefore, the need for a shutoff valve is not warranted.

In the event of flooding in the area, the owner installs the boards across the driveway opening. A small amount of fine sawdust is sprinkled in front of the boards on the flood side. As water seeps through the area between the concrete and wood, it draws the sawdust in. The boards and sawdust then become saturated, expand, and effectively seal off the opening. As floodwaters rise near the top of the first board, the owner then adds the second board. As the water seeps between the boards, they become saturated and seal off the opening between the two boards. The three electrical pumps operate automatically when their sumps fill with water. Thus, once the boards are installed, the system operates automatically.

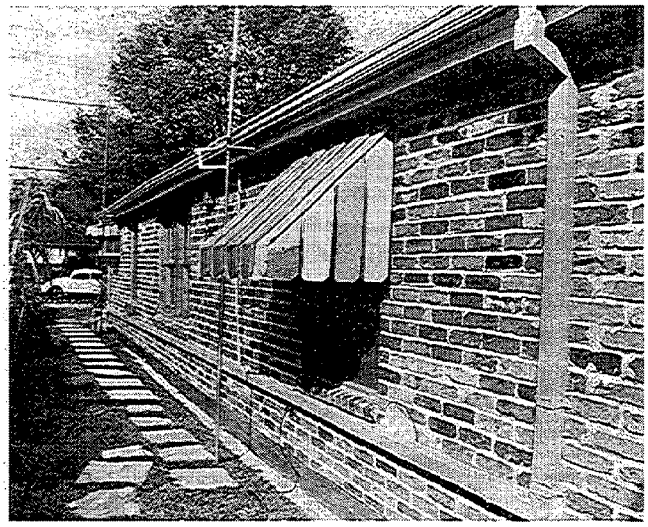
This property was flooded in the spring of 1977; about 3 inches of water entered the home. After this event, the owner designed and built this system. The floodwall was built and completed before the May 1978 flood at a total cost, including pumps and modified gutters, of approximately $5000 (1978 dollars).

Owner demonstrating gasoline engine pump. Hose on reel is discharge line which goes to front of house for discharge.



Discharge of sump pump on south side of house.

Owner inserting suction line and filter for gasoline driven pump. This is a standby pump in case of electrical outages.



Modified gutter on south side of house. Discharge goes to front of house.

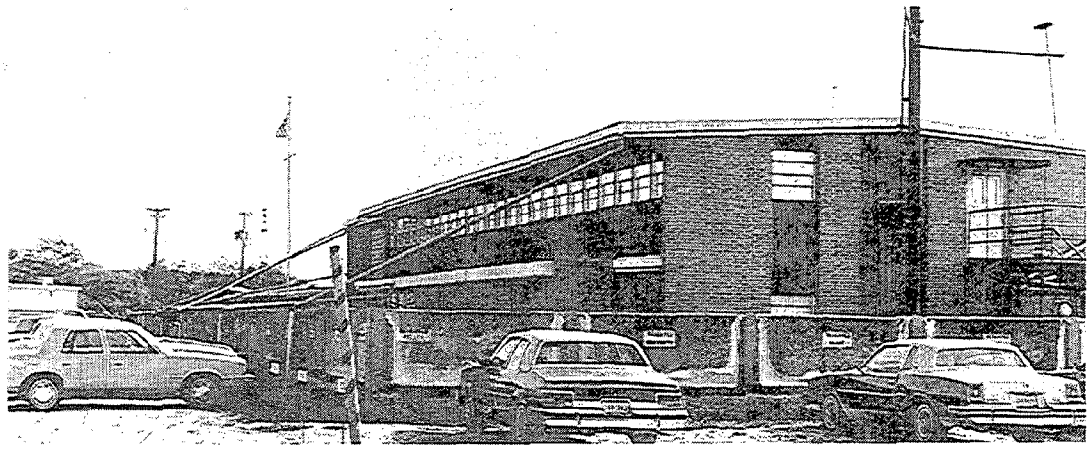
Figure A30.

Since construction of the floodwall in early 1978, the owner has installed the boards in the driveway 11 times, with various heights of water against the boards. In the April 1980 flood, the water depth on the outside of the floodwall was 18 inches. The pumping system effectively kept the inside water level from entering the house. Because of the short duration of flood events and the shallow flooding in this area, piping under the floodwall does not present any problems. Even with 18 inches of water against the floodwall, no piping under the floodwall occurred. Therefore, it appears as though the owner has built an effective flood proofing system to protect his residence against the 100-year flood elevation.

Marine operations service and supply company with a concrete floodwall, Morgan City, Louisiana

This industry is located on Berwick Bay near the confluence of Bayou Boeuf and the Atchafalaya River. Numerous tugs and offshore supply and service boats are operated out of its extensive docking and servicing facilities; thus, its operation requires a location in the flood plain. Because of its potential flooding from the Atchafalaya River, the company has constructed a concrete floodwall around its 15,000-square-foot building that consists of a metal frame warehouse and a two-story office building, both on a concrete slab. The floodwall is constructed to an elevation approximately 5 feet above ground level and is 8 inches thick (Figure A31). It is braced with 6-inch I-beams. The base of the wall extends 3 feet below ground and rests on a concrete foundation. The wall has gates that are removed during flood-free periods to allow ingress or egress. It is estimated that the flood proofing system cost $500,000. The wall was constructed in 1974, following a disastrous flood the year before which put about 3 feet of water on the first floor of the main building.

The floodwall was tested in 1979 when floodwaters reached a depth of 4 feet on the floodwall facing the river and 12 to 20 inches on the side facing land. At that time, as a dangerous flood situation developed in February, the company was forced to start closing the gates. Prior to closing the gates, and in precaution against possible seepage, a new fiberglass sealant was applied to the floodwall as flooding became imminent. All gates were closed by April, which severely hindered operations. Electric pumps had been installed inside the floodwall when it was built in order to pump out seepage and rainwater. In addition, a large diesel pump had been installed as a backup system in the event electricity was lost. As the flood situation

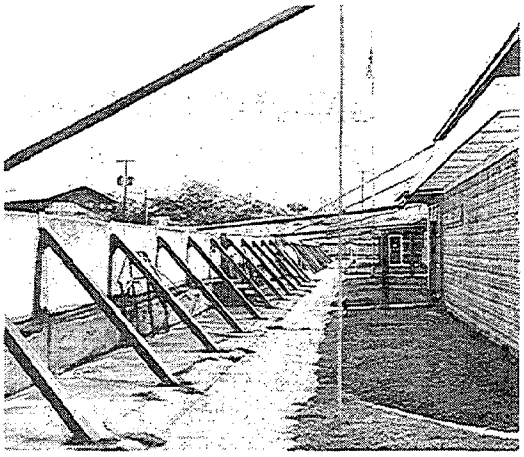


Marine building and floodwall looking southeast.

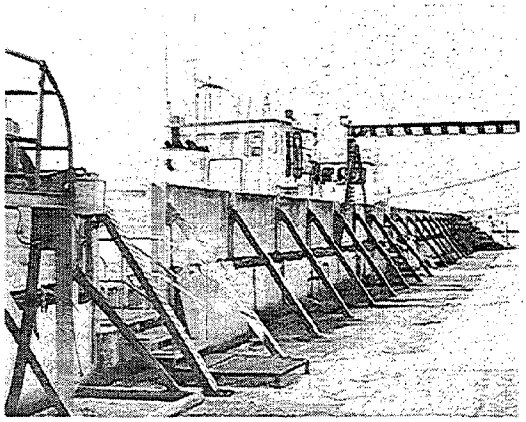
Figure A31. Warehouse and office building with concrete floodwall

developed, numerous geysers were spotted within the compound on the riverside area. Therefore, as an added precaution, several additional diesel pumps were rented to ensure adequate pumping capacity in case of power failure. During the flooding, which reached its peak on 1 May 1979, the yard area outside the main levee on the south side of the facility was under water to a depth of up to 2 feet. Normal operations were severely hindered. In order for office workers to get to the main building, a large elevated catwalk (about 12 feet high) was constructed from the East Atchafalaya protection levee, over the top of the seawall, and then down into the main yard. In addition, crushed limestone rockfill was hauled in to raise the road to the warehouse area so the trucks could still enter to unload. In anticipation of worse flooding, all the computer operations on the first floor of the headquarters building were moved upstairs, and arrangements were made for office space elsewhere should the floodwall fail and operations become impossible.

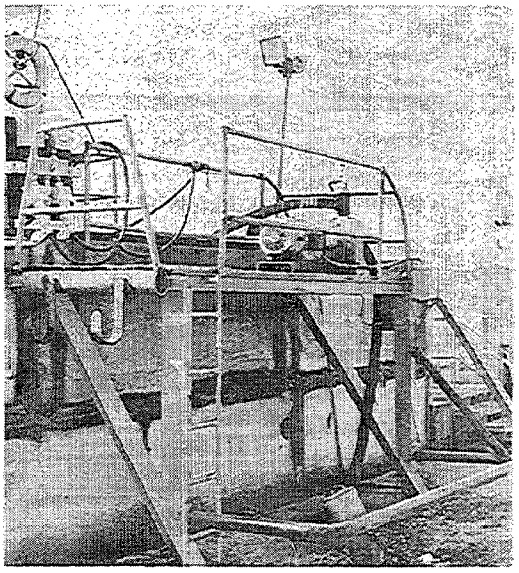
Flood proofing in this particular case was immensely successful. In 1973, this building was flooded extensively with 3 to 6 feet of water. Most of the contents had been evacuated prior to the high water that year; however, the cost to refurbish and repair the building after flooding was $600,000 (1973 dollars). In 1979, with the protective floodwall in place, operations were able to continue and no physical losses were sustained within the area protected by the floodwall.



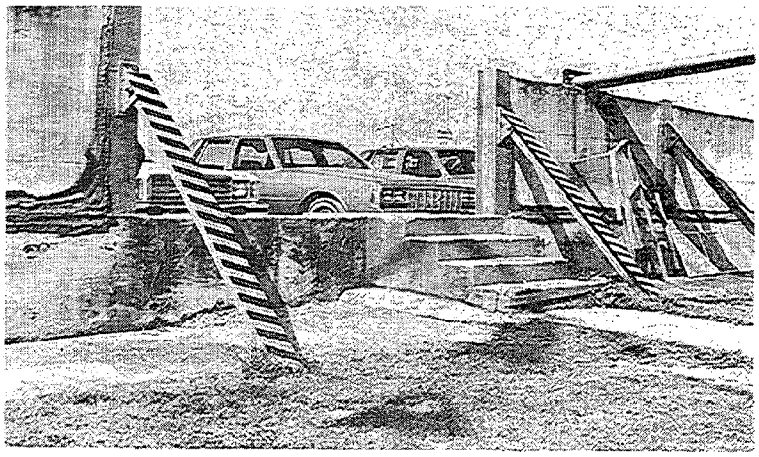
North floodwall looking east.



South floodwall looking west.



Sump pump system along south floodwall.



Personnel entrance in west floodwall.

Figure A31.

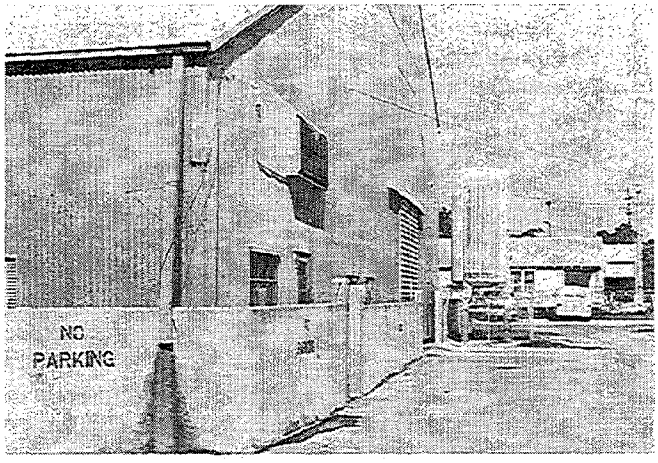
Barge construction and boat repair company with a concrete floodwall, Morgan City, Louisiana

Located in the vicinity of the industry previously discussed, this barge construction and boat repair operation likewise requires siting in the flood plain adjacent to Berwick Bay. The main structure is a two-story 16,000-square-foot metal building protected by a large concrete floodwall (Figure A32). Built in 1975 following major flooding in 1973, the 8-inch-thick wall was constructed to an elevation of 5.5 feet above ground level and rests on a concrete foundation several feet below the surface. The floodwall is reinforced with steel rebars and is braced by steel tie-bars. Ingress and egress are allowed through steel gates that are welded shut during floods. Rough estimates of the cost of the floodwall run over $100,000.

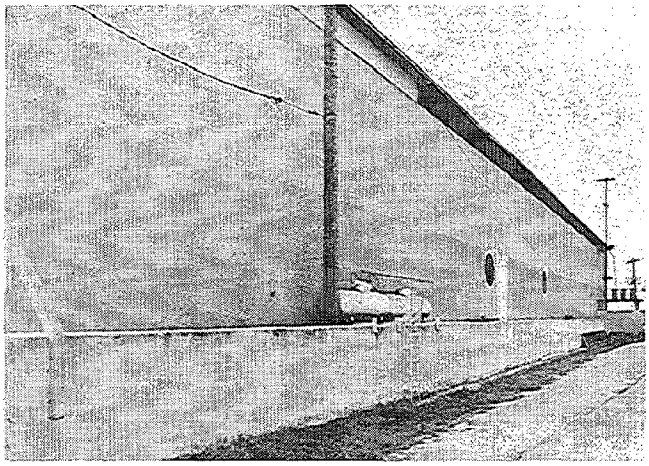
Flooding from the Atchafalaya River can last more than 90 days. It is estimated that this industry would likely be protected from the 100-year flood, although the floodwall has never been tested. During the last major flood in 1979, floodwaters were not even high enough to force closing of the gates.

Front of building. Note Morgan City floodwall in foreground.

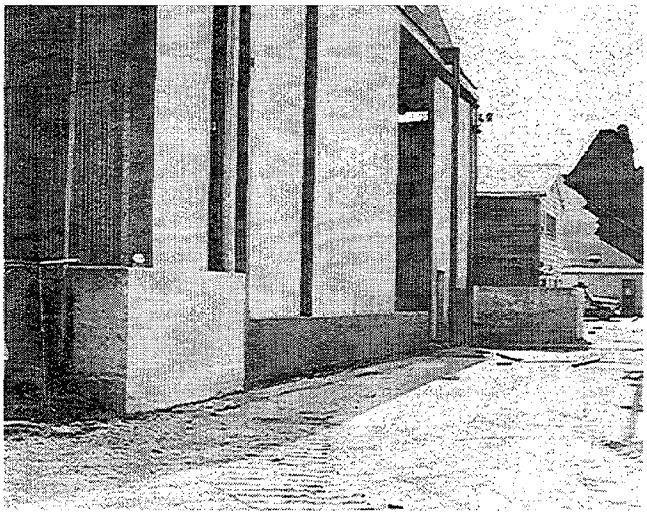
Figure A32. Industrial building with a concrete floodwall



Front of floodwall looking northwest.



North floodwall.



West floodwall (this floodwall fronts on the Atchafalaya River.

Figure A32.

Sawmill with earthen levee, Vicksburg, Mississippi

This 20 acre site contains a sawmill, finishing plant, and storage facilities for both raw materials and finished products. The buildings, equipment, raw materials, and finished products have an estimated market value of about $12 million. Floods can thus be very damaging to the operation, particularly since flooding from the Mississippi River can last up to 90 days or more with depths of up to 10 feet. Construction of an earthen levee (Figure A33) around the entire sawmill complex was begun in 1970, with continuous upgrading and repair of the system since then. The levee has a top elevation of approximately 102 feet, National Geodetic Vertical Datum (NGVD). This compares to the 100-year flood elevation for the area of 104 feet, NGVD. Four 30-inch steel culverts with flap gates provide interior drainage during flood-free periods, while portable pumps are moved in temporarily during high water to handle interior drainage. Temporary wavewash protection is applied prior to a flood emergency. Cost of construction of the levee system over the last 10 years is estimated at $1 million.

Flooding experience at the sawmill since construction of the levee has been mixed. The 1973 flood overtopped the existing structure with no estimate as to the total damage caused. That flood was approximately a 45-year event. The levee was repaired and upgraded following that flood. It subsequently withstood the floods of 1974, 1975, and 1979. The present level of flood protection is about as great as can be economically undertaken. The current height of the levee should keep the compound dry during a repeat of the 1973 flood. A major limitation now is the additional space required for further raising of the structure.

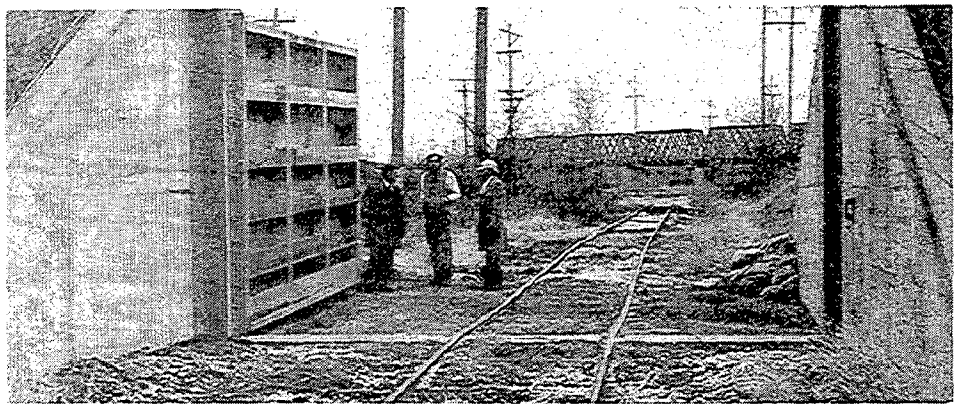
While the cost of construction of the levee has been high, the owner estimates that it has been very cost effective since it has protected property and materials valued at almost $12 million during three floods.

Figure A33. Sawmill with earthen levee

Steel and wire manufacturing plant with ring levee and floodgate system, Bartonville, Illinois

This large industrial complex contains several scattered buildings, all of which are subject to flooding from the Illinois River to the southeast and Kickapoo Creek to the north. The complex is protected by an extensive levee and floodgate system that was built in stages and is currently 21,000 feet in length with an average height of 12 to 15 feet. On the southern face of the levee is an unprotected opening that allows industrial traffic to pass. During flood emergencies, this opening is closed by means of sandbags and fill.

Following a flash flood from Kickapoo Creek in 1974, the company made some additions to the levee system. A new section was constructed along the western portion of the property which included two openings fitted with floodgates approximately 10 feet high and 16 feet wide (Figure A34). These openings are to allow railroad access into the complex. A third floodgate was built at a viaduct which connects the east and west portions of the complex. This viaduct cuts through a bank supporting a railroad line elevated 12 feet above ground level. With the floodgate closed, the bank serves as a secondary levee to protect one end of the complex should flooding occur at the other end. These three floodgates are built to lock into a



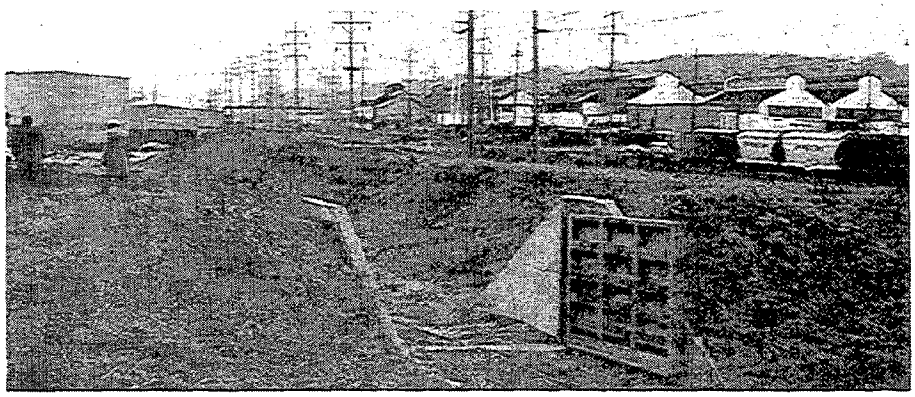


Figure A34. Manufacturing plant with ring levee and flood gate system

concrete frame. Pliable rubberlike material seals the gates for watertightness. The gates are manually operated.

The company also extended their levee system on the eastern side of their property to tie into the elevated bank of the expressway. Riprap was used to stabilize the bank along the canal. Cost to extend the levee system is estimated to be $125,000. The company has a regular maintenance program every 4 months which includes examination of the gates for watertightness and a check of the levees for burrows or erosion.

The original levee system had a side-slope ratio of approximately 1 to 1. The new system has a wider base resulting in approximately a 3 to 1 sideslope ratio and is constructed with soil and slag, compacted down, and then covered with a clay face that extends below ground. The clay is covered with more soil and slag.

The company's security force maintains a formal flood emergency response plan that identifies procedures for personnel to follow during a flood. The plan is rehearsed once a year to familiarize employees with flood emergency procedures. The company relies on flood stage information from the Rock Island District's Peoria Project Office to decide when to implement the plan.

The spring flood of 1979, estimated to be a 50-year event, was the last flood to strike the area. At that time, the emergency plan was implemented and the floodgates were closed in the southern portion of the levee. Floodwaters came to within 5 feet of the top of the levee and remained up for about a week. Water that ponded within the confines of the levee was pumped through pumphouses into the plant's cooling system and used in processing steel. The levees remained free from seepage and boils during that time, and business was carried on through other openings.

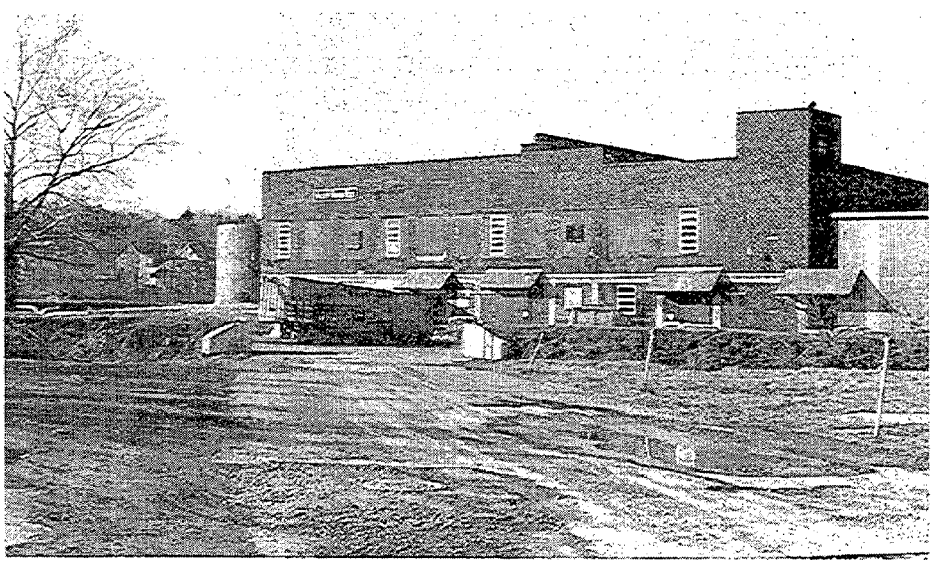
Minor seepage was noted at the southern opening where sandbags and fill are used. Company officials believe water seeped through an opening underneath the railroad tracks that pass through the levee opening. As a result, after the 1979 flood, poured concrete has been placed under the tracks to protect against future seepage.

Company officials have rejected plans to replace the floodgate that once existed in this southern opening. This floodgate incurred damage from the daily operation of a crane that carries equipment through the opening. The officials determined it would be more cost-effective to employ a sandbagging-fill operation during flood threats than to replace the gate. This operation consists of a base of timbers placed into a frame on both sides of the opening. Sandbags are then laid over the timbers. Because of the success of the levee system, plant officials have expressed pleasure with this flood proofing technique.

Paper manufacturing company with ring levee, Modena, Pennsylvania

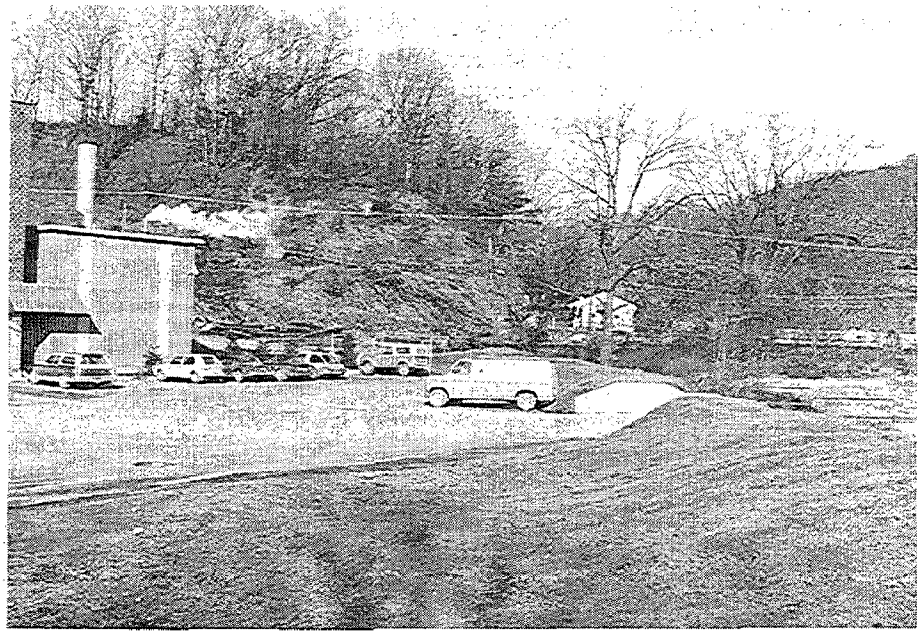
This paper manufacturing plant is located partially within the 100- and 500-year flood plain of the West Branch of Brandywine Creek. Flooding occurs on the average of twice a year with overbank depths reaching 3 to 4 feet and lasting for several hours. The original plant was constructed over 200 years ago, with an addition added around 1920. The structure has a concrete superstructure with a brick-veneer exterior, and a mat foundation with a basement under part of the building. The building is two stories high with over 60,000 square feet of working area. Due to the age of the structure, management made a decision to build a ring levee around the entire plant (Figure 35) rather than use another flood proofing method. The levee has a top width of 9 feet and a bottom width of 15 feet and is 3 feet high. A 24-foot opening in the levee provides access to the building. Three 1.25-inch plywood panels are to be used to close the opening during flooding. The panels slide into metal channels, but no gaskets or seals are used to eliminate seepage. At other times the panels are stored in an accessible location. Cost of constructing the levee is estimated to be $10,000.

The plant operates 24 hours a day, seven days a week. Since its construction, the levee has allowed the plant to stay open during two floods. Both times, high water did not reach the level of the access opening; therefore, the flood shield (plywood panels) was not needed. The general manager estimates that the levee has paid for itself during the two flood events by eliminating damages and allowing the plant to remain in operation.

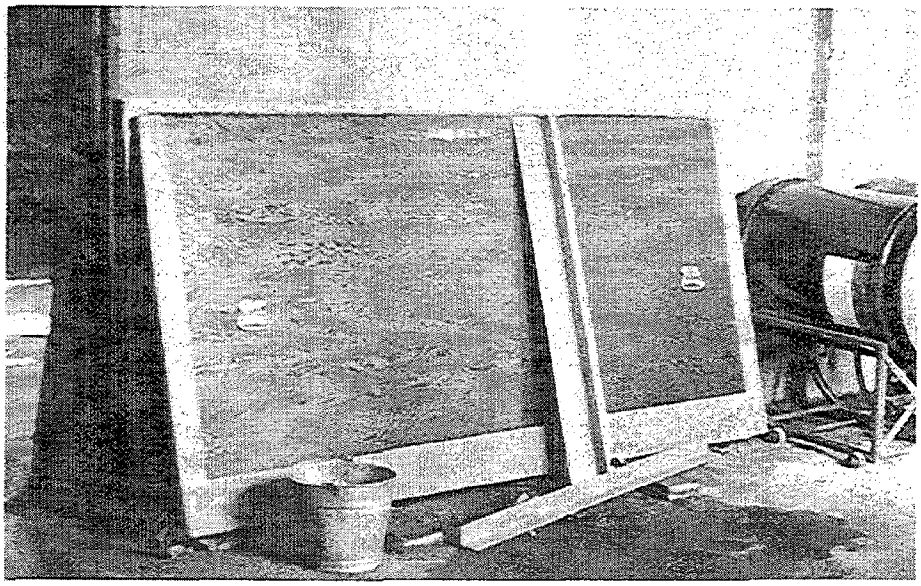


Front view of plant and gate.

Figure A35. Manufacturing plant with ring levee



Inside view of plant and gate.



Stored plywood panels.

Figure A35.

Gas and electric company substation with cinder block floodwall, Ewing Township, New Jersey

This power substation was built in 1955 near the West Branch of Shabakunk Creek in New Jersey. Flood depths of up to 2 feet were experienced in the vicinity of the substation during an August 1971 flood. As a result, a 3-foot-high cinder block wall (Figure A36) was constructed around the facility in 1972 at an estimated cost of $6000. Passageways for use by vehicles are fitted with hinged metal shields. These shields remain closed since the substation is generally unmanned. Pumps are used to handle any seepage through the floodwall. The floodwall has worked well in controlling nuisance flooding and has not overtopped.

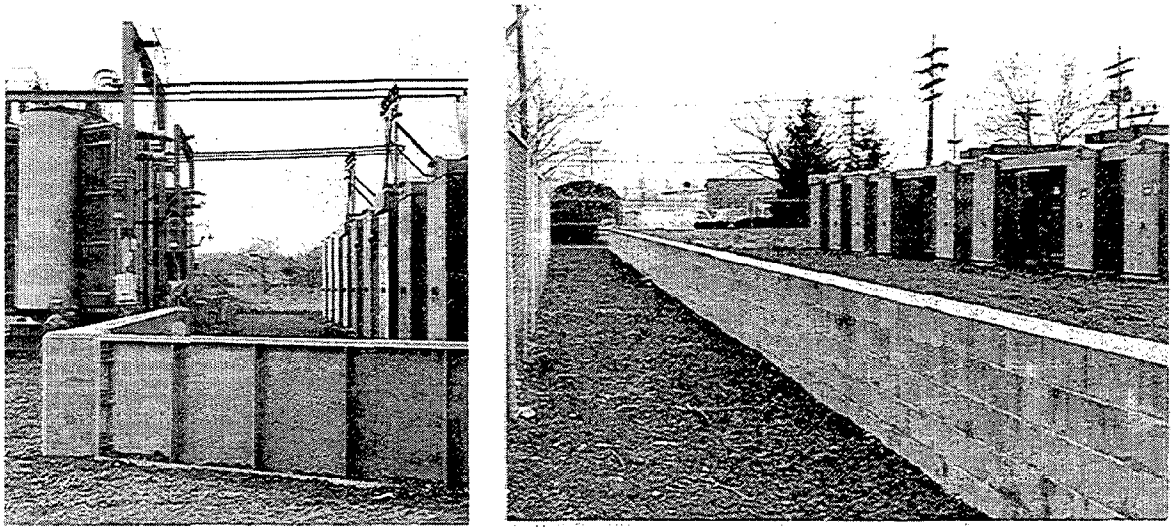


Figure A36. Gas and electric substation with cinder block floodwall

Leyden Township Flood Wall, Leyden Township, Illinois

This floodwall was built in 1975 to protect three single-story ranch homes from flooding from Silver Creek. The poured concrete floodwall is approximately 210 feet long, 8 inches wide, and 5.5 feet high (2 feet of which is above ground). The floodwall is entrenched in the ground behind a concrete retaining wall designed to prevent erosion along the creek (Figure A37). The 1975 cost of constructing the flood wall was $2940. An additional $5760 was spent at that time for constructing 120 feet of retaining wall, for a total cost of $8700.

Flooding has always been a problem to residents in the area. Prior to the construction of the floodwall, residents claimed to get basement flooding three to four times a year. Water would enter residents' backyards and get as high as 4 inches near the side of the house facing the creek. Water has never overtopped the floodwall.

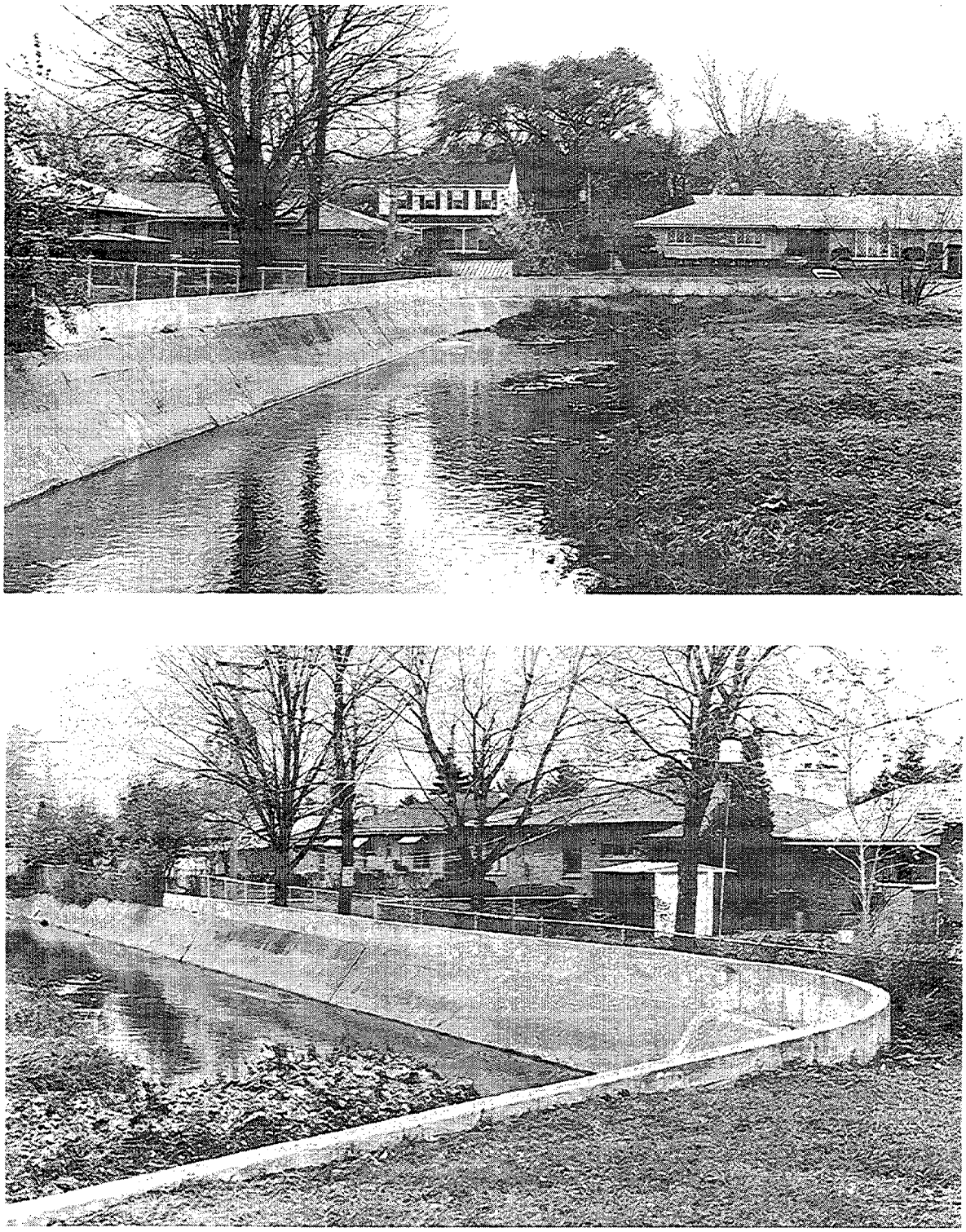
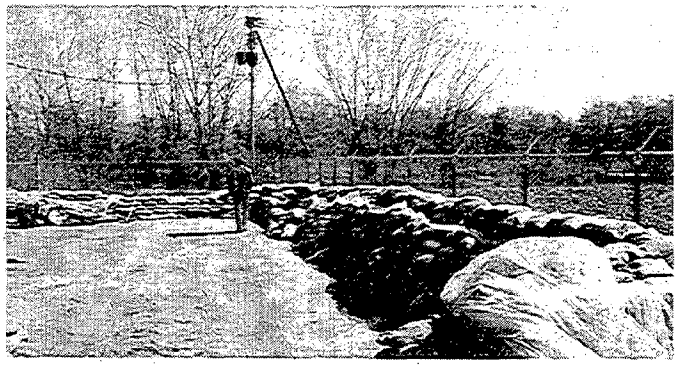


Figure A37. Floodwall and retaining wall built to protect homes

Wastewater treatment plant with levee, Port Byron, New York

The Port Byron, New York, Wastewater Treatment Plant is subjected to flooding from the Owasco Outlet (Owasco Lake). In 1972 and again in 1979, serious flooding occurred, although minor flooding is experienced yearly. During the 1979 flood, an emergency sandbag levee was built around the facility.

The 4-foot-high levee, which included an impervious plastic liner surrounding the main building, was found to be successful in preventing flood damage to the facility. Following the 1979 flood, the levee was upgraded and has become a permanent feature. This latest levee ranges in height from 30 to 48 inches and provides 500-year flood protection for the facility (excluding icejams or debris). It is approximately 660 feet long and protects an area about 0.6 acre in size. Top width is 2 feet; bottom width, 8 to 10 feet. The levee has a key that extends 1 foot below the surface and is made of dross, a byproduct of steel. The levee has a core of compacted dross which is covered with topsoil and seeded. Crown vetch was added in 1983 to further protect the levee from erosion. The levee has one opening, approximately 20 feet wide. It is sealed during flooding by use of a large plastic liner which is filled with sand, doubled over, and reinforced with sandbags (Figure A38). Cost of constructing the permanent levee is estimated at $10,550.



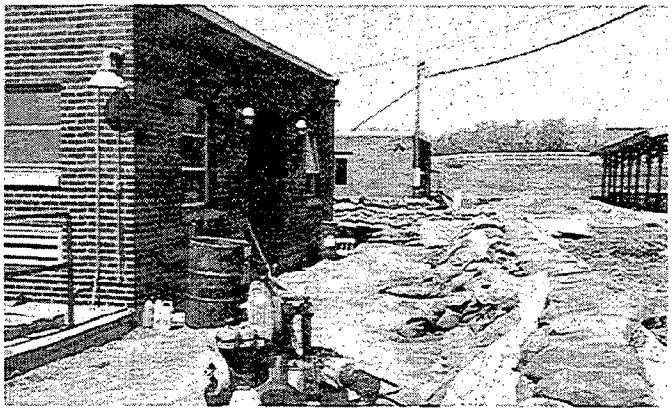


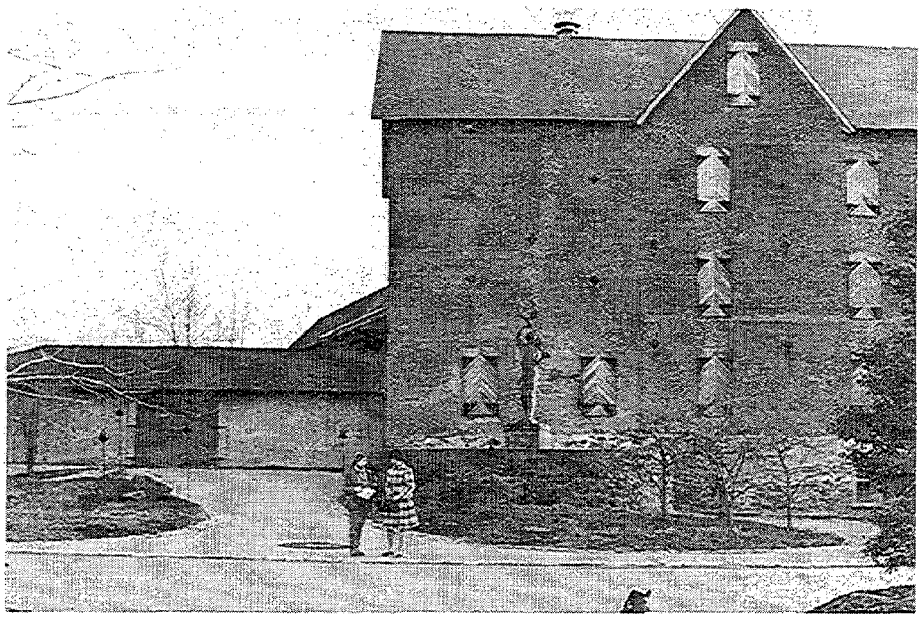
Figure A38. Wastewater treatment plant with levee

Closures and sealants

Brandywine River Museum fitted with flood shield, Chadds Ford, Pennsylvania

The Brandywine River Museum is a converted 19th century brick, four-story grist mill with a 1970 concrete and frame addition built over Old Mill Race (Figure A39). The building houses objets d'art plus offices, a restaurant, a bookstore, and a lecture hall.

Due to its location adjacent to the Brandywine River and the Old Mill Race, the structure is subject to overbank flooding which has been known to reach 4 feet deep at times. Flooding has occurred seven or eight times in the last few years and has lasted several hours each time. To protect the lower levels of the building from flooding, doors have been fitted with 3/8-inch removable aluminum shields. The shields along with portable pumps are installed during times of predicted high water. Neoprene seals have been built into the lecture room floor (ground level) and flanged up the wall 18 inches above the floor. Lag bolts for doors are built into the door frames to assure a tight fit. Butyl caulking is placed around the shield for extra seal. The sump pumps are installed in elevator wells to eliminate water seepage that cannot otherwise be controlled. Any seepage around the flood shields is handled by shop-vacs.



General view of original building.

Figure A39. Flood proofed museum

The most recent flood experience occurred in January 1979. At that time, 2 feet of water existed outside the ground floor level and only minor seepage occurred inside. In 1981, gabions were placed along the streambank to provide additional protection. The adequacy of the system appears to be dependent on the amount of warning time available. Previous warnings have not always been accurate. Through the years, as more flood experience has been gained, flood fighting procedures have been developed. Today, lists of these procedures are posted throughout the building for quick reference by employees.

ABOVE: General view. Note flood proofed door at right.

RIGHT: Closeup of door framing and latch devices for flood shield.

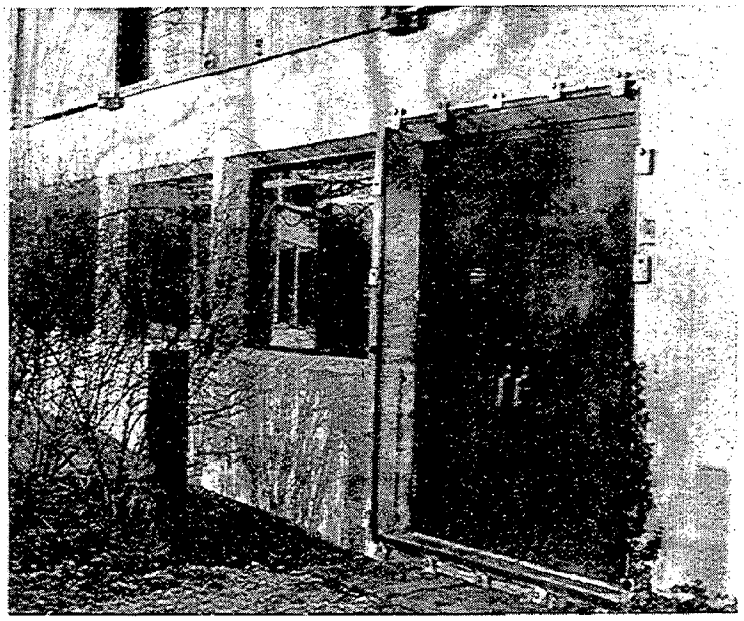
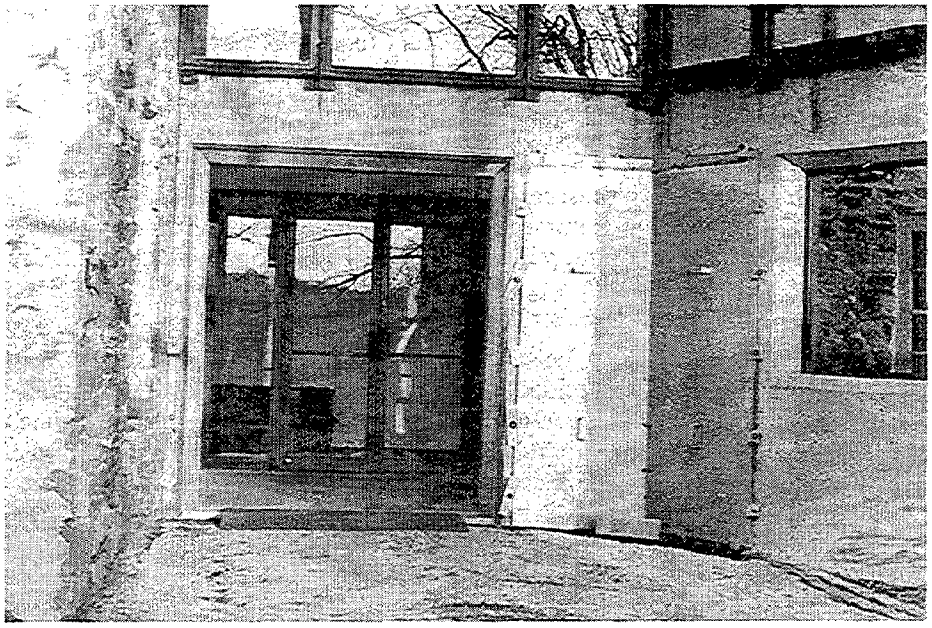
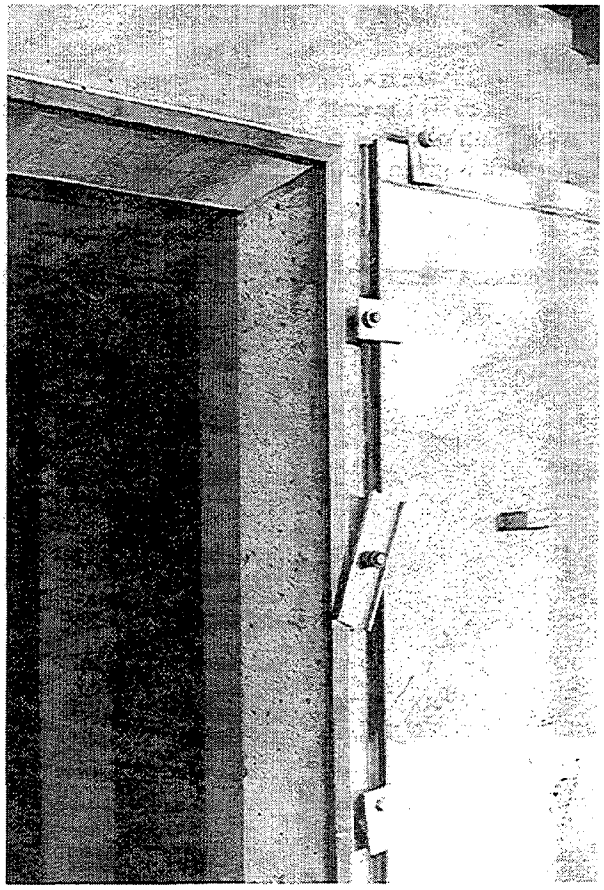


Figure A39.





ABOVE: Closure for door in stored position.

LEFT: Closeup view of shield, framing, and latch devices.

Figure A39.

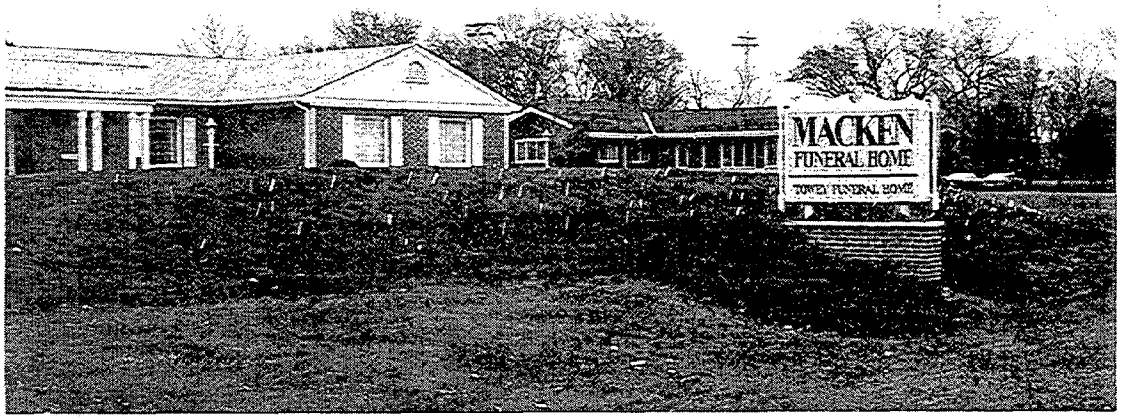
Funeral home equipped with flood barriers, bricked lower windows, and debris protection berm, Rochester, Minnesota

This single-story funeral home (Figure A40) is presently made up of two parts—the original section built in 1962 with a first floor of wood construction with a crawl space beneath, and a new addition added in 1982 which is a concrete slab on grade. The walls are concrete block with a brick veneer. The structure is susceptible to flooding from Bear Creek. The last flood, in the summer of 1978, was of relatively short duration (3 to 4 hours) but put about 2 feet of water on the first floor. Flow velocities during that flood were great, although overall flood damage to the structure was minimal.

Following the flood of 1978, the owner of the structure decided to build the new addition. City regulations required that it be flood proofed, but a decision was made to include the entire structure in the flood proofing system. The completed system includes four main features:

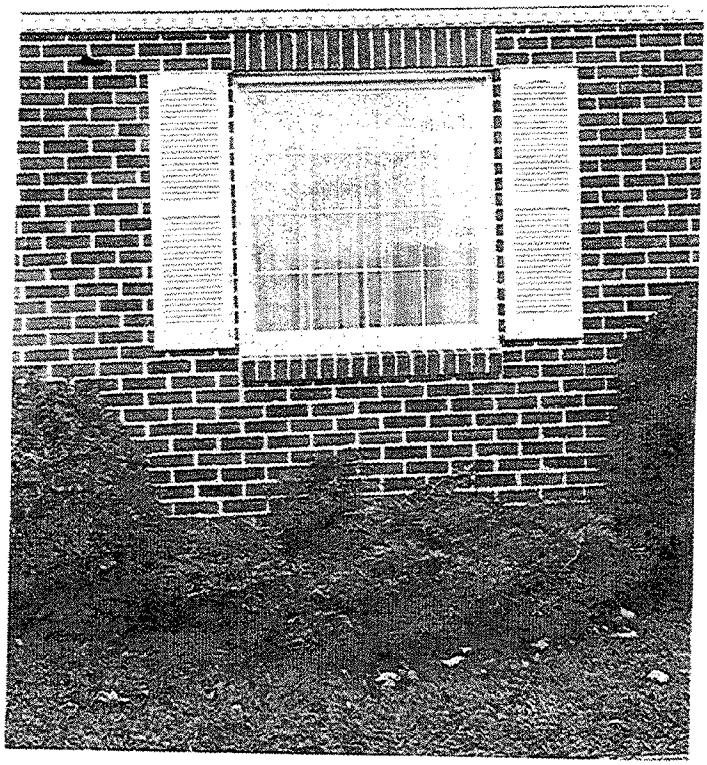
- The lower portions of windows were bricked up.
- Aluminum flood barriers were built for use over door openings.
- A 3- to 4-foot-high berm was constructed in front of the building to protect it from floating debris.
- A secondary sewer backup valve was installed.

The overall flood proofing system cost approximately $30,000. It is designed to protect the funeral home against a regional level flood. The system's effectiveness, however, depends on actions taken by the staff to secure the building. As a result, a flood protection plan was developed. A brief description of this plan is given below.

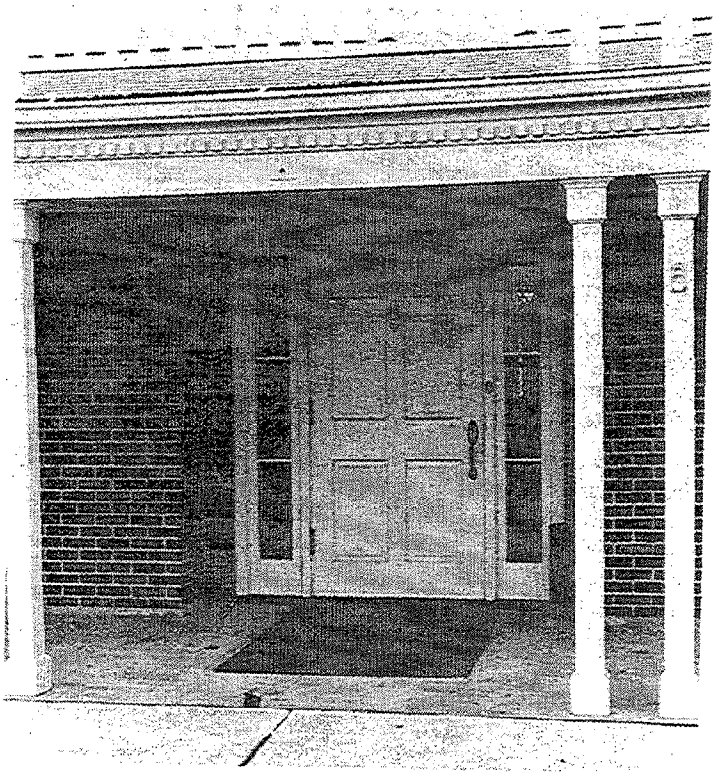


Earthern berm in front of building.

Figure A40. Funeral home with flood barriers, bricked lower windows, and debris protection berm



Window to right of main entrance. Bottom portion of window replaced with brick. Windows now above regional flood level.



Main entrance. Aluminum closures designed for placement in doorway.

Figure A40.

The temporary flood barriers are to be installed by employees of the facility under the direction of the person in charge of flood emergency coordination.

When the protective flood barriers are in place, access to the building is limited to two openings on the north side of the building. The panels are to be installed at times when the National Weather Service has issued a flood watch for the area, and the building will be unoccupied or unattended for 8 hours or longer or when the Weather Service has issued a flood warning with flood crests in the area above 1005.0 feet mean sea level (msl).

All damageable items located in the new addition below 2 feet 1 inch above the floor are to be relocated or removed. The facility and owner's home are equipped with a weather service radio that will constantly monitor National Oceanic and Atmospheric Administration weather broadcasts.

An emergency flood watch indicates that conditions exist which could possibly cause flooding. When a watch is issued the owner or his emergency coordinator for the facility shall make phone contact with the staff to inform them that it may be necessary to implement flood protection procedures. The owner or coordinator shall monitor the weather radio and/or local commercial radio or TV every 4 to 5 hours for any change in the flood status. If the watch is canceled, further contact with the flood personnel is not required. If the watch is upgraded to a warning, the flood protection plan is put into effect.

An emergency flood warning indicates that the rivers, streams, and creeks in the area will experience some flooding. When the warning is issued, the owner or coordinator must meet at the staff facility to install the flood barriers. Once the flood warning has been issued, the weather service will attempt to predict the projected crests of the rivers and streams involved. This information is generally broadcast an hour or two after the flood warning has been issued.

When project flood crests at the 12th Street bridge over Bear Creek are above 1005.0 msl, action shall be taken to fully implement the flood protection plan, i.e., remove cadavers and other items in the building that are to be protected.

The funeral home employs five people on a full- and part-time basis. At any particular time, day or night, at least five people will be available to provide the work force necessary to implement the flood protection plan. The flood protection team will be led by the owner and/or his emergency coordinator, both of whom shall be thoroughly familiar with all aspects of implementing the flood protection plan. At times when flood warnings have been issued, at least one of the coordinators shall immediately go to the facility and remain there until the flood

warning is canceled or flood protection is completed or until floodwater makes contact with the building. The flood coordinator at the facility shall contact all workers required to execute the contingency plan. The workers shall report as soon as possible to the flood coordinator. The coordinator shall assign two people to install flood protection panels at the exterior door locations and caulk all but one barrier on the north side. Another person is to disconnect all electrical equipment, and the remaining staff is to start relocating damageable items. Once the floodwaters have reached the perimeter walls of the building, all people working within the space must leave.

The following is the company's estimation of the time and number of people required to prepare the building for flooding:

Activity	No. of Persons		Time, hour		Total man-hour
Install flood panels	2		2.0		4.0
Disconnect equipment	1		0.5		0.5
Call all workers	1		0.5		0.5
Supervision	1		5.0		5.0
Relocate contents	2		4.0		8.0
TOTAL	5 people	×	3.6 hours	=	18 man-hours

The temporary flood barriers are set in place and secured with a quick operating latch. As an additional precaution, the space between the door and frame at the locked doors can be caulked with a nonhardening sealant. The flood panels are to remain in place until the floodwaters recede and/or the flood warnings are canceled.

Once each year the coordinators shall review with the employees the flood protection plan and install all flood panels. Also at this time, the building shall be inspected for defective caulk joints and cracks in the masonry, and repairs made as required to maintain the integrity of the flood proofing.

This contingency plan is to remain in effect until such time that the regulatory Flood Datum Elevation changes or the building is no longer located in the flood plain. This plan is to be reviewed by an architect or engineer every 5 years and revised to reflect changes in staff and contents in the facility.

The owner believes the system should be effective. By bricking in the bottom portion of the windows to an elevation above the regional flood level and installing the flood barriers, seepage and flooding should be prevented. The berm may not have been required, but should provide additional protection in the event that floodflows come from another direction. If the system is implemented as designed, the building and contents should be protected from all flood damages up to the regional flood level.

Two-story brick building with sealed walls, flood barriers, and raised windows, Hot Springs, Arkansas

Two two-story buildings of brick construction were connected to make a commercial complex containing specialty shops and a restaurant. At a cost of approximately $5000, the basement and first floor walls were sealed, windows on the first floor were raised above the 100-year flood elevation, and exterior doorways were closed and sealed, except for one doorway which was fitted with a removable flood shield made of 3/4-inch plywood (Figure A41). The effectiveness of the flood shield is questionable, since no seals are to be used around its edges and no reinforcement is present to stiffen the shield or to lock it in place. No floods have occurred since construction to test the system.

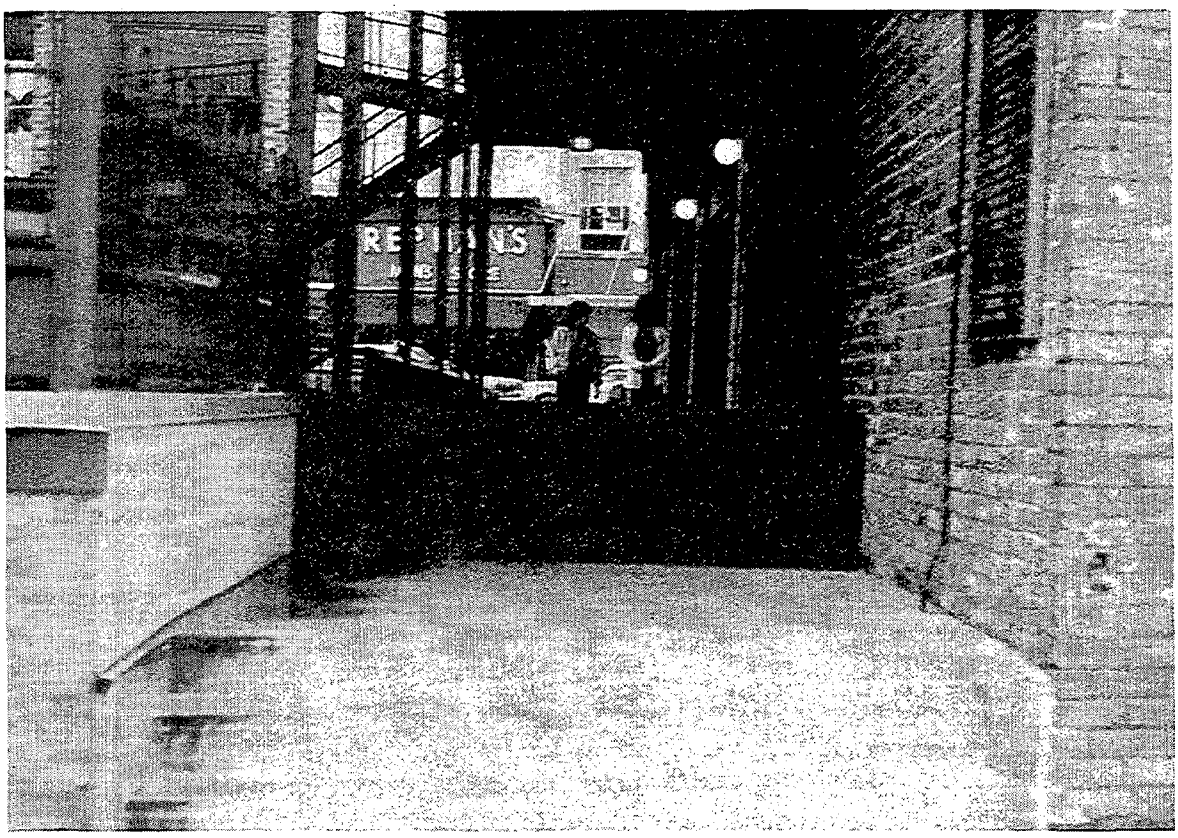


Figure A41. Brick building with sealed walls, flood barriers, and raised windows

Miscellaneous flood proofing techniques

Single-family house with raised equipment, Rochester, Minnesota

This single-family house located near the Zumbro River in Rochester, Minnesota, has its heating, cooling, and electrical equipment raised on the outside of the house above the regional flood level. The utilities are built on a platform supported by steel supports that are attached to the house (Figure A42). Cost to raise the utilities was minimal—perhaps $1000. A sewer backup valve has also been installed and proved effective during the 1978 flood. At that time, flooding lasted 9 to 10 hours and reached a depth of 3 feet. The basement of the house was flooded, and if the utilities had been located there, they would have been damaged or perhaps destroyed.

It is interesting to note that the owners purposely flood the basement to relieve hydrostatic pressures on basement walls. Glass is removed from windows to prevent damage from debris.

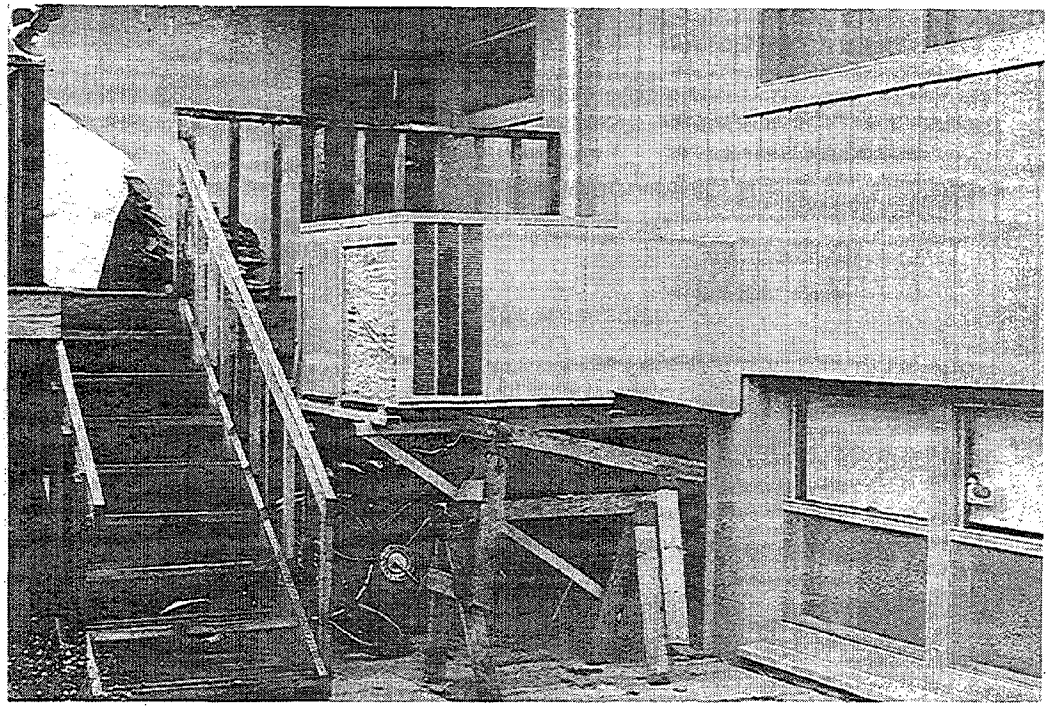
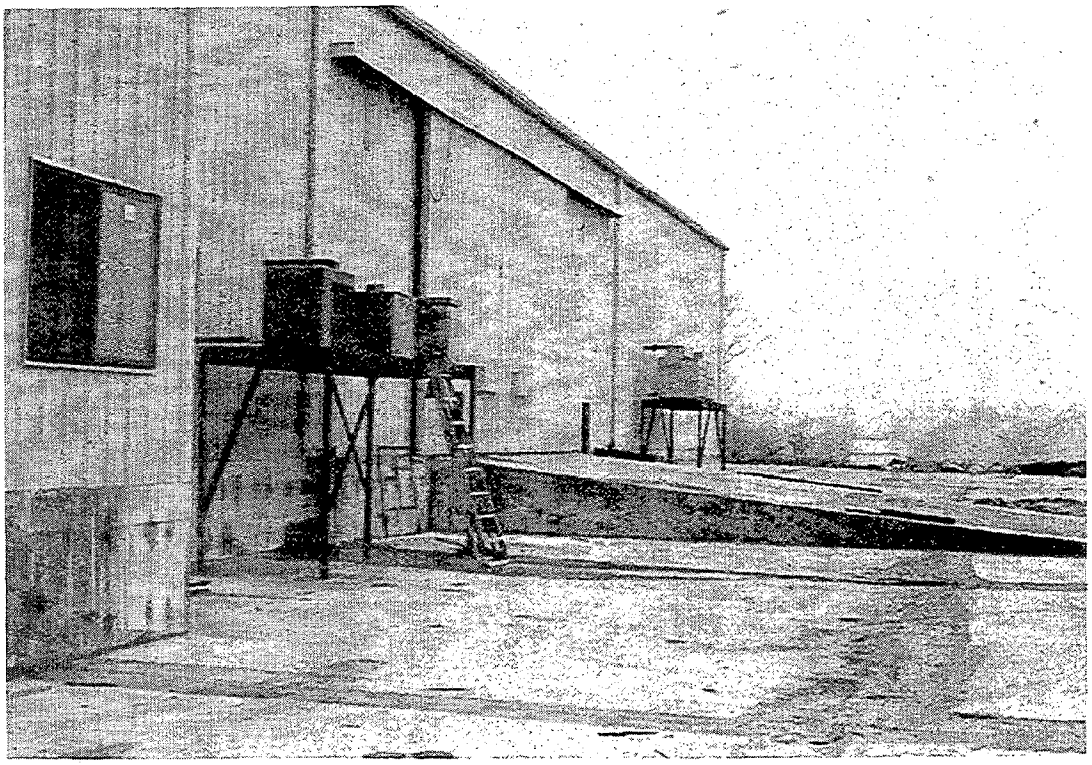


Figure A42. Single-family house with raised heating-cooling and electrical equipment.

Warehouse with electrical/mechanical equipment raised, Greenville, Mississippi

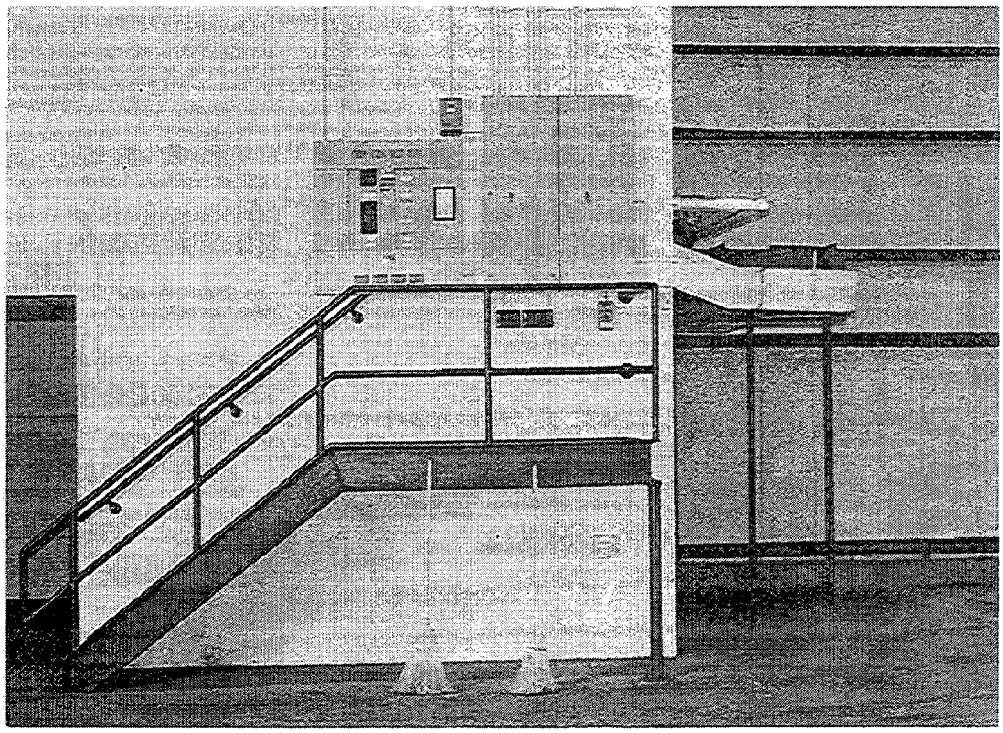
This 28,000-square-foot warehouse of steel construction was built on a reinforced concrete foundation and slab. The site is subject to overbank flooding from the Mississippi River. The floor slab of the building, along with rail and truck docking and loading platforms and related access facilities, were constructed at elevations about 2 feet below the 100-year flood elevation for economic reasons. The owner estimates it would have cost an additional $22,000 to elevate the entire building above the 100-year flood, and he was unwilling to make this investment. Instead, the critical electrical and mechanical equipment was elevated 8 feet above the 100-year flood elevation for aproximately $4500.

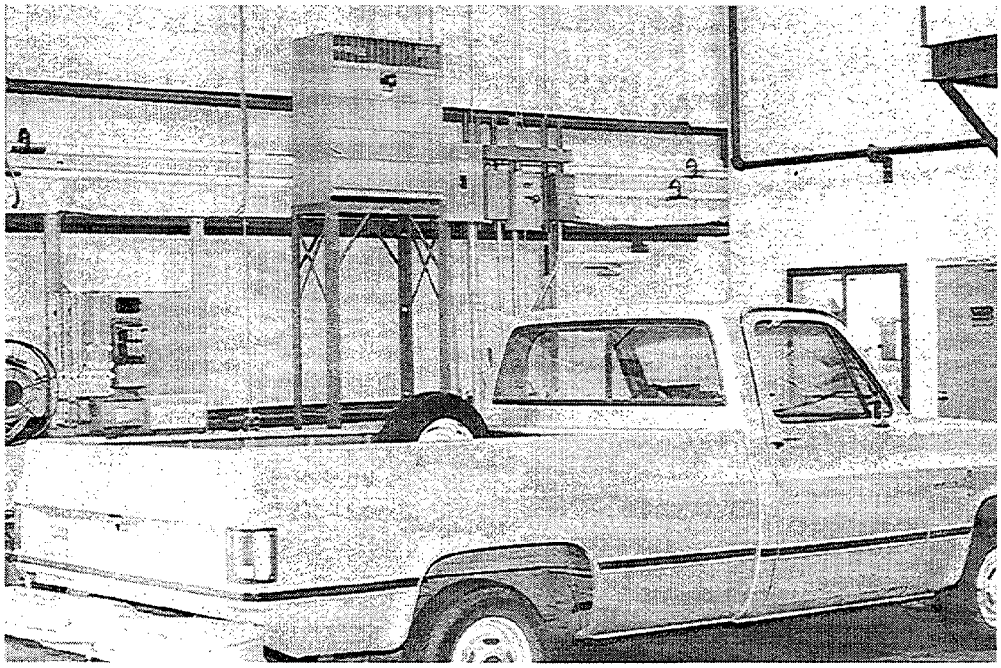
During flooding, the area has been known to remain inundated for as long as 26 days. Electrical/mechanical equipment submerged for this length of time would almost certainly be ruined. Exterior equipment was placed on steel platforms accessible by portable ladders; interior electrical control panels were mounted on interior walls accessible by steel stairs (Figure A43).



Elevated exterior equipment.

Figure A43. Warehouse with raised electrical/mechanical equipment





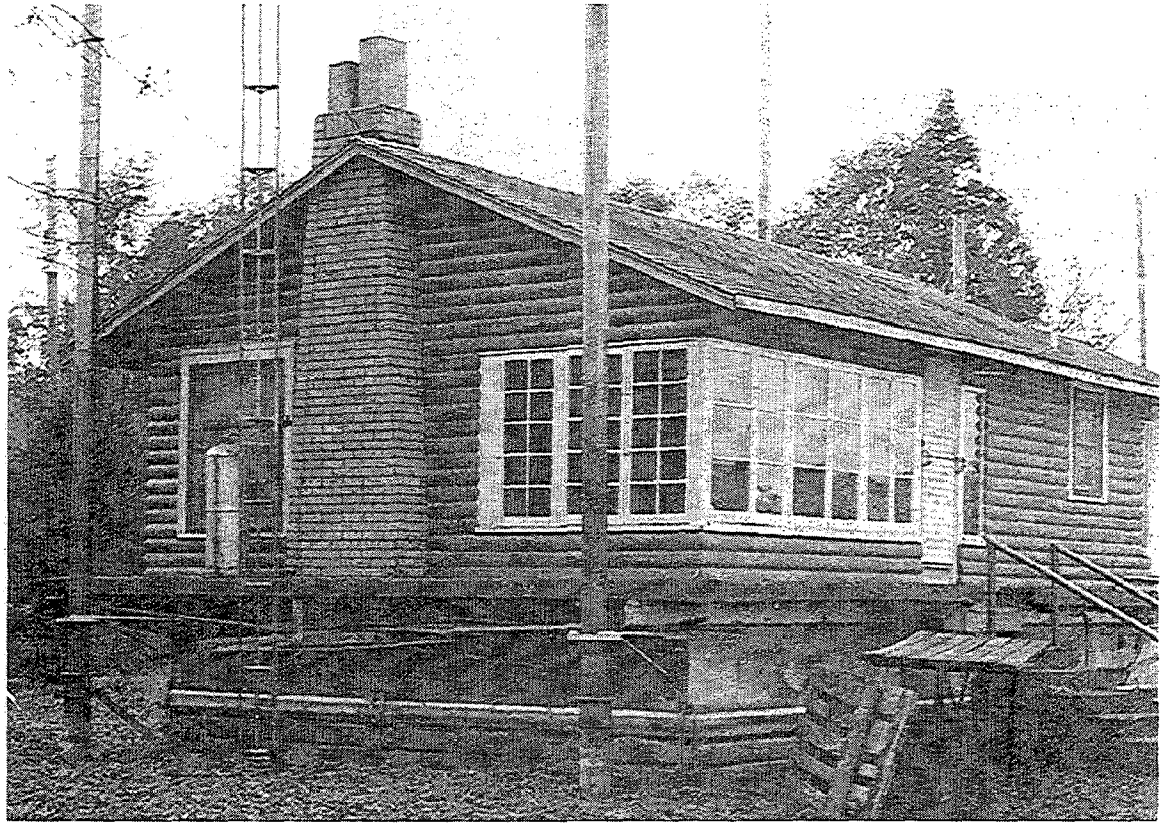
Elevated interior equipment

Figure A43.

One-story house mounted on a barge-like flotation system, Ouachita River, Arkansas

Flooding from the Ouachita River in the vicinity of this structure occurs on an almost annual basis and can last from several weeks to 6 months. Damage to a structure inundated this frequently and for this length of time could be devastating. To avoid such a dilemma, this one-story conventional frame house was mounted on a barge-like flotation system attached by collars to four metal guide pylons anchored in the ground at each corner (Figure A44). When the area is not flooded, the barge rests on a concrete foundation that is hidden by wooden aprons attached to the sides of the barge. When flooding occurs, the structure rises vertically with the water, guided by the pylons. Water and sewage hookups are made of flexible pipe and are serviceable during flooding. The estimated cost of flood proofing is $6000.

This system of flood proofing appears to work well in areas of relatively deep flooding of long duration with nondamaging flow velocities. During the 1973 flood, floodwaters reached 15 feet in depth with no failure to the system. Aside from the relatively high cost of the system, however, is the fact that maintenance is required to keep the barge apparatus from deteriorating. The owner indicated that if he were to build again, he would likely use styrofoam pontoons in lieu of the metal barge.



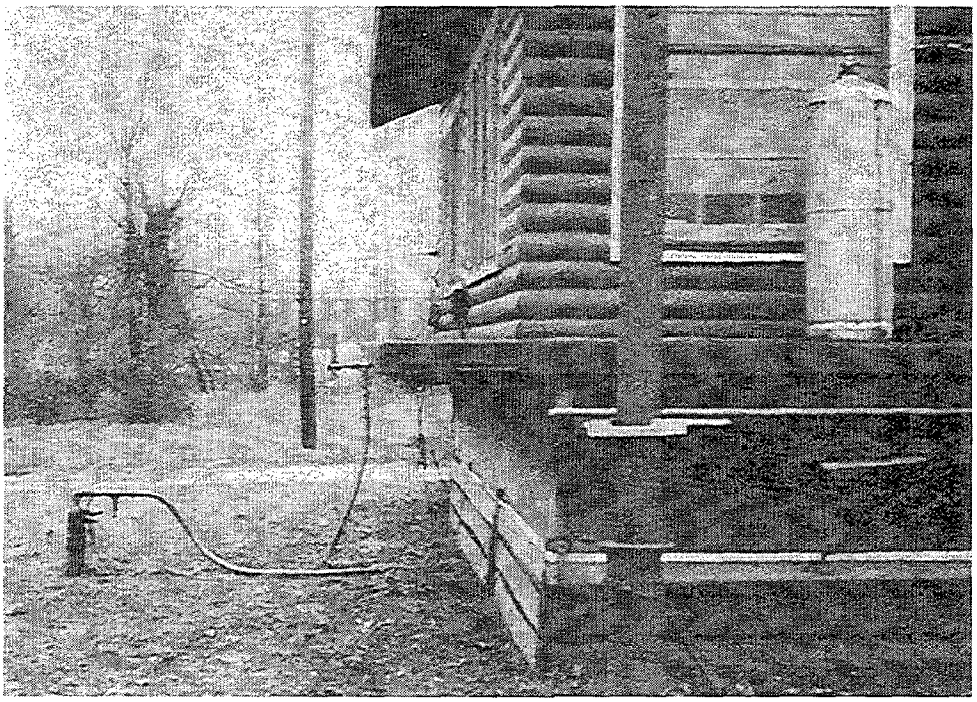
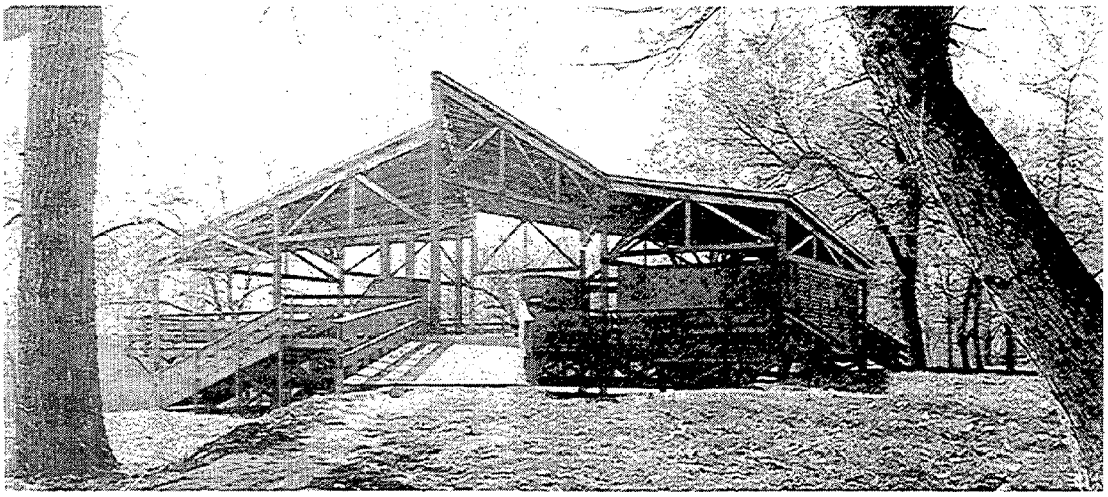


Figure A44. One-story house mounted on barge-like flotation system

Park pavilion built of flood damage-resistant materials, Kirkwood, Missouri

This park pavilion was built in the Meramac River flood plain only a few feet from the high bank of the river using flood damage-resistant materials. It was designed by students of Washington University for location in a flood hazard area and is built of treated wood. The foundation consists of wood posts bolted to low-level concrete piers. The floor is elevated 3 to 6 feet above natural ground. It is an open structure (without walls) designed to allow floodwaters to pass through with little resistance (Figure A45), thus reducing the chance of damage to the structures. During the spring 1979 flood, the structure was inundated for several days, yet no damage was sustained. It thus represents an ideal structure for use in flood-prone areas such as parks adjacent to rivers.



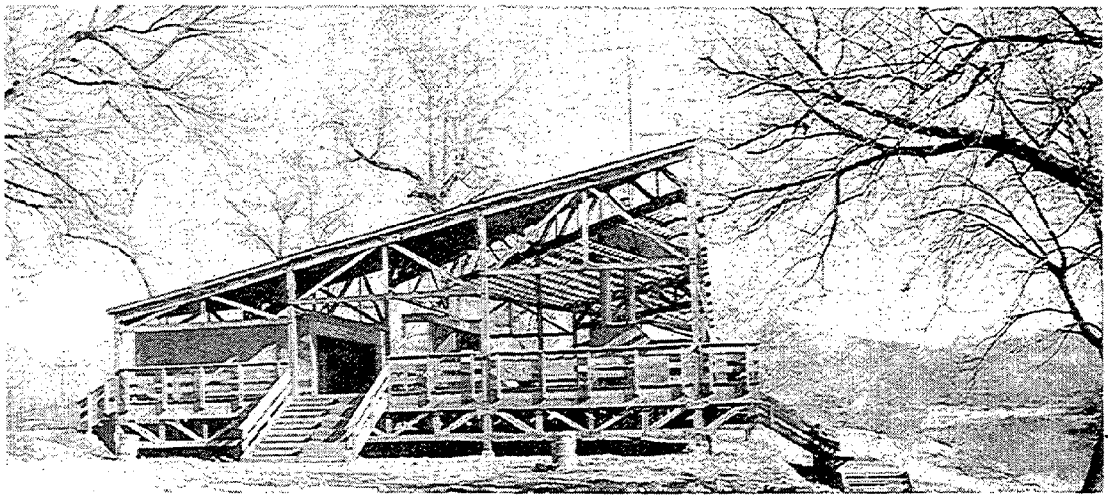


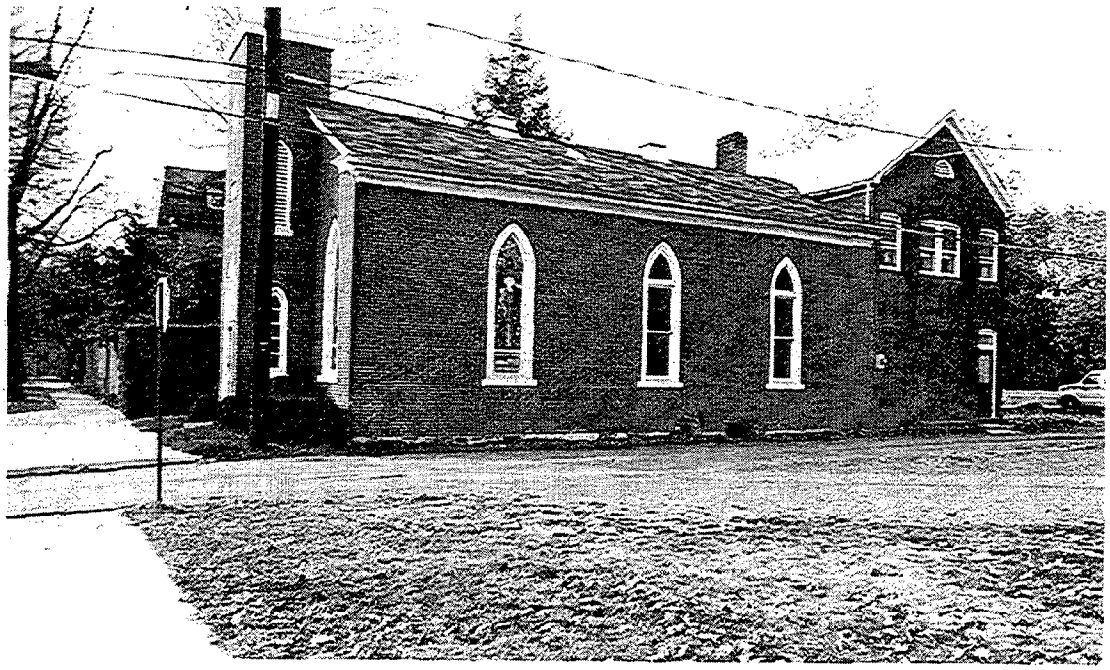
Figure A45. Park pavilion built of flood damage-resistant materials

Christ Episcopal Church, Milton, Pennsylvania, (evacuation of damageable items and use of flood-resistant materials)

Christ Episcopal Church is located within 0.5 mile of the West Branch of the Susquehanna River. It was built in 1849 and presently consists of the main church building, which has a stone foundation and basement walls, and an attached parish house. The first floor of the church is constructed of timber beams and joists with wood flooring. First-floor walls are brick exterior and plaster interior.

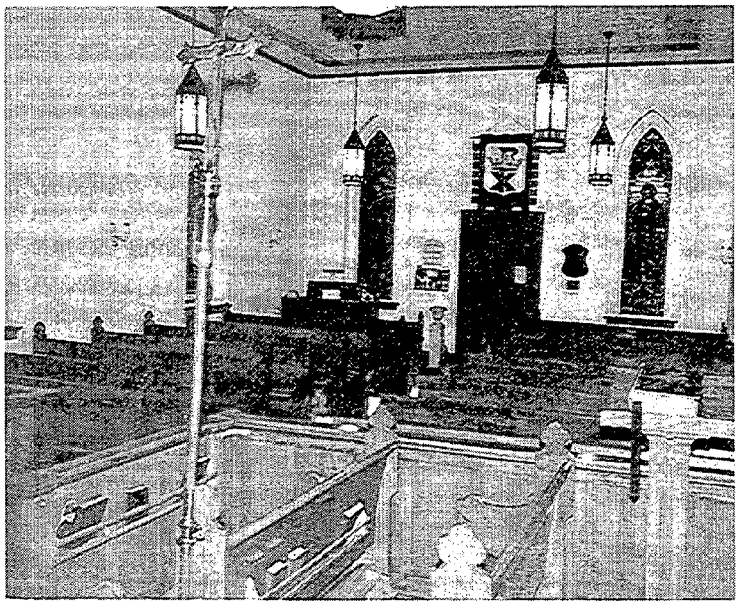
The Town of Milton has been flooded many times. Tropical Storm Agnes in 1972 caused severe flooding and inundated the first floor of the church to a depth of 8 feet. Following that flood, the minister and his congregation decided to make certain alterations to the building to make it more resistant to flood damage. Flooring in the parish house and the altar platform were replaced with creosoted exterior plywood. All exterior surfaces, including the brick walls and window frames, were treated with silicone both for protection and to facilitate cleaning after a flood.

All floor-mounted fixtures, such as the altar, pews, altar rails, and choir screen, are bolted through the floor where they are secured in the basement with washers and wing nuts (Figure A46). Wall-mounted fixtures are fastened by means of cabinet hangers. All such items can be quickly disconnected and



Outside view of church.

Figure A46. Evacuation of damageable items and use of flood-resistant materials



Inside view of church. Basement ceiling showing bolts.

Figure A46.

removed prior to a flood. Tiles in the suspended ceiling of the basement are also removed. To facilitate cleanup and to reduce damages, basement walls and floors are coated with moisture-resistant materials. Space has been left behind the paneling in the basement so that mud can be washed out. Water drains out through openings exposed by removing the base molding. Electrical outlets have been fitted with watertight coverings.

Implementation of these flood damage reduction measures requires adequate flood warning, personnel to carry it out, and a high degree of organization. There appears to be no written plan. One or two church officials are responsible for implementing the measures. A copy of the river stage forecast map prepared by the Baltimore District is posted in the basement and is used to decide when to implement protection measures. Different degrees of response are taken for different levels of predicted flooding. Full evacuation takes 6 to 10 hours to complete. Evacuated items are placed in trucks supplied by local firms and taken to high ground.

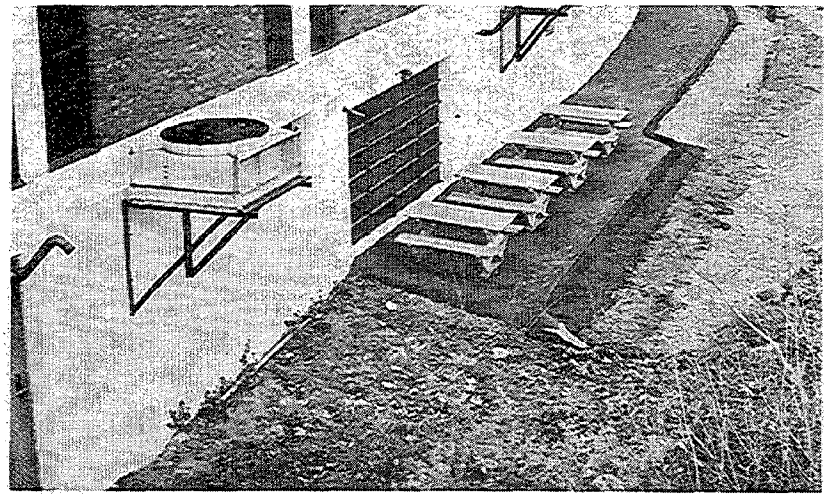
All of the measures that have been incorporated have been done over a period of time. Estimated cost to complete these alterations is $90,000.

By the time the September 1975 flood occurred, most of the alterations to the church had been accomplished. The result was only $1800 in damages even though 1.5 feet of water was on the first floor. Evacuation of damageable items was completed in less than 10 hours during that flood. The success of the congregation's efforts was evident.

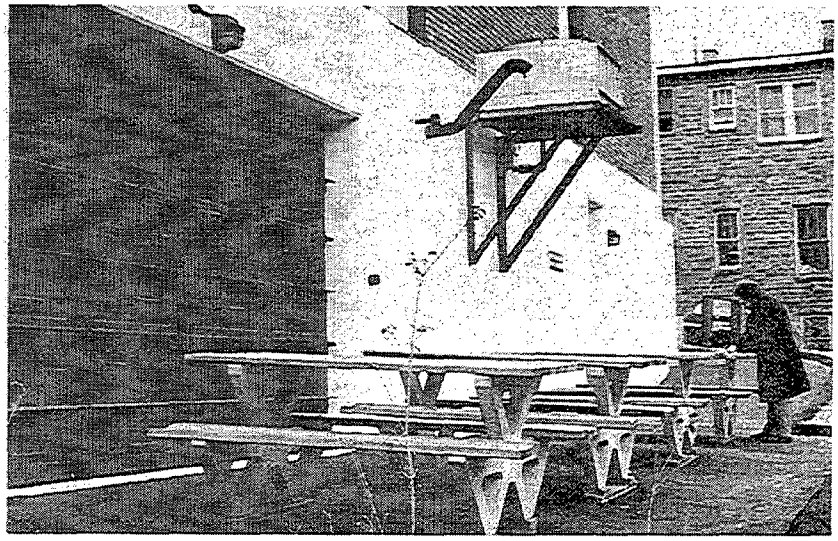
Multistory office building using multiple flood proofing techniques, Wheeling, West Virginia

This multistory office building is located adjacent to the south bank of Wheeling Creek. It is a reinforced concrete frame structure with all glass curtain walls on one side and brick block curtain walls on the other three sides. It is supported on piles and consists of reinforced concrete piers, grade beams, and reinforced concrete floor slabs with expansion joints. The foundation is generally porous, uncompacted rubble with waste fill material that extends to the bank of Wheeling Creek. The lowest floor level, the subbasement, is about 6 feet below the 100-year flood level.

Flood proofing and alterations to this building (Figure A47) were accomplished in two phases, prior to the June 1972 "Agnes" flood and subsequent to the flood, as described below.

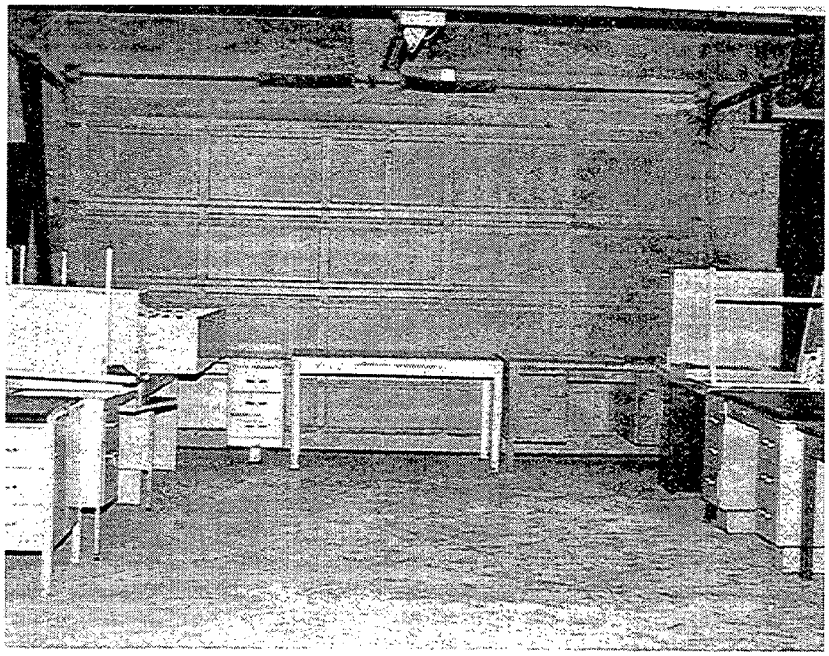


Curtain walls, exterior openings, and wall connections reinforced with steel angle bracing.

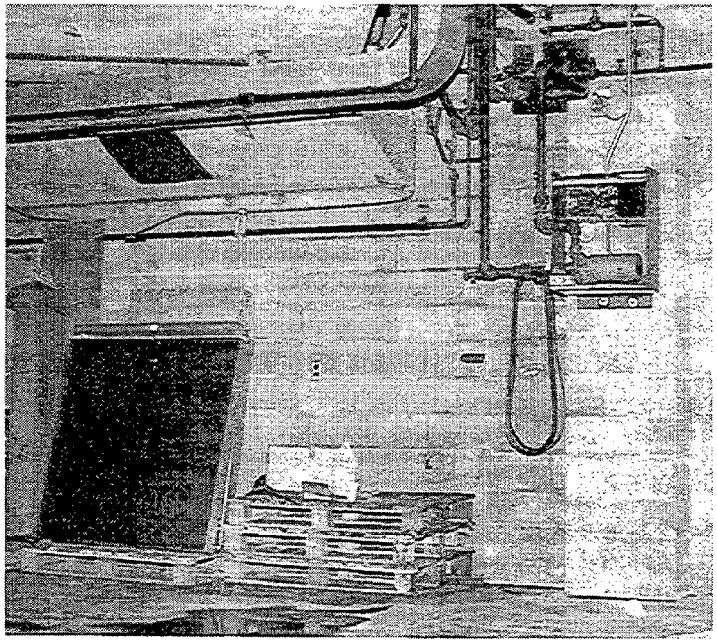


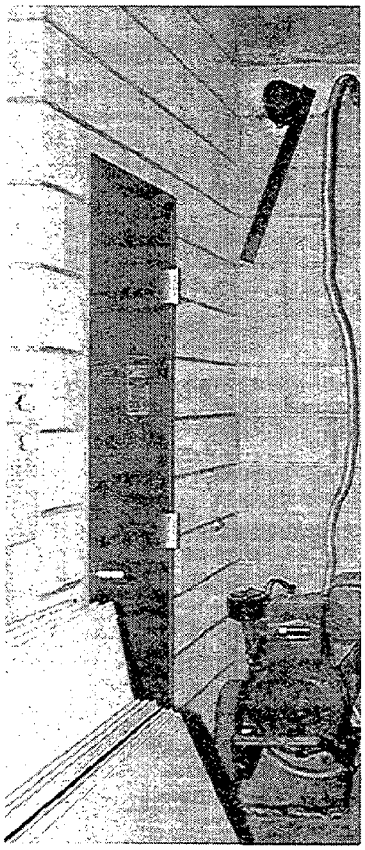
Steel plate closure panels frabricated for the garage door opening.

Figure A47. Use of multiple flood proofing techniques for office building



Supplies previously stored in subbasement were moved to higher floors.





ABOVE: Critical electrical and mechanical panels, switches, and control boards were relocated to a higher level.

RIGHT: Electric pump was installed in the elevator shaft.

Figure A47.

Prior to June 1972 Flood

- ☐ Curtain walls, exterior openings, and wall connections at framing members reinforced with steel angle bracing members at the subbasement level to resist exterior water loads.
- ☐ Curtain wall at rear elevation of subbasement and mechanical room reinforced with backup column or pilaster of block to resist exterior water loading.
- ☐ Damageable supplies previously stored in the subbasement removed to higher floors for storage.
- ☐ Electric sump pump (1-inch) installed in building elevator shaft (sump).
- ☐ Rubber stoppers or plugs secured for installation in floor drains during periods of high water.
- ☐ Steel plate closure panels or bulkheads and support members fabricated for the garage door opening at the rear subbasement level to minimize water seepage and door and interior damages.
- ☐ Two exterior personnel doors at rear subbasement level fitted for temporary sealing using panels and sandbags to minimize seepage.
- ☐ Planned removal during high water of the two air exchange fan units at the rear of the building at ground level.
- ☐ Planned removal of damageable items, electrical switches, and motors in the air-conditioning evaporator unit, located in the open bay at the rear of the building.
- ☐ Storage of sufficient sandbags to seal around all openings after panels or bulkheads are in place.
- ☐ Planning for additional dewatering equipment, when and if needed.

Subsequent to June 1972 Flood

Since the June 1972 flood, critical electrical and mechanical panels, switches, and control boards within the subbasement were relocated to a higher level. Of particular note was the high-voltage electrical switch formerly located at a very low level. This electrical power is critical to continued operation of the sumps and was consequently moved. Electric pumps were placed in the elevator shaft, and two gasoline-operated pumps were acquired for dewatering the subbasement and mechanical room levels (mechanical floor elevation is 1 foot below the subbasement floor level).

The total cost to accomplish all of the above changes is estimated at $12,000. Had no flood proofing measures been taken to protect the building prior to and during the June 1972 flood, the damages and ensuing costs could have ranged from a minimum of $100,000 to a maximum of almost $500,000 because of the concentration of mechanical and electrical equipment at the subbasement level. The remedial flood proofing steps taken prevented flood damages from 10 to 50 times more than the minimal amount ($9000) spent on flood proofing the building. The cost of damages prevented during this one flood (Tropical Storm "Agnes") has paid back the initial $9000 investment for flood proofing many fold.

In retrospect, the subbasement would have had some 2 to 3 feet of water over the floor, with water 3 to 4 feet deep in the mechanical room. Most of the electrical equipment, pumps, motors, switches, panels, gages, meters, and mechanical equipment would have been seriously damaged.

The June 1972 flood was the only flood that affected the building since its construction in the fall of 1970. Although floodwaters reached approximately 3.8 feet deep at the rear of the building, no costly flood damages occurred to the structure or its contents. The only costs incurred were for the installation of flood proofing measures previously described (a total cost of approximately $6000) and for flood proofing preparations prior to the June 1972 flood and cleaning the debris after the flood (an additional $3000). Therefore, the total cost to keep the building from flooding during the June 1972 Flood is estimated at $9000.

It should be noted that there are limitations to flood proofing of this type. Because of dewatering, high water on the outside of the building could reach a height that could cause excessive structural loads and ultimately floor slab or rear wall failure. Although a rare possibility, it could happen when floods of greater magnitude than the 100-year frequency flood occur. This would amount to 6 feet or more flooding at the rear of the building.

A recent inspection revealed that bulkhead installation at two personnel doors could possibly be difficult due to gasket deteriorations and/or obstructed anchor holes. Since no standby electric generation capability exists, the dewatering of the subbasement and mechanical room may not be sufficient to avoid damage. Also, no sandbags are presently stored on site, as originally designed.

Fiberglass manufacturing facility with miscellaneous flood proofing measures, Ashton, Rhode Island

The facility is located directly alongside the Blackstone River and, as a result, is subject to frequent flooding. The facility consists of two major buildings: the main factory building, constructed in 1867, and a warehouse built in 1957. The factory has a stone and masonry foundation with brick walls and is comprised of four floors. The warehouse is a single-story structure with a concrete foundation and corrugated steel walls. It was built so that the first floor is above the 100-year flood elevation. Ramps provide access to the building for forklift and heavy equipment. Employees can also use stairways and ladders to get in and out of the warehouse.

The flood proofing system for the factory is more complex. It consists of 45 flood proofing stations. Each station is designed to protect a specific area within the plant. These stations are numbered and located throughout the plant. They are painted bright red, with their respective numbers in yellow. Three times a year, the minutest detail of each station is inspected, and any alterations or adjustments are given top priority by the plant engineer. Each station in the flood proofing system is coordinated with the elevation of the river and is based on the known elevation of critical areas within the plant and past flood experiences. The plant engineer has installed a gage on the Blackstone River and can accurately determine the elevation of the river. As the river reaches various stages, corresponding flood proofing procedures are put into operation. The plant engineer is currently storing the entire flood proofing system on a computer, so that as the gage indicates the level of the floodwaters, the computer will print out the appropriate action to be taken.

The majority of stations within the system employ two basic flood proofing techniques. These are wooden planks used as barricades at doors and passageways, and steel plates that are bolted over windows and vents. Each door and passageway is equipped with slots on each side, and as the river rises, the wood planks which are located at that particular station are dropped into the slots, a sheet of plastic is applied, and then a row of sandbags is placed in front of the barricade to help seal it off. Adjacent to each window and vent is a steel plate. When that station is flood proofed, it is covered with a sheet of plastic, the steel plate is bolted on, and then a row of sandbags is placed over the steel plate. Other stations that require action during times of flooding are shutoff valves which prevent floodwaters from entering the building through drain pipes. In addition to these stations, pumps have been permanently located in areas within the building where seepage has been experienced in the past. Critical equipment located in these areas has been elevated a few inches to prevent damage from the small amount of water that does seep in. In addition to the flood proofing stations, an emergency trailer is located in an upper-level parking area. This trailer contains portable pumps, gas cans, and plastic and sand

bags. In the event that all sandbags are used, the salt spreader used during snow emergencies has been specially equipped to fill sandbags.

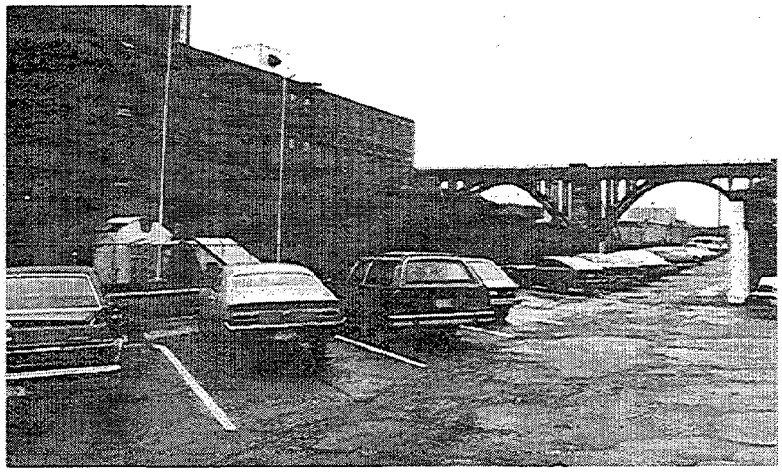
In addition to these active flood proofing techniques, permanent measures have been taken to prevent flood damages. Nonessential windows and openings have been bricked up, the electrical switching station has been surrounded by concrete walls, storage tanks have been anchored and surrounded by concrete walls, and the three sewage pumping stations located within the facility have been completely enclosed. Bulkheads were built in the basement to isolate floodwaters to certain areas should the external closures fail. Interior drainage, from roofs, and seepage has been routed to multiple-sump discharge points.

Outside of the building, critical electric substations (whose shutdown would stop plant operation) were fitted with closures. Exterior motors were modified to allow rapid physical and electrical disconnects and movement to dry ground.

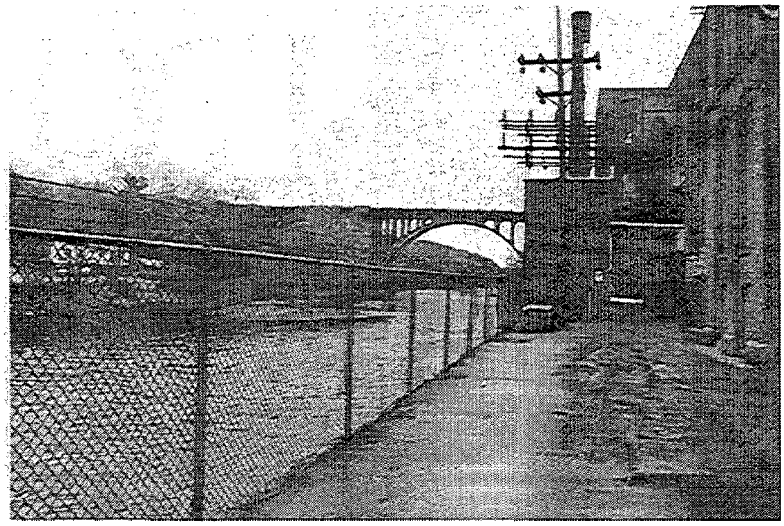
The system has evolved since 1955 and continues to be modified as needed. It is basically a "home-grown" system, designed and implemented by staff with no outside expertise provided. Special devices, such as a sandbag-filling jig and a forklift extension, are examples of the innovative approach to flood proofing. Some miscellaneous flood proofing measures used by the facility are shown in the 21 views of Figure A48.

Because it is imperative to management that the plant operates continuously, they have expended a great deal of time and money to ensure that flooding does not interrupt their flow of production. They have a well-documented, detailed system, which leaves nothing to chance, and every piece of necessary equipment is on site. Equipment is regularly checked and kept in good working order. Since the site is subject to frequent flooding, the personnel know where the problem areas are and how to protect them. The flood proofing system is extremely effective because the plant engineer views flood proofing as an essential element to operation of the facility.

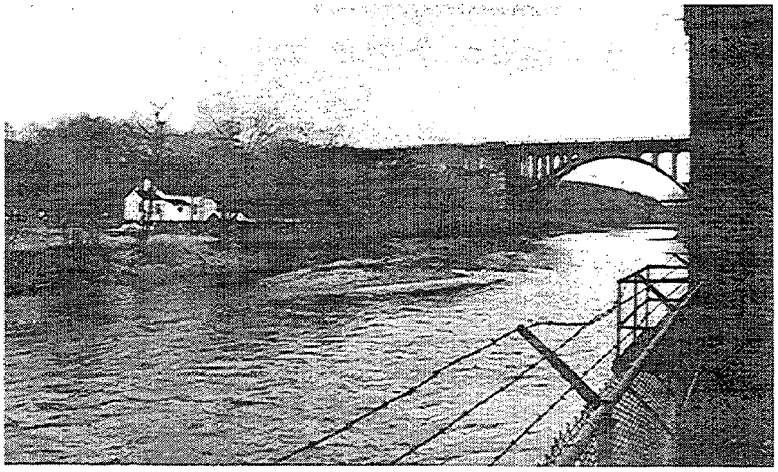
The total estimated cost of flood proofing the plant is $100,000.



1. View of fiberglas plant from parking lot (river on far side of building).

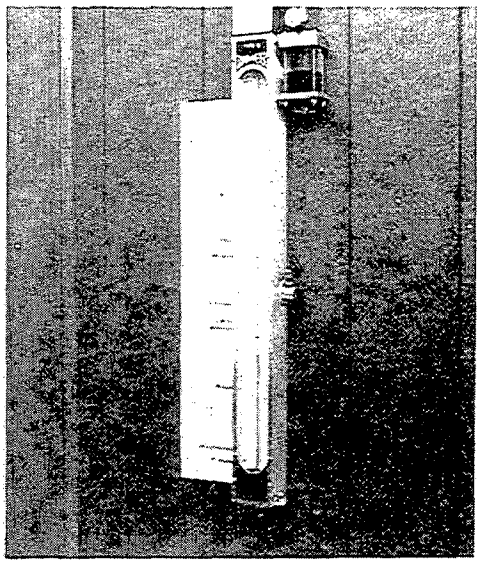


2. Looking upstream on Blackstone River. Note substation location.



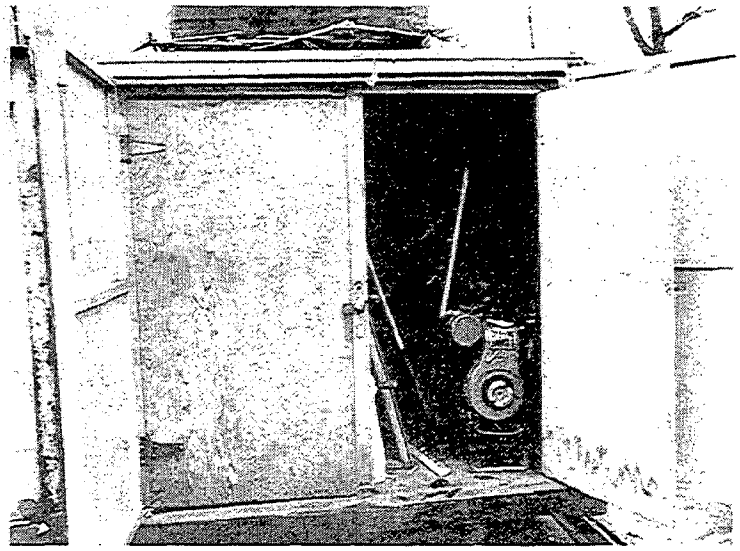
3. Note deposition of riverbank washout material in river, reducing conveyance.

Figure A48. Manufacturing facility using miscellaneous flood proofing measures

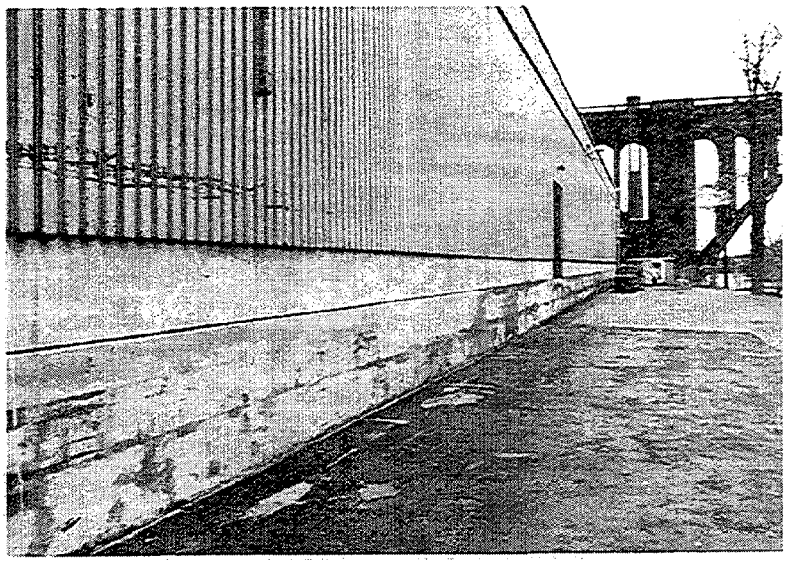


4. Manometer type gage in flood coordinator's office. Calibrations are in inches above datum and also invoke certain procedure phases.

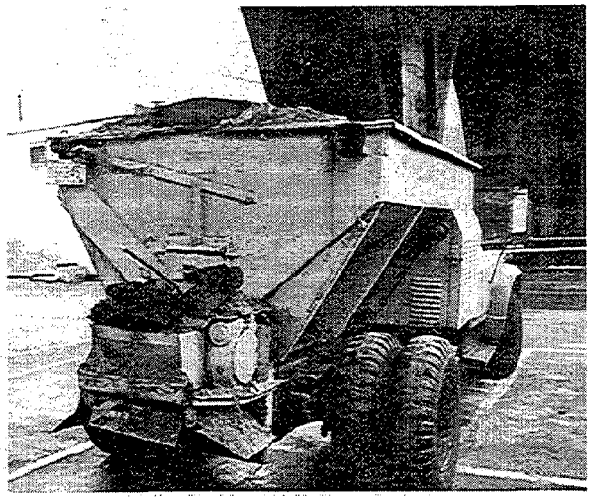
5. Flood control equipment storage shed, masterlocked for security.



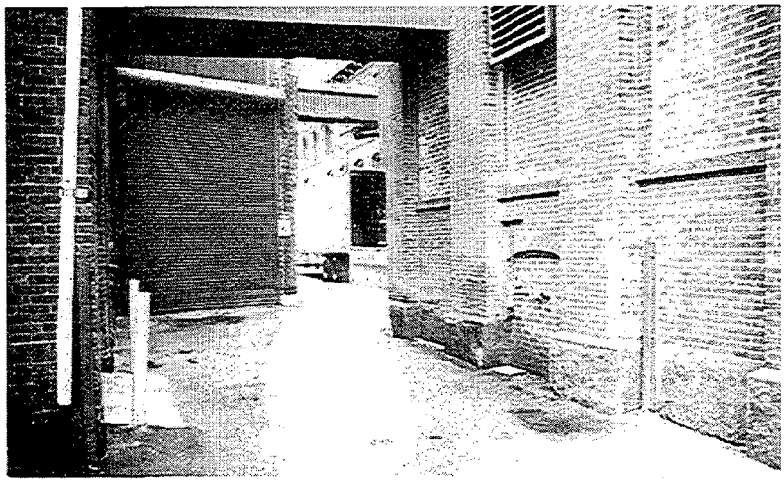
6. Shed open—note pump.



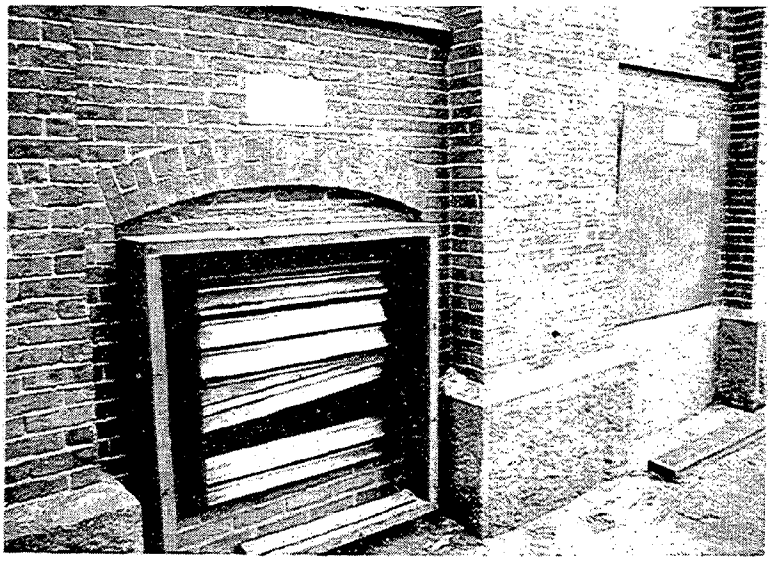
7. Finished product warehouse was under construction when 1955 flood hit. Floor grade was subsequently raised by 4 feet.



8. Sand spreader fitted with special jig which flip-flops to fill sand bags.

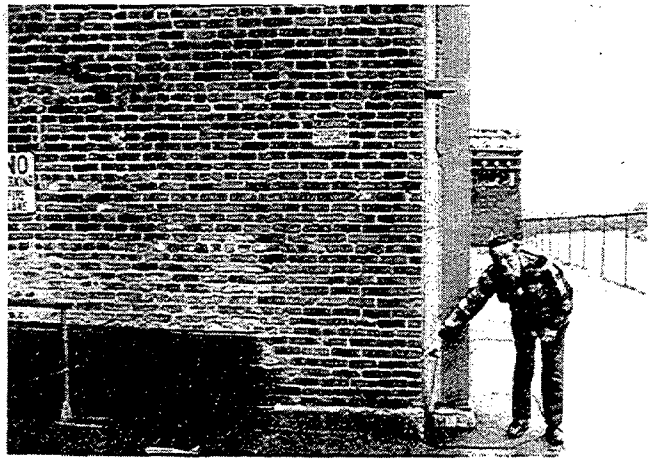


9. Outside flood control station: (1) foreground is allowed to flood, (2) background is protected by stoplogs in vertical channels, and (3) note two pump exit ports (electric & steam syphon) at former window which has been bricked.

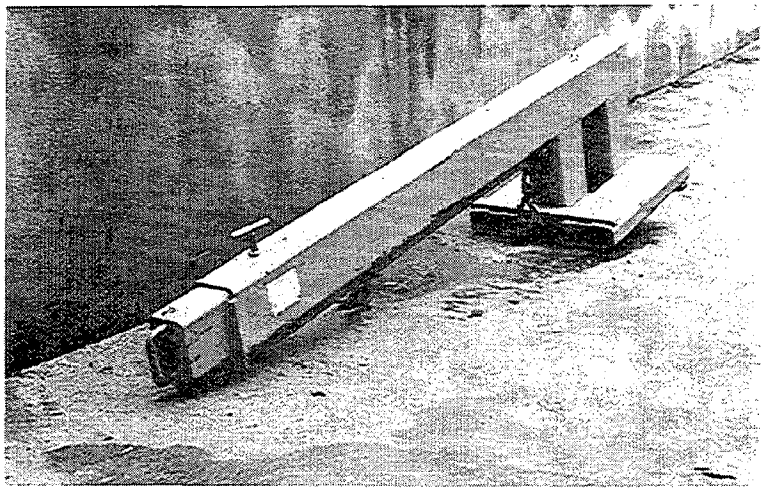


10. Vent opening and nearby cover. Bolts are inspected, loosened, and lubricated periodically (2 or 3 times per year)

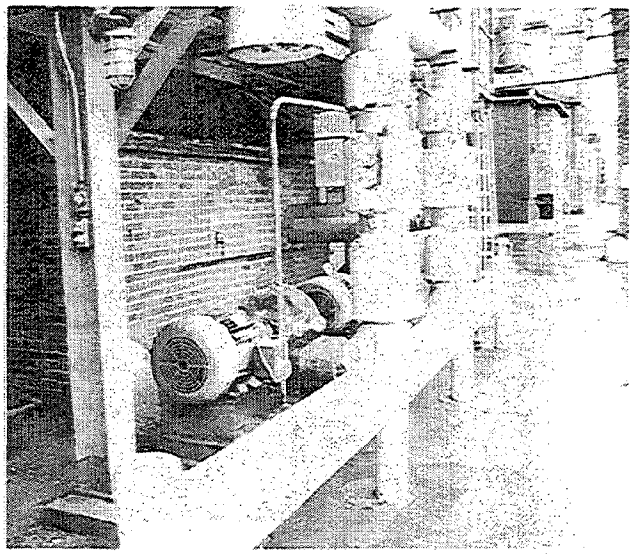
11. Building door with closure fittings.



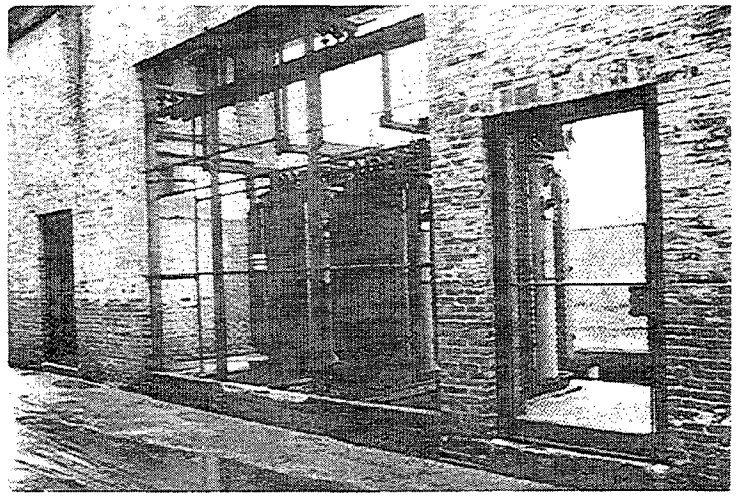
12. Height of water during 1982 flood.



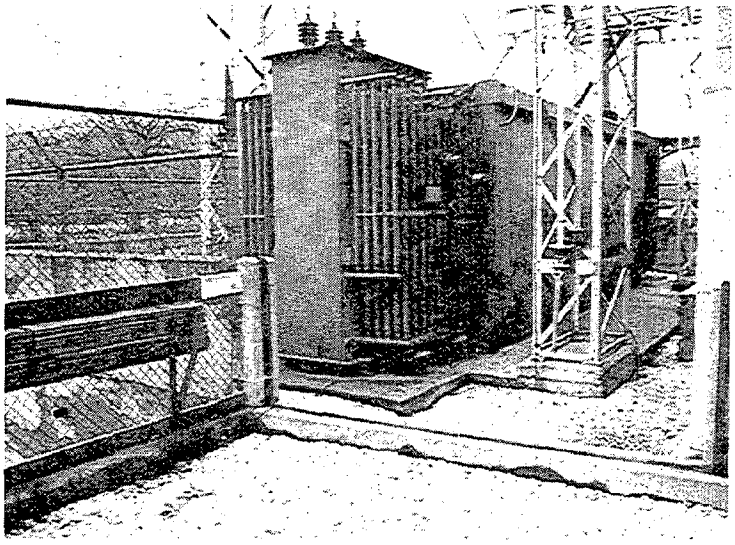
13. Specially fabricated extension for forklift allows sufficient reach to extract electrical motors.



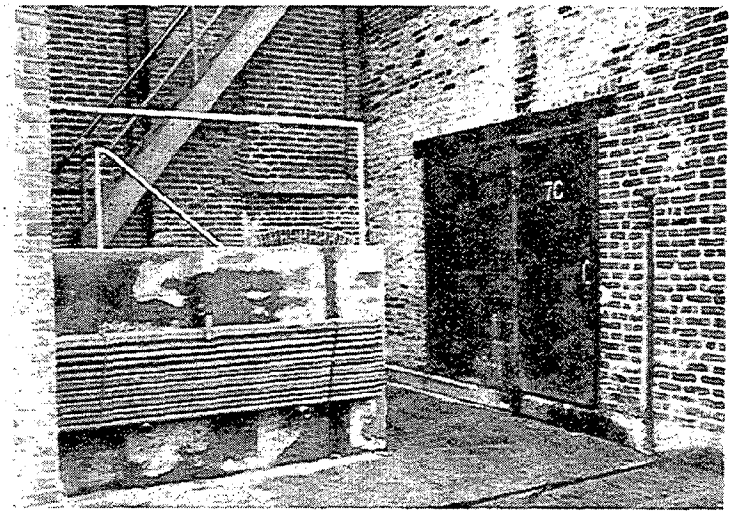
14. Motors located in flood area: (1) characterized by quick disconnect mounts & electrical connections, and (2) note rings on top for fork lift pickup.



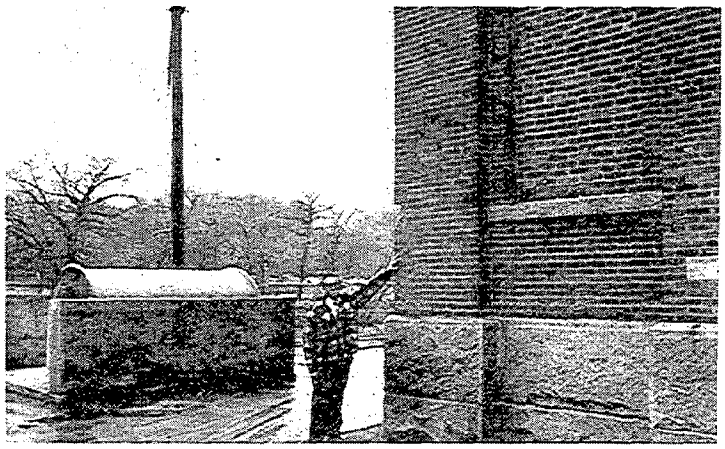
15. Electrical substation: lip offers protection for higher frequency, lower stage flooding.



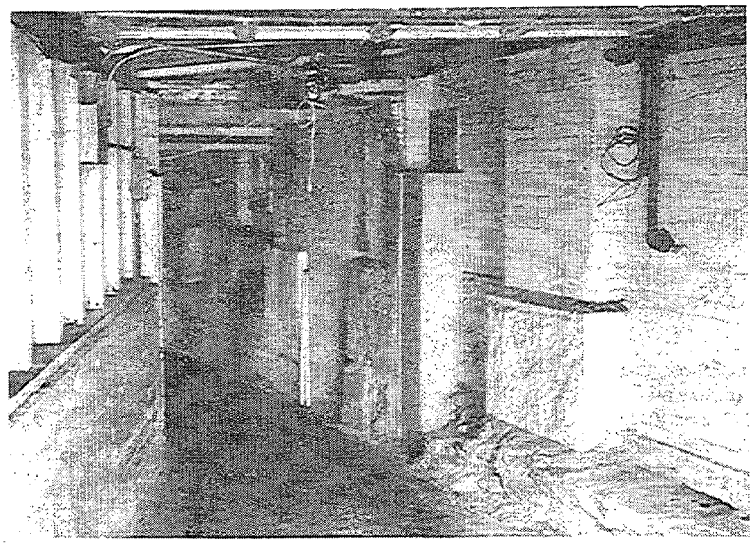
16. Another substation: (1) note closure fittings and stoplogs stored nearby, (2) note drain for normal rainfall, and (3) during flood, interior drainage is pumped.



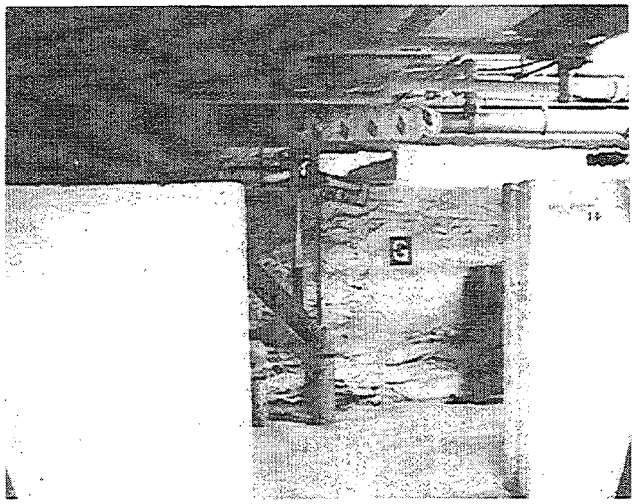
17. Stoplog panels stored close to point of usage.



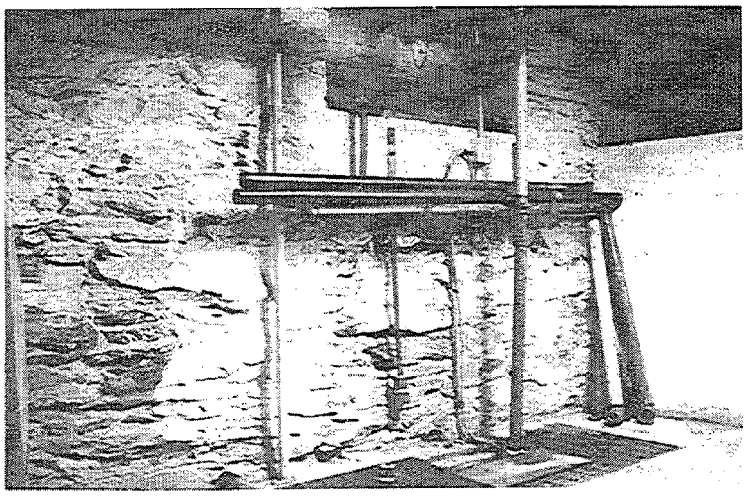
18. Height of water during 1955 flood.



19. Main basement entrance & closure point.



20. Interior bulkhead: (1) if exterior closures fail, water is held to the foreground area, and (2) note "Flood Control Station 14" notation. This type of marking is used throughout, and ties in with flood-fighting procedural steps, as well as "dry-run" procedures.



21. Basement sump: (1) discharge pipe shown is attached to electrically operated pump, triggered by float switch; (2) in event of failure or lack of capacity, standby pipes are connected to a steam syphon; and (3) note stone foundation, allowing a certain amount of seepage.

Appendix B: Corps of Engineers District Offices

Flood Plain Management Services Program representatives in each of the following Corps District offices can provide additional information concerning flood proofing techniques. A map showing the location of these offices is shown on page 104.

U.S. ARMY CORPS OF ENGINEERS OFFICES

US Army Corps of Engineers
Headquarters
20 Massachusetts Ave., NW
Washington, D.C. 20314-1000
Attn: CECW-PF
202/761-0169

US Army Corps of Engineers
Lower Miss. Valley Division
P.O. Box 80
Vicksburg, MS 39181-0080
Attn: FPMS Coordinator
601/634-5827

US Army Corps of Engineers
Memphis District
B-202 Clifford Davis Fed. Bldg.
167 North Main Street
Memphis, TN 38103-1894
Attn: FPMS Coordinator
901/544-3968

US Army Corps of Engineers
New Orleans District
P.O. Box 60267
New Orleans, LA 70160-0267
Attn: FPMS Coordinator
504/862-2539

US Army Corps of Engineers
St. Louis District
1222 Spruce Street
St. Louis, MO 63103-2833
Attn: FPMS Coordinator
314/331-8491

US Army Corps of Engineers
Vicksburg District
2101 North Frontage Road
Vicksburg, MS 39180-5191
Attn: FPMS Coordinator
601/631-5416

US Army Corps of Engineers
Missouri River Division
12565 West Center Road
Omaha, NE 68144
Attn: FPMS Coordinator
402/697-2471

US Army Corps of Engineers
Kansas City District
700 Federal Building
Kansas City, MO 64106-2896
Attn: FPMS Coordinator
816/426-3854

US Army Corps of Engineers
Omaha District
215 North 17th Street
Omaha, NE 68102-4978
Attn: FPMS Coordinator
402/221-4596

US Army Corps of Engineers
North Atlantic Division
90 Church Street
New York, NY 10007-2979
Attn: FPMS Coordinator
212/264-7175

US Army Corps of Engineers
Baltimore District
Supervisor of Baltimore Harbor
P.O. Box 1715
Baltimore, MD 21203-1715
Attn: FPMS Coordinator
301/962-3314

US Army Corps of Engineers
New York District
Supervisor of New York Harbor
Jacob K. Javit Federal Building
26 Federal Plaza
New York, NY 10278-0090
Attn: FPMS Coordinator
212/264-4663

US Army Corps of Engineers
Norfolk District
Supervisor of Norfolk Harbor
Waterfield Building
803 Front Street
Norfolk, VA 23510-1096
Attn: FPMS Coordinator
804/441-7779

US Army Corps of Engineers
Philadelphia District
Wanamaker Building
100 Penn Square East
Philadelphia, PA 19107-3390
Attn: FPMS Coordinator
215/656-6550

US Army Corps of Engineers
North Central Division
111 North Canal Street
Chicago, IL 60606-7205
Attn: FPMS Coordinator
312/353-1277

US Army Corps of Engineers
Buffalo District
1776 Niagara Street
Buffalo, NY 14207-3199
FMS Coordinator
9-4143

US Army Corps of Engineers
Chicago District
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Dallas, TX 75242-0216
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Albuquerque, NM 87109
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Galveston, TX 77553-1229
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Little Rock, AR 72203-0867
Attn: FPMS Coordinator
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Tulsa, OK 74128-4629
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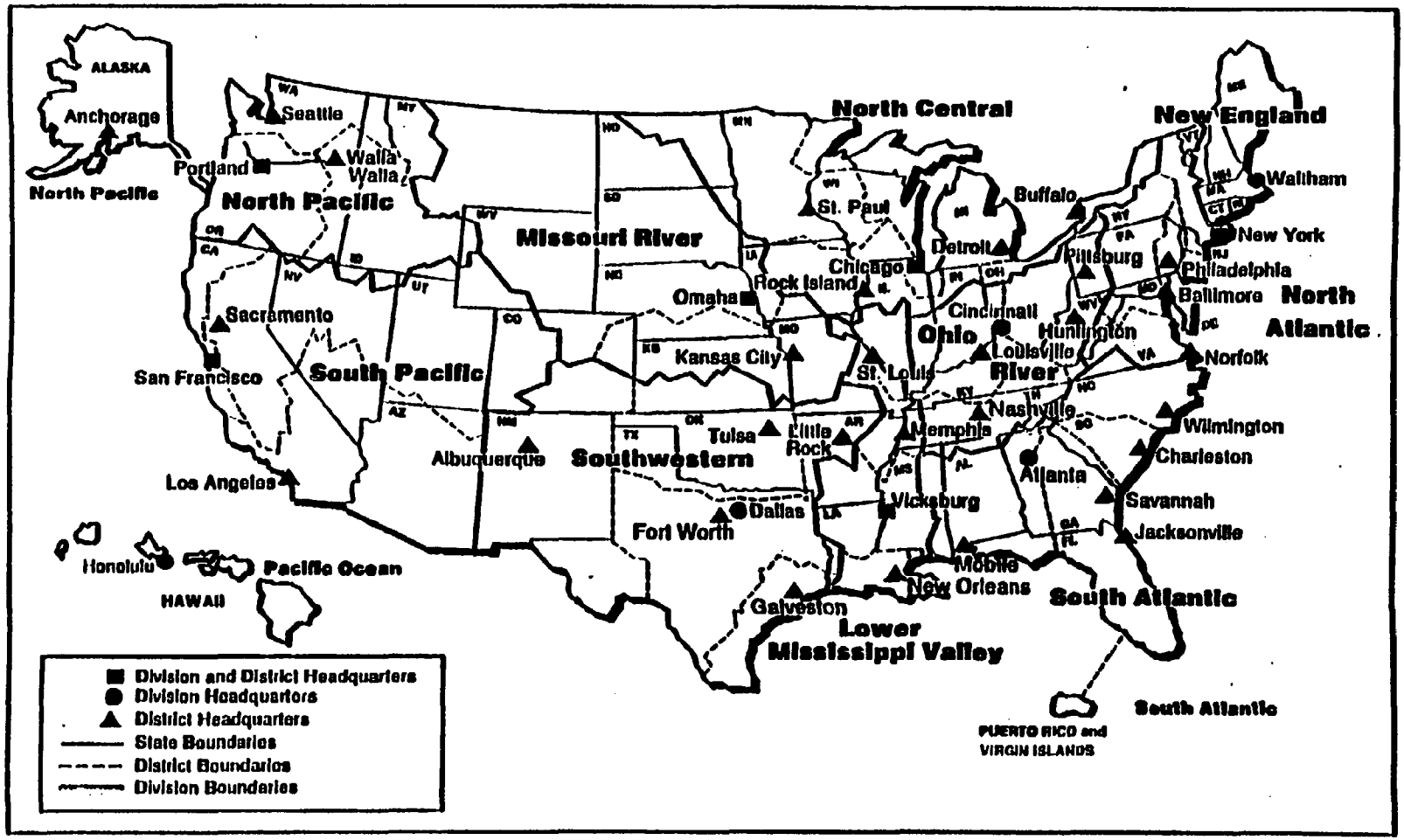

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