FAIRFIELD RESERVOIR AND DAM

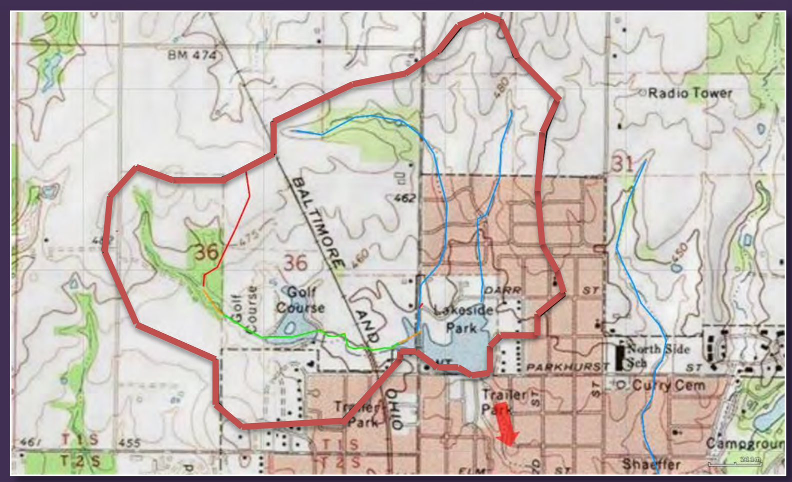
Collaboration of Faculty, Students, and Licensed Professional Engineers

Lakeside Park, in Fairfield, Illinois, obtained its name from the 100-year-old lake that was constructed in the late nineteenth century on a 454 acre watershed. The lake was used for recreational purposes by local residents, but the deteriorating earth dam was declared unsafe in 2007 and ordered breached by the Illinois Department of Natural Resources. Successful collaboration between a ten-member student team, five licensed engineers, four faculty, the Fairfield Parks Board, and the Fairfield Town Council resulted in a design for constructing a new dam, reestablishing a 12-acre lake, and protecting residents of the city of Fairfield.

Project Description

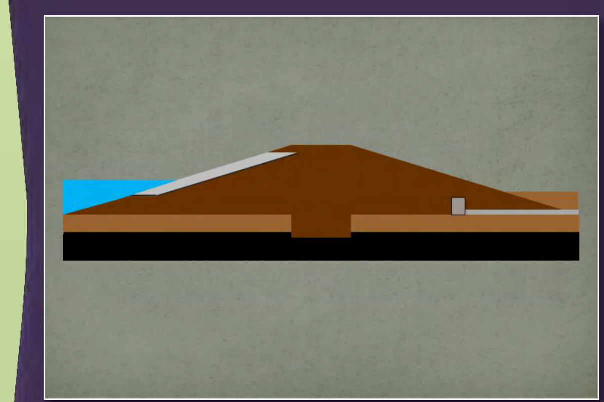
In 2012, the Fairfield Park District reached out to our team of ten civil engineering students for assistance in designing a new dam at Lakeside Park and restoring the aquatic ecosystem that existed for over 100 years. The scope of work for the project included designing a new earth dam and spillway system, creating a reservoir in Lakeside Park, and enhancing the aesthetic appeal of the area. The project was designed to meet Illinois dam safety guidelines and provide flood protection to the city of Fairfield.

Multidisciplinary Approach

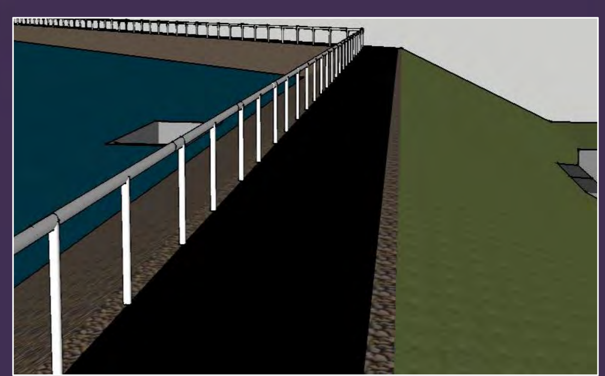


HYDROLOGY /HYDRAULICS- The HEC-HMS and HEC-RAS models were used to analyze different spillway configurations. A spillway system was designed to create a 12-acre lake with 5-feet of freeboard. A large reinforced concrete drop inlet structure will provide moderate flood protection. The spillway system includes precast concrete box conduits, a drawdown pipe and gate valve, and a stilling basin

ENVIRONMENTAL - A lake aeration system consisting of multiple diffusers will maintain healthy dissolved oxygen levels in the lake and promote vertical mixing to greatly reduce stratification and eutrophication. The aeration system, combined with two new sediment dams, will increase the clarity of the lake for aesthetics, providing a healthier lake where aquatic wildlife will thrive.

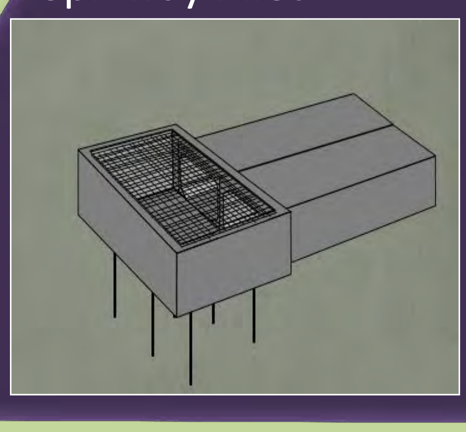


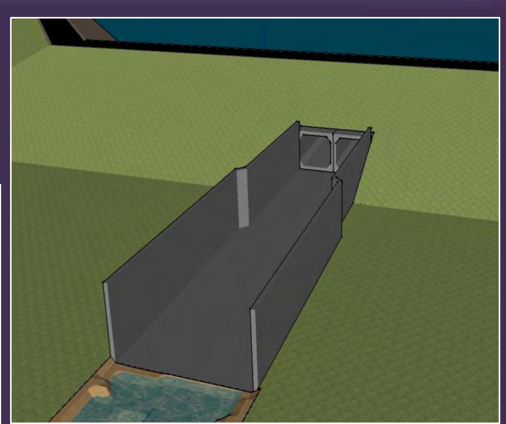
GEOTECHNICAL - A homogeneous earth fill dam was designed with 3H:1V slopes , a 12-foot crest, riprap slope protection, and a core trench excavated to bedrock. A stability analysis was conducted to determine the factors of safety for slope stability under six loading conditions. A trench drain and exit pipe were designed to enhance stability and keep the downstream slope of the dam dry for maintenance.



WALKING PATH - A walking trail will encircle the lake. A 10-foot wide shared-use path with guard rail will accommodate pedestrians as well as bicycles. A two-foot minimum graded shoulder will provide clearance from trees, poles, or other obstructions. The trail surface will consist of an asphaltic concrete surface and crushed limestone aggregate base course.

Spillway inlet

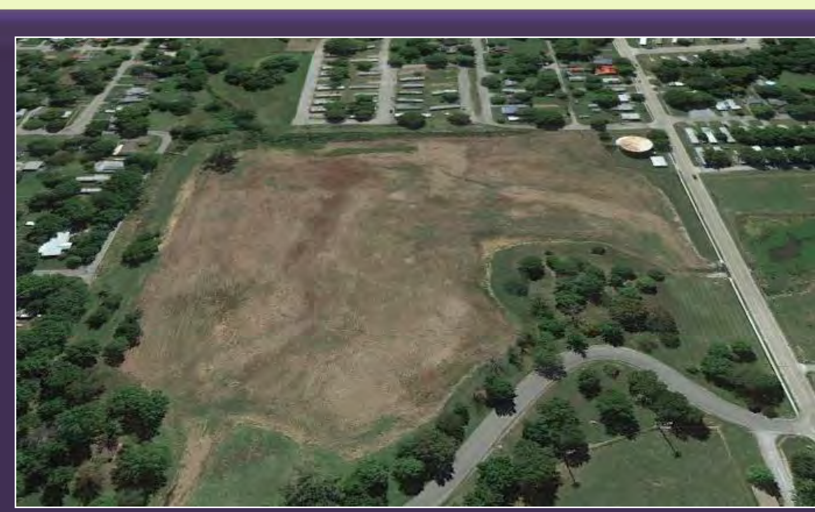




Stilling basin

STRUCTURAL - The spillway inlet consists of a large reinforced concrete drop inlet structure. The inlet will be capable of discharging runoff from a 50% PMF through two 8-foot by 6-foot concrete conduits leading to Johnson Creek. To ensure that no large limbs or debris are discharged through the conduits, steel grates will be placed on top of the inlet. Steel anchors will be attached to inlet foundation and anchored to bedrock.

Hydraulic, geotechnical, structural, and environmental engineering teams were organized early in the design phase. Team meetings were held each week to encourage frequent communication, brainstorming, and coordination with professional engineers .



FINAL DESIGN - A drop inlet spillway, stilling basin, homogeneous earth dam, and lake basin excavation will create a new 12-acre reservoir in Lakeside Park. A walking trail around the site and aeration system will add aesthetic appeal.

Public Safety, Health, and Welfare

The new earth dam will revitalize Lakeside Park and resurrect the Fairfield Reservoir. It will protect public safety by providing flood protection for downstream residents. Children walking to school and the park currently use an unsafe log bridge to cross Johnson Creek. The new design eliminates that dangerous crossing with the new asphalt path on the dam crest. A maintenance and operation plan and an emergency action plan were developed to ensure the long-term operation of the dam.

Knowledge, Skills, and Experience

- Technical: learned to analyze alternatives with a weighted decision matrix, prepare federal 404 permit applications, design a high hazard dam to meet state safety standards, and use SketchUp 3D to evaluate design options
- Codes and Standards: New dam and reservoir were designed to meet state and federal dam safety laws, regulations, and guidelines, building codes, ACI codes, AISC codes, and sustainability guidelines
- Communication:
  - *Writing*-Preparation of an SOQ, Proposal, PER, Decision Matrix for Alternatives, permit applications, final engineering report, and design drawings.
  - *Oral*-Presentations to project sponsor, regional undergraduate conference, and state ASCE meeting
- Project Management: weekly team meetings, MS Project schedule, time management

Fairfield Reservoir and Dam

Abstract

All civil engineering students complete a two-semester long, real world, team capstone design project with an external project sponsor. For this project, the student team prepared a statement of qualifications (SOQ), visited the project site, met with the project sponsor, developed a scope of work, and prepared a project proposal. The proposal included the scope of work, a project schedule, and a list of tasks and deliverables. After the proposal was accepted by the project sponsor, students spent the fall semester performing site investigations, engineering surveys, code and standards familiarization, and permit research. The team evaluated four alternatives and prepared a decision matrix. A preliminary engineering report (PER) and conceptual drawings were developed and presented to the project sponsor. After the project sponsor selected a preferred alternative, the student team spent the spring semester performing final design. The team had two project managers and was advised by a faculty member who is a registered professional engineer. Throughout the two-semester project, the student project managers provided written updates to a four-person professional engineering advisory group, maintained an electronic project file, and conducted numerous meetings.

Lakeside Park, in northwest Fairfield, Illinois, obtained its name in honor of the over-100-year-old lake that was constructed in the late nineteenth century. For most of its existence, the lake was used for recreational purposes by local residents, but the deteriorating earth dam was declared unsafe in 2007 and ordered breached by the Illinois Department of Natural Resources. Since 2007, the absence of the reservoir caused increased flooding downstream of Lakeside Park in the community of Fairfield. The park's aquatic ecosystem transitioned to a low quality wetland, forcing any future construction to require U. S. Army Corps of Engineers approval.

In 2012, the Fairfield Park District contacted the university and requested assistance from a team of ten civil engineering students in designing a new dam at Lakeside Park and restoring the aquatic ecosystem that existed for over 100 years. The scope of work for the project included designing a new earth dam and spillway system, creating a 12-acre reservoir in Lakeside Park, and enhancing the aesthetic appeal of the area. The spillway was designed to meet Illinois dam safety guidelines for high hazard dams and provide flood protection to the city of Fairfield.

The Fairfield Park District was presented with four design alternatives by the team in December 2013, and a final design was selected. The new earth dam was designed with 3H:1V slopes, a 12-foot wide crest, a riprapped upstream slope, and a 21'-8" x 11'-8" reinforced concrete spillway inlet. The inlet will be connected to two 8-ft by 6-ft precast concrete conduits capable of safely discharging runoff from the 50% Probable Maximum Flood (PMF) to a concrete stilling basin. Keeping with the Park Board's desire to create an aesthetically appealing park the community would embrace, the design includes a walking trail around the lake, a lake aeration system, two sediment dams upstream of the lake, and a deeper reservoir to increase recreational opportunities. Permit applications were prepared to allow the Park Board to obtain state and federal approval for the project and resolve any wetlands issues prior to construction. The design was complicated due to the structure's location in a residential area, its classification as a high-hazard dam, and the large 37:1 watershed-to-reservoir ratio which required the design of an innovative high capacity spillway system.

Fairfield Reservoir and Dam

I. Project Description

Civil engineering students designed a new dam in Fairfield, Illinois to replace a 100-year old dam breached in 2007. Fairfield is located near the epicenter of natural gas and oil development in the New Albany shale formation. Similar to energy development in the Bakken shale in North Dakota and the Marcellus shale in Ohio and Pennsylvania, southern Illinois has witnessed an increased use of horizontal drilling and hydraulic fracturing technology to expand energy resource development. Yet Fairfield, a community of 5,154 with a poverty rate of 17.4% and an unemployment rate of 9.5%, has not experienced the economic benefits of the increased energy exploration and production (U.S. Census Bureau, 2012). Fairfield is the county seat of Wayne County which had a peak population of 27,626 in 1900 (about the time the original dam was constructed) and currently has a population of 16,760. The reservoir created by the old dam was a community asset, a 9-acre lake used for recreation by both city and county residents. However, the dam had inadequate spillway capacity and structural stability issues. In 1985, the Illinois Department of Natural Resources classified the dam as a high hazard structure (Class I) due to the presence of a trailer park and other residences located immediately downstream of the dam. The dam was classified as a small structure due to the reservoir's impounding capacity and dam height. After an inspection and analysis of the dam by IDNR revealed it was a safety hazard, the dam was subsequently breached and the reservoir drained in 2007 under official order. This activity was authorized by a 404 permit (NWP #27) issued by the Louisville District Corps of Engineers to the Fairfield Park District; the permit has since expired. The following year, the old reservoir bed was designated as a wetland by the U.S. Army Corps of Engineers. Since then, the existing lakebed has become overgrown with vegetation, valuable storage capacity was eliminated, and increased flooding has occurred along Johnson Creek downstream of the dam in the city of Fairfield. A study of the lakebed was performed by Engineering Firm A in 2012 and the area was classified as 9-acres of wetland. The site is shown in Figure 1.

Figure 1. Existing lakebed at Lakeside Park.

II. Collaboration of faculty, students, and licensed professional engineers

The ten-member student team engaged in frequent and detailed communication with groups including university faculty, practicing professional engineers, the Fairfield Park District, the Fairfield mayor's office, the U.S. Army Corps of Engineers, and several other organizations. The civil engineering faculty of the university contributed advice and knowledge during the design process in their areas of expertise, and the chair of the civil engineering department served as faculty advisor throughout the project. Our team worked closely with a professional advisory board that consisted of several practicing engineers from reputable engineering firms, including firms that currently work for the Fairfield Park District and the City of Fairfield (two completely separate political entities). The professional advisory board received written project updates every three weeks during the spring 2014 semester, and they actively contributed advice and recommendations based on their years of engineering experience that aided the design process. The project sponsor was the Fairfield Park Board. The team followed stringent dam safety design procedures that met codes, standards, and regulations.

Team members met with members of the Fairfield Park Board in early September 2013 at Lakeside Park and discussed design options for the site. Describing the current park as an eyesore, the Park Board's primary desire was to construct a new lake and enhance Lakeside Park to allow it to serve as a gathering place as it did for over 100 years.

On September 25, 2013, our faculty advisor attended a meeting in Fairfield led by the mayor. In attendance were the Chair of the Fairfield Park Board, members of the City Council, two members of the U.S. Army Corps of Engineers regulatory branch, the City's consulting engineers, and staff representing the local state representative, the district congressman, and a United States senator. The situation at Lakeside Park, primarily the increased flooding in Fairfield downstream of the park, was discussed. The Corps of Engineers members visited Lakeside Park prior to the meeting and explained that wetland mitigation may not be necessary to the extent originally thought, as it appeared to them that only 2-3 acres of low-quality wetlands existed in the old lake bed.

In December, the student team presented four design options to the Fairfield Park Board in a preliminary engineering report. A planned presentation was cancelled due to heavy snowfall and the options were discussed over a conference call. The team's preferred alternative was selected by the Park Board. This option is shown in Figure 2 and included designing

- a new dam slightly upstream of the old dam, a spillway, and stilling basin
- a walking path around the lake and on the dam crest
- sediment dams at the two lake inlets
- a lake aeration system, and
- a new 400 foot long culvert in a ditch to route Johnson Creek around the eastern edge of the lake.

Additionally, the lake would be deepened, increasing its overall storage capacity.

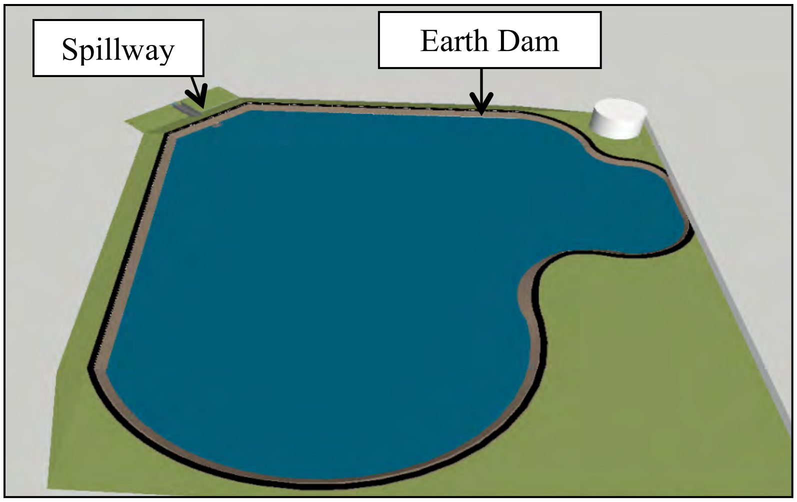


Figure 2. Proposed layout of the new Fairfield Reservoir.

Professional engineers from Engineering Firm A answered geotechnical team questions about Fairfield's historical and geological data which was not readily available. A 2003 soil boring report was provided to the team by the Fairfield Park Board. The soils report included four boring logs, SPT test data, Atterberg Limits test data, and consolidated undrained triaxial test data for undisturbed samples from the old dam and foundation. Two professional engineers from Engineering Firm B reviewed team calculations and reports in addition to suggesting additional design steps. Engineering Firm C contributed experience in filing Corps of Engineers permits and critiquing reports. Team members then met with the Corps of Engineers in February to discuss the wetland permits.

Having the opportunity to work with practicing professionals and organizations allowed the team to gain valuable communication and collaborative skills. Throughout most of the design phase, the team provided progress reports to professional engineers working with the Fairfield Park Board and the city of Fairfield. These engineering firms will ultimately be responsible for ensuring the dam design project comes to fruition after the members of the team graduate. In addition, two professional engineers specializing in dam design were consulted for advice in development of the site. Through the interaction with professional engineers, students learned how to accept criticism and advice. Design is much more than simply complying with codes and standards. Meeting the needs of the project sponsor, understanding the needs of the community, protecting public safety, and developing a sustainable design are very important. Team members learned intermediate design steps which assisted them in delivering a complete and thorough design. The professional engineers were aware of current practices in the real-world as compared to information in handbooks and text books that can be dated. Using this modern knowledge and wealth of experience, the team was able to efficiently complete a design.

III. Benefit to public health, safety, welfare

The final design will revitalize Lakeside Park and resurrect the Fairfield Reservoir, but will also establish a safe living area downstream of the dam by providing flood attenuation. The most important governing factor was protecting public safety, and that was accomplished by designing a stable earth dam and a spillway that could safely pass runoff from the 0.5PMF event. The design incorporated the concerns of the Fairfield mayor's office by providing some inflow hydrograph attenuation to lessen downstream flooding. The final design is expected to attenuate 13% of the peak inflow for the 100-year storm and 17% of the peak inflow for the 0.5PMF event.

The high watershed to reservoir ratio (37:1) and a lake site surrounded by residential development forced the team to develop an innovative spillway design that met state dam safety criteria. The new spillway inlet structure and stilling basin system were integrated with the new earth dam design to create a 12-acre reservoir. The walking trail and aeration system will add aesthetic appeal to the site. The dam will contain an internal drain to control seepage, improve embankment stability, and keep the downstream slope of the dam dry. A drawdown pipe was designed with the spillway inlet to allow the lake to be drained to comply with Illinois DNR regulations. During the design of these project features, students gained an awareness of how each design aspect would influence the outcomes of future features and the final design.

A maintenance and operation plan was prepared for the Park Board to specify procedures for operating and caring for the new dam, spillway system, and outlet works. Items addressed include preventing overgrowth of trees and vegetation on the dam, erosion control measures, inspection of the dam and spillway system, seepage measurements, lake drawdown limits, and a schedule for routine testing of the facilities to be performed in compliance with state regulations.

The team prepared an emergency action plan that outlines steps to be taken in the event of three levels of emergencies at the dam. Examples include anticipation of heavy rainfall that could cause high reservoir levels and large spillway discharges that pose a flooding risk downstream of Lakeside Park, discovery of high levels of uncontrolled seepage, and the presence of slides in the dam. This document requires the owner to notify local law enforcement, fire department, emergency management officials, and the state dam safety office in determining the appropriate course of action for any severe event that could threaten the safety of the dam and areas downstream. These types of plans are very site-specific, but the general idea can be applied to any community project.

Although the City of Fairfield was neither the property owner nor project sponsor, their flood protection concerns were reflected in the design of the new hydraulic structures. Learning code requirements compelled students to develop a sense of responsibility for the citizens of Fairfield. The learning process was a group effort, but with the small team size, students were forced to focus on becoming "experts" in particular areas such as dam safety, wetland mitigation, park utilization, and aquatic wildlife. This emphasized the importance of self-reliance and confidence. Students may not routinely use their knowledge of these specific codes, but having the experience of researching and utilizing available resources allowed the team to make educated decisions to solve future problems.

IV. Multidiscipline and/or allied Professional Participation

After the Park Board approved the recommended design at the end of the fall semester, specialty teams were formed to complete various aspects of the design. Several branches of the civil engineering discipline were involved in the design of the dam and reservoir. Hydraulic, geotechnical, structural, and environmental engineering teams were developed, and team meetings were held each week to encourage frequent communication and brainstorming.

The hydraulic team used the Corps of Engineers HEC-HMS model to analyze different spillway designs, with a goal of keeping the normal pool elevation five feet below the crest of the dam and preventing the reservoir from overtopping the dam and a busy street upstream. Providing flood attenuation downstream was also desired. The team surveyed Johnson Creek downstream of the dam and used the HEC-RAS model to develop water surface profiles for design spillway flow rates to determine the impact of spillway flows on downstream residents.

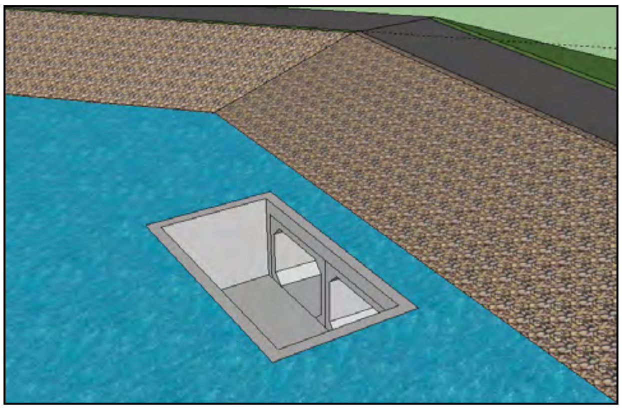


Figure 3. 3-D rendering of drop-inlet structure (without the steel debris grate).

Separate principal and emergency spillways could not be constructed due to the proximity of the dam to residential areas immediately downstream of the dam. Public safety dictated that a combined spillway system be designed to safely pass both 100-year and 0.5 PMF design flows. Spillway conduits were analyzed for various flow conditions and designed to ensure that pressurized pipe flow did not occur during the 0.5 PMF. A 10-inch diameter ductile iron pipe will be connected to the spillway inlet and controlled with a gate valve to allow the Park District to comply with state regulations for draining the lake. A Type II SAF stilling basin was designed to dissipate energy from the water exiting the spillway conduits and reduce damage to Johnson Creek downstream.

The geotechnical team determined the approximate elevation of bedrock from a 2003 soil investigation report and the amount of fill that could be removed from the existing lakebed. The homogeneous earthfill dam was designed with 3H:1V upstream and downstream slopes and a 12-foot crest. To limit seepage, a key (cutoff) trench excavated to competent bedrock was included in the dam design.

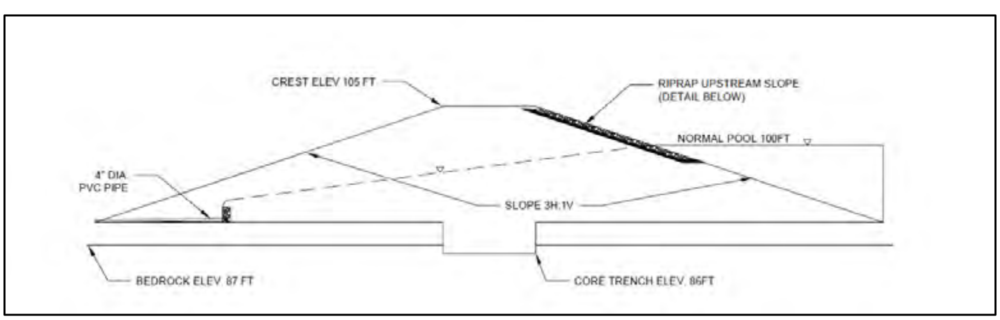


Figure 6. Dam cross-section, including trench drain location.

A stability analysis was performed using the STEDWin and PCSTABL6 computer models. PCSTABL6 uses the simplified Bishop Method to evaluate slope stability. The analysis was conducted to determine the factors of safety for slope stability under the six required loading conditions. The dam is located close to both the Wabash Valley Fault system and the New Madrid Fault system, forcing the dam design to accommodate a peak seismic acceleration of 0.4g. A trench drain was included in the design to increase the stability of the dam, provide the owner with a means of monitoring seepage, and keep the downstream slope of the dam dry for regular mowing. The trench drain will include a perforated pipe that will exit into a solid 4-inch diameter PVC pipe that runs along the edge of the spillway conduits and exits above the base of the stilling basin, allowing the Park Board to monitor and measure seepage.

The environmental team focused on designing two sediment dams upstream of the lake and a lake aeration system. Using the results of a lake aeration undergraduate research study performed by a recent civil engineering graduate, the team determined that the aeration system will maintain healthy dissolved oxygen levels in the lake and promote the vertical mixing of lake water to greatly reduce stratification and eutrophication. The aeration system will increase the clarity of the lake for aesthetics and vastly decrease the amount of chemical usage, providing a healthier lake where fish and other aquatic species will thrive. Using information from a meeting with regulatory personnel from the Corps of Engineers, the environmental team prepared permit applications for wetland mitigation.

The structural team designed a spillway that will consist of a 21’-8” by 11’-8” reinforced concrete inlet structure. The inlet is capable of discharging runoff from a 50% PMF through two 8-foot by 6-foot concrete conduits leading to a stilling basin and Johnson Creek. To ensure that no large limbs or debris are discharged through the conduits, steel grates will be placed on top of the inlet, supported by three beams attached to the top of the 9-foot high spillway inlet structure. The foundation of the spillway inlet structure will be anchored to shallow bedrock beneath the lake.

A walking trail will encircle the lake. A ten foot wide shared-use path with guard rail will accommodate pedestrians as well as bicycles. The trail surface will consist of an asphaltic concrete surface and aggregate base course on top of the compacted subgrade. The aggregate base course will be a crushed limestone. Children currently use an unsafe log bridge over Johnson Creek downstream of the old breach. The new shared-use path on the dam crest will provide them with a safe means of walking to and from school and park facilities.

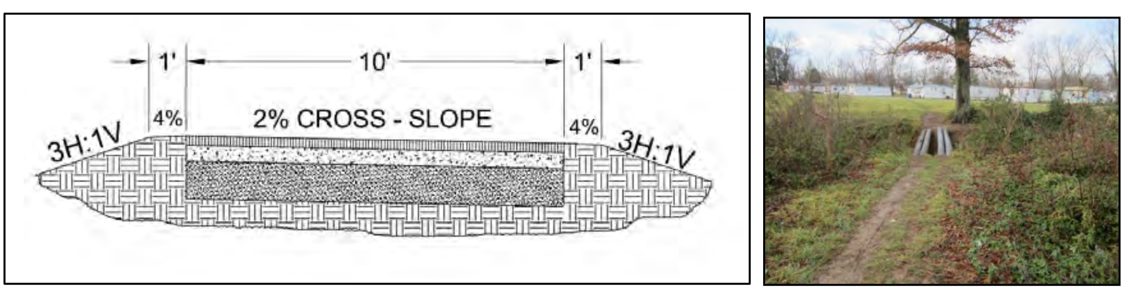


Figure 7. Proposed shared-use path cross-section photo of log bridge over Johnson Creek

V. Knowledge or Skills Gained

The real-world experience gained by completing this design project was an incredible learning opportunity. Researching existing projects, utilizing design codes and standards, working with professional engineers, politicians, community leaders, and project sponsors, as well as completing the iterative design process allowed team members the opportunity to complete an actual design before graduation.

Classroom learning transfers knowledge to students, but the development of engineering judgment requires students to engage in a real-world design project. The design of the Fairfield Dam required collaboration between several groups and a strong management team. Two co-project managers used MS Project scheduling, team meetings, and electronic document management throughout the project. This encouraged team members to meet goals and deadlines throughout the two-semester project duration. Other project management tasks included completing cost estimates, preparing plans and specifications, preparing posters, and making presentations at an undergraduate conference, the state ASCE meeting, and the university's civil engineering advisory council meeting.

Team design projects are common in professional practice, and civil engineering projects usually require expertise from several branches of the discipline. Team members must develop positive and dynamic relationships with one another so that constructive comments can be made and progress can continue. Often, one project task cannot be started until another task is complete. In the Fairfield Dam project, the slope stability analysis could not begin until the spillway design was complete. With the iterative nature of the design process, it can be difficult to move forward with a design when some features are being redesigned. Patience and technical competence are crucial in this phase. Being technically proficient allows team members to determine which aspects of the project can be designed using current information and which aspects need to be redesigned as changes occur. Spreadsheets and numerical tools developed during design were very helpful and can be used for future projects.

Ethical decision-making was considered throughout the entire design process. The design team participated in several ethics sessions to discuss ethical behavior and professionalism. Team members learned that the ethical choice is not always clear. For example, the team felt that although the occurrence of the 50% PMF controlled the design, other failure scenarios (uncontrolled seepage, piping, and slope failure) were more likely. However, a good location for an emergency spillway did not exist, and team made the engineering decision to design a large spillway inlet to ensure that the dam would not overtop and threaten public safety. The team was also forced to consider whether the design should conform primarily to the project sponsor's (the Park Board) goal of a recreational lake or the city of Fairfield's goal of maximum flood attenuation, qualifying the project for more government funding.

The team designed the new dam in accordance with standards from the Illinois Department of Natural Resources (IDNR), Illinois Department of Transportation (IDOT), and United States Army Corps of Engineers (USACE). The project was completed and presented to the Fairfield Park Board on May 2, 2014. Both electronic and hard copies of project deliverables (engineering report, design drawings, permit applications) were presented to the Park Board to allow them to proceed with their goal of resurrecting a 100-year old reservoir for a community that actively uses and treasures Lakeside Park.