Designing an Island Habitat for the Interior Least Tern

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ABSTRACT

The purpose of this project was to develop a design that will create an island environment for the nesting habitation of the Interior Least Tern, an endangered species. The U.S. Army Corps of Engineers (USACE) and the bird's habitat and nesting requirements set forth the following design criteria for the team:

- Island surface area about 0.8 to 1.2 ha (2 to 3 acres)
- Concentrated in the center of the channel
- Island should have gently sloping, sandy beaches
- Less than 10% vegetation
- Withstand high flows

Diverting and manipulating flow by implementing a structure or structures to promote sediment deposition within the center of the Arkansas River near Jenks, Oklahoma was investigated. Both physical and computer modeling were used to explore the development of these hydraulic structures. Each experimental method has its own strengths and weaknesses and the utilization of more than one method provided verification of the overall feasibility of the designs. Based on the data and results gathered during the testing phase, a rectangular riprap structure followed by a chevron riprap structure open to the flow was selected as the final design. Recommendations for implementing the structure along with a cost analysis for the materials and labor required to construct the structure are reported herein. Because of the large expense involved in the implementation of the design structure, it is strongly recommended that a small prototype be built and tested in or near the straight reach of the Arkansas River adjacent to 121st Street south of Jenks, Oklahoma. This will allow for final design verification without affording the total expense of the project.

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INTRODUCTION

The purpose of this project was to develop a design that will create an island environment for the nesting and habitation of the Interior Least Tern. The creation of this island is expected to facilitate the recovery of this endangered species. The 2002-2003 Oklahoma State University Biosystems Engineering Senior Design Team was selected by the U.S. Army Corps of Engineers (USACE) Tulsa District to analyze and propose a solution to the problem.

The Interior Least Tern was listed as an endangered species in 1985, with a total population estimated at 5000. Channelization, irrigation, and construction of reservoirs and pools have drastically depleted the nesting habitats used by the Least Terns. The U.S. Army Corp of Engineers has done various studies on the habitation and breeding styles of the least tern species in the Arkansas River area in order to devise a plan to stabilize the species in that area.

Analysis into the possibility of implementing a structure or structures in the river to divert and manipulate flow to promote sediment deposition within the center of the channel was conducted by the team. The analysis was accomplished through several testing methods to determine a possible design structure that creates an island habitat for the birds. The structures that best served in the manipulation of the river mechanics for island creation are discussed in detail herein.

STATEMENT OF PROBLEM

A solution to problem must conform to a variety of specifications determined both by the habitation preferences of the Least Tern and by the U.S. Army Corps of Engineers. These criterion include location, flow conditions, island design specifications, and cost limitations.

Location

The island habitat should adhere to the following location criterion. The location boundaries are the Arkansas River natural channel from Keystone Dam to Muskogee, Oklahoma. An ideal location is one that is not be too close to the dam, where excess scouring can occur, and not too far downstream, where excess sediment can deposit.

Flow Conditions

The design of the island habitat should be such that the listed conditions should occur at the following flow rates:

- The average flow conditions to maintain proper scour around the island and prevent land bridging are 710 m^3/s (25,000 cfs).

- The minimum flow conditions to maintain proper scour around the island and prevent land bridging are 57 m^3/s (2,000 cfs).
- The maximum flow conditions to scour vegetation from the top of the island are 1130 m^3/s (40,000 cfs). Investigation of the feasibility of scouring the island will be done to determine if it will be a reasonable maintenance procedure, or if it will degrade the remaining structure of the island beyond reasonable expectations.
- The island design should be able to withstand a flood event of 1700 m^3/s (60,000 cfs).

Island Design Considerations

The design of the island habitat should conform to the following criteria. The surface area of the island should be 0.8 to1.2 ha (2 to 3 acres) and should be concentrated in the center of the channel. The island should have gently sloping sandy beaches, less than ten percent vegetation, and should withstand high flow conditions.

Cost Limitations

No specified cost limitation was provided by the USACE as a guideline for the project. However, the proposed solution should fall within reasonable limits, resulting in a feasible and practical design for implementation.

BACKGROUND INFORMATION ON LEAST TERNS

As previously mentioned, the least tern is currently on the endangered species list. An intensive literature review was conducted to determine the specific characteristics of the terns in order to gain knowledge to successfully recover the species.

Habitat Requirements

The Interior Least Tern is migratory and breeds primarily on sandbars, sandbar islands, and lake and reservoir shorelines in lower and mid-American rivers and lakes. The breeding season in these areas ranges from arrival in late May through the end of August (Sidle, 1990). They usually nest on elevated areas away from the edge of the water. Least terns prefer habitations with very little or no vegetation; however, pieces of driftwood are often utilized for protection shelter on islands where it is available. The birds are colonial, and they often return to a particular site for consecutive breeding seasons (Keenlyne, 1986). Numbers of nests in a specific area vary from year to year and month to month due to river level fluctuations causing variations in island widths and heights. Least terns feed on forage fish of two to eight centimeters in length and may rely on distance from food sources for determining a suitable nesting habitat (Keenlyne, 1986).

Changes in Habitat Conditions

Use of artificial habitats such as sand and gravel pits and dredged islands has increased due to the reduction of islands caused by constructing dikes and other systems in many rivers (Sidle, 1990). Because of the nature of the tern's habitat requirements, careful consideration must be used in selecting an island design that will be environmentally stable over a long period of time, and it must also be a habitat that the birds will consistently use each season.

PREVIOUS ISLAND DESIGN CONSIDERATIONS

A literature review was conducted on the previous attempts for preserving island habitats to explore possible options to implement a successful design. The first investigation into literature consisted of searching for past ideas that would support a cost effective, long-term preservation of the design structure resulting in an island. However, this research proved that this type of preservation had not been previously performed. Previous attempts primarily consisted of labor intensive and expensive methods of preserving the habitats.

Missouri River Project

Several projects have been proposed and implemented in the Missouri River between the Niobrara River and Ponca, Nebraska by the Army Corp of Engineers Omaha Division. The 1993-1995 Plan for Habitat Improvement for the Interior Least Tern and Piping Plover was finalized in May 1993, and it consisted of a ten-year plan, in which suggested activities would be researched and implemented to improve breeding of these species.

Many of the projects analyzed by the Omaha Division involved the repair of previously used habitats. Twenty sites, ranging from 0.01 to 20 ha (1.3 to 49 acres), were selected to develop for habitats. These sites were chosen based on final elevations of 0.3 to 0.6 m (1 to 2 ftt) above the water surface elevation during high range flows of 1090 m^3/s (38,500 cfs) (Meuleners, 1994). The vegetation was mechanically leveled and the islands were capped with 0.6 m (2 ft) of sand. Shoreline Erosion Arrestor bags were used on the upstream and channel sides of the islands to prevent erosion. Biological as well as socioeconomic repercussions were evaluated for the habitation rehabilitations. Various alternatives were considered for different aspects of the project. Alternatives for mechanically controlling vegetation were chemical clearing, hand clearing, burning, and flow manipulations. Instead of bulldozing the islands for recapping, the expensive alternative of dredge capping was considered (Meuleners, 1994).

Additionally, the implementation of floating islands and bulldozing low-elevation islands were also considered (Meuleners, 1994). The success of floating islands for least tern habitation was not known at the time the document was written. These islands had been installed in two test areas before the 1993 breeding season, but the birds did not use them during that first season of their existence (Meuleners, 1994). No information was found listing the success or failure of the prescribed projects.

Arkansas, Canadian, and Red Rivers Study

The U.S. Army Corp of Engineers Tulsa District conducted a study in July 2002 resulting in the Management Guideline and Strategies for Interior Least Terns. Long-term strategies of the document were to develop and maintain islands with suitable nesting habitat by implementing various methods and to evaluate and monitor the project impacts (USACE-TD, 2002). In addition, short-term strategies were developed to initiate steps for achieving the long-term goals and to provide immediate relief to the birds. These strategies include releases of floodwater to scour islands for vegetation removal, dredging of current islands to replenish sand deposits, and providing appropriate water releases from reservoir dams when possible to ensure optimal nesting conditions for the terns (USACE-TD, 2002). Season pool plans will be executed for Keystone to allow for minimum flow requirements during the late part of the nesting season (USACE-TD, 2002). Plans have also been devised for water conservation and water operations regarding water supply, water quality, and hydropower.

Zink Island Habitat

Zink Island is a manmade island on the Arkansas River near the 21st Street bridge in Tulsa, Oklahoma. A photograph of the island showing least tern activity is shown in Figure 1.

Figure 1: Zink Island in 1995

The Tulsa Audubon Society has done an annual study for the last decade to determine patterns in fledged young and nests on the island. The survey extends from the middle of May through the middle of July, the majority of the breeding season for the species. The results show a dramatic decrease in the number of fledged young per nest from 1.44 in 1992 to 0.35 in 2002 (Harwood, 2002). The dramatic decrease in breeding rates is largely due to excessive vegetation growth on the island that discourages the birds from nesting and breeding at this location, yet the presence of Canadian geese and occasional flooding were also noted as possible threats that caused a decrease in the number of fledged young found. It is unknown whether or not the island would see increased use if the vegetation were greatly reduced.

ANALYSIS OF NESTING HABITAT CONDITIONS

The Tulsa Division provided the design group with an airboat inspection of the Arkansas River ranging from Jenks, Oklahoma to several miles past the bridge at Bixby, Oklahoma. The tour consisted of visiting different habitations frequently used by the least terns during the 2002 breeding season. Various reasons for frequent use included sparse vegetation, gently sloping banks, surface areas consisting of at least 0.4 ha (1 acre), and locations separated from adjacent river banks such as islands. Two of the well-used islands are shown in Figure 2.

Figure 2: Some Examples of Good Islands Used for Least Tern Habitation

The tour also consisted of observing several habitations that were not used by the terns for breeding. Various reasons for lack of use included land bridging of the island, heavy vegetation, steep banks, and human recreation. Some examples are shown in Figure 3.

(a) (b)

Figure 3: Some Examples of Islands Not Used by Least Terns for Habitation Due to (a) Heavy Vegetation and (b) Human Recreation

ORIGINATION OF DESIGN CONCEPT

A jetty is a rock structure that extends almost perpendicularly from the bank into the river to divert flow and prevent erosion (Fischenich, 2003). These structures are generally used within straight stretches of river and are efficient due to the relatively small amount of material needed for their construction.

Riprap is used extensively in the stabilization of riverbanks. Additionally, it provides protection from scour for a variety of hydraulic structures. The average diameter of the rock used in these applications is dependent on the characteristics of the river it is being used in or the hydraulic structure it is protecting. Use of a mixture of rock with a determined average diameter is recommended to provide proper settlement of the structure and less opportunity for structure movement caused by water flow. The riprap structure allows for flow manipulation to decrease erosion of the banks (Frizell, 2003).

These concepts could be used for designing a structure to build and maintain an island. The single jetty structure symmetrically doubled would provide a chevron shape to manipulate the flow of the river and cause deposition in the middle of the river for island formation.

METHODS OF DESIGN ANALYSIS

The design strategy followed in this project utilized a system of checks and balances in determining the overall feasibility of design considerations. Several methods of simulation were used to verify the validity of the design. The initial studies were conducted using a stream trailer to simulate the flows and particle movement in the river. A physical scale model consisting of a concrete flume provided more accurate results with the use of similitude modeling. The final design concept developed by the physical modeling analysis was further verified using two-dimensional computer modeling analysis.

Stream Trailer Design Method

After careful investigation of previous design attempts in other environmental conditions and of basic hydrodynamic prototypes used for various projects, several basic design considerations were selected and tested. A rudimentary examination of the possible design concepts was performed using a stream trailer to simulate river flow. The stream trailer was available for use from the Oklahoma State University Biosystems and Agricultural Engineering Department.

Description of Stream Trailer Design Method

The first set of tests involved the basic setup of the stream trailer without any alterations. Finely crushed buttons in the stream trailer represented sand particles. These buttons were molded into a riverbed with a normal slope symmetric on both sides. Gravel was set up in various arrangements in the center for flow manipulation, and two test flows, 3.2×10^{-4} and 1.6×10^{-4} m^3/s (2.5 and 5 gpm), were used to approximately simulate typical river conditions. Particulate was introduced into the initial flow to critique and analyze the formation of islands.

It was determined that the flow should originate from the center of the streambed rather than at the sides for more accurate design analysis. PVC pipe was used to extend the original flow outlet to the middle of the bed. Also a thin tarp was placed over the riverbed particulate to keep the sides of the channel and the riverbed stable throughout the experiment. The main design considerations and their respective setups are outlined in the following sections.

Results of Stream Trailer Design Method

A variety of designs were tested using this method with varying success. The designs that provided the most promising results are detailed below.

Preliminary Design 1. The first design consideration consisted of two inverted V's placed in the center of the river channel. The shaping and spacing of the gravel caused sediment to fall out behind the gravel, forming an island in the center of the river channel. The channel upstream of the structure was straight, so the flow would evenly hit the tip of the first riprap frontally. The shape of the gravel was a triangular structure with a wide base that gradually becomes narrow towards the top. A picture of design simulation produced in the stream trailer is shown in Figure 4. Figure 4 illustrates the deposition of material that occurred in the center of the channel with scour on either side.

Figure 4: Stream Trailer Simulation of Preliminary Design 1

Preliminary Design 2. The second design consideration consisted of two inverted V's placed in the center of the river channel. The gravel was shaped in the same triangular structure as preliminary design 1. Both sides of the riverbed were reinforced with triangular shaped gravel structures with the points toward the inside of the river channel to concentrate all flow to the center of the river. A picture of design simulation produced in the stream trailer is shown in Figure 5.

Figure 5: Stream Trailer Simulation of Preliminary Design 2

Preliminary Design 3. The third design consideration was similar to preliminary design 1 in that it consisted of two inverted V's placed in the center of the river channel. The second structure had the point of the V facing in the downstream direction. Deposition of material occurred in the center of the channel with scour on either side.

Preliminary Design 4. The fourth design consideration is similar to Design 2 except the point of the second structure is facing downstream, resembling Design 3.

Discussion of Stream Trailer Design Method Results

The methods used for stream trailer testing were not accurate enough for design verification. Because the dimensions of the models were not scaled correctly to portray the prototype dimensions. Therefore the results of this testing procedure were used only to determine possible designs that could be further tested using other methods.

Both preliminary designs 1 and 3 appeared to be reasonable based on the location of the deposition and scour. These designs yielded the most promising results and were used as the basis for the designs tested using physical scale modeling.

Physical Scale Model Design Method

The stream trailer analysis provided initial design concepts that could be considered as possible solutions for the project. However, it was necessary to develop a testing method that would render a more exact analysis of the design considerations. The USDA-Agricultural Research Service (ARS) Hydraulic Engineering Research Unit located adjacent to Lake Carl Blackwell in Stillwater, Oklahoma houses a variety of hydraulic testing resources available for the research purposes of this project. A setup for physical scale modeling of the Arkansas River was provided at this facility.

Description of Physical Model Design Method

The apparatus and the theory used in this method are described in the following section. The calibration and modeling parameters that were determined during initial testing are described in detail as well.

Concrete Flume. A concrete flume with dimensions of 29 m (96 ft) long by 1.8 m (6 ft) wide by 2.4 m (8 ft) tall was utilized in this procedure. The flume consisted of a 21 m (70 ft) straight reach of usable testing area. The north side of the flume allowed the experiments to be viewed from above, while the south side of the flume allowed the model to be viewed just below eye level. Two windows located in the south wall of the flume permitted a better view of the model and easy access to the model. Tracks were in place on the top of the flume walls for a gondola structure that was used to set up structures in the flume and analyze results without disturbance of the bed material. A maximum flow rate of 0.08 m^3/s (3 cfs) through a 0.1 m (4 in) orifice plate was available for the flume. Flow rates for testing could be adjusted using the pressure differential of a manometer and a calibration table relating pressure to flow for the orifice plate. Concrete sand with an average diameter of 0.6 mm (0.024 in) was utilized as the bed material.

Regime Theory of Modeling. The Lacey regime theory is a method of dimensional similitude used for self-formed channels. It states that width is directly proportional to the square root of the flow rate, and depth is directly proportional to the cubed root of the flow rate (Henderson, 1966). These conditions result in scaling equations of

$$X_r = Q_r^{1/2}$$

and

$$Y_r = Q_r^{1/3}$$

for the horizontal and vertical components, respectively. These yield scaling factors of 165 for X_r and 40 for Y_r. The width and flow rate for the model, which are shown in Table 1, were calculated based on this theory. The theory also assumes that the bed material of the model is the same dimension as the bed material of the prototype (Henderson, 1966). To match the ideal island height of 8.5 feet, a model height of approximately 2.55 inches was targeted for each design.

Table 1: Flow rates and depths for the prototype and the model

Prototype		**Model**	
Flow Rate, Q (m^3/s)	Depth (m)	Flow Rate, Q (m^3/s)	Depth (m)
1700	3.7	6.2×10^{-2}	0.09
1130	3.0	4.2×10^{-2}	0.08
710	2.4	2.6×10^{-2}	0.06

Calibration of the Flume. The sand was leveled in the flume bed using a screed attached to the gondola. This was repeated for each testing procedure to ensure that the same conditions existed in each analysis. The flume was properly calibrated at each of the flow rates before actual testing was started to ensure accuracy of the model. This was done through bed and water surface profile analyses, which are shown in Figure A-1 of Appendix A.

Determination of Modeling Parameters. Initial studies were done to determine the parameters of the physical model. It was found that two designs could be tested at a time without interference with each other. The structures needed to be left overnight or for approximately 15 hours to allow sediment deposition and scour to occur. Several materials were tested for use as the structure material and gravel ranging from 0.03 to 0.1 m (1 to 4 in) in diameter was determined to be the most suitable material for use in the flume. The designs were constructed, and initial flow rates relating to 40,000 cubic feet per second were continuously run through the flume to simulate river flow for island development. It was later determined that flow rates relating to 1700 m^3/s (60,000 cfs) would provide better simulation due to the size of the bed material.

Progression of Design Ideas. The design structures tested in the flume began with the most feasible designs determined in the stream trailer testing. The angles, heights, and spacing of the basic two chevron designs were adjusted to determine the impact of each characteristic. The orientation of the chevrons in the channel and the number of structures in each design were also adjusted to determine their respective impacts on island development and scour positioning. Finally the shape and slope of the design structures were adjusted to determine the impact on island formation.

Confetti Analysis. In order to observe how the design structures affected the velocities of the flow approaching and leaving the structures, confetti was introduced into the flume for several of the designs. The confetti was distributed across the flume upstream of the structures. Pictures were taken at approximately three second intervals to analyze the movement of water over the structures. This allowed for a rough estimation of how the surface velocities changed with the structures.

Results of Physical Model Design Method

A variety of structures incorporating different design concepts were testing using the model. All of the designs tested are outlined in the following sections and the specific details of each design are listed in Appendix A.

Designs 1a – 7b. The first sixteen designs utilize structures in the shape of chevrons combined in different numbers, orientations, and spacings. Although these designs provide varying island lengths and scour positions, they are listed together because they all produce results that left a shallow pool or gap in the center of the deposited formation. This can be seen in Figure 6, which shows the results of design 2a.

Figure 6: Physical Modeling Simulation of Design 2a

Design 8a. This design used a variation on the preceding attempts. Two chevrons were used in this design and were spaced 1.2 m (4 ft) apart. The first chevron was a straight horizontal line with a width of 0.3 m (1 ft). The second chevron was in a ‘V’ shape with an angle of 90 degrees and a width of 0.8 m (32.5 in). Both had heights of 0.06 m (2.5 in), with the middle of the second chevron slightly lower to increase sediment movement across it. The resulting island dimensions were a length of 3.7 m (12 ft), a width of 0.254 m (10 in), and a height of 0.05 m (2 in) from the water surface. Scouring occurred at the front and sides of the design at a depth of 0.1 m (5 in) from the water surface with a width of 0.18 m (7 in). The design after testing is shown in Figure 7.

Figure 7: Physical Modeling Simulation of Design 8a

Design 9a. This design is similar to design 8a, with the spacing changed from 1.2 m (4 ft) to 0.9 m (3 ft) between the chevrons. The resulting island dimensions were a length of 3.4 m (11 ft), a width of 0.18 m (7 in), and a height of 0.05 m (2 in) from the water surface. Scouring occurred at the front and sides of the design at a depth of 0.15 m (6 in) from the water surface and a width of 0.2 m (8 in). The design after testing is shown in Figure 8.

Figure 8: Physical Modeling Simulation of Design 9a

Design 9b. This design was similar to design 8a with the width of the first chevron extended to 0.6 m (2 ft). The resulting island dimensions were a length of 3.7 m (12 ft), a width of 0.4 m (17 in), and a height of 0.08 m (3 in) from the water surface. Scouring occurred at the front and sides of the design at a depth of 0.14 m (5.5 in) from the water surface with a width of 0.15 m (6 in). The design after testing is shown in Figure 9.

Figure 9: Physical Modeling Simulation of Design 9b

Results of Confetti Analysis

The result of a confetti analysis performed on one of the design structures is shown in Figure 10. A definite separation of the confetti was exhibited on most of the analyses. This shows a large decrease in velocity over the structures that will likely result in sediment deposition in the actual river.

Figure 10: Confetti Surface Velocity Test after 3 Seconds

Discussion of Physical Model Design Results

The greatest limitation of the model is its inability to accurately display the proper amount of sediment deposition. The average particle size of the sand used in the model is larger than the average particle size found in the Arkansas River. The model is unable to move the sediment to heights that would accurately portray island height development. Therefore the physical modeling results can be used to determine only the placement of sediment and the position of scour that would occur, not the height of deposition.

Designs 1a-7b consistently contained large gaps in the middle of the deposition area, which does not lead to an effective solution to the problem because it would be possible that the least terns would not utilize this type of island. Therefore, these designs should not be considered as possibilities for a suitable final design. Design 8a, 9a, and 9b all utilized variations of a similar design. Design 9a yielded the best results because it produced a wider island than design 8a and, although the island created by design 9b was considerably wider, the island from 8a was much more consistent in its deposition area. The two-dimensional and three-dimensional surface graphs for design 9a are shown in Figures A-2, A-3, A-4, and A-5 of Appendix A. The design schematics for the final flume design, design 9a, are shown in Figures B-1 and B-2 of Appendix B.

Computer Model Design Method

A two-dimensional computer modeling program was used to further analyze the validity of the best design determined using physical scale modeling. The model was developed at the National Center for Computational Hydroscience and Engineering at the University of Mississippi. The model software is still in its Beta version and has not yet been introduced onto the market due to final system changes that are being implemented.

Description of Computer Model Design Method

The two dimensional depth-averaged mass and momentum governing equations used in the program are

$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial \eta}{\partial x}=\frac{1}{\rho h}\frac{\partial h\tau_{xx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{xy}}{\partial x}-\frac{\tau_{bx}}{\rho h}+f_{cor}v$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \eta}{\partial y}=\frac{1}{\rho h}\frac{\partial h\tau_{yx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{yy}}{\partial x}-\frac{\tau_{by}}{\rho h}+f_{cor}u$$

where h is depth of flow, *u* and υ are longitudinal and transverse velocity components, x and y are spatial coordinates in the longitudinal and transverse directions, t is time, g is the acceleration of gravity, η is water surface elevation, ρ is water density, τ_{xx} and τ_{yy} are normal turbulent stresses in the longitudinal and transverse directions, τ_{xy} and τyx are shear stresses, τ_{bx} and τ_{by} are bed shear stresses in the longitudinal and transverse directions, and f_{corr} is a Coriolis parameter (Khan, 2001). The bed shear analyses were performed using

$$\tau_{xx}=2\rho v_t\frac{\partial u}{\partial x}$$

$$\tau_{xy}=\tau_{yx}=\rho v_t\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

$$\tau_{yy}=2\rho v_t\frac{\partial v}{\partial y}$$

$$v_t = 0.17\kappa u_* h$$

where v_t is turbulent eddy viscosity. The model uses a numerical scheme to solve the momentum equations using a quadrilateral mesh system (Khan, 2001).

Results of Computer Model Design Method

The velocity and shear analyses resulting from the computer modeling are shown in Figures C-1, C-2, and C-3 of Appendix C. The scaled velocity analysis of the Arkansas River is shown in Figure C-4 of Appendix C. The sediment analyses of the flume and river were not performed during modeling due to complications in the program.

Discussion of Computer Model Design Results

The computer modeling reinforced the conclusions drawn in physical scale modeling regarding the validity of design 9a. Low or no velocity occurred over the central region between and following the structures where sediment deposition is expected to occur. Relatively high shear occurred evenly on the sides of the structure indicating a continual flow through this area that will decrease the possibility of land bridging.

ASSESSMENT OF TESTING RESULTS

Three design methods were utilized in determining a feasible solution to the problem. Each design method has its own strengths as well as weaknesses and the utilization of more than one method provided verification of the overall feasibility of the designs. The discussion of the different designs shows that varying success was obtained from the solutions. The designs that appeared to be suitable in the stream trailer proved to be ineffective when tested in the more precise physical model. This led to the development of a design variation that proved to be quite effective; utilizing a straight riprap structure followed by a chevron structure. This design provided the proper scour conditions and deposition in the required areas of the river channel. Further verification of the position of scour and velocity using the computer model was also obtained.

In order to determine if the velocities over the top of the island are high enough to scour vegetation from the island, velocity was calculated and compared to permissible velocities for grassed waterways (USDA-SCS, 1954). The empirical calculations of the expected velocities through the use of Manning's equation show that the velocities will be sufficient to scour the island of sparse vegetation during flows of 1130 m^3/s (40,000 cfs). However, if dense clumps of vegetation occur on the island, flows of 1700 m^3/s (60,000 cfs) will be necessary for complete removal of vegetation.

RECOMMENDATION

The following is a recommendation of the design solution that should be implemented to solve the least tern habitation problems. The location of the island, the description of design structure, the implementation of design structure, and a cost analysis have been developed so that the USACE may determine the feasibility of utilizing the design structures in the Arkansas River or other rivers to aid in recovery of the Least Tern habitat and species population.

Location of Island

The proposed location of the island structure is in Tulsa County within the section of the river adjacent to 121st Street south of Jenks, Oklahoma, as shown in Figure 11. This location is ideal for several reasons. It is centered in a straight section of river channel, which will cause the flow to evenly distribute itself on either side of the structure upon initial impact. A large tributary, Polecat Creek, feeds into the river upstream of the location providing a source of food for the birds. Additionally, the City of Tulsa is considering financial assistance with the construction of an environmental refuge for the least tern species in this area.

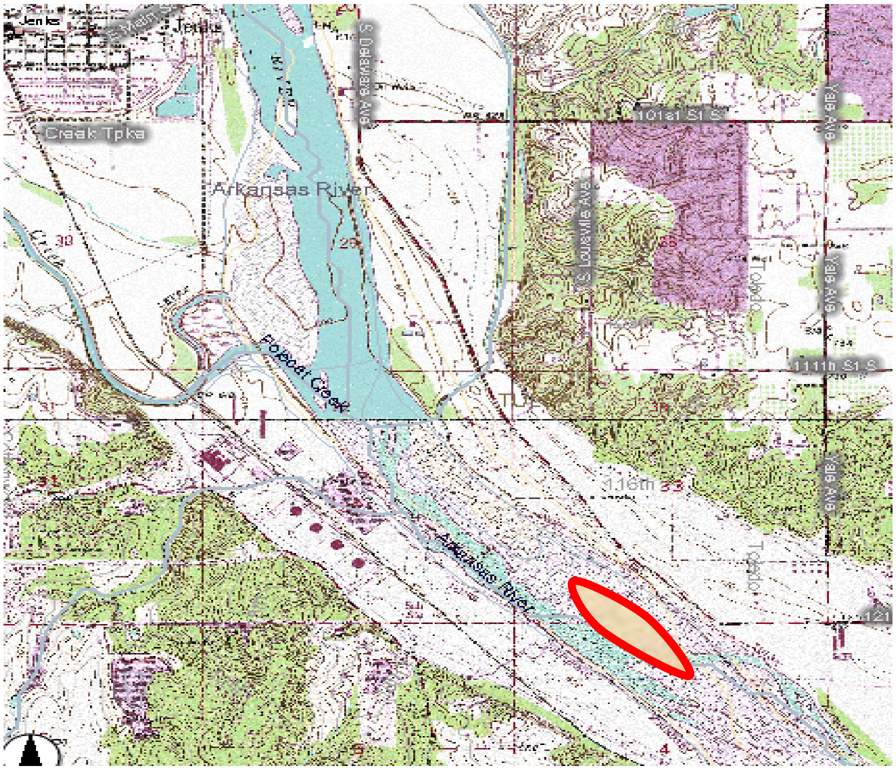

Figure 11: Proposed Location of Island

Descriptions of Design Structure

The final design schematic is shown in Figures D-1 and D-2 of Appendix D. The schematic is the scaled up prototype version of the final design with the addition of 1.5 m (5 ft) of tow below the front of each piece of the structure to prevent undercutting and degradation of the structure. Riprap diameter of 0.76 m (2.5 ft) is recommended for the structure. This was calculated based on the Colorado State University (CSU) procedure (Haan, 1994). The equations used in this procedure are

$$\eta = \frac{21\tau_{\max}}{\gamma(SG-1)D_{50}}$$

$$\eta' = \eta\frac{1+\sin(\lambda+\beta)}{2}$$

$$SF = \frac{\cos\alpha\tan\phi}{\eta'\tan\phi+\sin\alpha\cos\beta}$$

where η is stability factor, η' is channel wall stability factor, $\tau_{\max}$ is maximum shear on the channel bank, γ is specific weight, λ is the stream line angle, α represents the sideslope angle, and ϕ is the angle of the repose (Haan, 1994). Since the CSU equations are typically used to calculate riprap for bank stabilization, the λ angle was tripled to account for riprap placed in the middle of the river channel. The safety factor (SF) was determined to be 1.3 for our design structures. Stabilization of the banks on either side of the structure is also recommended based on the increased velocities expected on either side of the structure shown in the velocity profiles from the computer modeling.

Implementation of Design

The structure should be implemented during low flow conditions of the late summer months. Construction in August or September would provide minimal interference with nesting of the least terns due to the small overlap with the typical nesting season. It would also provide easier access to the river for construction due to the lower flows typical of the later season, and would allow for a longer period to establish the initial island. It was not possible to estimate sediment deposition time using the testing procedures, but full deposition can be expected to occur before the habitation period of the following nesting season. Allowing a full year for the island to develop would make it feasible for Keystone Dam to release a series flows greater than or equal to the necessary 1130 m^3/s (40,000 cfs).

Cost Analysis

An approximation of $50 per cubic yard was used to determine the cost of design material and construction (Bass, 2003). This results in a total cost of $270,000. Because of the large expense involved in implementation of the design structure, it is strongly recommended that a small prototype be built and tested in or near the proposed location. This will allow for final design verification without affording the total expense of the project. Setting a limit of $10,000 for the cost of materials and construction, the dimensions of a riprap structure would be 13 m (43 ft) wide by 3 m (10 ft) long by 0.9 m (3 ft) high for the front structure and 17 m (56 ft) wide by 3 m (10 ft) long by 0.9 m (3 ft) high for the rear structure. In order to reduce installation time and the use of heavy machinery, Quikrete® was proposed as the design structure material of a small prototype. The use of Quikrete® and a limit of $10,000 would allow for a structure with dimensions of 9.3 m (30.5 ft) wide by 2.1 m (7 ft) long by 0.76 m (2.5 ft) high for the front structure and 12 m (40 ft) wide by 2.1 m (7 ft) long by 0.76 m (2.5 ft) high for the rear structure. The small prototype would be best served if it were installed on an existing low-level island. This would allow the design structures to be verified and for the existing island to be stabilized.

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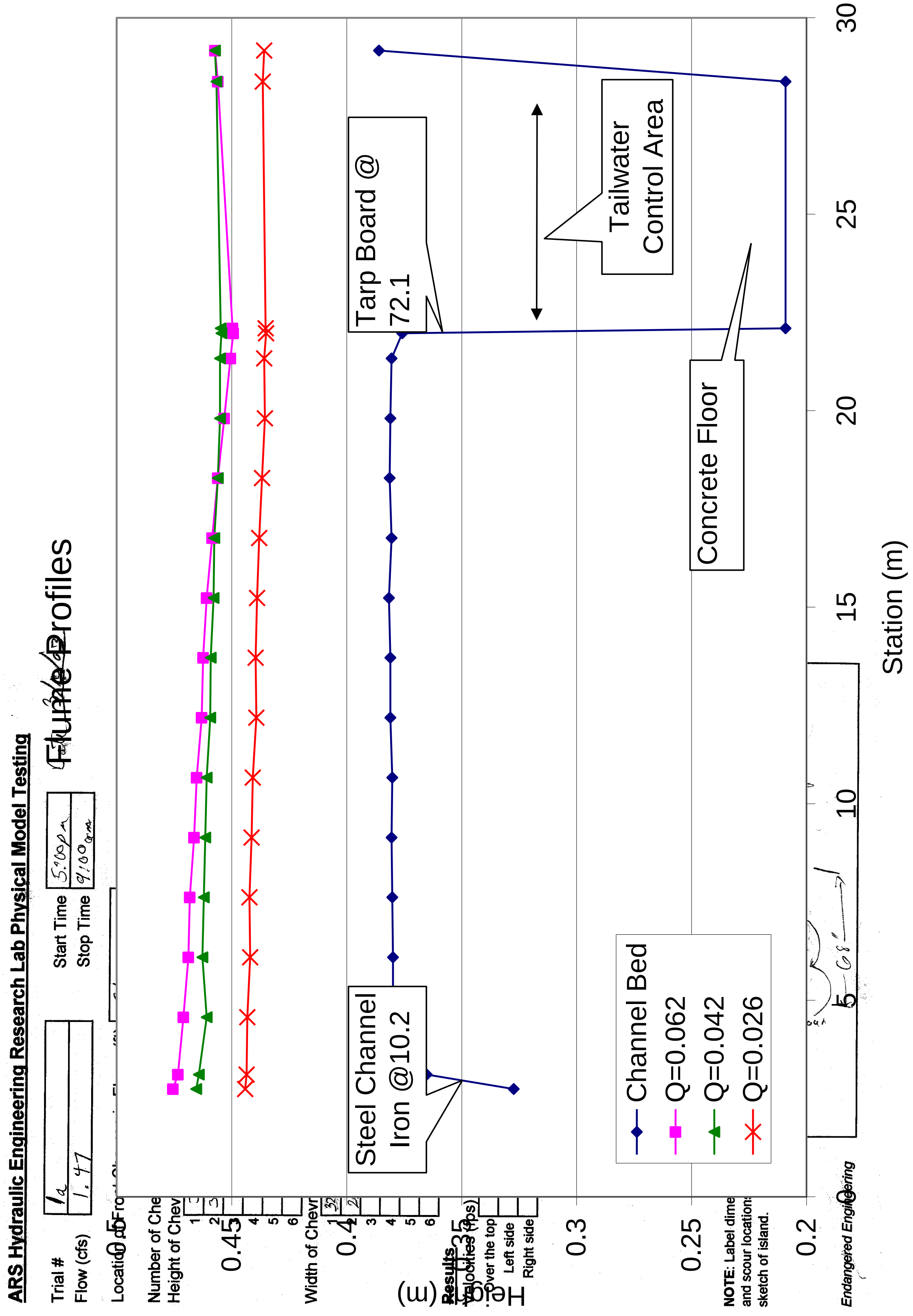
APPENDIX A: FLUME TESTING RESULTS


Flume Profiles
Head (m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
Station (m)
0
5
10
15
20
25
30
Steel Channel Iron @10.2
Tarp Board @ 72.1
Tailwater Control Area
Concrete Floor
Channel Bed
Q=0.062
Q=0.042
Q=0.026
ARS Hydraulic Engineering Research Lab Physical Model Testing
Trial #
1a
Flow (cfs)
1.47
Start Time
5:00 pm
Stop Time
9:00 am
Number of Chevrons
Height of Chevrons
Width of Chevrons
Results
Velocities (fps)
Over the top
Left side
Right side
NOTE: Label dimensions and scour locations on sketch of island.
Endangered Engineering

ARS Hydraulic Engineering Research Lab Physical Model Testing

Date 3/10/03

Trial #	1b	Start Time	
Flow (cfs)	1.47	Stop Time	

Location of Front Chevron in Flume (ft) 48

Number of Chevrons 2

Height of Chevron (in)	
1	3
2	3
3	
4	
5	
6	

Angle of Chevron (degrees)	
1	22" bw
2	32.5" bw
3	
4	
5	
6	

Need Protractor

Width of Chevron (in)	
1	22
2	32.5
3	
4	
5	
6	

Length of Chevrons
1.) 2ft
2.) 2ft

Spacing of Chevrons (in)	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

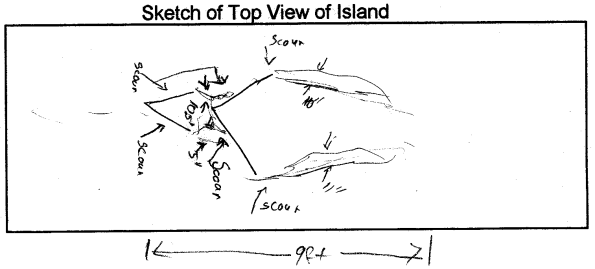
Date 3/11/03

Velocities (fps)	
Over the top	
Left side	
Right side	

Island Dimensions	
Width (in)	10.5", 5", 10", 11"
Length (in)	~ 9ft
Height (in)	1" from H2O surface

Island Scour	
Location	front Both chevrons
	Back of last chevron
Depth (in)	4.5" side back 5" front chevrons
Width (in)	7" side back

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

ARS Hydraulic Engineering Research Lab Physical Model Testing

Date 3/10/03

Trial #	1d	Start Time	
Flow (cfs)	1.47	Stop Time	

Location of Front Chevron in Flume (ft) 21

Number of Chevrons 2

Height of Chevron (in)

1	3
2	3
3	
4	
5	
6	

Angle of Chevron (degrees)

1	22" bw
2	22" be
3	
4	
5	
6	

Width of Chevron (in)

1	22
2	22
3	
4	
5	
6	

Length of Chevrons
1.) 2ft
2) 2ft

Spacing of Chevrons (in)

1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)

Over the top	
Left side	
Right side	

Island Dimensions

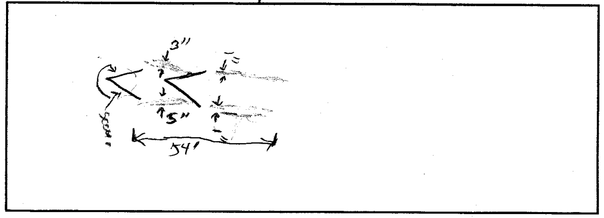
Width (in)	3", 5", 1"
Length (in)	54"
Height (in)	3" below water surface

Date 3/11/03

Island Scour

Location	Front of 1st chevron
Depth (in)	.5
Width (in)	2

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

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ering Research Lab Physical Model Testing

Date 3/10/03

		Start Time	
		Stop Time	

Flume (ft) 35

2

Angle of Chevron (degrees)

1	32.5" bw
2	32.5" bw
3	
4	
5	
6	

Length of Chevron
1.) 2ft
2.) 2ft

Spacing of Chevrons (in)

1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Island Dimensions

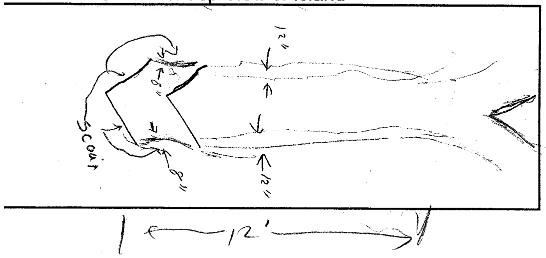
Width (in)	8" front 12" Back
Length (in)	12' = 144"
Height (in)	2.5" from H₂O surface

Date 3/11/03

Island Scour

Location	sides, front of 1st chevron
Depth (in)	4.5" on sides 3" front (from water surface)
Width (in)	17" on both sides 3" front

Sketch of Top View of Island



ARS Hydraulic Engineering Research Lab Physical Model Testing

Date 3/12/03

Trial # 2b
Flow (cfs) 1.47
Start Time 5:00pm
Stop Time 9:00am
Location of Front Chevron in Flume (ft) 48
Number of Chevrons 2

Height of Chevron (in)		Width of Chevron (in)		Angle of Chevron (degrees)		Spacing of Chevrons (in)	
1	3	1	22	1	~60°	1 to 2	30
2	2.25	2	32.5	2	90°	2 to 3	
3		3		3		3 to 4	
4		4		4		4 to 5	
5		5		5		5 to 6	
6		6		6			

Results

Velocities (fps)
Over the top
Left side
Right side

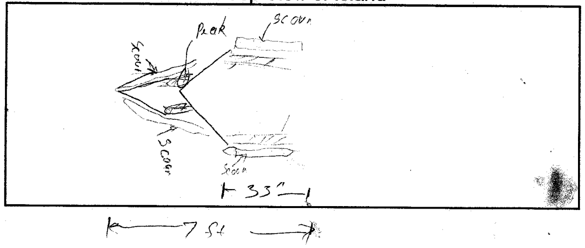
Date 3/13/03

Island Dimensions
Width (in) 4"
Length (in) 7ft
Height (in) .5" from surface

55
46

Island Scour
Location front, sides
Depth (in) 3" front 3.5" sides
Width (in) 4" front 8" sides

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

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ering Research Lab Physical Model Testing

Date 3/12/03

Start Time 3:00
Stop Time
n Flume (ft) 24
2

Angle of Chevron (degrees)		Spacing of Chevrons (in)	
1	90°	1 to 2	30
2	~60°	2 to 3	
3		3 to 4	
4		4 to 5	
5		5 to 6	
6			

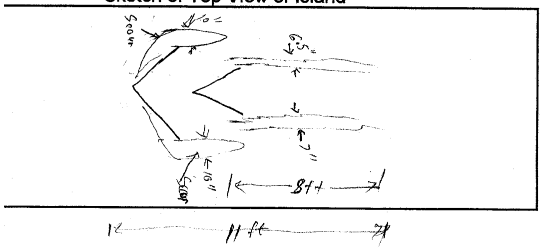
Date 3/13/03

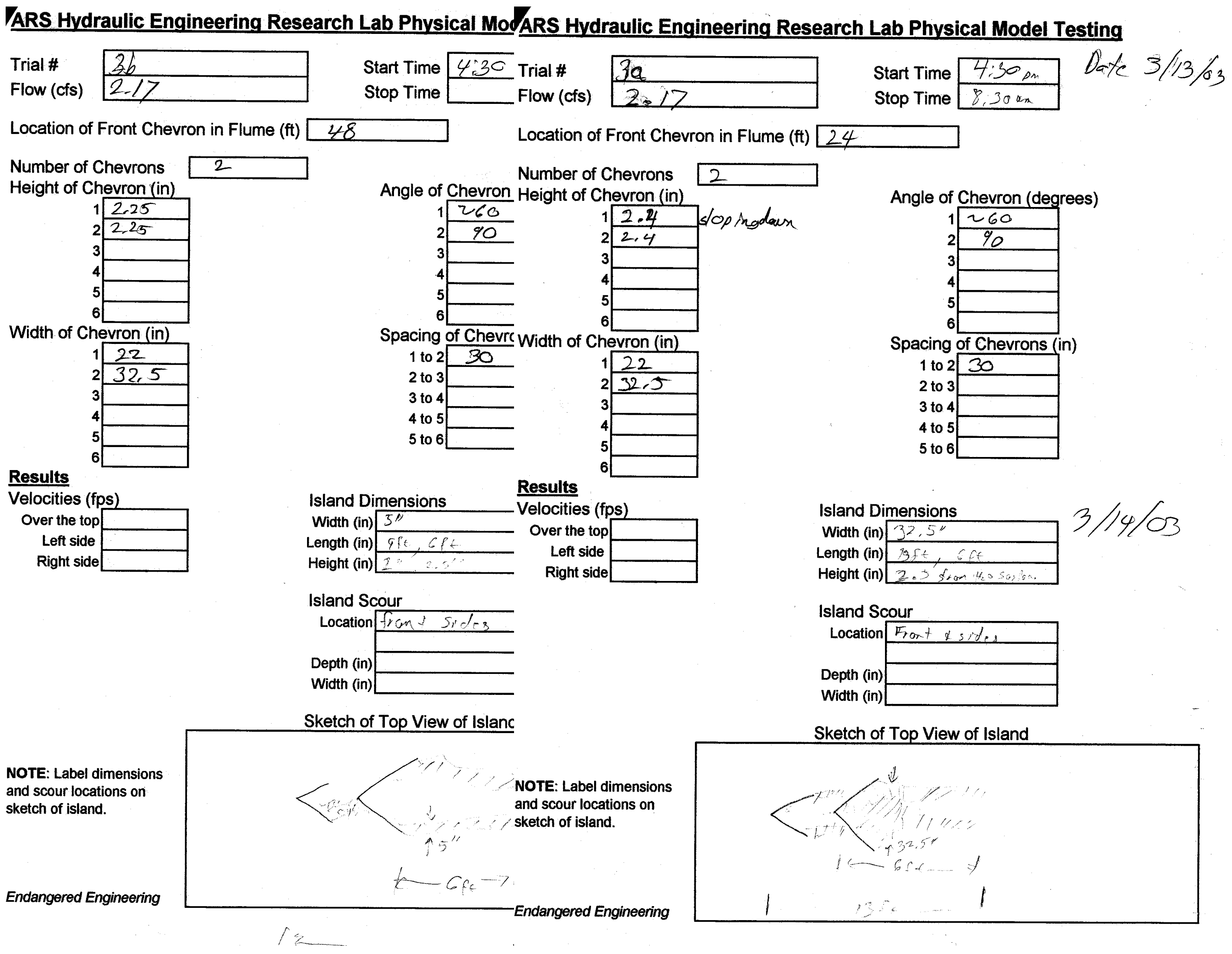
Island Dimensions
Width (in) 6.5" 7"
Length (in) 8ft
Height (in) 1.5" from H₂O surface

35 24
-27

Island Scour
Location Front of 1st & along sides
Depth (in) 5", 5.5" sides 4.5" front
Width (in) 10" side 7" front

Sketch of Top View of Island





ARS Hydraulic Engineering Research Lab Physical Mo

Trial # 3b
Flow (cfs) 2.17
Start Time 4:30
Stop Time

Location of Front Chevron in Flume (ft) 48

Number of Chevrons 2

Height of Chevron (in)	
1	2.25
2	2.25
3	
4	
5	
6	

Angle of Chevron	
1	~60
2	90
3	
4	
5	
6	

Width of Chevron (in)	
1	22
2	32.5
3	
4	
5	
6	

Spacing of Chevr	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)	
Over the top	
Left side	
Right side	

Island Dimensions	
Width (in)	3"
Length (in)	9ft, 6ft
Height (in)	2", 2.5"

Island Scour	
Location	front sides
Depth (in)	
Width (in)	

Sketch of Top View of Islanc

NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

ARS Hydraulic Engineering Research Lab Physical Model Testing

Date 3/13/03

Trial # 3a
Flow (cfs) 2.17
Start Time 4:30 pm
Stop Time 8:30 am

Location of Front Chevron in Flume (ft) 24

Number of Chevrons 2

Height of Chevron (in)	
1	2.4 slop Inydown
2	2.4
3	
4	
5	
6	

Angle of Chevron (degrees)	
1	~60
2	90
3	
4	
5	
6	

Width of Chevron (in)	
1	22
2	32.5
3	
4	
5	
6	

Spacing of Chevrons (in)	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)	
Over the top	
Left side	
Right side	

3/14/03

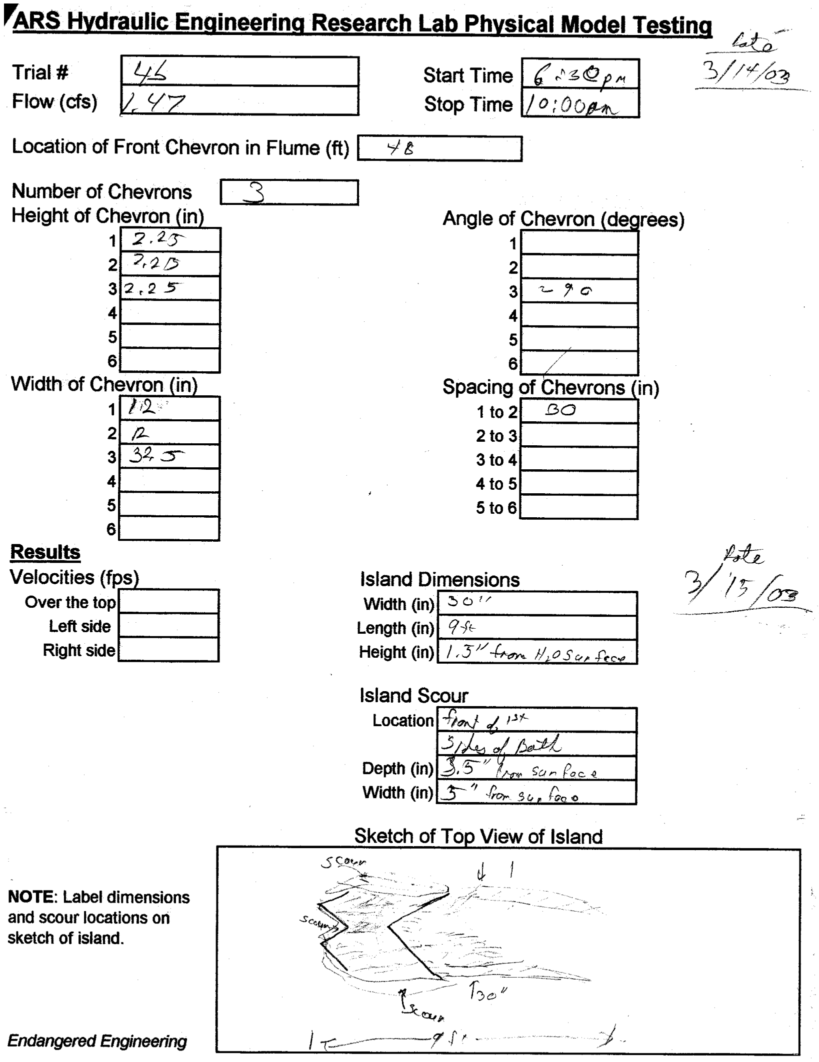
Island Dimensions	
Width (in)	32.5"
Length (in)	13ft, 6ft
Height (in)	2.5 from H_2O Surface

Island Scour	
Location	Front & sides
Depth (in)	
Width (in)	

Sketch of Top View of Island

NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering



ARS Hydraulic Engineering Research Lab Physical Model Testing

Date 3/14/03

Trial #	46	Start Time	6:30pm
Flow (cfs)	1.47	Stop Time	10:00pm

Location of Front Chevron in Flume (ft) 48

Number of Chevrons 3

Height of Chevron (in)	
1	2.25
2	2.25
3	2.25
4	
5	
6	

Angle of Chevron (degrees)	
1	
2	
3	~90
4	
5	
6	

Width of Chevron (in)	
1	12
2	12
3	32.5
4	
5	
6	

Spacing of Chevrons (in)	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)	
Over the top	
Left side	
Right side	

Date 3/15/03

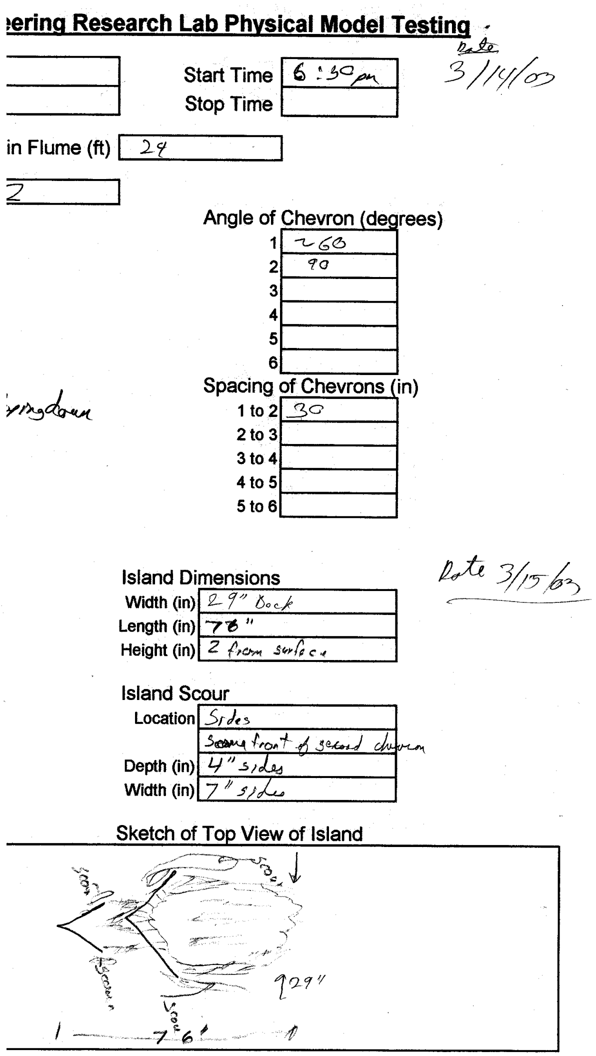
Island Dimensions	
Width (in)	30"
Length (in)	9ft
Height (in)	1.5" from H2O surface

Island Scour	
Location	front of 1st
	Sides of Both
Depth (in)	3.5" from surface
Width (in)	5" from surface

Sketch of Top View of Island

NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering



eering Research Lab Physical Model Testing

Date 3/14/03

		Start Time	6:30pm
		Stop Time	

in Flume (ft) 24

2

yingdown

Angle of Chevron (degrees)	
1	~60
2	90
3	
4	
5	
6	

Spacing of Chevrons (in)	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Date 3/15/03

Island Dimensions	
Width (in)	29" Back
Length (in)	76"
Height (in)	2 from surface

Island Scour	
Location	Sides
	Scour front of second chevron
Depth (in)	4" sides
Width (in)	7" sides

Sketch of Top View of Island

ARS Hydraulic Engineering Research Lab Physical Model Testing

3/1[illegible]/03

Trial #	56	Start Time	1:00pm
Flow (cfs)	7 turns back wide open	Stop Time	10:00am

Location of Front Chevron in Flume (ft) 48'

Number of Chevrons 4

Height of Chevron (in)	
1	2.25
2	2.25
3	2.25
4	2.25
5	
6	

Angle of Chevron (degrees)	
1	60
2	60
3	40
4	270
5	
6	

Width of Chevron (in)	
1	22
2	22
3	32.5
4	32.5
5	
6	

Spacing of Chevrons (in)	
1 to 2	0
2 to 3	30"
3 to 4	6ft
4 to 5	
5 to 6	

Results

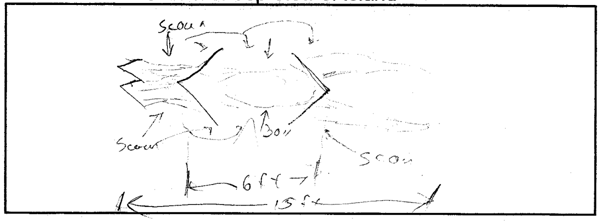
Velocities (fps)	
Over the top	
Left side	
Right side	

3/18/03

Island Dimensions	
Width (in)	30"
Length (in)	15ft from surface all
Height (in)	1.5" from surface on [illegible]

Island Scour	
Location	Sides
Depth (in)	5.5" all
Width (in)	5"

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

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ering Research Lab Physical Model Testing

3/17/03

		Start Time	1:00pm
	wide open	Stop Time	10:00am

n Flume (ft) 24

2

Angle of Chevron (degrees)	
1	~60
2	90
3	
4	
5	
6	

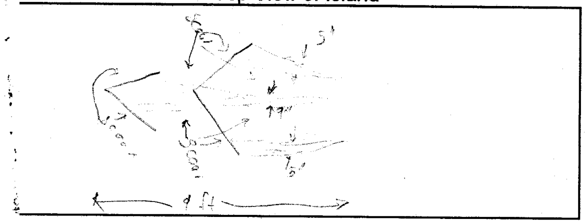
Spacing of Chevrons (in)	
1 to 2	30
2 to 3	
3 to 4	
4 to 5	
5 to 6	

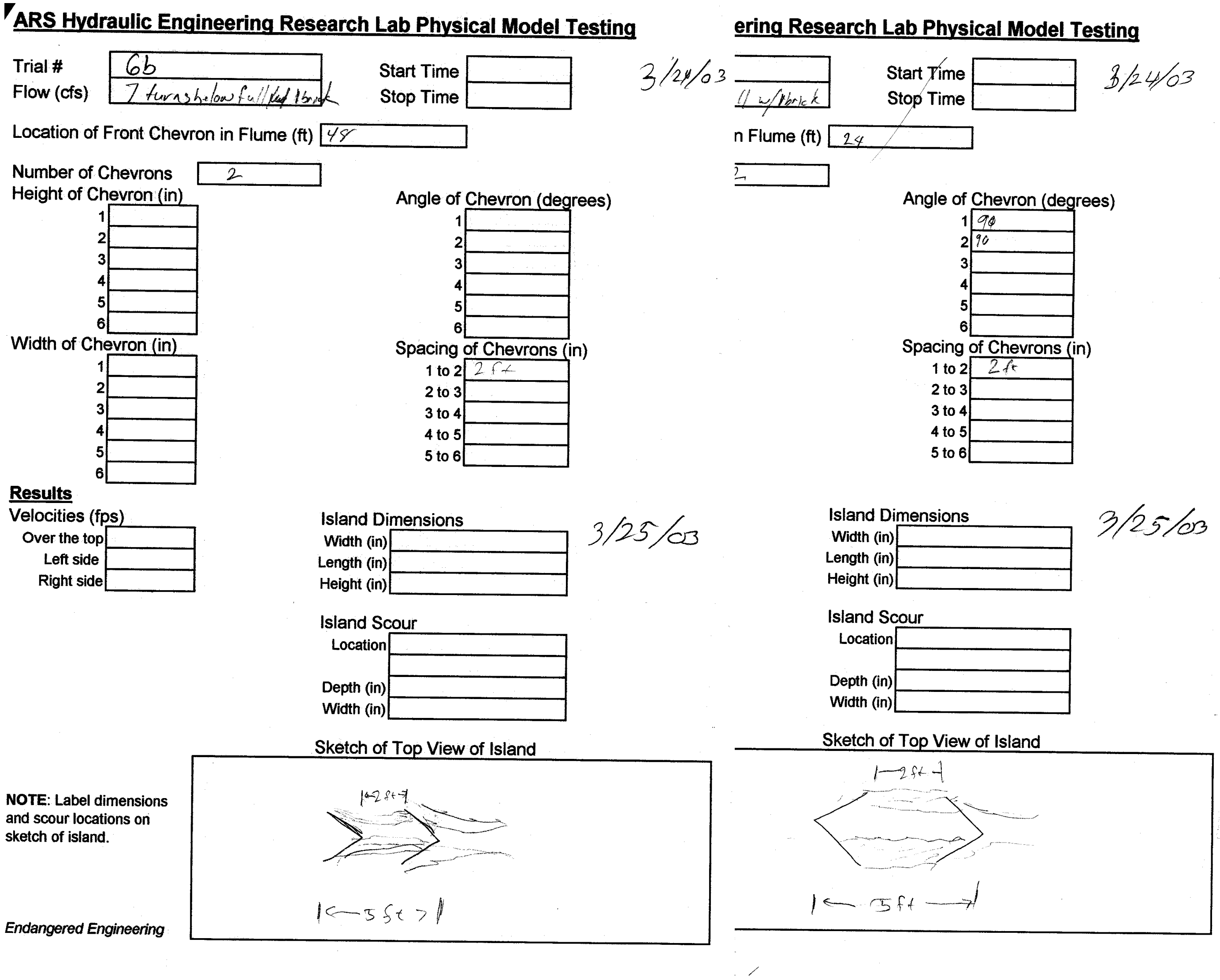
3/18/03

Island Dimensions	
Width (in)	9", 5"
Length (in)	9ft
Height (in)	2" from surface

Island Scour	
Location	front, middle, behind
Depth (in)	5, 4.5", 4.5'
Width (in)	4", 2", 4"

Sketch of Top View of Island





ARS Hydraulic Engineering Research Lab Physical Model Testing

3/24/03

Trial #	6b	Start Time	
Flow (cfs)	7 turns below full w/ 1 brick	Stop Time	

Location of Front Chevron in Flume (ft) 48

Number of Chevrons 2

Height of Chevron (in)		Angle of Chevron (degrees)	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	

Width of Chevron (in)		Spacing of Chevrons (in)	
1		1 to 2	2 ft
2		2 to 3	
3		3 to 4	
4		4 to 5	
5		5 to 6	
6			

Results

3/25/03

Velocities (fps)		Island Dimensions	
Over the top		Width (in)	
Left side		Length (in)	
Right side		Height (in)	

Island Scour	
Location	
Depth (in)	
Width (in)	

Sketch of Top View of Island

NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

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ering Research Lab Physical Model Testing

3/24/03

		Start Time	
	11 w/ 1 brick	Stop Time	

n Flume (ft) 24

2

Angle of Chevron (degrees)	
1	90
2	90
3	
4	
5	
6	

Spacing of Chevrons (in)	
1 to 2	2 ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

3/25/03

Island Dimensions	
Width (in)	
Length (in)	
Height (in)	

Island Scour	
Location	
Depth (in)	
Width (in)	

Sketch of Top View of Island

ARS Hydraulic Engineering Research Lab Physical Model Testing

3/26/03

Trial #	7b	Start Time	4:09pm
Flow (cfs)	133" deflection	Stop Time	9:00am

Location of Front Chevron in Flume (ft) 48

Number of Chevrons 3

Height of Chevron (in)	
1	2.5
2	2.5
3	2.5
4	
5	
6	

greater than that

Angle of Chevron (degrees)	
1	60
2	60
3	90
4	
5	
6	

Width of Chevron (in)	
1	16
2	16
3	32.5
4	
5	
6	

Spacing of Chevrons (in)	
1 to 2	4ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

60
48
12

Results

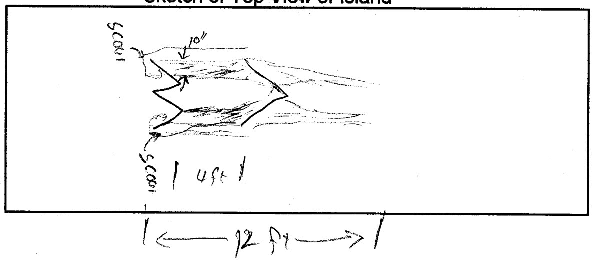
Velocities (fps)	
Over the top	
Left side	
Right side	

3/27/03

Island Dimensions	
Width (in)	10"
Length (in)	12 ft
Height (in)	2.5 from H₂O surface

Island Scour	
Location	front, sides
Depth (in)	6.5
Width (in)	14"

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

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ering Research Lab Physical Model Testing

3/26/03

		Start Time	4:09pm
		Stop Time	9:00am

n Flume (ft) 24

Angle of Chevron (degrees)	
1	60
2	60
3	96
4	
5	
6	

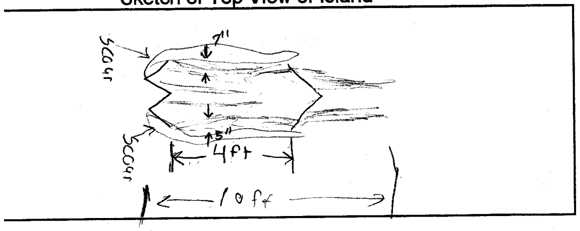
Spacing of Chevrons (in)	
1 to 2	4ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

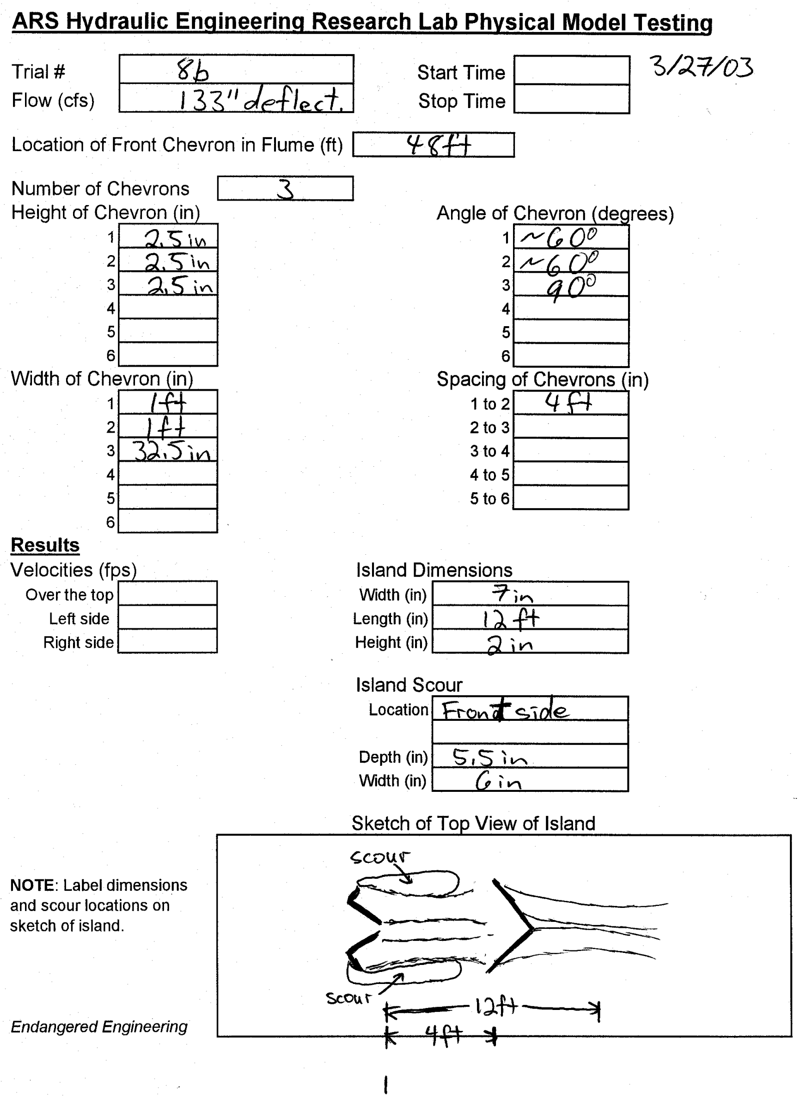
3/27/03

Island Dimensions	
Width (in)	7"
Length (in)	10 ft
Height (in)	4" from H₂O surface

Island Scour	
Location	front, sides
Depth (in)	6"
Width (in)	8"

Sketch of Top View of Island





ARS Hydraulic Engineering Research Lab Physical Model Testing

3/27/03

Trial # 8b
Flow (cfs) 133" deflect.
Start Time
Stop Time

Location of Front Chevron in Flume (ft) 48ft

Number of Chevrons 3

Height of Chevron (in)

1	2.5in
2	2.5in
3	2.5in
4	
5	
6	

Angle of Chevron (degrees)

1	~60°
2	~60°
3	90°
4	
5	
6	

Width of Chevron (in)

1	1ft
2	1ft
3	32.5in
4	
5	
6	

Spacing of Chevrons (in)

1 to 2	4ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)

Over the top	
Left side	
Right side	

Island Dimensions

Width (in)	7in
Length (in)	12ft
Height (in)	2in

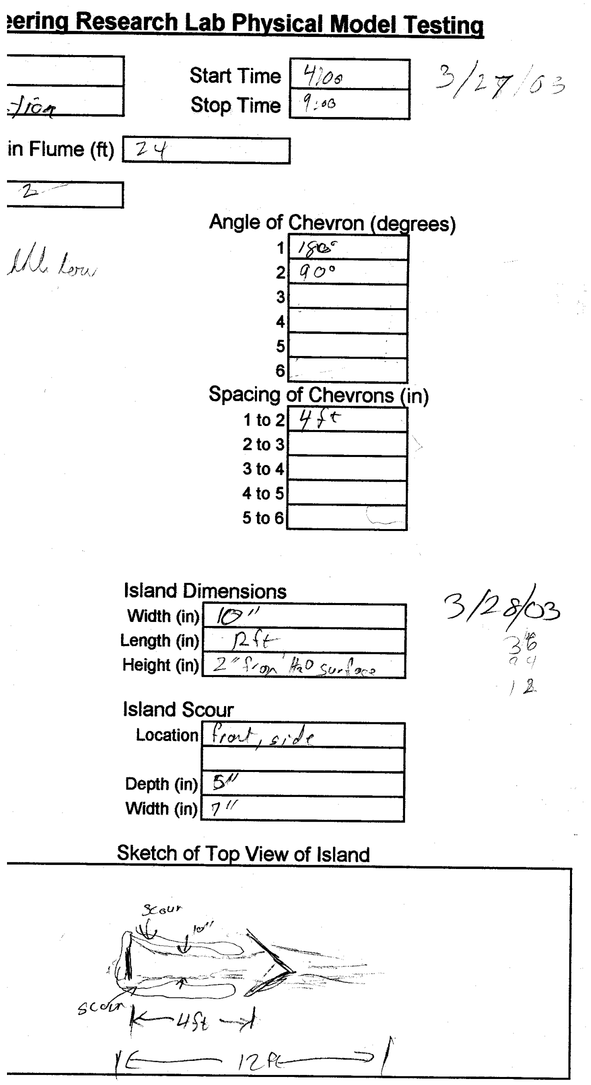
Island Scour

Location	Front side
Depth (in)	5.5in
Width (in)	6in

Sketch of Top View of Island

NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering



eering Research Lab Physical Model Testing

3/27/03

tion
Start Time 4:00
Stop Time 9:03

in Flume (ft) 24

2

Ml Low

Angle of Chevron (degrees)

1	180°
2	90°
3	
4	
5	
6	

Spacing of Chevrons (in)

1 to 2	4ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

3/28/03
36
24
12

Island Dimensions

Width (in)	10"
Length (in)	12ft
Height (in)	2" from H2O surface

Island Scour

Location	front, side
Depth (in)	5"
Width (in)	7"

Sketch of Top View of Island

ARS Hydraulic Engineering Research Lab Physical Model Testing

Trial # 96

Flow (cfs) 133in deflect.

Start Time 4:00PM

Stop Time 9:00AM

Location of Front Chevron in Flume (ft) 48ft

4/1/03

Number of Chevrons 2

Height of Chevron (in)

1	2.5in
2	2.5in
3	
4	
5	
6	

low middle pt.

Angle of Chevron (degrees)

1	180°
2	90°
3	
4	
5	
6	

Width of Chevron (in)

1	24in
2	32.5in
3	
4	
5	
6	

Spacing of Chevrons (in)

1 to 2	48in
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)

Over the top	
Left side	
Right side	

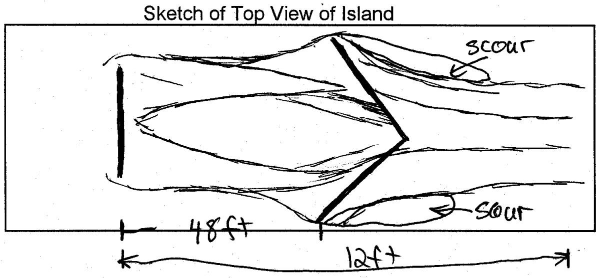
Island Dimensions

Width (in)	17in
Length (in)	12ft
Height (in)	3in from H2O Surface

Island Scour

Location	Front and sides
Depth (in)	5.5in from H2O Surface
Width (in)	6in

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

Endangered Engineering

---

ering Research Lab Physical Model Testing

deflect.

Start Time 4:00pm

Stop Time 9:00AM

n Flume (ft) 24ft

4/01/03

2

w chevron pt.

Angle of Chevron (degrees)

1	180°
2	90°
3	
4	
5	
6	

Spacing of Chevrons (in)

1 to 2	36in = 3ft
2 to 3	
3 to 4	
4 to 5	
5 to 6	

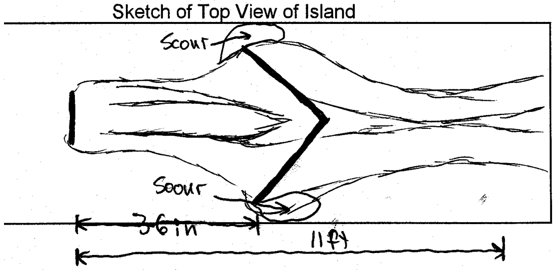
Island Dimensions

Width (in)	7in
Length (in)	11ft
Height (in)	2in from H2O surface

Island Scour

Location	Front and sides
Depth (in)	6in from H2O surface
Width (in)	8in

Sketch of Top View of Island



ARS Hydraulic Engineering Research Lab Physical Model Testing

Trial # 10a

Flow (cfs) 128in deflect.

Start Time 1:00PM

Stop Time 9:00AM

Location of Front Chevron in Flume (ft) 42ft

Number of Chevrons 2

Height of Chevron (in)

1	3in
2	3in
3	
4	
5	
6	

low middle pt.

Angle of Chevron (degrees)

1	180°
2	90°
3	
4	
5	
6	

Width of Chevron (in)

1	12in
2	32.5in
3	
4	
5	
6	

Spacing of Chevrons (in)

1 to 2	36in
2 to 3	
3 to 4	
4 to 5	
5 to 6	

Results

Velocities (fps)

Over the top	
Left side	
Right side	

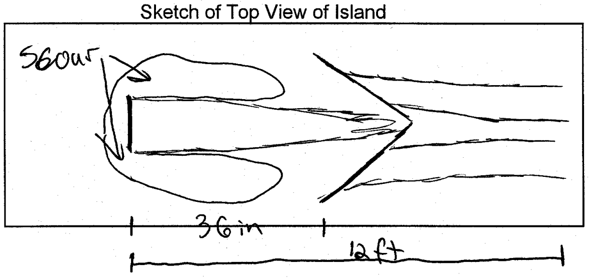
Island Dimensions

Width (in)	9in
Length (in)	12ft
Height (in)	2.5in from H2O surface

Island Scour

Location	Front sides
Depth (in)	4.5in
Width (in)	4.0in

Sketch of Top View of Island



NOTE: Label dimensions and scour locations on sketch of island.

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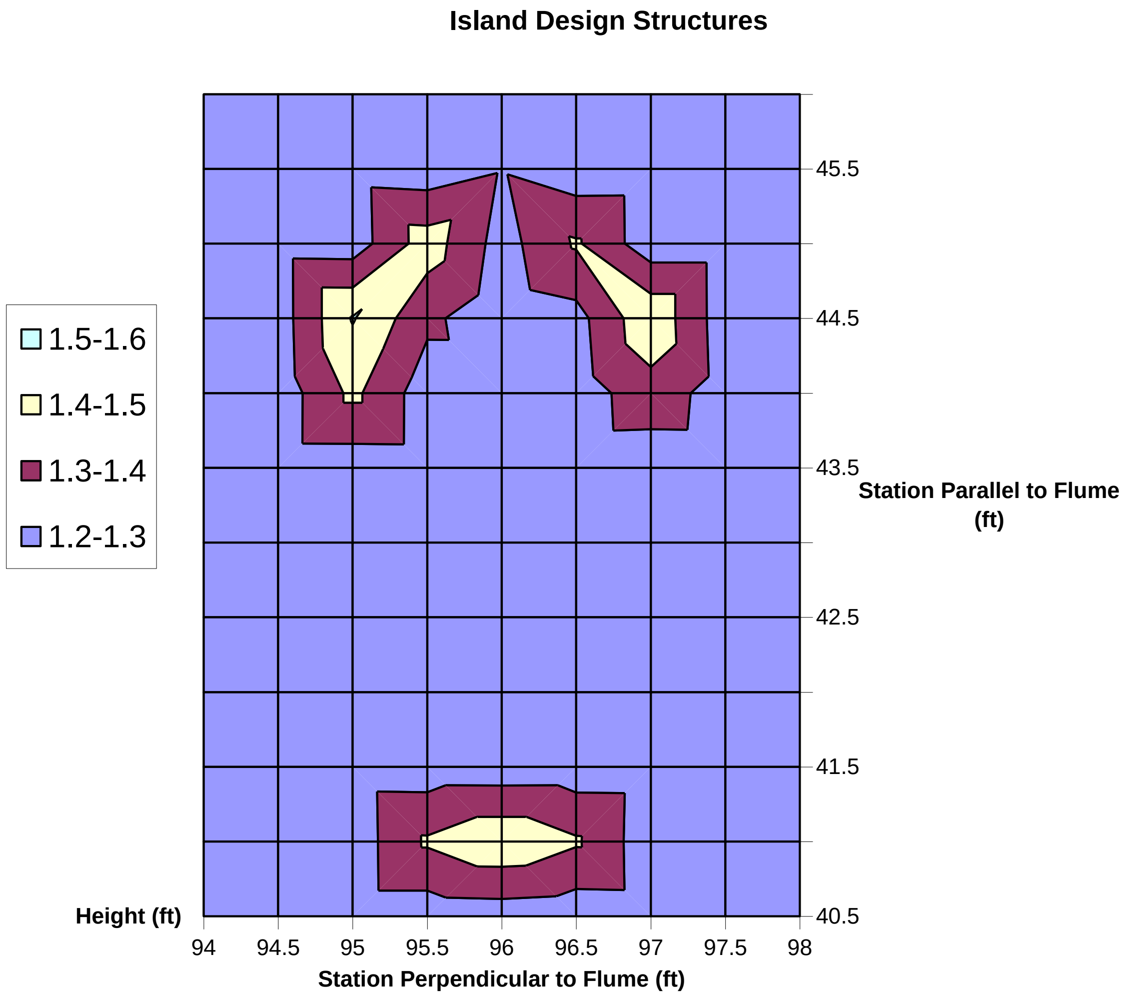


Figure A-2: Top View of Final Flume Design

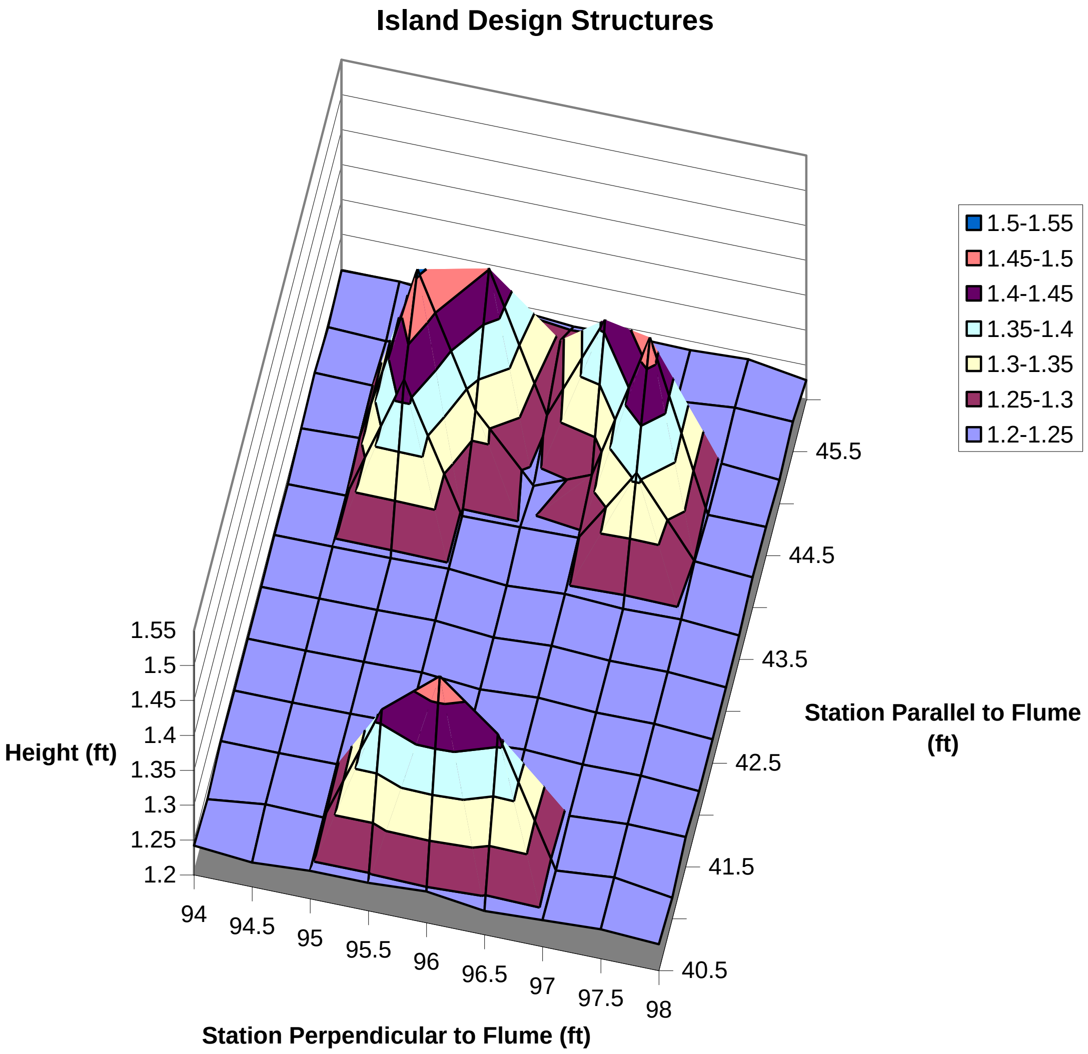


Figure A-3: Three Dimensional View of Final Flume Design

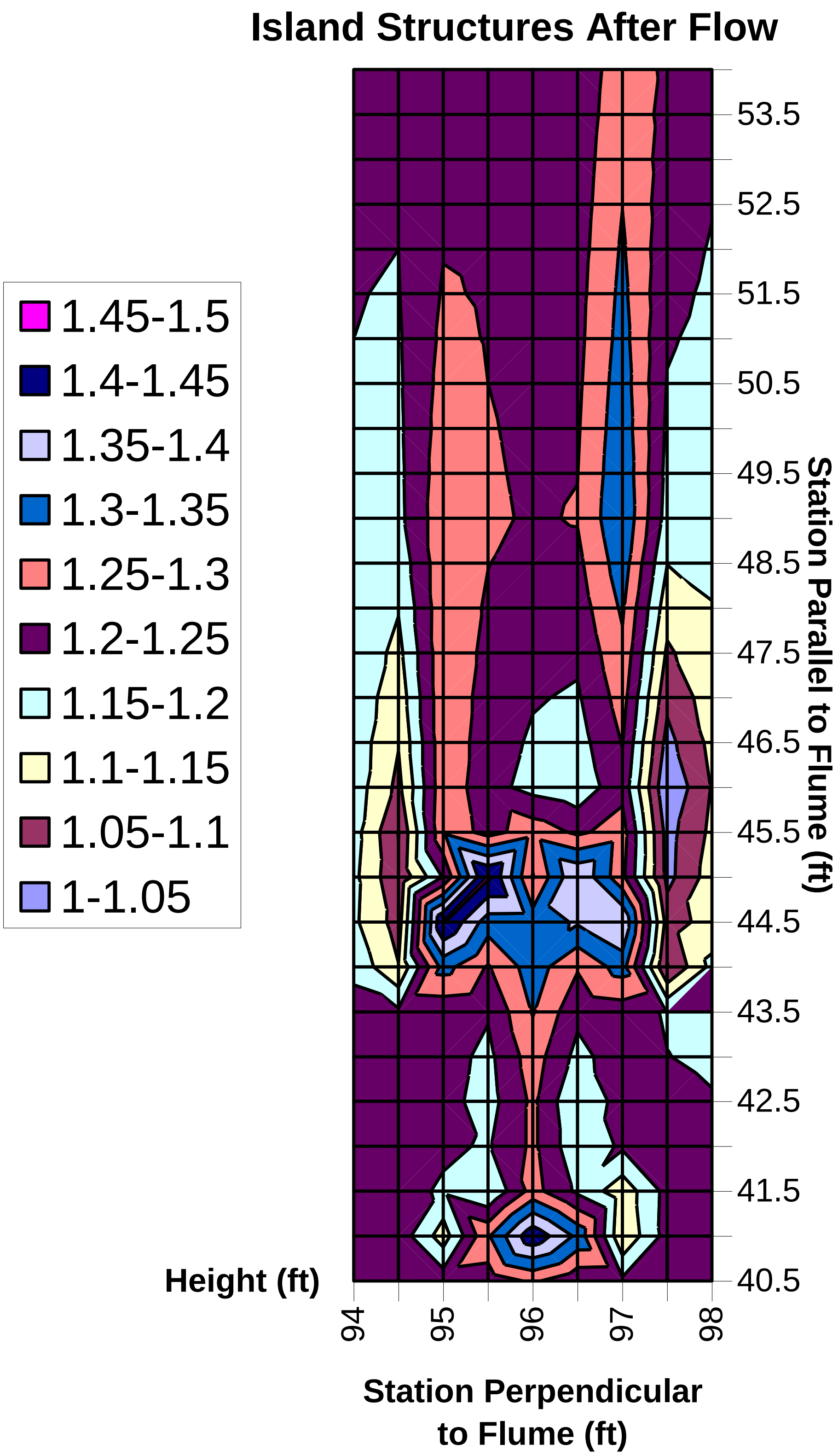


Figure A-4: Top View of Final Flume Design after Testing

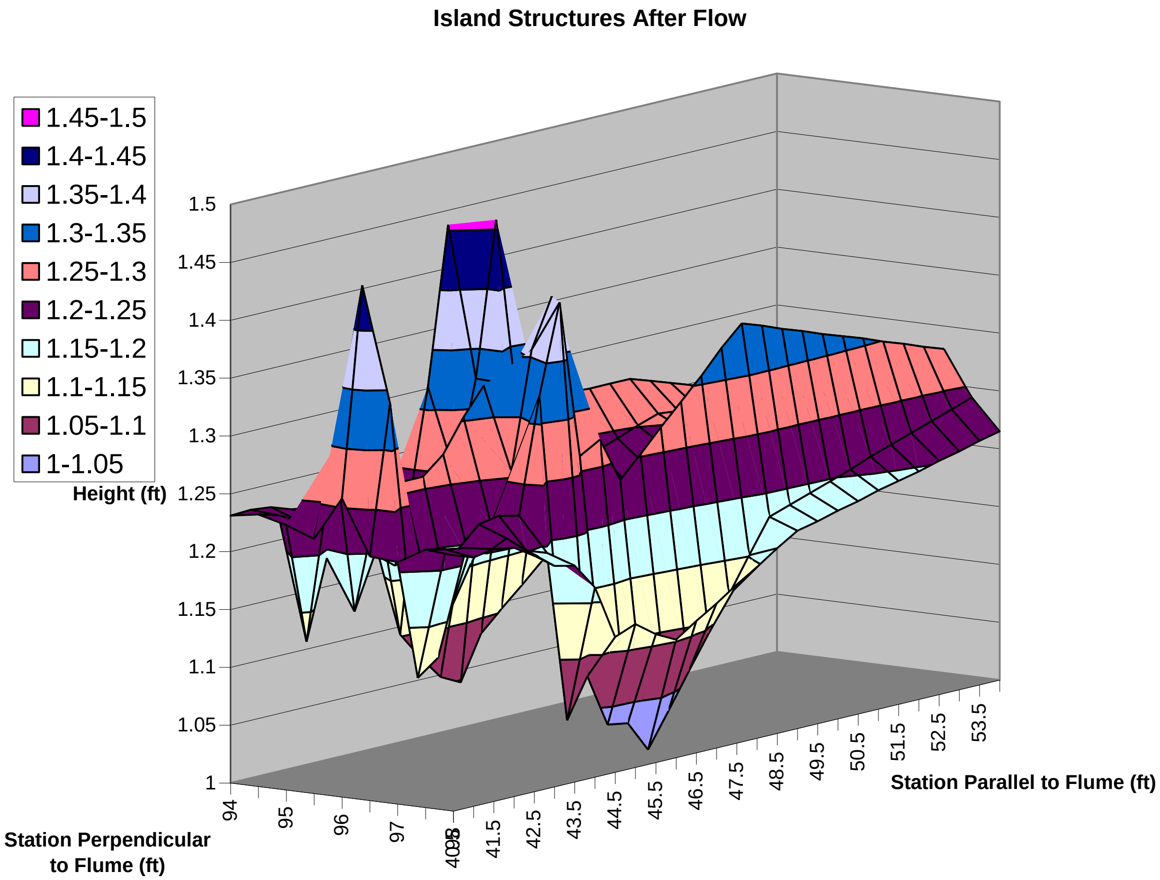


Figure A-5: Three Dimensional View of Final Flume Design after Testing

APPENDIX B: FINAL DESIGN DRAWINGS OF FLUME DESIGN STRUCTURES

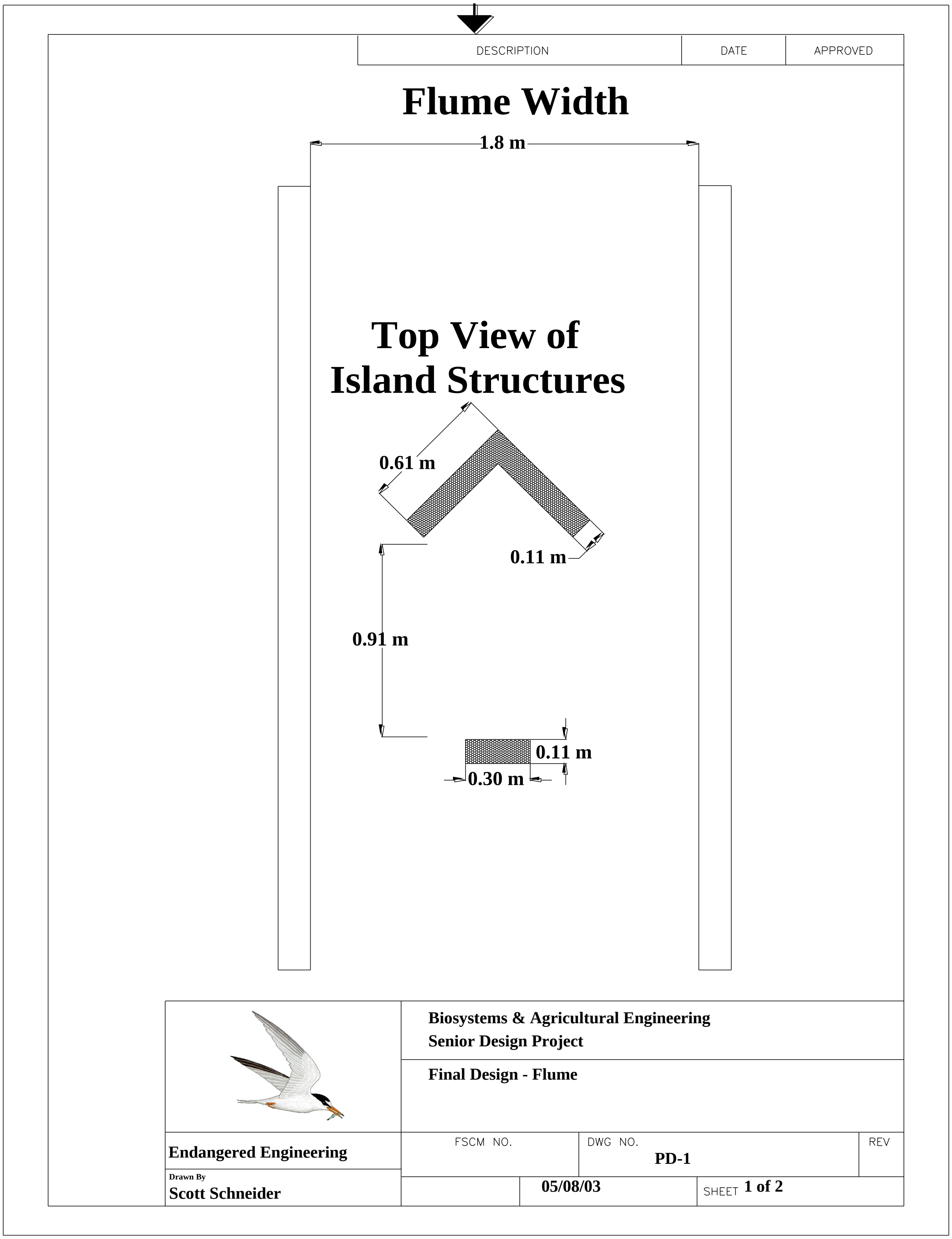


Figure B-1: Top View of Design Schematic for Flume Structure

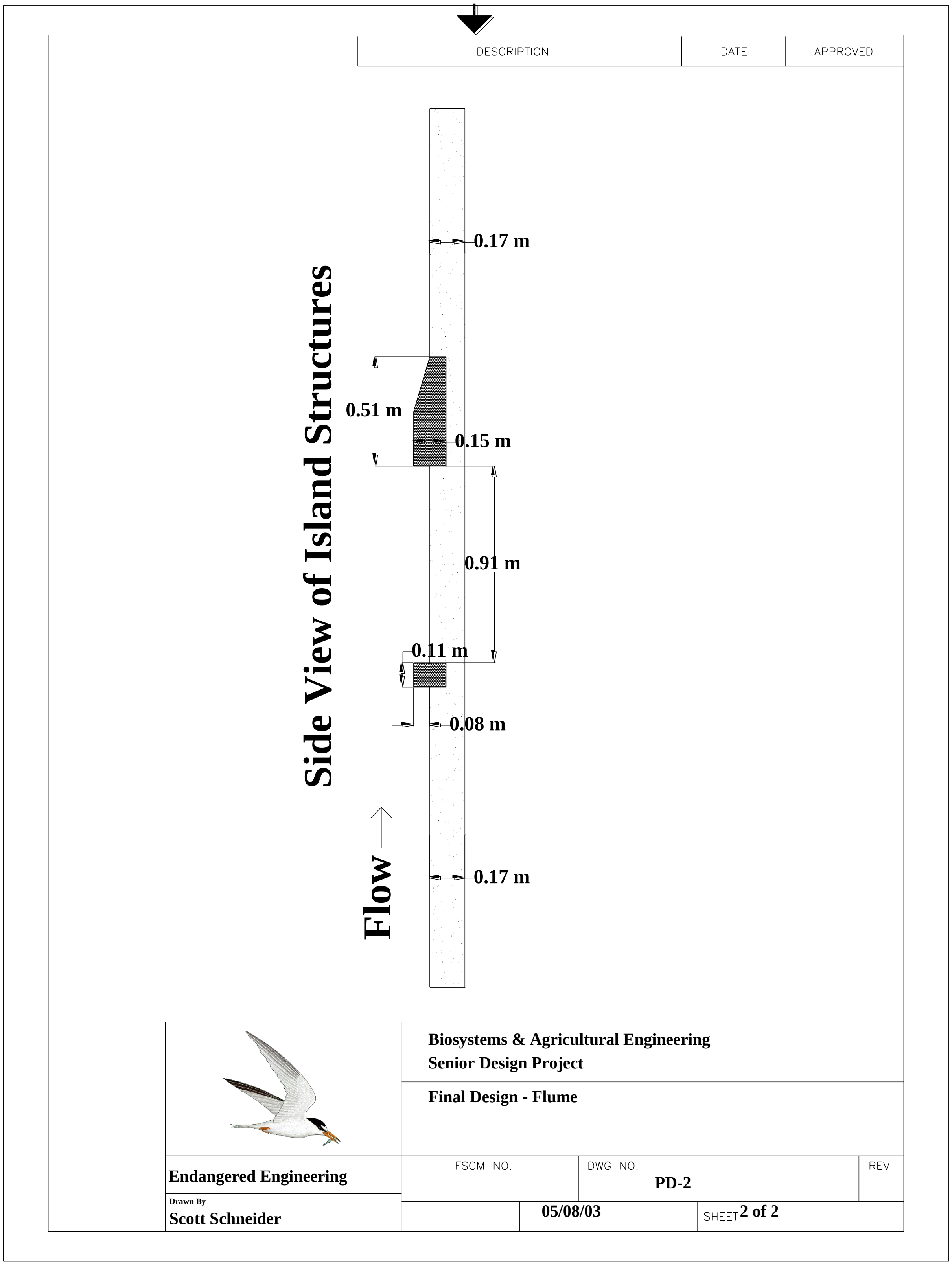
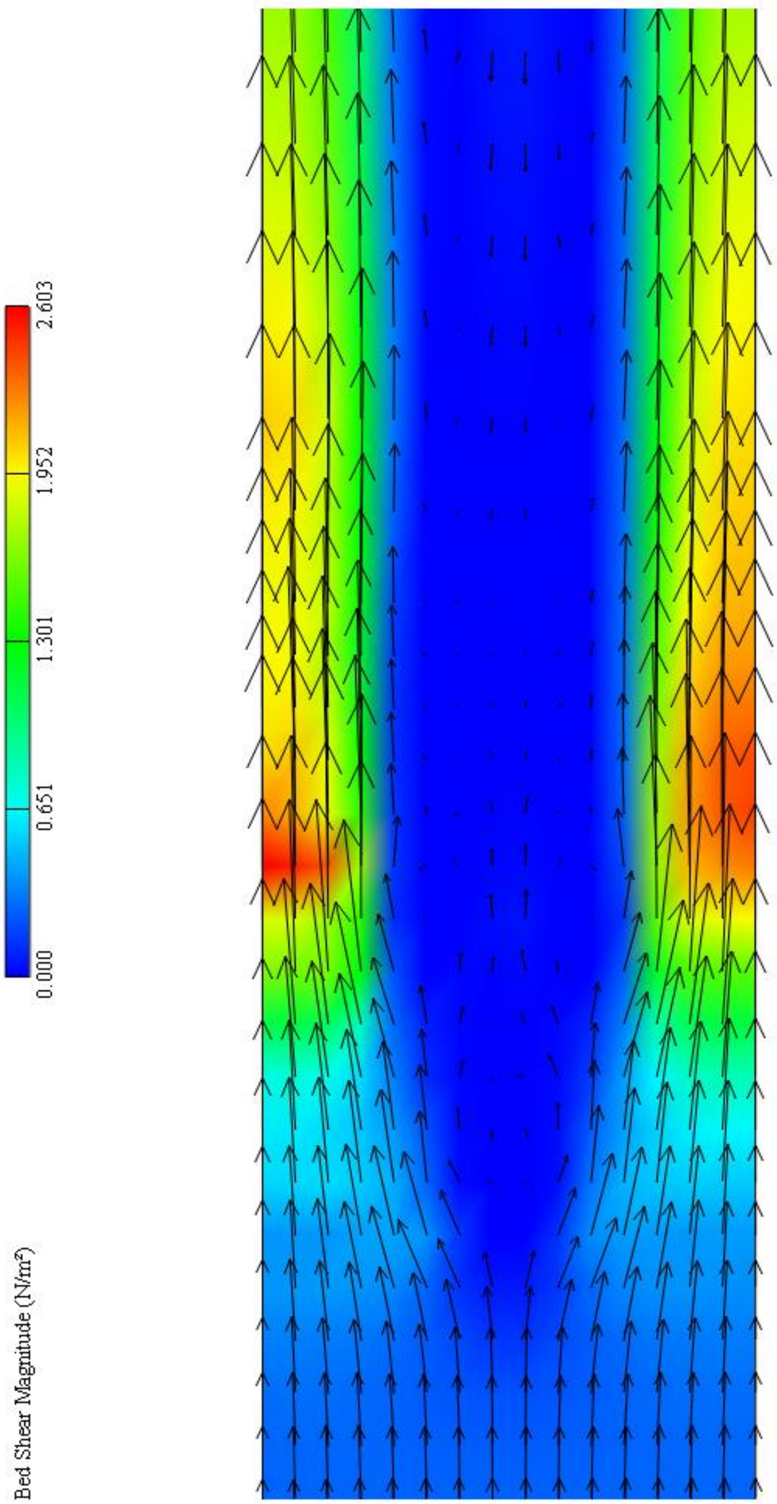
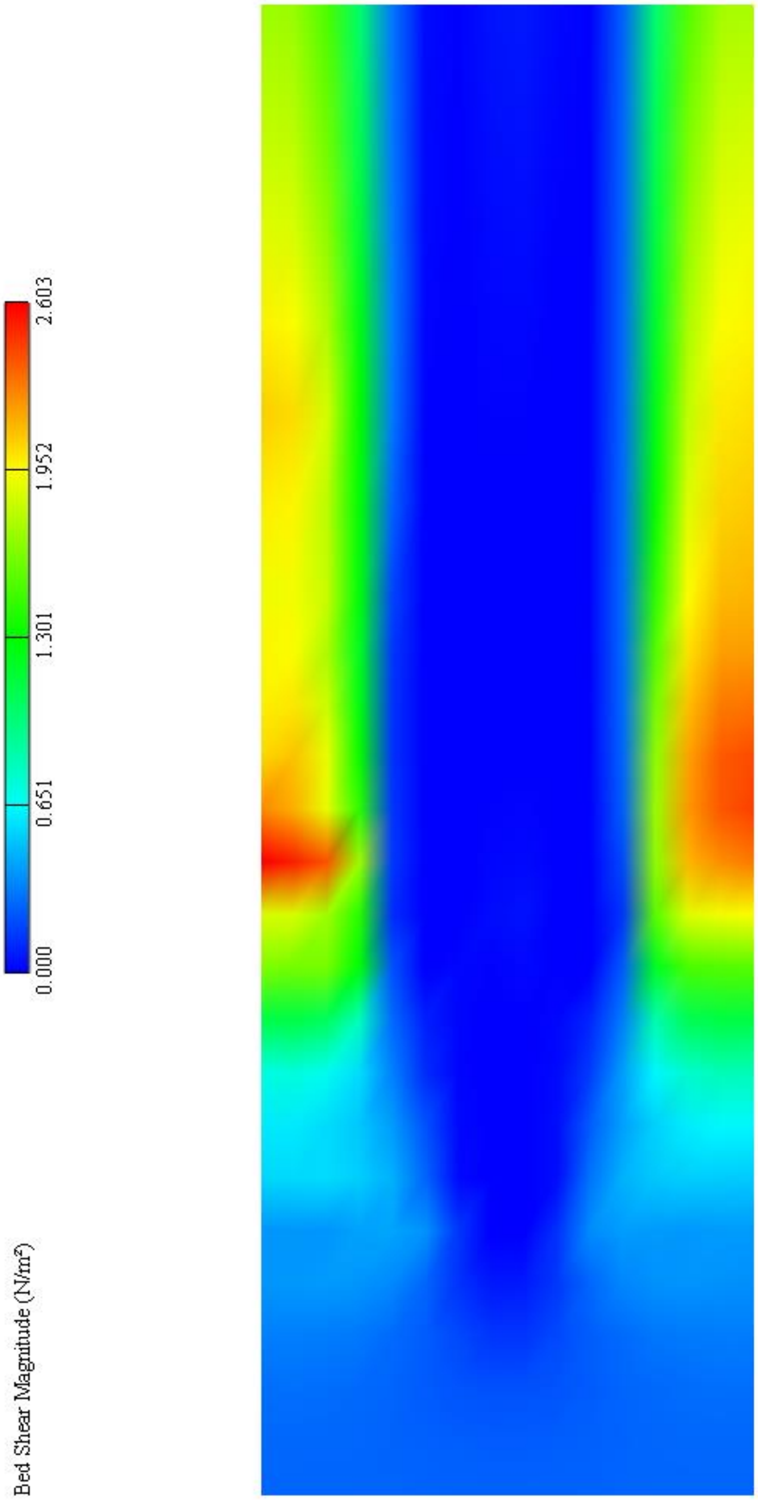


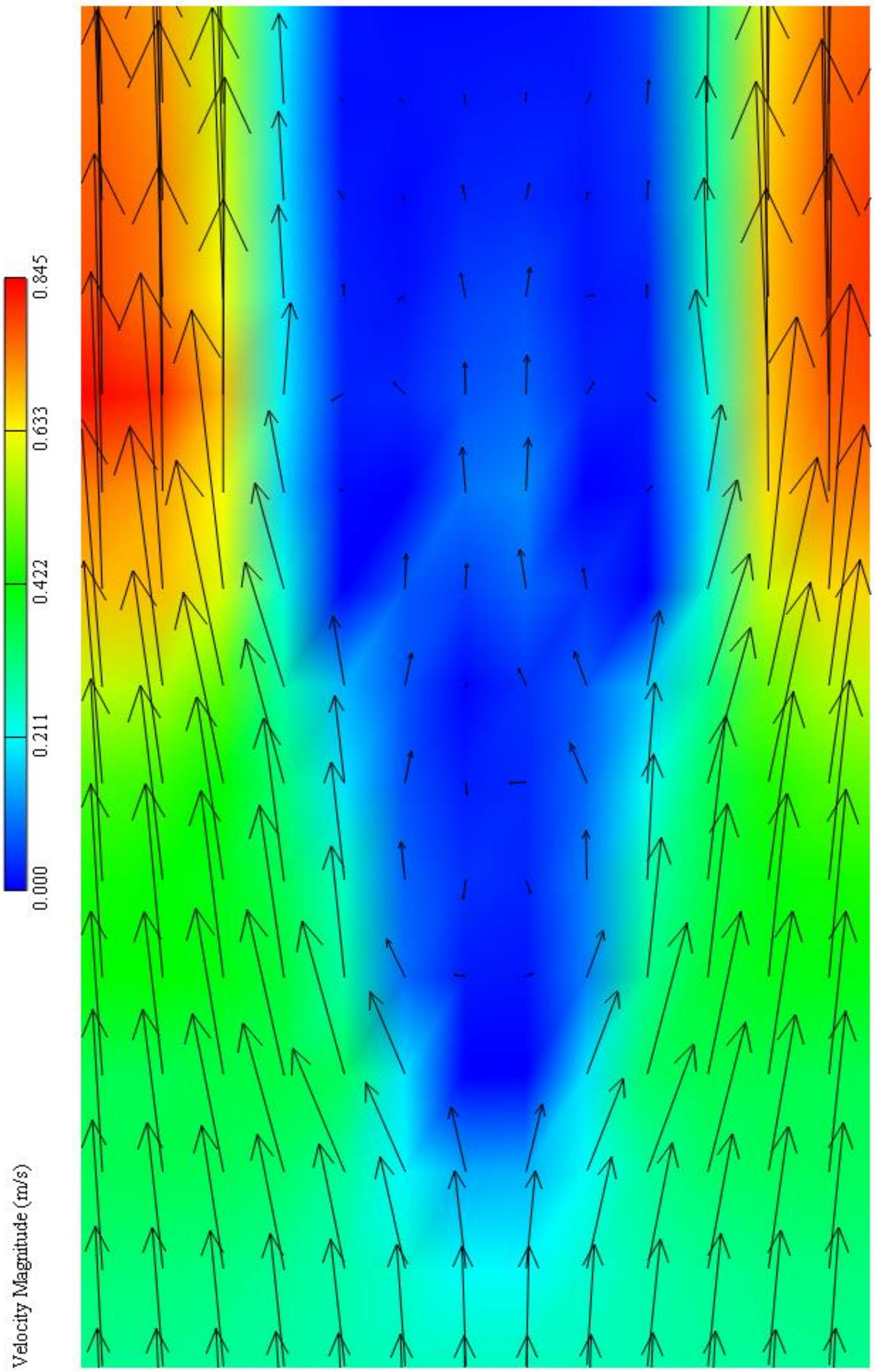
Figure B-2: Side View of Design Schematic for Flume Structure

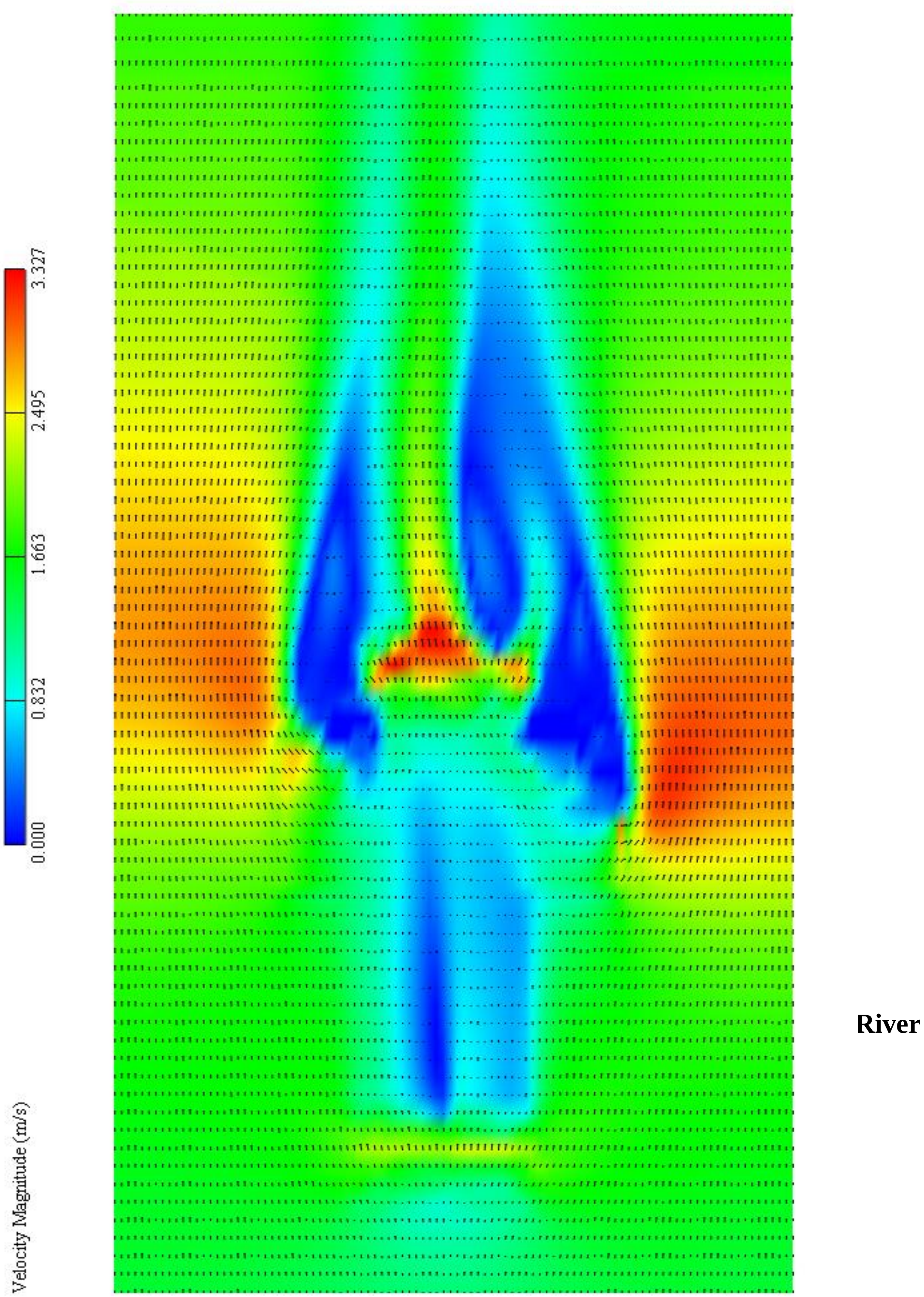
APPENDIX C: COMPUTER MODEL TESTING RESULTS



rrows


Bed Shear Magnitude (N/m²)
0.000
0.651
1.301
1.952
2.603


Velocity Magnitude (m/s)
0.000
0.211
0.422
0.633
0.845


Velocity Magnitude (m/s)
0.000
0.832
1.663
2.495
3.327
River

APPENDIX D: FINAL DESIGN DRAWINGS OF PROTOTYPE DESIGN STRUCTURES

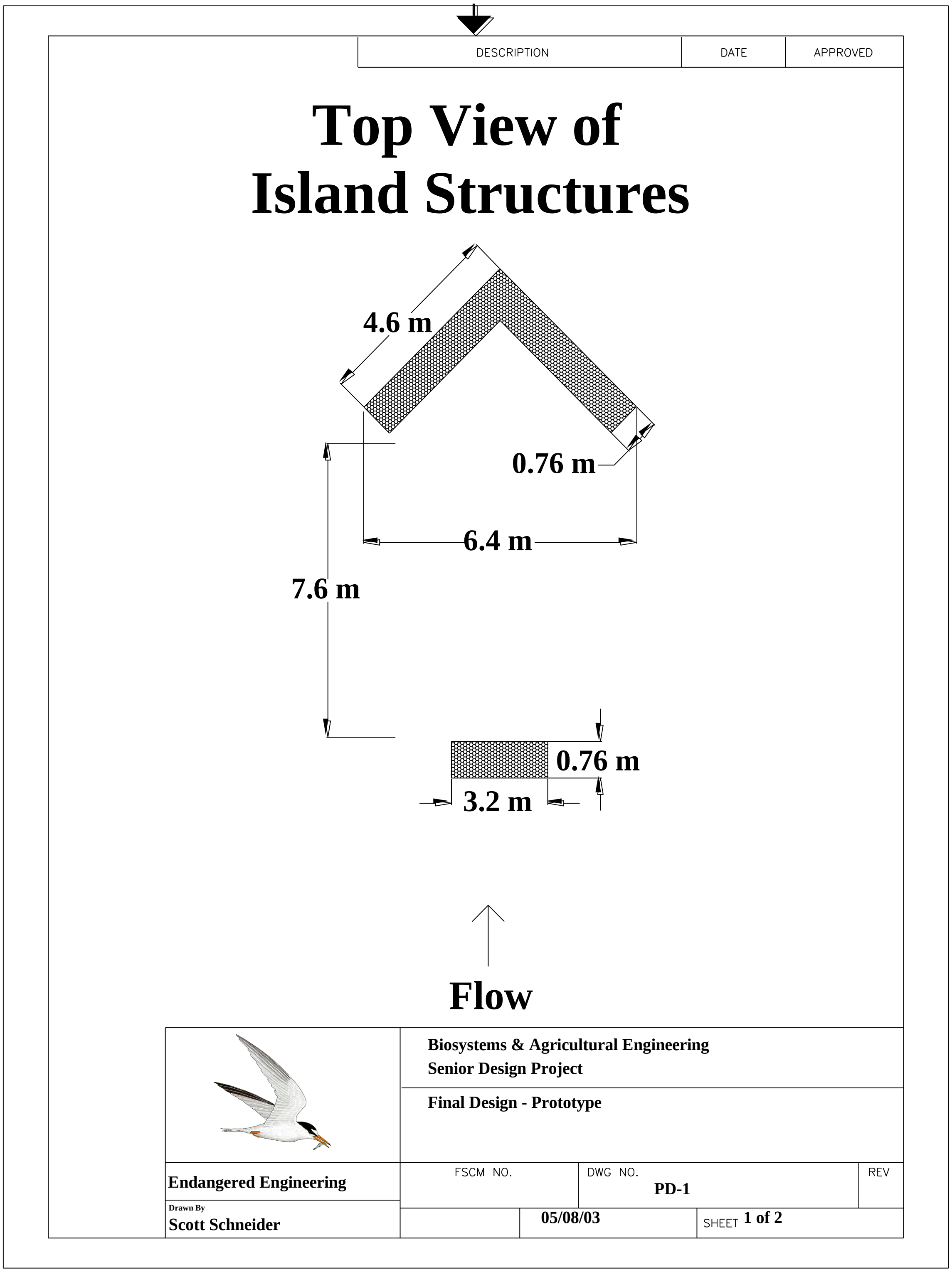


Figure D-1: Top View of Design Schematic for Prototype Structure

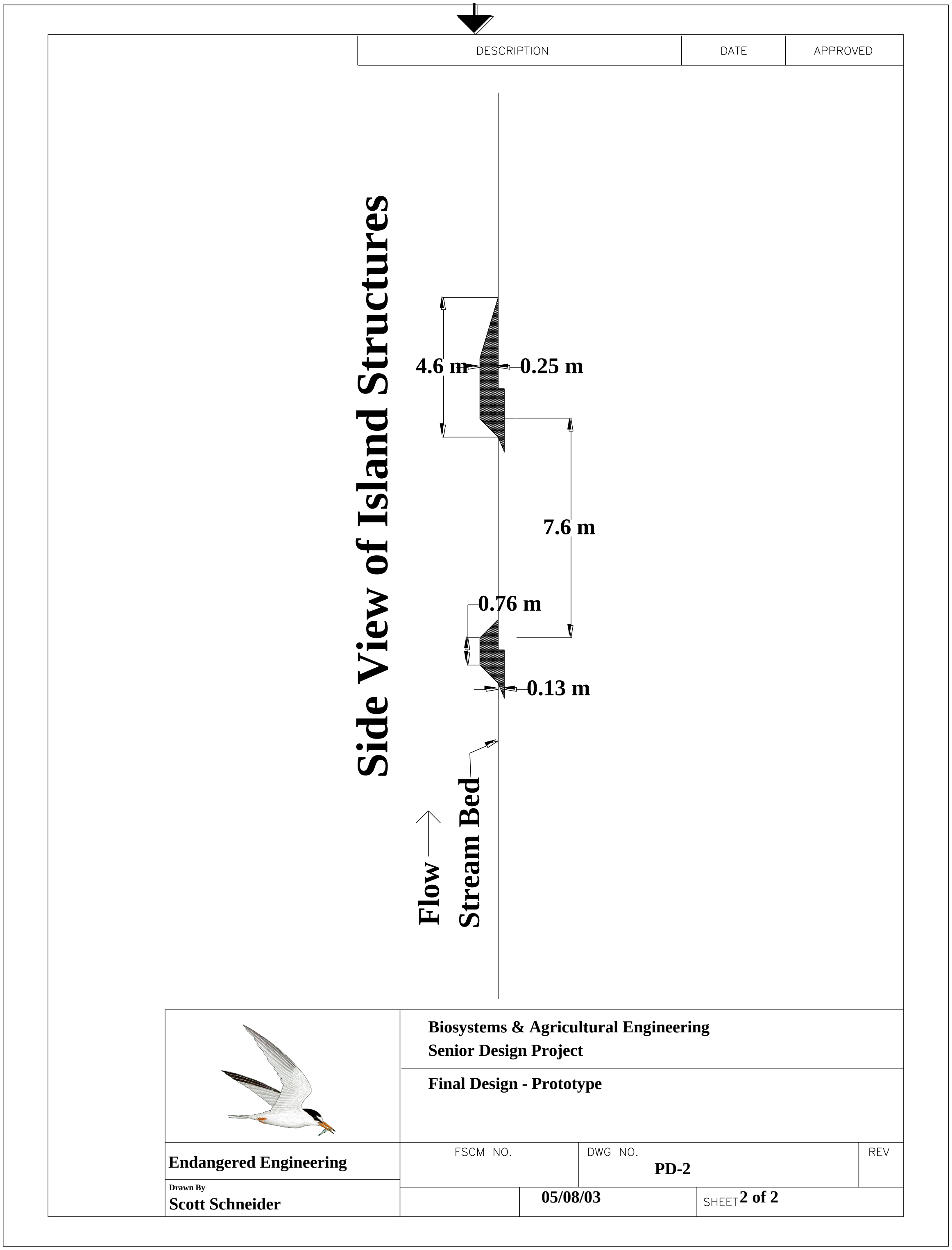


Figure D-2: Side View of Design Schematic for Prototype Structure

Least Tern Island Project

Endangered Engineering

Design Team

Scott Schneider
Mary Crawford
Matthew Simpson

Sponsor

The U.S. Army Corps of Engineers ®

Tulsa, Oklahoma District

The U.S. Army Corps of Engineers Project Proposal

- Create a method for establishing an ideal Least Tern habitat
- Must be cost effective
- Create little impact to the natural surroundings
- Provide long term sustainability

Least Tern Habitat Preferences

- 10% to 0% vegetation cover
- Sandy, sloping beaches
- Large island
    - Greater than one acre

Adult Interior Least Terns

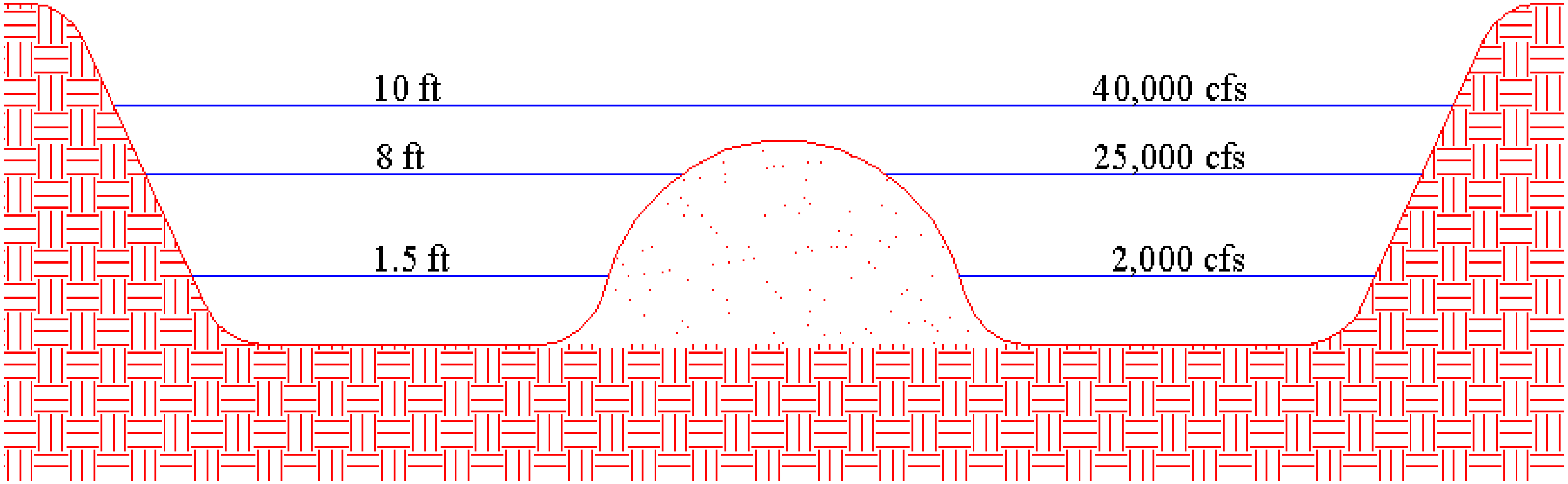
Island Requirements

- Island must be at a height in which vegetation can be scoured off by flooding
- Maintain a constant flow on all sides
  - Keep out predators and recreational vehicles
  - Prevent land bridging
- Island Area should be about 2 to 3 acres

Flow Requirements

- 1 year flood flow – 40,000 cfs
  - Scour vegetation from the top of the island
- Average flow – 25,000 cfs
  - Maintain proper scour around the island
  - Island visible above waterline
- Minimum flow – 2,000 cfs
  - Prevent land bridging

Island Flow and Stage Comparison



Location Specifications

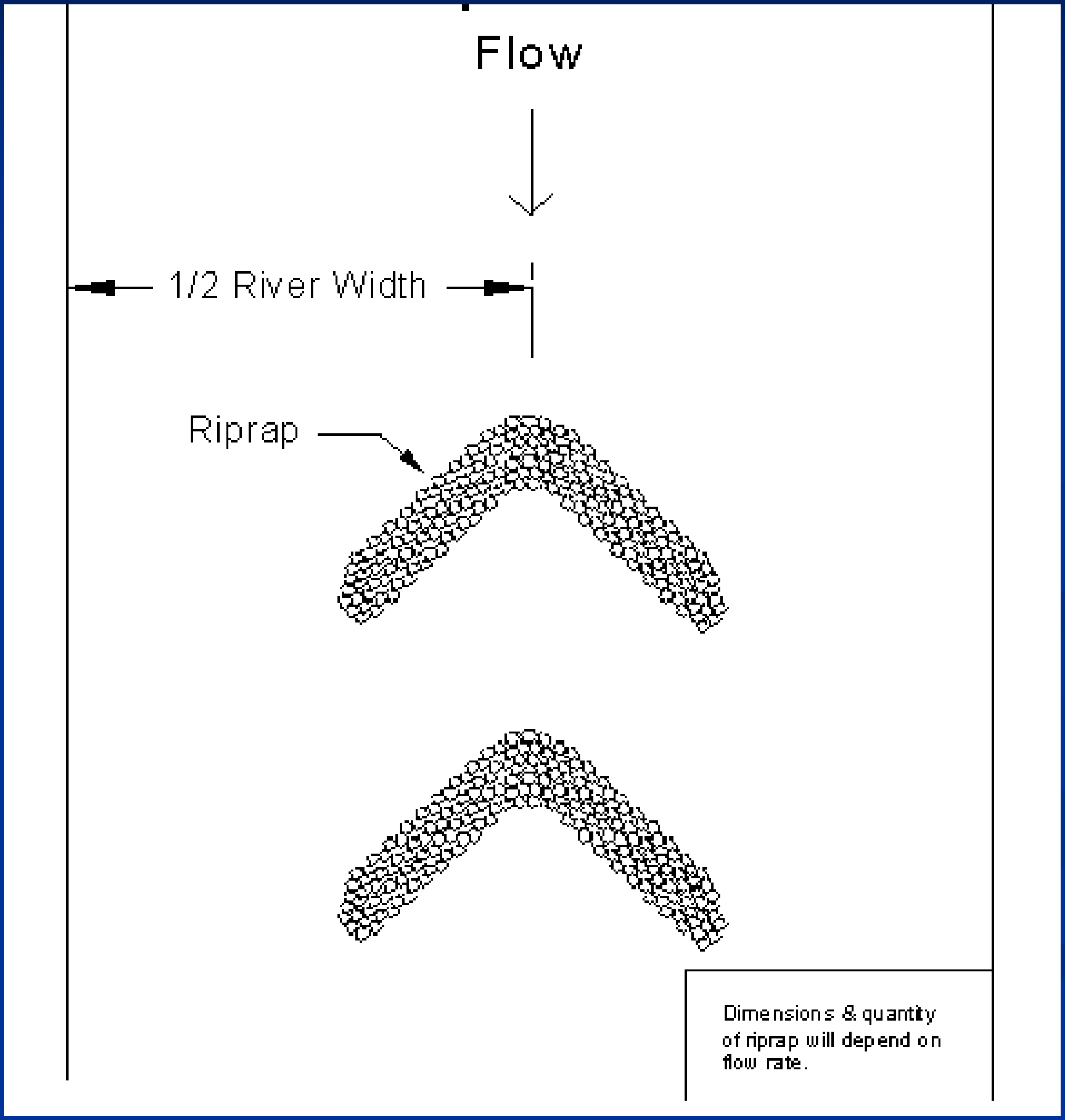
- Straight reach immediately upstream and downstream
- Proper flows available
- Stable banks
- Large sediment transport capabilities
- Between Keystone Dam & Muskogee, OK
- Tributaries immediately upstream and/or downstream

Army Corps Arkansas River Inspection

- Jerry Sturdy, Army Corps Biologist, conducted the inspection
- Air boat tour of the Arkansas River - Jenks Bridge to just past Bixby Bridge
- Observed examples of both good and bad island habitats

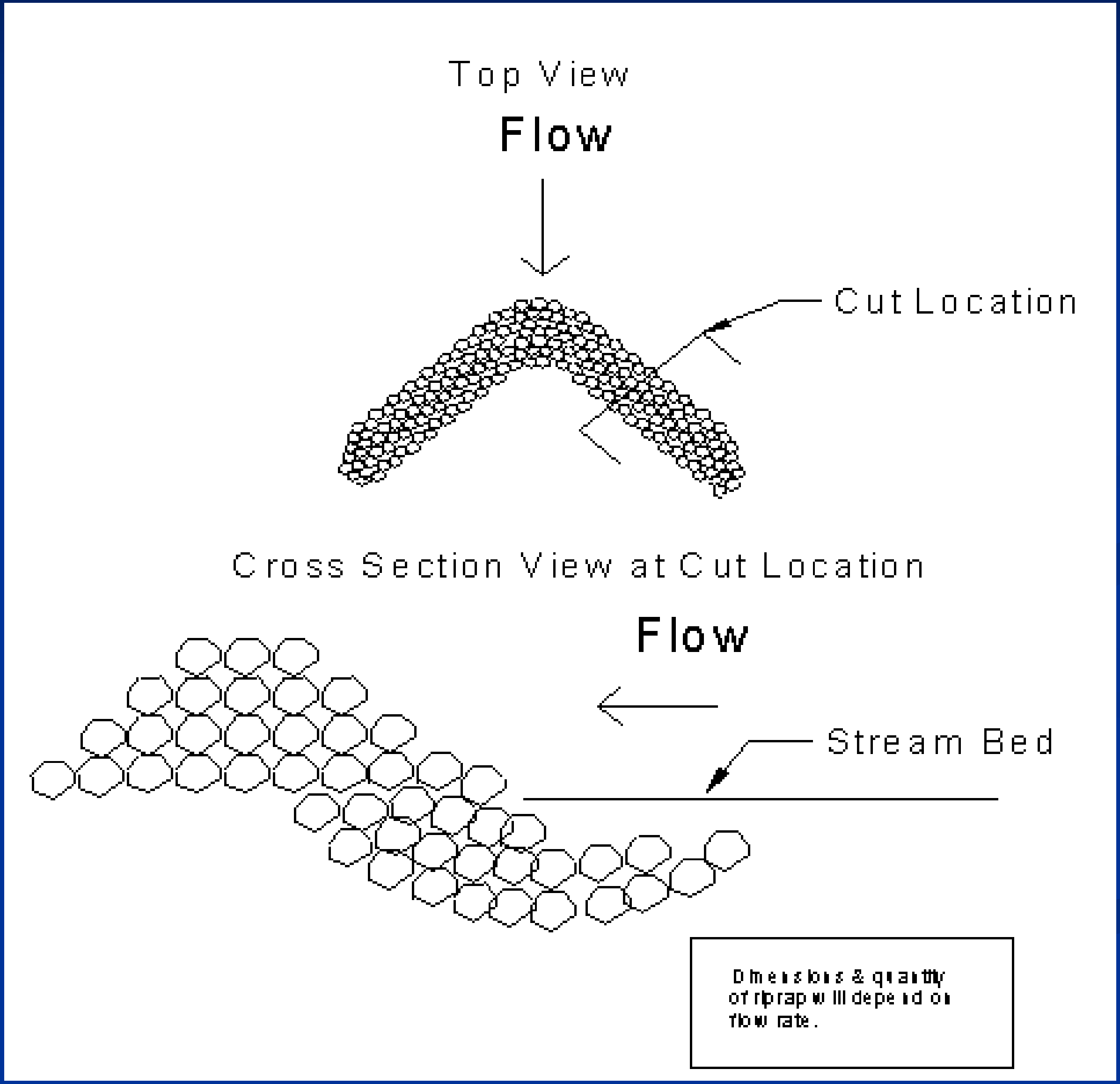
U.S. Army Corps Air Boat

Proposed Design Top View



Dimensions & quantity of riprap will depend on flow rate.

Proposed Design Side View



Dimensions & quantity of riprap will depend on flow rate.

ARS Hydraulics Lab

- Adjacent to Lake Carl Blackwell, Stillwater, OK
- Contributing ARS Personnel – Kem Kadavy, Sherry Britton, and Darrel Temple
- Physical scale model
  - Concrete flume
  - Regime theory

Concrete Flume

- 90ft x 6ft x 10ft
- Flow rate available – 3 cfs
  - Measured by a 4 inch orifice and manometer
- Concrete sand as bed material
  - D_{50} = 0.6 mm (0.024 in)
- Various sizes of gravel utilized for island structure material
  - Diameter 4 to 1 in

Regime Theory

- Width $\propto Q^{1/2}$
  - Scaling factor = $1000/6 \cong 165$
- Depth $\propto Q^{1/3}$
  - Scaling factor = 40
- Bed material of model = bed material of river

River Flow (cfs)	River Depth (ft)	Model Flow (cfs)	Model Depth (in)
60,000	12	2.2	3.6
40,000	10	1.5	3.0
25,000	8	.92	2.4

ARS Concrete Test Flume

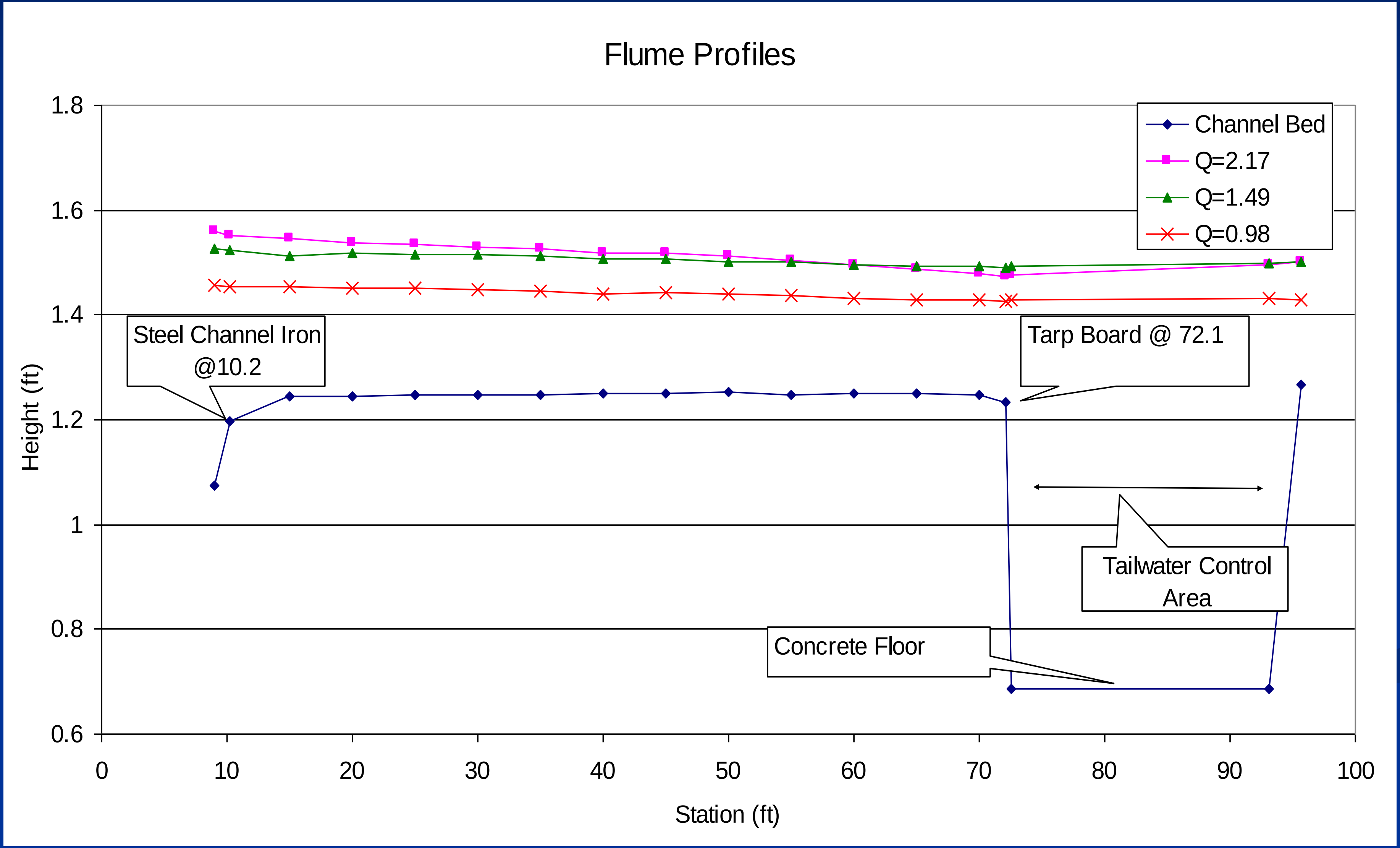
Model Construction

Prepare Level Bed

Prepare Structures Using Template

Bed and Water Surface Profile

Week 1



Velocity Analysis with Confetti

Week 2

0 seconds

3 seconds

6 seconds

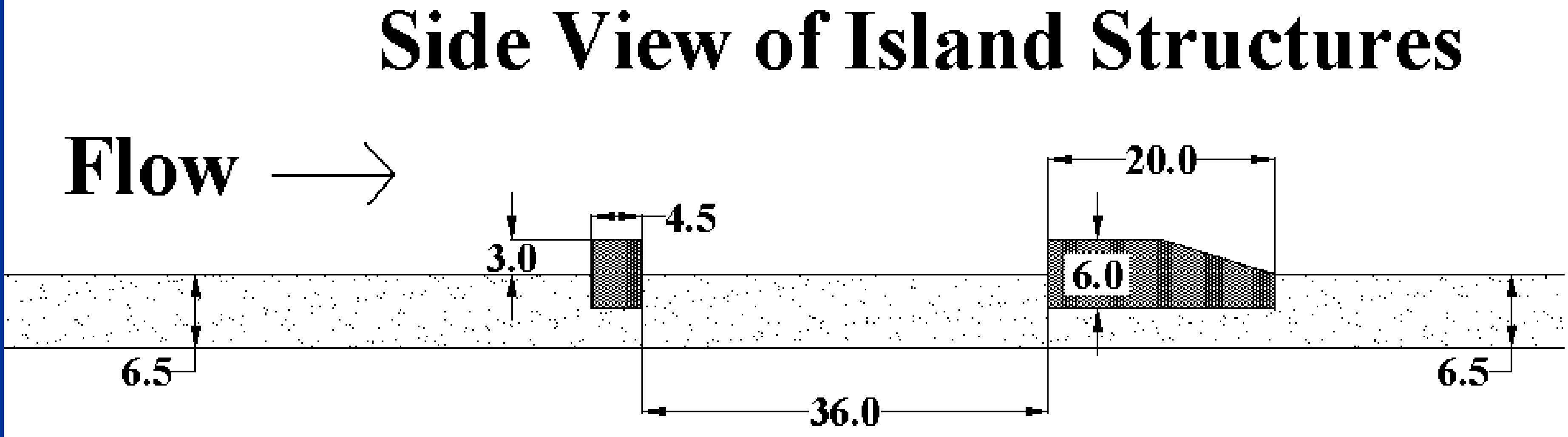
10 seconds

↑

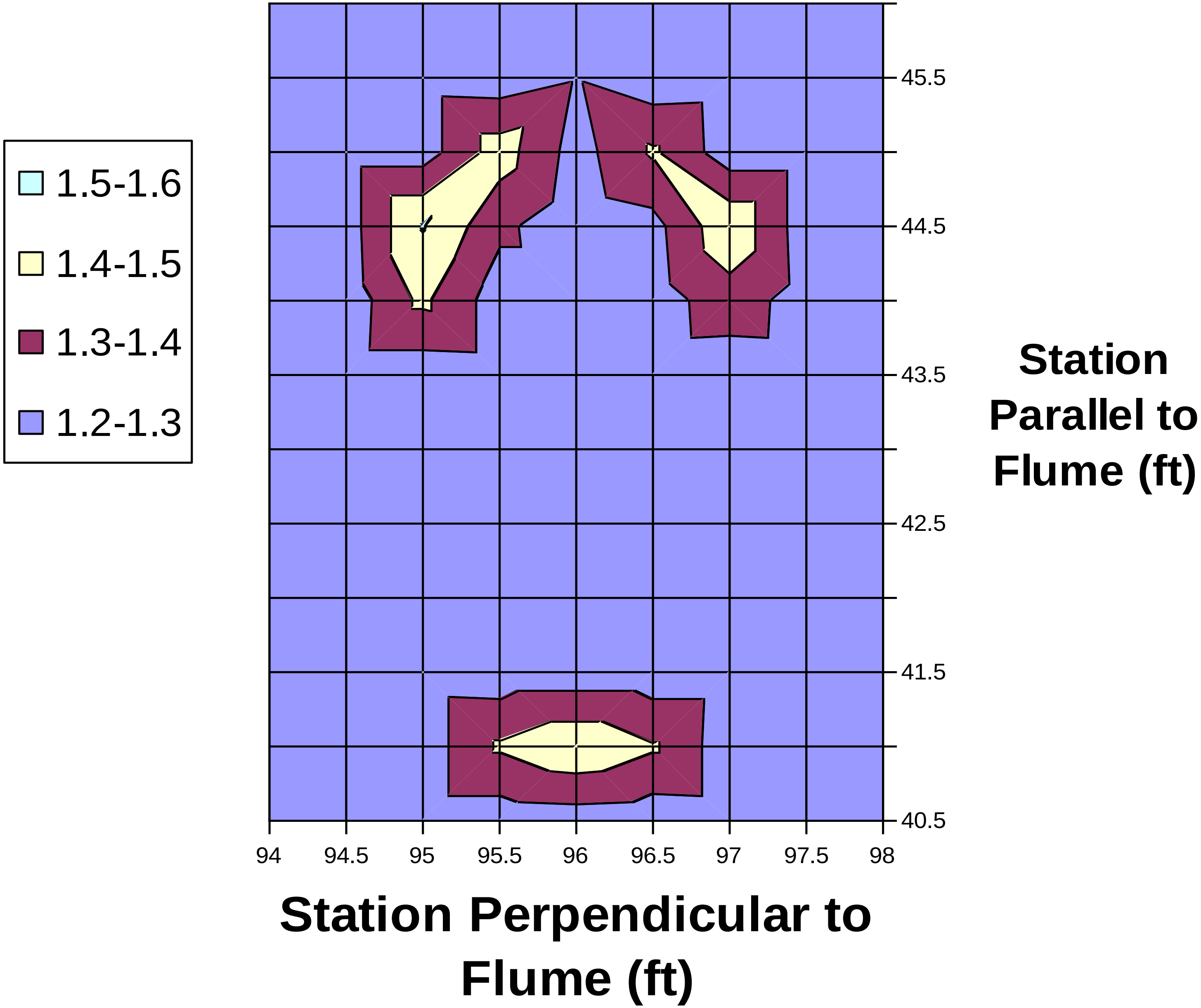
Flow

Final Design

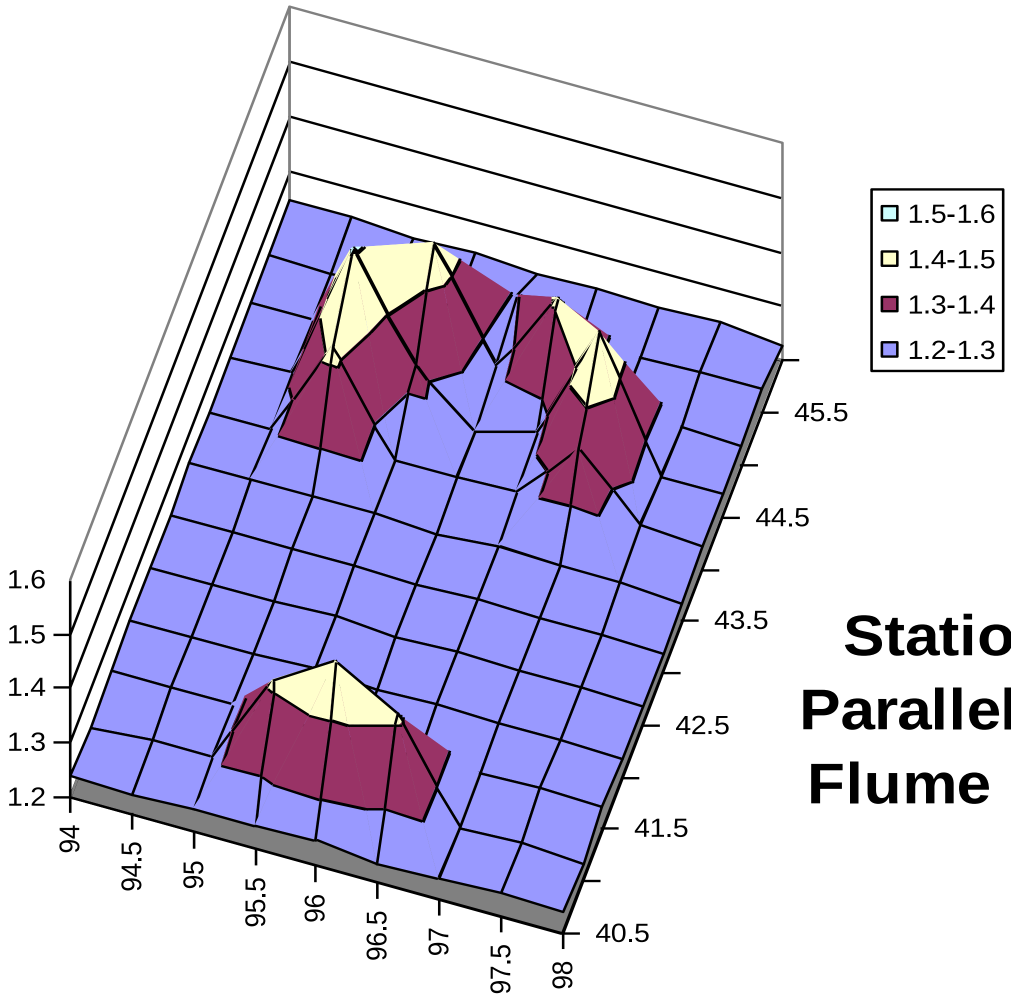
Units in inches



Flume Surface Graph



Flume Surface Graph

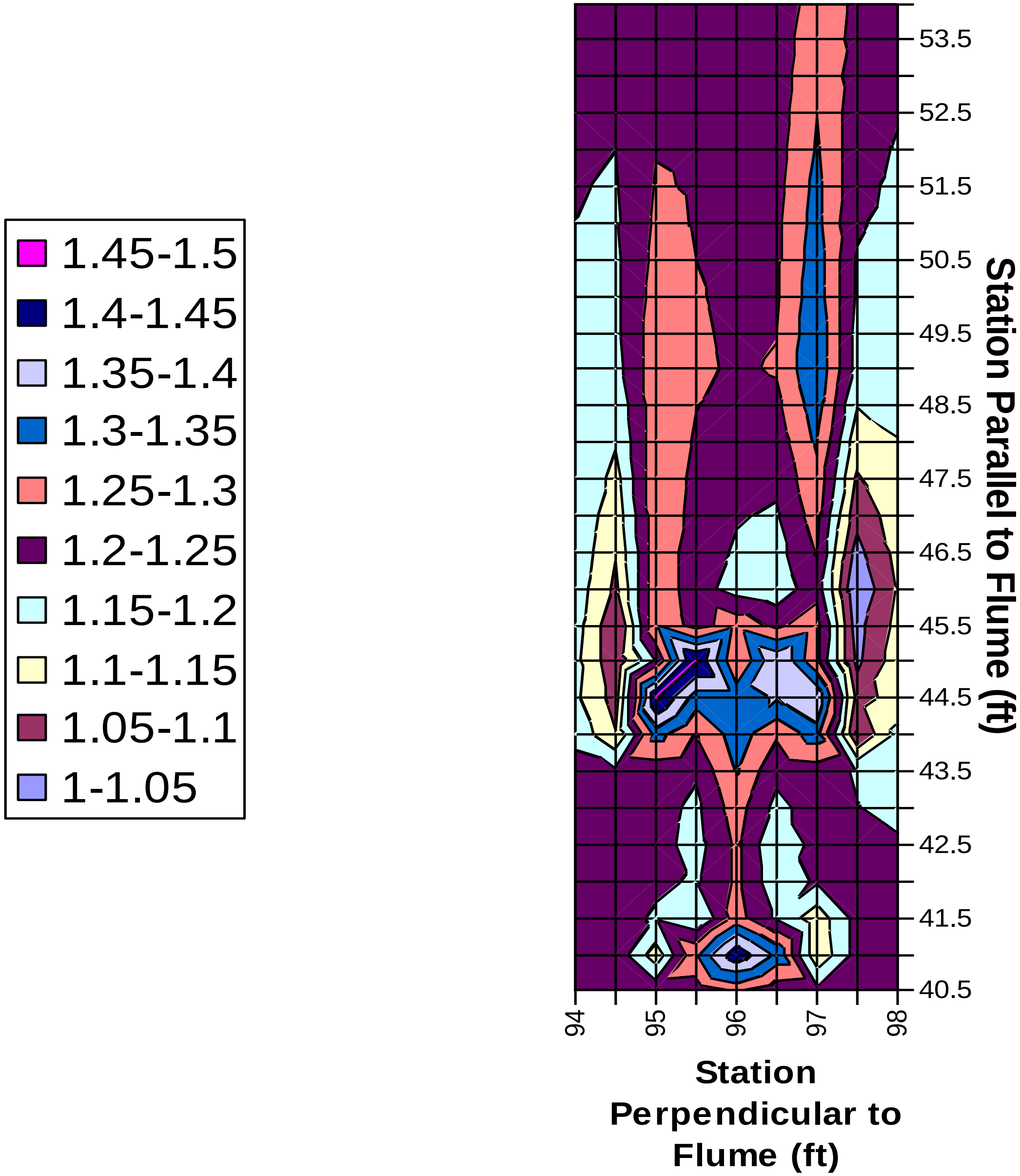


Height (ft)

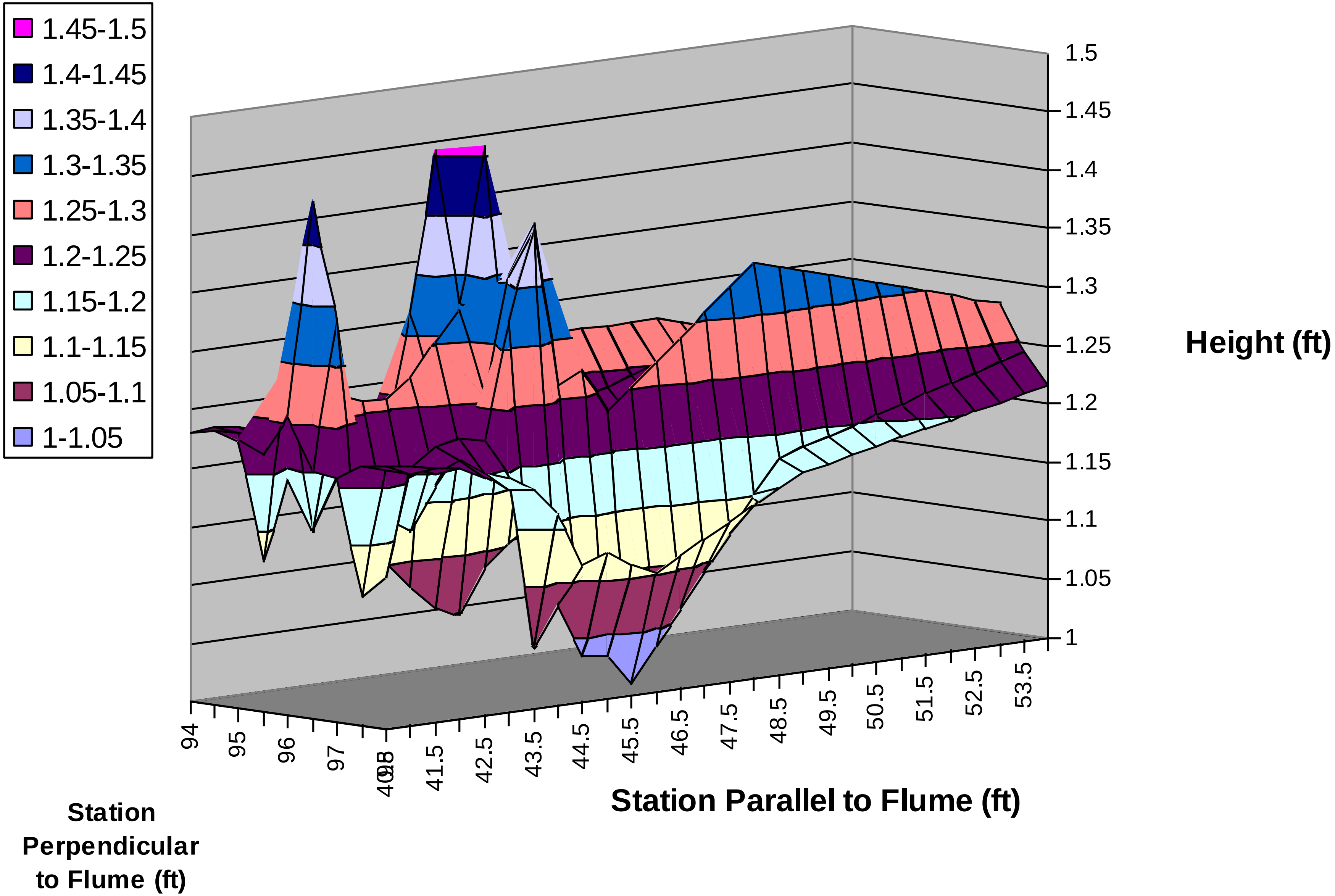
Station Parallel to Flume (ft)

Station Perpendicular to Flume (ft)

Flume Surface Results



Flume Surface Results



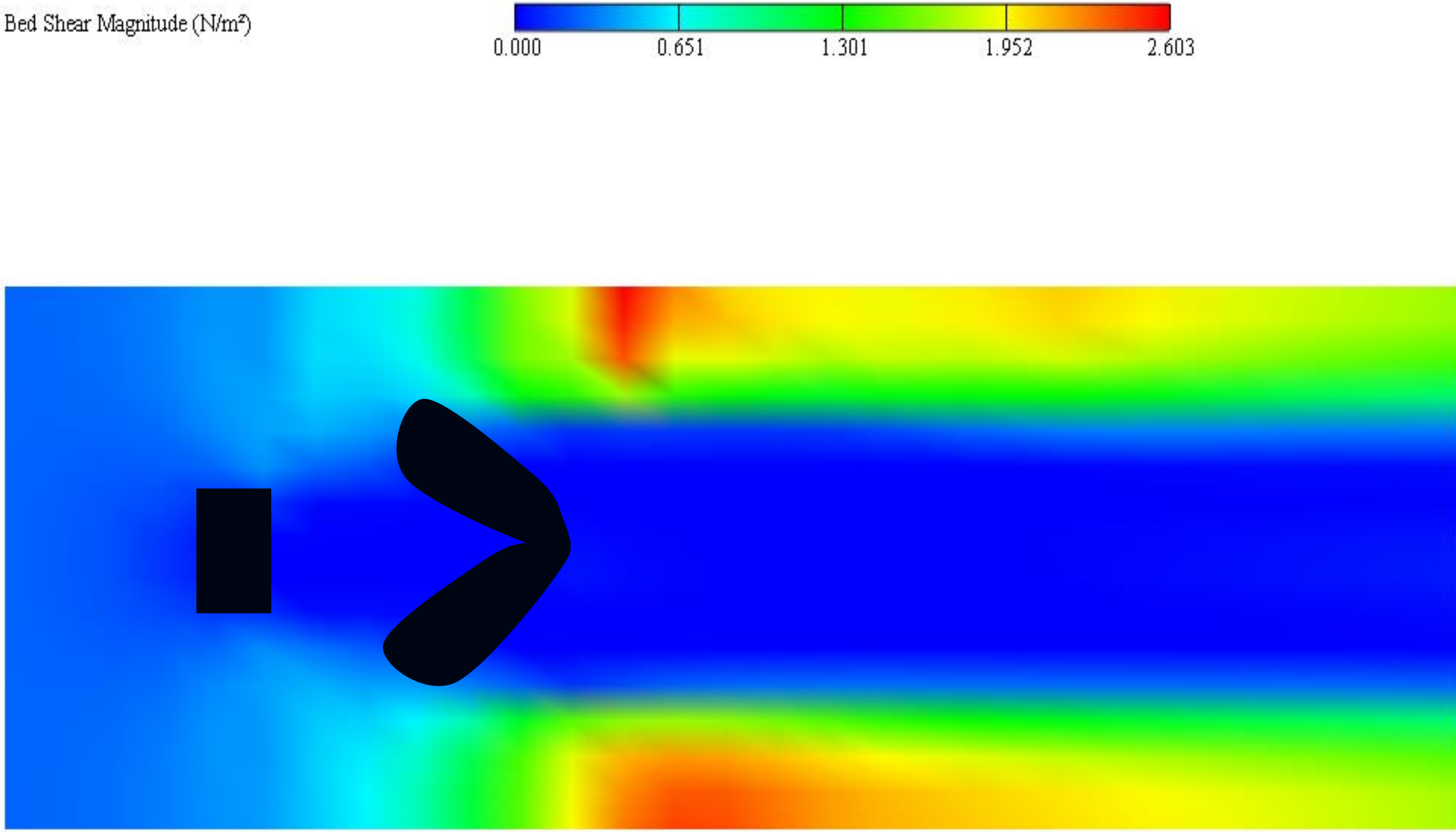
CCHE2D Computer Model

- Developed at the National Center for Computational Hydroscience and Engineering, University of Mississippi
- 2-D depth-averaged mass & momentum governing equations

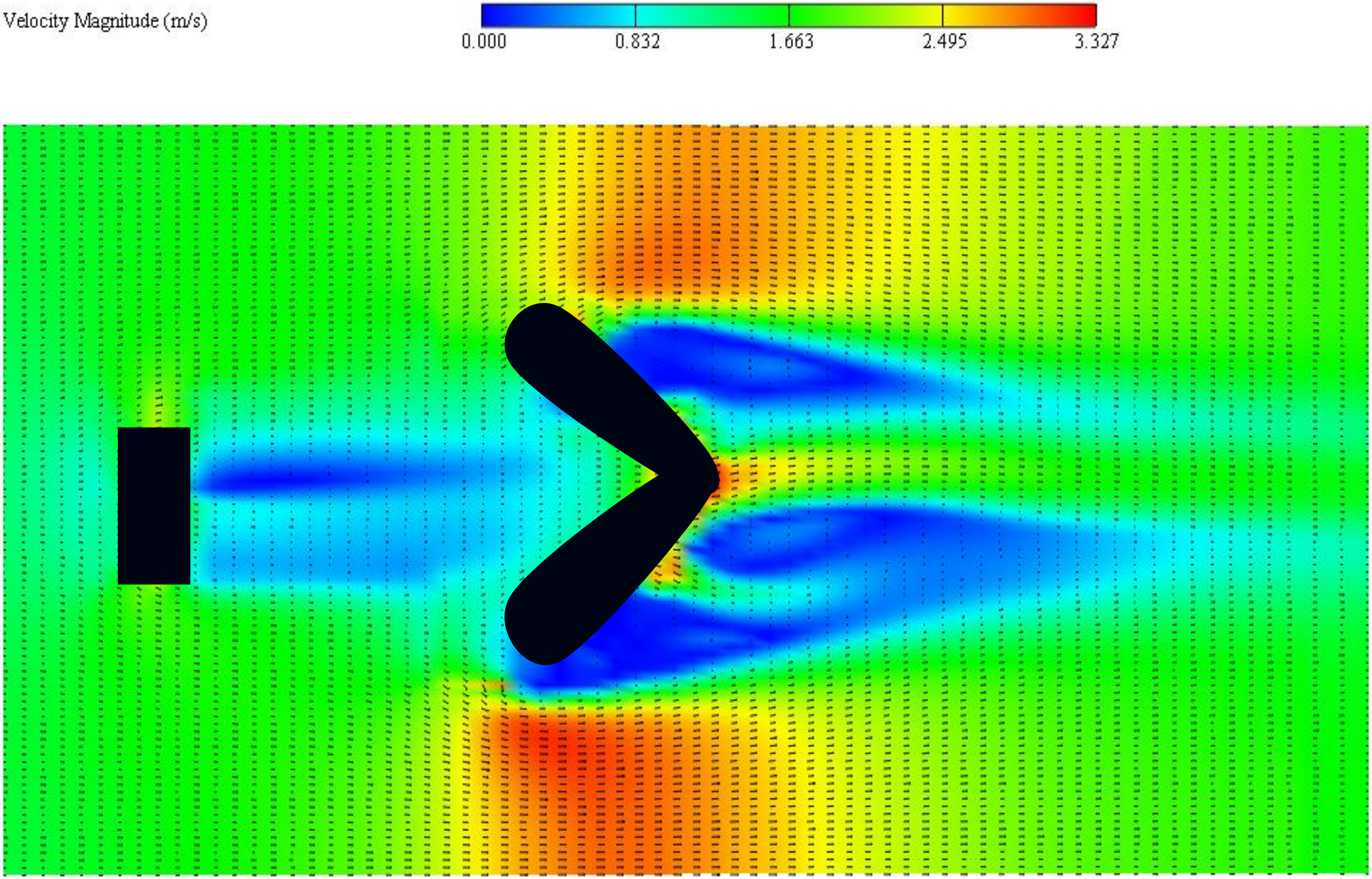
$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial \eta}{\partial x}=\frac{1}{\rho h}\frac{\partial h\tau_{xx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{xy}}{\partial x}-\frac{\tau_{bx}}{\rho h}+f_{cor}v$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \eta}{\partial y}=\frac{1}{\rho h}\frac{\partial h\tau_{yx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{yy}}{\partial x}-\frac{\tau_{by}}{\rho h}+f_{cor}u$$



Bed Shear for Flume Data



Velocities for Arkansas River Data

Design Verifications

- Flume modeling
  - Favorable amount of scour/deposition in appropriate areas
  - Stagnation of velocities behind structures
- Computer modeling
  - Stagnation of velocities behind structures
  - Low velocities area ~ 8 acres during Arkansas River simulation
  - Increase of velocities around structures
- Velocity calculations
  - Velocities are great enough to scour vegetation during flow rates greater than 40,000 cfs

Riprap Calculation

- Colorado State University (CSU) Procedure as reported by Simons and Senturk (1977, 1992)
  - Safety Factor (SF)=1.3
  - D_{50}=2.5 ft (30 in)

$$\eta = \frac{21\tau_{\max}}{\gamma(SG-1)D_{50}}$$

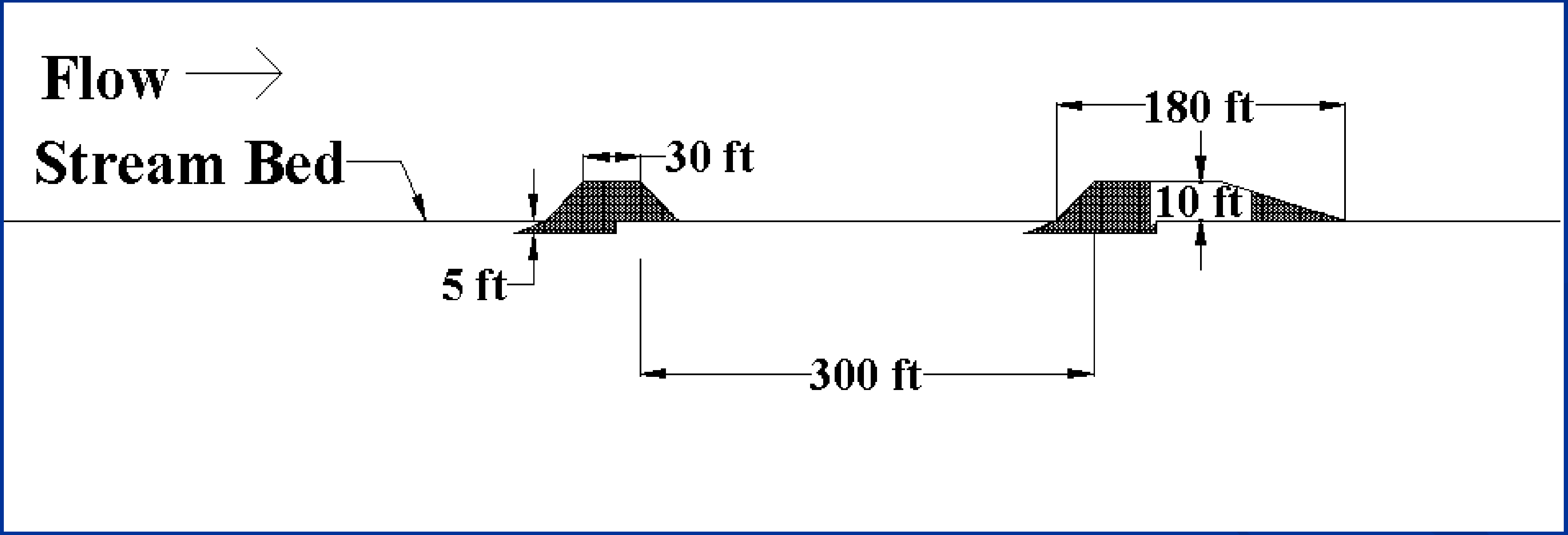
$$\eta' = \eta\frac{1+\sin(\lambda+\beta)}{2}$$

$$SF = \frac{\cos\alpha\tan\phi}{\eta'\tan\phi+\sin\alpha\cos\beta}$$

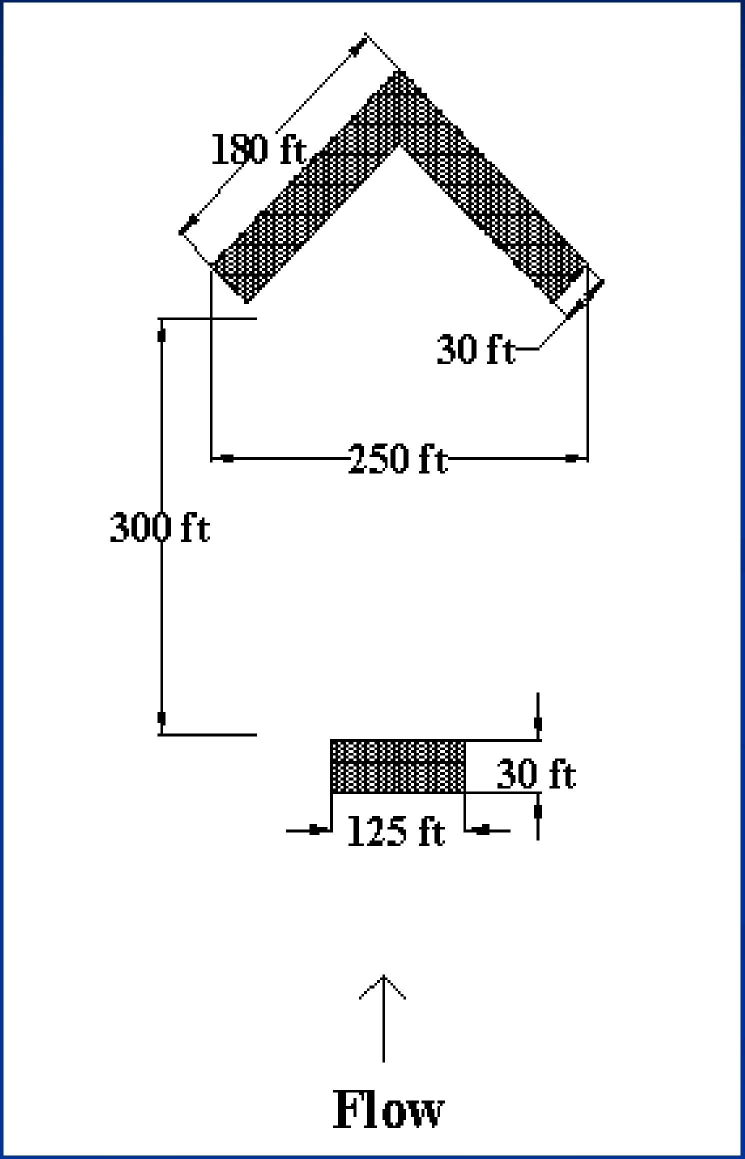
Construction for Full Scale Prototype

- Full Scale Riprap Structures
  - Based on an estimated $50/yd^3
  - $270,000 for material and construction
- Located in a straight reach within 1-2 miles of Polecat Creek (South of Jenks)
- Suggest stabilizing banks adjacent to the island with riprap

Arkansas River Prototype Side View



Arkansas River Prototype Top View



Recommendations

- Construct prototype during low flow periods
- Confirm design by constructing a small prototype
  - Riprap – $10,000
    - Front – 43ft x 10ft x 3ft
    - Rear – 56ft x 10 ft x 3ft
  - Quikrete® – $10,000
    - Front – 30.5ft x 7ft x 2.5ft
    - Rear – 40ft x 7ft x 2.5ft
  - Stabilize an existing island

Visit our website at

http://biosystems.okstate.edu/seniordesign/envr/

Least Tern Island Project

Endangered Engineering

December 11, 2002

Submitted By:
Scott Schneider
Mary Crawford
Matthew Simpson

BAE 4012

Dr. Paul Weckler

Table of Contents

Introduction

The Least Tern was listed as an endangered species in 1985, with a total population estimated at 5000. Channelization, irrigation, and construction of reservoirs and pools have drastically depleted the nesting habitats used by the Least Terns. The U.S. Army Corp of Engineers has done various studies on the habitation and breeding styles of the least tern species in order to devise a plan to stabilize the species. The 2002-2003 Oklahoma State University Biosystems Engineering Senior Design Team has been selected to determine a solution to the problem. The purpose of this project is to develop a feasible island habitat for Least Tern nesting and habitation to facilitate the recovery of the species.

Statement of Work

The desired content of the final design is outlined in the following breakdown. The specifications recommended by the Army Corp of Engineers are included in this statement. These are the goals and specifications that should be followed in completion of the project.

The island habitat should follow the following location criterion. The location boundaries are the Arkansas River natural channel from Keystone Dam to Muskogee, Oklahoma. An ideal location will be determined that will not be too close to the dam, allowing for excess scouring, and not too far down river, allowing for excess sediment buildup.

The design of the island habitat should be such that the listed conditions should occur at the following flow rates. The average flow conditions are 30,000 cubic feet per second to maintain proper scour around the island and prevent land bridging. The minimum flow conditions are 10,000 cubic feet per second to maintain proper scour around the island and prevent land bridging and the maximum flow conditions are 60,000 cubic feet per second to scour vegetation from the top of the island. Investigation of the feasibility of scouring the island will be done to determine if it will be a reasonable maintenance procedure, or if it will degrade the remaining structure of the island beyond reasonable expectations. The island design should be able to withstand a flood event of 100,000 cubic feet per second.

The design of the island habitat should conform to the following criteria. The area should be two to three acres and should be concentrated in the center of the channel. The island should have gently sloping sandy beaches, less than ten percent vegetation, and should withstand high flows.

The final product that will be submitted to the U.S. Army Corp of Engineers Tulsa District should be of the following form. One working model of the ideal island habitat will be provided to the U.S. Army Corp of Engineers, Tulsa District along with project specifications and cost estimates. If feasible given project time constraints, one or more secondary alternative models may be designed and provided.

Background Information on Least Terns

As previously mentioned, the least tern is currently on the endangered species list. Intensive research has been done to determine the specific characteristics of the terns in order to know what must be done for successful recovery of the species. This bird is migratory and breeds primarily on sandbars, sandbar islands, and lake and reservoir shorelines in lower and mid-American rivers and lakes. The breeding season in these areas ranges from arrival in late May through the end of August. (Sidle 1990) They prefer to nest on elevated areas away from the edge of the water. Least terns prefer habitations with very little or no vegetation. However, pieces of driftwood are often utilized for protection shelter on islands where it is available. The birds are colonial and often return to a particular site for consecutive breeding seasons. (Keenlyne 1986) Numbers of nests in a specific area vary from year to year and month to month due to river level fluctuations causing variations in island widths and heights. Use of artificial habitats such as sand and gravel pits and dredge islands has increased due to the reduction of islands caused by implementing dikes and other systems in many rivers. Least terns feed on forage fish of two to eight centimeters in length and may rely on distance from food sources when determining a suitable nesting habitat. (Keenlyne 1986) Because of the nature of the tern's habitat condition requirements, careful consideration must be used in selecting an island design that will be environmentally stable over a long period of time and also be a habitat that the birds will consistently use each season.

Previous Island Design Considerations

Several projects have been proposed and implemented in the Missouri River between the Niobrara River and Ponca, Nebraska by the Army Corp of Engineers Omaha Division. The 1993-1995 Plan for Habitat Improvement for the Interior Least Tern and Piping Plover was finalized in May 1993 and consisted of a ten year plan in which suggested activities would be researched and implemented to improve breeding of these species. Many of the projects analyzed by the Omaha Division involved the repair of previously used habitats. Twenty sites were selected to develop for habitation ranging from 1.3 to 49 acres. Islands were chosen for development based on final elevations one to two feet above water surface elevation during high range flows of 38,500 cubic feet per second. The vegetation was mechanically leveled and the islands were capped with two feet of sand. Shoreline Erosion Arrestor bags were used on the upstream and channel sides of the islands to prevent erosion. (Meuleners 1994) Biological, as well as socioeconomic repercussions were evaluated for the habitation rehabilitations. Various alternatives were considered for different aspects of the project. Alternatives for mechanical vegetative control were chemical clearing, hand clearing, burning, and flow manipulations. (Meuleners 1994) Instead of bulldozing the islands for recapping, the expensive alternative of dredge capping was considered. Also the implementation of floating islands and bulldozing low-elevation islands were also considered. The success of floating islands for least tern habitation was not known at the time the document was written. These islands had been installed in two test areas before the 1993 breeding season, but were not used by the birds during that first season of their existence. No information was found listing the success or failure of the prescribed projects.

Zink Island is a manmade island on the Arkansas River near the 21st Street Bridge in Tulsa, Oklahoma. A photograph of the island is shown in Figure 1.

Figure 1. A photograph of Zink Island in 1995.

The Tulsa Audubon Society has done an annual study for the last decade to determine patterns in fledged young and nests on the island. The survey extends from the middle of May through the middle of July, which is the majority of the breeding season for the species. The results show a dramatic decrease in the number of fledged young per nest from 1.44 in 1992 to 0.43 in 2001. (Tulsaaudubon) The dramatic decrease in breeding rates is largely due to excessive vegetation growth on the island that discourages the birds from nesting and breeding at this location. It is unknown whether or not the island would again be used if the vegetation was greatly reduced.

The U.S. Army Corp of Engineers Tulsa District conducted a study in July 2002 resulting in the Management Guideline and Strategies for Interior Least Terns. Long-term strategies of the document were to develop and maintain islands with suitable nesting habitat by implementing various methods and to evaluate and monitor the project impacts. Short-term strategies were also developed to initiate steps for achieving the long-term goals and to provide immediate relief to the birds. These strategies include releases of floodwater to scour islands for vegetation removal, dredging of current islands to replenish sand deposits, and providing appropriate water releases when possible to ensure optimal nesting conditions for the terns. Season pool plans will be implemented for Keystone to allow for minimum flow requirements during the late part of the nesting season. Plans have also been devised for water conservation and water operations regarding water supply, water quality, and hydropower.

The Tulsa Division provided the design group with an airboat inspection of the Arkansas River ranging from Jenks, Oklahoma to several miles past the bridge at Bixby, Oklahoma. The tour consisted of visiting different habitations frequently used by the least terns during the 2002 breeding season. Two of the well-used islands are shown in Figure 2.

Figure 2. Some examples of good islands used for least tern habitation.

The tour also consisted of observing several habitations that were not used by the terns for breeding. Various reasons for lack of use included land bridging of the island, heavy vegetation, steep banks, and human recreation. Some examples are shown in Figure 3.

Figure 3. Some examples of islands not used by least terns for habitation due to (a) heavy vegetation and (b) human recreation.

Generation of design concepts

After careful analysis of previous designs used in other environmental conditions and of basic hydrodynamic prototypes used for various projects, several basic design considerations were selected and tested. A rudimentary examination of the possible design concepts was performed using a stream trailer to simulate river flow. The first design procedure involved the basic setup of the stream trailer without any alterations. The finely crushed buttons in the stream trailer simulated sand particles and were molded into a riverbed with a normal slope symmetric on both sides. Riprap was set up in various arrangements in the center of the river flow and two levels of flow were used to simulate typical river conditions. Particulate was introduced into the initial flow and the formation of islands was analyzed and critiqued.

It was determined that the flow should originate from the center of the streambed rather than at the sides for more accurate design analysis. PVC pipe was used to extend the original flow outlet to the middle of the bed. Also a thin tarp was placed over the riverbed particulate to keep the sides of the channel and the riverbed stable throughout the experiment. The main design considerations are outlined in the following sections.

Preliminary Design 1

The first design consideration is shown in Appendix A Drawing PD-1 Sheet 1. The design consists of two inverted V's placed in the center of the river channel. The shaping and spacing of the riprap will cause sediment to fall out behind the riprap forming an island in the center of the river channel. The ideal location would be a point of the Arkansas River that is straight so the flow will evenly hit the tip of the first riprap frontally. The riprap will be shaped as a triangular structure with a wide base that will gradually become narrow towards the top, as shown in Sheet 2. A shelf will be extended below the front of the riprap for reinforcement to prevent sediment in this area from eroding away and causing undercutting of the structure. Using this shelf structure will provide additional stability to the design. A picture of design simulation produced in the stream trailer is shown in Figure 4.

Figure 4. Stream trailer simulation of preliminary design 1.

Preliminary Design 2

The second design consideration is shown in Appendix A Drawing PD-2 Sheet 1. The design consists of two inverted V's placed in the center of the river channel. Again the ideal location would be a point of the Arkansas River that is straight so the flow will evenly hit the tip of the first riprap frontally. The riprap will be shaped in the same triangular structure as Design 1. A shelf will be extended below the front of the riprap as in Design 1. Both sides of the river bed would be reinforced with riprap in a triangular shape with the points toward the inside of the river channel to concentrate all flow to the center of the river. Cross section and side views of the riprap are shown in Sheet 2. A picture of design simulation produced in the stream trailer is shown in Figure 5.

Figure 5. Stream trailer simulation of preliminary design 2.

Preliminary Design 3

The third design consideration is shown in Appendix A Drawing PD-3 Sheet 1. It is similar to Design 1 in that it consists of two inverted V's placed in the center of the river channel. The second riprap would have the point of the V facing in the downstream direction. Cross section and side views of the riprap are shown in Sheet 2.

Preliminary Design 4

The fourth design consideration is shown in Appendix A Drawing PD-4 Sheet 1. The design is similar to Design 2 except the point of the second riprap is facing downstream, resembling Design 3. The inside and side views of the riprap are shown in Sheet 2.

Determination of suitable designs

The four designs considered in the previous section will be equally weighted in quality until they can be more accurately tested and scrutinized using in-depth flow calculations and computer simulation. The three dimensional computer simulation instruction will be provided by Professor Sam Wang who is the University of Mississippi Head of National Center for Hydraulic Computation. After test analysis the most suitable design for the proposed location will be determined and a small-scale model will be built and tested for further analysis and determination of necessary design alterations.

Based on the initial stream trailer simulations, Design 1 appears to be the most feasible design. If this assumption is backed up by the calculations and computer simulation, this will be the design used for the island.

Development of engineering specifications

The specifications of the design will be determined during the following semester contingent upon selection of the exact location of the island. The flow rates will be determined for this location and the best design concept will be selected based on flow calculations and computer simulation. The size, spacing, and quantity of riprap for the ideal design will then be decided. Other configurations and layout specifications of the design structure will be considered. Further analysis of the types of materials must be conducted to determine if there is a better alternative for creation of the ideal island. It may be determined that riprap is not the best material to use in the structure and it will then be replaced by the optimal material.

Project schedule

The project schedule is outlined in the Gantt chart shown in Appendix B. The main goals for completion during the spring semester are as follows. To ensure that the design is feasible, it will be approached through two different methods almost simultaneously. The first approach is to design the island using hydrology analysis calculations. Specifications for the location and riprap will be determined in the order shown in the chart. Two dimensional modeling applications will be used to verify the calculations. The second approach will be to use a three dimensional computer modeling program to determine the best design. A physical model at a scale of 1:20 will also be used to verify the design. Results of the two approaches will then be combined to produce the optimal island design. Construction guidelines and specifications will be outlined and presented in the final report.

Proposed budget

At this point in the project, the design is not at a stage for us to determine the exact costs of completion. We predict that the scale model could cost up to $350 for supplies and initial setup. Also a portion of the cost of travel for Professor Sam Wang to provide lecture and tutorial for the team on the modeling program may need to be included in the cost considerations. A detailed analysis of full-scale development will be estimated and provided upon completion of the final island design.

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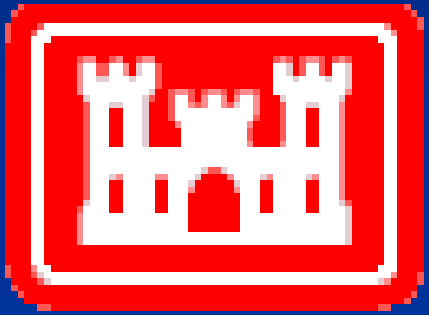
Least Tern Island Project

Endangered Engineering

Design Team

Scott Schneider
Mary Crawford
Matthew Simpson

Sponsor



The U.S. Army Corps of Engineers ®

Tulsa, Oklahoma District

The U.S. Army Corps of Engineers Project Proposal

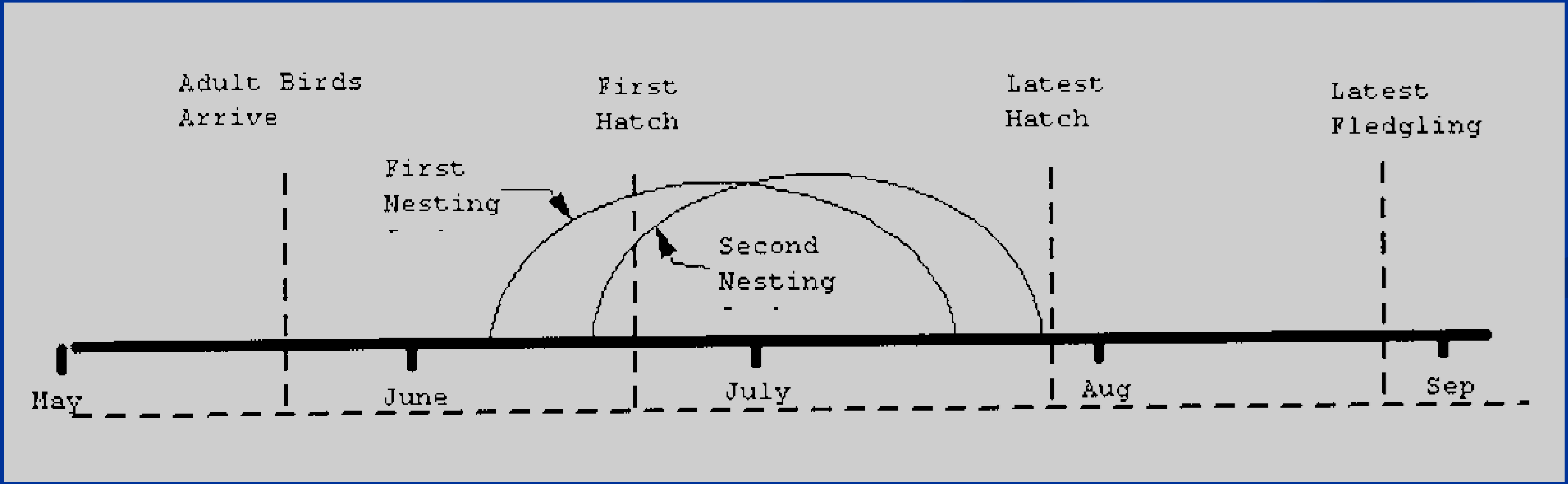
- Create a method for establishing an ideal Least Tern habitat
- Must be cost effective
- Create little impact to the natural surroundings
- Provide long term sustainability

Habitation Preferences

- 10% to 0% vegetation cover
- Sandy, sloping beaches
- Large island
  - Greater than an acre

Nesting Period

- Critical time period – June to August
- Island flow conditions must be
    - High enough to prevent land bridging
    - Low enough to prevent disturbing the terns



Island Requirements

- Island must be at a height in which vegetation can be scoured off by flooding
- Maintain a constant flow on all sides
  - Keep out predators and recreational vehicles
  - Prevent land bridging
- Island Area should be about 2 to 3 acres

Flow Requirements

- Flood event - 30,000 cfs
  - Scour vegetation from the top of the island
- Average flow - 10,000 cfs
  - Maintain proper scour around the island
- Minimum flow - 2,000 cfs
  - Prevent land bridging

Location Specifications

- Proper flows available
- Stable banks
- Large sediment transport capabilities
- Between Keystone Dam & Muskogee

Previous Attempts

- Army Corp of Engineers- Omaha District
  - Missouri River Project- 1993
    - Repair of previously used habitats
    - 20 sites ranging from 1.3-49 acres
    - Chosen based on final elevations 1-2 feet above water level during flows of 38,500 feet

Missouri River Project

- Island Maintenance
  - Mechanically leveled vegetation
  - Prevented erosion with shoreline arrestor bags
  - Recapped islands with approximately 2 feet of sand

Zink Island

06/29/95

Army Corps Air Boat Inspection

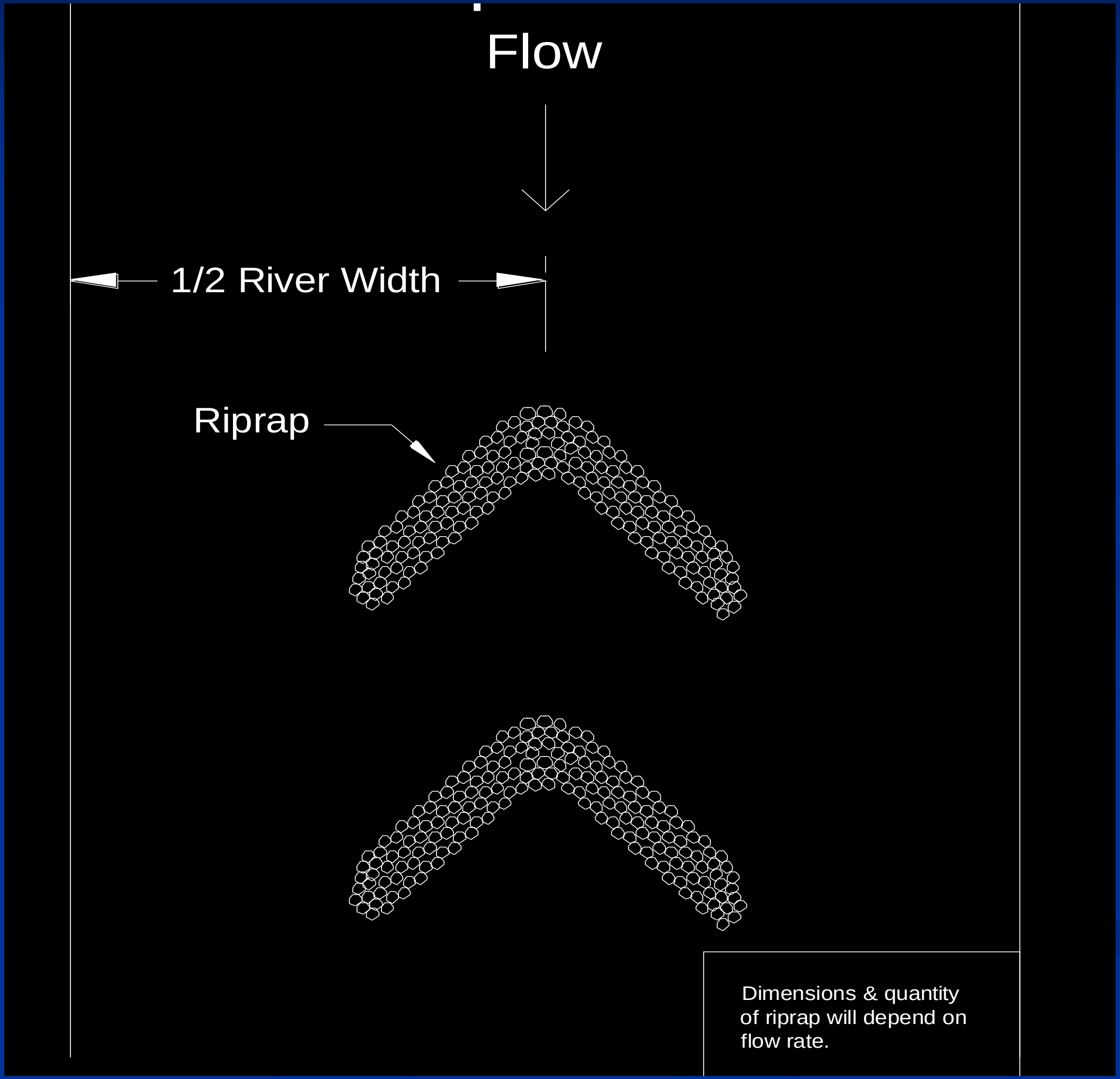
- Jerry Sturdy, Army Corps Biologist, conducted the inspection
- Arkansas River-Jenks Bridge to just past Bixby Bridge
- Observed examples of both good and bad island habitats

Area of Interest

Successful Nesting Site

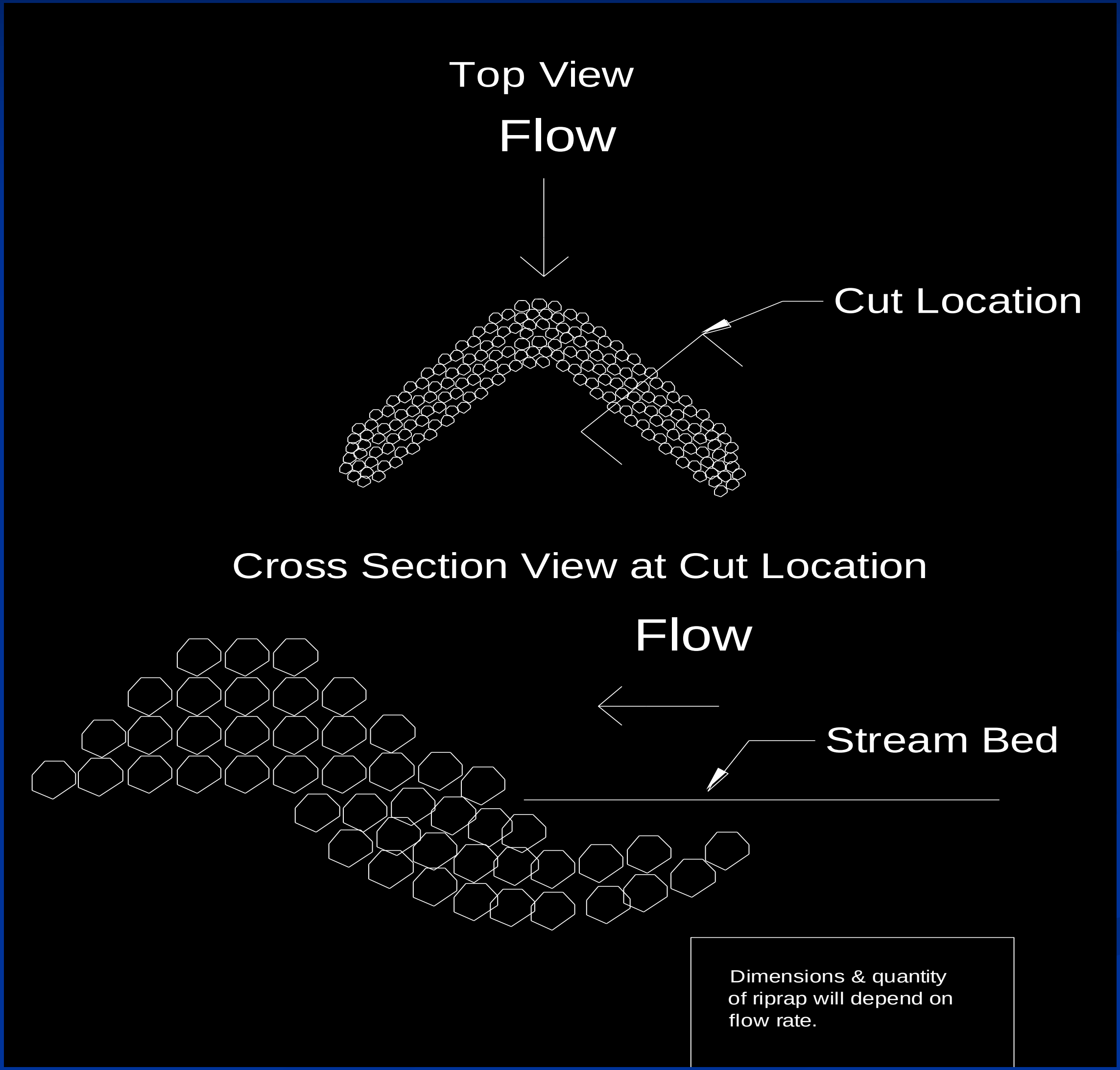
Poor Nesting Site

Proposed Design Top View



Dimensions & quantity of riprap will depend on flow rate.

Proposed Design Side View



Dimensions & quantity of riprap will depend on flow rate.

Design Modeling

- Rudimentary examination of possible design concepts
- Stream Trailer
  - Ground up plastic buttons used to simulate sediment
  - Gravel used to simulate design structure material
  - Two levels of flow available with this model
    - High - ~5 gpm
    - Low - ~2.5 gpm

Stream Trailer

Design Verification

Low Flow Conditions

High Flow Conditions

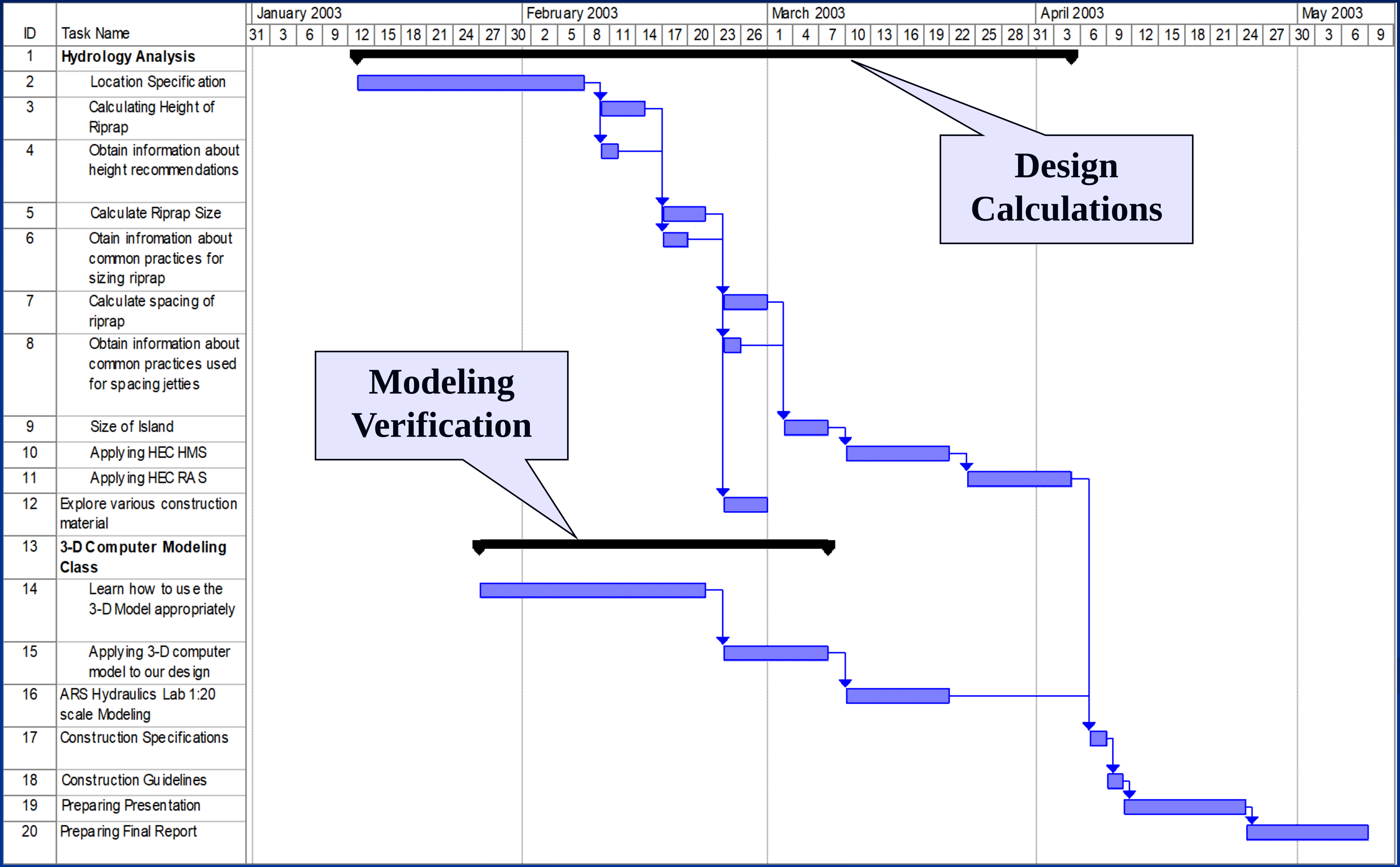
Design Completion Requirements

- Height of design structure material
  - Proper deposition occurs
  - Must allow flow to scour vegetation from island at 30,000 cfs
- Spacing of Structures
  - Allows appropriate sediment deposition for anticipated island dimensions
- Material Size
  - Appropriate mass to prevent repositioning due to high flow

Proposed Completion Methods

- Researching common practices
  - Sizing riprap
  - Spacing jetties
  - Minimum velocity to scour vegetation
- 3-D and 2-D computer modeling programs
- 1:20 scale physical model

Gantt Chart



ID	Task Name
1	**Hydrology Analysis**
2	Location Specification
3	Calculating Height of Riprap
4	Obtain information about height recommendations
5	Calculate Riprap Size
6	Otain infromation about common practices for sizing riprap
7	Calculate spacing of riprap
8	Obtain information about common practices used for spacing jetties
9	Size of Island
10	Applying HEC HMS
11	Applying HEC RAS
12	Explore various construction material
13	**3-D Computer Modeling Class**
14	Learn how to use the 3-D Model appropriately
15	Applying 3-D computer model to our design
16	ARS Hydraulics Lab 1:20 scale Modeling
17	Construction Specifications
18	Construction Guidelines
19	Preparing Presentation
20	Preparing Final Report

Design Calculations

Modeling Verification

Final Design Requirements

- Location
- Legal & Regulatory Issues
- Construction Specifications
- Cost Estimation