EVALUATING SHALLOW-FLOW ROCK STRUCTURES AS SCOUR COUNTERMEASURES AT BRIDGES

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Benjamen P. Dahle in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

EVALUATING SHALLOW-FLOW ROCK STRUCTURES AS SCOUR COUNTERMEASURES AT BRIDGES

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Master of Science

The Utah Department of Transportation commissioned a study to determine whether or not shallow-flow rock structures could reliably be used at bridge abutments in place of riprap. Research was conducted in a two-phase effort beginning with numerical modeling and ending with field verification of model findings. As part of phase one, two finite element meshes were created in Surface-water Modeling Software (SMS) and analyzed with FESWMS-2DH. Second, field studies were conducted and a preliminary database was developed to track field studies conducted on 98 shallow-flow rock structures in Utah. Data organization in ArcGIS® and Microsoft Access® is presented followed by instructions on how to use the database. Both numerical model and field research results indicate that shallow-flow rock structures are not viable scour countermeasures at bridges.

ACKNOWLEDGMENTS

I would like to thank my advisor Dr. Alan Zundel for his guidance and input throughout the process of field studies, modeling, and preparing this paper. I am grateful to Wood Miller and Jim Nelson for their service on my graduate committee. I would like to thank Wood Miller, Brandon Jacobsen, and others for their assistance in field work. I extend thanks to Brandon Jacobsen for his assistance in research. I would like to thank personnel from the Utah Division of Wildlife Resources, Uinta National Forest and the Wasatch National Forest that assisted in my research, all of which would not have been possible without their valuable input. In addition, I would like to thank Janice Sorenson for her help coordinating administrative efforts in my absence from BYU. Further, I would like to thank Diana DeHaven for her assistance in formatting and editing. I wish to thank my wife Mary Ann and my family for their continual support as I researched and prepared this paper.

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1 Introduction

The Utah Department of Transportation (UDOT) commissioned a study to determine whether or not shallow-flow rock structures (SFS) could reliably be used at bridge abutments in place of riprap. The purpose of this research is to use numerical models and field studies to determine whether or not SFS can reliably be used in place of riprap and other scour countermeasures. Shallow-flow rock structures (SFS), for the purpose of this thesis, include river restoration structures such as vanes, j-hook vanes, bendway weirs, vortex weirs, and cross-vanes.

There are two objectives of the UDOT study. Objective one is to verify that SFS can be modeled in the Surface-water Modeling Software (SMS) software package. The second objective is to evaluate the performance of SFS in the vicinity of bridges in Utah where they had been previously installed.

1.1 Scope and Phasing of Research

The scope of this thesis consists of creating numerical models for shallow-flow rock structures and then field verifying modeling effort findings. A literature search was conducted as both activities previously mentioned occurred. The study spanned the years of 2003 to 2008 and was separated into two phases.

Phase one research was conducted in 2003-2006 and consisted of: selecting appropriate structures to model, data collection, site observation and numerical modeling.

Phase one efforts were intended to meet objective one. Phase two consisted of field studies to verify phase one results and meet objective two. This phase included: monitoring 13 new sites (82 new structures), conducting a literature search and creating a database.

1.1.1 Phase One Research

Phase one research will be presented in chapter 3 of this thesis. Four sites where SFS were recently installed were investigated. These sites are: Sundance, Upper and Lower Nunns Park in Provo Canyon, and Thistle Creek in Spanish Fork Canyon. Modeling efforts started in Provo Canyon and eventually shifted to Thistle Creek because it contained river restoration structures proposed for hydraulic scour countermeasures at bridges.

Numerical models were created by establishing benchmarks, taking velocity measurements, and surveying to capture base flow conditions for a j-hook and cross-vane on Thistle Creek south of Thistle, Utah. The streambed topography (bathymetry) of small sections of Thistle Creek surrounding the SFS was used to create finite element meshes in Surface-water Modeling Software (SMS). These meshes were analyzed using the FESWMS-2DH finite element package adopted as a standard for 2D hydraulic modeling by the Federal Highway Administration (FHWA). The models, analyses, and field observations are presented in chapter 3 of this thesis.

1.1.2 Phase Two Research

Phase two consists of research to field verify results obtained during phase one. In phase two, 12 new sites were added to those established in phase one (see Table 4-3 for monitoring sites). Hydraulic performance and river response to the study group was observed over the course of time from 2004 to 2008. A database was created to manage

and analyze data obtained from observations of the study group. The majority of the data was gathered from 2004 to 2006 after which the focus shifted from adding structures to the study group and monitoring them, to creating the database. Database development occurred generally from 2006 to the present time. Field observations and structures failure rates will be presented in section 4.5.

2 Literature Survey

A literature survey was conducted to better define the current conventions for the classification of structures as well as to identify design methodologies for structures within the study group. Issues surrounding structures in the study group and how best to study them arose during the literature review. Research methodologies for the study group were refined based on issues and examples that were identified.

2.1 Structure Classification and Design Criteria

The structures in the study group are classified as weirs, bendway weirs, vanes, cross-vanes, and j-hook vanes. Weirs are divided into two categories, drop structures and porous weirs (also known as vortex weirs). The defining difference between drop structures and porous weirs is that porous weirs are designed to have distinctive chutes or spaces between rocks along the length of the structure whereas drop structures do not. See Figure 2-1 and Figure 2-2 for illustrations of drop structures and porous weirs, respectively.

The theory and design methodology for both types of weirs can be found in *Integrated Streambank Protection Guidelines* (WDFW 2002).

Figure 2-1. Drop Structure on the North Fork of the Provo River.

Figure 2-2. Porous Weir on the San Pitch River.

To classify the structures grouped under bendway weirs more accurately, a distinction is made between bendway weirs and groins. Bendway weirs and groins are similar in orientation with respect to the streambank, but differences lie in the structure size when comparing profiles. Bendway weirs are designed to be, "…fully submerged during most or all flows…" (Fischenich and Allen 2000), whereas groins "…project into the channel from the bank and extend above the high-flow, water-surface elevation..." (WDFW 2002). Design criteria for bendway weirs are described by Lagasse et al. (2001) and for groins in the *Integrated Streambank Protection Guidelines* (WDFW 2002).

There are two variations with respect to bendway weirs and vanes. The variations of bendway weirs (barbs) and vanes can best be described using Figure 2-3 from *Stream Investigation, Stabilization and Restoration* (SISR) (Freeman 2005[1]).

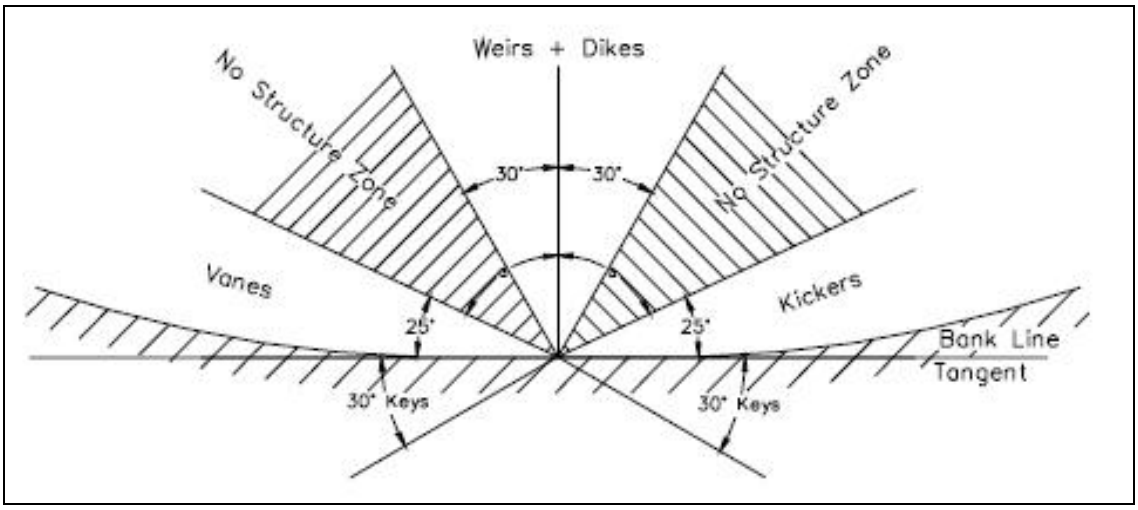

Figure 2-3. Bendway Weir and Vane Variations.

Variations of bendway weirs relate to the orientation of the structures with respect to the streambank. Bendway weir (barb) placement ranges from perpendicular to the bank or up- and downstream 30º from perpendicular. Vane orientation is always upstream as shown in Figure 2-3. Kickers are the mirror reflection of a vane from perpendicular as shown in Figure 2-3. See Figure 2-4and Figure 2-5 for illustrations of a bendway weir and vane, respectively. Vane theory and design methodologies are found in *Stream Investigation, Stabilization and Restoration* (SISR) (Freeman 2005[1,2]) and Johnson et al. (2001).

Figure 2-4. Bendway Weirs on the Provo River.

Figure 2-5. Vane on the San Pitch River.

Cross-vanes and j-hook vanes were developed by David Rosgen. Design criteria for these structures are described by Rosgen (1996 and 2001) and Johnson et al. (2002[1]). See Figure 2-6 and Figure 2-7 which illustrate a cross-vane and j-hook vane, respectively.

Figure 2-6. Cross-Vane Near Park City Utah.

Figure 2-7. J-Hook Vane on the Spanish Fork River.

2.2 Definitions

Bendway weirs are also known as barbs and are defined by Lagasse et al. (2001) in the following passage:

> "…low elevation stone sills used to improve lateral stream stability and flow alignment problems at river bends and highway crossings. Bendway weirs are used for … bankline protection on streams and smaller rivers."

Fischenich and Allen (2000) describe bendway weir hydraulics:

> "Flow passing over [a bendway weir] is redirected so that the flow leaving the structure is perpendicular to the centerline of the structure…"

As water passes over a bendway weir, it is redirected downstream perpendicular to the structure as illustrated in Figure 2-8. (Freeman 2005[2]).

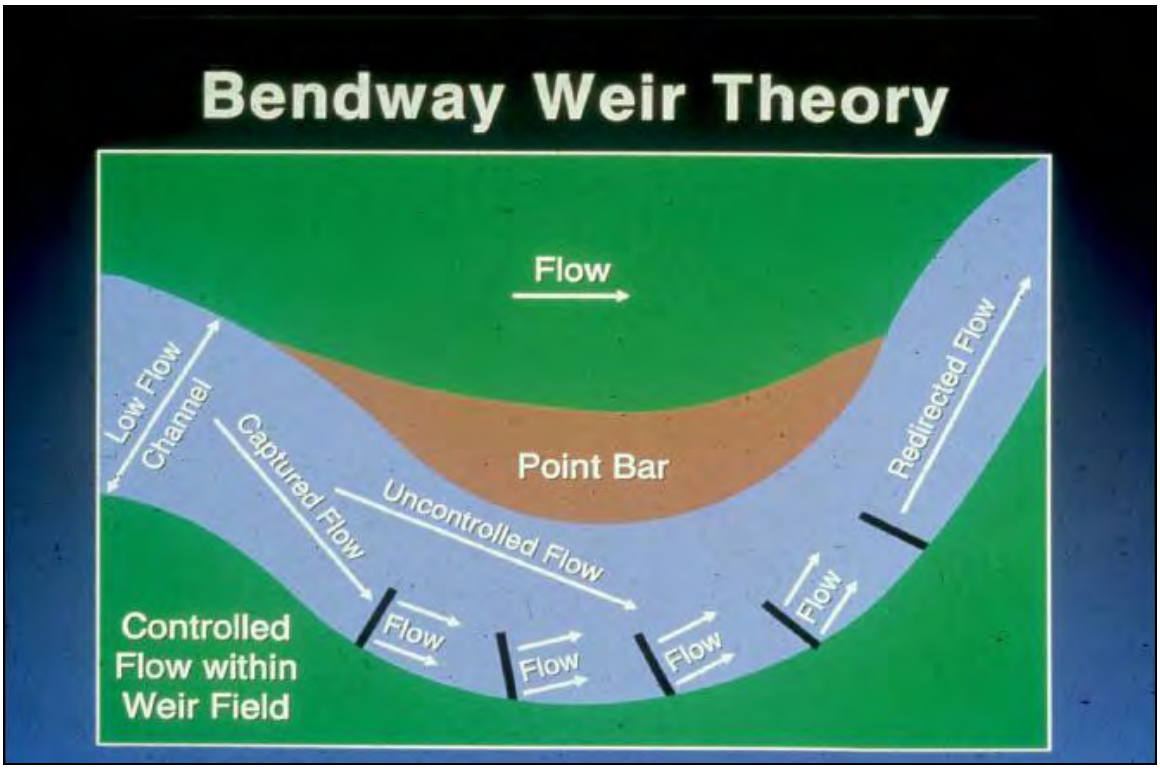

Figure 2-8. Bendway Weir Theory.

Vanes are oriented upstream 20º to 30º from the bank whereas bendway weirs are perpendicular to the bank give or take 30º (see Figure 2-3). Vanes, for the purposes of this study, have separate design criteria from bendway weirs, but by definition are the same. See the definition for bendway weir and Figure 2-9 for vane weir theory. (Freeman 2005[1]). Further, Johnson et al. (2001) described the similarities between vanes and bendway weirs, "bendway weirs are low elevation stone sills similar to vane structures."

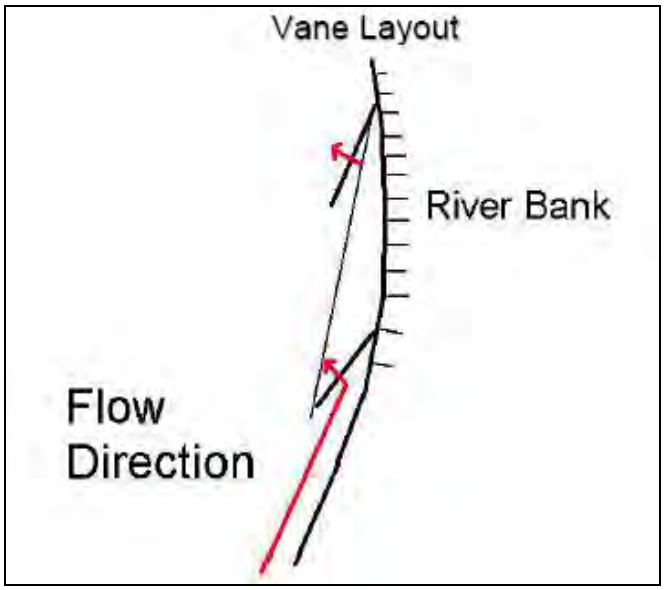

Figure 2-9. Vane Weir Theory.

Weir is a classification used in the study group to define grade-control structures other than cross-vanes. Water is redirected over the structure in the same manner as found in bendway weirs. Porous weirs and drop structures are categorized as weirs for the purposes of this study.

Cross-vane is a structure developed by David Rosgen use for grade-control (see Figure 2-6).

J-hook vane is a structure developed by David Rosgen. J-hook vanes are adapted vanes with a hook in the stream with rock spaces similar to those in porous weirs (see Figure 2-7).

2.3 Scour Countermeasures

In the field of river engineering, there are three ways to classify scour countermeasures: armor, hydraulic control, and grade control (Johnson and Niezgoda 2004).

In some cases environmental engineering structures are used as scour countermeasures and can be classified in a similar manner. Scour countermeasures mitigate the erosion induced by horizontal and vertical movement of waterways. Shallow-flow structures are defined in section 2.2 and can be viewed as an intersection of river and environmental structures. Shallow-flow structures include: vanes, j-hook vanes, bendway weirs, vortex weirs, and cross-vanes. See Figure 2-10 for an illustration of how shallow-flow rock structures are related to river and environmental engineering structures.

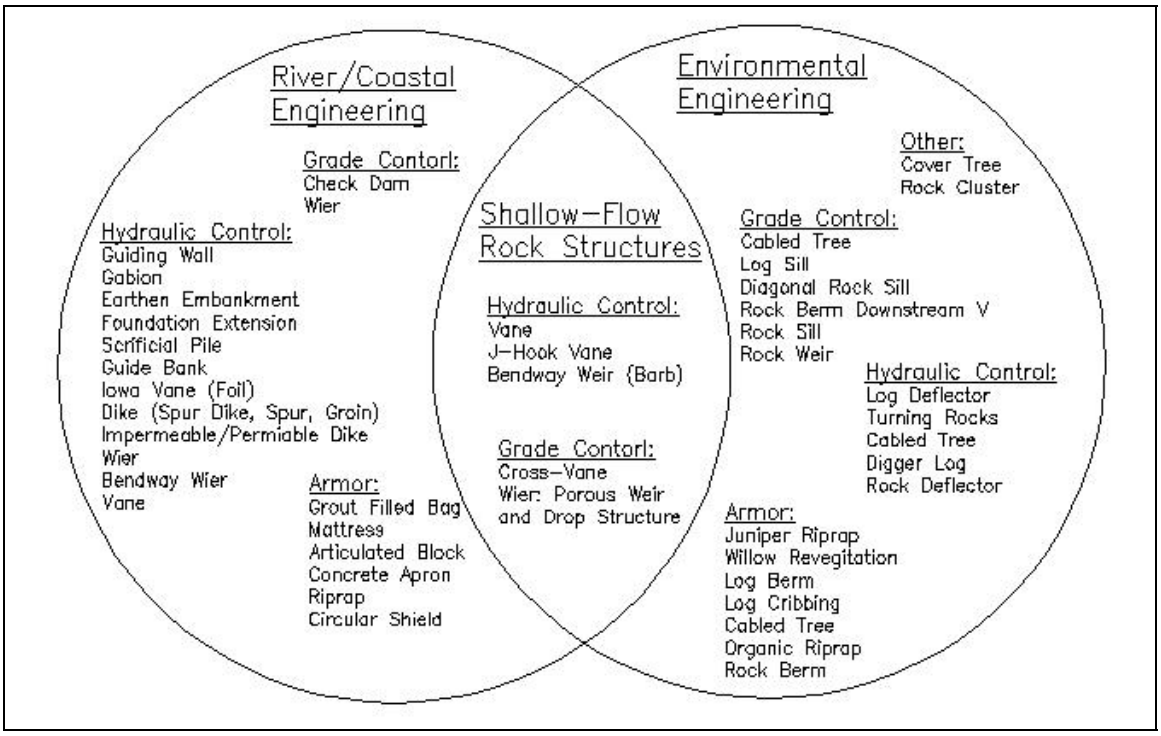

Figure 2-10. Shallow-Flow Structures and River and Environmental Engineering Structures.

River and coastal engineering structures protect bends in rivers, coastal areas, or abutments in river or coastal applications. These structures are constructed out of a variety of materials and are typically larger structures than those in the study group

(Yanmaz and Ozdemir 2004). Some examples of these structures are grout-filled bags, sacrificial piles, riprap, and impermeable dikes (Lagasse et al. 2001).

Environmental Engineering seeks to increase riverine biodiversity by using environmentally friendly materials. Environmental river improvements include natural vegetation such as juniper riprap or plantings along rivers edges. Shallow-flow structures include structures that are commonly used for river restoration and may be considered some of the "harder" types of the techniques used. They increase biodiversity by increasing riverine diversity in terms of depth, velocity, and cover. When the structures are designed and constructed in a way that leads to a stable installation, they also have been found to reduce erosion (Biedenharn et al. 1997 and URMCC 1995 and Harman et al. 2001).

River Engineering structures are used in Environmental Engineering stream restoration even though they were not originally developed for that purpose. McCoy and Webber (2008) indicate that the design criteria for groins (groynes) used for stream restoration is often different than for River Engineering applications. The river restoration structures are micro installations of the River Engineering structures and, from a hydraulic standpoint, are based on the same theories and design criteria.

2.4 Discussion

In the process of researching these topics, a number of issues surfaced which are applicable to this study. The issues that arose include: scale, definition conflicts, balanced research plan, tweaking design criteria, failure modes and effects analysis, siting and scour analysis.

2.4.1 Scale

Methodologies are typically based on laboratory experiments as opposed to actual field studies and scaling effects can cause application of lab results to be unreliable (Parola et al. 1997). The effects of scale and grain size distributions evaluated recently by D'Agostino and Ferro (2004) were meant to model field conditions more closely to increase the reliability of field applications.

2.4.2 Tweaking Design Criteria

Most design criteria are developed in laboratories and scaling effects may cause guidelines to result in unreliable structures when applied in the field. Harman et al. (2001) stated, "In order to increase the reliability of river protection techniques, it is important that local evaluation and critique occur."

2.4.3 Definition Conflicts

It became apparent that the relative size of a structure can cause confusion in comparing reference materials. For example, bendway weirs were first developed for use on the Mississippi River in 1990 where the crest depth was about 15 feet compared to small stream applications were the crest depth is less than a foot (Fischenich and Allen 2000).

There is a size spectrum when talking about bendway weirs that range from large structures used on the Mississippi River to medium-size structures that are comparable to groins and small structures that are comparable to barbs (WDFW 2002). Scale variability of this type can cause confusion when defining structures and comparing literature.

2.4.4 Balanced Research Approach

As the literature was surveyed for studies conducted on structures comparable in composition and relative size, components of a balanced approach methodology were scattered throughout the literature. Shea and Ports (1997) asserted that a balanced approach to evaluation of scour at bridge crossings can produce cost savings with a high degree of reliability. Figure 2-11 shows an illustration of the balanced approach methodology for evaluation of scour at bridge crossings (Parola et al. 1997).

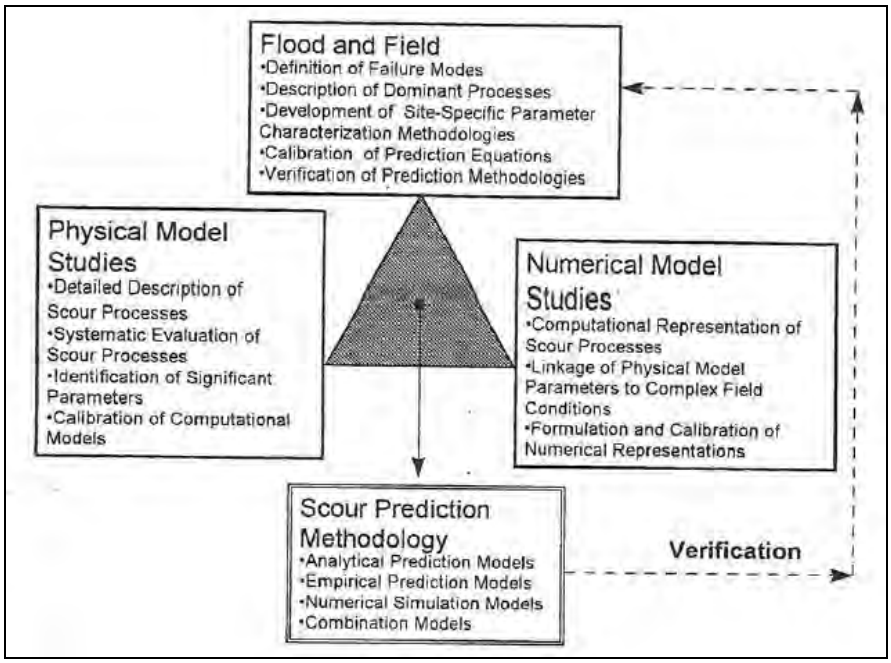

Figure 2-11. Balanced Research Approach Model.

The current study has components of all areas shown in Figure 2-11 except physical model studies. Modeling trends seem to be moving from physical to numerical modeling (Bryson et al. 2000).

2.4.5 Failure Modes and Effects Analysis

Failure modes are a key component of a balanced research approach (see Figure 2-11) for evaluating scour. Johnson et al. (2004) describes failure mode analysis:

"Failure modes and effect analysis is a qualitative procedure to systematically identify potential component failure modes and assess the effects of associated failures on the operational status of the system (Dushnisky and Vick 1996)."

Johnson et al. (2004) tabulate failure modes for the following scour countermeasures: riprap, rock vanes, w-weirs, bendway weirs, submerged vanes, and check dams. Failure modes are listed for each countermeasure along with how the failure mode affects components of the countermeasure, effects on the whole system, detection methods and compensating provisions.

Failure modes analysis and effects analysis during field studies are essential to a balanced approach to research as described by Parola et al. (1997).

> "Flood and field studies provide several critical functions. First, such studies identify and describe dominant scour processes…Second, such studies characterize complex sequences and specific mechanisms of …failure so that prediction methodology can be targeted at actual rather than hypothetical failure modes…failure modes and sequences of scour mechanisms is critical for cost-effective design of countermeasures. Understanding of mechanisms and sequences of scour processes is essential to develop simplified physical and numerical models that quantify scour effects." (pg. 127)

Parola et al. (1997) indicate that the third reason to conduct field studies is to verify scour prediction and calibration of models.

2.4.6 Siting

Siting or "…structure placement relative to natural channel features and fluvial patterns…" may increase the reliability of scour countermeasures (URMCC 1995). Recommended structure siting is given in *Stream Habitat Improvement Evaluation Project* (URMCC 1995) in Table 4.48, *Bridge Scour and Stream Instability Countermeasures – Experience, Selection and Design Guidance* (Lagasse et al. 2001) in Table 2.1, *Using Technical Adaptive Management to Improve Design Guidelines for Urban Instream Structures* (Johnson et al. 2002[2]) in Tables 1 and 2., and class notes sections five and nine of the *2005 Stream Investigation, Stabilization and Restoration Conference* held in Niagara Falls, Ontario (Freeman 2005[1,2]). Being familiar with common siting practices will enable more consistent monitoring during flood and field studies. See Figure 2-11 for elements of flood and field studies components.

2.4.7 Scour Analysis

Scour analysis methodologies are outlined in class notes section nine of the *2005 Stream Investigation, Stabilization and Restoration Conference* held in Niagara Falls, Ontario (Freeman 2005[1]). Scour methodologies included in the class notes are: critical sheer stress, water sheer stress, and incipient motion to determine if riprap used for structures is stable.

2.5 Response

By using a standard glossary as found in *Bridge Scour and Stream Instability Countermeasures – Experience, Selection and Design Guidance* (Lagasse et al. 2001) and by defining structures above, confusion related to terminology and definition differences

is mitigated. In the future, structures now classified as vanes, bendway weirs, cross-vanes, j-hook vanes, and weirs can be more precisely identified.

Studies at BYU between 2003 and 2006 combined field studies and numerical modeling as part of a shallow-flow structure monitoring methodology. The monitoring methodology included an informal failure modes analysis summarized in chapter 4. Failure modes and effects analysis as discussed above will assist in standardizing qualitative monitoring methodologies for more consistent and time-efficient monitoring methodology approach.

Critical sheer stress, water sheer stress, and incipient motion equations and methodologies can be applied in numerical models to predict stream and river response to scour countermeasures. Scour analyses will aid in refining current numerical model studies.

2.6 Summary

A literature survey was conducted for the structures in the study group. Deeper understanding of the study group was obtained; naming conventions and quantitative monitoring methodologies were refined.

3 Numerical Models

Numerical modeling was the first phase of evaluating SFS and made up the first half of the study conducted. Numerical modeling of the initially selected structures began in 2003 and ended in 2004. This chapter presents numerical model creation, model calibration, field observations, effective depth analyses, and scour analyses.

The first objective of modeling is to verify that shallow-flow structures can be modeled in the Surface-water Modeling Software (SMS) software package. This objective is met by the models presented in this chapter. The scope of numerical modeling included two models on the Provo River and two models on Thistle Creek. In conjunction with numerical modeling, limited field studies were performed to obtain calibration data and to observe general hydraulic conditions at the model sites.

3.1 Selection of Existing Installation – Provo River

The initial recommendation from UDOT for this study was to select structures on the Provo River in Provo Canyon for the study. Based on this recommendation, three sites were selected. Two are just above and below Nunn's Park and the third is just north of the Sundance turnoff. These sites included a series of bendway weirs projecting from the alternating sides of the bank.

Using a total station, a velocity meter, and range rod, data points were gathered for the following:

1. Bathymetric data points to define the riverbed
2. Bank lines defining the shape of the river
3. Velocity and depths at locations across the river and at various points interior to each site.

Using the bathymetric and bank data, two finite element meshes were created for the three reaches. Boundary conditions of flow rate and a downstream water surface elevation were computed from the velocity and depth measurements.

These initial finite element meshes were analyzed using the FESWMS-2DH finite element package. The results indicated that, although we could predict flow rates, these sites had several weaknesses. Namely:

1. The structures in these sites were not similar in design to the structures used for hydraulic scour control for experimental bridge applications.
2. The flow in this reach of river, while variable, is controlled by Deer Creek Dam and would never see high flow rates that should be analyzed when considering the use of SFS as scour countermeasures in controlled and uncontrolled river applications.
3. The data gathered was not highly enough resolved to represent the complex nature of the flow.

As the Provo River models were conducted, two cross-vanes and one j-hook vane on Thistle Creek had been recently installed. The structures matched the design methodologies defined by Rosgen. Based on this information and with the consent of the technical contact

at UDOT, the focus of the modeling effort shifted to the Thistle Creek site in Spanish Fork Canyon. Figure 3-1 and Figure 3-2 show aerial photos of the study site selected on Thistle Creek. The section of the stream has seen many reclamation works over the past few years and work continues. This area is also of interest because it has had erosion problems historically, and is therefore well suited to evaluate the stability of the structures.

3.2 Selection of Existing Installation – Thistle Creek

Using the experience gained by gathering data in Provo Canyon, data-gathering efforts began again at Thistle Creek. This time a high-resolution survey was conducted to capture the river geometry to allow accurate modeling of the site in FESWMS. Benchmarks were identified, and cross sections measured at one-foot intervals through the area of a selected cross-vane and j-hook structure. Cross sections were also gathered upstream and downstream of the two structures. In addition, velocity and depth measurements were taken at approximately twenty-five locations to be used for boundary condition computation and model verification/calibration.

Figure 3-1. Aerial Photo of Study Site.

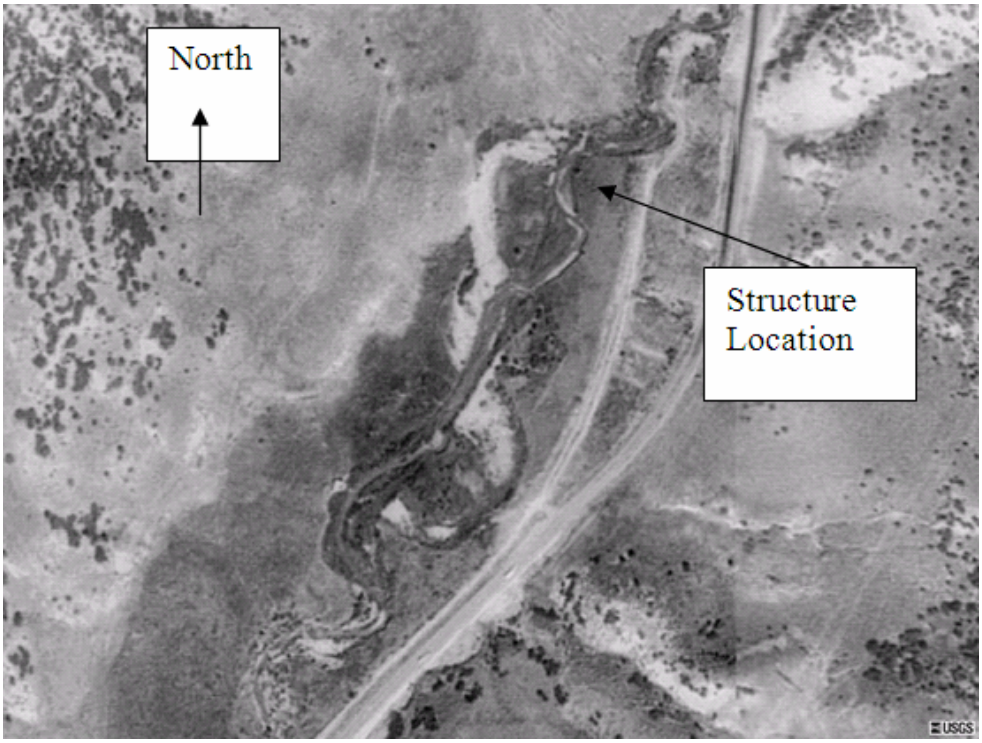

Figure 3-2. Zoomed Aerial Photo of Study Site.

The site chosen for modeling includes many structures including: two cross-vanes, one j-hook and a number of vanes. Figure 3-3 shows the cross-vane modeled. Note the flow approaches the structure mostly on the right side of the channel and moves across the structure. This is reflected in the results of the numerical model.

Figure 3-3. Cross-Vane Structure Observed and Modeled.

Figure 3-4. J-Hook Structure Observed and Modeled.

Figure 3-4 shows the j-hook structure modeled. Flow is from left to right in the picture. This structure is just downstream around a meander bend from the cross-vane. There is another cross-vane between these two structures on the meander bend. This is part of an ongoing restoration after the mudslide near Thistle, Utah. Also of note in this area is one of four experimental installations (in the study group for this paper) of SFS at bridges. The existing installation is located at Utah County State Park upstream of the Spanish Fork River and Diamond Fork confluence. SFS are installed upstream of a pedestrian-trafficked bridge. Figure 3-5 and Figure 3-6 show the relationship of a j-hook being constructed next to this footbridge.

Figure 3-5. View of Construction of Structure Near Footbridge.

Figure 3-6. View of Construction From Bridge.

3.3 Numerical Models

The Thistle Creek site modeled includes two separate finite element meshes. They represent two reaches of the stream that are very close together. The first includes a cross-vane structure and the second includes a j-hook. Figure 3-7 and Figure 3-8 show the meshes constructed around the cross-vane and the j-hook, respectively. The color keys in the upper left-hand corners indicate elevations. The resolution around the structure is very high, defining the elevation of each boulder, the elevation of the chutes between boulders and the pools upstream and downstream of the chutes are also illustrated.

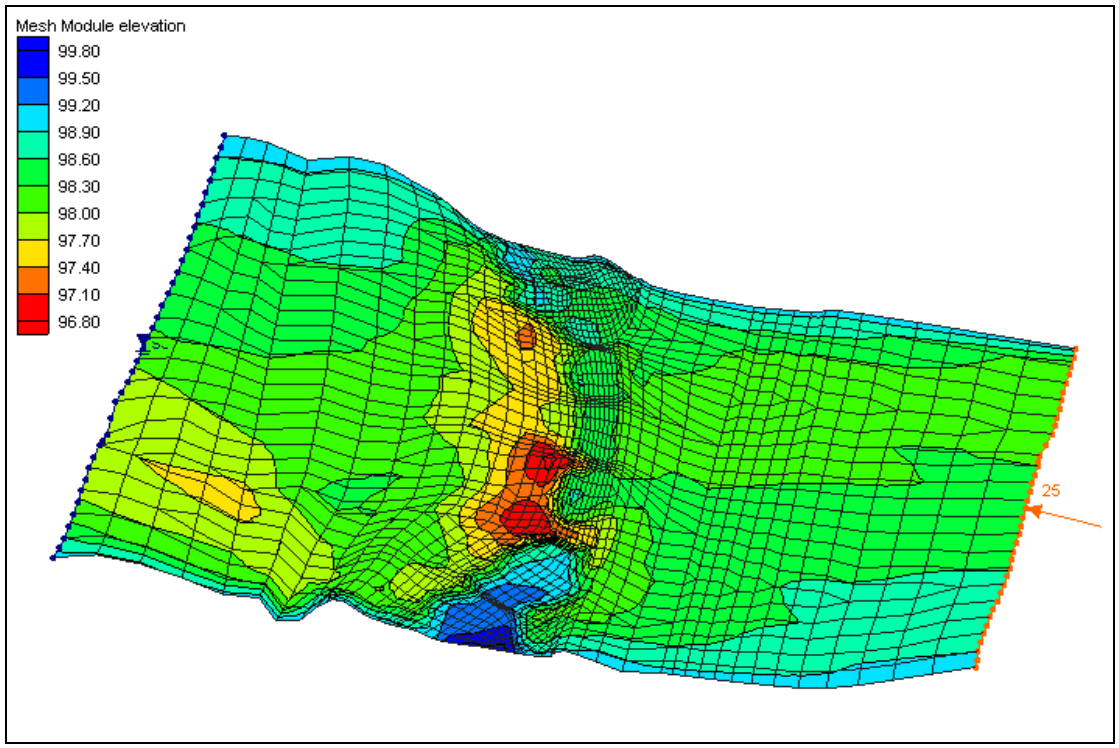

Figure 3-7. Layout of Mesh for the Cross-Vane Model.

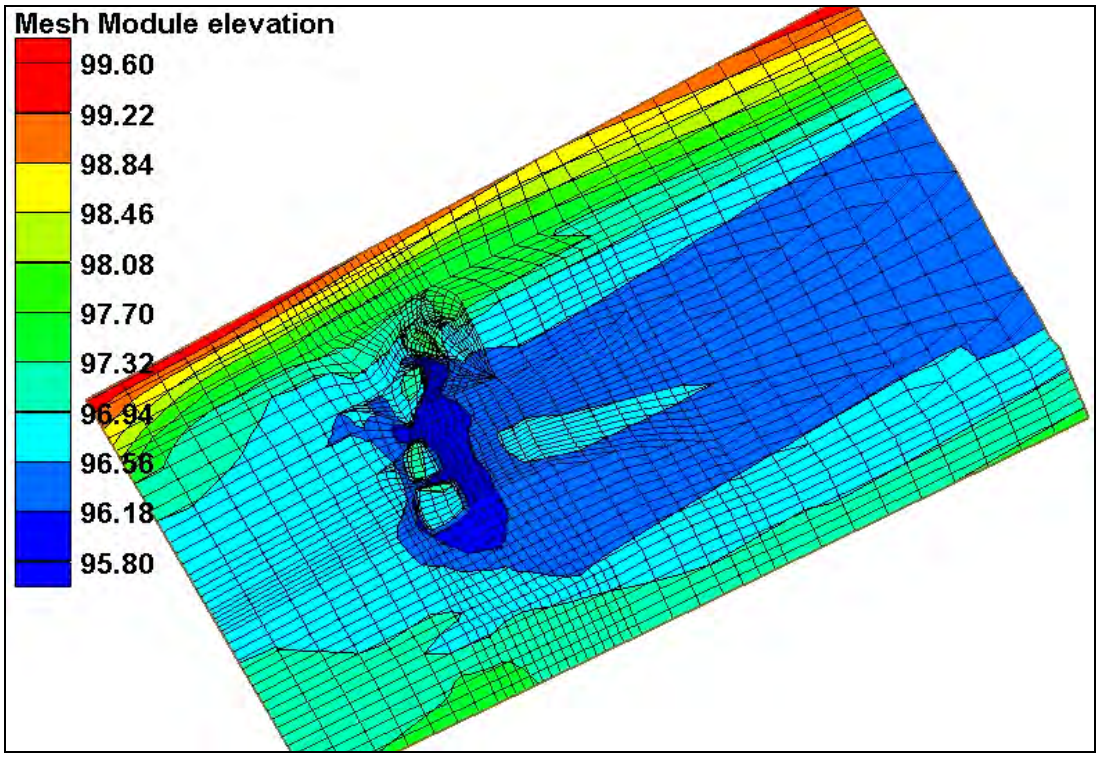

Figure 3-8. Layout of Mesh for the J-Hook Vane Model.

Figure 3-9 and Figure 3-10 show the geometry of the meshes from an oblique view. This view accentuates the scour holes that are developing downstream of the structures. Results shown later in this chapter illustrate additional scour has occurred during the year of phase one monitoring. Also note the scour occurring upstream on the j-hook. Field observations support that failure of SFS occurs not only by downstream scour, but also by an upstream erosion mechanism. The initial elevations came from the survey data that are displayed along with contours of the survey points in Figure 3-11 and Figure 3-12.

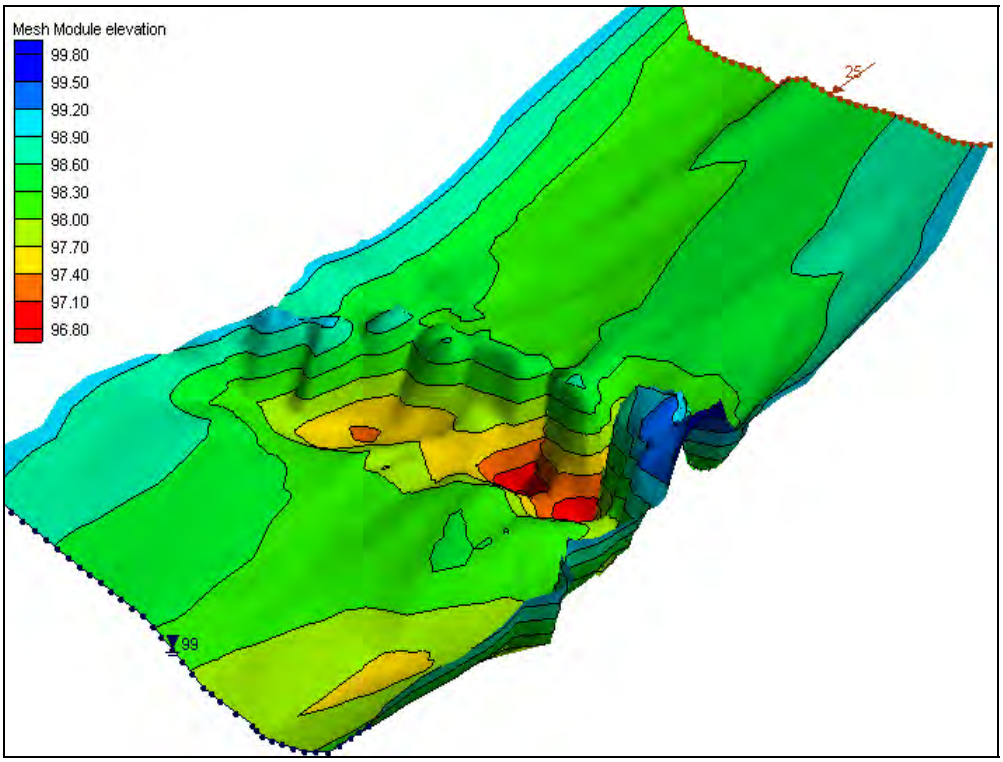

Figure 3-9. Oblique View of Geometry of the Cross-Vane Structure.

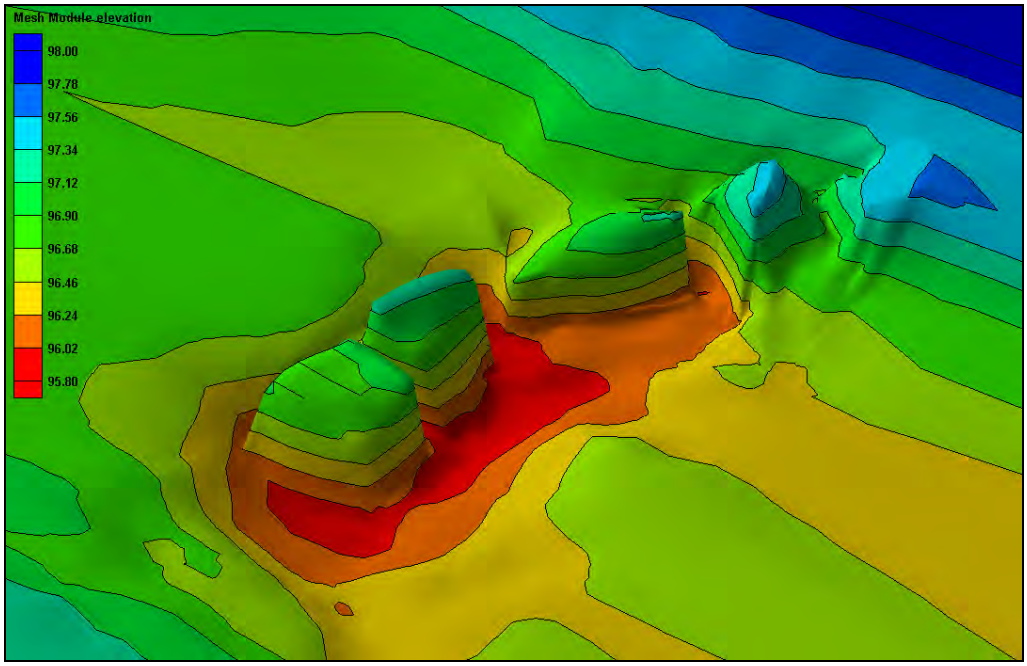

Figure 3-10. Oblique View of Geometry of the J-Hook Structure.

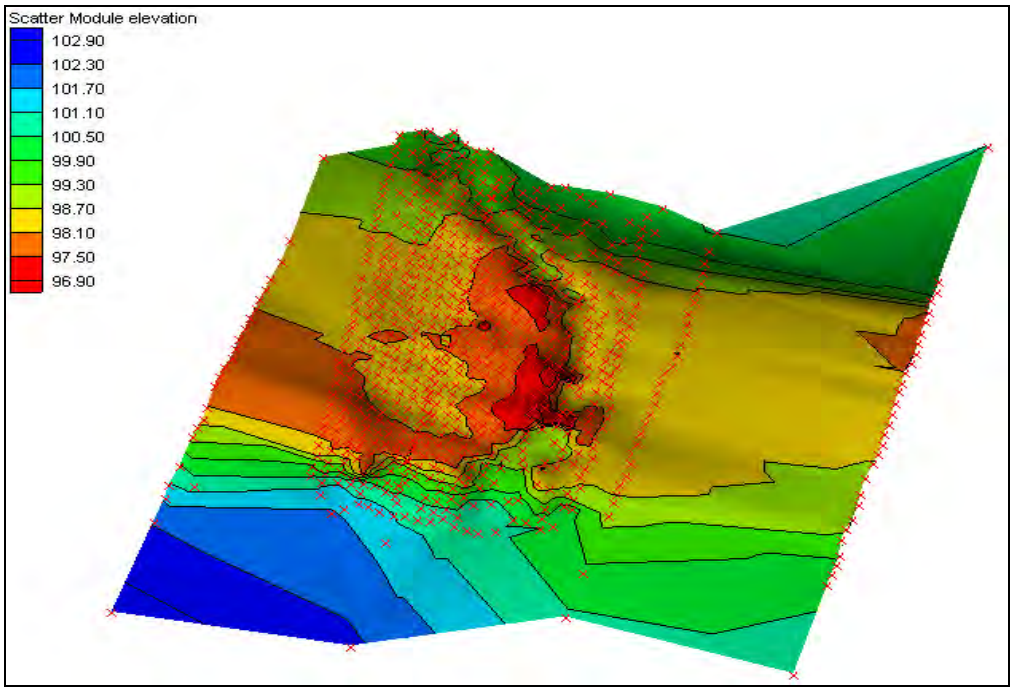

Figure 3-11. Survey Data of Cross-Vane.

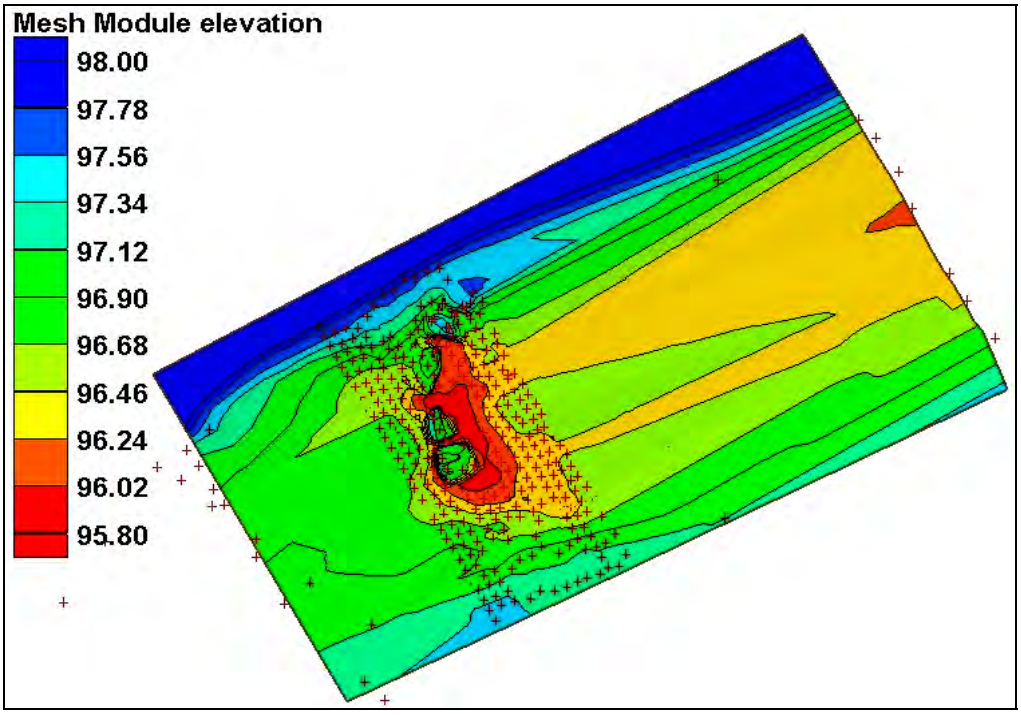

Figure 3-12. Survey Data of J-Hook.

Initially, a flow of 25 cfs was simulated through the two meshes. This corresponds to the flow rate computed from the date when the original survey data was gathered. In addition to bathymetric data at 1-foot intervals, velocity samples were obtained across the cross section and at several points around the structure. The following images display the computed flow directions and magnitudes computed by the model. Note that the model has dried out portions of the rocks and reproduced the flow conditions coming from the right side of the channel and crossing over to the left at the structure.

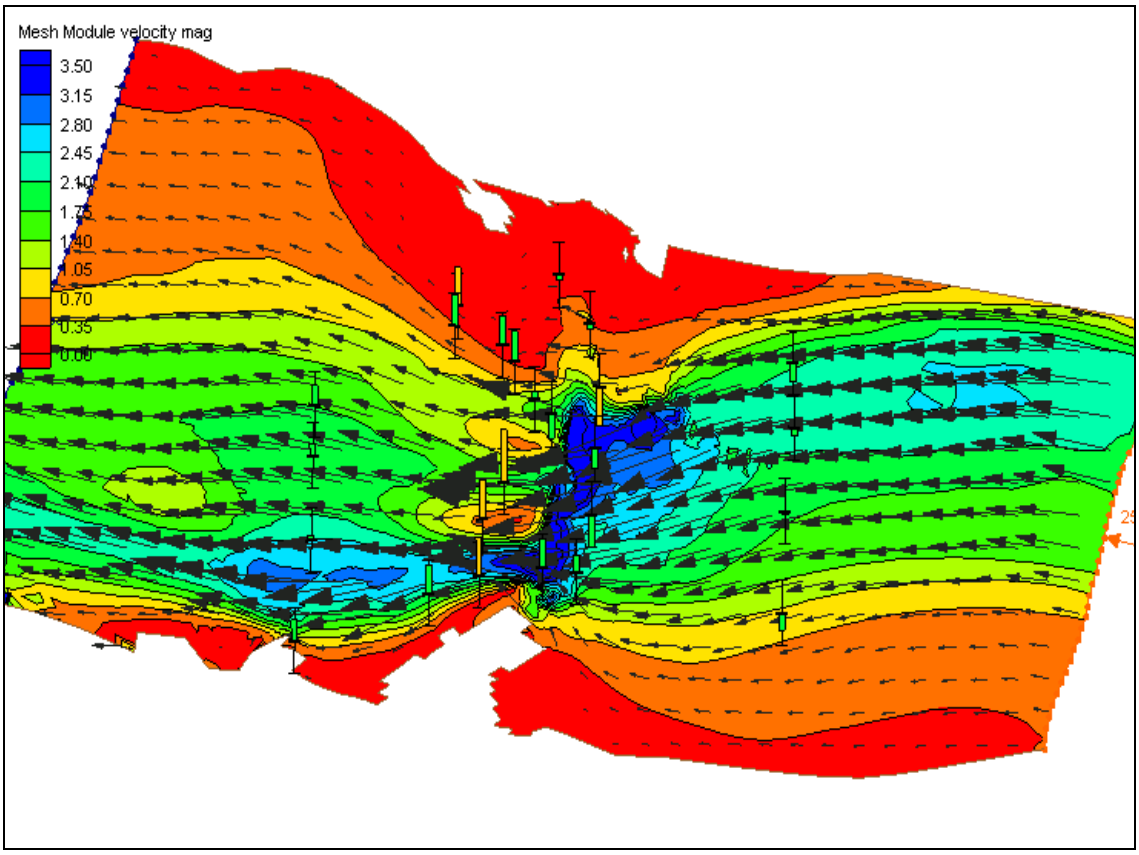

Figure 3-13. Velocity Magnitudes Computed for Cross-Vane.

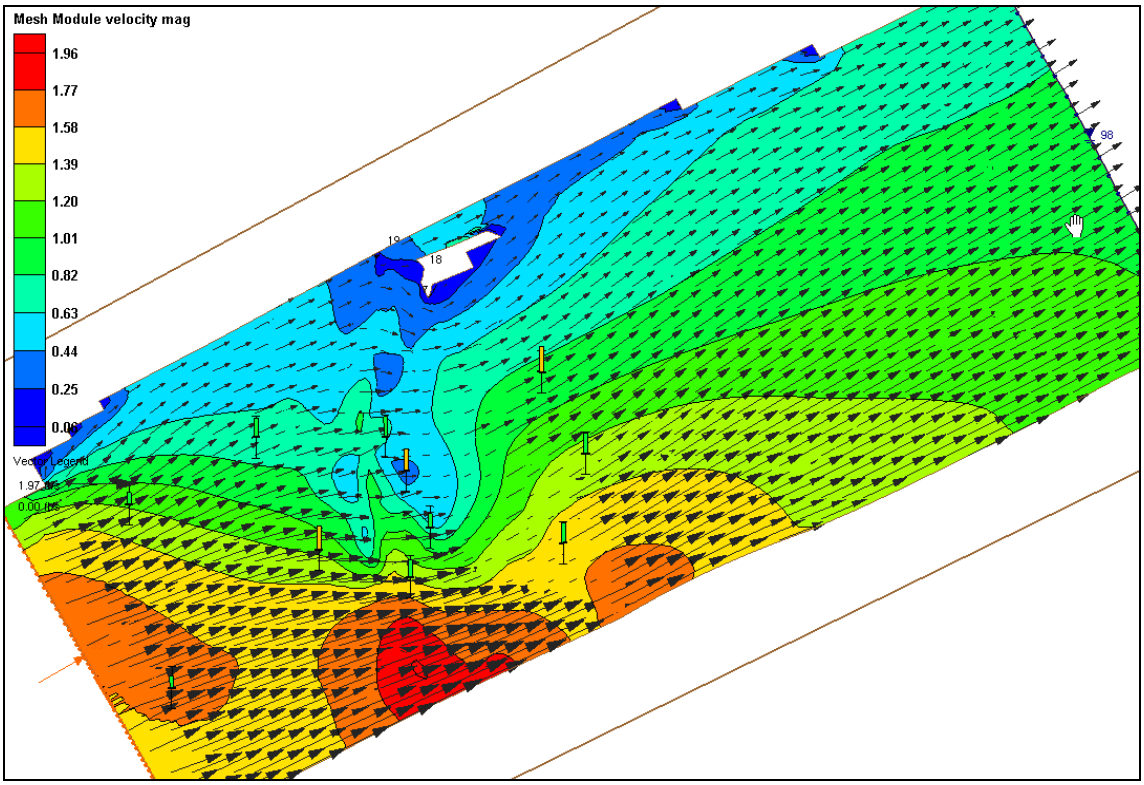

Figure 3-14. Velocity Magnitudes Computed for J-Hook.

Figure 3-13 and Figure 3-14 also show the calibration targets at various sample points. Any target showing a green staff indicates a computed velocity magnitude within .26 ft/sec of the measured value. A yellow staff indicates a computed value within .52 ft/sec of the measured value. The data sets were calibrated using the measured velocities and depths gathered at the site. Based on the calibration results and flow conditions observed during data gathering, it appears that the models are performing reasonably well to predict flow conditions. This includes water depths and flow velocities from which scour forces can easily be computed.

3.4 Application Methodology

Numerical models were conducted on a cross-vane and j-hook at Thistle Creek in 2003 and 2004. During this modeling phase, the Utah Department of Wildlife Resources promoted the use of cross-vanes and j-hooks as scour protection countermeasures at bridges (see Figure 3-5 and Figure 3-6). As such, appropriately dated cross-vane and j-hook design methodologies are presented in detail in the proceeding section, followed by an evaluation of the installations.

3.4.1 Methodology

Applied River Morphology describes river classification criteria (Rosgen 1996). In the Applications section of the book, various structures are rated. Each structure is rated based on stream type. In the original publication, cross-vanes and j-hooks were not included in these ratings; however, at that time, revisions were posted on Rosgen's web page (www.wildlandhydrology.com), which included both of them.

In Rosgen's *The Cross-Vane, W-Weir and J-Hook Vane Structures…Their Description, Design, and Application for Steam Stabilization and River Restoration*, the guidelines for placing these structures is outlined. The guidelines include: rock size, appropriate use of footers, cross-section shape, profile shape, appropriate channel locations, angles, slopes, spacing, and elevations. Rosgen (2001) outlines six design elements in the installation of cross-vanes and j-hooks:

1. Vane Angle – 20-30 degrees measured upstream from the tangent line.
2. Vane Slope – Equations and tables are provided to determine angle, generally between 2-7 percent.

3. Bank Height – The structure should only extend to the bankful stage elevation.
4. Footers – Three times the protrusion height of the invert for cobble and gravel bed streams; for sand bed streams, the minimum depth is doubled.
5. Rock Size – Graph provided based on the bankful shear stress. Rosgen warns that the use of the relationship between the bankful shear stress and rock size should be limited to rivers with a bankful discharge between 0.5 and 114 cms and corresponding bankful mean depths between 0.3 and 1.5 meters.
6. Materials – Rocks, logs, or both may be used according to Rosgen. He notes that if used in sand or silt/clay bed channels, geotextile fabric is required to prevent scour under the structure.

Rosgen (2001) asserts the following concerning the use of j-hooks and cross-vanes protecting bridges:

> "Bridges constructed on a skew to the channel and/or placed on an outside bend often experience abutment scour and embankment erosion. This problem can be reduced by the placement of an offset Cross-Vane in the upstream reach. The vane on the outer bank in the bend has a flatter slope and smaller angle (20^o), while the vane arm on the inside bank has a steeper slope and a larger angle (30^o)…the Cross-Vane…can provide grade control, prevent lateral migration of channels, eliminate fish migration barriers, increase sediment transport capacity and competence and reduce footer scour. J-Hook Vanes can reduce bank erosion on outside banks both for the approach and downstream reaches of the bridge."

See Figure 3-15 for Rosgen's (2001) proposed cross-vane installation upstream of bridges.

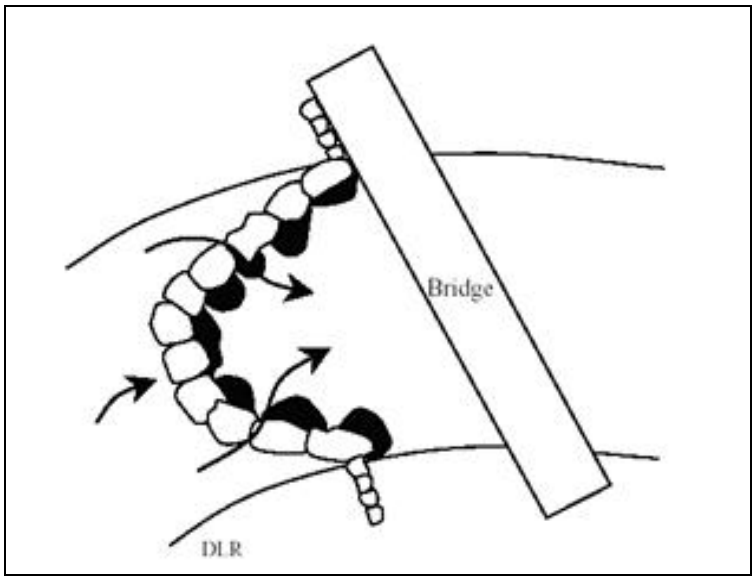

Figure 3-15. Proposed Design Methodology for Cross-Vane Installation at a Bridge.

3.4.2 Observed Deficiencies in the Methodology

Sensitivity and Precision Requirements

The gap between Rosgen's theory of installation and the actual physical installation of these structures on Thistle Creek has become evident as monitoring was conducted on the cross-vane and j-hook. It is important to note that these structures in Thistle Creek were installed for the purpose of restoration and not bridge application. However, these installations are based on the same hydraulic principles; therefore, hydraulic responses to the structures are applicable to this research.

This gap between the theory of installation and the actual physical installation is described for the cross-vane. The thalweg passed through the cross-vane, moved from one side of the main channel to the other, rather than toward the center of the channel as seen in Figure 3-15. The structure is lopsided and the rocks are different shapes as shown in Figure 3-13. Initial observation of the structures indicates that symmetry is essential in cross-vane installations. This accentuates literature search findings that the installation of

these types of structures is very sensitive to the detailed placement of materials (Harman et al. 2001 and URMCC 1995). At Thistle Creek, the incongruity of the rocks may also contribute for the ill-directed thalweg. This brings up two observations. First, when dealing with natural materials (and sensible sourcing), it may be impractical to have the right shape of rocks to meet the required symmetry to create structures that perform according to design as seen by Harman et al (2001). Secondly, the precision of rock placement during construction may be unfeasible when considering the high quality of work required to create structures that perform according to design as indicated by Yanmaz and Ozdemir (2004). This is compounded when consideration is given to the natural variability in a river site. Results from controlled lab or flume examples may not be applicable.

The asymmetrical cross-vane also has erosion problems illustrated in the photos taken in the fall of 2003 and the summer of 2004 during spring runoff (Figure 3-16 and Figure 3-17). In Figure 3-16, two large boulders are visible on the far bank. Figure 3-17 illustrates that due to erosion around the boulder, the left of the two boulders on the bank has shifted and broken. That is why the boulder is not visible in this figure. The erosion is caused by the water moving across the structure from the upstream (north) to the downstream (south) side. The velocity of the water is increased as it runs over the structure and is redirected to the south bank as seen in Figure 3-13.

Construction Materials

Rock decay was also observed during the study. As noted above, one of the main boulders broke after shifting due to erosion. The crumbling rock in the foreground of Figure 3-17 illustrates the inferior quality of these materials.

Figure 3-16. Cross-Vane Photo Taken Before Spring Runoff 2004.

Figure 3-17. Cross-Vane Photo Taken During Spring Runoff 2004.

3.5 Results and Recommendations

This section presents the results and recommendations of the phase one research. The calibrated models were used to estimate the effective flow range for both a cross-vane and a j-hook.

3.5.1 Effective Flow Range

After calibrating the models using the base flows and calibration data gathered in the field, higher flows were simulated through both the cross-vane and j-hook structures. Velocity magnitudes, depths and directions were calculated for 65, 100, 200, 300, 400, 500, 800 and 1000 cfs. The results of these simulations were used to determine when the structures stopped affecting the patterns of flow over them. This depth was determined by analyzing the flow direction verses the water depth and the change in velocity magnitude verses the water depth.

To view the depth verses flow direction, data points were selected across the structure. The depths and directions at that point were recorded for each flow rate. The results are presented in Figure 3-19 and Figure 3-21. To view the change in velocity versus depth, an additional data point was chosen just upstream to correspond with each of the points along the structure. The depth of the upstream point was plotted against the change of velocity between the upstream and downstream points. The results for the second set of data are illustrated in Figure 3-18 and Figure 3-20.

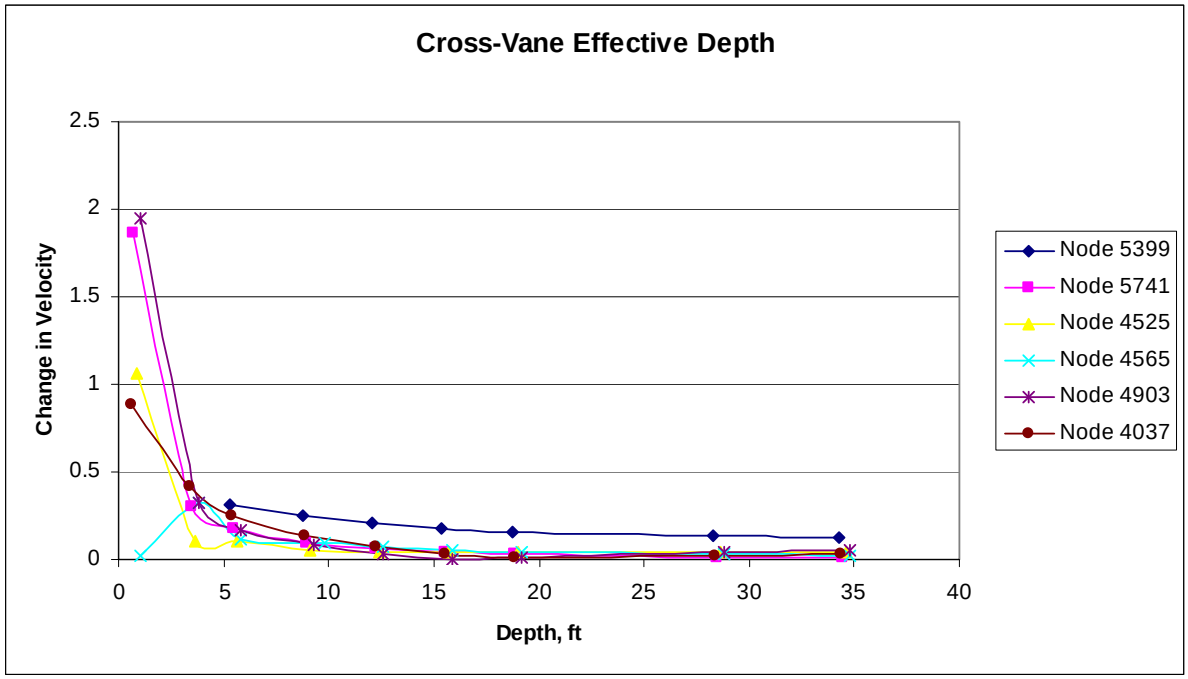

Figure 3-18. Cross-Vane Effective Depth from Change in Velocity Magnitude.

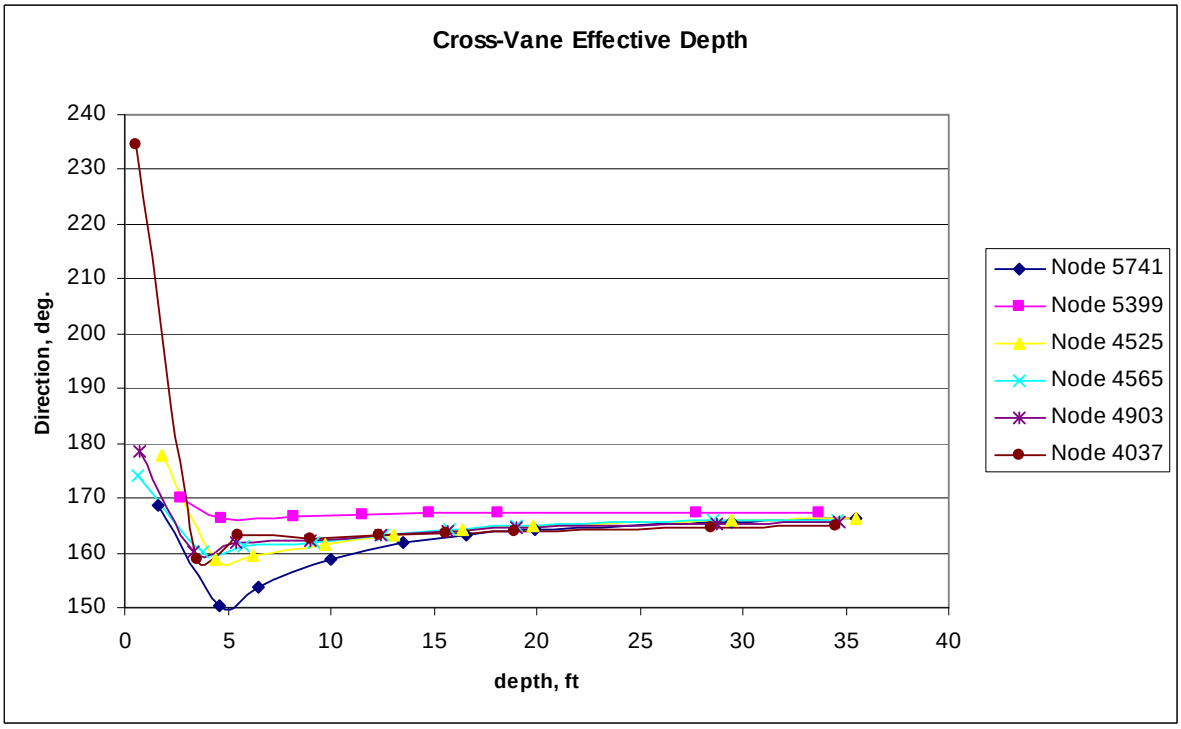

Figure 3-19. Cross-Vane Effective Depth from Change in Flow Direction.

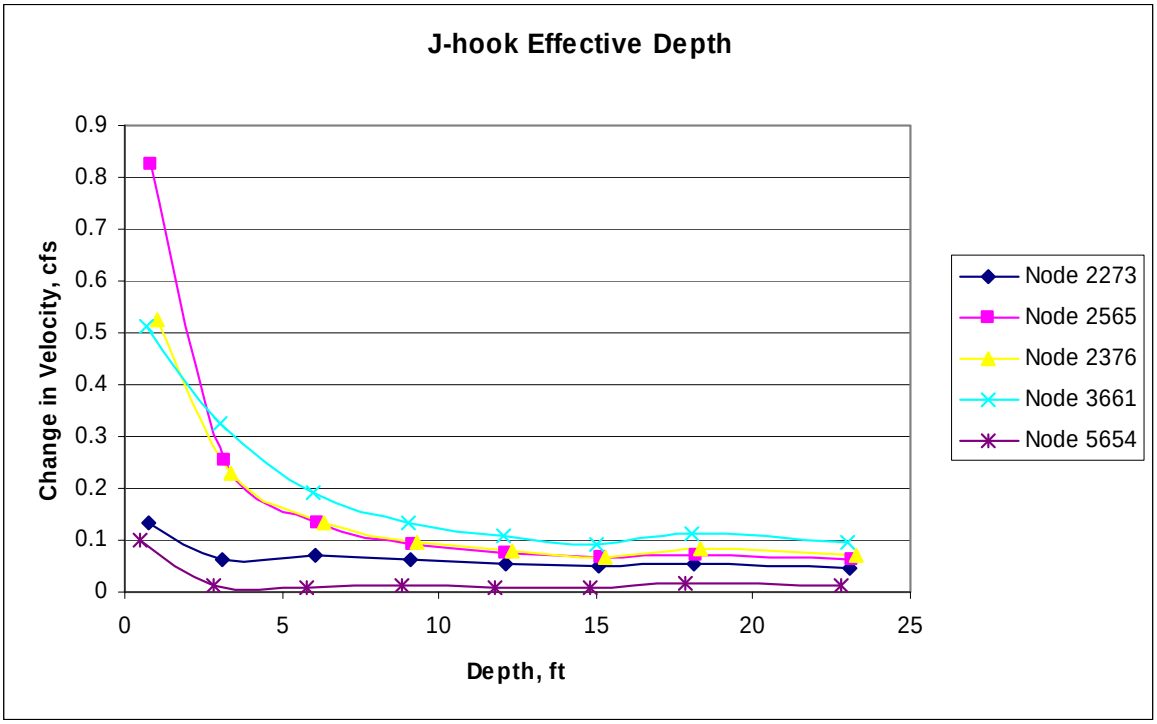

Figure 3-20. J-Hook Effective Depth from Change in Velocity Magnitude.

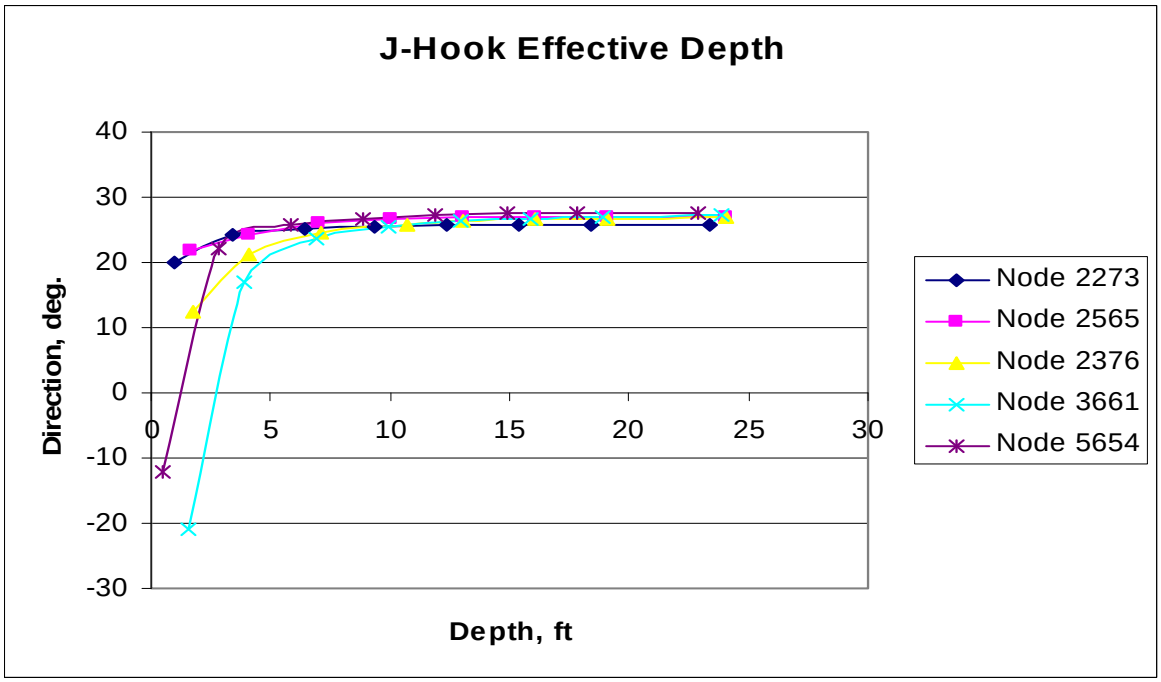

Figure 3-21. J-Hook Effective Depth from Change in Flow Direction.

By looking at these plots, one can readily see that the structures appear to have impact on the flow patterns (direction and speed), only when the depths are smaller than four feet. Further, this depth is reached rapidly in the rising limb of a hydrograph at this site. This would indicate that the structure becomes invisible to the flow rapidly in a large flood event. This means the structure would not have significant impact on scour performance during a large flow event. Therefore, other measures should be taken to protect adjacent banks and structures for such an event.

With that observation made, it is important to qualify it. This is for a stream whose base flow is less than one foot deep. It is recommended that these results not be extended to larger rivers without direct evaluation of such situation. As stated in section 3.4.2, these structures have proven to be very sensitive and therefore results cannot be easily extracted. Also of import, is that the model was not calibrated for larger flows. The spring runoff of 2004 was far smaller than a typical spring runoff. Based on the preceding statement, extending the calibration of this model to larger flows also requires caution and judgment.

3.5.2 Erosion

A fourth observation can be made by evaluating the erosion that took place over the year of monitoring at this site (2003-2004). To do this, bathymetric data from the fall of 2003 is compared to post spring runoff measurements in 2004. The results are shown around the vicinity of the structures themselves.

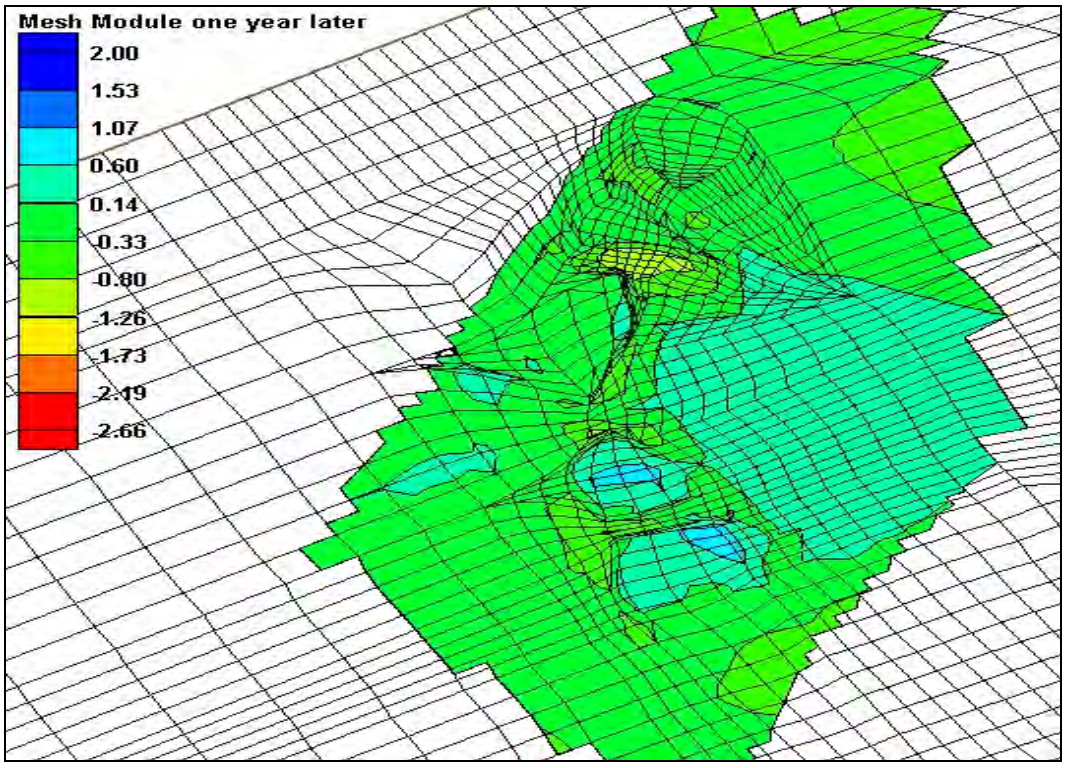

Figure 3-22. Erosion of J-Hook at Thistle Creek Site Between 2003-2004.

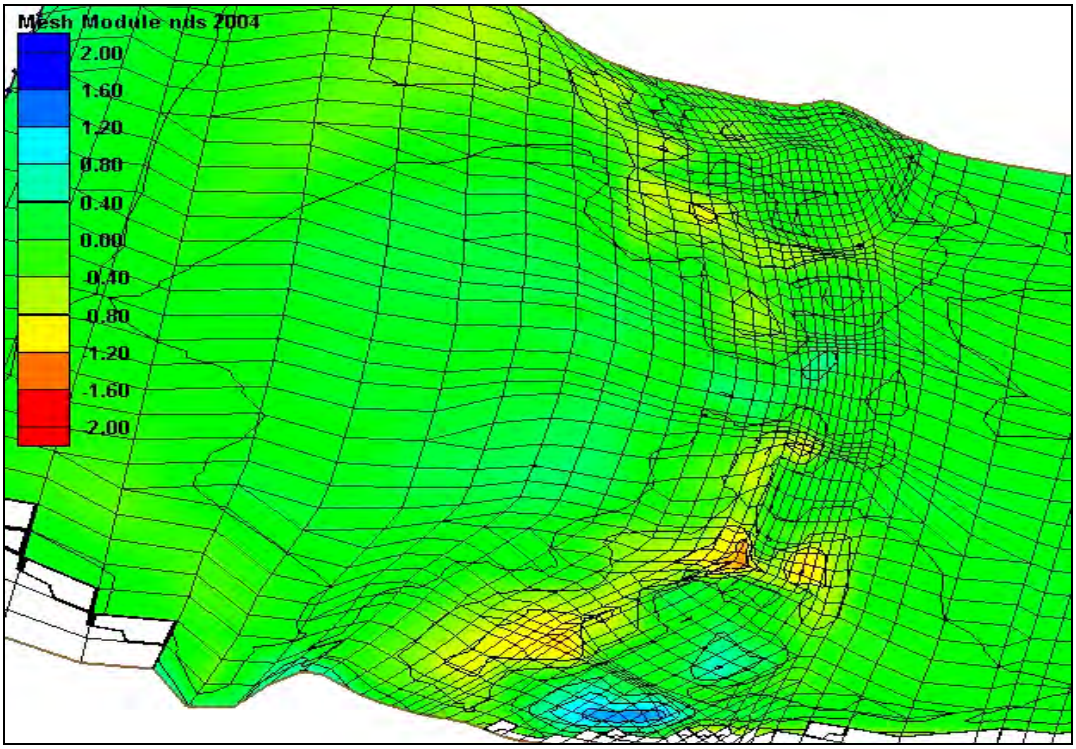

Figure 3-23. Erosion of Cross-Vane at Thistle Creek Site Between 2003-2004.

Both sites showed significant change in bed elevations, especially when it is considered that this was a much smaller than average spring flood. Generally speaking, this raises the question as to whether this type of structure could be maintained in this area.

As was noted earlier, the cross-vane site has some asymmetric characteristics, and discussions with the agency that placed the structure indicate that it may be replaced because of these construction issues. However, since construction took place in 2001, and erosion had become a factor in 2004, it was concluded that a new structure would not be stable. This proved to be the case as shown in field studies conducted between 2004 and 2006, see section 4.5.5.

3.6 Summary

Mesh models of a cross-vane and j-hook were created in SMS and successfully modeled and calibrated for base flow conditions (25 cfs) with FESWMS-2DH meeting objective one as described in the Introduction. Caution must be used when viewing these results as high flow calibration was not obtained.

Both the numerical model and field studies at Thistle Creek indicate that due to symmetry issues, the cross-vane, rather than redirecting stream flow away from both banks (as illustrated in Figure 3-15) is redirecting the thalweg toward the left vane arm.

This hydraulic condition was observed during the initial survey and appeared to be aggravated after spring runoff as the bank began to fail after spring runoff in 2004 as seen in Figure 3-16 and Figure 3-17. The cross-vane, rather than redirecting the thalweg to the center of the stream channel to reduce bank scour, is in fact redirecting it toward the bank and inducing scour during base flow conditions.

Effective depth and scour analyses were performed using the calibrated model to predict the direction and velocity of flow at increasing flow rates. Results indicate that cross-vanes and j-hooks effective depth is less than four feet for structures one foot high from bed to top of in-stream structure rocks. Further, scour is induced upstream and downstream of cross-vanes and j-hooks.

4 Field Studies

Field studies and extended structure monitoring were conducted for phase two of research for this thesis. The purpose of field studies is to field verify phase one modeling results and establish a method of cataloging structures for future analysis in a database. The definition of such a database, along with a sample implementation embodies a future tool for continued research in this area. Both phases, numerical modeling and field studies, were conducted to meet objective two. Objective two is to evaluate the performance of SFS in the vicinity of bridges in Utah.

Not all the structures monitored were located just upstream of bridges. Similar structure to those used at bridges were sought after and added to the study group. The general characteristics of the study group sites and structures are presented below followed by monitoring methodologies and a database used for evaluation. Results of field studies efforts are presented in section 4.5

4.1 Study Group Composition and Characterization

Structures in the study group are all permeable rock structures. Permeability with respect to stream stabilization structures is defined by Richardson and Wacker (1991) as, “the percentage of the [structure] surface area facing the stream flow that is open.” These structures can be further classified as either grade control structures or river training structures (hydraulic control). Grade control structures in the study group are cross-vanes

and rock weirs. River training structures in the study group are vanes, bendway weirs (barbs), and j-hook vanes. Grade control structures are similar to vanes but are basically two vanes on either side of the river that meet at the thalweg. Structures used for hydraulic control and grade control (see Figure 2-10) reduce spiral (helical) motion of flow thereby reducing erosion at the bank.

There are six rock weirs and seven cross-vanes in the study group. These structures have profiles that start from just above the bankful river stage and slope down into the streambed and usually have the lowest elevation at the location of the thalweg. Their length or distance into the streambed varies depending on what type of structure it is. Rock weirs extend from one bank to the other.

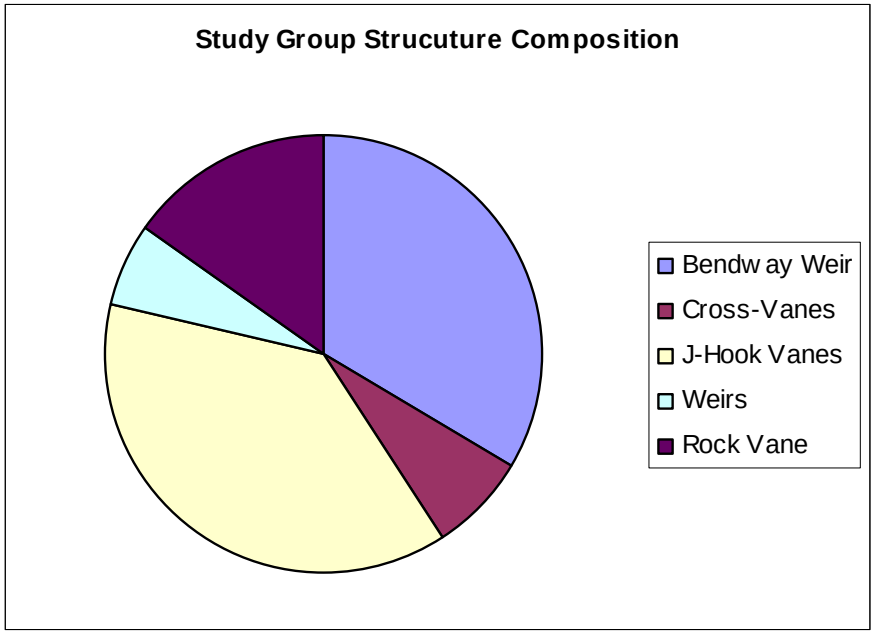

Figure 4-1. Study Group Structure Composition.

There are thirty-seven j-hook vanes, thirty-three bendway weirs and fifteen vanes in the study group. These structures are permeable river-training energy-reducing

structures where flow is guided away from the bank toward the center of the channel. These structures profiles start at or above bankful and extend down into the stream channel. The alignment of the structures usually starts at bankful and extends upstream and across the thalweg. At that point j-hook vanes arch in a “J” shape back downstream (see Figure 2-7). The angles at which the structures extend upstream vary depending on the structure type. See the Structure Classification and Design Criteria section of chapter 2 for in-depth design criteria.

There are a total of seven cross-vanes as part of the study group as shown in Figure 2-6. These structures were developed by David Rosgen and are easily identified. They have a distinctive design as presented in the Structure Classification and Design Criteria section of chapter 2.

4.1.1 Study Group Function and Siting

In this study, shallow-flow structures protect vehicle traffic bridges, pedestrian bridges, and homes; in other applications the structure may protect land from degrading, promote restoration, and allow recreational uses of the waterway. Many of the recently installed shallow-flow structures are used to both enhance river diversity in terms of bends, water depths, and velocity and to protect riverbanks from erosion.

There are four sites in the study group where shallow-flow structures are used to protect bridges from erosion. Two sites are vehicle traffic bridges and two are footbridges. At both sites with vehicle traffic, the scour countermeasure structures are used in conjunction with riprap.

4.1.2 Study Group Watershed and River Characterization

Study group structures are found in six different watersheds, on six rivers and two creeks throughout Utah (see Table 4-1). Each river of stream can be classified as either a controlled or uncontrolled waterway.

Controlled and Uncontrolled Rivers

The structures in this study are found in Utah streams and rivers that are both controlled and uncontrolled. Of the eight gauge stations chosen to best represent the rivers in which the structures in this study are installed, seven out of the eight gauge stations are on controlled rivers i.e. rivers on which the flow is diverted or dammed (see Table 4-2). Each site is located in a unique watershed which are identified by numbers called Hydraulic Unit Codes (HUC).

Table 4-1. Site Characterization

	Watershed				
	Name	HUC Code	Site	Water Way	River Condition
1.	Lower Weber	16020102	Morgan High School	Weber River	Controlled
2.	Upper Weber	16020101	Henefer	Weber River	Controlled
3.	Upper Weber	16020101	Coalville	Weber River	Controlled
4.	Upper Weber	16020101	Wanship	Weber River	Controlled
5.	Upper Weber	16020101	Rockport	Weber River	Uncontrolled
6.	Provo	16020203	Mirror Lake Road	North Fork Provo River	Uncontrolled
7.	Provo	16020203	Nunns Park-Upstream	Provo River	Controlled
8.	Provo	16020203	Nunns Park-Downstream	Provo River	Controlled
9.	Provo	16020203	Provo City	Provo River	Controlled
10.	Strawberry	14060004	Strawberry Visitors Center	Strawberry River	Uncontrolled
11.	Spanish Fork	16020202	Spring Haven	Left Fork Hobble Creek	Uncontrolled
12.	Spanish Fork	16020203	Diamond Fork	Diamond Fork River	Uncontrolled
13.	Spanish Fork	16020204	Utah County Park	Spanish Fork River	Uncontrolled
14.	Spanish Fork	16020205	Thistle Creek	Thistle Creek	Uncontrolled
15.	San Pitch	16030004	Fairview	San Pitch River	Uncontrolled

Flow Range of Rivers

Few of the structures have gauge stations nearby that measure flow and/or stage. Based on the flow data records of eight stations determined to be representative of the flow for the structures in this study, some flow and stage data are available. Data from the USGS Water Resources web site was the sole source of data for the following preliminary analysis of stream-flow data.

Table 4-2. Flow Characterization

Flow Data Record No.	Flow Data Record Title	Controlled Flow	Peak Flow [cfs]	Peak Stage [ft]	Max Monthly Average [cfs]	Min Monthly Average [cfs]
1.	Diamond Fork River at Red Hollow, UT	Y	464	5.68	348.3	40.5
2.	Provo River at Provo, UT	Y	2,520	7.67	1,571	0.68
3.	Provo River nr Woodland, UT	Y	6,040	7.4	1,653	26.6
4.	Spanish Fork at Castilla, UT	Y	5,000	11.53	2,077	33.5
5.	Weber River at Coalville, UT	Y	2,190	5.05	1,550	23.5
6.	Weber River at Echo, UT	Y	3,060	7.34	2,158	0.29
7.	Weber River nr Oakley, UT	N	4,170	9.39	2,178	28.8
8.	Weber River nr Wanship, UT	Y	1,610	3.7	1,295	15.8
		Max	6,040	11.53	2,178	40.5
		Min	464	3.70	348.3	0.29

4.1.3 Definition of Failure

This study assumes failure to mean a structure ceases to function as it was designed from a hydraulic perspective. In other words, when a structure stops re-directing flow as intended during design, the structure is considered to have failed. Whether or not a structure failed was based on rock displacement.

4.2 Study Group Monitoring Methodology

Field studies were conducted to verify phase one results. Over the past five years, an increasing number of structures have been monitored. During this process various tools and levels of monitoring have been developed and implemented. At this time, there are 98 structures throughout the state being monitored at various levels using the following types of monitoring methods:

1. Sketching a site map
2. Using a GPS to obtain coordinates for a structure
3. Conducting high-density bathymetric surveys
4. Installing benchmarks where photos are taken
5. Using photos to document the site
6. Installing and surveying pins in SFS rocks
7. Building numerical models
8. Conducting numerical model mesh scour analyses.

The types of monitoring at each site range from basic to higher levels of data collection. The most basic level of monitoring performed is a combination of sketching a site map and taking photos of structures. This approach is fast and large amounts of data can be captured in a short amount of time. This also works well as a preliminary survey for future reference.

More complex monitoring includes obtaining a GPS point of the structures. These points are quick reference tools used in GIS to document the exact location of the structures. A new form of monitoring implemented in 2005 includes placing pins in the rocks of structures and then surveying them periodically. This allows monitoring rock

movement among numerous structures at sites quickly and more economically than with complete bathymetric surveys.

The highest level of monitoring includes a high-density bathymetric survey. These surveys are used to create 3D renderings of a site in SMS. Once the surveys are in SMS, they can be used to evaluate scour and/or to create meshes used with a numerical model.

The study group includes 16 sites and 98 structures. Table 4-3 shows the site names, the number of structures at the site, and monitoring methods currently used at each site.

Table 4-3. Monitoring Sites

Site	Structures	Monitoring Method
Rock Port	1	1,2,3,4,5,6,7
Coalville	10	1,2,4,5,6
Diamond Fork	1	1,2,5
Henefer	1	1,4,5,6
Morgan High School	15	1,2,4,5
North Fork Provo	4	1,2,4,5,6
Nunns Park Downstream	8	1,5
Nunns Park Upstream	5	1,5
Provo City	1	1,5
San Pitch	6	1,2,5,6
Spring Haven	1	1,2,3,4,5,6
Strawberry	3	1,2,4,5,6
Sundance	10	1,5
Thistle	3	1,2,3,4,5,7,8
UT county park	4	1,2,4,5,6
Wanship	25	1,2,4,5,6

4.3 Database Components and Organization

Phase 2 of the study included the design and creation of a database to organize and catalog the large amounts of gathered data during the monitoring period. The following section describes the current data organization in Microsoft Access® tables and in ArcGIS®. Appendix A. Linking Access Files to GIS describes how the Microsoft Access® tables are linked to ArcGIS® and gives instructions on how to use these tools.

4.3.1 Access Tables

Six tables in Microsoft Access® organize the current data. The tables are:

- Site Data
- Site Photo
- Site Status
- Structure Data
- Structure Photo
- Structure Status

Each table listed above is described in detail in the following paragraphs.

The Site Data table, shown in Figure 4-2, contains information that helps locate the site and also lists references to information available in the project notebooks.

SiteData : Table

Field Name	Data Type	Description
ORGANIZE_ID	AutoNumber	
SITE_ID	Number	
DESCRIPTION	Text	Site Name
DRIVE_DIR	Text	Driving Directions-Book#Page#
SITE_MAP	Text	Site Map
SURVEY	Text	Survey
PIN_POINT_DOC	Text	Pin Point Documentation
PHOTO_PT_DOC	Text	Photo Point Documentation
BENCH_MARK_DOC	Text	Bench Mark Documentation
CALIBRATE	Text	Calibration Data
PHOTO_FOLDER_NAME	Text	Photo Folder
FOLLOW_UP_SURVEY	Text	Follow Up Survey
SITE_NOTES	Text	Brief Description of site

Field Properties

Figure 4-2. Site Data Table.

The Site Photo table, illustrated in Figure 4-3, contains a list of site photos arranged according to the site it is associated with. Site photos contain images that are not taken from a benchmark. Site Photos can capture large areas including the extent of the study area or only capture a photo of one or more structures.

SitePhoto : Table

ORGINIZE_ID	SITE_ID	LINK	PHOTO_TYPE	DATE	DESCRIPTION
1	12	C:\Temp\Photos\ThistleCreek\1_SP_1.jpg	Site Photo	9/6/03	SP-Site Photo
2	12	C:\Temp\Photos\ThistleCreek\1_SP_2.jpg	Site Photo	9/6/03	SP-Site Photo
3	12	C:\Temp\Photos\ThistleCreek\1_SP_3.jpg	Site Photo	5/8/04	SP-Site Photo
4	12	C:\Temp\Photos\ThistleCreek\1_SP_4.jpg	Site Photo	5/8/04	SP-Site Photo
5	12	C:\Temp\Photos\ThistleCreek\1_SP_5.jpg	Site Photo	5/8/04	SP-Site Photo
6	12	C:\Temp\Photos\ThistleCreek\1_SP_6.jpg	Site Photo	5/8/04	SP-Site Photo
7	12	C:\Temp\Photos\ThistleCreek\1_SP_7.jpg	Site Photo	7/22/04	SP-Site Photo
8	12	C:\Temp\Photos\ThistleCreek\1_SP_9.jpg	Site Photo	3/3/05	SP-Site Photo
9	12	C:\Temp\Photos\ThistleCreek\1_SP_10.jpg	Site Photo	3/3/05	SP-Site Photo
10	12	C:\Temp\Photos\ThistleCreek\1_SP_11.JPG	Site Photo	3/3/05	SP-Site Photo
11	12	C:\Temp\Photos\ThistleCreek\1_SP_12.JPG	Site Photo	3/3/05	SP-Site Photo
12	12	C:\Temp\Photos\ThistleCreek\1_SP_13.JPG	Site Photo	3/3/05	SP-Site Photo
13	12	C:\Temp\Photos\ThistleCreek\1_SP_14.JPG	Site Photo	5/11/05	SP-Site Photo
14	12	C:\Temp\Photos\ThistleCreek\1_SP_15.JPG	Site Photo	5/11/05	SP-Site Photo
15	12	C:\Temp\Photos\ThistleCreek\1_SP_16.JPG	Site Photo	5/11/05	SP-Site Photo
16	12	C:\Temp\Photos\ThistleCreek\1_SP_17.JPG	Site Photo	5/11/05	SP-Site Photo
17	12	C:\Temp\Photos\ThistleCreek\1_SP_18.JPG	Site Photo	5/11/05	SP-Site Photo
18	12	C:\Temp\Photos\ThistleCreek\1&2_SP_1.JPG	Site Photo	3/3/2005	SP-Site Photo
19	12	C:\Temp\Photos\ThistleCreek\1&2_SP_2.JPG	Site Photo	5/11/05	SP-Site Photo
20	12	C:\Temp\Photos\ThistleCreek\2_SP_1.jpg	Site Photo	9/6/03	SP-Site Photo
21	12	C:\Temp\Photos\ThistleCreek\2_SP_2.jpg	Site Photo	5/8/04	SP-Site Photo

Record: 1 of 242

Figure 4-3. Site Photo Table.

The Site Status table shown in Figure 4-4, provides a quick reference on the status of SFS sites. This table records SFS sites general characteristics and status over time. This table tracks annual site status and each year an entry must be made for each active site. A general note added in the description field allows for detailed information to be included about the site. In the future, effects analysis, as described in Failure Modes and Effects Analysis (section 2.4.5), may be used to standardize site data.

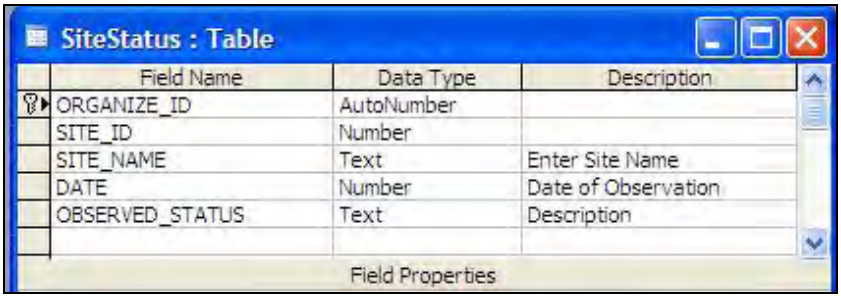

Figure 4-4. Site Status Table.

The structure data table lists each structure that has been or is being monitored (see Figure 4-5). It also contains information on the type of monitoring that is being or has been performed on that structure.

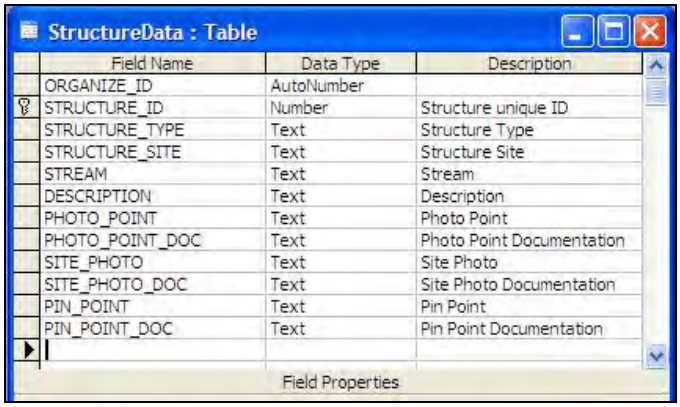

Figure 4-5. Structure Data Table.

The Structure Photos table shown in Figure 4-6 illustrates a table listing a second group of photos used in this database. These photos, taken from a benchmark, allow direct comparisons to be made between different periods of time enabling users to obtain cost effective semi-quantitative results. The labor intensive and expensive nature of complete surveys instigated the need for this table.

StructurePhoto : Table

ORGANIZE_ID	STRUCTURE_ID	LINK	DATE	PHOTO_TYPE	DESCRIPTION
1	4	C:\Temp\Photos\SpringHaven\4_BMD_1.jpg	10/15/05	Bench Mark Documentation	
2	4	C:\Temp\Photos\SpringHaven\4_DP_1.JPG		Photo Point Documentation	photo point is in nautural indention of rock
3	4	C:\Temp\Photos\SpringHaven\4_DP_2.JPG		Photo Point Documentation	photo point is in nautural indention of rock
4	4	C:\Temp\Photos\SpringHaven\4_PDP_1.JPG		Pin Point Documentation	
5	4	C:\Temp\Photos\SpringHaven\4_PDP_2.JPG		Pin Point Documentation	
6	4	C:\Temp\Photos\SpringHaven\4_PDP_3.JPG		Pin Point Documentation	
7	4	C:\Temp\Photos\SpringHaven\4_PPP&PDP_1.JPG		Pin Point Documentation	Both a photo from a photo point & a pin doc ph
8	4	C:\Temp\Photos\SpringHaven\4_PPP_1.JPG		Photo From Photo Point	
9	4	C:\Temp\Photos\SpringHaven\4_PPP_2.jpg	10/15/05	Photo From Photo Point	
10	4	C:\Temp\Photos\SpringHaven\4_PPP_3.jpg	10/15/05	Photo From Photo Point	
11	34	C:\Temp\Photos\MirrorLakeRoad\Misc 018.jpg	9/23/05	Pin Point Documentation	installed on remaining rock of struct. 34
12	34	C:\Temp\Photos\MirrorLakeRoad\A\DSCN0792.JPG	4/29/05	Photo From Photo Point	A-Just following installation spring 05
13	35	C:\Temp\Photos\MirrorLakeRoad\A\DSCN0792.JPG	4/29/05	Photo From Photo Point	A-Just following installation spring 05
14	36	C:\Temp\Photos\MirrorLakeRoad\A\DSCN0792.JPG	4/29/05	Photo From Photo Point	A-Just following installation spring 05
15	35	C:\Temp\Photos\MirrorLakeRoad\A\DSCN0795.JPG	4/29/05	Photo From Photo Point	A-Just following installation spring 05

Record: 1 of 205

Figure 4-6. Structure Photo Table.

The structure status table, shown in Figure 4-7, is used to track the condition of the structures annually. This table allows for statistical analysis of structures and associated failures. As described in Failure Modes and Effects Analysis, section 2.4.5, standardized failure mode descriptions can used in this table to describe how SFS fail in a more consistent manner. This information would produce not only standardized statistical performance rates (based on any definition of failure), but also standardize field research. During field research these failure mode descriptions would provide a basis for field evaluation. As the table is now, each structure is identified as either failed or to be functioning. A brief description of the failure may be entered into the description field.

StructureStatus : Table

ORGANIZE_ID	DESCRIPTION	OBSERVED_STATUS	DATE	STRUCTURE_ID
1		Fully Functional	2003	1
2		Fully Functional	2004	1
3		Burried	2005	1
4		Fully Functional	2003	2
5		Fully Functional	2004	2
6	stream has been pushed to opposite side of channel	Burried	2005	2
7		Fully Functional	2004	3
8	Displacement during spring runoff	Displaced Rock	2005	3
9		Fully Functional	2005	4
10		At minumum 1 displace	2005	5
11		Unknown	2005	6
12		Unknown	2005	7
13		Unknown	2005	8
14		Unknown	2005	9
15		Unknown	2005	10
16		Unknown	2005	11

Record: 1 of 126

Figure 4-7. Structure Status Table.

The preceding tables organize shallow-flow structure data. Future applications of this database will surely present standardized monitoring methodologies in terms of failure modes and effects analyses. These areas of the database can then be more fully developed. The database has been created and not all the data gathered from 2006 to the present time has been entered. Further work to fully populate the database tables is needed. Even though the database is not fully populated preliminary analyses can be performed based on data existing in the Structure Status table. The results of this analysis are presented in Database – Structure Status Analysis, section 4.5.1.

4.3.2 GIS Layers

ArcMap is used to organize and analyze spatial data pertaining to the study group. The extent of the project is limited to the state of Utah. The layers included are:

- Structures in Utah
- Sites in Utah

- Watersheds of Utah
- County Boundaries of Utah
- Streams of Utah
- Topographic Maps
- Arial Photographs

ArcMap also combines spatial data with event-driven data. The tables created for use in Access can be imported to ArcMap and analyzed. For example, the Structures in Utah layer (STR) contains all of the study group structures in Utah. Each structure is labeled with the structure's unique identification number (see Figure 4-8).

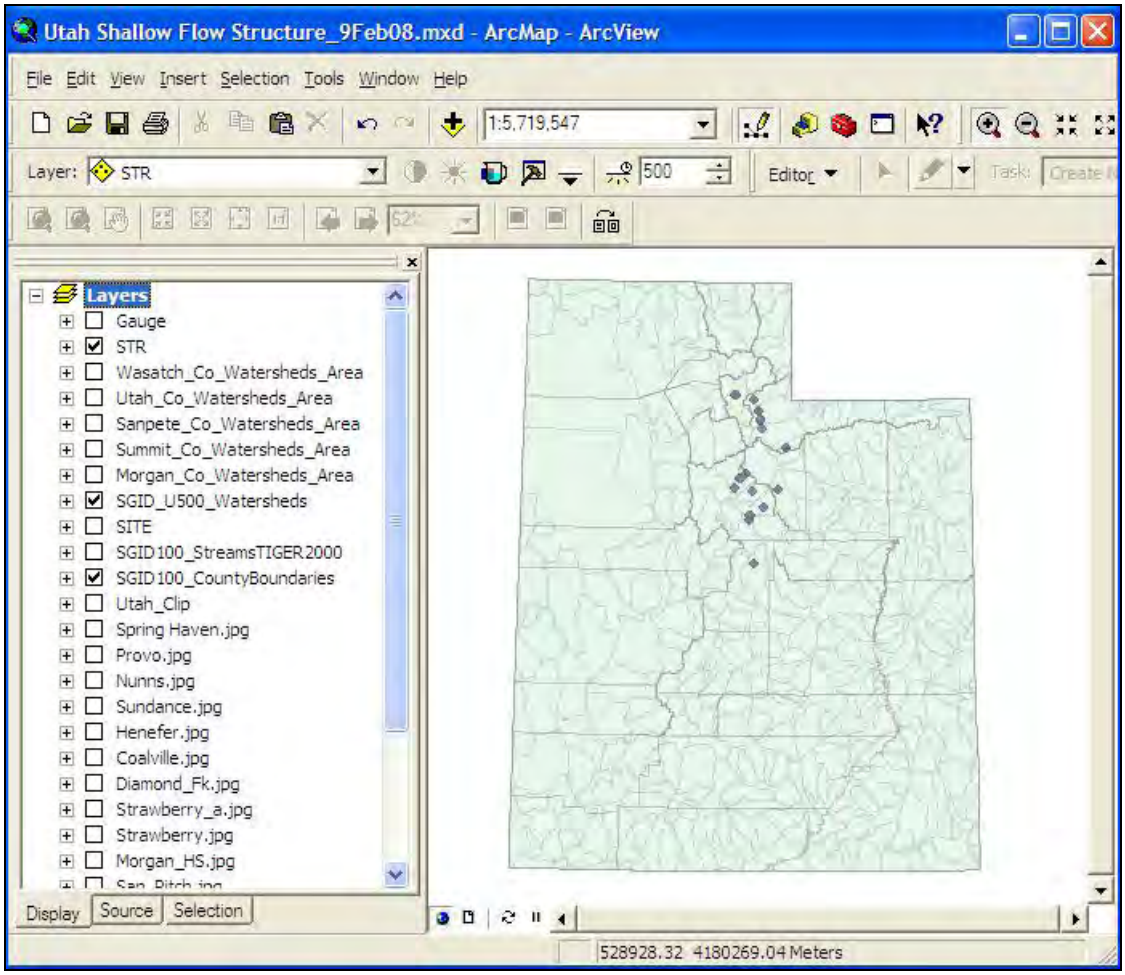

Figure 4-8. ArcMap Showing Structures in Study Group.

4.4 Using the Database

As described in Access Tables, section 4.3.1, data is organized according to data associated with a site or a structure. There are three tables associated with site data and three tables associated with structure data. In GIS, all structures are shown on the STR layer as point features and all sites are shown on the Site layer as polygons. Data associated with each point feature or polygon is accessed via the identify tool (located on the Tools toolbar). The identify tool is shown in Figure 4-9.

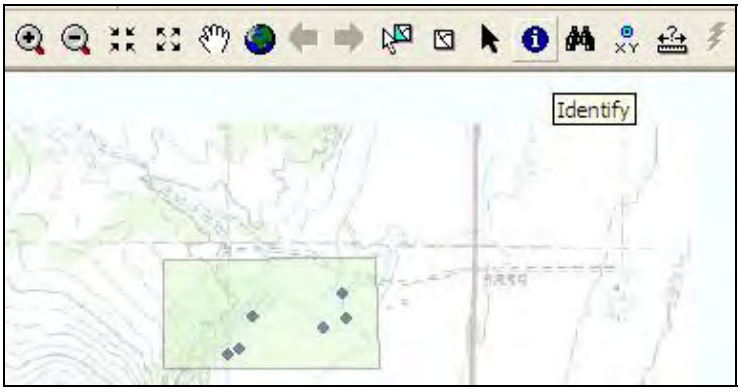

Figure 4-9. Identify Tool in ArcView.

Accessing SFS Data in GIS Via Point Feature (SFS) or Polygon (Site)

Accessing SFS data in GIS via point features or polygons is accomplished by using the identify tool. When the identify tool is activated and a point feature is selected, Access data tables linked to the structure are listed in the data tree on the left-hand side of the Identify dialogue box. Linked table data is summarized on the right-hand side of the dialogue box. See Figure 4-10 below showing structure number 36 (point feature) selected from the STR layer.

One advantage of accessing SFS data in GIS via point features or polygons is that all the linked data is accessed at one time (in the Identify dialogue box) and paths containing hyperlinks are recognized as such and one click on the link launches a browser opening the link.

Accessing SFS Data in GIS Via Feature Attribute Tables

Accessing SFS data in GIS via attribute tables is accomplished by a right-click on the STR layer and a left-click on the Open Attribute Table option (Figure 4-11). The preceding step will open the Feature Data Table (see Figure 4-12). The data linked to the attribute table must be manually opened in the Feature Data Table via the Options button | Related Tables option (see Figure 4-12). When a structure is selected, and linked tables are opened, all data linked to that structure is highlighted. By clicking on the Show Selection option while in GIS tables, only data linked to the selection is shown (see Selected Attributes of Structure Photo dialogue box in Figure 4-12).

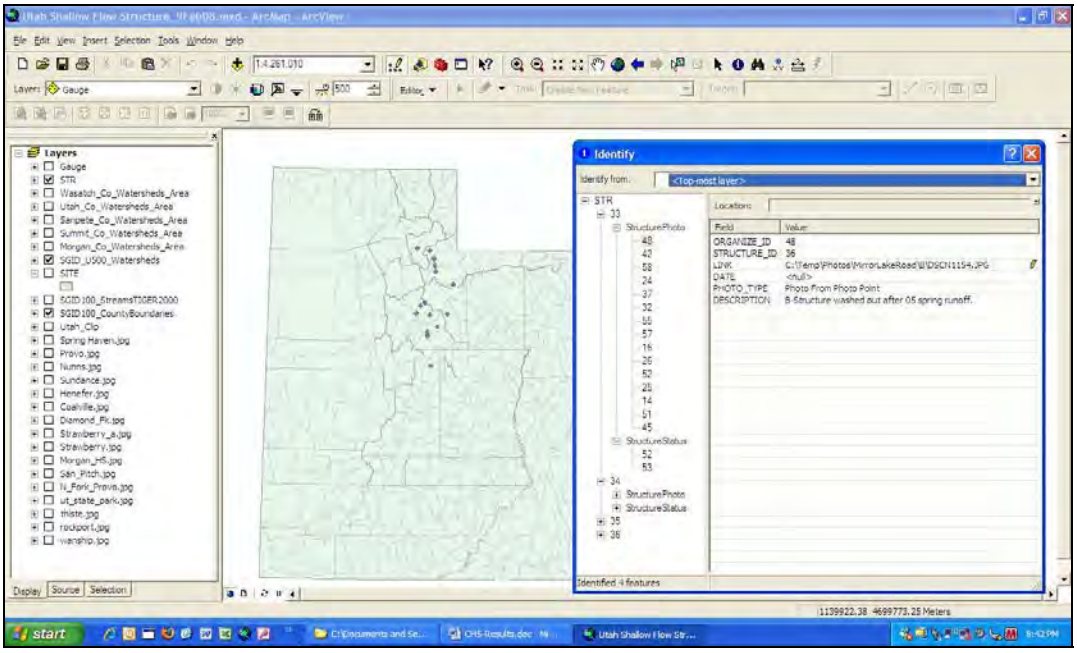

Figure 4-10. Structures 33-36 Accessed with the Identify Tool.

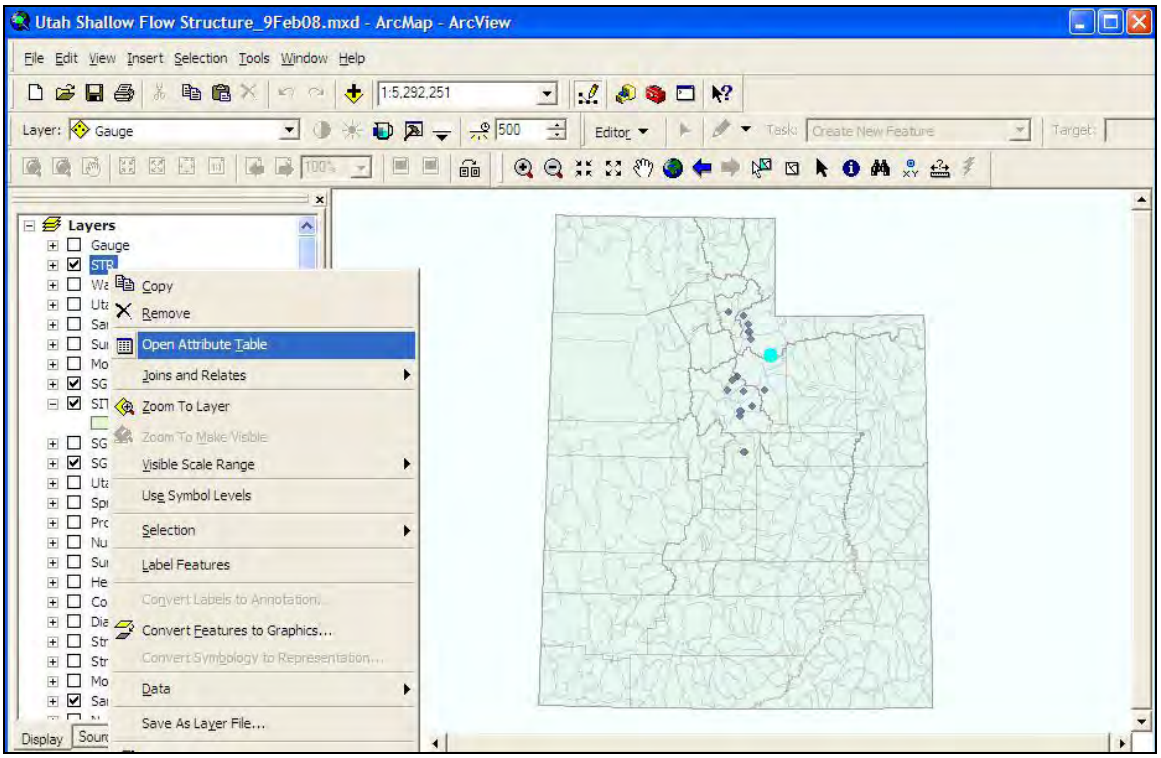

Figure 4-11. Accessing STR Feature Attribute Table.

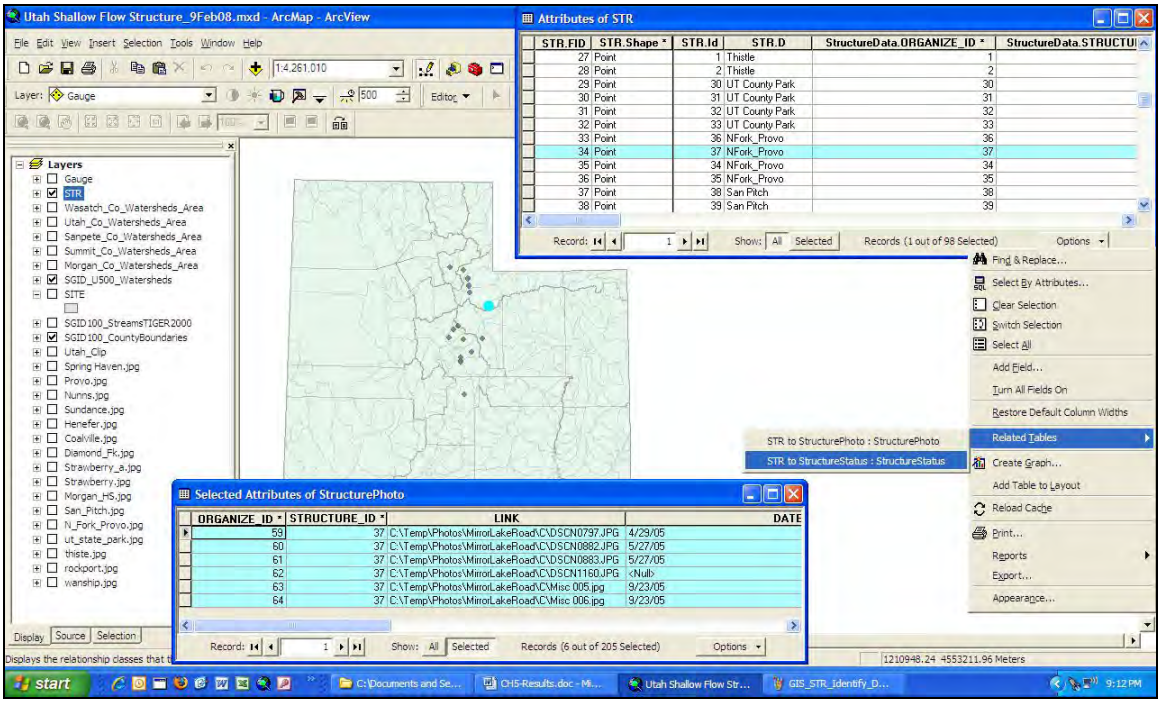

Figure 4-12. Structure No. 34 Data Accessed via the Structure Attribute Table.

Accessing SFS data in GIS – Zoom to Site

To zoom to a site, right click on the respective site layer and left click on the Zoom to Layer option (the respective site layer must be turned on). See Figure 4-13, Zoom to Layer in GIS, for an illustration of this step. This procedure zooms to the extents of the selected site. If both the STR layer and the respective site layer are turned on, both site and structure data can be selected using the procedures outlined in sections: Accessing SFS Data in GIS Via Point Feature (SFS) or Polygon (Site) and Accessing SFS Data in GIS Via Feature Attribute Tables. See Figure 4-14 for an example of zooming to the Wanship site and then accessing SFS data via point features.

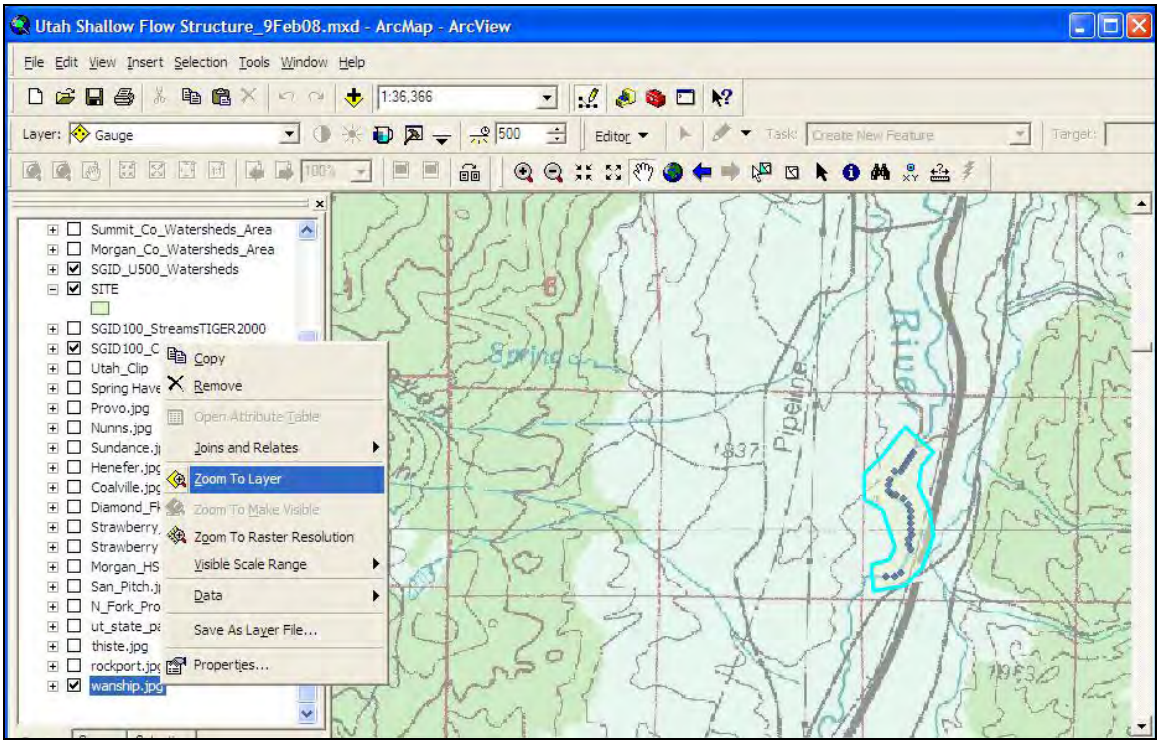

Figure 4-13. Zoom to Layer in GIS.

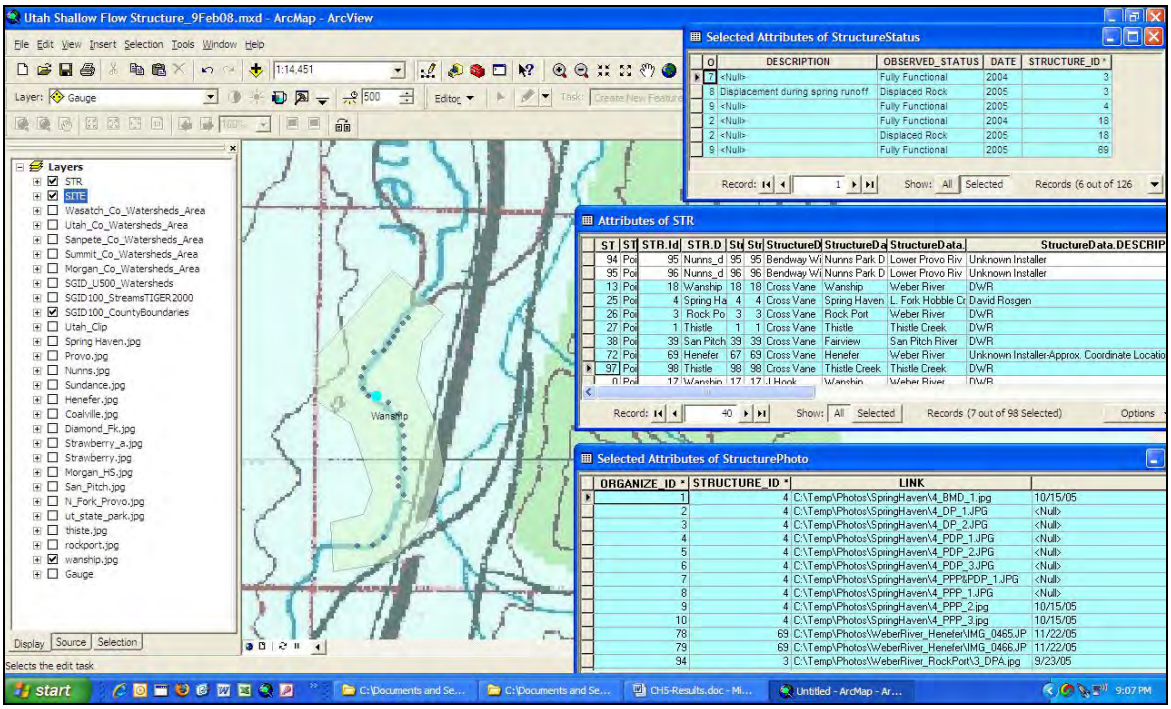

Figure 4-14. Accessing Structure Status and Structure Photo Data.

Field Studies data is organized in Microsoft Access® and ArcGIS®. Access tables store structure and site data which are linked to layers in ArcView. SFS data can be viewed by selecting individual features or by opening attribute tables.

4.5 Field Study Results

Field studies results comprises of an analysis of the data contained in the Structure Status table described earlier in Access Tables, section 4.3.1 and case studies of SFS. The Structure Status Access table tracks whether or not a structure has failed on an annual basis.

4.5.1 Database – Structure Status Analysis

Structure Status Analysis Data Composition

Structure status results are based on the Structure Status Access table. Although only a small percentage of study group data is available for analysis in the new database preliminary analysis is presented. For the years 2003 through 2005, there were 9, 21, and 24 structures monitored for more than one year (see Figure 4-15).

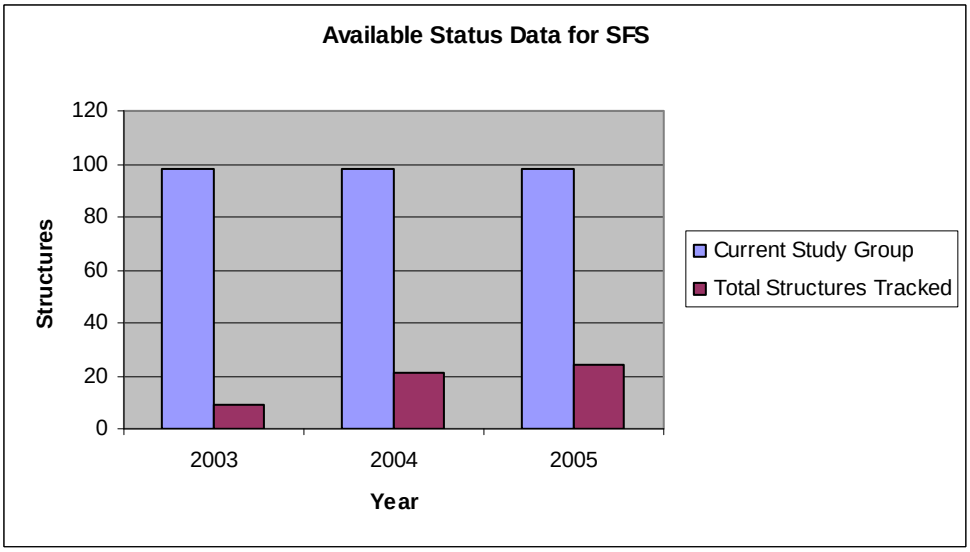

Figure 4-15. Available Status Data for Shallow-Flow Structures.

In 2003, the study tracked the functional status of nine new structures. Nine structures represent 9.2% of the current 98-structure study group. The structures tracked include two cross-vanes, five j-hook vanes and two weirs.

In 2004, the nine structures added in 2003 continued to be monitored and had not failed. In this same year, the study tracked the functional status of 12 new structures for a total of 21 structures tracked in 2004. Twenty one structures represent 21.4% of the

current 98-structure study group. Of the 12 new structures tracked, three were cross-vanes, five were j-hook vanes, three were weirs and one was a bendway weir.

In 2005, eight of the nine structures added in 2003 continued to be monitored as no data was available for one of the structures. Further, in 2005, the 12 structures added in 2004 continued to be monitored. In addition, in 2005, the study tracked four new structures. Two were cross-vanes and two were j-hooks. A total of 24 structures were monitored in 2005 which represents 24.5% of the current 98-structure study group.

Structure Status Analysis Results

The year 2005 was an average-water year and mixed results were found for the 24.5% of the monitored structures. In 2005, a total of seven cross-vanes were monitored. Only four were still functioning as designed after spring runoff for a 57.1% success rate. There were a total of 12 j-hook vanes, of which eight were still functioning as designed after spring runoff for a 66.7% success rate. There were a total of five weirs of which one was still functioning as designed after spring runoff for a 20.0% success rate. Overall 54.2% of the structures monitored in 2005 had not failed during that year.

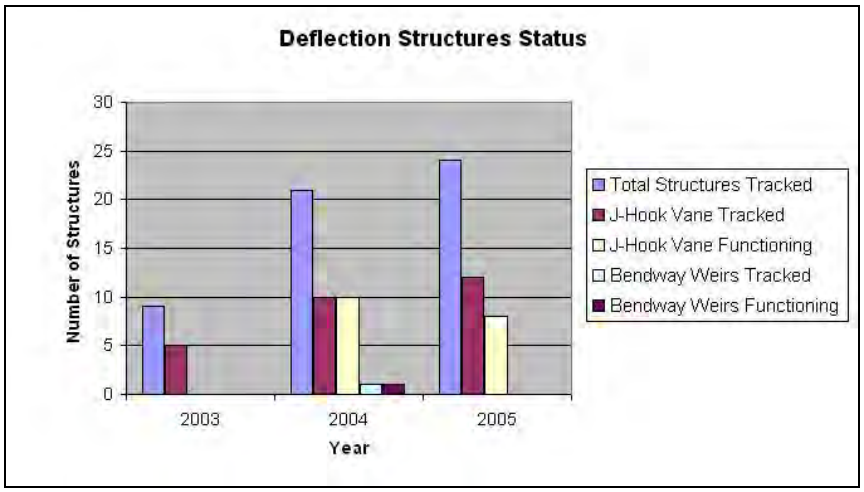

Figure 4-16. River Training Structure Status.

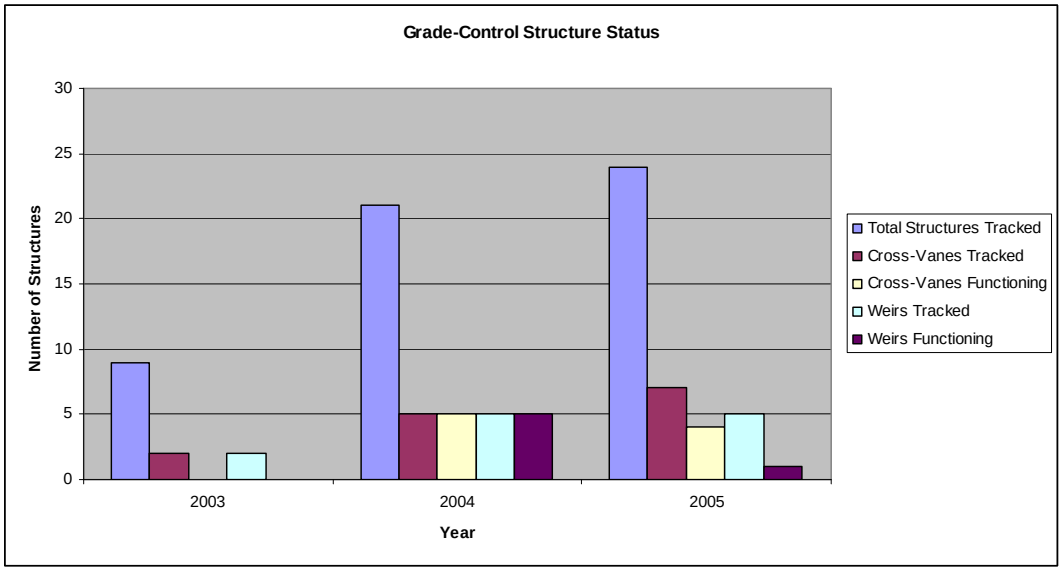

Figure 4-17. Cross-Vane Status.

This analysis of structure status shows SFS performance over two years. Preliminary analysis indicates SFS performance was 100% in 2004 and 54.2% in 2005. The year 2003 and 2004 did not have high water levels during spring runoff whereas 2005 was a high water year. The failure rate jumped in 2005 as a result of higher spring runoff flows. Flow variability is a factor in structure failure and has been documented as a problem in Utah waterways in 1995 in the *Stream Habitat Improvement Evaluation Project* (URMCC 1995).

4.5.2 Field Studies – Observed Failure Modes

The river engineering structures are used to mitigate scour. Scour is defined as horizontal and vertical movement of a stream bed. There were six failure modes observed in the study.

Erosion

The first was the erosion of material upstream of a SFS causing a rock to fall upstream. This failure mode was observed at the Sundance site on relatively old

structures in a controlled section of the Provo River. The second failure mode was erosion of bed material downstream of a rock causing rocks to roll downstream. This failure mode was observed at Utah County Park on at least one j-hook on a relatively new structure. These first two failure modes are examples of rocks failing by tipping.

Impact and Drag Force

The third failure mode observed was failure by dislocation of a structure element caused by drag force of water. This failure mode caused rocks to slide downstream as seen at the Rockport site (for example, see Figure 4-19 and Figure 4-26). The fourth failure mode was dislocation of a structure element caused by debris. Debris, washing downstream impacts the rock, resulting in displacement and failure (see Figure 4-24).

Bed Aggradation and Flanking

Bed load causing burial is the fifth failure mode. This failure mode was observed at Thistle Creek. Bypassing a structure (flanking) was the sixth failure mode observed. Flanking occurred when water bypassed the structure completely instead of being redirected by it. This type of erosion is horizontal erosion as observed at Thistle Creek at a cross-vane (see Observed Deficiencies in the Methodology, section 3.4.2).

4.5.3 Site Observations

Utah County Park Pedestrian Bridge

Three structures were placed upstream of a pedestrian bridge at Utah County State Park on the Spanish Fork River in an uncontrolled section of the river. The structures are j-hook vanes. At least one of these structures failed as four of twelve rocks were displaced in the water year of 2004.

Figure 4-18. Utah County Park Before Runoff.

Figure 4-19. Utah County Park After Runoff.

4.5.4 Field Studies – Bridge Application Results

North Fork of the Provo River Vehicle Bridge

Four structures were designed by UDOT and installed on the North Fork of the Provo River in the fall of 2004. These include one bendweir downstream of the bridge (Figure 4-21 and Figure 4-22) and three weirs upstream of the bridge (Figure 4-23 and Figure 4-24). The

structures were installed during low flow in the fall of 2004. Figure 4-21 and Figure 4-23 show the structures several weeks after installation. Photos taken after the following spring runoff are shown in Figure 4-22 and Figure 4-24.

Spring runoff in 2005 was an average event based on data from the U.S. Geological Survey (USGS). The closest monitoring gauge is approximately 9,100 meters downstream (obtained from ArcView in the database) of the site. June gauge records indicate that the peak flow was 2,070 cfs and the mean monthly discharge for the same month was 1,052 cfs. See Figure 4-20 for peak stream flows downstream of the site and Flow Data Record No. 3 in Table 4-2 for stream characterization data.

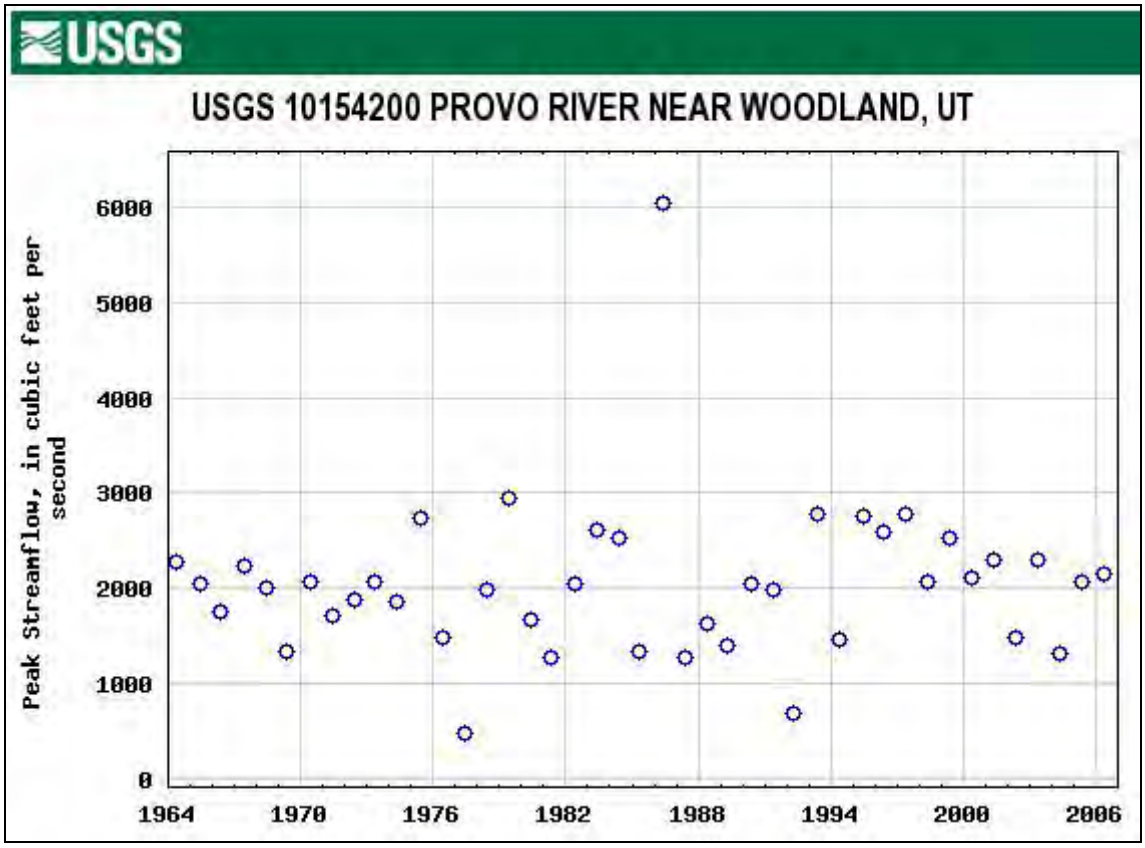

Figure 4-20. Stream Gauge Data for North Fork of the Provo River Site.

Average stream runoffs in the water year 2005 are assumed to be relatively uniform throughout Utah and therefore the stream runoff at the North Fork of the Provo River is assumed to be representative for the entire study group for the 2005 water year.

Figure 4-21. Bendway Weir on the North Fork Provo River Just After Installation.

Figure 4-22. Bendway Weir on the North Fork Provo River After Runoff.

Figure 4-23. Weirs on the North Fork Provo River Just After Installation.

Figure 4-24. Weir Site on the North Fork Provo River After Runoff.

The streambed aggraded up to but not above the bendway weir rocks when comparing the before and after photos of the bendway weir shown above. The bendway weir was not buried by incoming sediment nor were there any displaced rocks so the bendway weir was still functioning.

All three broad-crested weirs upstream of the bridge failed during the spring runoff in 2005 following installation in 2004 (see Figure 4-23 and Figure 4-24 above). In Figure 4-24 a log was washed downstream through the weirs. The log appears to have contributed to the majority of in-stream structure elements to be displaced. This site has high flow-variability where large deflectors are not advised (URMCC 1995). Debris appears to have played a large role in the failure of the weirs. Laursen et al. (1990) indicated that debris is unpredictable and can induce unwanted scour on hydraulic structures.

Rockport Vehicle Bridge

One structure was placed upstream of the bridge at Rockport State Park on the Weber River as shown in Figure 4-25 and Figure 4-26. The structure is a cross-vane placed just upstream of the bridge. The installation did not conform to Rosgen Design Methodology, which dictates the vane arms slope down at a slight angle upstream. In this installation, the vane arms were installed at a slight upstream angle.

Figure 4-25. Rockport Before Runoff.

Figure 4-26. Rockport After Runoff.

The structure failed during spring runoff in 2005 as elements of the structure were displaced (see Figure 4-26). Various elements (rocks) of the cross-vane were displaced downstream as seen in the center of the photo in Figure 4-26. Also of note, in the same photo is the substantial amount of streambed degradation that occurred which lowered the elevation of structure elements in the center of the cross-vane. The change in elevation and displacement of the structure rocks affected the symmetry of the structure. Figure 4-26 shows the thalweg directed toward the left bank of the river rather than to the center of the channel.

4.5.5 Field Studies – Thistle Creek Follow-Up

Numerical models and associated field studies were conducted at Thistle Creek in 2003-2004. Observations at the site since then are presented in this section. A hyper-sensitive response of Thistle Creek to the cross-vane and j-hook was observed in chapter 3, Numerical Models. It was also observed that the structures were in a historically unstable area. The Creek was very sensitive to the symmetry of the cross-vane under normal flow conditions which caused the thalweg to be redirected to the left bank and contributed to bank failure on the south bank downstream of the structure.

The response of the j-hook and cross-vane was unremarkable under normal flow conditions as compared to spring flows of 2005. In 2005, under average spring flows, both structures were active as water was breaking over the top of them. See Figure 4-27 for cross-vane during 2005 spring runoff. Figure 4-28 and Figure 4-29 were photos taken after 2005 spring runoff.

Figure 4-27. Cross-Vane at Thistle Creek During 2005 Runoff.

Figure 4-28. Cross-Vane at Thistle Creek After Runoff.

Figure 4-29. J-Hook at Thistle Creek After Runoff.

Once the spring flows subsided the cross-vane was buried by approximately 1.5 feet of sediment with no noticeable changes to the thalweg of the Creek (see Figure 4-28). The cross-vane became inactive due to sediment deposition over the structure (aggradation).

The stream response to the j-hook after 2005 flooding occurred was notable. The in-stream elements of the structure were buried and the creek shifted away from the j-hook and the structure became inactive as shown in Figure 4-29.

Failures due to “burial by incoming sediment” and “rapid lateral migration away from vane” are modes of failure listed by Johnson and Niezgoda (2004). Thistle Creek is an example of a creek with hydraulic risk due to high variability of flow, low slope, and high sediment load as described in URMCC (1995).

4.6 Field Study Conclusions

Field study results were conducted to confirm findings in phase one. The current study group characterization, monitoring methodologies, and SFS data organization is presented. The study group structure composition is described along with a river characterization summary and definition of failure for SFS. SFS data organization in Access and GIS is presented followed by structure status analysis and case studies of bridge applications and a follow-up on the phase one study site.

Constructibility continues to be an issue in structure installation as described in chapter 3. The issue here is not symmetry in installation but slope of the vane arms installed at the Rockport site. The structure failed after the 2005 spring runoff. The displacement of structure elements affected the symmetry of the structure. Once the structure failed it began to direct the thalweg toward the bank just upstream of the abutment of the bridge. This observation confirms those made at Thistle Creek during phase one modeling efforts (see sections 3.4.2 and 3.5)

SFS are unstable in high variable flow conditions observed during the average runoff events of 2005 as calculated in Structure Status Analysis Results, section 4.5.1 and the four case studies presented in Field Studies – Bridge Application Results in section 4.5.4 and in Field Studies – Thistle Creek Follow-Up in section 4.5.5.

5 Conclusions

The purpose of this research is to use numerical models and field studies to determine whether or not SFS can reliably be used in place of riprap and other scour countermeasures. The results show that SFS are not suitable scour countermeasures at bridges.

5.1 Literature Search

The literature survey indicated that hydraulic scour countermeasures for coastal and river engineering have been adopted and modified for river restoration purposes. The river restoration structures are essentially micro installations of coastal and river engineering structures of which the design criteria and placement requirements have been adapted for stream and small-river applications. Recently there has been a push to use these stream restoration structures for scour countermeasures at bridges in Utah.

The literature survey indicated that there are siting problems and common failure modes associated with using stream restoration structures in the Siting and Failure Modes and Effects Analysis sections of chapter 2. Some of these failure modes were observed during both phases of this study.

5.2 Numerical Modeling – Phase One

Phase one numerical modeling efforts were successful in creating two numerical mesh models in SMS and obtaining calibrated analysis for base flow conditions with the FESWMS-2DH finite element program. These modeling efforts met objective one to verify that SFS can be modeled with two dimensional numerical modeling programs.

Effective depth analyses for both the cross-vane and j-hook were conducted (see Effective Flow Range, section 3.5.1). The effective flow range for both modeled structures, in terms of velocity and direction, is four feet. At four feet, both the cross-vane and j-hook structures cease to train the flow and therefore cease redirecting flow away from the bank.

A scour analysis was conducted by comparing the bathymetries of the cross-vane and j-hook (see Erosion, section 3.5.2). This analysis showed that the structures induce scour upstream as well as downstream of the rock members even over the course of minor spring runoff events.

5.3 Field Studies – Phase Two

Phase two field studies included the development of monitoring methodologies and the creation of a database to track and analyze SFS data. These tools can be used for future analyses and a template for developing similar study databases Both phases, numerical modeling and field studies, were conducted to meet objective two. Objective two is to evaluate the performance of SFS in the vicinity of bridges.

Phase two field studies confirmed the symmetry issues observed in phase one. When symmetry matched design guidelines, flow was redirected away from the

streambank as described by Vane Weir Theory (see Figure 2-9). Cross-vanes functioning in this manner were seen at Rockport before spring runoff (Figure 4-25) and at a cross-vane near Park City (see Figure 2-6). However, when the prescribed design and related symmetry was not followed, whether during construction or due to rock member displacement by failure, the structure did not direct flow to the center of the channel. Further, flow was directed to the bank as seen in the modeling results (see Figure 3-13) at Thistle Creek and the case study results at Rockport after spring runoff (see Figure 4-26).

Both examples illustrate river flow directed to the bank rather than away from it due to symmetry problems. Symmetry issues were observed to arise from lack of precision in placing structure elements during construction, the shape of each rock member and displacement of structure rocks during failure.

The case studies, other than the follow-up for the site at Thistle Creek, were at bridge applications of SFS. Of the three bridge applications for which data were available, SFS failed at each site during the 2005 spring runoff event. A variety of failure modes were observed at these sites which included tipping of structure members due to erosion, displacement of structure members by debris and drag force and streambed aggradation and degradation. It was generally observed that in the spring runoffs of 2003 and 2004 SFS were stable under lower than average spring runoffs and unstable in average runoff events.

This trend is quantified in the results of the structure status table analysis in the database (see 4.5.1). There were no failures of structures monitored in 2004 under low runoff conditions. However, under average spring runoffs, there was a 46% failure rate in 2005. Observations during both phases of the research have shown a high percentage

of failures of SFS. Not only have SFS been shown to have high failure rates under average spring runoff conditions, but also that when the structures fail, they induce scour rather than protect against it. It is appropriate to note that failure from a hydraulic perspective does not mean that the structures do not function well with respect to habitat and stream restoration.

5.4 Summary

Objectives one and two have been met during the course of research for this thesis. SFS reliability has been evaluated with numerical models and field studies in terms of hydraulic performance. Based on the findings of the research, SFS are unreliable as scour countermeasures at bridges and should not be considered as an alternative for riprap for scour prevention at bridges.

References

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Appendix A. Linking Access Files to GIS

A. Linking Microsoft Access® Files to ArcGIS®

A.1 Data Types

Shallow-flow structure data are stored in two data categories. The first data category is spatial data and the second is event-driven data. Spatial data relate the sites and structures to one another through a common coordinate system. Event-driven data are used to monitor change over time of the sites and structures.

The programs, ArcMap 9.1® and Microsoft Access®, are used in this study to organize and analyze shallow-flow structure data. The event-driven data are stored in Access while the spatial data are stored in ArcMap. When ArcMap is linked to Access tables, it provides an interactive interface where both spatial and event-driven data are easily integrated and accessed.

In both ArcMap and Access, data records are separated into two groups. The first group pertains to sites and the second relates to structures.

A.2 ArcMap

A.2.1 Records

ArcMap stores and separates spatial data into layers. The first layer, STR (for structure) contains one point feature for every structure being monitored. The second, the SITE layer, contains one polygon that encloses structures close together. Each layer has

an attribute table associated with it, which contains a unique record for each feature contained in the layer.

Layer SITE is a shapefile that contains one polygon feature for every site recorded. Spatial information pertaining to sites is recorded in the SITE layer. The extents of the polygon represent the study area and are set to give a rough estimate of the study area.

A.2.2 Layout

All other layers are to help place the structures spatially and have been clipped to the boundary of the state of Utah. Currently, there are 22 layers. The layers are STR, SITE, streams, watersheds, county boundaries, streams, one or more raster layers for each site, and one large raster layer sized to take in all the sites for general reference only.

A.2.3 Locating the Sites

The database includes a large raster image of a topographic map that covers all the sites. This should be updated (expanded) as new sites are added outside the extents of this raster. The purpose for this image is to allow the user to identify the major roadways and cities to enable access to any site. To locate a site, use the Utah_Clip raster to get general driving directions to the site, then use a GPS to find each structure. ArcGIS displays the GPS coordinate for each structure when a user clicks on the structure using the Identify tool on the Tools tool bar. The coordinates in NAD 83 Utm Zone 12N are displayed in the Identify Results data frame.

Currently, the SiteData table in Access is used to reference driving instructions in the DRIVE_DIR field. One may choose to insert a reference to a notebook as is currently the case or insert the path to a document containing detailed driving directions to the site.

A.3 Access Records

The event-driven data are stored in Access tables. The event-driven data, like the spatial data, are separated into information pertaining to either sites or structures. There are three tables associated with structures and three tables associated with sites. Tables associated with structures are StructureData, StructurePhoto, and StructureStatus. Tables associated with sites are SiteData, SitePhoto, and SiteStatus.

A.4 Relationship Between Data Stored in Access and ArcMap

Every site and structure has a unique identification number. These identification numbers are consistent between ArcMap and Access. Each database table whether in Access or ArcMap references the same unique structure or site identification number. The unique ID numbers are “keys” relating the information stored in tables to one another in one-to-one, one-to-many, and many-to-many relationships.

A.5 Linking Access Tables to ArcMap

Access tables are added using the “Add Data” command. To add tables to ArcMap select the Add Data button on the standard toolbar (see Ormsby et al. 2004). In the Add Data dialogue box, browse to the location of the Access tables and select the three site and structure tables.

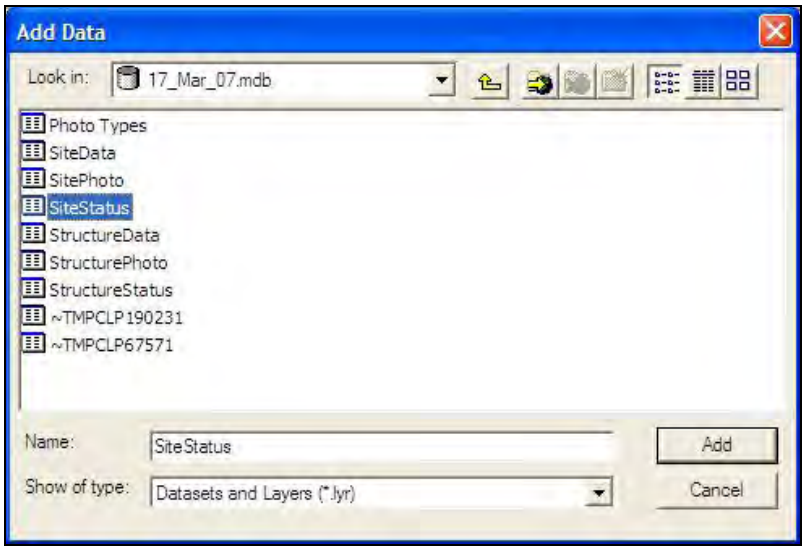

Figure A-1. Adding Access Tables to GIS.

By clicking the "Add" button (see Figure A-1), the tables are added to the ArcMap file (see Figure A-2) and the table of contents tab switches to Source. See Adding Tables to ArcMap by Ormsby et al. (2004).

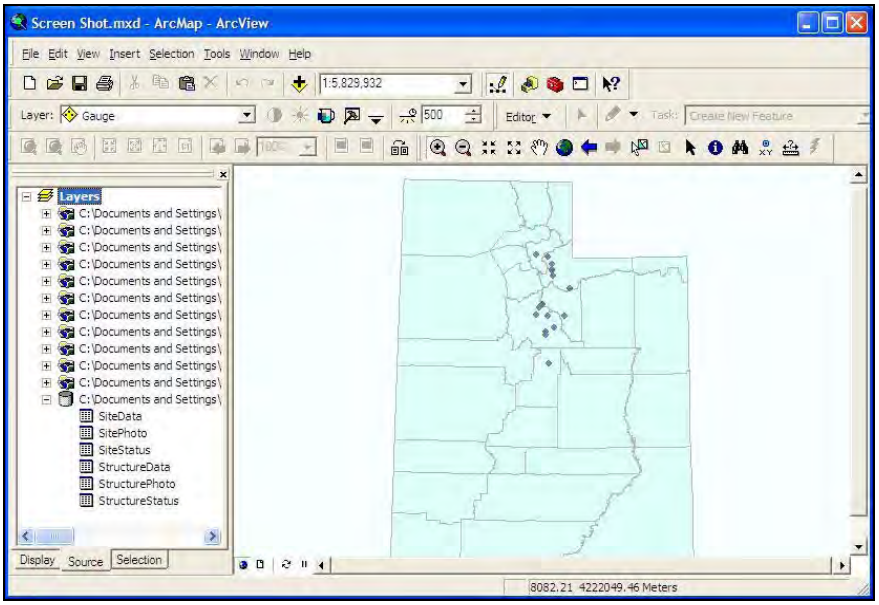

Figure A-2. Site and Structure Tables Added to the Table of Contents.

A.5.1 Joining and Relating Access Tables to ArcMap Attribute Tables

Once the Access tables are added to ArcMap, select either the STR or SITE layer, on the Display tab in the table of contents, and right click on it. Select “Joins or Relates” and select whether you want to join or relate data (see Figure A-3).

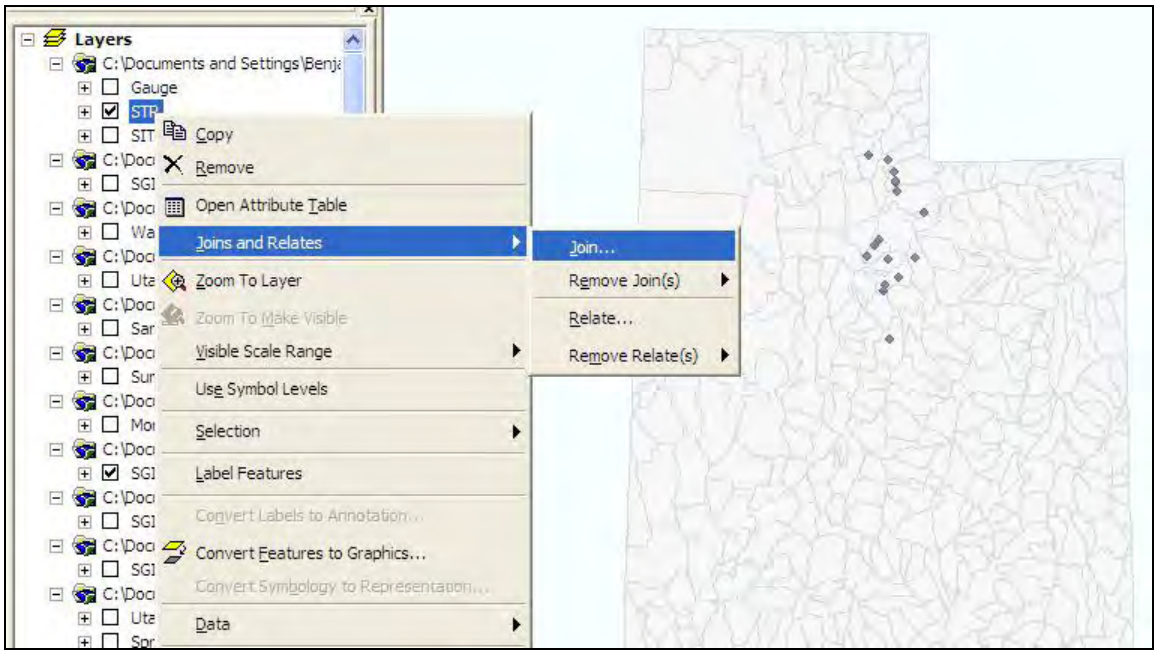

Figure A-3. Accessing the Join or Relate Dialogue Boxes.

Joining is performed in the Join Data dialogue box (see Figure A-4) by using the keys indicated in Table A.

Figure A-4. Join Data Dialogue Box.

Relating the Access tables StructurePhoto and StructureStatus to the layer STR is accomplished in a similar manner. In stead of choosing the join command, choose the relate command (see Figure A-3. Similarly, the GIS layer SITE is joined to the Access table SiteData and related to the Access tables SitePhoto and SiteStatus. Table A.1 shows all the keys that are used while performing the joins and relates commands to effectively link the Access tables to ArcMap in the Join Data dialogue box or the Relate Data dialogue box.

Table A-1. Corresponding Data Keys for Access and ArcGIS

GIS Layer	GIS Layer "key"	Access Table	Access Table "key"
STR	Id	StructureData	STRUCTURE_ID
STR	Id	StructurePhoto	STRUCTURE_ID
STR	Id	StructureStatus	STRUCTURE_ID
SITE	Id	SiteData	SITE_ID
SITE	Id	SitePhoto	SITE_ID
SITE	Id	SiteStatus	SITE_ID

In the shallow-flow structure database, structure and site data is contained in the "Data" tables in Access (StructureData and SiteData) and has a one-to-one relationship with each record in the STR and SITE attribute tables. The event-driven data are in the "Photo" and "Status" tables (StructurePhoto, SitePhoto, StructureStatus, SiteStatus). The relationship between the layers STR and SITE have a one-to-many relationship with the "Photo" and "Status" tables.

A.5.2 Accessing Site and Structure Data Example

To access SiteData and StructureData for the Spring Haven site in the database:

1. Select the STR, Site, and Spring Haven layers by checking the box next to them in the table of contents (see Figure A-5).

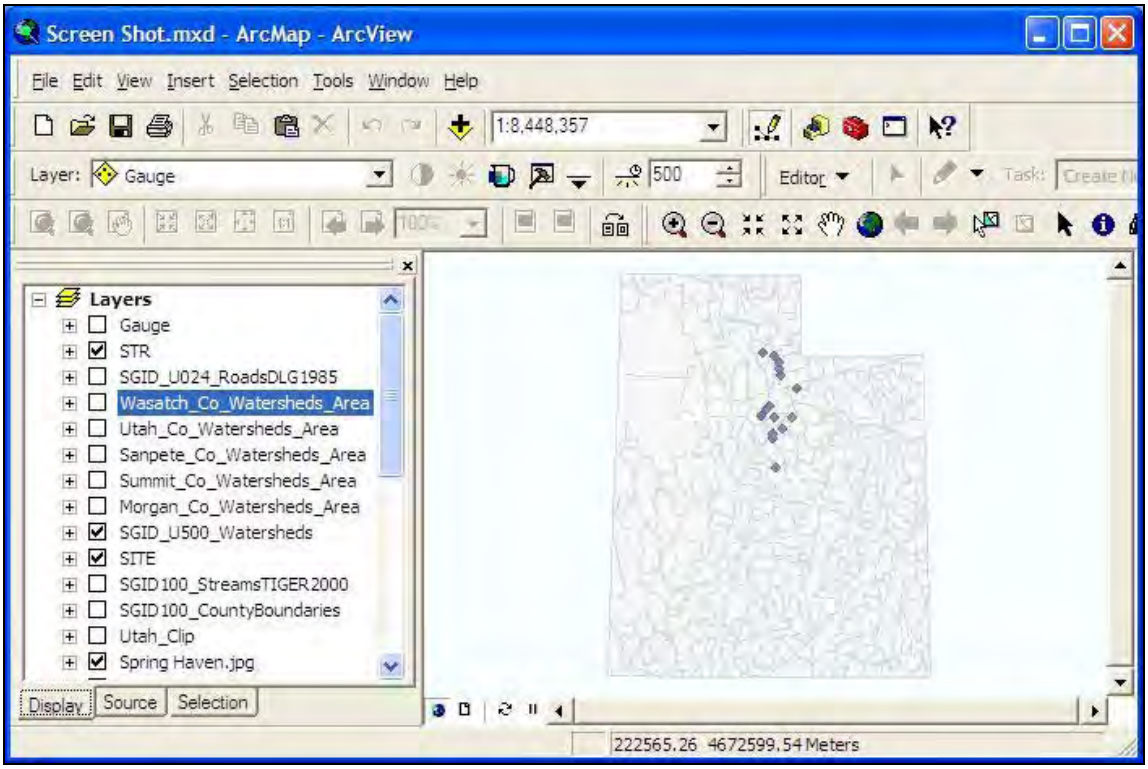

Figure A-5. Select Layers in the Table of Contents.

2. Right click on Spring Haven raster and select Zoom to Layer. This action pans the view to the Spring Haven site (see Figure A-6).

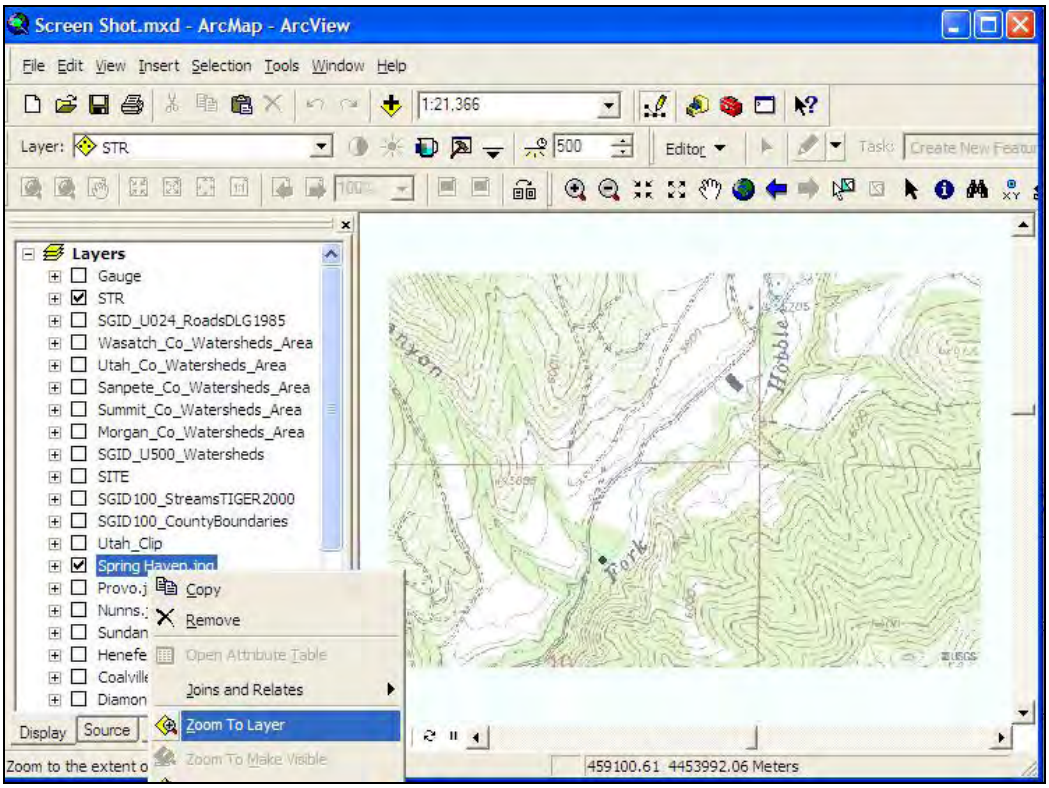

Figure A-6. Using the Zoom to Layer Command.

3. Select the Identify button in the Tool toolbar (see Figure 4-9).
4. Select the area away from Structure 4 in the boundary of the Spring Haven site polygon to access site data for Spring Haven (see Figure A-7).

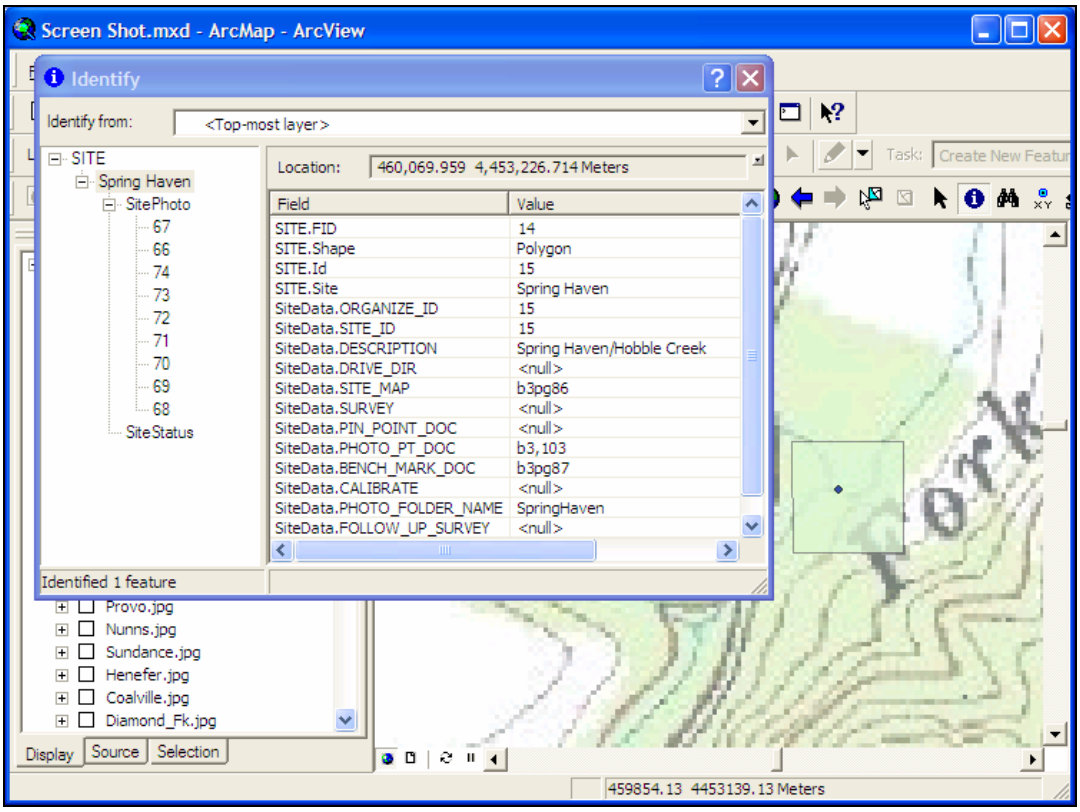

Figure A-7. Identify Dialogue Box Accessed by Using the Identify Tool for the Spring Haven Site.

5. The site data is listed in the Identify Results dialog (see Figure A-8).

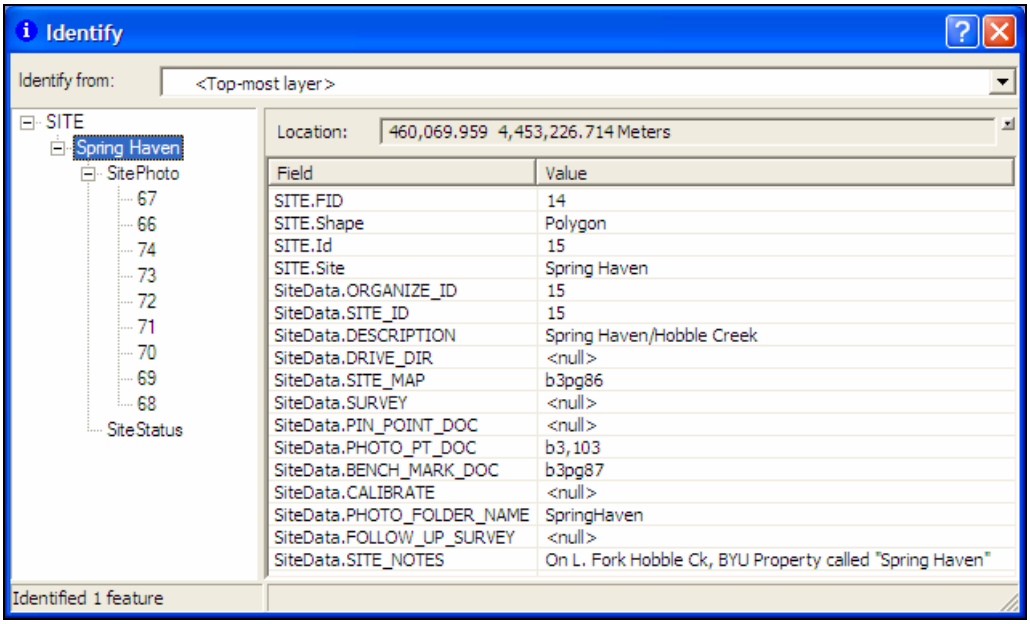

Figure A-8. Spring Haven Site Data Displayed in the Identify Dialogue Box.

6. Now, click on the point feature that represents Structure 4 to access available structure data (see Figure A-9).

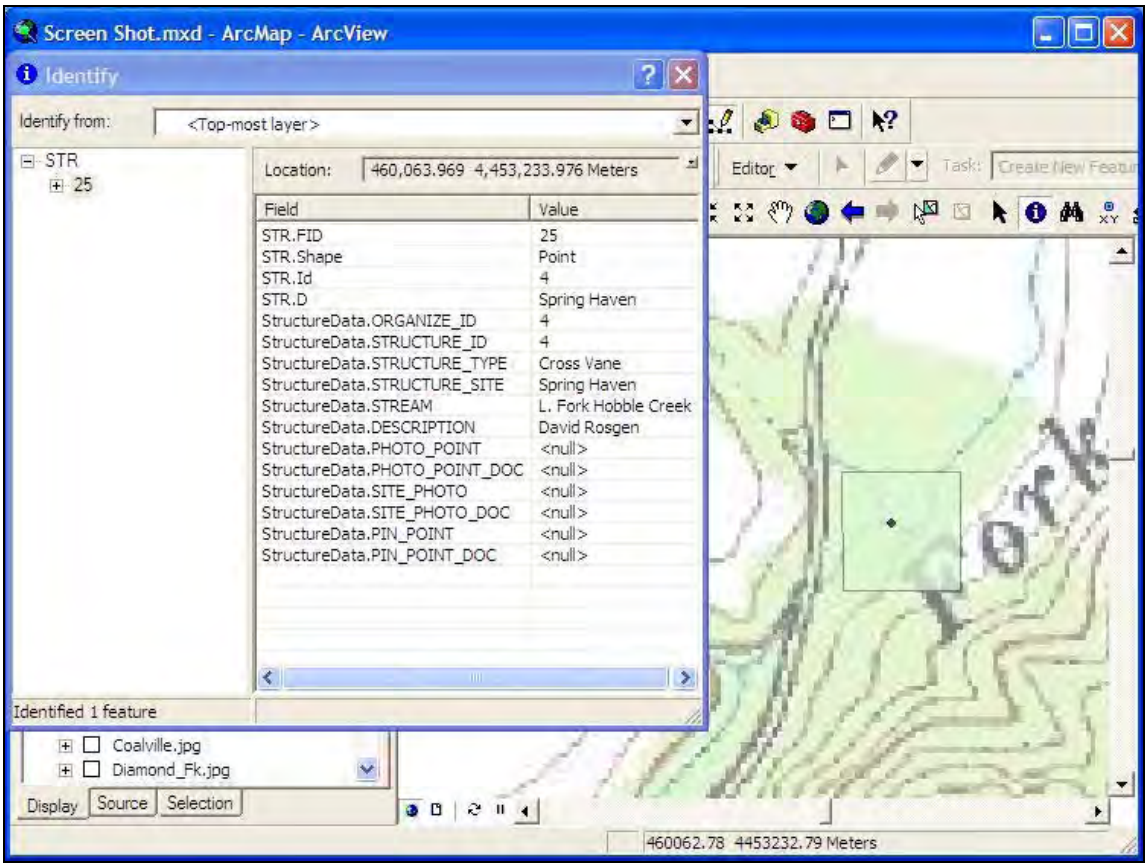

Figure A-9. Identify Dialogue Box Accessed by Using the Identify Tool for Structure 4.

7. Structure photo record ten is shown for study group structure 4 in Figure A-10.

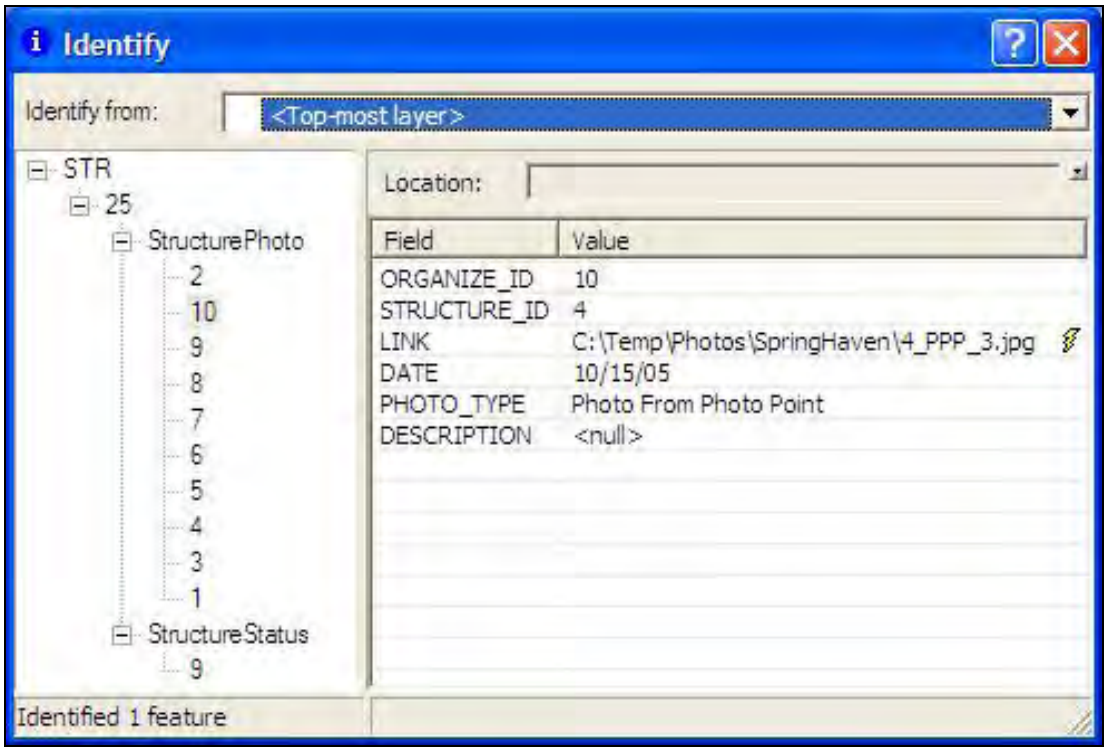

Figure A-10. Structure 4 – Structure Photo Record Ten.

A.5.3 Accessing Event-Driven Data in GIS

Event-driven data are stored in the "Photo" and "Status" tables in Access. The "Photo" and "Status" tables are related to the site and structure features in GIS. The data that change overtime can be visualized in the ArcMap environment. To access event-driven data for the Spring Haven structure, structure number four, follow steps 1, 2, 3, 6, and 7 above to come to the Identify dialogue box shown above. Entries from both the StructurePhoto and StructureStatus tables for structure number four are displayed on the left side of the Identify dialog box. When the record is selected, the record details are shown on the right side of the dialogue box (See Figure A-11).

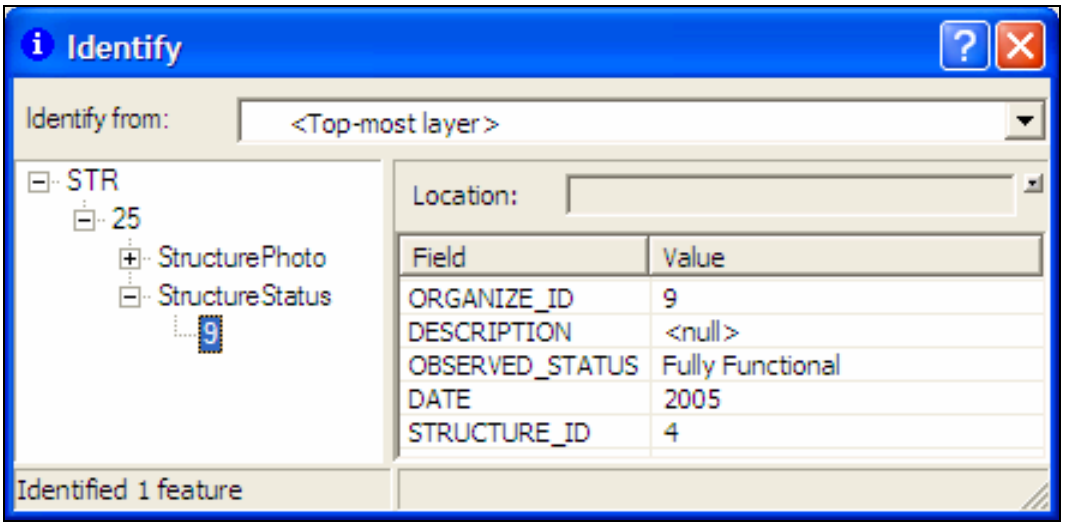

Figure A-11. Structure 4 Status Data Displayed in the Identify Dialogue Box.

A.5.4 Using Attribute Tables to Access Event-Driven Data

The user can select one or more sites or structures or both and view the available photos that are related to the features. An example of viewing the available site data for the site Thistle Creek follows:

1. Ensure that the SITE layer and thistle.jpg layer is turned on in the table of contents and use the Zoom to Layer command to zoom to thistle.jpg (see Figure A-12).

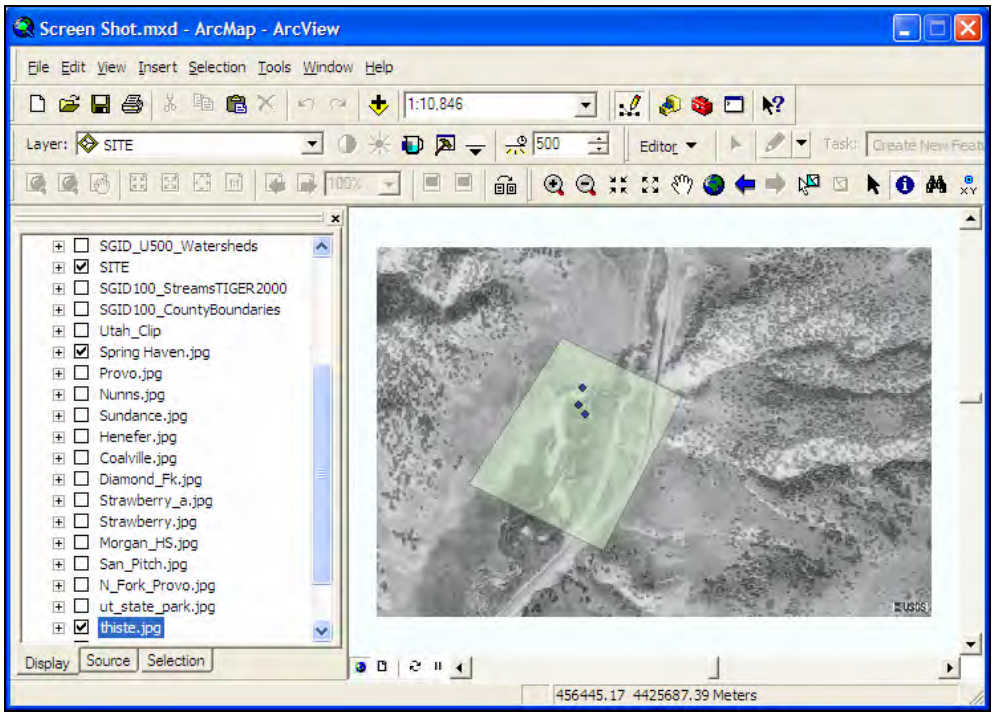

Figure A-12. Thistle Creek Site Polygon and Structure Features.

4. One the menu click Selection | Set Selectable layers and turn on the SITE layer and turn off all the other layers. Click close (see Figure A-13).

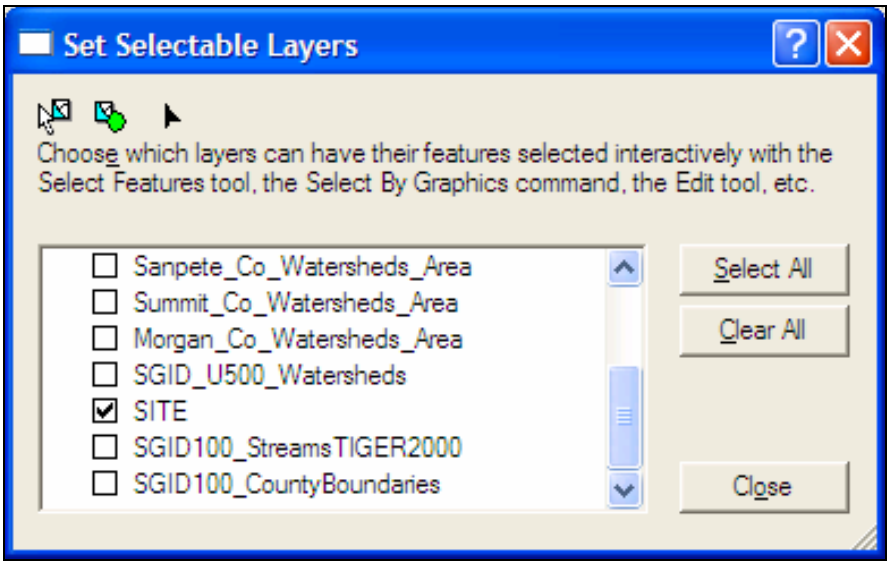

Figure A-13. Set Selectable Layers Dialogue Box.

5. Click on the Select Feature tool in the Tools tool bar (see Figure A-14).

Figure A-14. Select Elements on the Tools Toolbar.

6. Click anywhere on the site polygon (see Figure A-15).

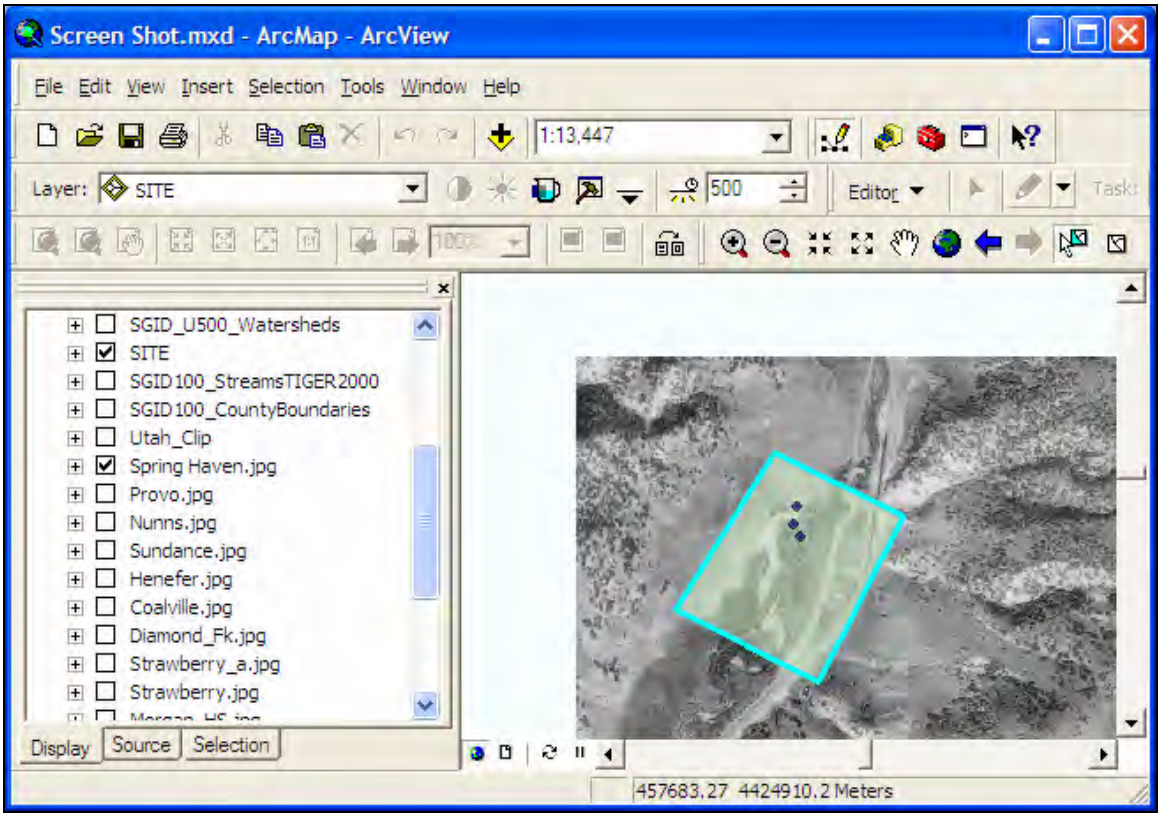

Figure A-15. Selected Site Polygon for Thistle Creek.

7. Right Click on SITE layer and open the attribute table (see Figure A-16).

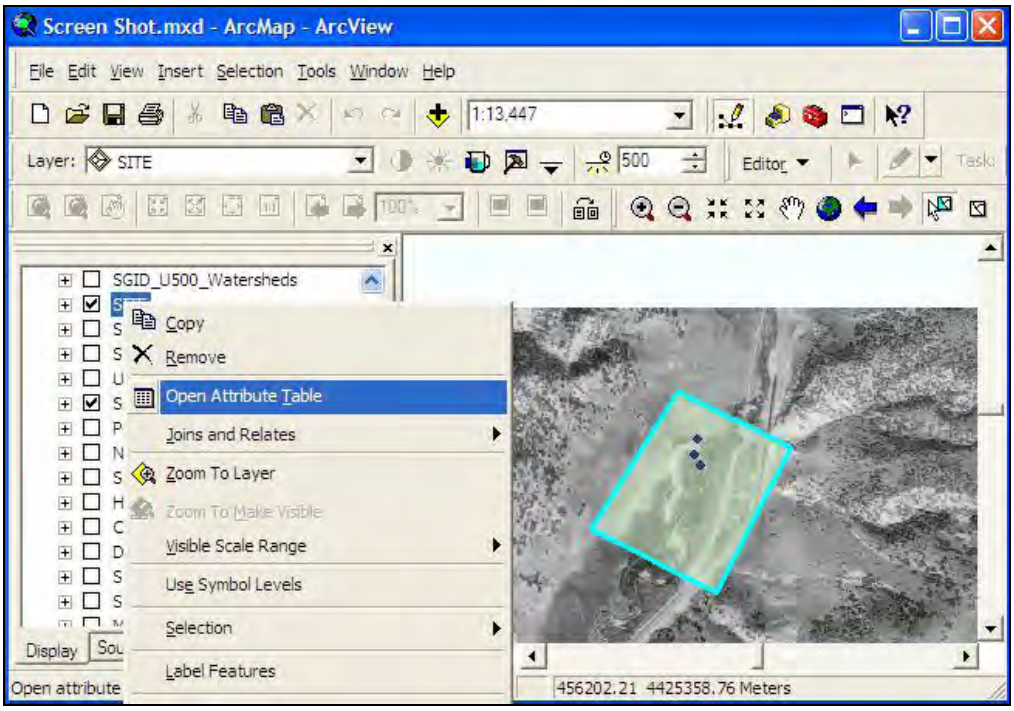

Figure A-16. Opening the STR Feature Attribute Table.

8. Click the "Selected" button and then click Options | Related Tables | SITE to SitePhoto : SitePhoto (Figure A-17).

Figure A-17. Opening Event Driven Data Tables.

9. Click the Selected button and browse the Access table data in GIS (see Figure A-18).

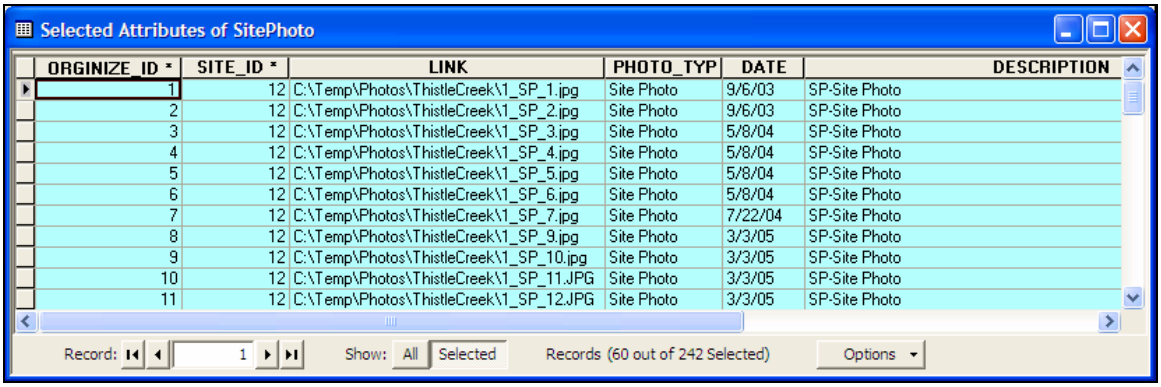

Figure A-18. Selected Records Containing Site Photo Event Driven Data.

This exercise was an example of retrieving event-driven data via spatial data. The process is easily reversed by clicking on the SITE layer and viewing the attribute table, selecting one or more records, and then panning the view in ArcMap to see where the sites are located. The same procedures can be followed to view Access data related to sites via the SITES layer and the associated attribute table.

Often event-driven data are photos. To access Thistle Creek site photos:

1. Select the Thistle Creek site with the Identify tool (see Figure A-19).

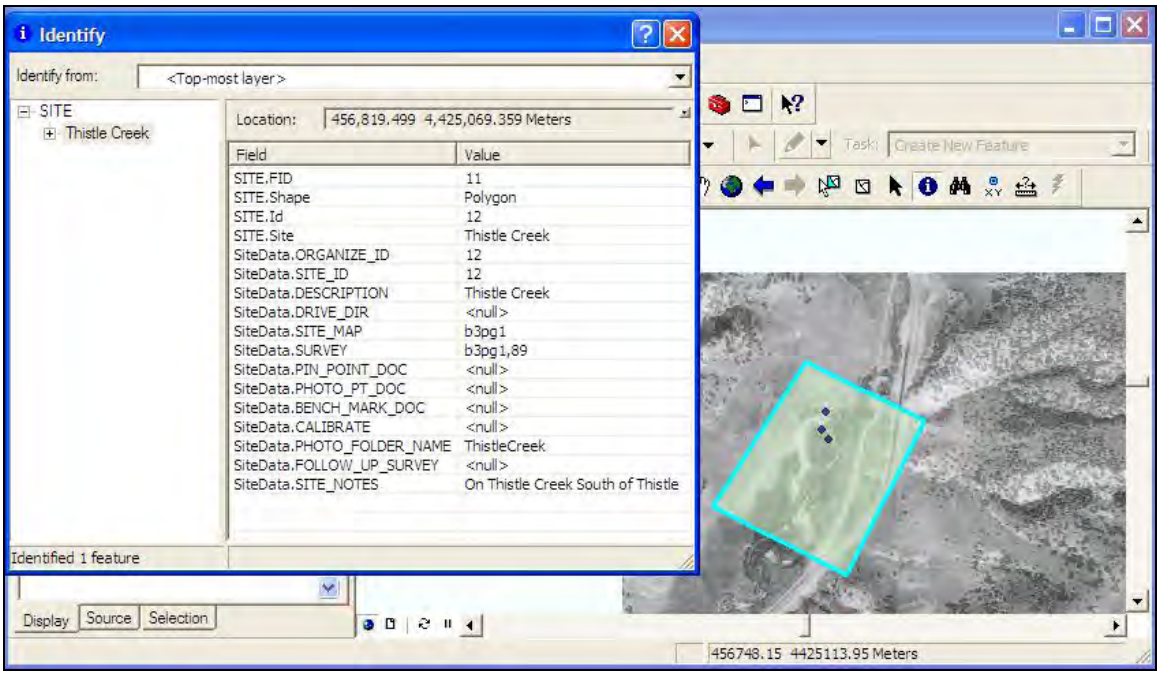

Figure A-19. Identify Dialogue Box for the Thistle Creek Site.

2. In the Identify dialogue box, expand the box next to Thistle Creek and SitePhoto in the data tree on the left side of the dialogue box. Click on any SitePhoto record number listed; the information box on the right displays associated data including available hyperlinks.

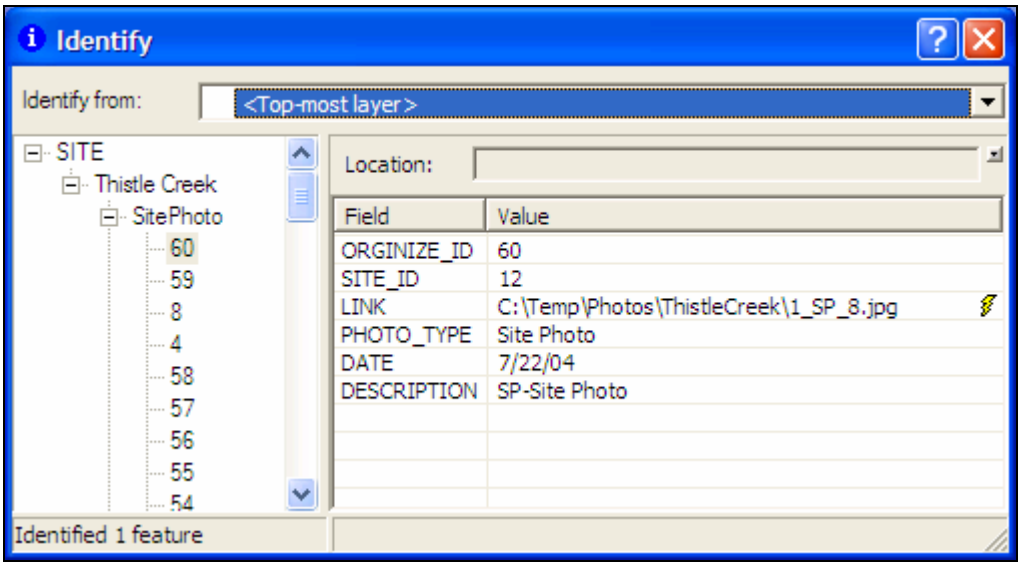

Figure A-20. Site Photo Record 60 Data Field Values.

5. To view more than one photo at a time, launch Paint by clicking on the edit button on the Windows Viewer tool bar for each photo intended to view and then toggle back and forth to compare.

The same method is used to view data associated with structure feature points by selecting a structure feature point rather than selecting a site polygon.

A.6 Adding a New Structure to the Database

When adding a new structure to the database one needs to edit both ArcMap and Access.

A.6.1 Adding New Structures to Access

When adding a new structure to Access, three tables must be edited. These tables are listed in the A.3 Access Records section of this Appendix. The tables are listed under those associated with structures. The tables are StructureData, StructureStatus, and

StructurePhoto. Each structure added is entered as a new record and all fields are filled out with available information. The description for each column is given in the design view of each table.

A.6.2 Adding New Structures to ArcMap

A structure is added to the STR layer by editing the layer:

1. Click the Edit button on the Edit toolbar and click Start Editing (see Figure A-21).

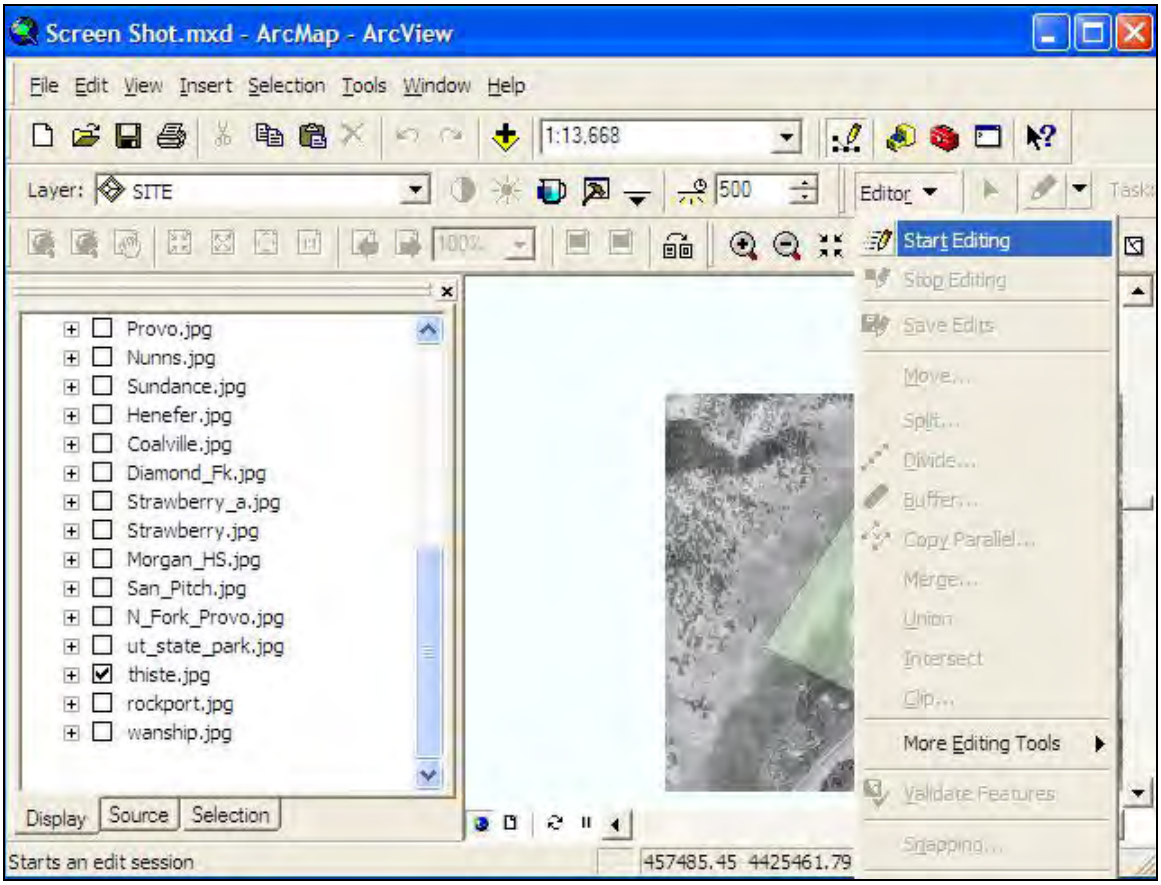

Figure A-21. Start Edit Command for the STR Layer.

2. Second, select the correct location for the STR layer in the Start Editing dialogue box. Select paths until the layer STR appears in the Start Editing dialogue box then click OK (see Figure A-22).

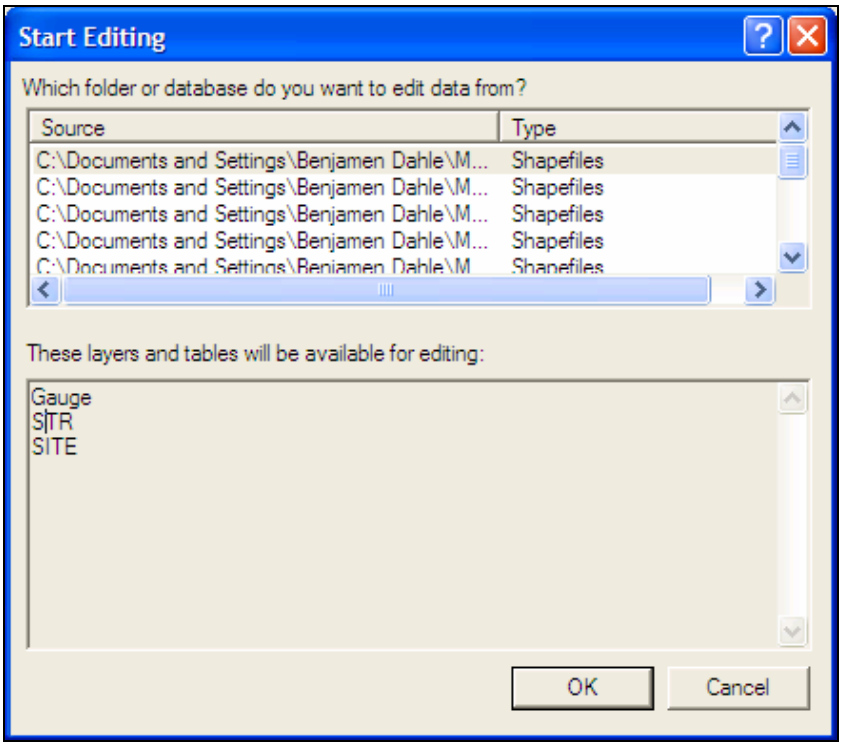

Figure A-22. Start Editing Dialogue Box.

3. Third, set the target to STR and set the Task to Create New Feature on the Editing Toolbar (see Figure A-23).

Figure A-23. Editing Toolbar.

4. Fourth, select the dropdown menu and select the Sketch Tool on the palette (see Figure A-24).

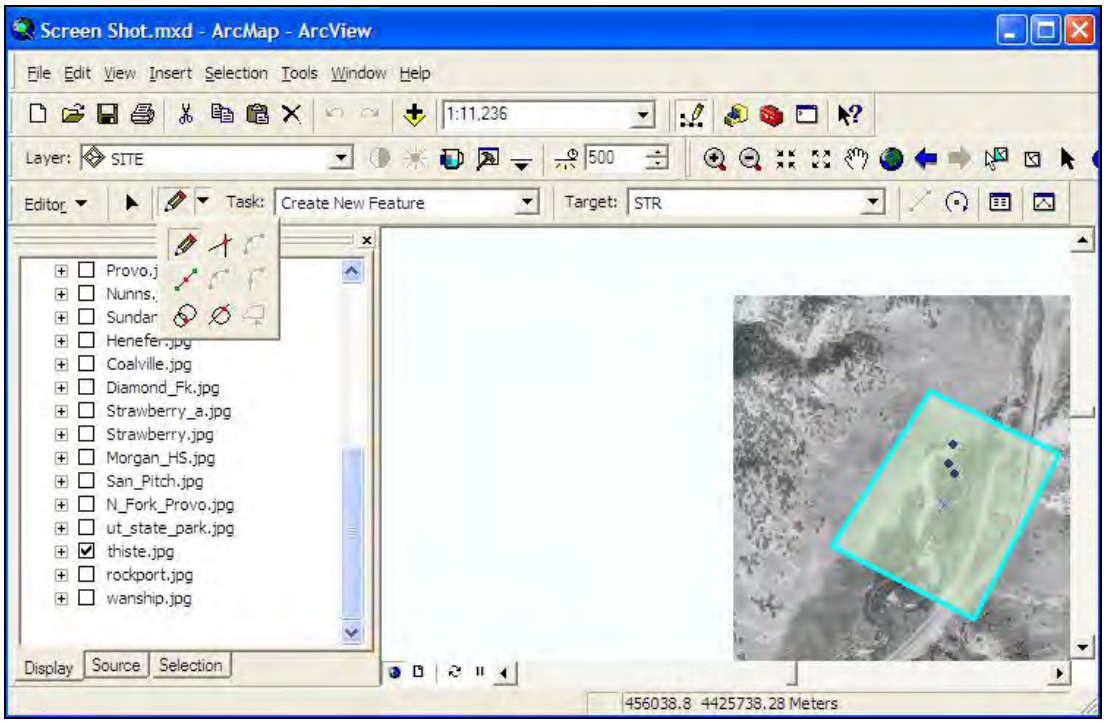

Figure A-24. Sketch Tool Drop Down Menu on the Editing Toolbar.

5. Fifth, click off to the side of the map to create a point feature (see Figure A-25).

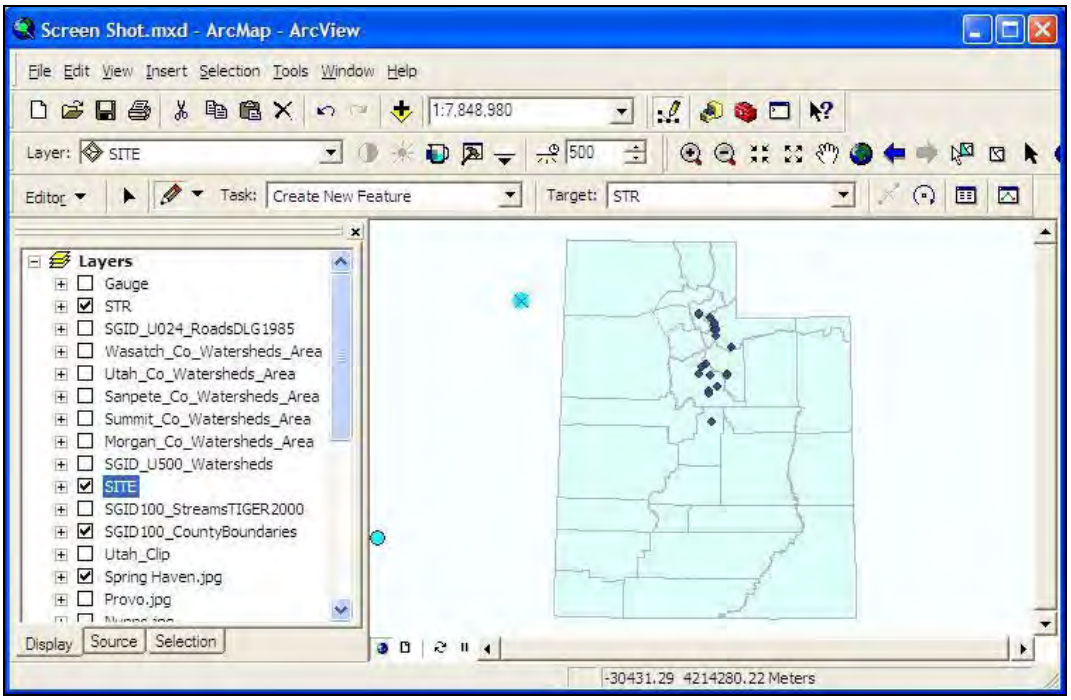

Figure A-25. Creating a New Point Feature on the STR Layer.

6. Sixth, select Modify Tasks | Reshape Feature (see Figure A-26).

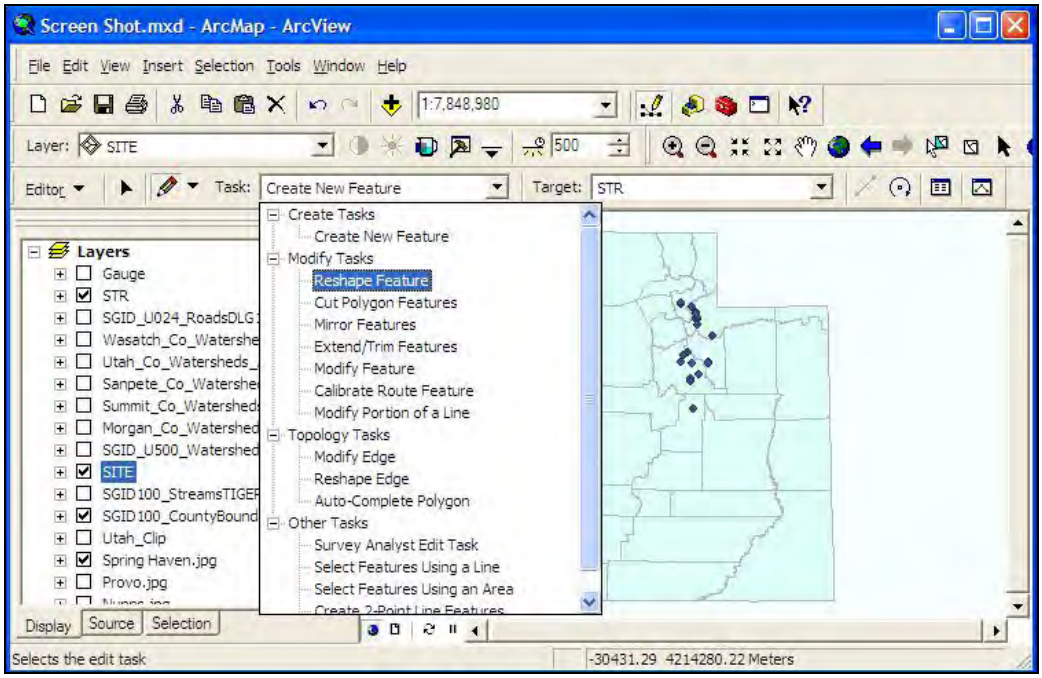

Figure A-26. Selecting the Reshape Feature Task.

7. Seventh, set the task to Modify Feature and click the Edit Tool button.

Figure A-27. Edit Tool on the Edit Toolbar.

8. Next, single click on the new point, right click and select the Move To command (see Figure A-28).

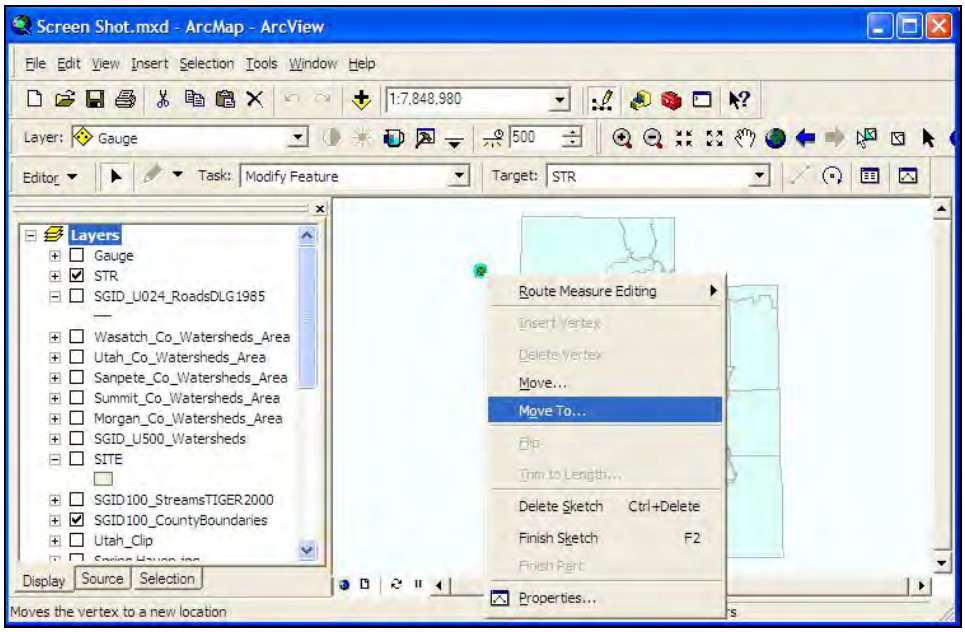

Figure A-28. Move To Command.

9. Last, edit the grid data (see Figure A-29) based on GPS data taken at the structure (coordinates in NAD 83 Utm Zone 12N).

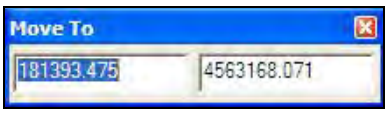

Figure A-29. Move to Dialogue Box.

After the point has been added, open the attribute table for STR and edit it. Sort the Id column, in the Attributes of STR dialogue box, to order the structures starting with the number one and scroll down the structures list (Id) to find the number that comes next sequentially. This number is the new structure's Id number and must match the STRUCTURE_ID in the Access tables (see Table A-1 on page 94). Also, enter the site name in the D field. Close the table and on the Editor toolbar Select Editor | Stop Editing and, when prompted, select Save Edits to save your work.

If the GPS coordinates are not readily available and the user knows where the structure is relative to river features (and can be identified from a site map), the user can estimate the location first from a topographic/overhead image raster and then edit the location of the structure with GPS coordinates later. First, download a topographic map and import it using the Define Projection command (see Ormsby et al. 2004) and move the point manually to the approximate location of the structure's location.

Follow these steps to download a topo map from TerraServer:

1. Browse to teraserver.homeadvisor.msn.com.
2. Zoom to applicable layer.
3. Click on Download.
4. Right click on image and choose Save Picture As.
5. Name and save picture (*.jpg).
6. Click on world file.
7. Click File | Save As then save the file name exactly as the file name in step 5, but add the letter w to the file extension (*.jpgw).

8. In ArcMap use the Define Projection command to add the layer to ArcMap. The coordinate system is in NAD 83.

If the new structure in the database is also at a new site then the user must add a new site to the database. This requires adding the new site to Access as well as ArcMap. The same procedures are used as described for adding a point feature, but the Access tables SiteData, SitePhoto, and SiteStatus are modified. In ArcMap, a new polygon is created (instead of a point feature) in the SITE layer by using the Arc Tool rather than the Sketch Tool in the Edit toolbar.