DEVELOPMENT
OF
MADISON BLUE SPRING-BASED MFL

TECHNICAL REPORT

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
DEPARTMENT OF WATER RESOURCES REPORT WR 03/04-05
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CERTIFICATION

I certify that all Engineering work performed for the "Development of Madison Blue Spring-Based MFL Technical Report" prepared for the Suwannee River Water Management District Department Of Water Resources Report WR 03/04-05 was prepared under my direct supervision.

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LIST OF ACRONYMS

Acronym	Definition
~	Approximately
BRA	Biological Research Associates
cfs	Cubic feet per second
cm	Centimeter
DO	Dissolved Oxygen
DRASTIC	Depth Recharge Aquifer Soil Topography Impact Conductivity
EPT	Ephemeroptera, Plecoptera, and Trichoptera
F.A.C.	Florida Administrative Code
F.A.S.	Floridan Aquifer System
F.S.	Florida Statutes
FAS	Floridan Aquifer System
FCREPA	Florida Committee on Rare and Endangered Plants and Animals
FDC	Flow Duration Curve
FDC	Flow Duration Curve
FDEP	Florida Department Environment of Protection
FDEP	Florida Department of Environmental Protection
FDNR	Florida Department of Natural Resources
FGFWFC	Florida Game and Fresh Water Fish Commission
FNAI	Florida Natural Areas Inventory
ft	Feet
HEC	Hydrologic Engineering Centers
IAS	Intermediate Aquifer System
K_{sd}	The square root of the semivariance, or uncertainty, between data points in a kriged map. Units are in standard deviations.
MBS	Madison Blue Spring
MFL	Minimum Flow and Levels
mgd	Million gallon per day
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
RAS	River Analysis System
SAS	Surficial Aquifer System
SAV	Submerged Aquatic Vegetation
Spp.	species
SRWMD	Suwannee River Water Management District
SWFWMD	South West Florida Water Management District
USACOE	US Army Corps of Engineers
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency

1.0 INTRODUCTION

1.1 Statutory Requirements for Establishing MFLs

The Suwannee River Water Management District (SRWMD) is required by Florida Statutes to establish Minimum Flows and Levels (MFLs) as defined by Chapter 373.042 F.S (Appendix A, Exhibit 1). For each identified priority water body, the SRWMD will develop a definition of significant harm to provide protection to the water resources and water resource related ecology. The SRWMD will utilize the best available information, in accordance with 373.042 F.S., to provide the basis for information to be provided to the SRWMD Governing Board in the determination of significant harm and the related MFL.

The determination of the MFL will vary for each priority water body depending on a combination of scientific, legal, social, and economic issues as determined by the SRWMD Governing Board. Further, the Florida Department of Environmental Protection has adopted Chapter 62-40.473 F.A.C., Minimum Flows and Levels that provide ten defined areas of ecological and resource values to address when evaluating the potential for significant harm to the priority water body.

The Florida Legislature has provided an opportunity for water management districts to implement a scientific peer review process to assist in the development of MFLs. Peer review provides an opportunity for the water management districts and stakeholders to be afforded independent review of District data and science used to develop the MFL s. The SRWMD has elected to implement a voluntary peer review process, in accordance with 373.042 (4) (a) & (b) F.S.(Appendix "A": Exhibit 2).

<u>Madison Blue Spring MFL</u>

Madison Blue Spring (MBS) is a first magnitude spring located in eastern Madison County, Florida. First magnitude springs have a median annual discharge in excess of 100 cubic feet per second (cfs) or 64.6 million gallons per day (mgd). Because of the quantities of water discharged from first magnitude springs, they are important resources to Florida. One aspect of their significance stems from the fact that they are typically locations of great beauty and recreational value. They also support important plant and animal communities in the springs, spring runs, and stream systems that they supply. Finally, they make up much of the base flow

of Florida's streams and rivers, including a number of streams that have been designated Outstanding Florida Waters. In recent years, springs have been threatened by ground-water use and contamination, especially with nutrients. As a result, the State of Florida has mandated that minimum flows and levels (MFL) be established for each first magnitude spring in the state (Chapter 373.042 (2) Florida Statutes). The SRWMD has, therefore, developed the MFL for MBS.

1.2 MFL Implementation

Upon completion of an MFL rule adoption, the SRWMD will employ its regulatory program to implement the MFL into the SRWMD water use permitting program under Chapters 40B-2 and 40B-8 and the Environmental Resource Permitting Program, Chapter 40B-4. The regulatory program will ensure that withdrawals are managed so that flows and levels will not be reduced to a point that would cause significant harm as determined by the Governing Board.

Each adopted MFL will also be reviewed periodically to ensure that the established MFL is effective in preventing significant harm as determined by the Governing Board.

1.3 Goal for Madison Blue Springs MFL Establishment

Adopt and implement an effective MFL that will prevent significant harm, as defined by the SRWMD Governing Board, to Madison Blue Spring and its related ecological and resource values.

1.4 Objectives for Madison Blue Spring MFL Establishment

1. Utilize "best available information" to provide a basis for the MFL analyses;
2. Utilize recognized and accepted methods and practices in the analyses of best available information;
3. Receive input from interested parties in the determination of the MFL;
4. Provide clear and understandable results, conclusions and recommendations for MFL adoption; and
5. Provide an MFL that can be effectively implemented by the SRWMD.

1.5 Public Participation in the MFL Establishment Process

The SRWMD has implemented a public participation process for the establishment of an MFL for MBS. The process provides for two public participation workshops where invited participants and others are presented with information relative to the MFL establishment process for MBS. The first of two public workshops was held in Lee, Florida on October 28, 2003. The meeting minutes and comments made by participants are provided in Appendix A, Exhibit 3. The second public workshop was held on July 27, 2004. SRWMD staff and consultants responded to participant questions. Information provided by the participants has been considered in the MFL development process.

2.0 OVERVIEW OF BASIN

2.1 Introduction

Madison Blue Spring (MBS) is a first magnitude spring located in eastern Madison County, Florida (Figure 2-1). First magnitude springs have annual average discharges in excess of 100 cubic feet per second (cfs) or 64.6 million gallons per day (mgd) (Meinzer, 1927). In 2003, the State of Florida adopted a new definition for first magnitude spring status, which is a median discharge in excess of 100 cfs or 64.6 mgd (Copeland, 2003). According to Scott et al. (2002), MBS discharge has ranged from 72 to 141 cfs. Unpublished data supplied by the SRWMD indicate a range in discharge from 52 to 224 cfs. See Copeland (2003) for a discussion of spring classification and also for definitions of other terminology utilized in this report.

MBS consists of a single vent located on the eastern border of Madison County adjacent to the Withlacoochee River (Figure 2-1). The spring is located at 30° 28' 48" north latitude and 83° 14' 40" west longitude (Hornsby and Ceryak, 1998) or SW¼, SE¼, SW¼, section 17, Township 1 North, Range 11 East (Scott et al., 2003).

2.2 Geology and Geomorphology

2.2.1 Geology

The drainage basins of MBS and the Withlacoochee River are characterized by a sequence of Tertiary aged sedimentary deposits (Table 2-1). Figure 2-2 illustrates the strata that either crop out or are present in the shallow subsurface in the study area.

The oldest strata in the Floridan Aquifer System (FAS), the Eocene Avon Park and Oldsmar Formations, are of little concern for the purposes of this report. They do not crop out in the area and do not represent the majority of the flow system related to MBS.

The relevant strata in the study area include the Ocala Limestone, Suwannee Limestone, Torreya Formation, Statenville Formation, Miccosukee Formation, and undifferentiated surficial sand deposits. The following discussion of these strata is excerpted from Scott et al. (1991). Figure 2-2 is a geologic map showing the locations of

Table 2-1

Lithostratigraphic and Hydrostratigraphic Columns for the Study Area

Modified from Ad Hoc Committee on Hydrostratigraphic Unit Definition (1986) and Scott (1988)

System	Series	Lithostratigraphic Unit		Hydrostratigraphic Unit
		Panhandle	North Florida	
Quaternary	Holocene	Undifferentiated Pleistocene-Holocene Sediments Miccosukee Formation		Surficial Aquifer System
	Pleistocene			
Tertiary	Pliocene			
	Miocene		Statenville Fm./ Coosawhatchie Fm.	Intermediate Aquifer System or Confining Unit
		Torreya Fm.	Markshead Fm.	
			Penney Farms Fm.	
	Oligocene	Suwannee Limestone		Floridan Aquifer System
	Eocene	Ocala Limestone		
		Avon Park Formation		
		Oldsmar Formation		
	Paleocene	Cedar Keys Formation		
Cretaceous and Older		Undifferentiated		Sub-Floridan Confining Unit

near-surface occurrences of these formations. Additional litho- and hydrostratigraphic data for the study area are available in Ceryak et al. (1983) and Hoenstine et al. (1990).

Ocala Limestone (To; Figure 2-2) - The Eocene Ocala Limestone is subdivided into lower and upper units based on distinct lithologic differences. The lower subdivision consists of granular limestone. The lower facies is not present everywhere and may be partially to completely dolomitized in some regions (Miller, 1986). The upper unit is composed of variably muddy, granular limestone. Often this unit is very soft and friable. Chert is a common component of the upper portion of the Ocala Limestone.

The sediments of the Ocala Limestone form one of the most permeable zones within the FAS. The Ocala Limestone comprises much of the FAS in the central and western panhandle. The extensive development of secondary porosity by dissolution has greatly enhanced the permeability, especially in those areas where the confining beds are breached or absent.

The Ocala Limestone crops out in a small area near the confluence of the Suwannee and Withlacoochee Rivers (Figure 2-2). Elsewhere, it is found in the shallow subsurface.

Suwannee Limestone (Ts; Figure 2-2) - The Oligocene Suwannee Limestone consists primarily of variably vuggy and muddy limestone. The occurrence of a vuggy, porous dolostone is also recognized in the type area, the eastern to central panhandle and in southwest Florida. The dolostone often occurs interbedded between limestone beds.

The Suwannee Limestone is absent throughout a large area of the northern and central peninsula, probably due to erosion; though scattered outliers are present. Where present, Suwannee Limestone forms much of the upper portion of the FAS. See Miller (1986) for a map of the occurrence of the Suwannee Limestone in the Florida peninsula.

Within the study area, the Suwannee Limestone crops out along the major rivers (Figure 2-2). Bluffs and shoals of the Suwannee Limestone control thalweg locations and depths within the river systems.

Hawthorn Group – The Hawthorn Group (Scott, 1988) is primarily Miocene in age. In north Florida siliciclastic sediments, including clay and phosphatic sand, dominate it. Two Hawthorn Group formations are of importance in the study area.

The Hawthorn Group, ***Torreya Formation*** (Tht; Figure 2-2) sediments are Miocene in age. These strata occur in the eastern panhandle, where they are predominantly composed of

siliciclastic sediment with limited amounts of carbonate (Scott, 1988). In the study area, the basal Hawthorn sediments are fine-grained carbonates. Above these, clayey siliciclastic sediments form an effective intermediate confining unit. The carbonate sediments may locally be permeable enough to form the upper portion of the FAS. The Torreya has been mapped west of the Withlacoochee River (Figure 2-2; Scott, 1988).

The Torreya gives way to the Miocene ***Statenville Formation*** (Ths; Figure 2-2) east of the Withlacoochee River. The Statenville consists of carbonate and siliciclastic sediments. The Statenville characteristically has low permeabilities and it forms an effective aquitard.

For the purpose of this report, the Statenville has been lumped with the Torreya as the undifferentiated Hawthorn Group. Figure 2-3 illustrates the approximate thickness of the undifferentiated Hawthorn Group. Note that the Hawthorn Group is thickest to the northeast, north, and west where the Northern Highlands Physiographic Province (Section 2.2.2) is well developed. The areas where the Hawthorn is mapped to be less than 100 feet in thickness are characterized by discontinuous strata with many penetrations because of sinkhole activity and other forms of erosion.

Miccosukee Formation **(**Tmc; Figure 2-2) - The Plio-Pleistocene Miccosukee Formation consists of interbedded and cross-bedded clay, silt, sand and gravel of varying coarseness and admixtures. Limonite pebbles are common in the unit. The Miccosukee Formation occurs in the eastern panhandle from central Gadsden County on the west to eastern Madison County on the east. Due to its clayey nature, the Miccosukee Formation does not produce significant amounts of water. It is generally considered to be part of the surficial aquifer system (Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Undifferentiated Quaternary Sediments (Qu; Figure 2-2) – The uppermost and youngest stratigraphic unit mapped in the study area consists of undifferentiated sand and other sediments of Quaternary (Pleistocene to Recent) age. The sands were deposited during Pleistocene marine transgressions and regressions and consist of shallow marine, beach, and dune deposits. These sediments have been re-worked by fluvial and eolian processes.

These sand deposits are thick enough to be mapped within the vicinity of the Suwannee River (Figure 2-2). Elsewhere, they form a discontinuous, thin veneer over the strata shown in Figure 2-2.

2.2.2 Geomorphology

The study area straddles two major physiographic provinces: the Northern Highlands/Tallahassee Hills and the Gulf Coastal Lowlands (White, 1970). A karst escarpment known as the Cody Scarp (White, 1970) separates these two provinces. These landforms reflect the presence of marine terraces that formed as a result of Plio-Pleistocene marine transgressions and regressions. The River Valley Lowlands is a floodplain terrace that has developed along portions of the Withlacoochee and Suwannee Rivers. Figure 2-4 illustrates the physiographic provinces of the study area.

Northern Highlands (Tallahassee Hills) Province - The Northern Highlands lie north and east of the Withlacoochee and Suwannee Rivers in Hamilton and Madison Counties. The Tallahassee Hills portion of the Northern Highlands Province is west of the rivers in Madison County. Both areas consist of a moderately dissected plateau that is underlain by a thick sequence of relatively impermeable Miocene Hawthorn Group sediments as well as undifferentiated Plio-Pleistocene sediments. Elevations in the Northern Highlands range from 100 to over 250 feet NGVD.

The Northern Highlands include many lakes, swamps and streams. Because of the low permeability sediments that underlie the plateau, streams, such as the Suwannee and Withlacoochee rivers, carry surface water off the Highlands.

Gulf Coastal Lowlands Province - Thin Plio-Pleistocene sediments overlying thin and discontinuous, residual Miocene strata and Eocene to Oligocene limestone characterize the Gulf Coastal Lowlands. Because of the thin cover over limestone, karst features are numerous in the Lowlands. Elevation ranges from about 50 to 80 feet above sea level. The plain is devoid of local stream channels, but it is dotted with sinks. While limestone is near the surface in this region, many of the old sinks have become filled (some to a depth of 250 feet) with sand, clayey sand, and sandy clay. These soil materials result from marine submergence, soil creep and slumping, and stream transport from the Northern Highlands as the Cody Scarp retreated. This sinkhole fill tends to mask many of the karst irregularities of the limestone surface.

Cody Scarp (Escarpment) - The Cody Scarp (White, 1970), which separates the Northern Highlands from the Gulf Coastal Lowlands, is a region of active scarp retreat (Lawrence and Upchurch, 1982; Upchurch and Lawrence, 1984; Upchurch, 2002). The scarp area contains large sinkholes, sinking streams, and other large and well-developed karst features. The bottoms of the karst features often penetrate to limestone and the depressions are usually filled with organic soils, fluvial and lacustrine sediments, and clay-rich soils of Miccosukee and younger origin. The

hills within the scarp area contain intact and residual Miocene and Plio-Pleistocene sediments similar in texture and composition to the equivalent sediments of the Northern Highlands Province.

Many large, flat-bottomed lakes and wet prairies are associated with the scarp and represent coalescent sinkholes. Many of these level prairies and lakes, most of which are near or below 60 feet NGVD, are associated with ground water levels. Because of the sinking streams and large sinkholes, the Cody Scarp is thought to represent a major recharge area to the underlying aquifer.

Marine Terraces – As noted above, Plio-Pleistocene marine transgressions and regressions resulted in a veneer of sandy sediments that overlies much of the area. In addition, erosion and deposition during these marine transgressions and regressions caused the landforms discussed above to develop. The landforms reflect marine terraces that can be identified on the basis of elevation ranges. The terraces and approximate elevation ranges that have been mapped in the study area (Healy, 1975) are:

- Wicomico Marine Terrace (70 – 100 feet NGVD),
- Sunderland Marine Terrace (100 – 170 feet NGVD), and
- Coharie Marine Terrace (170 – 215 feet NGVD).

Figure 2-5 illustrates the locations of these terraces in the study area. The Wicomico terrace generally coincides with the Gulf coast Lowlands and the Sunderland and Coharie terraces with the Cody Scarp and Northern Highlands.

River Valley Lowlands - The Withlacoochee and Suwannee rivers are incised into the Suwannee Limestone in the study area, and floodplain development is somewhat limited. The River Valley Lowlands are mapped as a terrace where the floodplain is well developed. As shown in Figure 2-5, the River Valley Lowlands are limited in development on the west side of the Withlacoochee River. The River Valley Lowlands are well developed on the southeastern side of the Withlacoochee near the confluence with the Suwannee.

MBS is located within the River Valley Lowlands as part of the floodplain of the Withlacoochee River (Figure 2-4).

2.3 Hydrostratigraphy

The geologic strata discussed above constitute a system of aquifers and confining to semi-confining beds. Table 2-1 illustrates the association of the strata discussed in Section 2.2.1 to the comparable hydrostratigraphic units (Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

2.3.1 Surficial Aquifer System (SAS)

The SAS is the uppermost aquifer in portions of the study area. Because of its limited extent in the area, poor water quality, and low yield to wells, the SAS is only locally utilized for domestic water supplies. Where present, the SAS is contained within the undifferentiated Quaternary sediments and portions of the Miccosukee Formation.

This aquifer includes water-saturated sand deposits that overlie the Miccosukee Formation and Hawthorn Group in a few areas. According to nomenclature developed by the Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (1986), the SAS can only exist where confining beds separate the water-bearing sand deposits from the underlying FAS. As a result, the aquifer is of limited extent and can only be predicted to exist where the underlying confining strata are well developed, such as within the Northern Highlands.

2.3.2 Intermediate Aquifer System and Confining Unit (IAS)

The IAS includes portions of the Hawthorn Group and other, undifferentiated Miocene strata within the MBS ground-water basin. The Hawthorn and other strata include both permeable siliciclastic and carbonate horizons that may serve as minor, local aquifers. For the most part, the clay content of the Hawthorn limits water flow and, as a result, the IAS is a semi-confining unit that separates the SAS and FAS. Throughout most of the MBS ground-water basin, sinkholes (Figure 2-2) and zones where the Hawthorn and Miccosukee are either thin or have been eroded away reduce the ability of the IAS to confine the FAS and, as a result, recharge to the FAS is relatively effective. The exception is in the Northern Highlands to the north and west of the MBS ground-water basin where Hawthorn Group sediments serve as effective confining beds.

2.3.3 Floridan Aquifer System (FAS)

Aquifer Characteristics - The FAS is the primary source of water discharging from MBS. It is also the major source of base flow in the lower Withlacoochee River. This aquifer consists of limestone and dolostone ranging from the Eocene Avon Park Formation through the Oligocene Suwannee Limestone. Most of the flow system is within the Ocala Limestone and Suwannee Limestone, however.

The FAS is a doubly porous system. That is, water flows through two types of porosity. Most water flows through highly permeable, fractured and cavernous carbonate rocks. However, the limestone and dolostone also contain small pores that may or may not be interconnected. This porosity is intergranular and moldic, and, where the pores are interconnected, smaller amounts of water can be produced to wells.

The FAS is essentially unconfined in the Gulf Coastal Lowlands, River Valley Lowlands, and Cody Scarp areas (Figure 2-6). It is partially confined in areas where residual siliciclastic sediments overlie the aquifer in these areas and more-or-less confined under the Northern Highlands.

Recharge - Recharge to the FAS is difficult to quantify. Recharge or recharge potentials have been estimated on several occasions. Other studies have attempted to show the relative confinement of the FAS. Recharge potentials can be inferred from these studies as well.

Aucott (1988) estimated recharge for the FAS. Discharge in the Withlacoochee River corridor was estimated to be over 5 inches per year. Areas adjacent to the river, including the ground-water basin for MBS, were estimated to have over 10 inches of recharge per year. According to Aucott, this area of high recharge included the Northern Highlands near the Georgia state line.

Scott et al. (1991) published a confinement map for the FAS (Figure 2-6). In this map the FAS under the Northern Highlands is depicted as confined. The river corridors and adjacent areas were mapped as unconfined. The MBS is within an unconfined area, but confinement was depicted in the spring basin just west of the spring.

The recharge potential of the FAS was evaluated by the District (Suwannee River Water Management District, 1994) using a ranking system for use in a geographic information system context. High recharge was identified in eastern Madison and western Hamilton counties. Low recharge was identified in the Northern Highlands in eastern Hamilton and western Madison counties.

Grubbs (1998) prepared a map showing the degree of confinement in the District. The river corridors were mapped as unconfined, and the upland areas, including the location of the MBS ground-water basin, were depicted as poorly confined. Confined conditions were shown in Georgia, north of the study area.

In 1999, the Florida Department of Environmental Protection published DRASTIC maps of all Florida counties. These maps depicted estimates of aquifer vulnerability based on a scoring system that included Depth to the water table, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity of the aquifer (Aller et al., 1985). Figure 2-7 presents the DRASTIC map for the study area. This map shows that the river corridor is most vulnerable (DRASTIC score = 200-226). The MBS ground-water basin had a DRASTIC score of 100-139. The net recharge scores were nine for all polygons in the MBS ground-water basin, which indicates recharge in excess of 10 inches per year.

The SRWMD also prepared a recharge map based on the DRASTIC polygons. This map (Figure 2-8) illustrates relative recharge. The symbols H, MH, M, ML, and L indicate high, moderately high, moderate, moderately low, and low relative recharge, respectively. Note that the river corridor, which is typically a discharge area is classified as LM and the MBS ground-water basin is uniformly high.

The early recharge and confinement maps (Aucott, 1988; Scott et al., 1991) are not entirely consistent with the hydrostratigraphic framework of the study area, as discussed above. The most recent recharge and confinement maps (e.g., Grubbs, 1998;) are intuitively accurate, indicating low recharge or discharge in the river corridor, high recharge in the MBS ground-water basin, and low to moderate recharge in the Northern Highlands.

Water Levels – Collins and Freeman (1996) developed statistical summaries of well hydrographs for the SRWMD. As part of that study, hydrographs from 20 wells in Madison and Hamilton counties were summarized. The hydrographs reflected rapid responses to rainfall and water level recession rates typical of rapid recharge and a highly permeable aquifer.

The SRWMD and USGS have prepared a number of potentiometric maps of the FAS over the years. Several sample maps are discussed to demonstrate that the potentiometric surface has been relatively stable through time (Figures 2-9 through 2-11).

Johnston et al. (1980) present a “pre-development” potentiometric surface map for the Southeastern United States (Figure 2-9). This map shows a reentrant that extended upstream along the Withlacoochee and Suwannee rivers. There was a potentiometric high estimated to

exceed 80 feet NGVD located just southwest of Madison, Florida. The high extended as a ridge to the north and joined another high near Valdosta, Georgia. These potentiometric highs were located under confined or semi-confined areas, especially the Northern Highlands. The reentrant that followed the Withlacoochee extended to the west and was not drawn to be symmetrical to the river – presumably in response to discharge from MBS and other springs along the river.

Potentiometric surface maps based on the District's monitoring networks have been prepared periodically since 1976 (e.g., Fisk and Rosenau, 1977; Copeland, 1977, Oxford and Copeland, 1977; Meadows, 1991; Mahon et al., 1997; Figures 2-10 and 2-11). These maps illustrate a pattern that is similar to the one predicted by Johnston et al. (1980). The highs southwest of Madison and near the Georgia line are present, and potentials ranged from approximately 30 feet NGVD near the MBS to over 80-90 feet NGVD in the potentiometric high southwest of Madison.

2.4 Withlacoochee River Hydrology

The Withlacoochee River and its drainage systems dominate the geomorphology of the area surrounding MBS. The Withlacoochee River originates in south-central Georgia (LaForge et al., 1925) and then flows to the southeast and south into Florida. The river discharges into the Suwannee River at Ellaville.

Franklin et al. (1995) present a statistical summary of the data collected at the gauge on the Withlacoochee River near Pinetta (located about 10 miles upstream from MBS, near the Florida-Georgia border). For the period of record from October 1931 to 1993 the annual mean discharge was 1,718 cfs. The lowest annual mean and the lowest daily mean discharge were 236 cfs and 73 cfs, respectively. The instantaneous low flow was 70 cfs. The highest annual mean and highest daily mean discharge were 5,364 cfs and 73,600 cfs, respectively.

Giese and Franklin (1996a) analyzed low flows in the SRWMD. The magnitude and frequency of annual and monthly low flows was determined for the period of record from April 1932 to March 1994 for the gauge on the Withlacoochee River near Pinetta. Figure 2-12 shows the lowest average annual flows for various consecutive days between 1 and 30 at recurrence intervals ranging from 2 to 50 years. The curves all decrease sharply up to recurrence intervals of 10 years, where they tend to level off. So the greatest change in the magnitude of low flow events occurs at recurrence intervals up to 10 years, beyond this the relative difference in the magnitude of events is small. Figure 2-13 shows the lowest average flow by month for 1, 7, and 14

consecutive days at return intervals of 5 and 20 years. In general, the magnitude of low flows tends to be greatest during the period from February through April and lowest during the period from October through December.

Giese and Franklin (1996b) analyzed floods in the SRWMD. The discharge for the Withlacoochee River near Pinetta gauge for recurrence intervals ranging from 2 to 500 years was estimated using several methods. The best results were obtained from a combination of a log-Pearson Type II analysis and a regression equation of values derived from station analysis with basin parameters. Figure 2-14 shows the results of this analysis.

2.5 Karst Geology

As noted in Section 2.2.2, the Gulf Coastal Lowlands and Cody Scarp are characterized by karst topography (sinkholes, poljes, uvalas, sinking streams, etc.) and internal drainage. Figure 2-15 illustrates the surface-water drainage basins identified by Foose (1981) within the study area. Note that the basins near MBS that have been identified as part of the MBS ground-water basin bear the designation “karst”. These basins are not drained by surface water systems, and rainfall recharges the FAS through sinkhole systems within each basin.

Figure 2-16 depicts the topography of the study area. Large sinkholes (sinkholes, uvalas, poljes) are shaded and the many smaller sinks constitute many of the closed, circular contour lines on the map. Lakes near the western edge of the study area are also most likely karst-related. Most of the sinkholes are small and nearly circular in the Gulf Coastal Lowlands. They increase in size and abundance as the Cody Scarp is approached near the western, northern, and northeastern parts of the study area. The Northern Highlands areas are characterized by relatively few sinks. This change in the size and abundance of sinks is related to scarp retreat and erosional losses of cover sediments above the limestone (Upchurch, 2002).

Caves and solution-enlarged fractures are common in the FAS. A few can be identified by elongation of closed depressions on Figure 2-16. A cave system is associated with MBS (Hornsby and Ceryak, 1998). According to Upchurch (2002), the karst conduiting system develops primarily as a result of scarp retreat. Under the Highlands, karst conduits appear to be poorly developed, which further contributes to the FAS potentiometric highs under these confined or semi-confined areas. Near the inner edge of the scarp, where sinking streams originating in the Highlands maximize recharge, the majority of karst conduits appear to be near vertical. Within

the Gulf Coastal Lowlands and outer Cody Scarp, lateral, near-horizontal conduits have developed to transfer water from the recharge areas to discharge points, such as MBS.

2.6 Springs of the Withlacoochee River Corridor

MBS is the largest spring of over a dozen known springs on the Withlacoochee River (Figure 2-17). While MBS is the only known first magnitude spring, several named second magnitude springs are present either on the margin or a short distance from the river.

2.6.1 Madison Blue Spring

Description - MBS (Blue Spring) is located on the west side of the Withlacoochee River, just south of the SR 6 Bridge in Madison County. The spring consists of a pool approximately 70 feet in width and up to 35 feet in depth (Hornsby and Ceryak, 1998) (Photos 1 and 2). There is a small, rock sill at the head of the spring run to the river. At the time of this investigation, this rock sill had been partially breached, but the sill is often rebuilt by swimmers (David Hornsby, pers. communication, 2003).

Photo 1 - View of Spring Pool (Photo date 5/22/03)

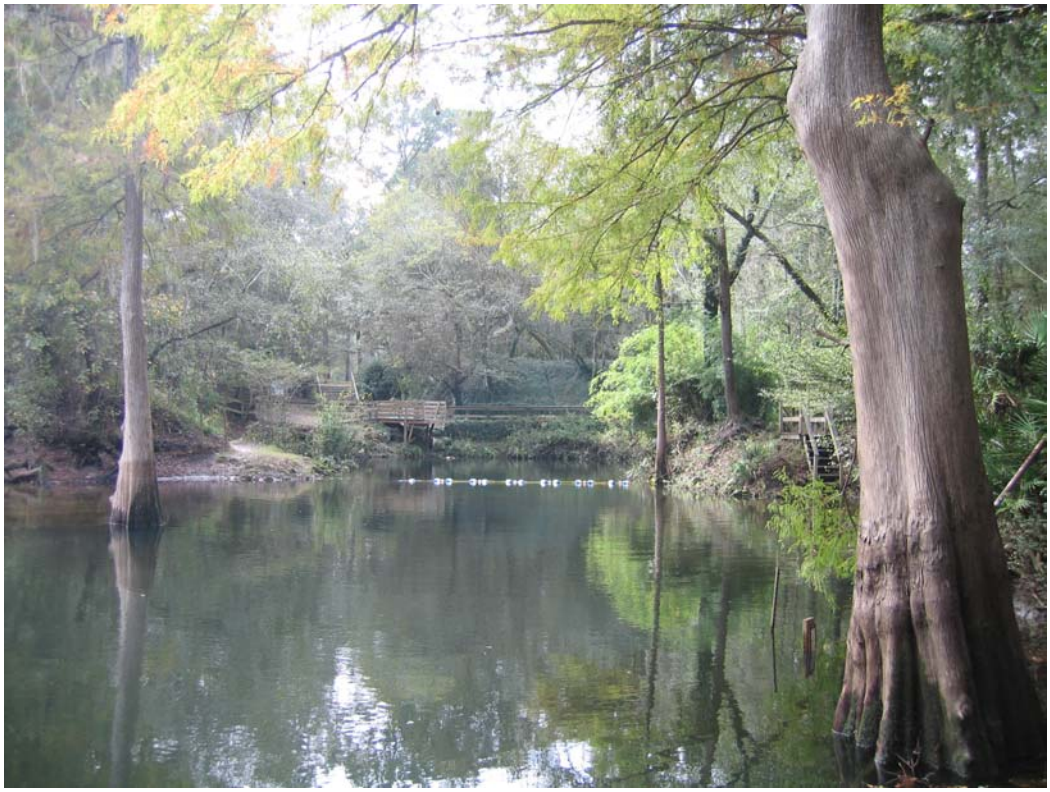


Photo 2 - View from Spring Run to Spring Pool (Photo date 11/6/03)

The spring run is approximately 150 feet in length (photos 3 and 4).

Photo 3 - View from Spring Pool to Spring Run (Photo date 11/6/03)

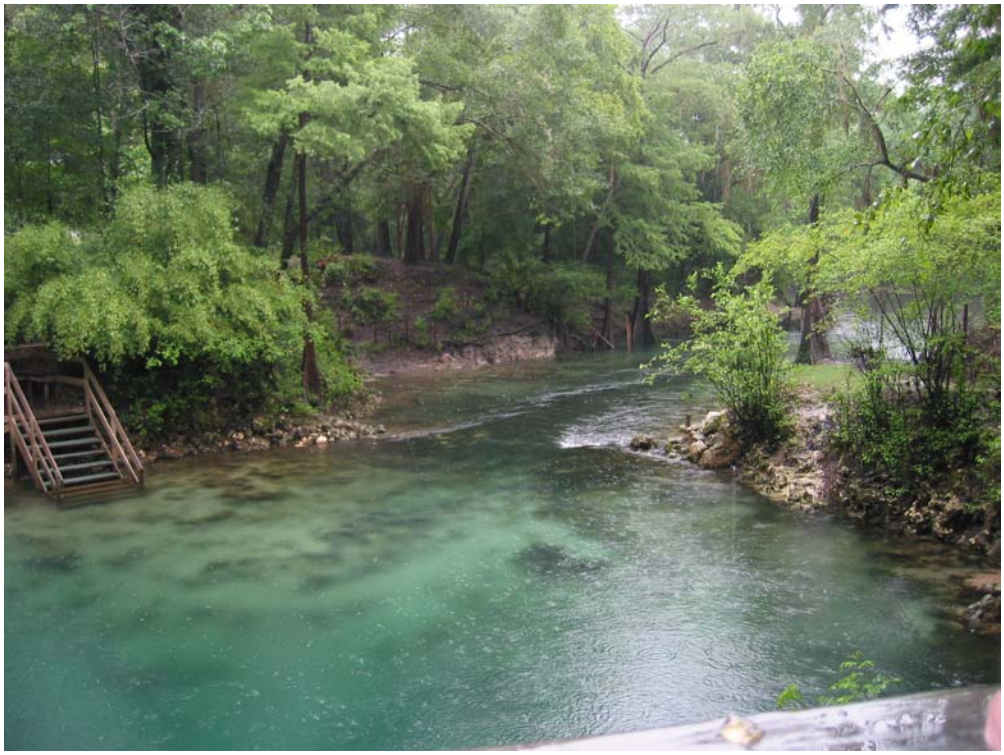


Photo 4 - View from Spring Pool to Spring Run (Photo date 5/22/03)

A significant displacement and then mixing zone can be observed in the river where the clear spring water enters the tannic-colored river (Photo 5).

Photo 5 - View of MBS discharge into Withlacoochee River (Photo date 5/22/03)

The spring is served by a phreatic cavern system that trends to the west and southwest from the throat of the spring. The cavern is reported to have a conduit system that continues to the east and southeast under the river (Peter Butt, 2003, pers. communication). In May, 2004, a qualitative dye trace was used to determine the discharge point(s) of the water that underflows the river through this conduit. Fluorescein dye was introduced into the conduit and within 24 hours water at Pot Spring (see Section 2.6.2) was stained by the dye (Butt, 2004, pers. communication). Pot Springs is approximately one mile southeast of MBS (Figure 17), so the apparent travel time was about a mile per 24-hours. Based on current knowledge of the conduit system under MBS, setting of a MFL for MBS will preserve flow in Pot Spring as well.

MBS is an estevelle, so discharge is controlled in part by the stage of the adjacent Withlacoochee River. When river stage is less than the head on the spring, the MBS discharges to the river. During periods of higher river stage, however, discharge is reduced by the counter-pressure of the river. At times, discharge even reverses and the river discharges to the spring causing intrusion of colored, river water partway into the FAS near the spring.

The spring and surrounding lands are owned by the State of Florida and the spring is operated as a State Recreational Area at the present time. A bottled-water facility is permitted to withdraw water from wells completed in the spring conduit system.

Monitoring – The spring has been monitored for many years on an ad hoc basis. The SRWMD has recently undertaken a systematic monitoring program as part of the Florida Springs Initiative (Florida Springs Task Force, 2000). The monitoring plan (Upchurch et al., 2001) calls for long-term monitoring of discharge and stage from the spring coupled with systematic monitoring of ground-water levels and quality in the MBS ground-water basin and biological monitoring in the spring system. This systematic monitoring has begun with the establishment of monitoring sites within the ground-water basin and installation of a gauge to measure discharge at the spring. The data utilized for establishment of the MFL were generated as part of this monitoring program and are summarized in the discussions of MFL development. The summaries that follow reflect the historic monitoring that has been previously published or obtained by SRWMD.

Three studies have summarized historic conditions at MBS. These include Rosenau et al. (1977), Hornsby and Ceryak (1998), and Scott et al. (2002). The following summary was drawn from these references.

Discharge from the spring has been measured 22 times since 1932 (Table 2-2). The majority of these measurements were obtained within the last decade, however. The discharge measurements have historically ranged from a low of 51 cfs (June 18, 2002) to a high of 224 cfs (June 30, 2003). Historic discharge was less than 100 cfs 46 percent of the time it was measured (10 of 22 measurement events).

Date	Madison Blue Springs Discharge (cfs)
03/16/32	75
07/23/32	145
04/24/56	78
11/15/60	141
05/28/63	113
05/18/77	164
07/26/95	107
11/28/95	87
05/11/98	187
05/18/98	197
05/25/98	160
06/01/98	161
06/15/98	141
10/23/01	71
02/27/02	57
04/18/02	95
05/24/02	62
06/18/02	51
08/06/02	53
10/28/02	65
01/23/03	140
06/30/03	224

Table 2-2. Historic discharge measurements for Madison Blue Spring. Measurements preformed primarily by the USGS (T. Mirti, pers. comm., SRWMD).

Ground-Water Basin Delineation – A preliminary delineation of the MBS ground-water basin was developed using geostatistical methods (Upchurch et al., 2004). Figure 2-18 depicts the approximate extent of the ground-water basin (springshed) based on September 2003 potentiometric surface data. Note that the distal portions of the basin were not characterized owing to a lack of synoptic data. The approximate areal extent of the basin is estimated to be about 100 square miles.

The drainage basin size can be confirmed qualitatively by comparing recharge and discharge of the spring system (Davis and DeWiest, 1966). Assuming that the drainage basin is 100 mi.^{2}

and long-term average discharge of MBS is 100 cfs or more, average annual recharge can be calculated to be approximately 10 inches, which is consistent with recharge estimates discussed in Section 2.3.3.

2.6.2 Other Springs

Morgan Spring – Morgan Spring (Morgan's Spring) is a second magnitude spring located on the Withlacoochee River in Hamilton County downstream from MBS. Morgan Spring is located on private property. The spring pool is approximately 90 feet wide and maximum depth was reported as approximately 80 feet (Hornsby and Ceryak, 1998). The spring discharges through a 250-foot run to the river. The cavern system feeding the cave has been mapped, and the mapped conduits trend to the north and west (Hornsby and Ceryak, 1998).

Morgan Spring is located in the NW¼, NW¼, NE¼, sec. 10, Township 1 South, Range 11 East (Rosenau et al., 1977), or 30° 25' 11" North Latitude and 83° 12' 25" West Longitude (Hornsby and Ceryak, 1998). While it was mentioned in Rosenau et al. (1977), the only known discharge measurement for Morgan Spring was 17.59 cfs on June 10, 1998 (Hornsby and Ceryak, 1998).

Pot Spring – Pot Spring is a second magnitude spring located at 30° 28' 14" North Latitude and 83° 14' 04" West Longitude (Hornsby and Ceryak, 1998). It is located on the east bank of the Withlacoochee River and is surrounded by SRWMD land. According to Hornsby and Ceryak (1998), the spring bowl is approximately 30 feet in width and has a depth of about 16 feet. The only available discharge measurement (Hornsby and Ceryak, 1998) is 38.19 cfs on June 15, 1998. This spring is apparently an estevelle.

The dye trace discussed in Section 2.6.1 indicated that Pot Spring discharges a significant portion of the water from the MBS conduit system that underflows MBS and the river. The dye trace results were characterized as reflecting a significant pulse at Pot Spring (Butt, 2004, pers. communication). The water was clearly discolored as a result of the dye indicating little dilution and dispersion.

Tanner Spring – Tanner Spring (HAM612981; Hornsby and Ceryak, 1998) is located in Hamilton County at 30° 27' 52" North Latitude and 83° 13' 03" West Longitude (Hornsby and Ceryak, 1998). The spring is surrounded by private property and apparently has three vents within the spring bowl. The bowl is approximately 45 feet in width and 24 feet in depth. There is

a 50-foot spring run to the river. Water is tannic colored and turbid, which suggests a surface-water source. Hornsby and Ceryak (1998) measured discharge at 92.5 cfs on June 12, 1998, making it a second magnitude spring. This spring is an estevelle.

Suwanacoochee Spring – Suwanacoochee Spring is located in on the west bank of the Withlacoochee River near its confluence with the Suwannee River. It is located in Madison County, at 30° 23' 22" North Latitude and 83° 10' 18" West Longitude (Hornsby and Ceryak, 1998) or SW¼, SW¼, NE¼, sec. 24, Township 1 South, Range 11 East (Rosenau et al., 1977). The spring is part of a Madison County park.

The spring pool is approximately 30 feet wide, and the run was modified by a concrete structure to impound water and create a swimming area in the 1900s (Hornsby and Ceryak, 1998). This spring is an estevelle (Rosenau et al., 1977).

Discharge measurements are difficult to obtain according to Rosenau et al. (1977) owing to uneven bottom and swift currents. Four measurements are reported from this second magnitude spring. They range from a low of 18.3 cfs (November 6, 1931; Rosenau et al., 1977) to a high of 51.6 cfs on October 24, 1997 (Hornsby and Ceryak, 1998).

Other Springs – Hornsby and Ceryak (1998) have identified a number of other second and third magnitude springs. All appear to be estevelles.

2.6.3 Relative Contributions of the Springs to River Flow

The discharge measurements by Hornsby and Ceryak (1998) provide a basis for evaluating the importance of MBS to flow in the Withlacoochee River. With the exception of the discharge measurement at Suwanacoochee Spring, the discharges were determined within a few days of each other (Table 2-2). If one assumes that these measurements are synoptic and that the proportions of discharge are relatively constant regardless of river stage, aquifer potentials, or rainfall, the importance of MBS becomes apparent.

MBS is the largest spring on the Withlacoochee River in terms of discharge. It represents an estimated 23.7 percent of the total measured spring discharge to the river. The Withlacoochee River downstream of the gage at Pinetta gains water primarily through spring discharge. The amount of gain from springs can be determined by comparing discharge at the gage at Lee with Pinetta discharge. The average gain is 579 cfs within this reach, though this does not represent the total supplied by spring discharge as several of the springs lie downstream from the Lee gauge. Assuming that this gain represents the majority of discharge to the river below the

Pinetta gauge and that the discharge values recorded in Table 2-2 are near average conditions (the average discharge of MBS is very close to 120 cfs), these fourteen springs contribute the majority of the gain in the river.

Even with the uncertainties associated with the above estimate, it is clear that MBS is a dominant source of water contributions to the river below Pinetta.

Table 2-3
Discharge and Proportion of Total Measured Discharge of Springs on the Withlacoochee River
(From Hornsby and Ceryak, 1998)

No.	Spring Name	County	Spring Magnitude	Date of Discharge Measurement	Discharge (cfs, Hornsby & Ceryak, 1998)	Percent of Total Measured Spring Discharge
1	Madison Blue	Madison	1	6/15/98	120	23.7
2	HAM612981 (Tanner)	Hamilton	2	6/12/98	92.5	18.3
3	HAM610981	Hamilton	2	6/10/98	40	7.9
4	MAD610982	Madison	2	6/10/98	40	7.9
5	Pot	Hamilton	2	6/15/98	38.19	7.6
6	Suwanacoochee	Madison	2	9/24/97	35.46	7.0
7	HAM610982	Hamilton	2	6/10/98	30	5.9
8	HAM610983	Hamilton	2	6/10/98	30	5.9
9	HAM610984	Hamilton	2	6/10/98	20	4.0
10	Morgan	Hamilton	2	6/10/98	17.59	3.5
11	MAD612981	Madison	2	6/12/98	15	3.0
12	MAD612982	Madison	2	6/12/98	15	3.0
13	HAM612982	Hamilton	3	6/12/98	6.01	1.2
14	MAD610981	Madison	3	6/10/98	5.84	1.2
				Total Measured Spring Discharge	505.6	

2.7 Land Use

Land use within the MBS ground-water basin is predominantly agricultural. Two towns, Madison and Lee, lie near the margins of the basin. Both have public water supply systems.

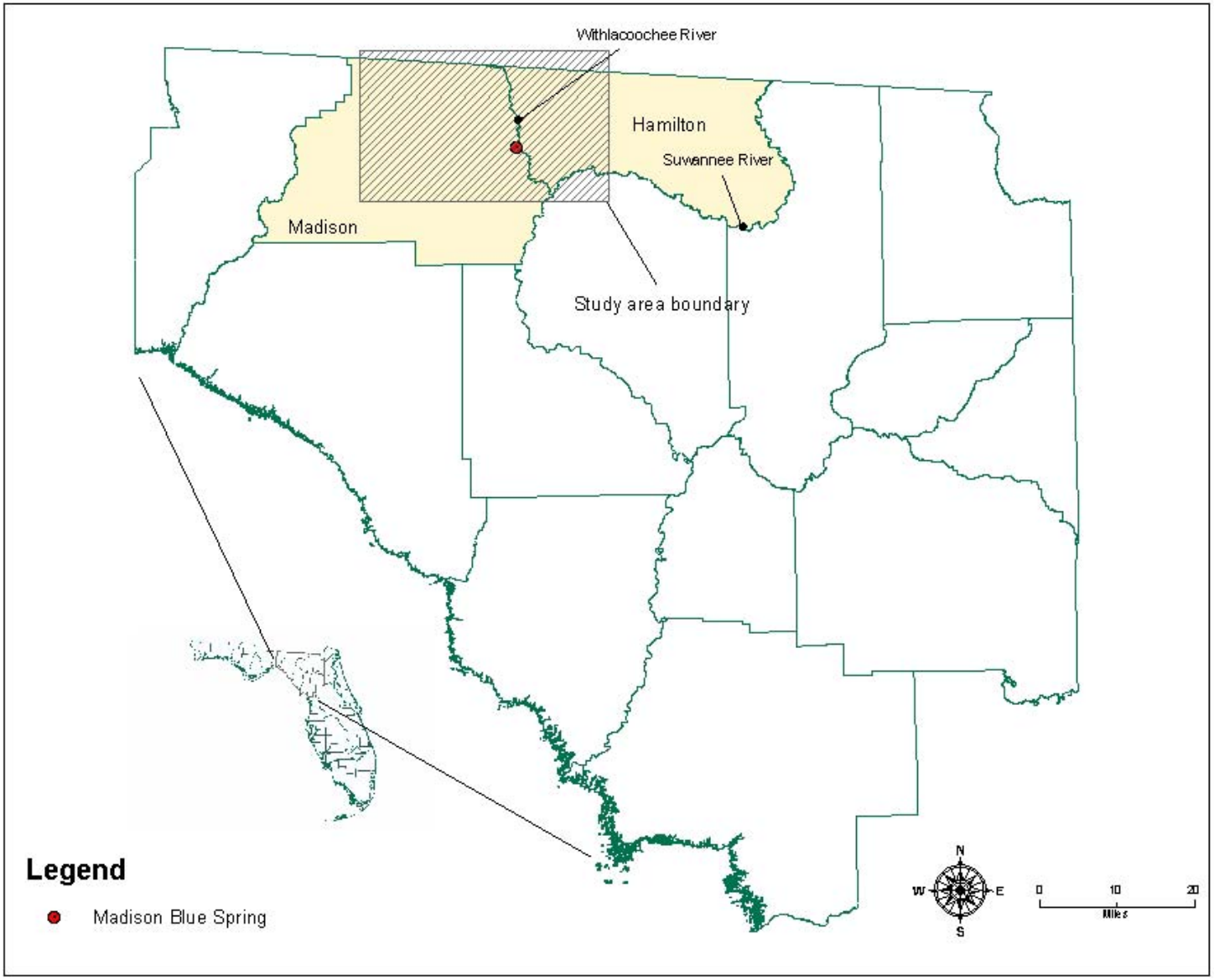


Figure 2-1. Location of Madison Blue Spring study area in the Suwannee River Water Management District.

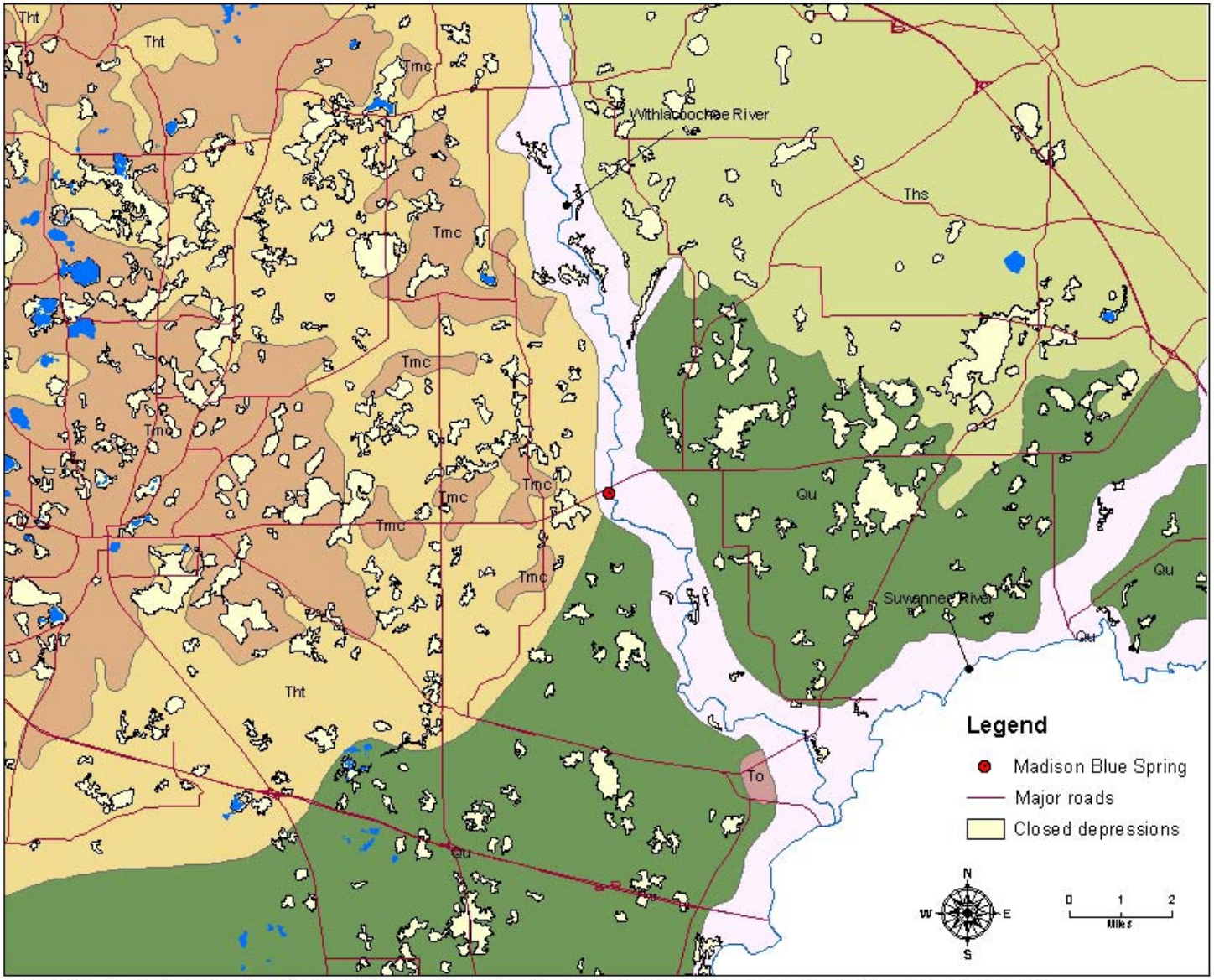


Figure 2-2. Geologic map of the Madison Blue Spring study area showing some of the larger closed depressions in the region.

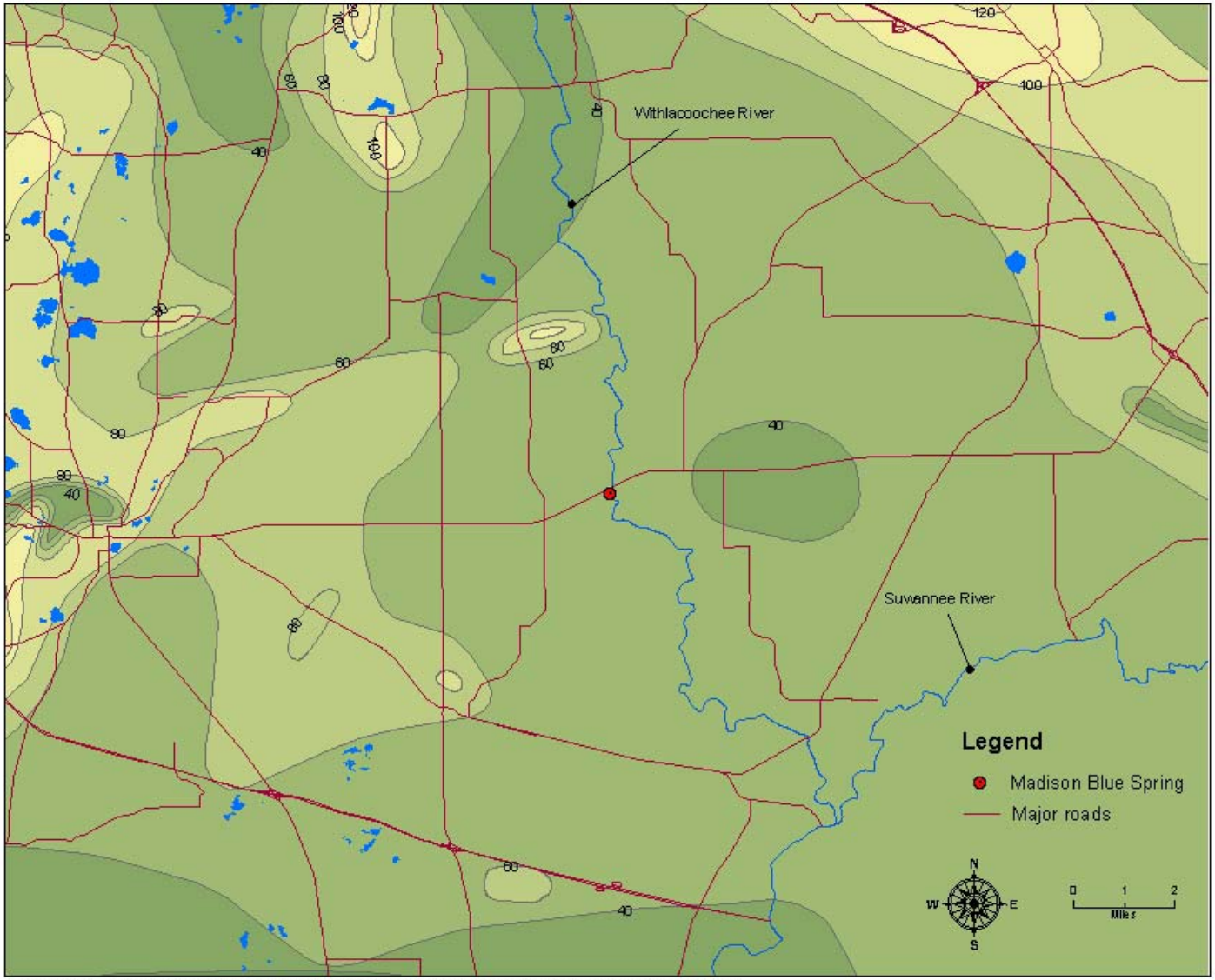


Figure 2-3. Isopach map of the Hawthorn Group in the Madison Blue Spring study area.

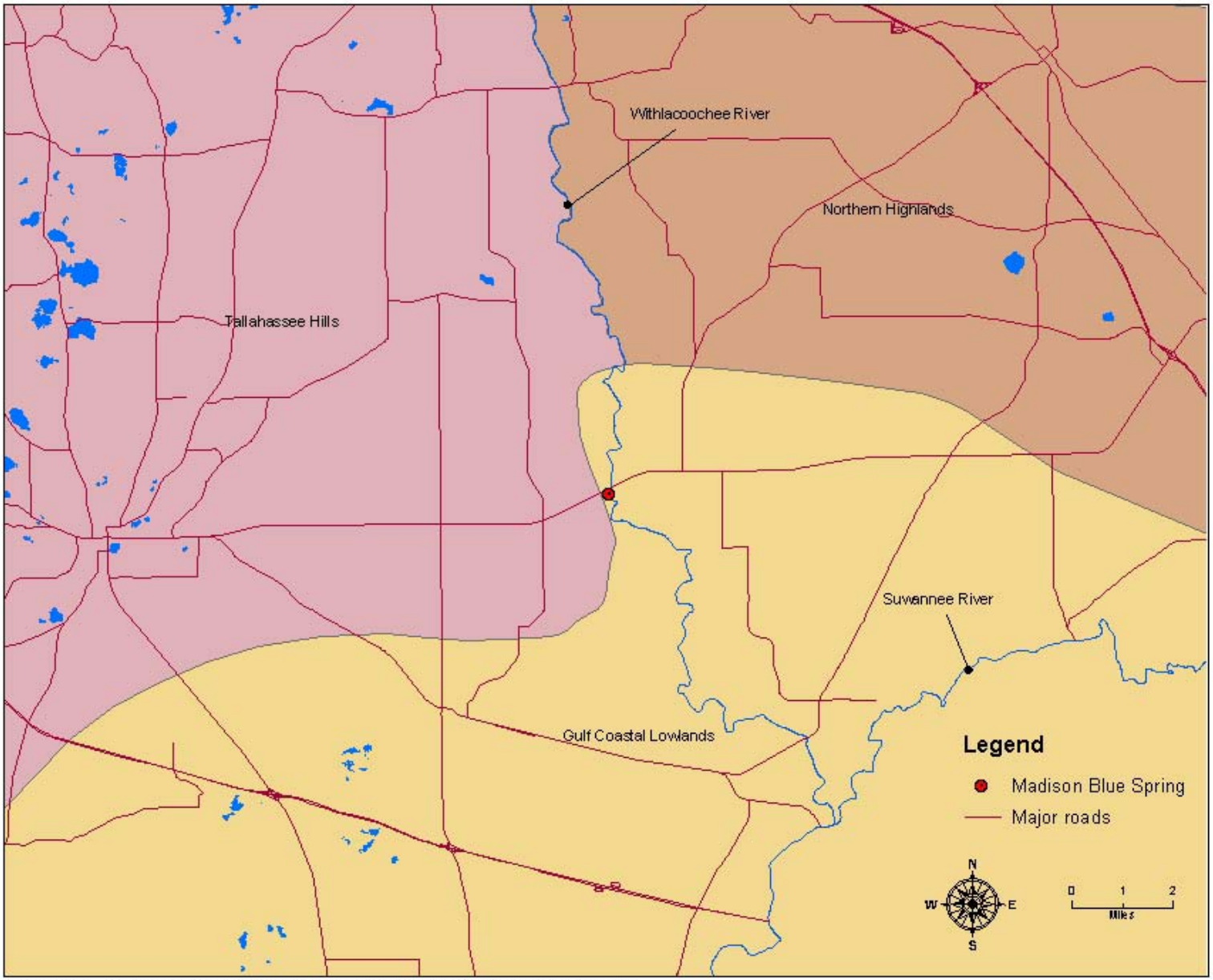


Figure 2-4. Physiographic provinces in the Madison Blue Spring study area.

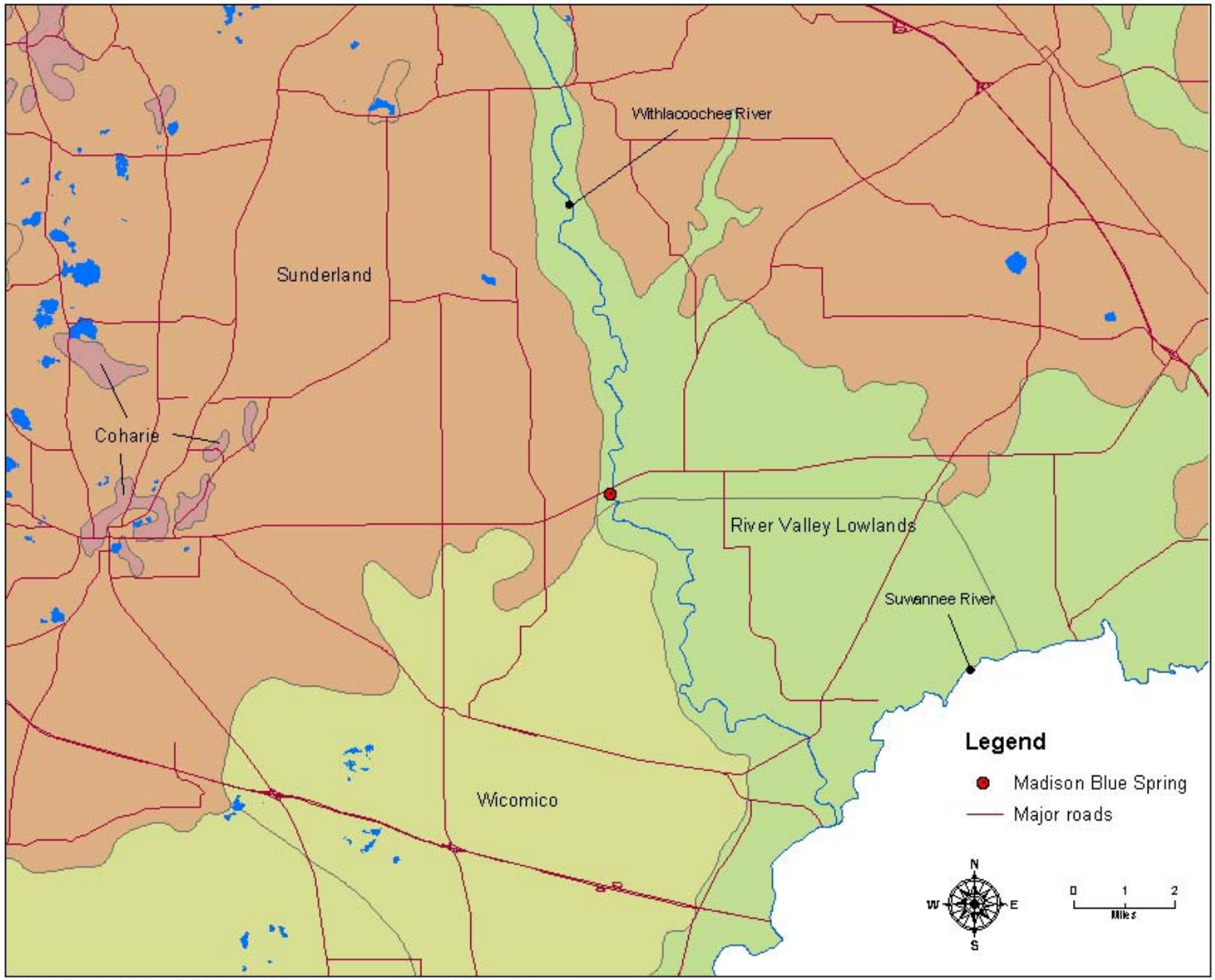


Figure 2-5. Marine terraces in the Madison Blue Spring study area.

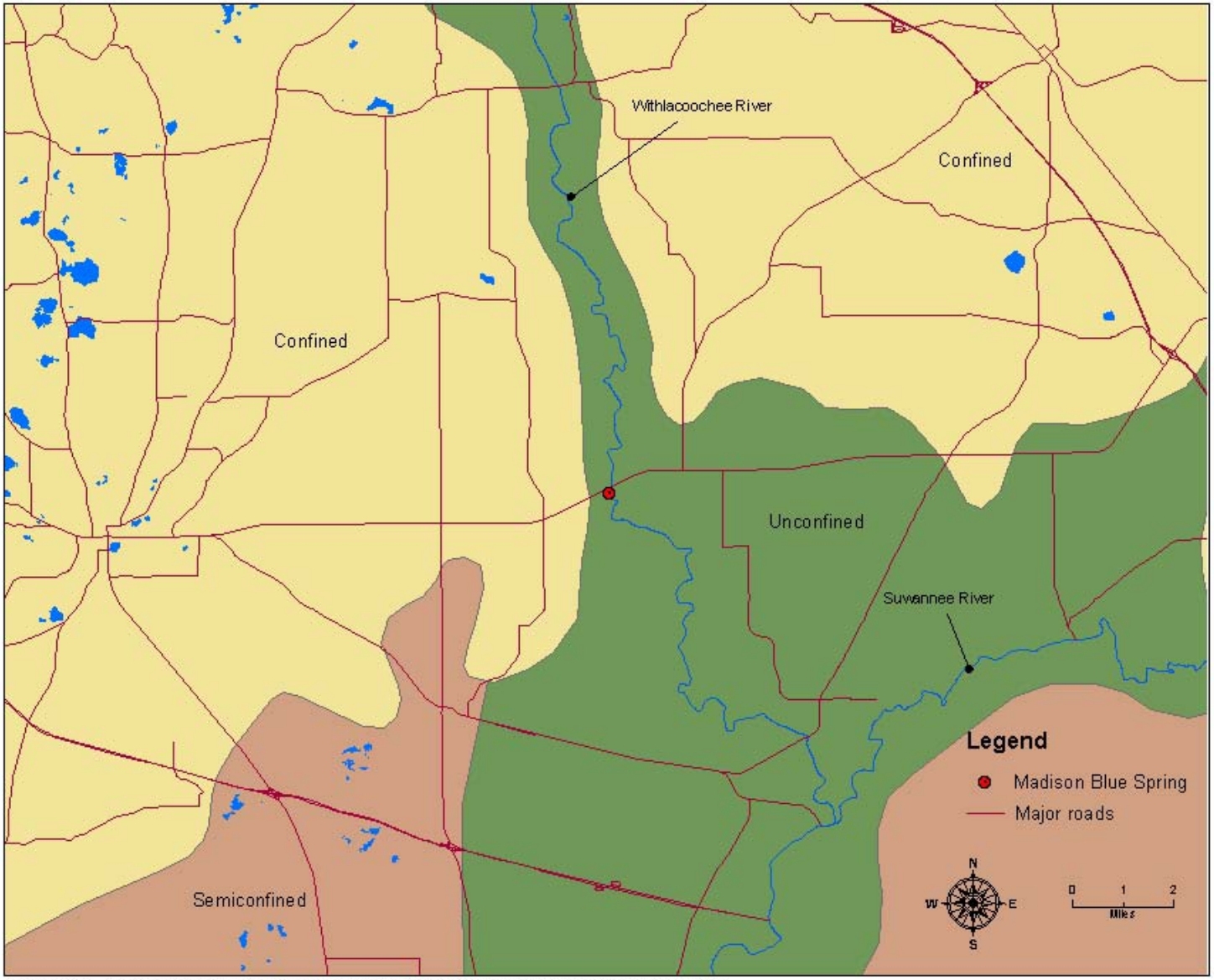


Figure 2-6. Confinement of the Floridan aquifer in the Madison Blue Spring study area.

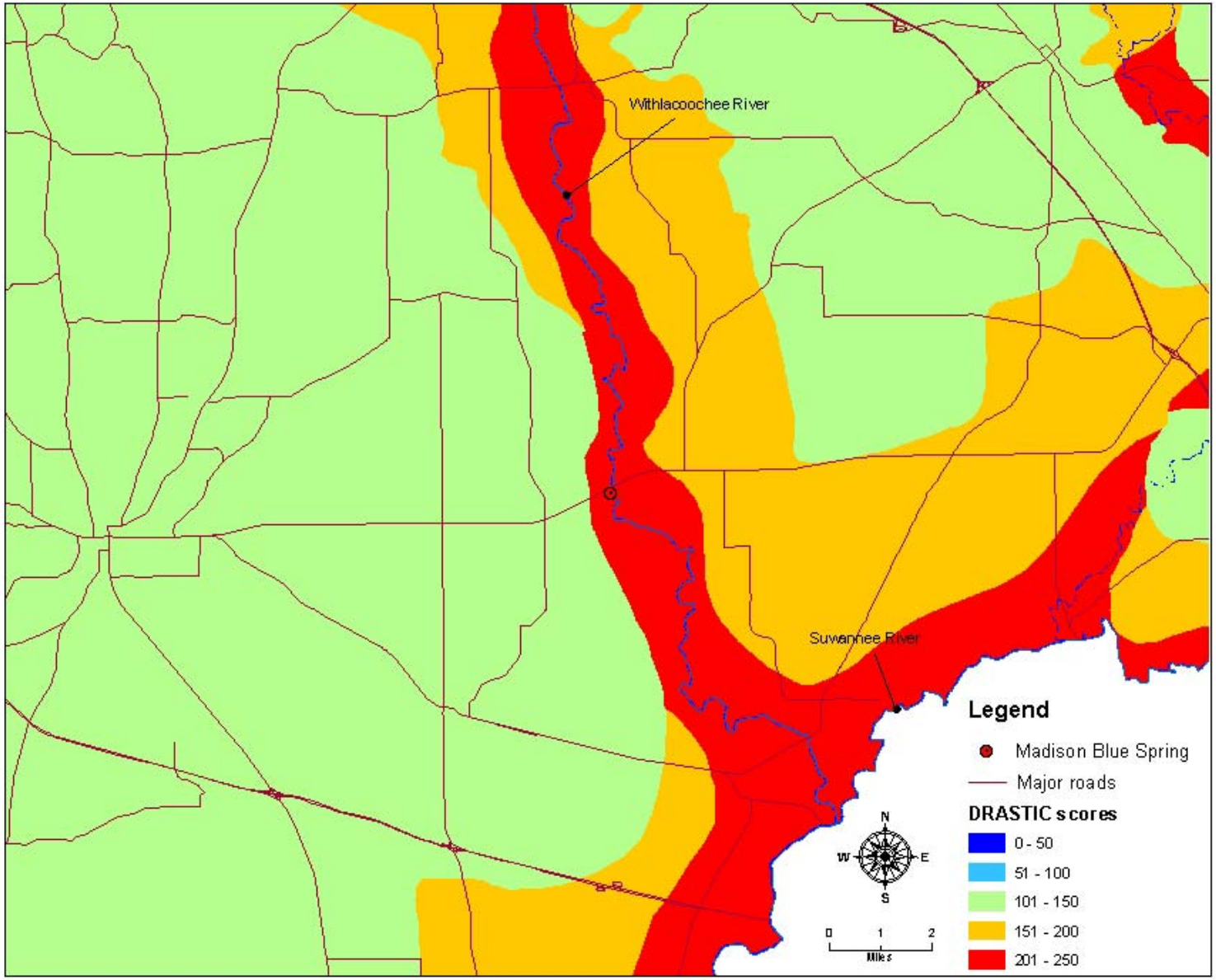


Figure 2-7. Aquifer vulnerabiltiy based on DRASTIC scores in the Madison Blue Spring study area.

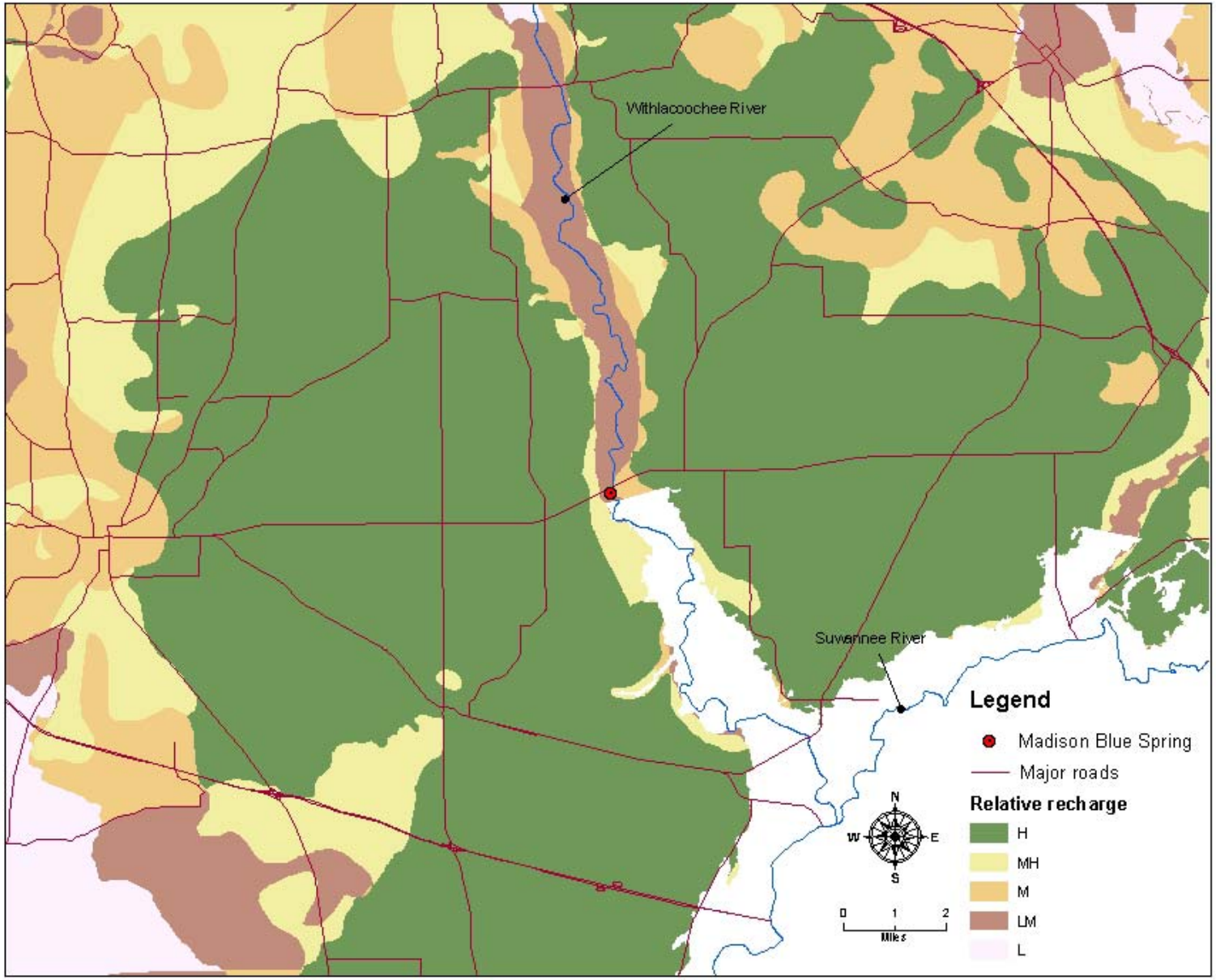


Figure 2-8. Relative recharge to the Floridan aquifer based on DRASTIC mapping in the Madison Blue Spring study area.

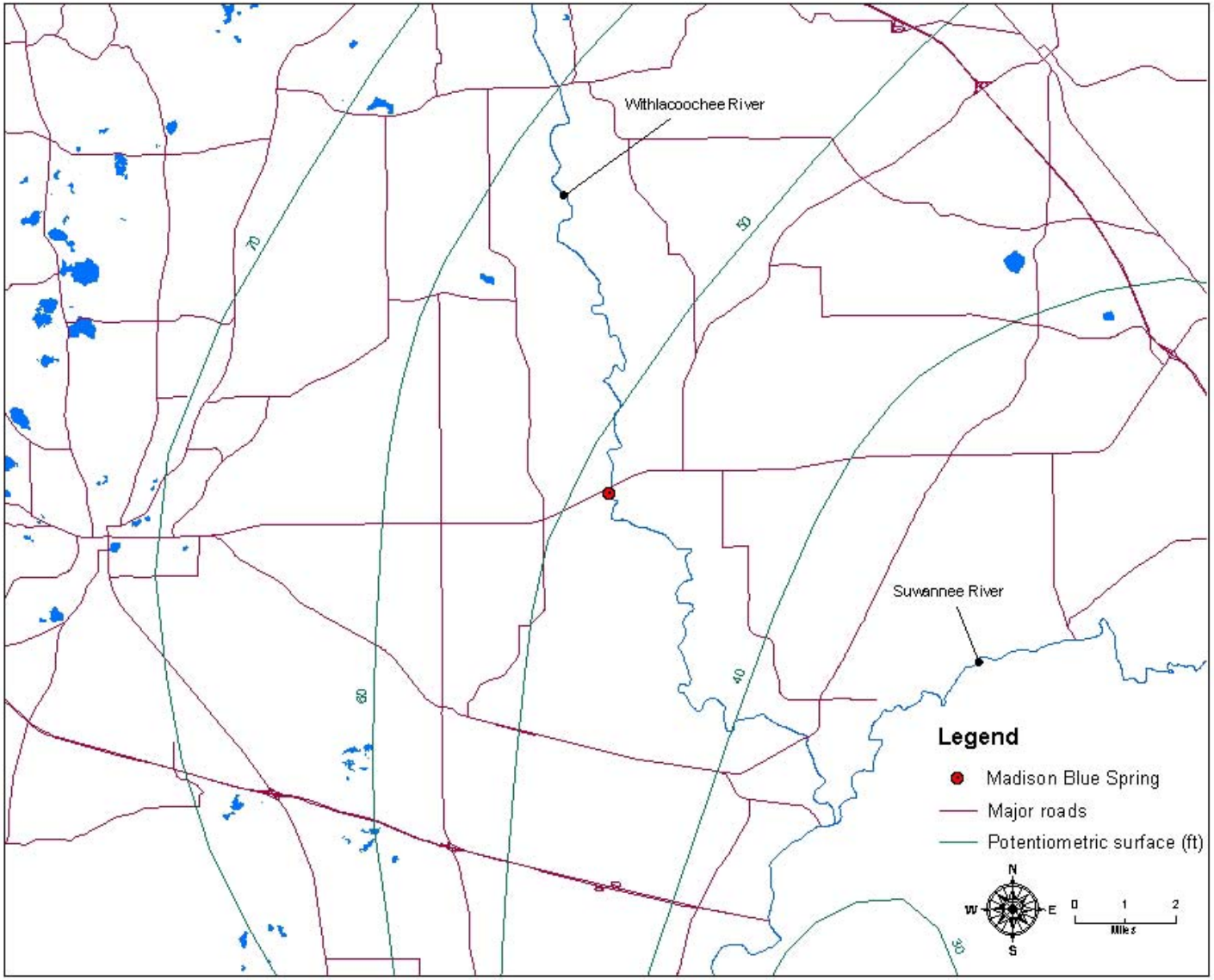


Figure 2-9. Predevelopment potentiometric surface of the Floridan aquifer in the Madison Blue Spring study area.

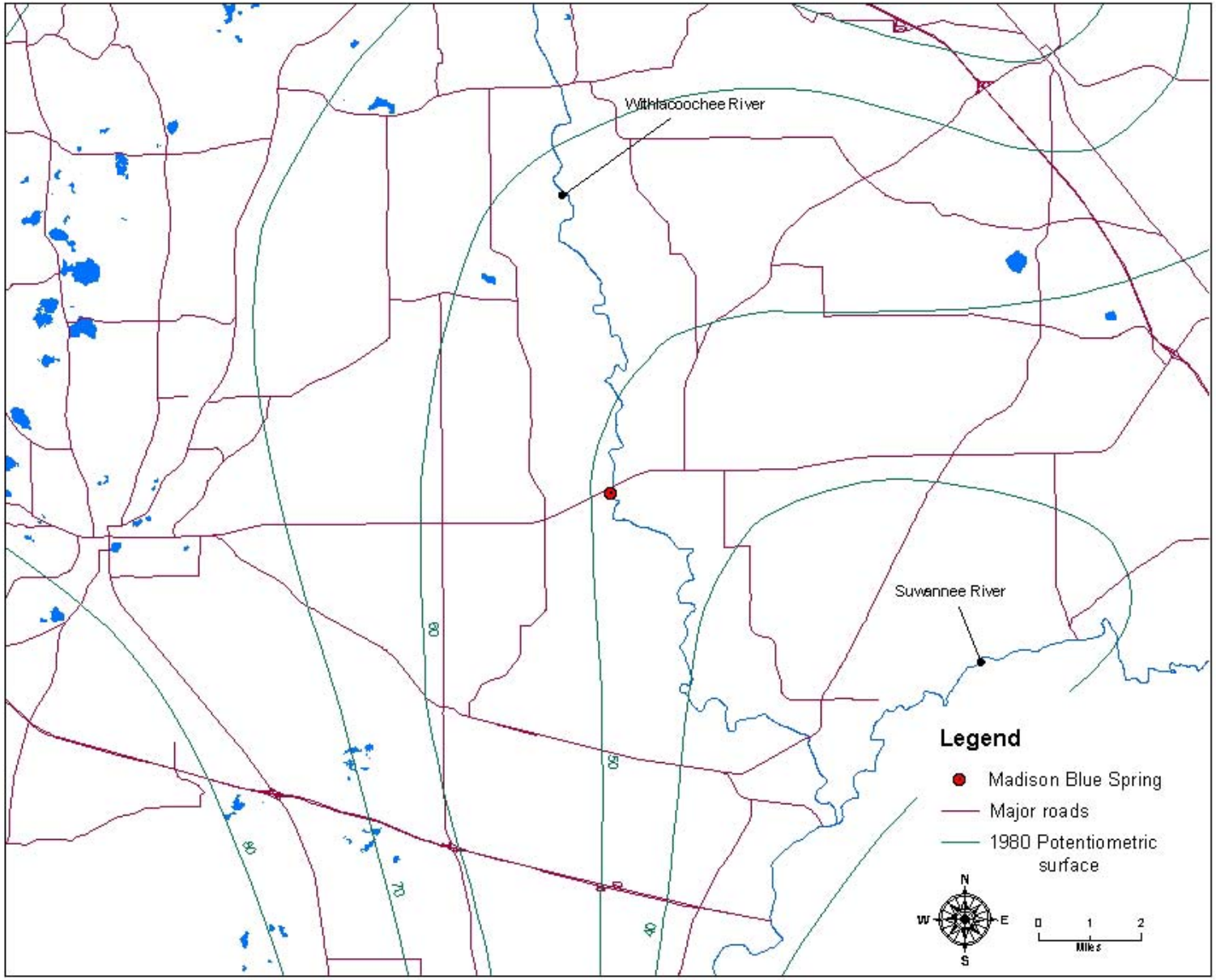


Figure 2-10. 1980 potentiometric surface of the Floridan aquifer in the Madison Blue Spring study area.

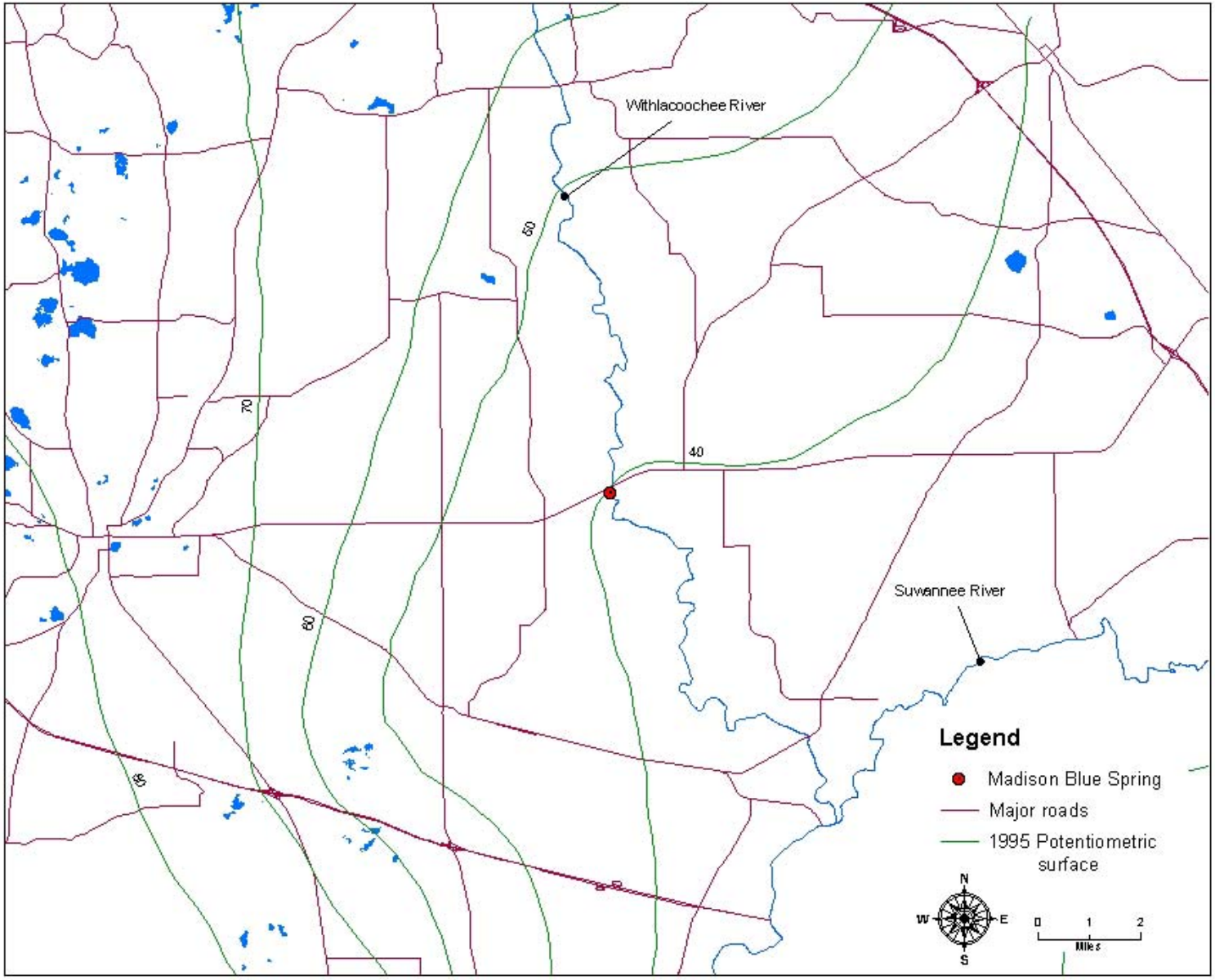


Figure 2-11. 1995 potentiometric surface of the Floridan aquifer in the Madison Blue Spring study area.

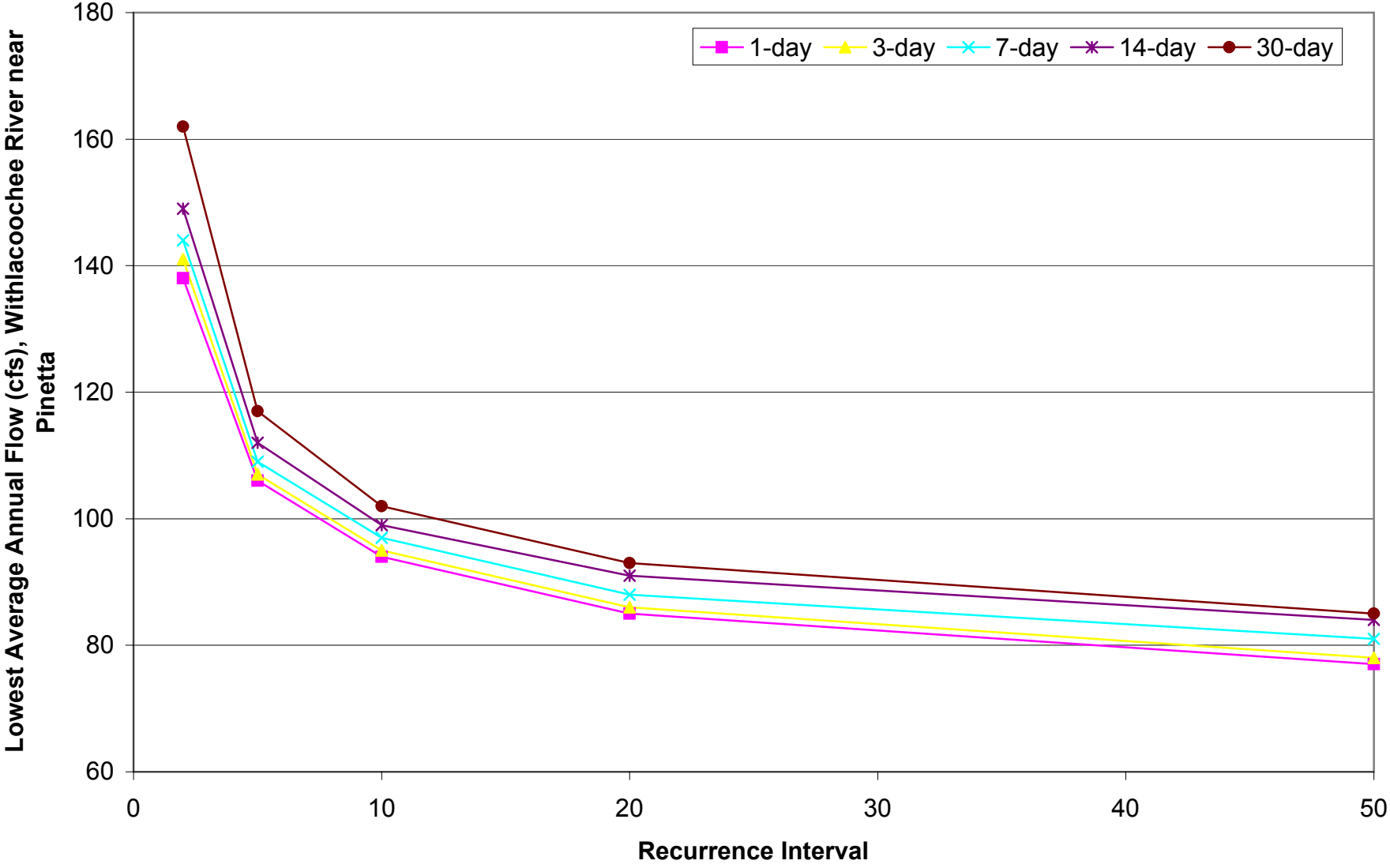


Figure 2-12. Lowest average streamflow within a single year for a range of timespans at the Withlacoochee River near Pinetta.

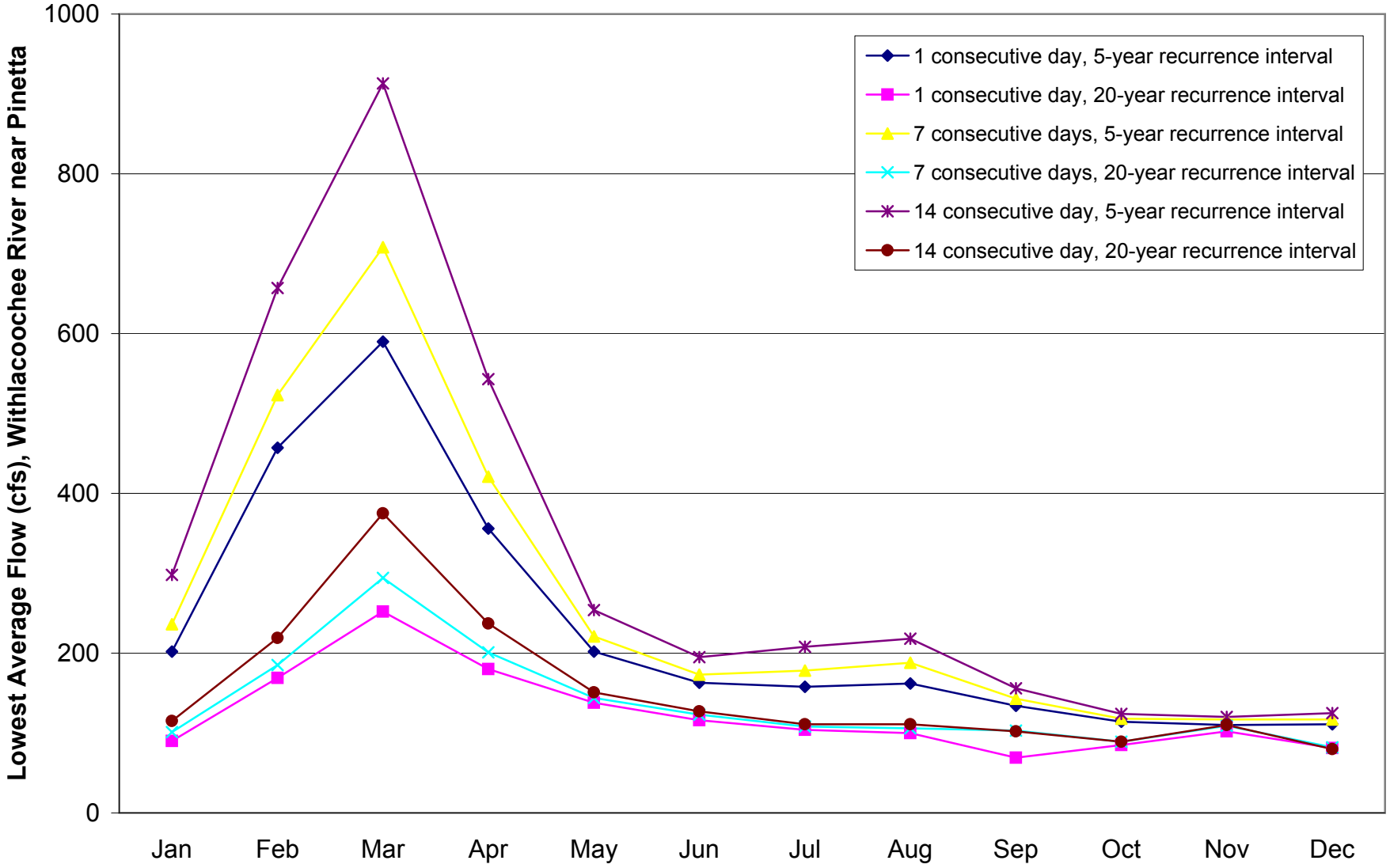


Figure 2-13. Lowest average streamflow for a range of timespans and recurrence intervals at the Withlacoochee River near Pinetta.

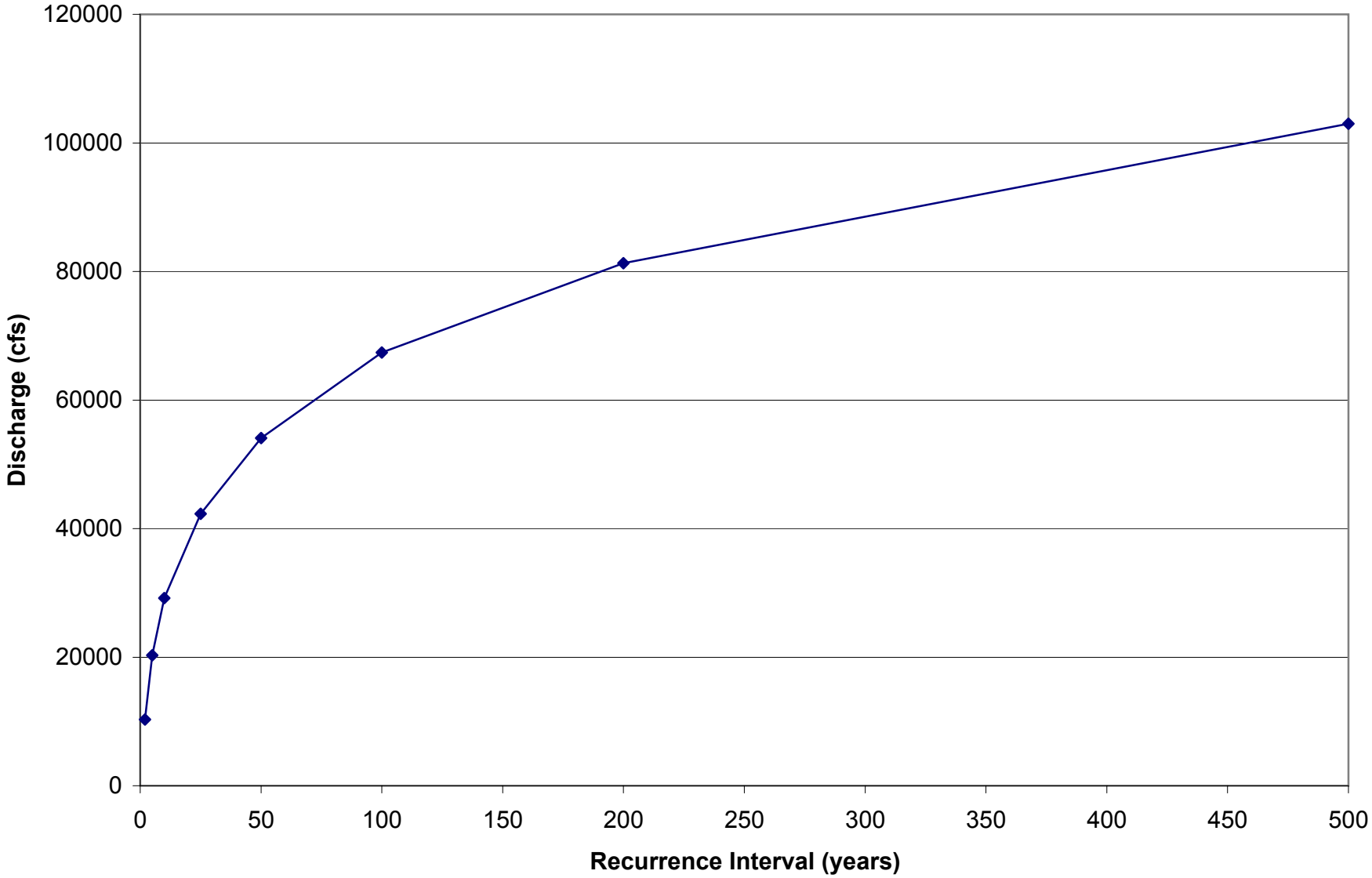


Figure 2-14. Flood recurrences at the Withlacoochee River near Pinetta.

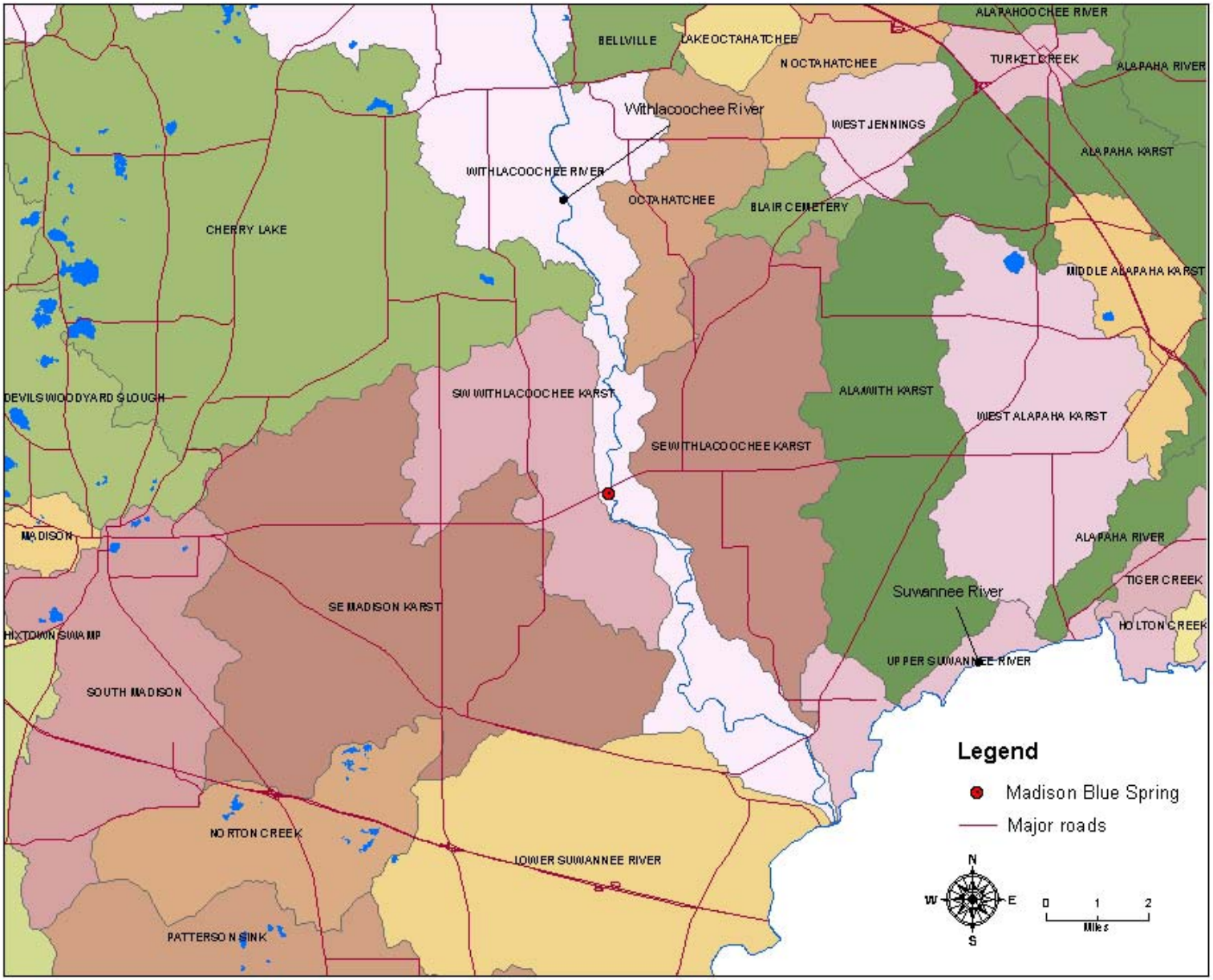


Figure 2-15. Surface-water drainage basins in the Madison Blue Spring study area.

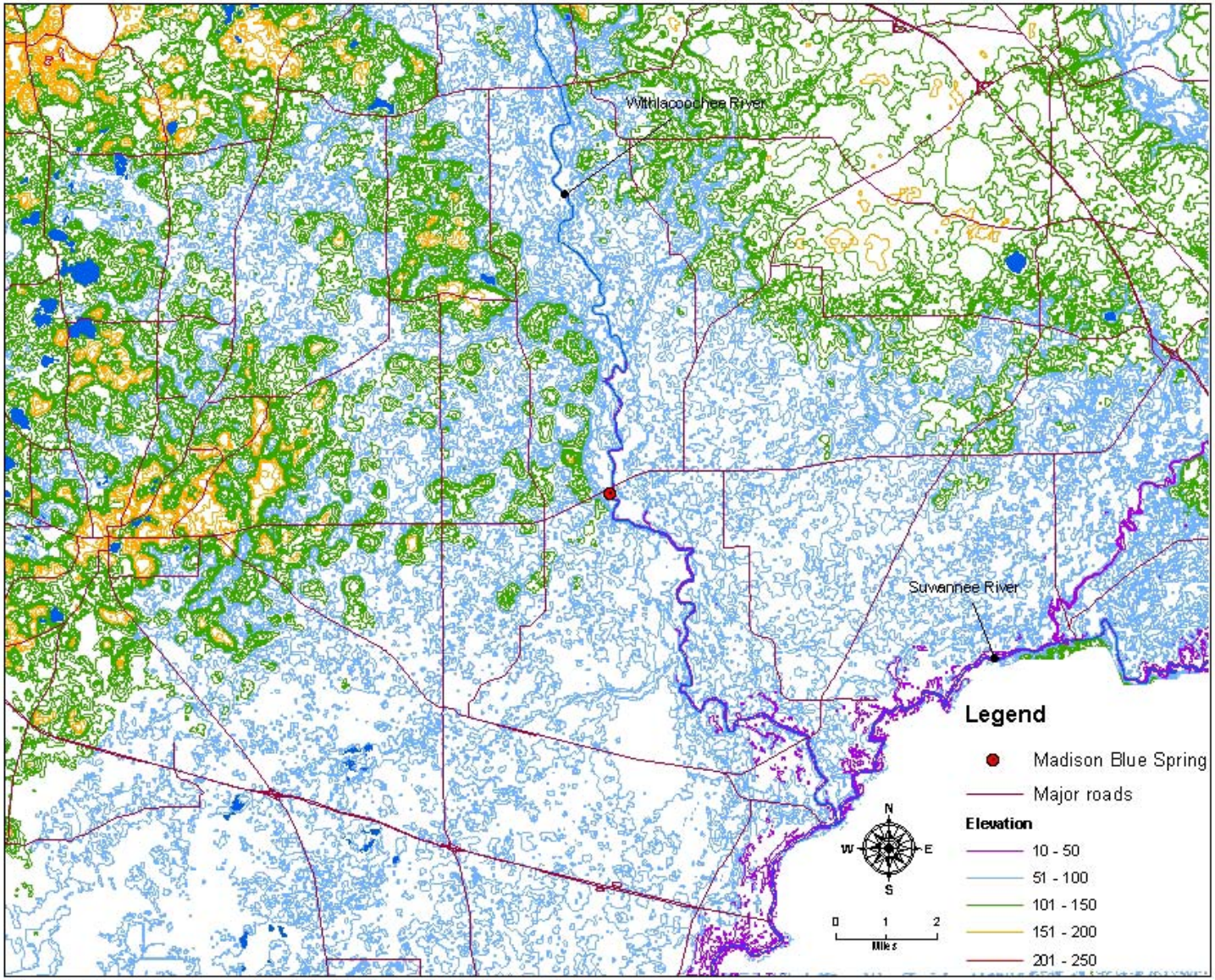


Figure 2-16. Surface topography in the Madison Blue Spring study area.

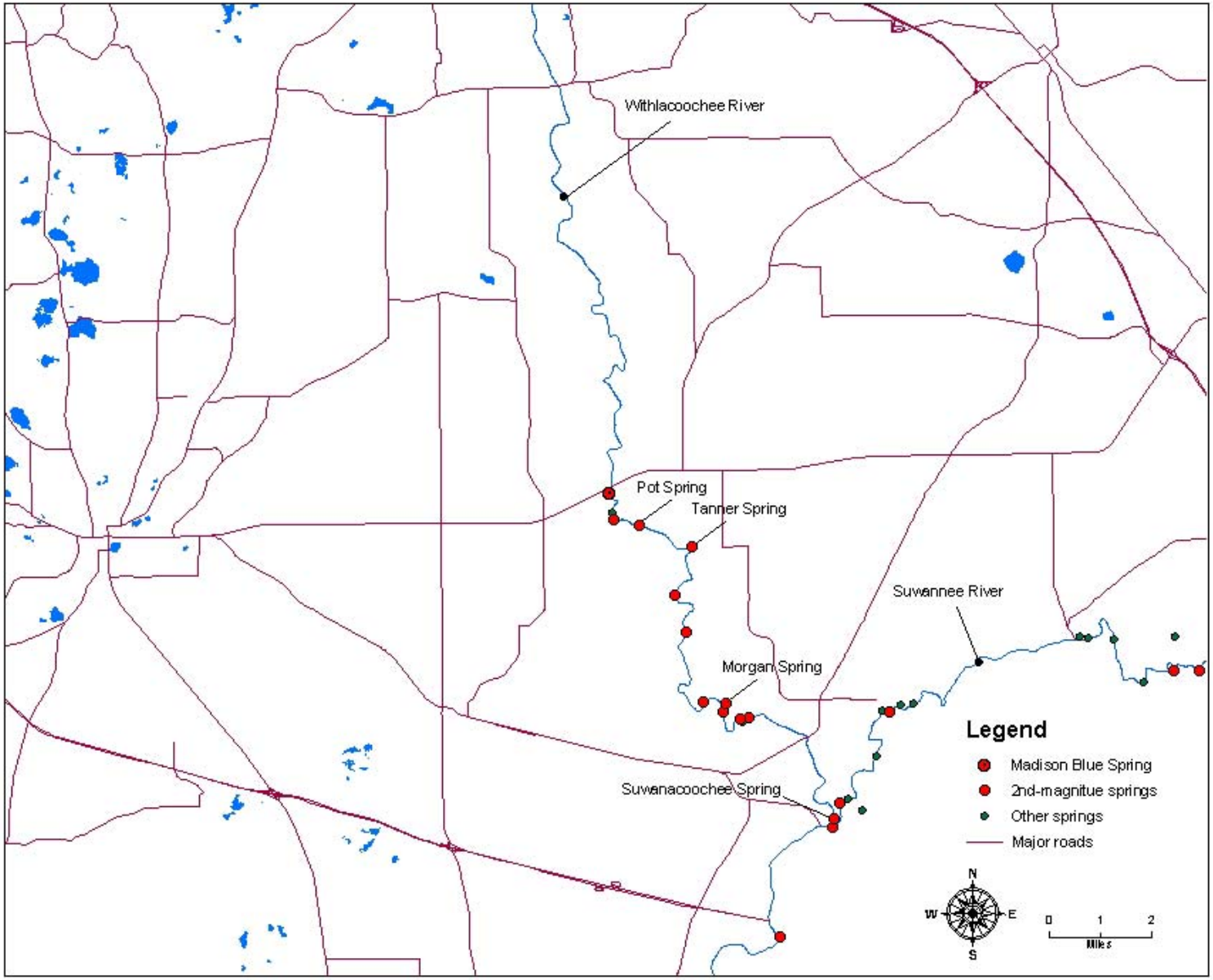


Figure 2-17. Location of known springs in the Madison Blue Spring study area.

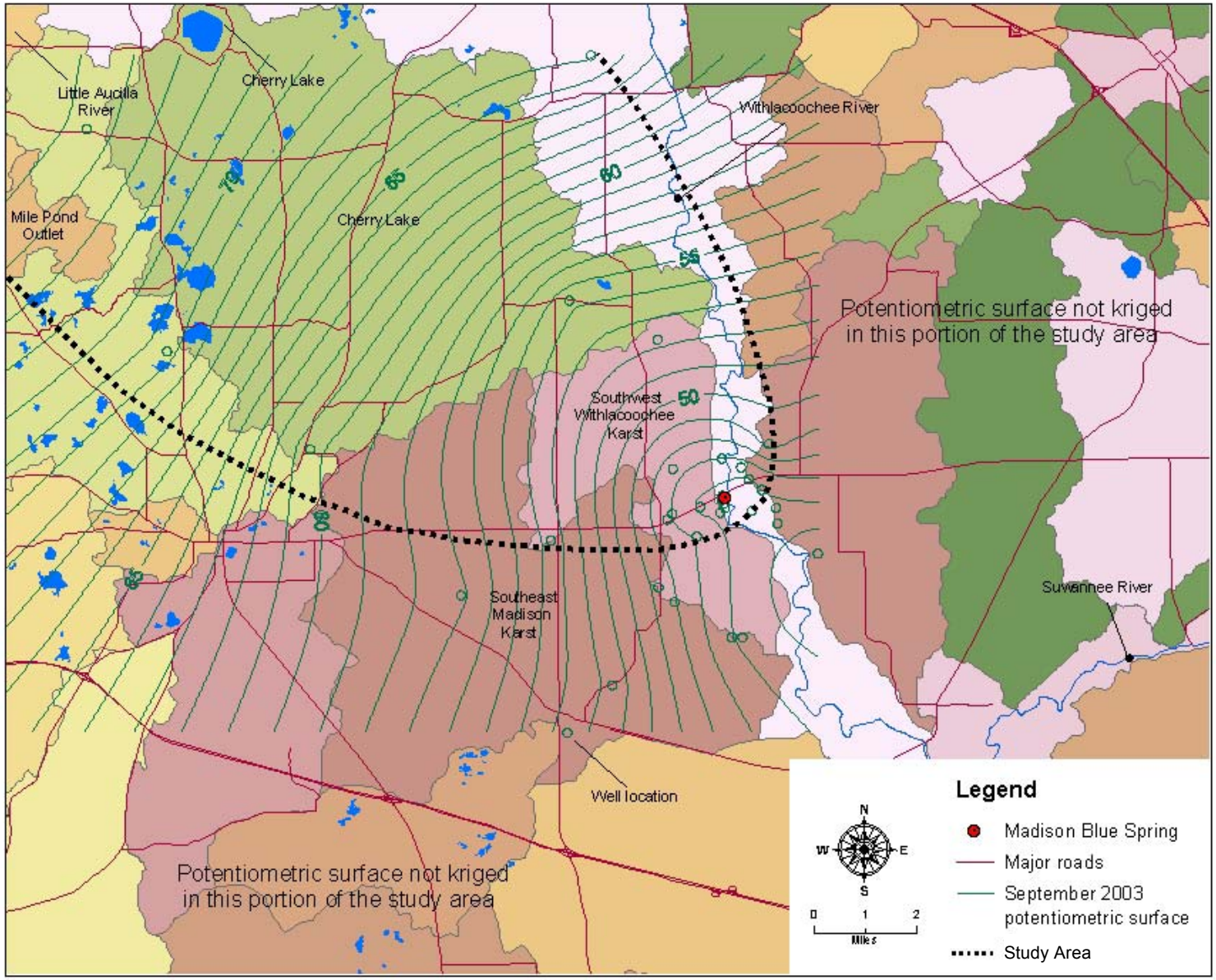


Figure 2-18. Geographic extent of the Madison Blue Spring study area.

3.0 HYDROLOGIC ANALYSES

3.1 Data (see Appendix A, Exhibit 4 – Data Sources Summary)

3.1.1 Surface Water Data

The SRWMD provided all available flow data for MBS. Additionally, data were provided for the Withlacoochee River gauges and the first gauge on the Suwannee River downstream from the confluence with the Withlacoochee River.

3.1.1.1 Madison Blue Spring Data

Stage and discharge measurements from MBS were provided by the SRWMD. Table 3-1 contains the time range of data collection and the number of stage and discharge readings. Two types of measurements were available: measured values, which represent manually recorded data, and daily values, which represent discharge data calculated by an automated recording device. Only measured values of discharge were available. These are discussed in Section 2.6.1 and are presented graphically in Appendix A1 (Figure A1-1a). A continuous stage and discharge monitoring system was installed by the USGS in April 2002. From this gage, a nearly continuous record of spring stage has been obtained from April 2002 to July 2003 (Figure A1-1b), though a few gaps do exist. However, this gauge is located in the spring run, not within the spring, so the measured stage actually reflects either the spring run itself during low river flows, the stage in the river when the river submerges the spring run, or the spring pool elevation when it in turn is submerged by the river. Calibration of the acoustic flow meter used to monitor spring discharge has been an ongoing process. Therefore, considerable gaps exist within the flow record obtained since April 2002, and the reliability of these data may be questionable. The measured values of spring discharge, though less numerous, are probably more reliable, so these data are primarily utilized in the MFL development.

3.1.1.2 Streamflow Data

Stage and discharge measurements were provided from four river gauges in the vicinity of MBS. Table 3-1 contains the time range of data collection, the basin size at each gauge, and the number of stage and discharge measurements. The data are presented graphically in Appendix A1. Three gauges are located on the Withlacoochee River (Figure 3-1). The gauge near Pinetta is located ~9 miles upstream from MBS. The gauge near Madison is located on the State Road 6 Bridge just upstream from MBS. The gauge near Lee is located ~9 miles downstream from MBS, near the confluence.

Station	Period of Record	Basin Size (mi^2)	Number of stage readings		Number of discharge readings	
			Measured values	Daily Values	Measured Values	Daily Values
Madison Blue Spring	03/16/32-07/31/03	--------	--------	352	22	210
Withlacoochee River near Pinetta	12/11/31-08/25/03	2120	N/A	26081	N/A	25930
Withlacoochee River near Madison	04/11/60-03/25/98	2240	486	--------	10	--------
Withlacoochee River near Lee	11/01/00-8/24/03	2330	19	1021	19	1027
Suwannee River at Ellaville	02/01/27-08/25/03	6970	N/A	27589	N/A	27966

Table 3-1. Stage and discharge measurements available near Madison Blue Springs.

with the Suwannee River. The fourth gauge is located on the Suwannee River at Ellaville, just downstream from the confluence of the Withlacoochee and Suwannee River. The most complete and extensive data sets are from the gauges on the Withlacoochee River near Pinetta and on the Suwannee River at Ellaville. Daily stage and discharge measurements have been collected at these gauges for the past 70+ years. The gauge on the Withlacoochee River near Lee was installed in 2000, so a fairly short, though continuous, set of daily stage and discharge data has been collected. The gauge on the Withlacoochee River near Madison has not been continuously monitored for any period. This gauge has been used to measure stage and

discharge during several extreme high and low flow events over the past ~40 years. Several hundred additional stage measurements have been obtained at this gauge during this period.

3.1.2 Precipitation Data

Monthly precipitation data were provided by SRWMD for seven stations in the vicinity of MBS (Figure 3-3). The date first and last measured, along with the largest rainfall total for a single month at that gauge, are presented in Table 3-2. The data are presented graphically in Appendix A2. All but one of the stations began recording data in February 1976. The station in Madison began recording data in February 1931. Data collection ceased at two of the stations (Mill Creek Tower and Gibson Tower) in recent years.

Daily precipitation data were also provided by SRWMD for two stations in the vicinity of MBS. The date first and last measured, along with the largest rainfall total for a single month at that gauge, are presented in Table 3-2. The data are presented graphically in Appendix A2. Daily rainfall recorders were only recently installed at these stations, so the data record only goes back a few years. Additional daily precipitation data were obtained from the National Oceanic and Atmospheric Administration (NOAA) for their rainfall recording station located in Madison (Figure 3-2). This data set includes over 50 years of continuous daily rainfall measurements.

Station	Type	First Measured	Last Measured	Maximum Event (Date)
Ellaville (6)	Monthly	February, 1976	Present	17.61 in. (Oct. 1994)
Madison (22)	Monthly	February, 1931	Present	20.68 in. (July 1935)
Alapaha Tower (46)	Monthly	February, 1976	Present	16.76 in. (July 1991)
Hopewell Tower (66)	Monthly	February, 1976	Present	18.6 in. (June 1994)
Mill Creek Tower (67)	Monthly	February, 1976	September, 2001	15.05 in. (Jan. 1991)
Madison Tower (68)	Monthly	February, 1976	Present	21.93 in. (Jan. 1991)
Gibson Tower (69)	Monthly	February, 1976	July, 1997	14.87 in. (Aug. 1992)
Alapaha Tower (246)	Daily	June 5, 2000	Present	5.13 in. (March 3, 2002)
Hopewell Tower (266)	Daily	September 21, 2001	Present	4.22 in. (March 3, 2002)
NOAA-Madison	Daily	November 21, 1950	Present	8.90 in. (Aug. 20, 1964)

Table 3-2. Available precipitation data in the area of Madison Blue Springs.

3.1.3 Ground-Water Data

The SRWMD provided data for the period of record for all ground-water monitoring wells contained within their database for both Madison and Hamilton counties. They also provided the data from their existing water-use permits for both counties.

3.1.3.1 Ground-Water Levels

The complete record for all monitored wells for both Madison and Hamilton County was analyzed. From this, a total of ninety wells were selected which are located between the regional potentiometric high that runs through Madison County to the west and the Alapaha River to the east (Figure 3-3). Table 3-3 contains information on these wells, including the date first and last measured, the frequency measured, total measurements, and minimum, maximum, and average groundwater level within each well. This provides a dataset of water levels for all wells within and surrounding the springshed for MBS within Florida.

Twenty-six of these wells appear to have a significantly long and/or frequent period of regular sampling. These data are presented in graphical form in Appendix A3. Information from these wells will be useful for analyzing short and long-term trends in aquifer levels and the relationship between rainfall, groundwater levels, and spring discharge. The remaining wells were monitored very infrequently, for only a short period of time (i.e. few years or less), and/or only several times.

Six of these twenty-seven wells (#1-6, Table 3-3) were monitored on a daily basis for some period of time. Four (#1, 2, 5, and 6) were monitored daily for a significant length of time (i.e. many years); the other two (#3 and 4) were only monitored on a daily basis for a short time period (i.e. ~one year or less). Total data available from each well ranges from ~200 to over 7000 water level measurements. Four of these wells (#1, 3, 5, and 6) were also monitored on a monthly basis for some length of time in addition to the daily monitoring period. Of these six wells, three are located within Madison County (#1-3) and three within Hamilton County (#4-6).

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
1	+010814001	11/1/76	5/27/93	Daily-Monthly	3176	71.04	89.39
2	+010921001	6/3/83	3/3/91	Daily	2920	67.27	90.21
3	-010920002	10/12/89	7/29/03	Daily-Monthly	396	75.93	94.29
4	+021108002	4/29/80	12/2/80	Daily	218	51.5	62.15
5	+021125001	7/27/81	7/15/03	Daily-Monthly	7190	40.2	69.89
6	+021211001	7/26/77	7/9/03	Daily-Monthly	5780	34.88	69.91
7	+010719001	11/1/76	7/8/03	Monthly	251	69.51	85.08
8	+020822002	6/14/89	7/8/03	Monthly	180	69.58	86.6
9	-020802001	7/23/87	7/8/03	Monthly	193	80.37	94.61
10	+010912001	1/09/02	1/30/03	Monthly	2	51.15	54.42
11	+021002001	11/1/76	7/8/03	Monthly	249	56.99	84.29
12	-011011002	3/21/88	7/2/03	Monthly	190	40.77	89.52
13	-011035001	11/1/76	7/8/03	Monthly	255	40.96	75.39
14	+021202001	11/2/76	5/13/96	Monthly-Quarterly	155	34.91	70.85
15	+021332004	6/12/89	7/9/03	Monthly	178	32.4	73.5
16	+010733003	8/14/89	1/2/03	Monthly-Yearly	32	70.15	76.79
17	+020820001	11/1/76	5/20/02	Quarterly-Yearly	29	79.71	94.34
18	-010833001	11/1/76	5/20/02	Quarterly-Yearly	28	80.13	92.26
19	+020907001	11/1/76	5/20/02	Quarterly-Yearly	27	70.01	87.5
20	-010913002	2/13/78	10/30/96	Monthly-Yearly	28	80.13	92.26
21	+011022001	11/1/76	5/20/02	Quarterly-Yearly	30	45.47	73.74
22	+011117001	11/1/76	6/24/98	Quarterly-Yearly	27	40.89	49.5
23	+011109001	11/1/76	2/25/03	Quarterly-Yearly	33	41.17	60.67
24	+011127001	11/1/76	5/8/03	Quarterly-Yearly	33	29.67	58.69
25	+021035001	11/1/76	5/20/02	Quarterly-Yearly	26	47.83	71.28
26	+031133001	11/1/76	5/12/03	Quarterly-Yearly	29	63.05	76.04
27	+011234001	11/1/76	5/31/02	Quarterly-Yearly	27	29.13	54.18
28	+010720006	2/9/79	1/29/03	Quarterly-Yearly	23	68.25	81.88
29	-010704002	5/17/79	6/5/02	Monthly-Yearly	16	74.14	85.18
30	-010729001	6/21/00	1/2/03	Quarterly	11	69.6	74.36

Table 3-3. Wells located within and surrounding the Madison Blue Springs springshed.

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
31	-010734002	7/24/87	12/5/90	Monthly	43	71.1	78.86
32	+030831001	6/21/00	10/31/02	Quarterly	10	70.23	72.86
33	-010832002	6/25/01	1/30/03	Yearly	3	76.42	80.86
34	+010834001	4/16/01	1/29/03	Yearly	3	91.93	95.71
35	-010824001	5/5/78	9/7/79	Quarterly	5	79.37	86.22
36	-010906001	5/10/78	10/23/83	Quarterly	8	70.05	78.37
37	+010904001	3/2/01	3/2/01	Periodic	1	63.34	63.34
38	+011030002	4/2/03	4/2/03	Periodic	1	66.31	66.31
39	+011028003	4/3/03	6/21/00	Quarterly	9	48.48	65.47
40	-021008001	5/10/78	5/3/84	Quarterly-Yearly	9	60.83	81.29
41	-021002002	5/10/78	5/3/84	Quarterly-Yearly	9	51.07	78.18
42	+021036001	10/4/00	7/2/03	Quarterly	13	45.77	62.5
43	-011008004	3/21/88	8/30/89	Monthly-Quarterly	14	46.55	57.6
44	-011004006	3/21/88	3/1/91	Monthly-Yearly	15	46.6	60.9
45	-011016001	3/21/88	3/1/91	Monthly-Yearly	17	43.37	60.34
46	-011003003	3/21/88	3/1/91	Monthly-Quarterly	14	45.67	57.47
47	-011015002	3/21/88	3/1/91	Monthly-Yearly	13	43.76	57.85
48	-011003005	3/21/88	3/1/91	Monthly-Yearly	16	43.15	74.84
49	-011010009	3/21/88	3/1/91	Monthly-Yearly	17	43.05	56.20
50	-011010008	3/21/88	3/1/91	Monthly-Yearly	16	43.16	54.51
51	-011010005	3/21/88	3/1/91	Monthly-Yearly	14	43.52	54.60
52	-011010003	4/27/88	1/31/91	Monthly-Yearly	14	43.16	50.65
53	-011010006	3/21/88	3/1/91	Monthly-Yearly	15	41.89	55.49
54	-011011010	3/21/88	3/1/91	Monthly-Yearly	14	42.82	55.51
55	-011002005	3/21/88	3/1/91	Monthly-Yearly	17	42.24	54.43
56	-011011006	3/21/88	3/1/91	Monthly-Yearly	16	42.77	54.4
57	-011011009	3/21/88	3/1/91	Monthly-Yearly	16	42.16	55.23
58	-011002004	3/21/88	3/1/91	Monthly-Yearly	16	43.27	55.41
59	-011001001	3/21/88	3/25/03	Monthly-Yearly	18	43.07	61.77
60	-011014003	3/21/88	3/1/91	Monthly-Yearly	15	42.63	54.8

Table 3-3 (cont.). Wells located within and surrounding the Madison Blue Springs springshed.

Well	Site ID	First Measured	Last Measured	Frequency Measured	Number of Measurements	Min (ft msl)	Max (ft msl)
61	-011012005	3/21/88	3/1/91	Monthly-Yearly	15	42.85	55.13
62	-011013001	3/21/88	3/1/91	Monthly-Yearly	17	41.67	53.97
63	+021121001	6/28/83	5/3/84	Quarterly	4	47.8	67.88
64	+011132003	3/27/03	3/27/03	Periodic	1	58.38	58.38
65	+011132004	3/27/03	3/27/03	Periodic	1	59.2	59.2
66	-011129001	6/28/00	1/3/03	Quarterly	12	36.67	40.44
67	-021104001	2/9/78	5/20/02	Quarterly-Yearly	24	30.63	52.1
68	+011025001	4/4/03	4/4/03	Periodic	1	59.67	59.67
69	+011130004	4/9/03	4/9/03	Periodic	1	54.57	54.57
70	+011130003	4/4/03	4/4/03	Periodic	1	58.15	58.15
71	+011118005	4/9/03	4/9/03	Periodic	1	51.48	51.48
72	+011117011	4/22/03	5/8/03	Periodic	3	45.26	48.86
73	+011117009	12/31/02	5/7/03	Periodic	2	45.29	47.04
74	+011117010	4/18/03	5/8/03	Periodic	3	44.3	65.16
75	+011120007	4/18/03	5/8/03	Periodic	3	45.16	54.35
76	+011120005	12/31/02	5/7/03	Periodic	2	45.32	46.93
77	+011117004	5/8/03	5/8/03	Periodic	1	46.72	46.72
78	+011117012	5/7/03	5/9/03	Periodic	2	45.76	46.06
79	+011117013	5/7/03	5/9/03	Periodic	2	45.01	45.51
80	+011117014	5/7/03	5/9/03	Periodic	2	45.33	45.63
81	+011120008	5/13/03	5/13/03	Periodic	1	45.25	45.25
82	+011121003	5/7/03	5/13/03	Periodic	2	44.06	45.32
83	+011121004	5/7/03	5/13/03	Periodic	2	44.07	45.24
84	+011121002	3/26/03	3/26/03	Periodic	1	59.49	59.49
85	-011112001	6/28/83	5/2/84	Quarterly	4	33.24	51.08
86	+021209001	6/28/83	5/3/84	Quarterly	4	45.72	65.08
87	+021227001	6/28/83	5/3/84	Quarterly	4	29.99	54.7
88	+011222001	2/22/01	2/25/03	Yearly	3	27.68	31.79
89	+011226001	7/26/01	2/25/03	Yearly	3	24.24	28.09
90	+011235006	3/20/01	2/14/03	Yearly	3	28.35	32.97

Table 3-3 (cont.). Wells located within and surrounding the Madison Blue Springs springshed.

Another eight of these twenty-seven wells (#7-10, 11-15, Table 3-3) were monitored on a monthly basis over a significantly long period of time (i.e. many years). Total data available from each well ranges from ~100 to ~250 water level measurements. Of these nine wells, seven are located within Madison County (#7-13) and two are located within Hamilton County (#14-15). The remaining twelve wells (#16-27) were monitored on a monthly to yearly basis, with total data available from each well ranging from ~25-30 water level measurements. Eight of these wells are located within Madison County, four within Hamilton County.

3.1.3.2 Ground-Water Use

Information was provided on the existing ground-water withdrawal permits for Madison and Hamilton County. There are currently 401 permits issued in Madison County and 251 permits issued in Hamilton County. Available data on these permits includes permit holder's name and location and the average and maximum daily rates of pumping allowed for the well. The total permitted average and maximum daily withdrawals for Madison County are 33.6 million gallons per day (Mgd) and 195 Mgd, respectively. The total permitted average and maximum daily withdrawals for Hamilton County is 557 Mgd and 867 Mgd, respectively.

3.1.4 Summary

The hydrologic and geologic data available for the determination of minimum flows and levels for MBS are:

- Limited stage and discharge measurements for MBS,
- Daily ground-water level data from six wells,
- Monthly ground-water level data from nine wells,
- Monthly to yearly ground-water level data from twelve wells,
- Ground-water usage information for Madison and Hamilton County,

- Water quality data from MBS,
- Stage and discharge measurements from four gauges on the Withlacoochee and Suwannee Rivers,
- Monthly rainfall data from seven stations in the vicinity of MBS, and
- Daily rainfall data from three stations in the vicinity of MBS (only one with a significant period of record).

Significant shortcomings of the available data include:

- The lack of a long-term data set of stage and discharge on the Withlacoochee River at and downstream from MBS,
- The small amount of available stage and discharge data for MBS, and
- Minimal ground-water level data within close vicinity (i.e. few miles) of MBS.

3.2 Methods

3.2.1 Simulating River Data

Given the lack of long term hydrologic and ecological data on MBS itself, the main basis for the MFL to be established for MBS is the spring's contribution to baseflow in the river. One of the major data needs for establishing the MFL for MBS is a time series of stage and discharge in the Withlacoochee River at and downstream from the spring. As discussed in Section 3.1.1.1, there are significantly long time series for the gauges on the Withlacoochee near Pinetta and on the Suwannee at Ellaville. Data from the gauge on the Withlacoochee River near Lee only go back to late in 2000. Data from the gauge on the Withlacoochee River near Madison is spotty, though they span several decades. The following sections describe how a time series of data for these two gauges was synthesized.

3.2.1.1 Simulation of River Stage Data

Stage data for the gauges on the Withlacoochee River near Madison and Lee were simulated for the 70-year period of record that already existed for the gauge on the Withlacoochee River near Pinetta (1932-2002) using deterministic statistical methods. In order to include the maximum number of data points and minimize the uncertainty in the results, only data sources that entirely overlapped the measured stage data from the Madison and Lee gauges were utilized. This left three "complete" data sets: stage at the Withlacoochee River near Pinetta, stage at the Suwannee River at Ellaville, and daily rainfall from the Madison recording station.

The existing stage data for the Madison and Lee gauges were first cross-correlated (Davis, 1986) with the other hydrologic data. This allowed the independent data (rainfall and stage at Pinetta and Ellaville) to be shifted in time to the point where it is most highly correlated with the appropriate hydrologic response, the dependant data (stage at Madison and Lee gauges). The statistical software package SYSTAT® was used to perform the cross-correlations.

Once the data had been cross-correlated and appropriated lag times had been identified, stepwise multiple linear regressions (Davis, 1986) were performed to develop polynomial equations to simulate data for the period of record for the Madison and Lee gauges. The regressions were begun with all time-shifted (lagged) and contemporaneous independent variables included. A backward, stepwise regression systematically removed each variable that exceeded the designated alpha value of 0.05. The result of each step-wise regression is a set of variables and associated coefficients for a polynomial equation that relates the statistically significant independent variables to the dependent one (stage). The polynomial can then be applied for the entire period of record of the independent variables to generate a simulated period of record data set for the dependent variable.

3.2.1.2 Simulating River Discharge Data

Once a period of record data set was simulated for stage at the Madison and Lee gauges, the discharge was simulated using a stage-fall-discharge rating curve (Rantz et al., 1982) for each gauge. The confluence with the Suwannee River creates backwater conditions on the Withlacoochee River, occasionally as far upstream as the Pinetta gauge. Figure 3-4 shows a

graph of stage versus discharge for the daily values recorded at the Lee gauge since November 2000. This demonstrates that discharge is not a simple function of stage on this river (i.e., for any given stage, the river experiences a range of discharge values).

A stage-fall-discharge rating curve was developed for each gauge using measurements obtained on days for which both stage and discharge were available (over 1000 data points for the Lee gauge, under 10 data points for the Madison gauge). The method requires both upstream and downstream stage measurements for each gauge in order to determine the fall for a given stage (i.e. discharge is dependent on stage and fall). In the absence of better data, the upstream gauge is at Lee and the downstream gauge is at Ellaville for the Lee gauge rating curve, and the upstream gauge is at Madison and the downstream gauge is at Lee for the Madison gauge rating curve. The ratings were then used to take the simulated stage data (and the corresponding fall for that stage) and compute simulated discharges for the 70-year period of record.

3.2.2 Predicting Spring Discharge

Of even greater importance to developing a MFL for MBS is estimating some partial or full period of record for discharge from the spring. By conducting an analysis of the relationships between river stage and discharge and measured spring discharge a time series of spring discharge data was simulated. Cross-plots of spring discharge (the 22 measured values) versus various river data, such as stage and discharge at the different river gauges, were created. Generating trendlines for the data and evaluating various types of trends (e.g. linear, polynomial) and the quality of their fit produced simplified relationships between spring discharge and the other variables. This relationship, or equation, relating spring discharge to river data was used to generate partial or full periods of record (depending on if the relationship can be extended to the full range of river data) for spring discharge.

3.2.3 Maintaining Flow Over Withlacoochee River Shoals

As noted in Section 3.2.1.2, MBS constitutes a significant portion of discharge in the Withlacoochee River, especially during low flow conditions. The maintenance of flow over shoals in the river, therefore, is dependent on MBS discharge and is the basis for MFL development. An existing HEC-RAS model was modified to simulate the stage of the river at the shoals over a range of low flows in the river. The range of stages at the shoals was then related to the discharge at the spring.

3.2.3.1 HEC-RAS Modeling

A study of the Suwannee River floodplain was published by the U.S. Army Corps of Engineers (USCOE) in 1989. The SRWMD was the local sponsor of the work.

A primary purpose of the study was to "consider the impacts and effects of an expected substantial increase in development along the Suwannee and its major tributaries, and of possible floodplain management." The hydraulic analyses portion of the study involved use of the Army Hydrologic Engineering Centers (HEC) Step Backwater Computer Program, known as HEC-2. A product of the 1989 study was GIS (Arc-Info) coverages that show the 10-year and 100-year floodplains and the 100-year floodway for the Suwannee River system, and cross-section locations.

A replacement for HEC-2 was developed and is now in its third revision. This replacement is called HEC-RAS (River Analysis System). HEC-RAS is an integrated package of hydraulic analysis programs and is capable of performing steady and unsteady flow water surface profile calculations.

In 2002, the District contracted with Taylor Engineering to convert the original HEC-2 files, for both the Aucilla River and the Suwannee River system, to HEC-RAS format (Taylor Engineering, 2002). The goal was to import the original HEC-2 files from the USCOE into HEC-RAS projects without the collection of significant amounts of additional field data or changing the boundary conditions.

The portion of the resulting HEC-RAS model covering the Withlacoochee River was provided to WRA by SRWMD. The original HEC-2 model was calibrated to extreme high flow events, in order to determine flood recurrences in the basin. To be used in the development of minimum flows and levels for MBS, the model geometry was used in a dynamic mode and recalibrated to a range of low flows experienced on the river. The results of the HEC-RAS model calibration were used to validate the simulated stage-discharge data on the Withlacoochee River.

New elevation data were obtained for selected shoals on the Withlacoochee River downstream from MBS. For each of the six river shoals, three to six closely spaced cross-sections were surveyed. An attempt was made to incorporate these new cross sections into the HEC-RAS model during the low flow calibration. However, the new cross-sections created areas with a level of detail in terms of vertical measurements, that was lacking in most of the model. The USGS HEC-RAS model could not accept this new level of detail within only a few localized segments. In order to successfully incorporate the shoals, a similar level of detail would be required for most of the river reach (i.e. cross-sections at a spacing of 100 feet for many miles); this was not practical for this study. So the attempt to actually include the new shoal cross-section data in the HEC-RAS model was abandoned and the model was calibrated without the new cross-section data. However, cross-sections were interpolated at the shoals using tools built into HEC-RAS to allow the generation of results at those locations.

3.2.3.2 Shoal Inundation vs. Spring Discharge

From the calibrated HEC-RAS model, stage-discharge data could be extracted at the location of each of the six shoals on the Withlacoochee River downstream of MBS, using interpolated cross-sections. The range of river levels experienced at each shoal was then related to the discharge at MBS using previously developed relationships as described in Section 3.2.2.

3.2.4 Uncertainty Associated With Data Simulation

The Withlacoochee River and its associated springs within the study area form a complex hydrologic system. As previously discussed, the river is affected by backwater conditions due to

the nearby confluence with the Suwannee River. MBS is the largest known spring on this segment of the Withlacoochee River. There are other smaller springs and undocumented discharge points of the FAS into the Withlacoochee River along this river reach.

Due to this level of complexity, there is a level of uncertainty that goes along with simulating data for the Withlacoochee River and its springs. For example, discharge on the Withlacoochee River is related to many factors, including inflows from upstream, inflows from or outflows to MBS, and inflows from or outflows to all of the other springs within the river channel. Each spring responds differently to changes in aquifer and river levels. For example, MBS is not affected by changes in river levels until the river rises above the sill in the spring run. In contrast, other springs located in the bottom of the river channel are affected by changes in river level all of the time.

The uncertainty created by the complexity of the system is additive at each step in the data simulation process. Even if the uncertainty associated with each step in the process of data simulation is kept to a minimum, by the time the last step is reached, the uncertainty can compound. As will be seen in the results (Section 3.3), uncertainty is kept reasonably low during each phase of data simulation, but the string of simulations and the inherent complexities of the system result in some uncertainty. This will be discussed further along with the results.

3.2.5 MBS Basin Delineation

Geostatistical analysis (Davis ,1986) was used to contour Floridan aquifer potentiometric data near MBS (Upchurch et al., 2004). The spring basin was mapped at 1- to 5-foot contour intervals through the use of high-resolution monitoring and geostatistical analysis as discussed below.

In order to perform the geostatistical analysis at MBS, water level data were obtained by the SRWMD from nearly 40 wells within the projected ground-water basin of the spring system. These wells consisted of both monitoring and domestic wells. All wells were located with a GPS system and their elevations surveyed by a District consultant. Water levels were measured in September 2003 to ensure synoptic sampling. These data were then supplied to SDII in electronic format.

Geostatistical analysis is a two-step process (Isaaks and Srivastava, 1989). First, a structural analysis is performed to determine the pattern of variance with distance between sample pairs. The results of this analysis assist in determining how far apart the samples can be before they are no longer correlated and beyond which contour lines can no longer be drawn. In addition, the structural analysis allows one to establish rules for estimating the uncertainty of interpolations between correlated data points.

Once the structural analysis is completed and the "rules" of uncertainty estimation are completed, the second step, kriging, is initiated. Two maps are prepared as part of the kriging process. The first is the traditional contour map showing the distribution of the property being contoured. The second map is an uncertainty map, which illustrates the uncertainty associated with interpolation between data points and the areas where one should not interpolate or extrapolate because the data points are too far apart, and the magnitudes of uncertainty between correlated points are too high. This map is used to select additional monitoring locations, if needed, and to evaluate the uncertainty associated with the contour map.
Kriging of the potentiometric surface data from the MBS ground-water basin was used to contour the potentiometric-surface data at high resolution (*i.e.*, 1 foot). The kriging allowed for estimation of the uncertainty associated with the contour maps. The structural analysis was performed using the U.S.E.P.A. code Geo-Eas (Englund and Sparks, 1991). Semivariograms, produced during the structural analysis, revealed at what level the water-level data could be contoured. This information was then used to develop kriged contour and uncertainty maps. The kriged maps were then contoured using Surfer® (Golden Software, Inc., 2002).

3.3 Results and Discussion

3.3.1 Simulation of River Data

Stage and discharge data for the gauges on the Withlacoochee River near Madison and near Lee were simulated. The stage data were simulated through step-wise multiple regressions. The discharge data were simulated by developing a stage-fall-discharge rating for each gauge. These analyses allowed for the generation of over 70 years of hydrologic data for the Withlacoochee River downstream from MBS.

3.3.1.1 Simulation of River Stage Data

As discussed in Section 3.3.1, the two steps in simulating the river stage data were (1) cross-correlating variables and (2) performing step-wise multiple regressions. The dependant variables (stage at Madison and Lee) were cross-correlated with the independent variables (Withlacoochee River stage near Pinetta, Suwannee River stage near Ellaville, rainfall from NOAA station in Madison). Figure 3-5 illustrates sample cross-correlation correlograms. The correlograms reflect broad peaks with maximum lags of approximately 1-15 days.

The first multiple regression was run for the stage at the Lee gauge. The original and lagged stage at Ellaville and Pinetta and rainfall at Madison were entered as the independent variables. The step-wise multiple regression proceeded to remove all non-significant ($\alpha > 0.05$) variables except the unshifted stages (h) at the Pinetta and Ellaville gauges. The resulting polynomial for the stage at Lee is:

$$h_{Lee} = -7.053 + 0.195h_{Pinetta} + 0.887h_{Ellaville}$$

As might be expected, the stage at Lee is most dependant on the stage at Ellaville (the Lee gauge is about 2 miles from Ellaville and over 15 miles from the Pinetta gauge). This equation reproduces the Lee stage data with an R^2 of 0.996, a very good and statistically significant fit. A plot of the measured daily values for the original period of record is shown in Figure 3-6. The simulated data follows the daily values almost exactly.

Next a multiple regression was run for the stage at the Madison gauge. The original and shifted stage at Lee and Pinetta and rainfall at Madison were entered as independent variables. The step-wise multiple regression proceeded to remove all variables except the statistically significant ($\alpha < 0.05$) contemporaneous stage at the Pinetta and Lee gauges. The resulting polynomial for the stage at Madison is:

$$h_{Madison} = -3.198 + 0.588h_{Pinetta} + 0.428h_{Lee}$$

In this case, the stage at Madison is more evenly dependant on the two independent variables. This reflects the fact that the Madison gauge is located approximately equally distant from the Lee and Pinetta gauges. This equation reproduces the Madison stage data with an R^2 of 0.996, again a statistically significant fit. The measured stage data at Madison are infrequent, but there are several intervals when the data were collected on a daily basis. The measured stage values

for the Madison gauge during the first seven months of 1984 are shown in Figure 3-7, along with the simulated stage values, which follow the measured values quite well.

It should be noted that while short data sets (approximately 500-1000 records) are being used to generate a much longer data set (over 70 years of daily data), the measured values cover a wide range of values. So the polynomial generated by the multiple regression can be relied upon over a wide range of river stages.

3.3.1.2 Simulation of River Discharge Data

The river discharge data were simulated from the simulated stage data using stage-fall-discharge ratings (Rantz et al., 1982). These ratings were developed from the measured stage-discharge data at each gauge. This involves calculating a rating discharge (Q_r) for each measured discharge using the following equation:

$$Q_r = Q_m/(F_m+y)^a,$$

where Q_m and F_m are the measured discharge and fall respectively, y is a small adjustment factor that can be either positive or negative, and the exponent a is typically between 0.4 and 0.6.

The rating discharge was plotted versus stage and the variables y and a were adjusted through trial and error until a best-fit curve through the data was obtained. Figures 3-8 and 3-9 show these graphs for the Lee gauge and Madison gauges, respectively. As the figures show, the fit of the polynomial curves to the data is significant (R^2 of about 0.99). The polynomials were then solved for the rating discharge, and a value for the rating discharge was computed for every simulated stage value for each gauge. For the Madison gauge, the polynomial does not yield a real number for stage above 70 ft; discharge was assumed to be a simple function of stage when stage was greater than 70 ft for this gauge. Once a rating discharge had been computed for each stage, the simulated discharge values were computed using the above equation solved for Q_m.

Figures 3-10 and 3-11 show the simulated period of record of river discharge for the Lee and Madison gauges, respectively. Figures 3-12 and 3-13 show the stage-discharge plots for these

periods of record, comparing the simulated data to the measured data and the daily values. The measured data and daily discharge values tend to fall within the area of the simulated data in both plots.

3.3.2 Predicting Spring Discharge

The 22 measurements of spring discharge were compared to various data from the Withlacoochee River to find relationships that could be used to predict spring discharge. The basis for the MFL for MBS is the spring's contribution to flow in the river, so spring discharge was plotted against discharge in the Withlacoochee River for the gauge near Lee (downstream from the spring). Figure 3-14 shows this cross-plot and a polynomial that best fits the data. A polynomial trendline fit the data better than a linear one. Also, the nature of MBS discharge suggests a curvilinear relationship. Spring discharge increases with river discharge to some river stage. As river stage continues to increase, spring discharge should begin decrease as the river floods the spring. It should be noted that use of the equation in Figure 3-14 to predict spring discharge is limited to the range of river discharges shown on the plot. So spring discharge can be calculated for river discharge at Lee of less than about 2,500 cfs (0.25 exceedance probability). This is still useful for the purposes of this study, since low flows are of greatest interest.

Using this relationship between river discharge and spring discharge is an oversimplification of this hydrologic system. Obviously, the river discharge will increase and decrease at times and for reasons unrelated to spring discharge. Changes in spring discharge may be offset by other factors resulting in no net change in river discharge. This simple relationship does not account for any of these possibilities. The significant data fits, however, demonstrate that discharge from MBS is normally related to the riverine regime.

To understand the value of this relationship between spring and river discharge, the predicted values of spring discharge were plotted against the corresponding daily values for total inflows or outflows to the river (calculated by subtracting Pinetta discharge from Lee discharge). Intuitively, gains (inflows) represent baseflow, while losses occur when the springs are flooded and functioning as estevelles.

It is reasonable to expect that the predicted spring discharge values would have a direct relationship with the total inflows to or outflows from the river. This is not always the case when spring discharge is calculated using the relationship in Figure 3-14. Figure 3-15 shows that the river experiences a range of inflows and outflows at times of high predicted spring discharge. Below spring discharge of about 80 cfs there is a direct relationship between spring discharge and total inflows to the river. This analysis suggests that the relationship between simulated spring discharge and river discharge may be valid at spring discharge below 80 cfs and that uncertainty in the discharge prediction increases with increasing predicted MBS discharge above 80 cfs.

Another possible relationship for predicting spring discharge was explored by plotting the 22 spring discharge measurements from MBS against their corresponding daily values for total inflow to or outflow from the river between the Pinetta and Lee gauges. Figure 3-16 shows that a statistically significant linear relationship exists within this small dataset. By assuming that this linear relationship holds for the full range of inflows to and outflows from the river experienced over the period of record, a complete period of record data set can be synthesized for discharge at MBS.

While this relationship is a better predictor of spring discharge than the relationship between spring discharge and river discharge, it still oversimplifies the hydrologic system to some degree. The numerous springs along the Withlacoochee River all respond to changes in river levels differently. MBS is not appreciably affected by changes in river level when the river is below the sill in the spring run. Other smaller springs located within the river channel should respond to all changes in river levels, even during low flows. The relationship in Figure 3-16 assumes equal responses from all conduits between the river and ground-water. During extreme high flow events, there is certainly some aspect of overland flow, both into the river at times and out from the river into the flood plain at other times. The relationship in Figure 3-16 assumes that all inflows to and outflows from the river occur through the ground. Despite these simplified assumptions, this relationship is a reasonable predictor within the most common range of spring discharges, especially at low flows.

Relationships between spring discharge and other data (e.g., groundwater levels in wells) exist, however, these relationships are not as useful as those described above because of the limited period of record and/or data frequency associated with the well data. Only the simulated and

measured river stage and discharge data can allow for development of the 70+ year period of record for spring discharge.

A continuously monitored stream gauge was installed by the USGS within the spring run of MBS in late 2002. Until very recently, the data from this gauge could not be relied upon because the gauge had not been calibrated. The gauge has been calibrated at this point and Figure 3-17 presents some of these data. Also plotted are the simulated discharge based on the relationship between spring and river discharge, simulated discharge based on the relationship between spring discharge and inflows to and outflows from the river, and stage at the Withlacoochee River near Madison (secondary axis).

A number of observations can be made from Figure 3-17. The spring discharge simulated from inflows to and outflows from the river has a continuous record and follows the USGS spring discharge reasonably well. The spring discharge simulated from river discharge is discontinuous and doesn't always follow the other two spring discharge lines. The two simulated spring discharges have opposite reactions to changes in river stage. As stage goes up, the spring discharge simulated from river discharge also goes up (because as river stage goes up, river discharge goes up), but spring discharge simulated from inflows to or outflows from the river goes down. This is because an increase in river stage results in reduced discharge in some or all of the springs on the Withlacoochee River.

The calculation of spring discharge from river inflows/outflows assumes that all springs are equally affected by changes in stage, which is probably not the case. For example, the small increases in stage in August and September 2002 probably did not result in significant reductions of spring discharge, as the prediction based on river inflows/outflows would indicate. During these events the predictions of spring discharge based on river discharge may be more accurate (unfortunately the USGS gauge data do not go back this far). On the other hand, the large flooding events beginning in November 2002 probably did result in significant reductions in MBS discharge, as the USGS gauge and simulated data from inflows/outflows show. During these events the spring predictions based on inflows to and outflows from the river are surely most accurate. During periods of stable low stage, the two methods of simulating spring discharge agree fairly well. Since these low flow periods are of greatest interest in establishing a MFL for the spring, simulated spring discharge from either method should be equally useful for the purposes of looking at these flows. However, to look at long-term statistics of flows

probabilities, the simulated data from inflows/outflows should be used because this method produces a full and more accurate period of record.

While a good linear relationship is seen between total inflows/outflows to the river and Madison Blue Spring discharge (Figure 3-16), this relationship apparently breaks down at the extremes of the flow regime of Madison Blue Spring. The spring discharge measurements were all obtained during times of relatively low river stage, because of difficulties accessing the spring when the river stage is high.

Note that, times of low river stage are of primary concern with respect to the MBS MFL. In order to examine the MBS flow regime during times of low river stage, a flow duration curve for the Madison Blue Spring discharge data (simulated from inflows/outflows to the river) during the time when the stage in the Withlacoochee River near Pinetta is below 55 ft. was generated (Figure 3-18). The stage in the Withlacoochee River near Pinetta is below 55 ft approximately 50 % of the time, and corresponds to a stage in the Withlacoochee River near Madison of 42.7 ft. The minimum stage recorded (or simulated in the case of the Madison gauge) in the Withlacoochee River near Pinetta and near Madison are 53.26 ft and 40.37 ft, respectively. So, at the 50 % exceedance probability of stage in the Withlacoochee River, there is approximately 2 ft of water flowing in the river channel, considerably more than the river stages discussed in the MFL criteria below. The MBS run was recently surveyed and the spillway within the run is at an elevation of approximately 42 ft. Therefore, Figure 3-18 provides a good representation of the flow regime of MBS when the river has little if any effect on spring discharge and during the times of low stage in the river, the focus of the MFL for MBS.

As discussed above, there is a certain level of uncertainty associated with each step in the process of simulating spring discharge data. The accumulated uncertainty at the end of these steps may be quite high. However, it would appear that while overall uncertainty may be high, the uncertainty associated with simulated spring and river data at low flows is certainly much less. An examination of Figures 3-14, 3-15, and 3-16 shows the relationships between spring and river discharge are much more significant at low flows than at high flows. Therefore, the simulated spring discharge is assumed have an acceptable level of uncertainty for low spring discharge rates, which are of primary concern with respect to an MFL for MBS.

3.3.3 Maintaining Flow Over Withlacoochee River Shoals

The effect of a range of spring discharges on the stage of the river over a series of shoals located downstream from MBS was investigated. A HEC-RAS model was calibrated to low river flows to look at the range of stages over these shoals during low flows. The stages were then related to spring discharge.

3.3.3.1 HEC-RAS Modeling

The Army Corps of Engineers HEC-RAS model of the Withlacoochee River as originally developed, was recalibrated as a dynamic model to a low-flow data set. The calibration period chosen was the 100-day period between August 1, 2002 and November 8, 2002. This period was chosen because the river experienced record low flows during this time and a good representative range of low flows occurred. There was no measured data at the time the cross sections were taken to calibrate the HEC-RAS model.

To begin with, the model size was reduced to include only the portion of the river between the Pinetta and Lee gauges. Next, the boundary conditions were specified. The upstream limit was set as a flow boundary and the downstream limit of the model was set as a stage boundary. In other words for each day in the model simulation, the upstream flow was fixed at the daily value for flow at the Pinetta gauge and the downstream stage was fixed at the daily value for stage at the Lee gauge. Two uniform inflow boundaries were also entered into the model. The difference in flow from the Pinetta to the Madison gauge was uniformly entered into the model along that reach, and the difference in flow from the Madison to the Lee gauge was uniformly entered into the model along that reach. Inflow to the river is obviously not uniform, particularly between Madison and Lee (inflow is concentrated at the springs), but this was a necessary simplification. The data used for these boundary conditions can be found in Appendix A – Exhibit 5. The initial condition for the model was set as the initial value of flow at the Pinetta gauge for the 100-day period.

The calibration parameter in a HEC-RAS model is the roughness coefficient (Manning's n). Adjusting the roughness coefficient upwards increases streambed friction in the model and increases stage for a given flow. Conversely, reducing the roughness coefficient decreases streambed friction, decreasing stage for the same flow. The model was calibrated to the pattern of stage simulated for the Madison gauge. It was immediately apparent that a single value of

the roughness coefficient for the channel would not result in a good model calibration. So a flow dependant roughness coefficient was used. Table 3-4 illustrates the full range of roughness coefficients used in the calibrated model. At the lowest flows, the roughness coefficient was very high (0.14 below 300 cfs) and was gradually reduced as flow was increased (down to 0.0275 at 1100 cfs). This is not surprising; at very low discharge values flow tends to be very turbulent, wetted perimeter is high relative to cross-sectional area, and water takes a much more tortuous path down the stream channel. As discharge increases, flow becomes more efficient.

Flow Range (cfs)	Manning's n
> 1100	0.0275
900 – 1100	0.0325
700 – 900	0.0375
500 – 700	0.045
300 – 500	0.065
< 300	0.14

Table 3-4. Range of roughness coefficients used in HEC-RAS model calibration.

The results of the calibration are shown in Figure 3-19. The HEC-RAS simulated data cluster fairly well around the data simulated for the Madison gauge as described in Section 3.3.1.1. It should be emphasized that at this point we are calibrating the model to statistically simulated data, not measured or daily values of stage and discharge. This therefore adds uncertainty to the results.

3.3.3.2 Shoal Inundation vs. Spring Discharge

With the HEC-RAS model calibrated, the stage and discharge hydrographs for the location of each of the six shoals located downstream from MBS were extracted from the model. For each value of discharge at the shoals in the model, a corresponding value of discharge at the gauge near Lee on the same day was obtained. Then the discharge of MBS was calculated from river discharge at the Lee gauge from the relationship discussed in Section 3.2. Following this process, a corresponding value of spring discharge was computed for each value of stage over each shoal from the HEC-RAS model. These data were used to calculate shoal inundation and the percent of shoals passable by fish populations for various values of spring discharge (Section 4).

3.3.4 Madison Blue Spring Basin Study Area

Based on the structural analysis of aquifer potentials (See Section 3.2.5), FAS water levels were modeled using a linear model with a range of 50,000 feet. The range is the distance over which the water-level data are correlated. When distances greater than the range separate monitoring points, the data points are not correlated and contouring between the points is theoretically incorrect. The sill is the highest local variance (semivariance) achieved within the range of the data. The sill was 45 $feet^2$ for water levels. The nugget is the local variance that is present over ranges that are too short to characterize. The nugget was 0 $feet^2$ for water levels.

Figure 3-20 illustrates the potentiometric-surface map of the FAS for September 2003. Surface water basins drawn by Foose (1981) are shown on the figure for reference. This map has been contoured at 1-foot intervals and selected roads have been superimposed on the map for reference. Note that the level of detail presented in the map is high, and some distinctive features are visible on the potentiometric surface map; the most important being the consistent gentle gradient that slopes downward from the northwest to the spring. This area represents a region of well-developed karst and high hydraulic conductivity. Areas where isopleths are somewhat closer together, such as under the Cherry Lake surface-water basin, are regions of slightly lower hydraulic conductivity. Regions of higher hydraulic conductivity appear to be separated by this slightly lower hydraulic conductivity zone. Higher hydraulic conductivities appear to be located in areas near Mile Pond Outlet and the Little Aucilla River basins, as well as near the spring in the Southeast Madison Karst and Southwest Withlacoochee Karst basins. The apparent variations in hydraulic conductivity and their influence on the shape of the potentiometric surface of the Floridan aquifer suggest that the aquifer is influenced to a greater extent by recharge through karst features than by surface-water drainage divides. Note that the data do not allow for closure of the ground-water basin to the northwest and north. Also note the absence of wells in the distal portion of the basin. The absence of well control may cause error in distal basin delineation.

Figure 3-21 depicts the K_{SD} (the level of uncertainty in the contours) map for the Floridan aquifer potentials for September 2003. Low K_{SD} values surround monitoring points and indicate areas of high confidence in the data. The high K_{SD} values represent uncertainty in feet. Uncertainty exceeds 4 feet in the areas north and northwest of the spring where monitoring locations are sparse or absent.

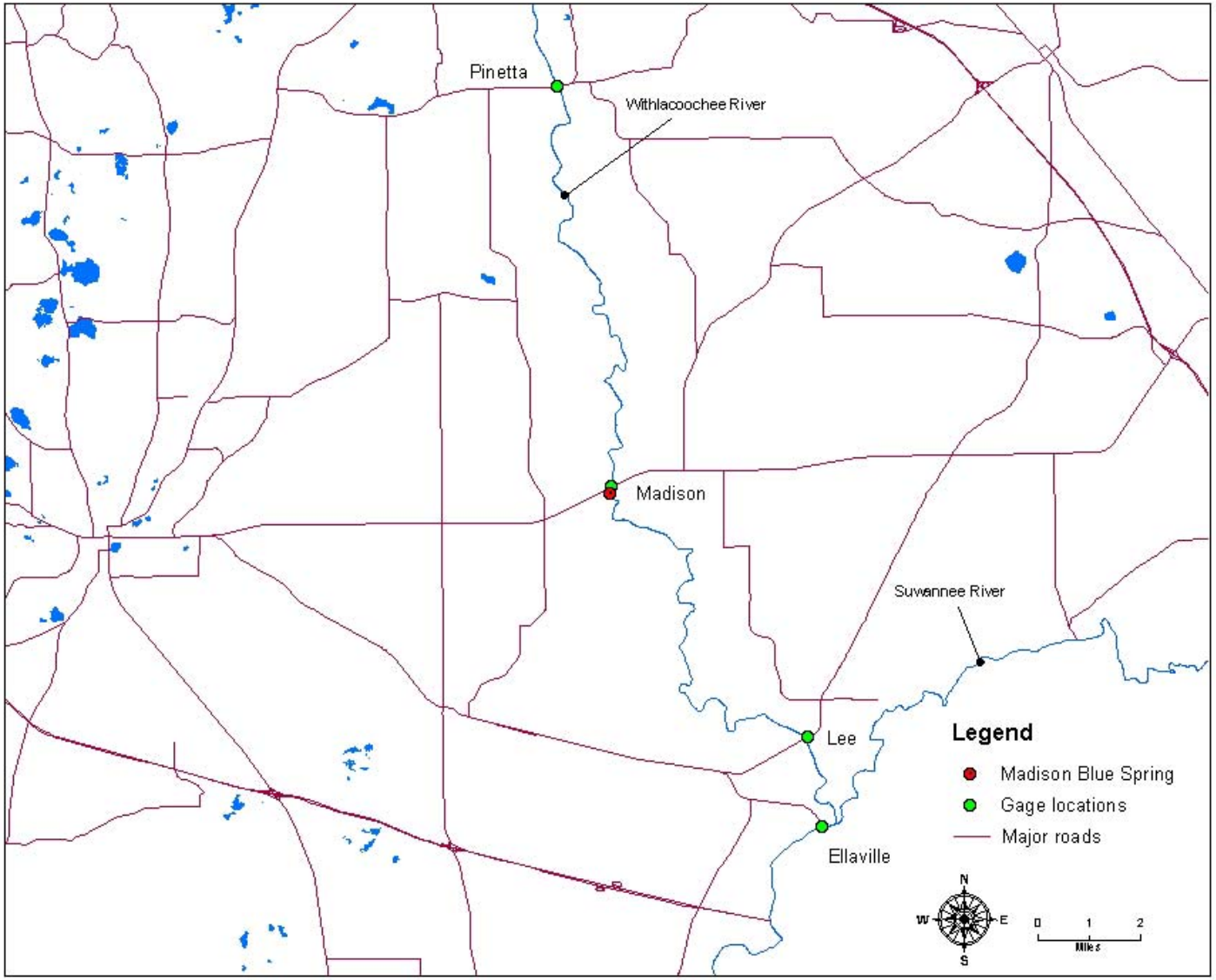


Figure 3-1. River gage locations in the Madison Blue Spring study area.

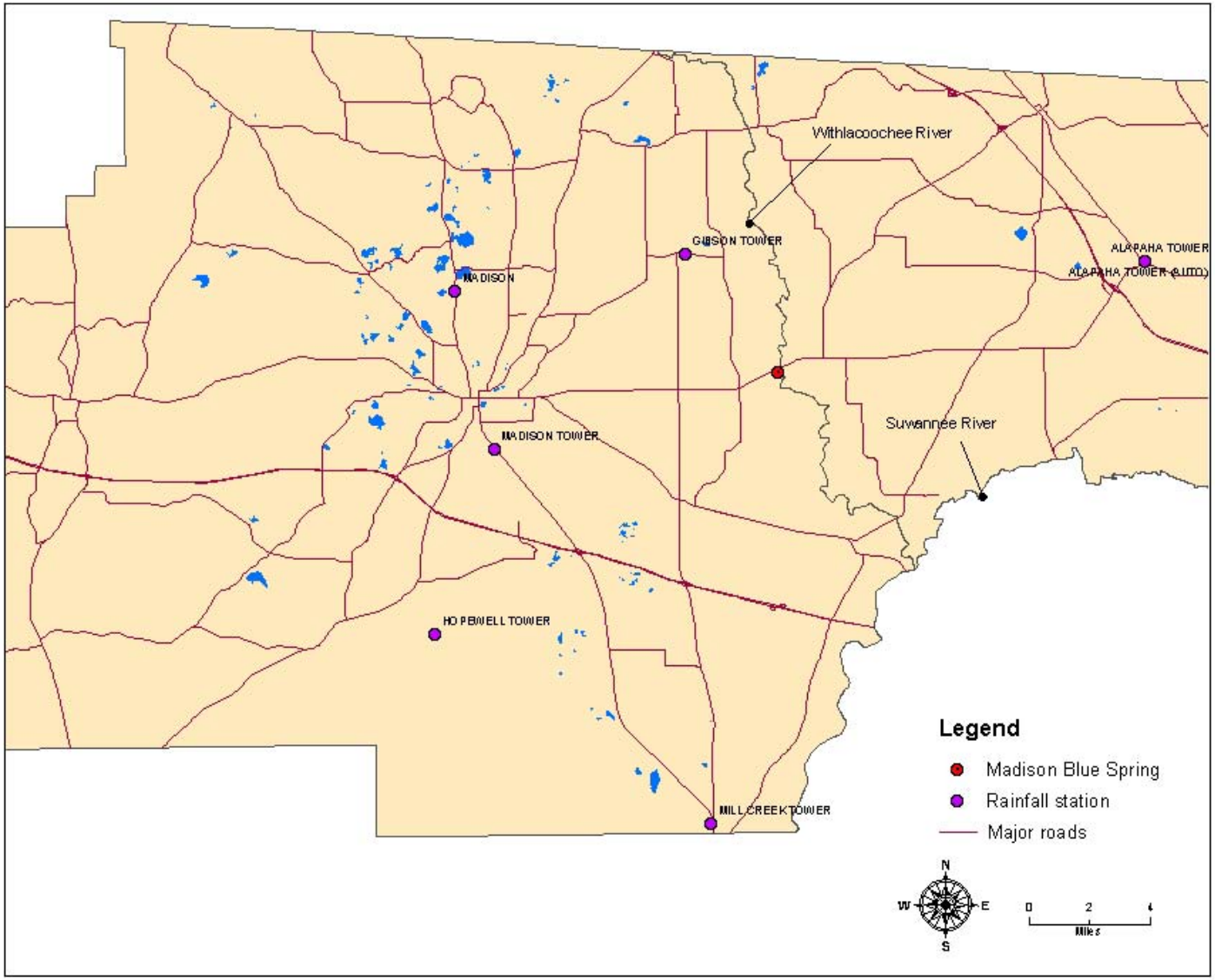


Figure 3-2. Location of rainfall stations in the Madison Blue Spring study area.

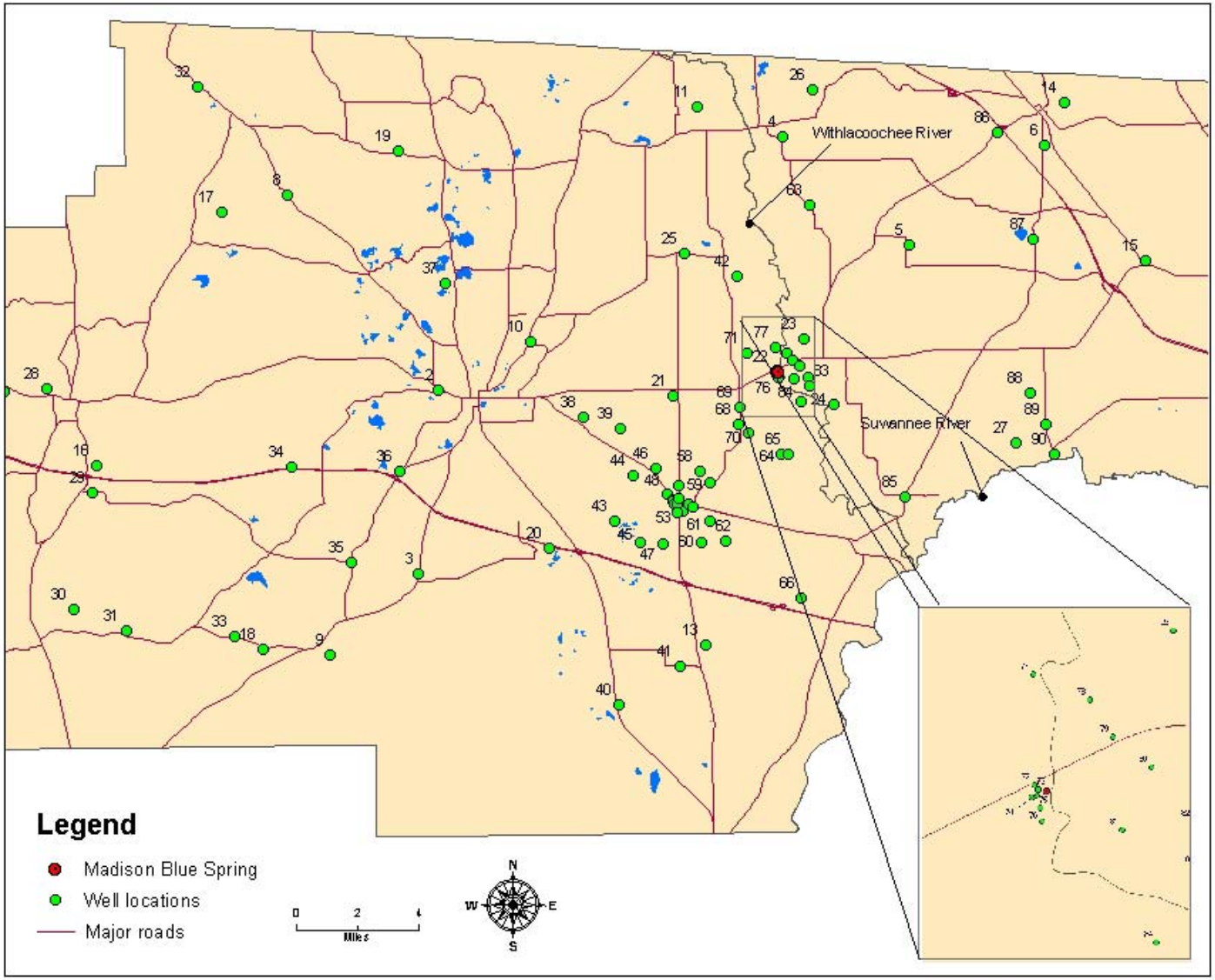


Figure 3-3. Location of wells in the Madison Blue Spring study area.

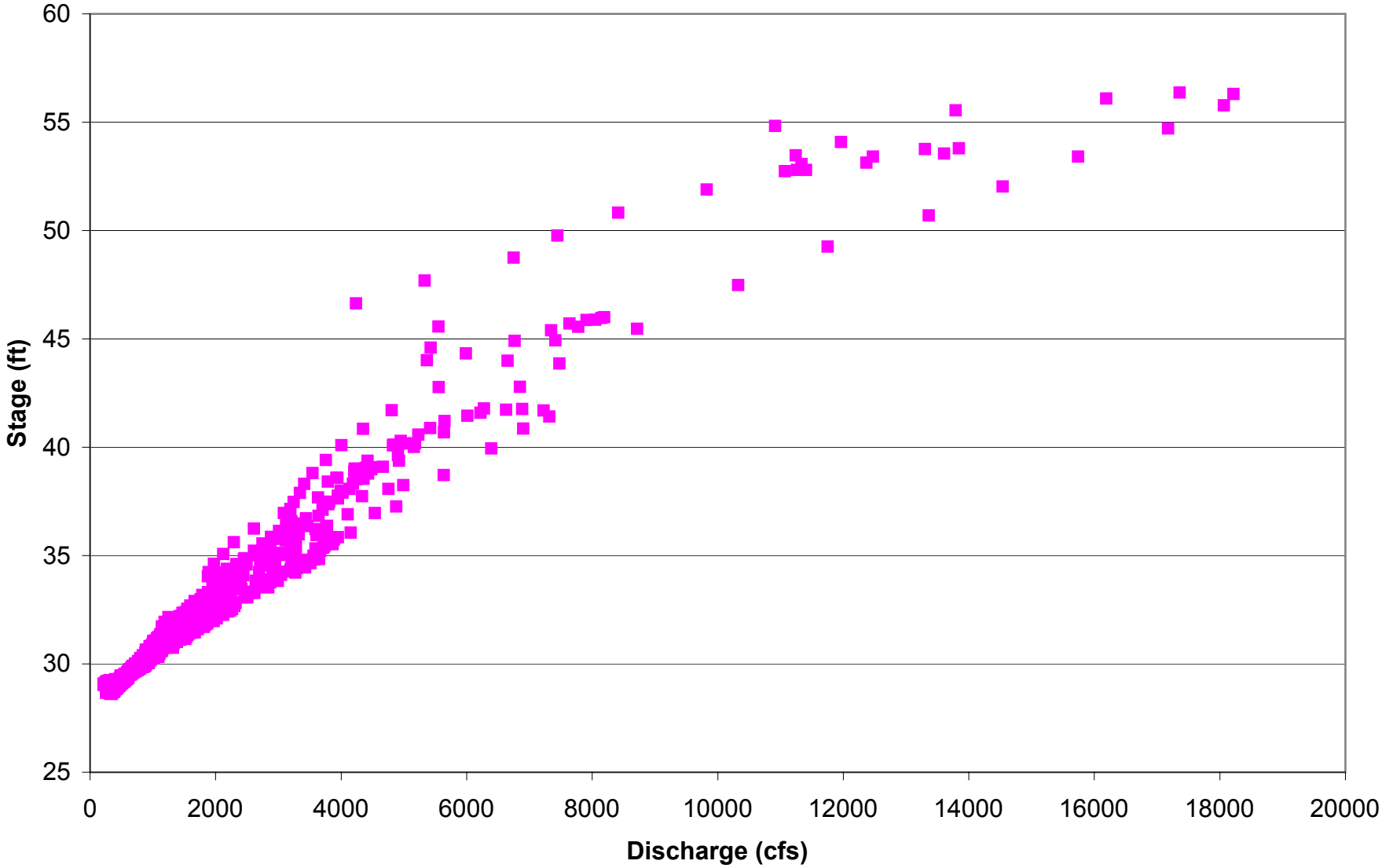


Figure 3-4. Stage-discharge plot of daily value data from the Withlacoochee River near Lee gauge

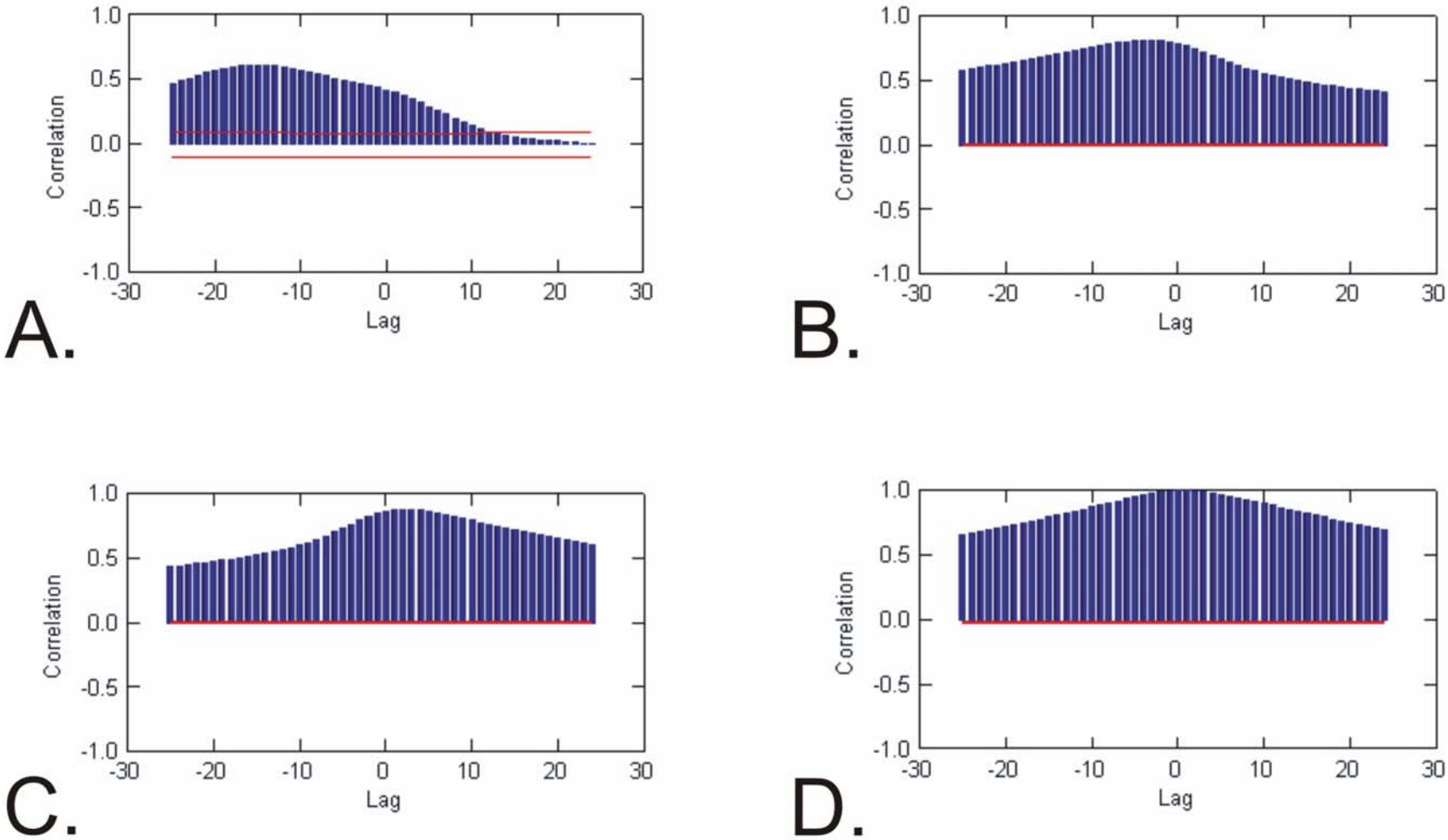


Figure 3-5. Cross correlation plots between: A. Rainfall at the Madison station and stage at the Lee gauge, B. Stage at the Pinetta gauge and stage at the Ellaville gauge, C. stage at the Lee gauge and stage at the Pinetta gauge, and D. Stage at the Ellaville gauge and stage at the Lee gauge.

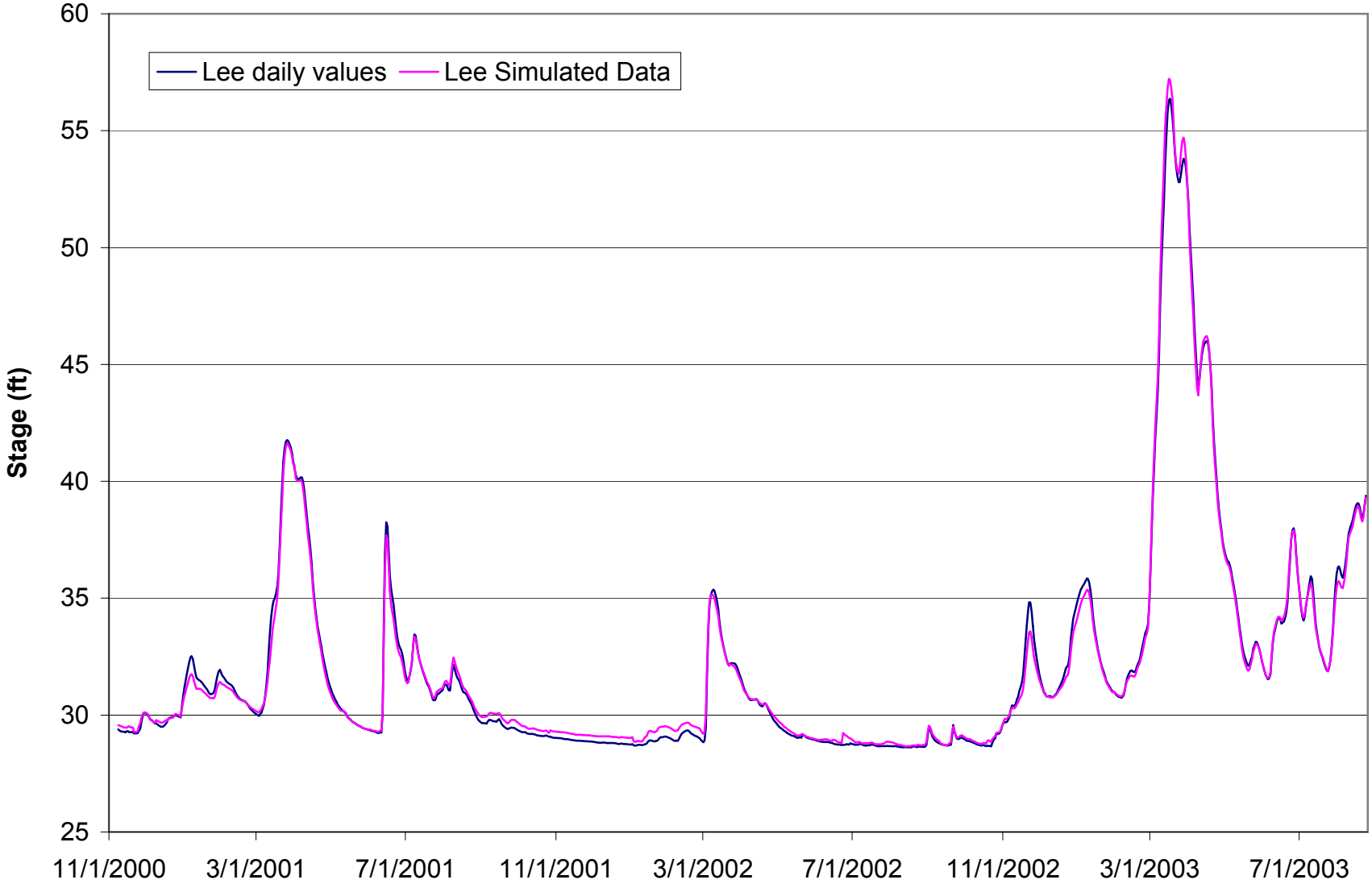


Figure 3-6. Comparison of daily value and simulated stage data for the Withlacoochee River near Lee gauge.

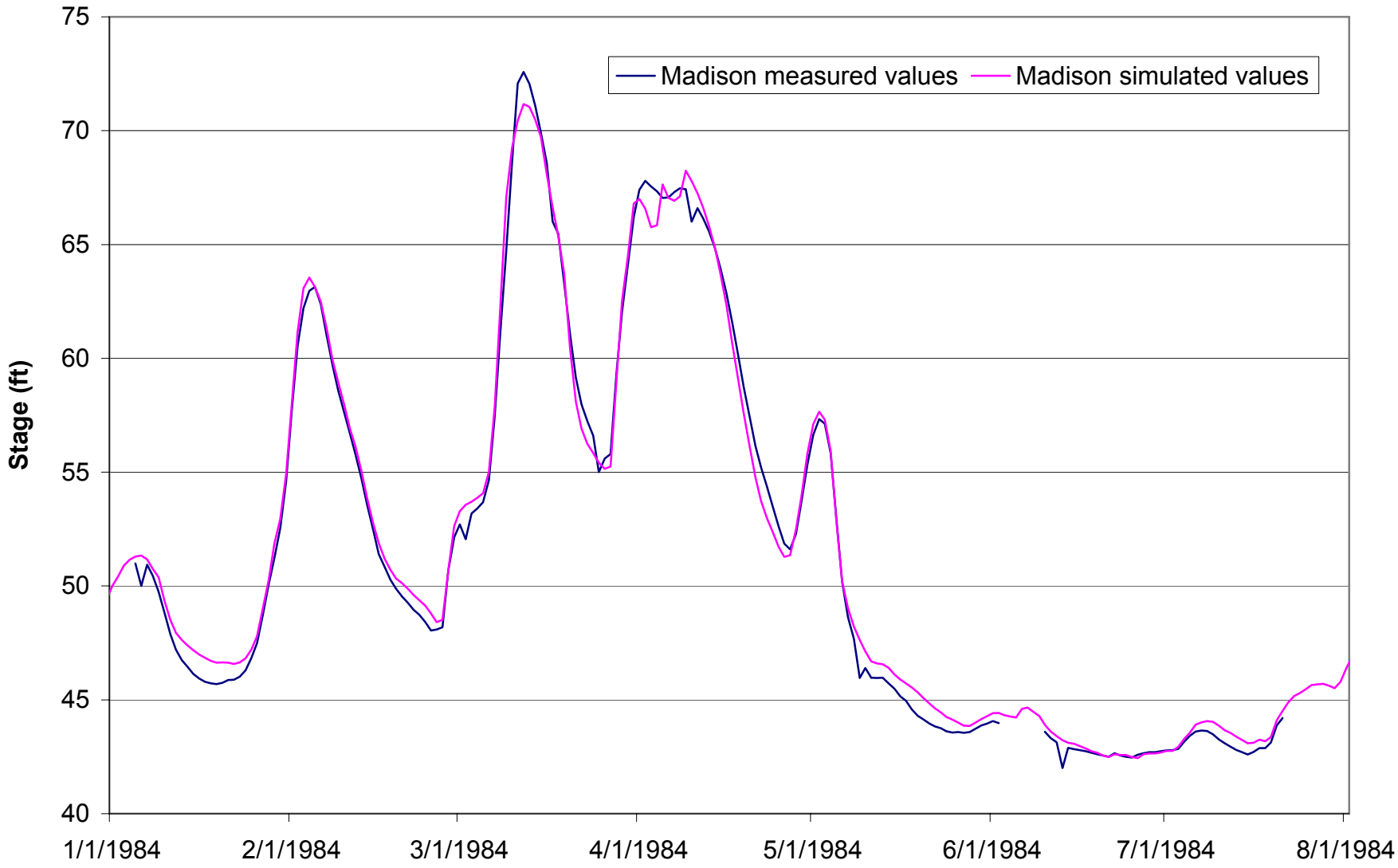


Figure 3-7. Comparison of measured and simulated stage values at the Withlacoochee River near Madison gauge.

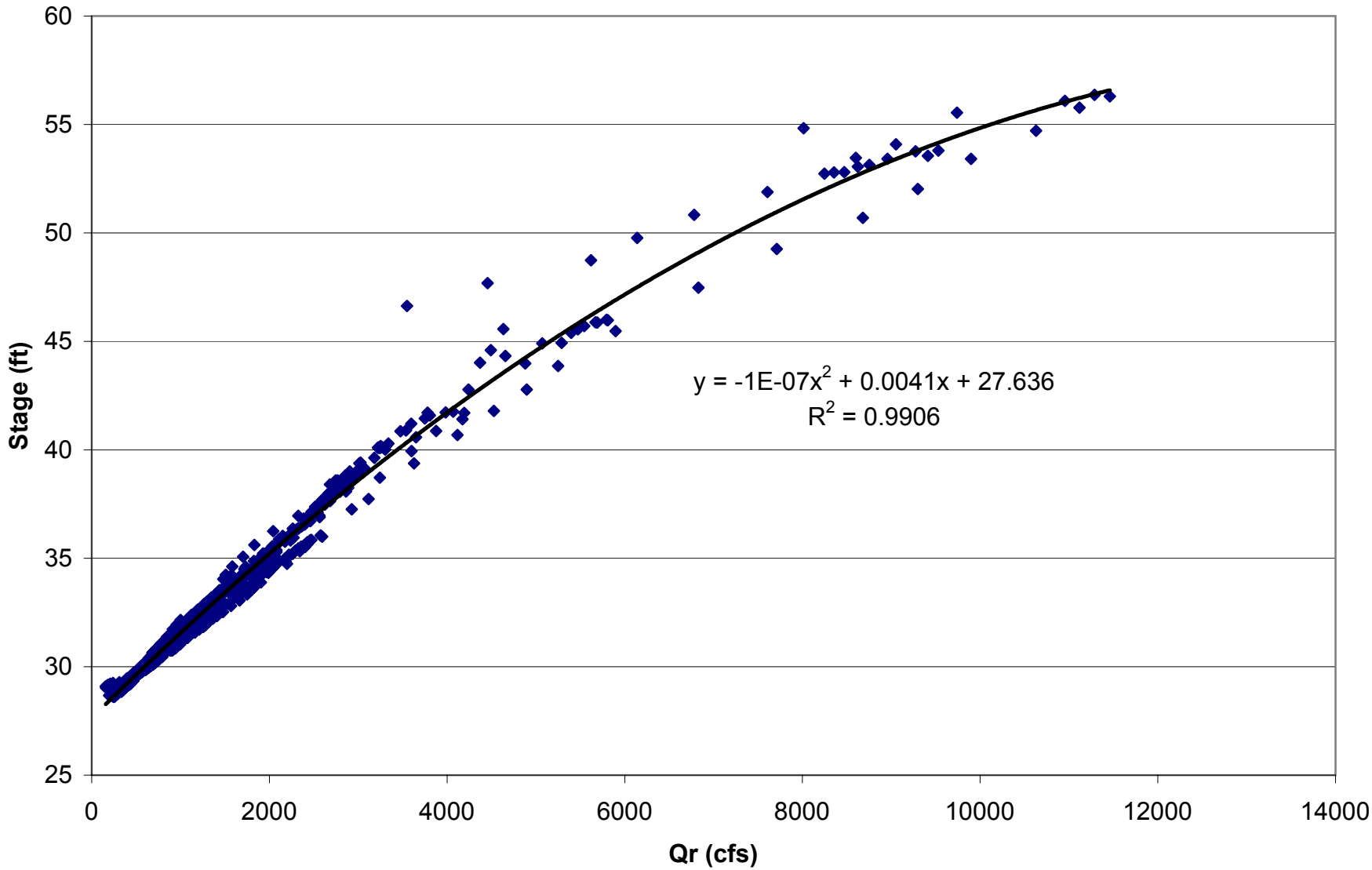


Figure 3-8. Stage versus the discharge rating for the Withlacoochee River near Lee gauge.

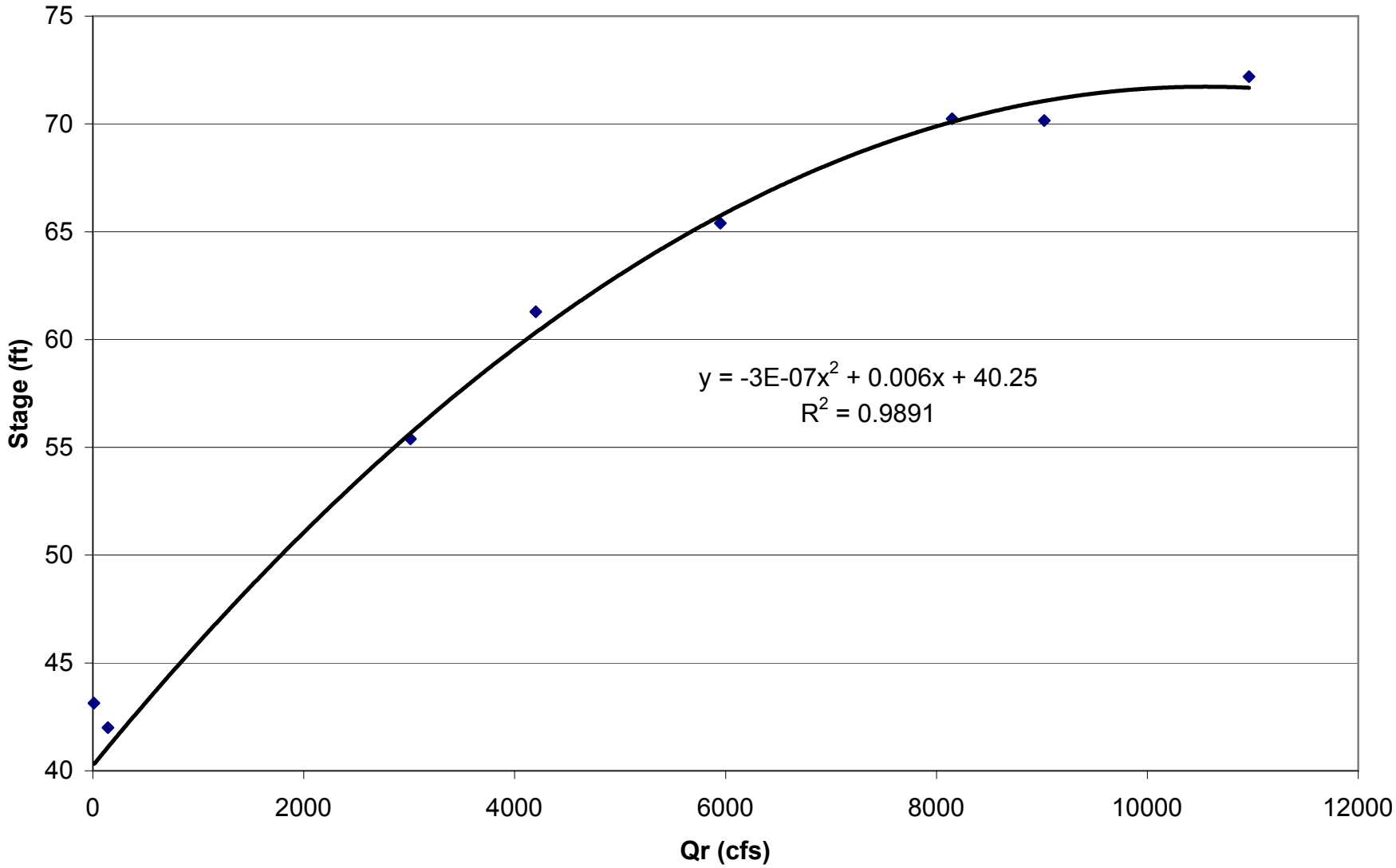


Figure 3-9. Stage versus the rating discharge for the Withlacoochee River near Madison gauge.

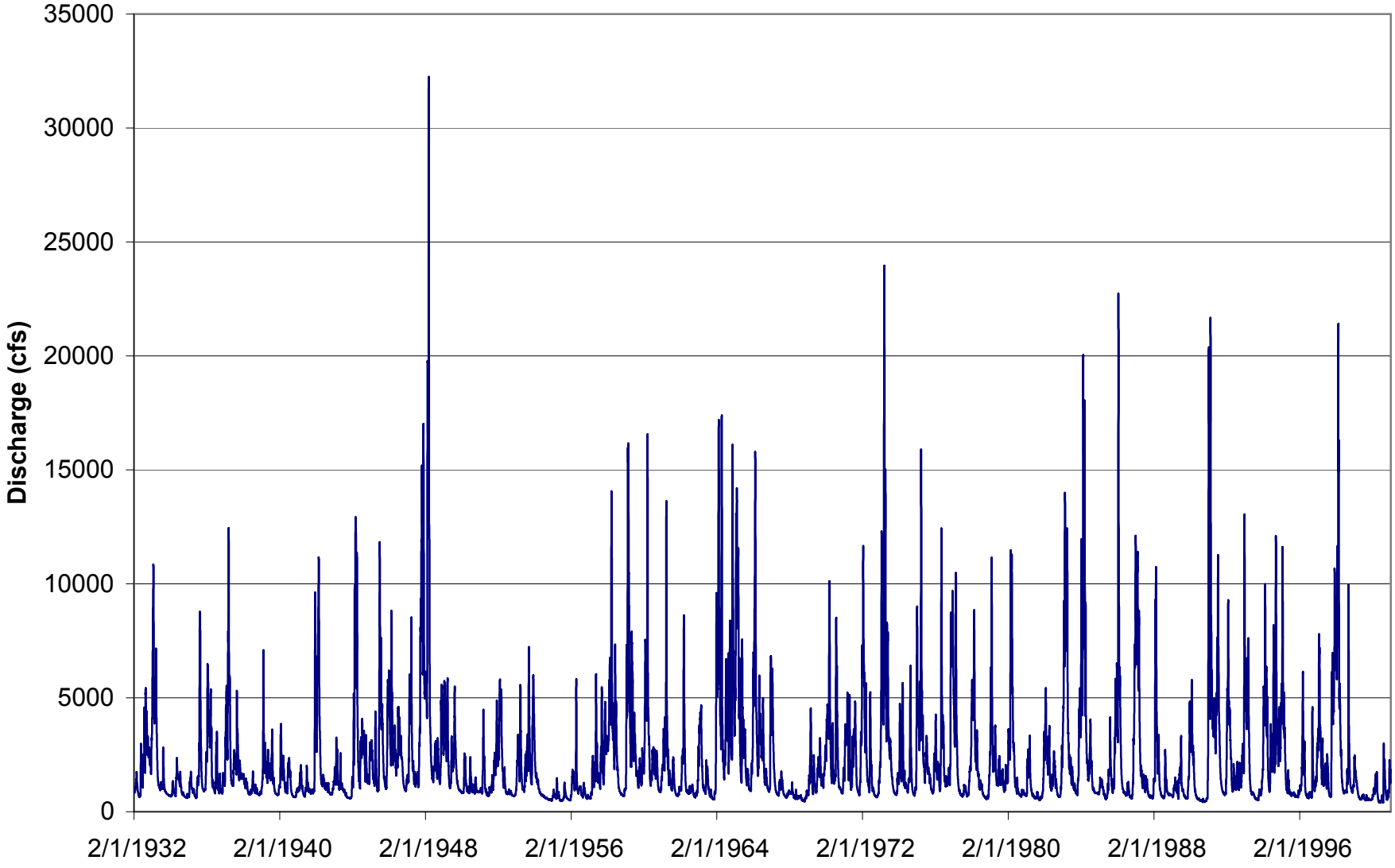


Figure 3-10. The simulated period of record for the Withlacoochee River near Lee gauge.

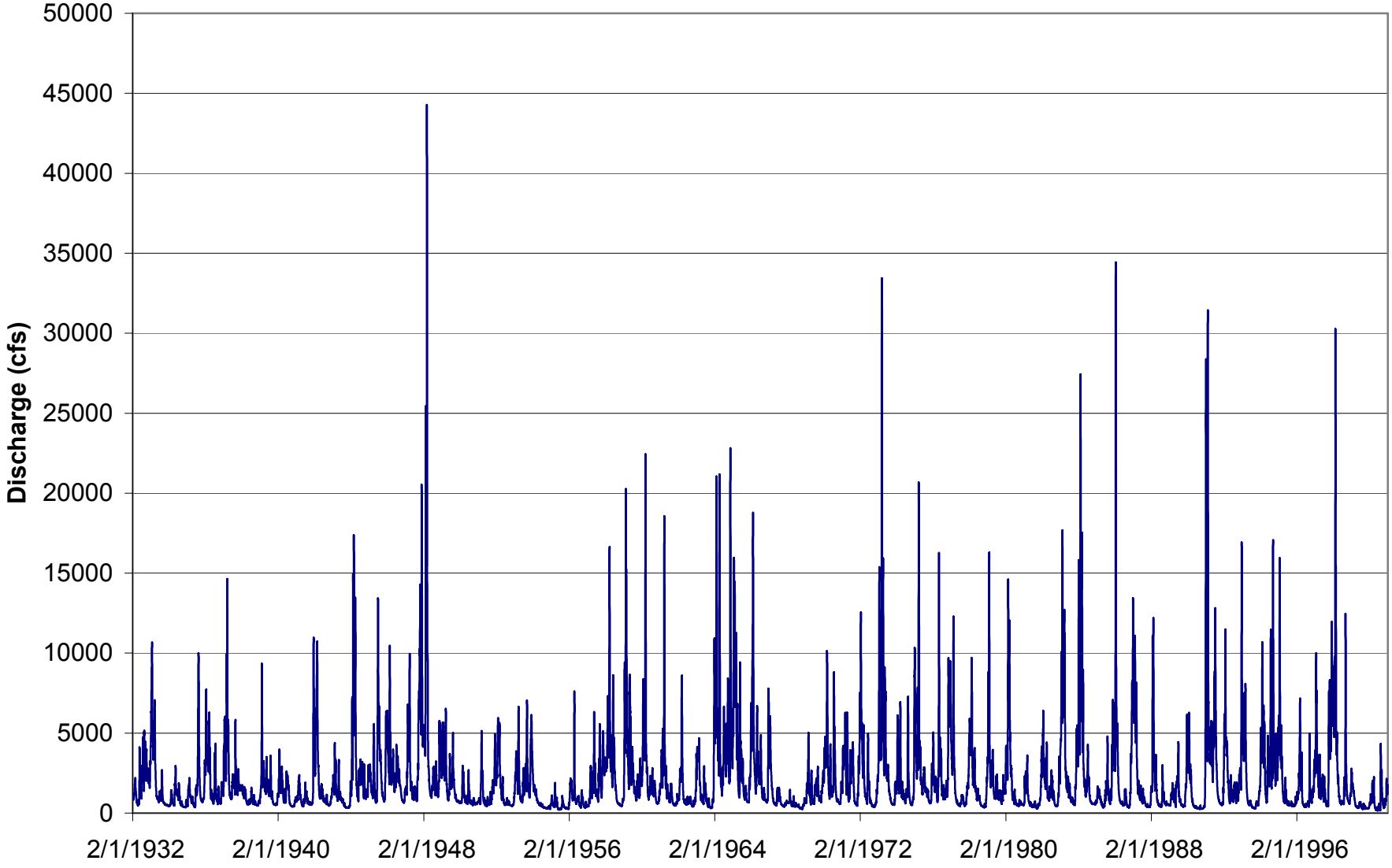


Figure 3-11. Simulated period of record for the Withlacoochee River near Madison gauge.

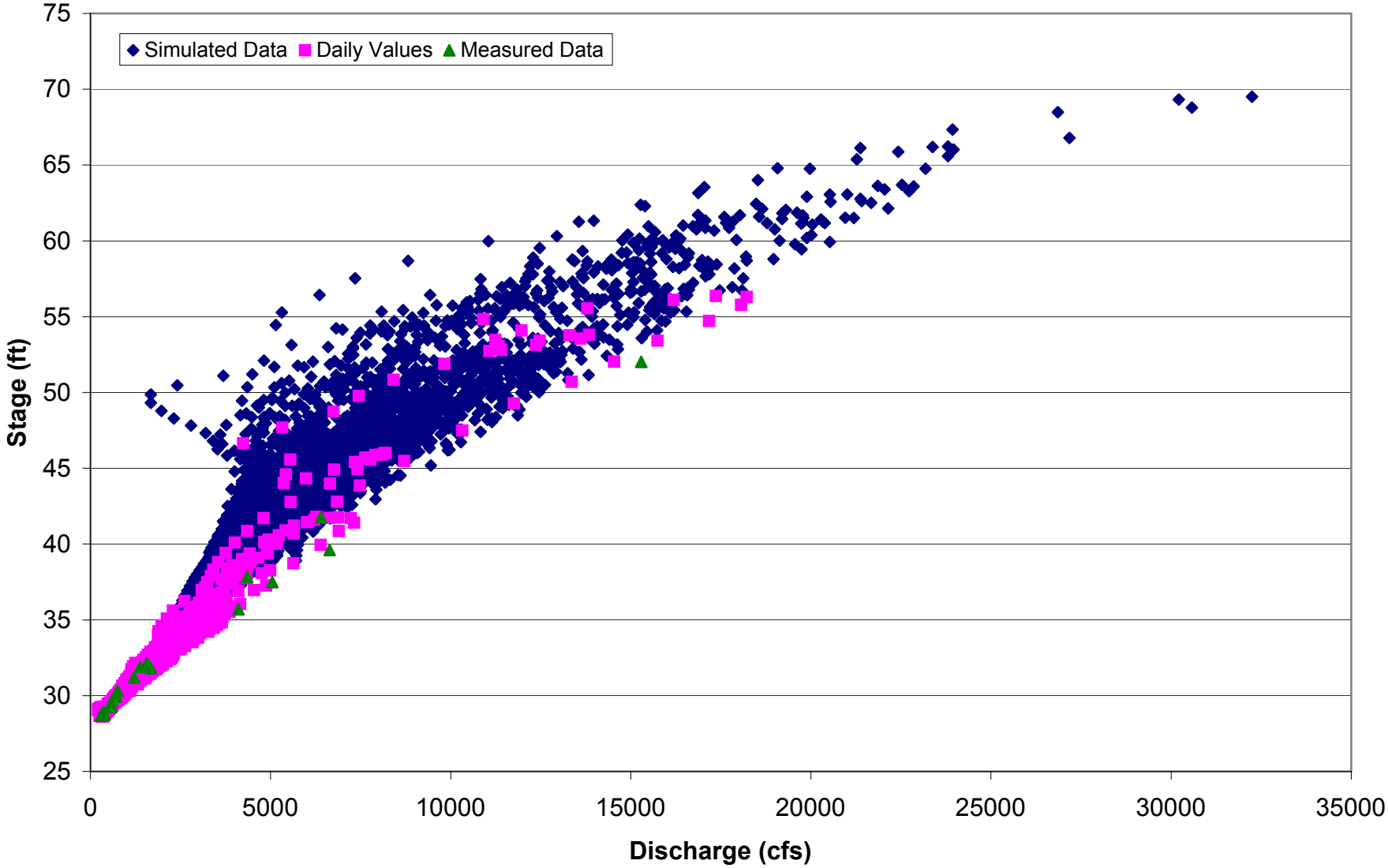


Figure 3-12. Comparison of simulated stage-discharge data with measured and daily value stage discharge data for the Withlacoochee River near Lee gauge.

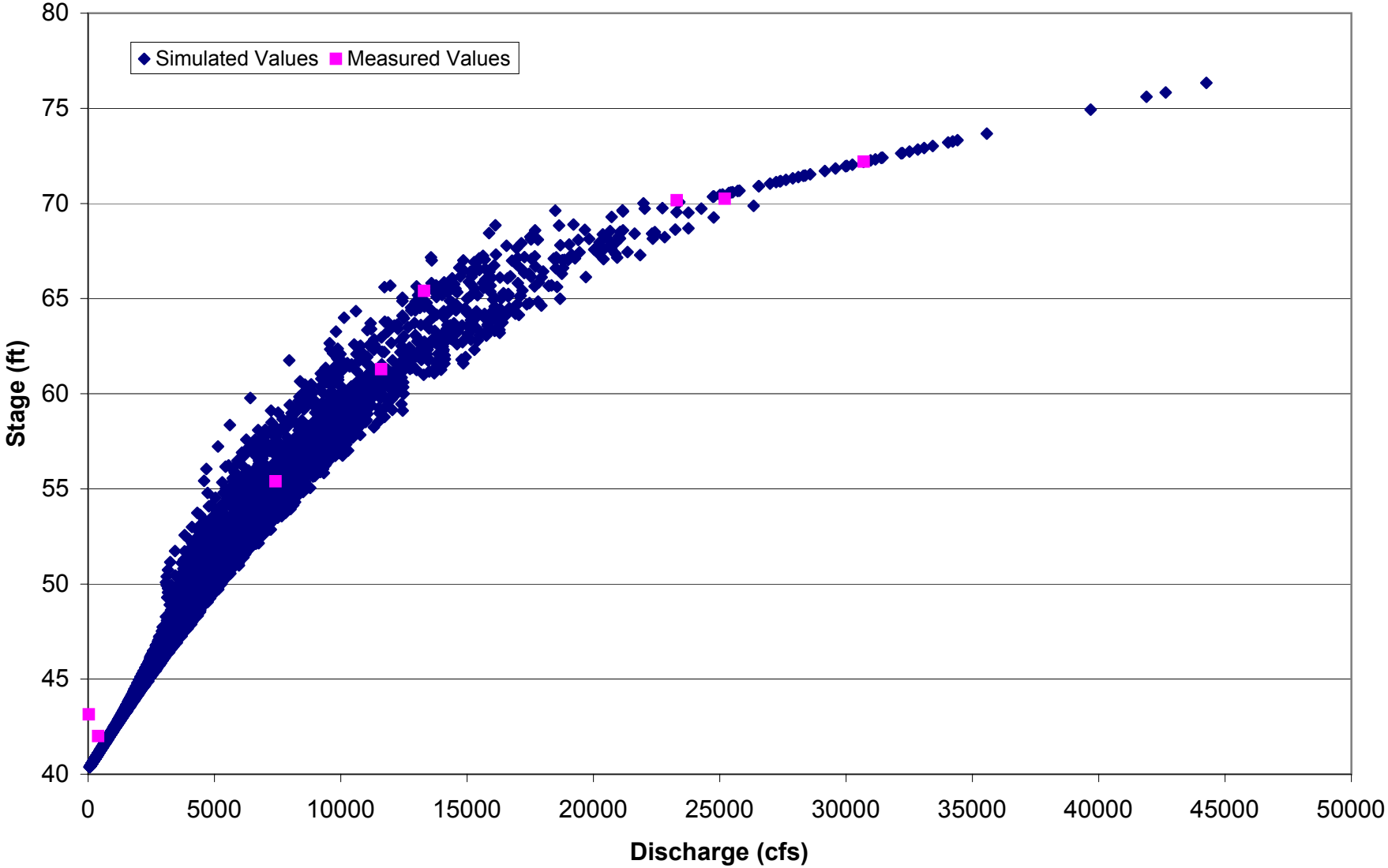


Figure 3-13. Comparison of simulated stage-discharge data with measured stage-discharge data for the Withlacoochee River near Madison gauge.

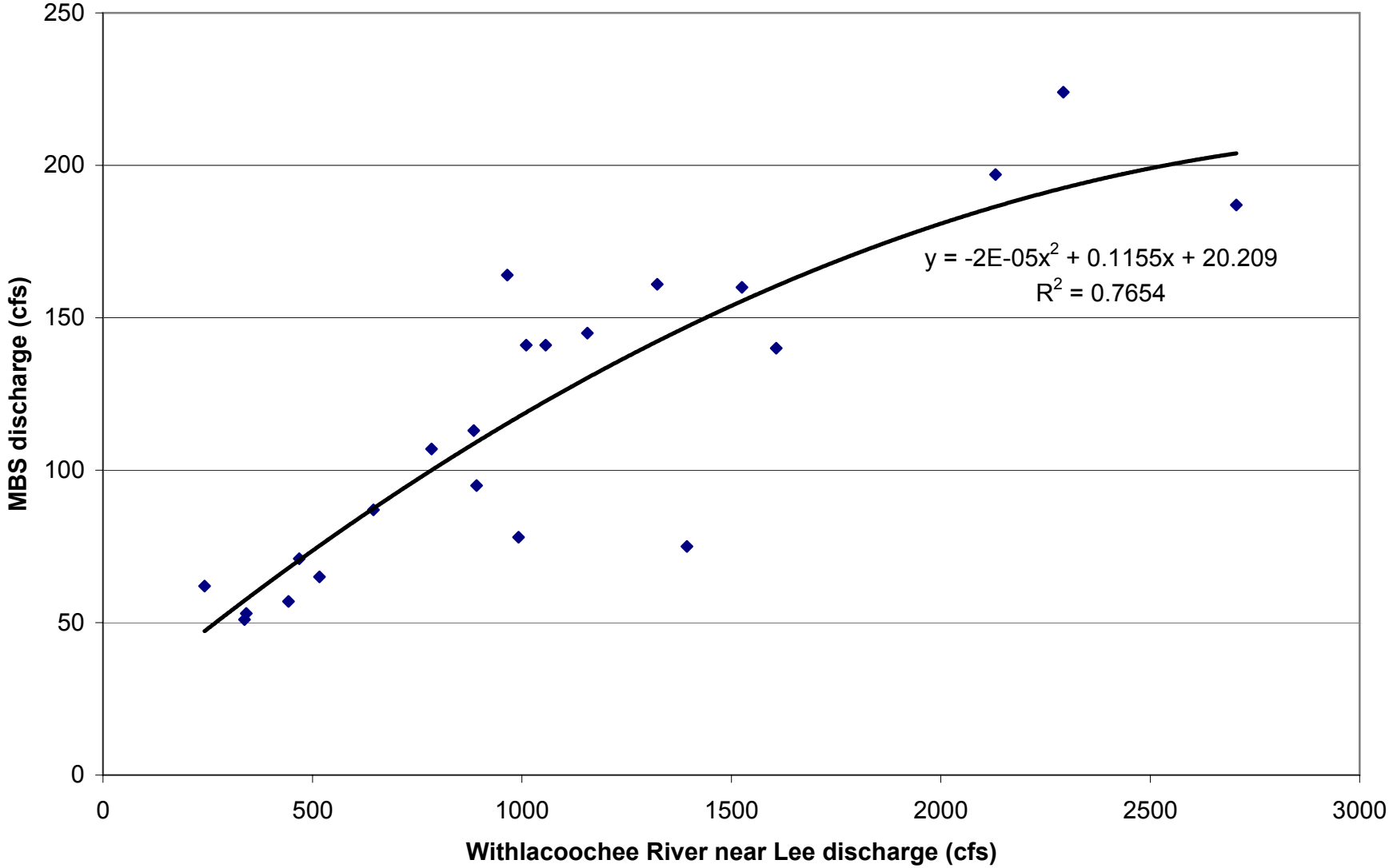


Figure 3-14. Relationship between Madison Blue Spring discharge and discharge at the Withlacoochee River near Lee gauge.

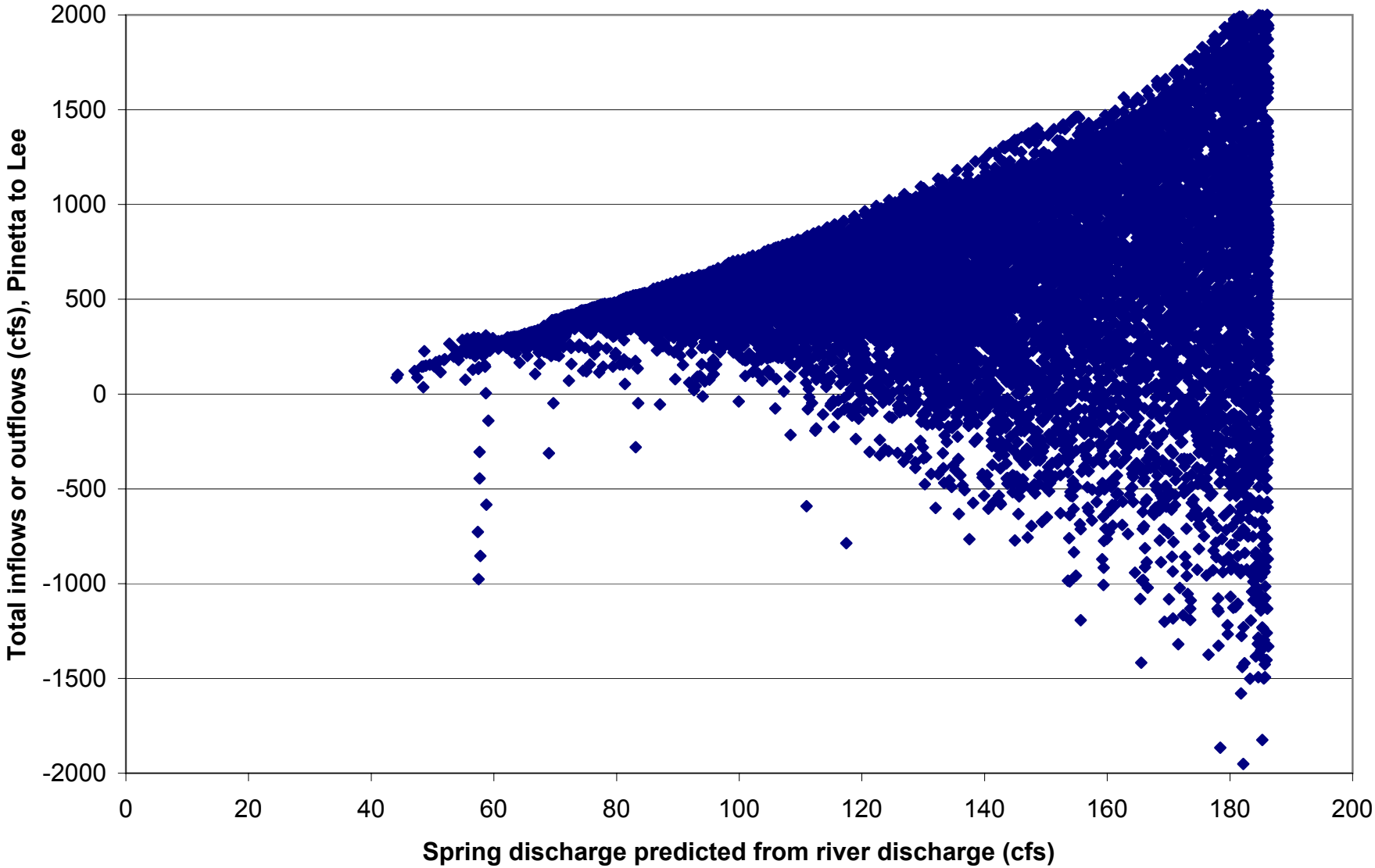


Figure 3-15. Comparison of the total inflows between the Pinetta and Lee gauges and the spring discharge predicted from the river discharge.

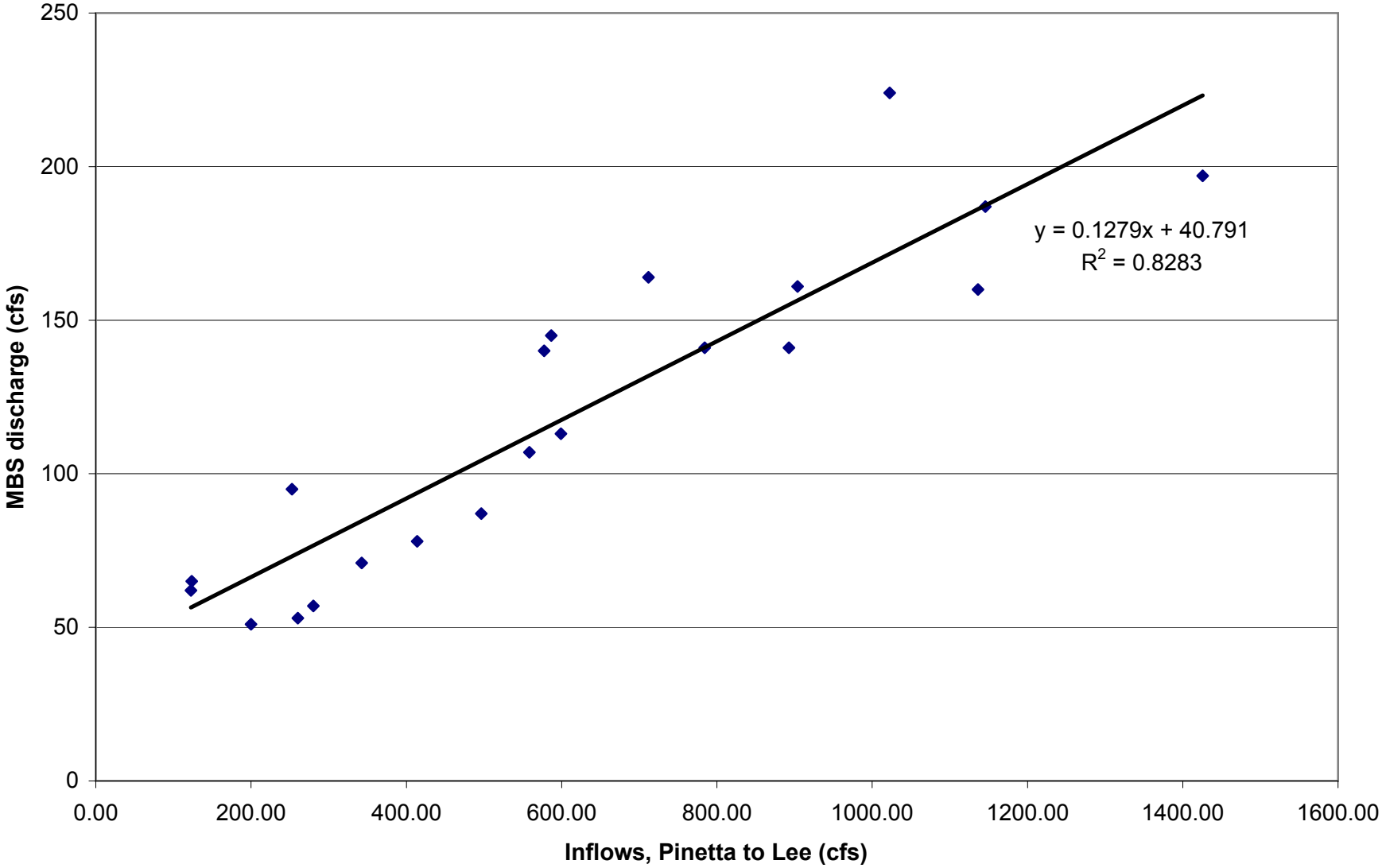


Figure 3-16. Relationship between total inflows to the river between the Pinetta and Lee gauges and Madison Blue Spring discharge.

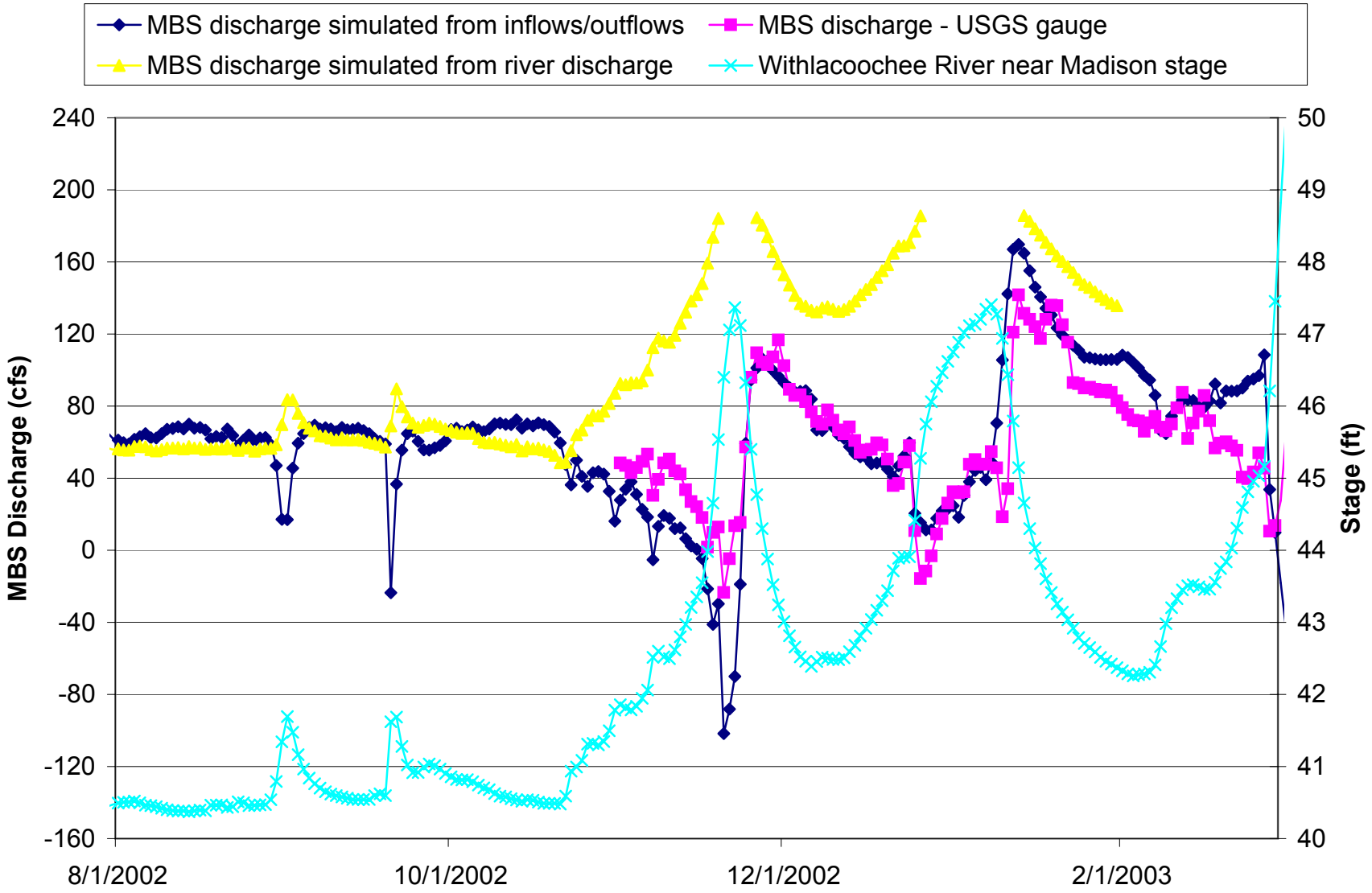


Figure 3-17. Comparison between Madison Blue Spring simulated discharges and discharge measured at the recently installed USGS gauge. Also plotted in the simulated stage at the Withlacoochee River near Madison.

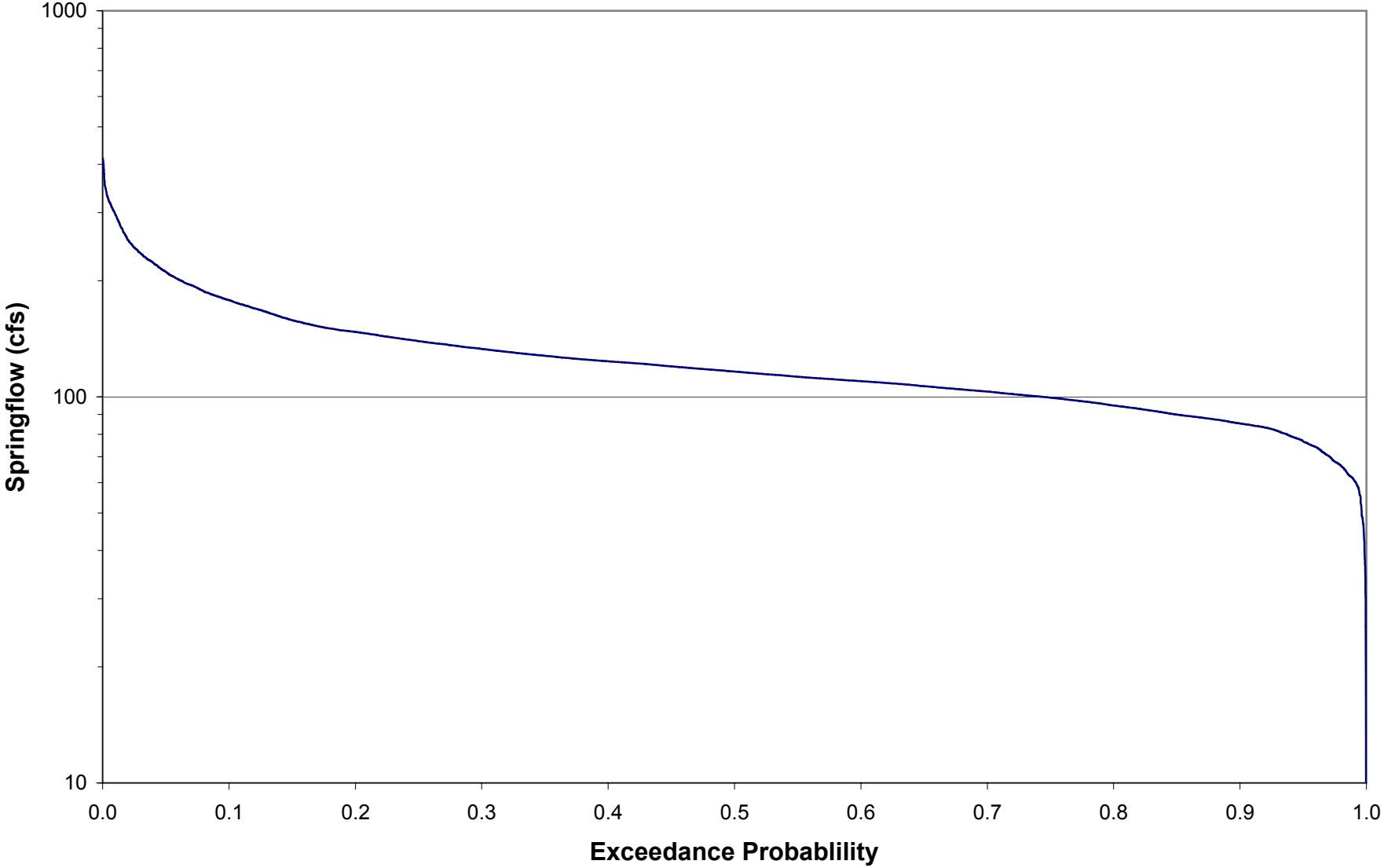


Figure 3-18. Flow duration curve for Madison Blue Spring discharge when stage in the Withlacoochee River near Pinetta was below 55 ft. (Period of Record 1932 - 2002)

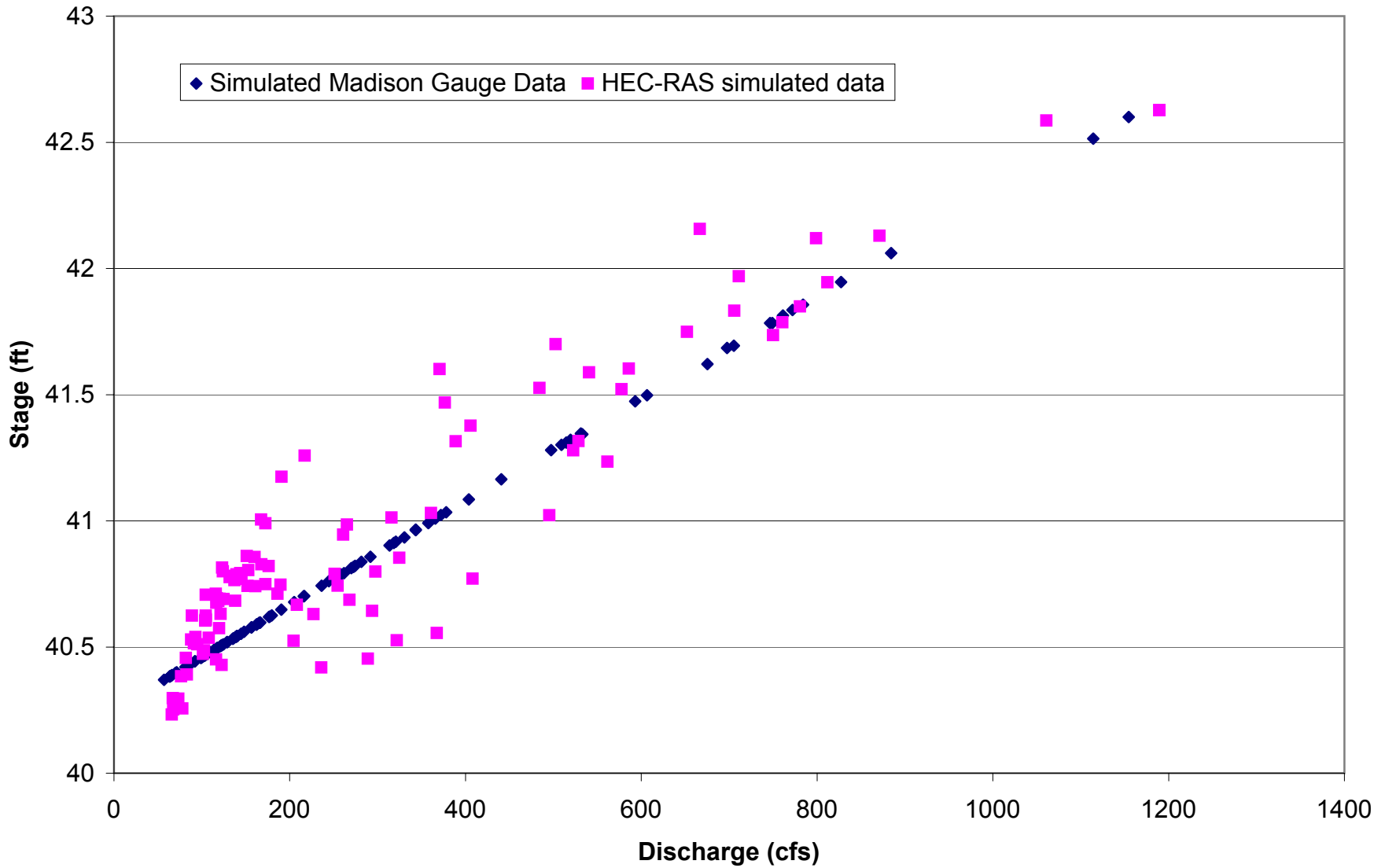


Figure 3-19. A. Results of the HEC-RAS calibration.

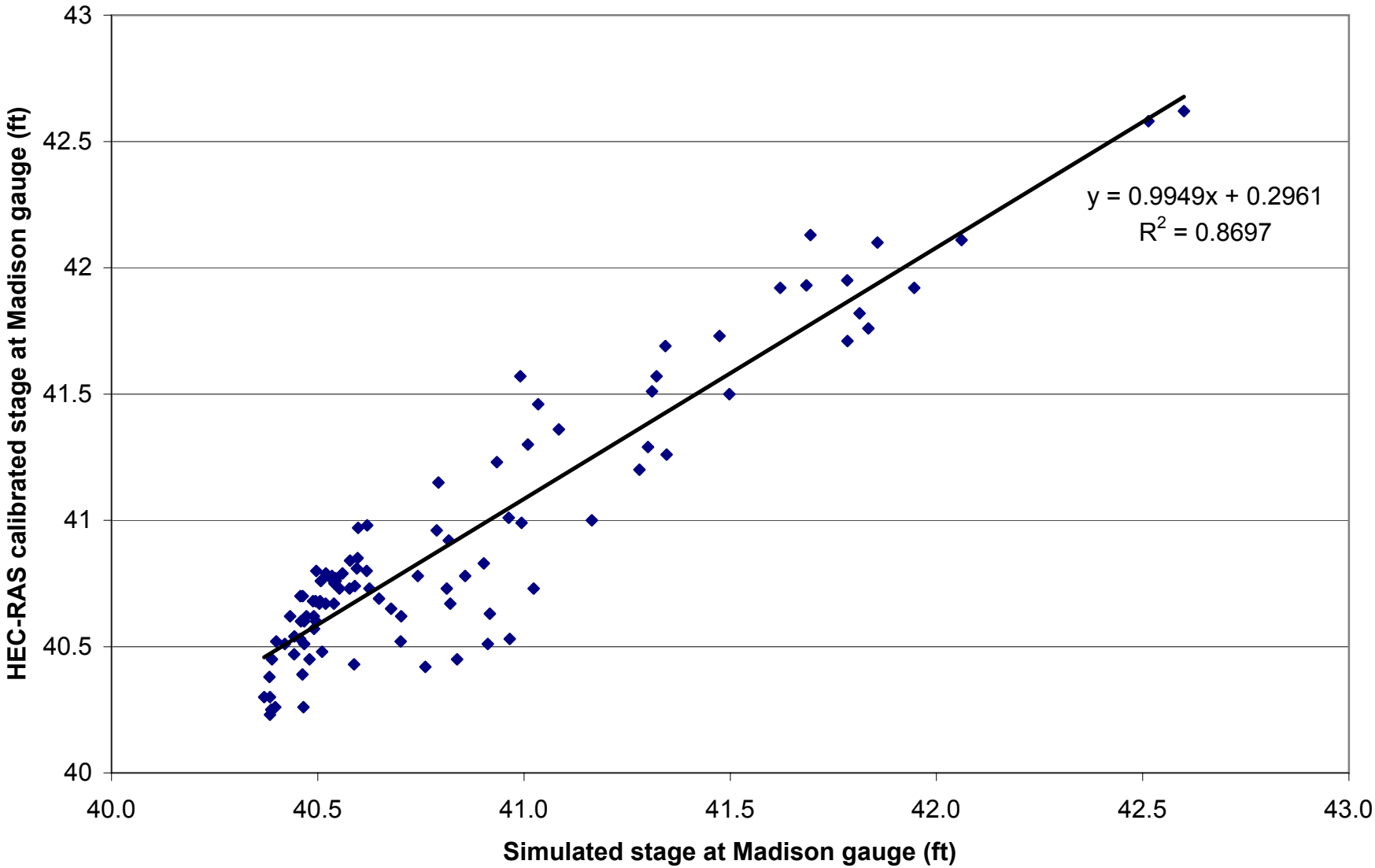


Figure 3-19. (cont.) B. Comparison of HEC-RAS calibrated stage and simulated

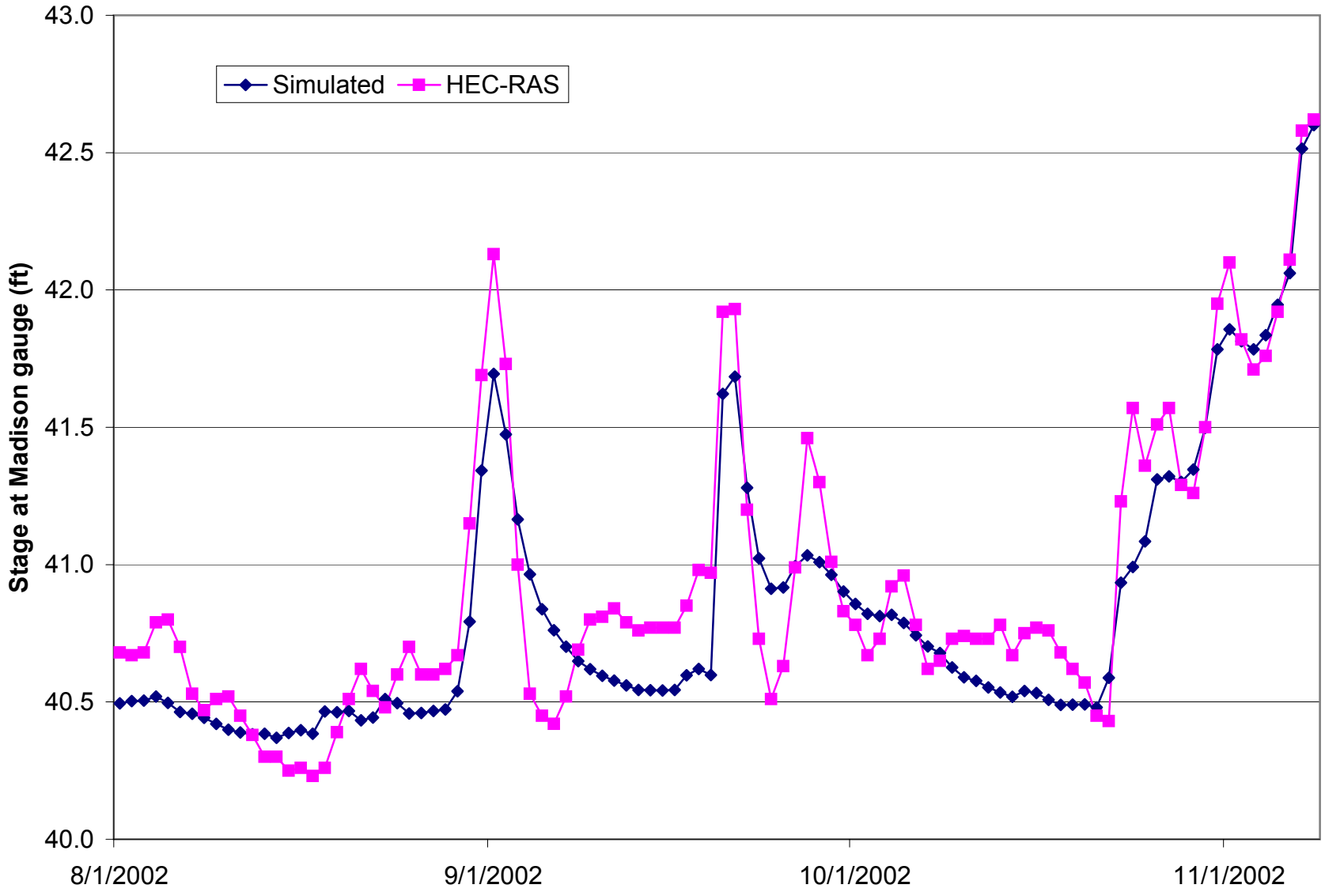


Figure 3-19. (cont.) C. Comparison of HEC-RAS calibrated stage and simulated

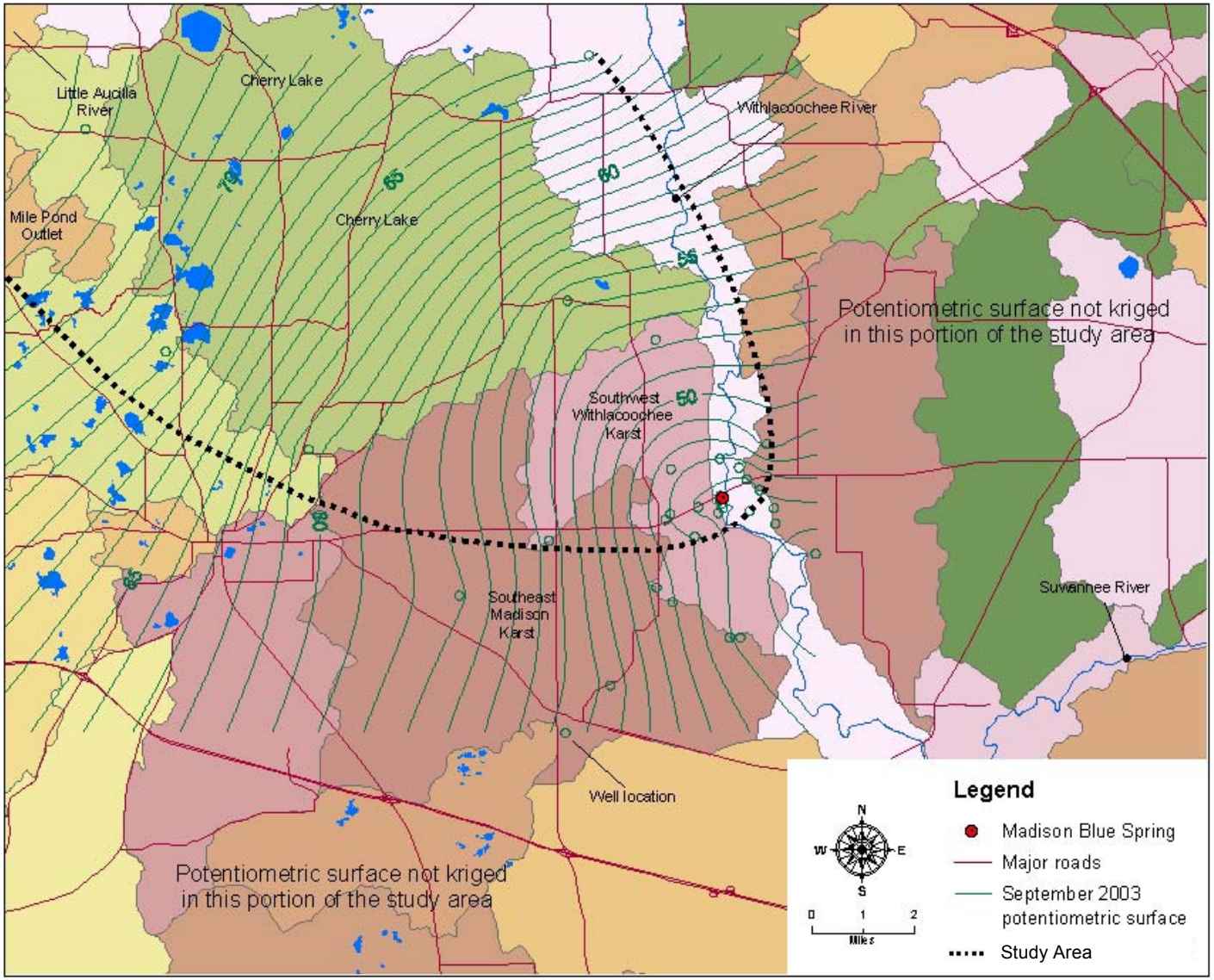


Figure 3-20. Geographic extent of the Madison Blue Spring study area.

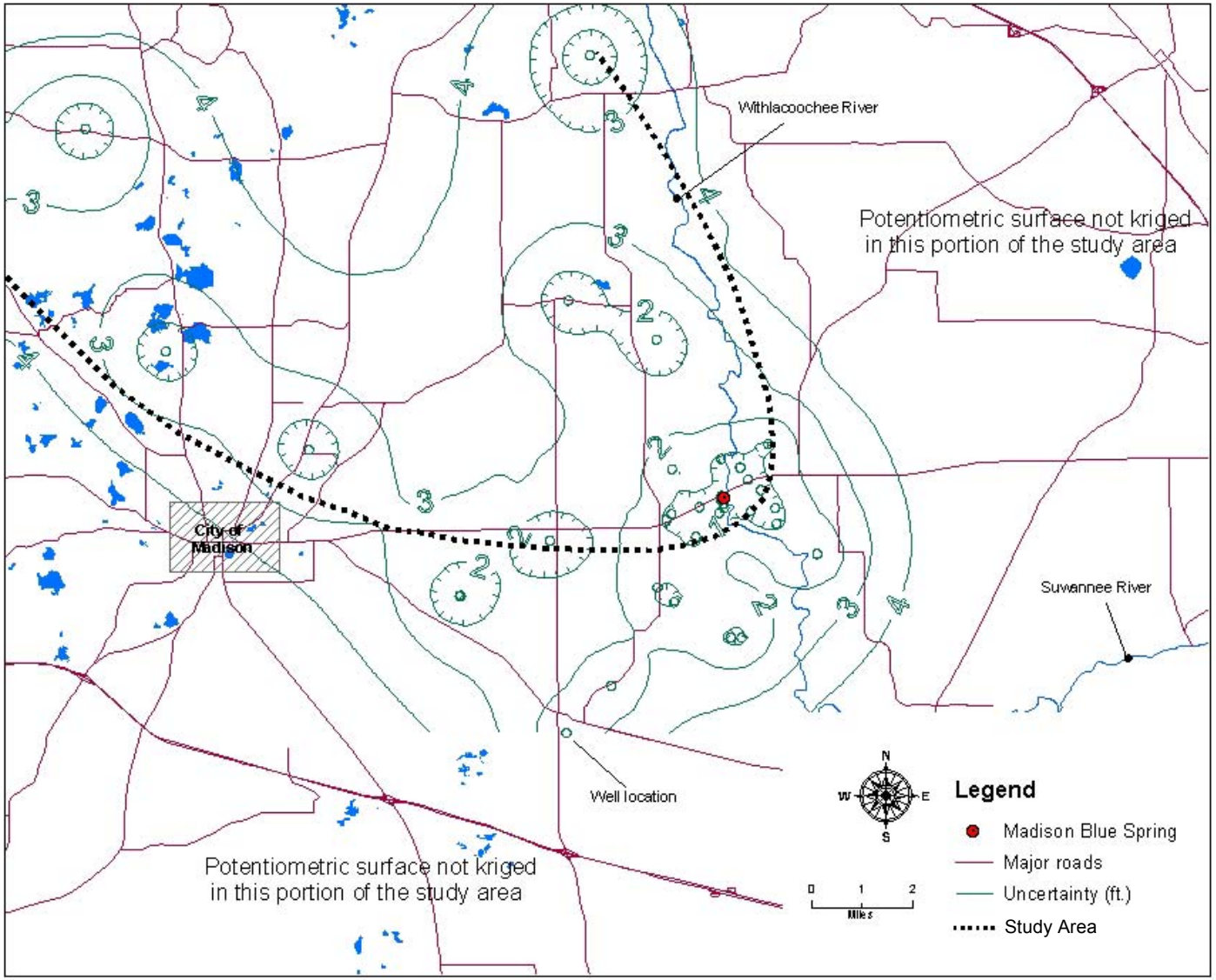


Figure 3-21. Uncertainty, or Ksd, (in feet) in the Madison Blue Spring study area.

4.0 ECOLOGICAL ANALYSES

4.1 Ecological Overview

General morphology with respect to ecological systems

MBS and the adjacent Withlacoochee River lie within the Tifton Upland/Tallahassee Hills subecoregion of the Southern Plains ecoregion (Griffith, et al., 1994). The area is characterized by low to moderate relief with soils ranging from well draining sands to clay. Karst influences on topography and physiography are evident (Section 2.5), in the form of sinks and depressional features. Upland forests tend to be mixed pine/hardwood associations.

The river channel is somewhat incised into the landscape, with high bluff banks ranging up to 30' above the riverbed at the crest. As a consequence of this geomorphology, the river is not very "interactive" with its floodplain (i.e., it takes a substantial flood to inundate the floodplain). The relatively infrequent and short periods of floodplain inundation, in conjunction with fairly well-draining, sandy soils in the floodplain, have not allowed for the formation of floodplain wetlands, and most of the forest communities fringing the river would be classified as upland forests, mostly mesic to xeric hardwood or mixed pine/hardwood forests. Many areas along the river have been cleared of native forest and replanted in pine (usually slash or loblolly pine) for silviculture. Riverine wetlands are only found in low-elevation slough or strand areas branching off the river channel. These are typically bottomland hardwood wetlands.

Blue Spring and Run

General morphological and hydrologic characteristics of the spring were described in Section 2.6. Very little biological sampling has been conducted in Blue Spring itself and the short spring run to the Withlacoochee River. Although the spring run is short, it does constitute a distinct aquatic habitat. The spring run is ecologically different from the spring basin or pool, due to the higher water velocities and related substrate differences. Recent biological sampling was conducted by a consultant as part of a baseline ecological assessment for a nearby water bottling facility (BRA, 2004). A total of 22 taxa of benthic macroinvertebrates were collected from the spring pool and 27 taxa from the spring run. The invertebrate community in the pool

was dominated by amphipods (*Hyalella azteca* and *Gammarus tigrinus*), which together accounted for about half of the total number of individuals collected in the pool. Other characteristics of the benthic invertebrate community of the pool and run are listed in Table 4-1.

Invertebrate communities in the spring run were dominated by *Hyalella*, which itself accounted for about half the total abundance in the samples. The midge *Dicrotendipes neomodestus* and the isopod *Caecidotea laticaudatus* also exhibited fairly high relative abundance in the run. The FDEP Stream Condition Index (SCI) scores for the invertebrate community of the spring pool and run were both in the 'good' range for streams characteristic of the Tifton Upland/ Tallahassee Hills subecoregion.

TABLE 4-1. Benthic macroinvertebrate community characteristics in the Blue Spring pool and run. Source: Biological Research Assoc., 2004.

	Spring Pool	Spring Run
Total taxa richness	22	27
EPT Score	2	1
# Chironomid taxa	9	15
Florida Index	8	11
SCI Score	25	23

There are no distinct plant communities found in the spring, run, or adjacent spring bank areas. Much of the bank area has been stabilized artificially to halt years of erosion from uncontrolled human use. This has included planting with non-native vegetation. No submerged vegetation is found in the spring run. Mats of filamentous green algae (possibly *Cladophora* and/or *Rhizoclonium* spp.) are found growing on rock and other hard surfaces in the spring pool.

Fish use of the spring pool and run is moderate, with centrarchids such as Largemouth bass (*Micropterus salmoides*) and sunfish (*Lepomis* spp.) commonly observed. Other fish likely to occasionally be observed in the spring would be Bowfin (*Amia calva*), catfish (Ictaluridae), and minnows (Cyprinidae).

Blue Spring Cave System

As noted earlier, a fairly extensive aquatic cave system is associated with the Blue Spring ecosystem. Approximately 24,000 feet of cave has been mapped and explored to date, and is considered by Gulden (2004) to be the fourth longest underwater cave in the United States.

This unique subterranean habitat is designated 'S2' (imperiled in the state because of rarity) by the Florida Natural Areas Inventory (FNAI and FDNR, 1990). The main source of primary production for the cave is decaying plant and animal material introduced through sinkholes (such as Martz Sink), or via backflow into the cave through the spring vent during river flooding.

A map of Blue Spring Cave is shown in Figure 4-1. Unfortunately, this map is incomplete, and does not show several important features, including the known downstream extension of the Courtyard Conduit under the Withlacoochee River, or its relationship with conduits that discharge to the river at Blue Spring. The Blue Spring Cave is characterized by a shallow and a deep section. The shallow cave passages, such as the Main Tunnel, are generally between 50 and 70 feet deep (below the water surface). The deeper parts of the cave, such as the Courtyard Tunnel, are generally 90 to 115 feet deep. The maximum depth in the cave is 120 feet. The Courtyard Tunnel, mapped for over a mile to the west of the spring, is one of the largest and longest conduits in the cave. Cave divers have long suspected that this is the main source of water to the spring, but reliable estimates of the Courtyards' contribution to the discharge of the spring are lacking.

Like most caves, passage dimensions in Blue Spring Cave vary by orders of magnitude, from conduits too small for a diver to enter, to large rooms that may be over forty feet across. Many of the long conduits, such as the Main Tunnel, and the Courtyard Tunnel, accommodate divers comfortably, and usually average from ten to fifteen feet wide and from four to fifteen feet tall. The dendritic pattern of cave passages shown on the map suggests that water discharging at Blue Spring comes from several source areas. This is supported by observations that conduits sometimes discharge water whose quality (temperature and color) differs markedly from water in other conduits during the same time period.

The hydrology of Blue Spring Cave is unusual because only part of the groundwater flowing toward the river in the Courtyard conduit actually discharges at the spring. The remaining water flows under the Withlacoochee River at a depth of about 100 feet. The destination of this water is not known, but it is probably flowing to other springs(s) down the river. Flow rates are an important factor in shaping the physical and biological aspects of aquatic caves. For instance, flow controls the distribution of soft bottom sediments and the import of detritus from outside the cave, which in turn influences the distribution and abundance of cave animals.

The dynamic interaction between aquifer level and river stage regularly produces rapid changes in flow regimes in Blue Spring Cave, leading to periods of high outflow, flow stagnation, and flow reversal. Flow rates have not been measured within the cave, but under normal conditions velocities in the Main Tunnel and the Courtyard Tunnel probably range between 0.5 and in excess of one foot per second. Leaf detritus found over 2000 feet into the cave, where no openings to the surface are apparent, suggest that high flow rates might be common during some flow reversal events. Strong backflow events may distribute detritus more widely and evenly than weak backflow events, and help explain the scattered distribution of troglobitic organisms in the Blue Spring Cave.

Franz, et.al. (1994) document the occurrence of three cave-adapted crustaceans from Blue Spring Cave: the pallid cave crayfish (*Procambarus pallidus*), the Florida cave amphipod (*Crangonyx grandimanus*), and Hobbs' cave amphipod (*Crangonyx hobbsi*). The amphipods share a common distribution pattern, and are widespread in subterranean habitats of the Florida peninsula, east of the Apalachicola River. Both amphipods were listed as Species of Special Concern by the Florida Committee on Rare and Endangered Plants and Animals (Franz, 1982) because of their dependence on specialized subterranean habitats. The distribution of the Pallid Cave Crayfish is limited to groundwater habitats in limestone areas of the Withlacoochee River, the upper Suwannee and lower Santa Fe Rivers, and the Newberry Karst Plain (western Alachua and northeast Levy counties. This crayfish was considered Rare by the Florida Committee on Rare and Endangered Plants and Animals (Franz, 1982). It is known from 65 sites. Morris (personal communication) recorded the sightings of cave animals in Blue Spring Cave during twenty dives made between 1985 and 1993. Based on his records, the three troglobytic species documented from Blue Spring Cave do not generally appear to be numerous, or even common, in the cave. Typically only a few widely scattered crayfish or amphipods were sighted. However, in September of 1986, *P. pallidus* were recorded as "numerous" beyond the area known as the Crossunder Tunnel.

Morris also noted the occurrence of several troglophilic species in Blue Spring Cave. These include the yellow bullhead (*Ameiurus natalis*), the brown bullhead (*Ameiurus nebulosus*, and white catfish (*Ameiurus catus*). White catfish were sometimes found in large schools of over a hundred fish, generally within a few hundred feet of the cave entrance. The bullheads roamed much farther into the cave, and were commonly found as far as several thousand feet from the entrance, usually as solitary individuals. Most catfish are nocturnal, and use caves primarily for

refuge during daylight hours. However, numerous fist-sized depressions in soft bottom sediments in the Blue Spring Cave show that catfish also feed in the cave. The depressions are made when hungry catfish ingest mouthfuls of food-bearing sediment. The primary targets of this feeding behavior are probably small aquatic annelid worms (Tubificidae) which colonize spring caves when rivers backflow into them. Catfish are known to prey on troglobytic crayfish, but they also can have a net positive effect on troglobyte populations by bringing food into caves in their bellies.

Morris (personal communication) has recorded the occurrence of hydrobiid snails over 2000 feet into the Blue Spring Cave in the area known as the Courtyard. F. G. Thompson (personal communication) examined hydrobiid snails (*Amnicola retromargo*) from another Withlacoochee River spring cave, and found them to be lighter in color than individuals found in surface streams. However, he did not consider them to be troglobitic. Specimen snails in Blue Spring have not been collected. Information on the Blue Spring hydrobiids might prove useful, as many species in this group are very sensitive to changes in their environments.

As part of the baseline ecological survey described above, surveys were conducted in certain areas of the cave, which will be repeated subsequently to monitor the status and condition of the cave fauna (BRA, 2004). The length surveyed each time and the time spent surveying is standardized to be able to compare effort. Troglobytic crayfish were observed in this survey, possibly *Procambarus pallidus*, as well as cave amphipods (*Crangonyx* sp.) in October and November 2003 surveys (BRA, 2004). Catfish (*Ameiurus* spp.) were very abundant, with in excess of 100 individuals (estimated) at one location. This corresponds well with the above observations made by Morris.

Withlacoochee River

The Withlacoochee River is one of the three major tributary streams of the Suwannee. The river's general morphology is that of a low gradient, eastern coastal plain stream with a sand bed channel (Brussock, et al., 1985). Using Beck's (1965) classification, the Withlacoochee is a "sand-bottom stream." Water chemistry in the river is moderately to highly colored, somewhat alkaline, and on occasion highly turbid. Because of the physiography and soils found primarily in the Georgia portion of the watershed, the Withlacoochee carries a higher sediment load than other streams in the Suwannee drainage (USDA, 1977), and consequently during higher flows,

the river is more of a "muddy" river than the Suwannee. This sediment load is obvious when viewing the confluence of the Withlacoochee and Suwannee at higher flows (generally average flow and greater). At baseflow, the river water is substantially less turbid and more reflective of a southeastern coastal plain blackwater stream. The inflow of hard, calcareous groundwater from the Floridan Aquifer at baseflow contributes to the higher pH and alkalinity of the water chemistry in Florida.

The river channel in Florida has numerous areas of shoal habitat, where limestone outcrops occur. These are important habitats for algal production and invertebrates. Previous work on the Suwannee and Santa Fe (Bass and Cox, 1985; Bass and Hitt, 1973) has shown that these areas support substantially higher benthic invertebrate densities than sandy bottom habitats in pool areas in the river channel or along the shoreline (Table 4-2). Shoal habitats have also been shown to be the preferred habitat of Suwannee bass (*Micropterus notius*), a state-listed Species of Special Concern.

Other important river habitats are the woody snags from treefall along the river bank and in shallow areas of the river channel. Studies in other southeastern

TABLE 4-2. Density of benthic invertebrates in different habitats on the Suwannee and Santa Fe rivers. Data adapted from Bass and Cox (1985) and Bass and Hitt (1973).

RIVER	HABITAT TYPE	BENTHIC POPULATION DENSITY (#/m^2)
Santa Fe	Shoreline/Littoral zone	876.8
Santa Fe	Coarse Sand (mid-river	412.6
Santa Fe	Limestone Shoals	2,109.6
Mid. Suwannee	Shoreline/Littoral zone	492.7
Mid. Suwannee	Coarse Sand (mid-river)	351.1
Mid. Suwannee	Limestone Shoals	4,553.5
Lower Suwannee	Shoreline/Littoral zone	766.5
Lower Suwannee	Coarse Sand (mid-river)	230.6

coastal plain streams have shown that this habitat supports high benthic invertebrate biomass and diversity (Benke, et al., 1984). Studies have also shown that a substantial fraction of the diets of certain riverine sportfish, particularly Redbreast sunfish (*Lepomis auritus*), consist largely of snag-associated invertebrates, and that the snags are the supporting habitat for a "invertebrates – sunfish" food web (Benke, et al., 1985).

Because of the variable flows and periodic high color and turbidity, the river does not support appreciable stands of submerged aquatic vegetation (SAV). Small patches of SAV are occasionally seen on some of the shoals, consisting of spring tape (*Sagittaria kurziana*). As noted earlier, hydrologic and soil conditions in the river floodplain are such that wetland communities have not developed. A narrow strip of wetland-type vegetation does exist along the immediate channel margin. Common trees include bald cypress (*Taxodium distichum*), water elm (*Planera aquatica*), river birch (*Betula nigra*), sweetgum (*Liquidambar styraciflua*) and blue beech (*Carpinus caroliniana*).

Periphytic algal communities in the Withlacoochee River adjacent to MBS were sampled for two years by SRWMD (1990-1991) using glass slide periphytometers. These algal communities are dominated by diatoms, by both taxa richness and relative abundance. Common genera included *Achnanthes, Cocconeis, Gomphonema and Melosira*, all indicative of hard, bicarbonate freshwater (Hein, 1993; Whitford, 1956). Green algae and blue-green bacteria make up the remainder of the periphytic algal communities in the Withlacoochee. Peak algal biomass (AFDW g/m^2) was generally seen in the spring (May/June), while peak abundance (as $cells/cm^2$) was seen in the summer fall period (Mattson, 1992a).

Benthic invertebrate communities in the river adjacent to MBS were sampled by SRWMD between 1989 and 1992 with Hester-Dendy multiplate samplers, and the shoreline communities were sampled by SRWMD in 1990 with dip nets. Historic sampling in the river was conducted by Cox (1970). More recently, macroinvertebrate dip net samples were collected upstream and downstream of the MBS inflow by BRA (2004). Invertebrate communities in both the historic and current studies are dominated by Chironomids, either by taxa richness and/or abundance (Mattson, 1992b; Cox, 1970; BRA, 2004). Other dominants in the benthic community include crustaceans (the amphipod *Hyalella* and grass shrimp, *Palaemonetes paludosus*), blackflies (*Simulium* spp.), aquatic beetles (Coleoptera), caddisflies (Trichoptera) and mayflies (Ephemeroptera).

Fish communities in the river are dominated by centrarchids, primarily Redbreast and Spotted sunfish (*L. auritus* and *L. punctatum*), and Largemouth bass (FGFWFC, 1990). Other common fish in the river (FGFWFC, 1990) include Blackbanded darter (*Percina nigrofasciata*), Spotted sucker (*Minytrema melanops*), and minnows (*Notropis* spp.). Suwannee bass (*Micropterus notius*) are common in this stretch of the river. This bass is confined to flowing water

environments and is endemic to the Suwannee and Ochlockonee River drainages (Gilbert, 1978). Another unusual occurrence in the river has been occasional collection of Mountain mullet (*Agonostomus monticola*). Also occasionally found in the river are marine invaders, primarily striped mullet (*Mugil cephalus*).

Species of Conservation Interest

Table 4-3 presents a listing of species known or highly likely to occur in the area which are officially listed by the U.S. or state governments, listed in the most recent book series of the Florida Committee on Rare and Endangered Plants and Animals (FCREPA), or listed by the Florida Natural Areas Inventory as 'S1' (critically imperiled in Florida because of extreme rarity), 'S2' (imperiled in Florida because of rarity), or 'S3' (rare or uncommon in Florida).

An important group of aquatic fauna, which has not been sampled well in the area, are the unionid clams or "freshwater mussels". Many of these are imperiled and there is a great deal of scientific and conservation interest in this group of freshwater mollusks (Williams, et al., 1992). A live specimen of *Elliptio* sp. was collected in the river in the "plume" of outflow water from the spring on October 10, 2003 (R. Mattson, personal observation). Sampling in the river upstream of MBS, near the state line, collected *Elliptio* spp., *Villosa* spp. and *Pleurobema* sp. (J. D. Williams, U. S. Geological Survey, personal communication). The complexity of developing a MFL which meets the needs of these mussels is complicated by the fact that not only must their own physical flow and habitat needs be met, but also those of the host fish which is needed to complete their life cycles.

As noted earlier, the aquatic cave system is a habitat of conservation concern, and all of the obligate troglofauna found in the cave (the amphipods and the crayfish) are listed by some entity as endangered, threatened, of special concern, or rare (Table 4-3). Future study and monitoring needs to focus on collecting data which may help better define the environmental and habitat requirements of these fauna.

The Suwannee River drainage supports the largest self-sustaining population of Gulf sturgeon (*Acipenser oxyrinchus desotoi*) in the Gulf of Mexico (Sulak, et al., 2001). These anadromous fish migrate up the Suwannee, from the estuary, in late winter and spring to spawn at shoal areas located upstream of the confluence with the Alapaha River (Sulak, et al., 2001). Use of

the Withlacoochee River by these fish has been sparsely documented to date, although the former owner of MBS notes that the rock dam constructed in the river just downstream from the spring run inflow was an historic feature which he believes was designed to trap sturgeon and other fish (M. Bruic, personal communication).

Table 4-3. Aquatic and wetland-dependent species of conservation interest in the Madison Blue Spring study area (including the immediately adjacent Withlacoochee River).					
Taxon	Common Name	Federal	State	FCREPA	FNAI
Plants					
Lobelia cardinalis	Cardinal flower		T		
*Zephyranthes atamasco***	Zephyr lily				
Invertebrates					
Caecidotea hobbsi	Florida cave isopod				S2
Chimarra florida	Florida finger-net caddisfly				S1
Crangonyx hobbsi	Hobb's cave amphipod			SSC	S2-S3
Dolania Americana	Sand-burrowing mayfly			T	S1-S2
Pleurobema reclusum	Florida pigtoe			T	
Procambarus pallidus	Pallid cave crayfish			R	S2-S3
Troglocambarus maclanei	MacLane's cave crayfish			R	S2
Fishes					
Acipenser oxyrinchus desotoi	Gulf Sturgeon				
Agonostomus monticola	Mountain mullet			R	S3
Ameiurus serracanthus	Spotted bullhead				S3
Cyprinella leedsi	Bannerfin shiner				S3
Micropterus notius	Suwannee bass		SSC		S2-S3
*Notropis harperi***	Redeye chub				
Reptiles					
Alligator mississippiensis	American alligator	T	SSC		S4

Table 4-3. Continued.					
Taxon	Common Name	Federal	State	FCREPA	FNAI
Reptiles					
Macroclemys temmincki	Alligator snapping turtle		SSC	SSC	S3
Pseudemys concinna suwanniensis	Suwannee cooter		SSC	SSC	S3
Birds					
Aramus guarauna	Limpkin		SSC	SSC	S3
Casmerodius albus	Great egret			SSC	S4
Egretta caerulea	Little blue heron		SSC	SSC	S4
Egretta rufescens	Reddish egret		SSC	R	S2
Egretta thula	Snowy egret		SSC	SSC	S4
Egretta tricolor	Tricolor heron		SSC	SSC	S4
Eudocimus albus	White ibis		SSC	SSC	S4
Mycteria Americana	Wood stork	E	E	E	S2
Haliaeetus leucocephalus	American bald eagle	T	T	T	S3
Federal and State are species officially listed by the U.S. or State of Florida (respectively); FCREPA=species listed by the Florida Committee on Rare and Endangered Plants and Animals; FNAI=species listed by the Florida Natural Areas Inventory; E=endangered; T=threatened; SSC=species of special concern; R=rare; S1=critically imperiled in Florida because of extreme rarity; S2=imperiled in Florida because of rarity; S3= rare or uncommon in Florida; S4=apparently secure in Florida;; ** - included due to restricted distribution in north central Florida or narrow habitat requirements.					

4.2 Selection of Candidate Minimum Flows Based on Physical Habitat Availability, Biological Integrity, and Water Quality.

The purpose of this step in the minimum flow recommendation process was to narrow the field of potential minimum flow candidates based on the "best available data" regarding how flows from MBS affect three components of ecological integrity. These three components of ecological integrity are:

- physical habitat availability,
- biological integrity, and
- water quality.

The overall concept of this first step was to start with the maximum range of minimum flows that are possible, from 0 cfs to the full natural discharge of MBS, and identify a short list of candidate minimum flows for further consideration

4.3 Rationale for Applying Ecological Integrity Criteria

Physical habitat availability was considered as one important criterion for narrowing the list of candidate minimum flows. For this criterion, we have chosen to take a resource-based approach by focusing on the availability of "target" habitats. By meeting the water needs of these habitats, in terms of providing adequate water through the use of MFLs, the structure and function of the system will be protected resulting in maintaining biological integrity. Impacts and changes to habitat are more easily measured than changes in species composition within ecosystems. Quantitative, repeatable measurement of many fish and wildlife populations are inherently difficult and remain subject to the potential for substantial error. Focusing on distinct target habitats, we may be able to predict or detect ecological changes due to hydrologic alteration at an early stage more reliably, allowing us to modify MFL criteria accordingly.

The best available data for physical habitat to be potentially affected by reduced flows from MBS were not from the spring or spring run, but were from six shoal areas located downstream of the spring in the Withlacoochee River (Figure 4-2). These six shoals were considered

representative of these types of habitats available elsewhere in the river and are most likely to be affected by small changes in river flow/stage during baseflows. The shoals range in size from 3,000-9,000 m^2 and are located downstream from MBS and upstream of the confluence of the Withlacoochee River with the Suwannee River. Shoal habitat is important as it provides a surface for autotrophic production and a productive and critical benthic invertebrate habitat. As previously described (Table 4-2), these shoal habitats have been observed to be sites of high benthic invertebrate density (Bass and Cox, 1985; Bass and Hitt, 1973). To maintain these ecologically important shallow water habitats, it will be necessary to maintain a flow from MBS that is sufficient to inundate some portion of the shoals.

In addition to defining habitat availability based on inundation of the shoals, the data were also examined to determine the minimum depth allowable for fish passage over the same six shoals. The fish passage depth criterion was obtained from that used for the Wekiva River MFL by the St. Johns River Water Management District (Hupalo et al., 1994). A fish passage depth criterion of 0.6 feet was selected for transects over bare substrate. The criterion was based on body depth measurements reported for large trout species (Thompson, 1972). This depth (0.6 feet) was also recently applied in the development of minimum flows for the Upper Peace River, Florida by the Southwest Florida Water Management SRWMD (SWFWMD, 2002; Gore et al., 2002). Very few studies have documented the minimum water depths necessary to maintain passage for fish. Thompson (1972) reported on passage flows for adult salmonoid fishes. Passage flows in coldwater streams are often based upon minimum passage depths and maximum allowable velocities. Passage depths of 0.8 ft for Chinook salmon and 0.6 ft for large trout were calculated based upon body dimensions (Thompson, 1972). Common fish species found in the MBS region include the Florida gar, various centrarchid fishes (bass and sunfish), bowfin, and minnows. Morphological characteristics of these species would allow passage at a minimum depth of 0.6 feet for nearly all individuals. A peer review of the SWFWMD depth target also considered supporting evidence of it reasonability based on transference of body dimension data to the fish species complex observed in the Withlacoochee River, Florida (Gore, J.A., C. Dahm, and C. Klimas, 2002. Specific data for establishing other fish habitat requirements (e.g., pool temperature, pool size) for the local region were not available.

With respect to biological integrity, biological data were available from the Withlacoochee River near MBS. Biological data were not available from MBS proper in sufficient quantities to establish minimum flow candidates. The abundance and distribution of the organisms present in

the river downstream of the spring are closely associated with the physical habitat and water quality of the region. Benthic (bottom-dwelling) invertebrates, such as aquatic insects, worms, snails, clams and shrimp, which live on or in the substrates of springs, rivers and other waterbodies and occur across a range of habitat condition. Specific taxa (e.g., caddisfly larvae-Trichoptera) only occur in clean waters, where dissolved oxygen is high and turbidity low. Other taxa (e.g., worms -Oligochaeta, snails- Gastropoda) are capable of inhabiting moderately or severely polluted waters with low dissolved oxygen, sometimes becoming ubiquitous only under those conditions. Generalized benthic feeding groups typically include shredders, collectors, scrapers, plant piercers, predators and parasites (Merritt and Cummins, 1984). Shredders (e.g., stone flies- Plecoptera) feed on dead plant or animal material, generally breaking it into smaller particles via their feeding/digestive process. Collectors can be divided into two main groups: filterers-suspension feeders (e.g., caddisflies), which filter fine particulate matter from the water column, and gatherer-deposit feeders (e.g., mayflies and midges), which ingest fine material from substrata in the river. Scrapers (e.g., snails- Mollusca) feed on attached periphyton or other associated materials found on the surface of rocks or plants. Plant piercers feed on the cell and tissue fluids of macrophytes and macroscopic algae. Predators (e.g., dragonflies - Odonata), also referred to as carnivores, feed directly on other invertebrates either by ingesting them whole or feeding on specific parts. Many species are generalists and may fit into more than one category.

Aquatic invertebrates occupy a very important niche within the ecosystem. From a bottom up approach invertebrates act as processors of organic material, acting as an essential link in the food web structure to higher organisms such as fish and waterfowl. Unlike species in higher trophic levels, most invertebrates lack the mobility to withstand large fluctuations in habitat; such changes in the abundance or composition of the benthic foodbase (i.e. benthic invertebrates) may have a negative cascading affect on commercial or recreationally important fish species. Benthic invertebrates were sampled by the SRWMD as part of water quality and/or biological monitoring programs because of their ecological importance and indication of conditions within the system. Additionally, data from other habitats has shown that a small percentage of loss in fish habitat may result in a two- or three fold loss in invertebrates (Gore, 2002). By combining critical habitat, which includes invertebrates, with minimum allowable fish passage depth, an MFL that protects both habitat and target species has been developed.

Water quality data were available from the Withlacoochee River near MBS. The relationships between these data and flow in the river channel were examined in order to identify any potentially useful quantitative relationships. Water quality data were not available from the MBS or spring run.

4.4 Rational for Establishing Candidate Low Flow Minimum Flows for Madison Blue Spring

The process to identify candidate minimum flows for MBS was focused on low flows conditions (baseflow) as opposed to high or multiple flows. Consideration was given to setting additional minimum flow levels for the high flow portions of the year in recognition that high flows are important in providing aquatic habitat in the higher elevations of the river channels coincident with critical snag habitat, and that all flows likely impact the ecological integrity of the spring, spring run, aquatic cave system and recreational/ aesthetic properties of the spring. Naturally variable flows create and maintain the dynamics of in-channel and floodplain conditions that are essential to habitat (Poff et al., 1997). High and low flow act to regulate ecological process that are critical to sustaining ecosystem health. High flows act to transport fine sediments that if deposited for long periods would fill interstitial spaces in productive habitats. Varying levels of flow act as a conduit for the transportation of detritus downstream. The movement of organic rich detritus acts to flush the river and provide numerous resources to the downstream estuarine ecosystem. Various life cycles are also dependent on variable flows which may allow fish and other organisms to complete critical stages to allow for reproduction.

However, in setting a minimum flow for this particular spring, it is important to recognize, as described in the previous section, that the relative importance of the MBS flow to the total flow at the downstream river habitats is the least relevant to ecological integrity when flows in the river and spring are high. Additionally, a lack of available data specific to the spring, spring run and aquatic cave system precluded the development and quantification of the relationships for this particular system. Thus, the focus of this process was placed on the low flow conditions of the river and spring.

The low flow focus of the minimum flow evaluations led to evaluation of environmental responses that would be potentially expected during low flow conditions (e.g., exposure of instream shoals, hypoxia conditions). Because the minimum flow analyses were focused on low flow conditions and because the river channel and spring run channel are well incised, impacts to riparian/floodplain wetlands as a response to minimum flow alternatives were not evaluated.

4.5 Constraints

The primary constraint for developing quantitative relationships between ecological integrity and MBS discharge was the limited availability of data for biological integrity, physical habitat availability, and water quality. The lack of available data within the spring, spring run and the aquatic cave system was an important initial constraint in the exploration of relationships between ecological integrity and flow. However, estimated MBS discharges to the Withlacoochee River were available, and physical habitat availability data, biological data, and water quality data were available for the river.

4.6 Available Data (see Appendix A, Exhibit 4 – Data Sources Summary)

Data used in the identification of biological criteria for MFL development were:

- the estimated discharge data from MBS,
- the estimated flow record at Lee (developed in the preceding section),
- surface water quality data from the Withlacoochee River,
- benthic biological data from the Withlacoochee, and
- cross-sections of six shoals in the river downstream of the spring.

4.6.1 Estimated Flow at Lee

Methods for determining estimated flow at Lee were described in the previous section. Two additional flow variables were calculated for use in the biological analysis:

- *30 Day Geometric Mean Flow* - represents flow conditions averaged over the entire time period the Hester-Dendy samplers were in place, and
- *28 Day Lag Flow* - represents flow conditions on the day the Hester-Dendy sampler was placed in the river; samplers are left in place for 28 days and this flow metric represents the flow on the first day the samplers were in the river .

4.6.2 Surface Water Quality Data

The SRWMD conducted surface water quality sampling at four sites along the Withlacoochee River (Figure 4-3). A total of 438 observations were available for analysis, ranging in date from February 1989 through September 2003.

Water quality parameters included:

- dissolved oxygen
- biological oxygen demand
- temperature, conductivity
- Secchi disk depth
- turbidity
- pH
- alkalinity
- chlorophyll a
- pheophytin
- potassium
- calcium
- magnesium
- various nitrogen species, and
- various phosphate species.

4.6.3 Benthic Biological Data

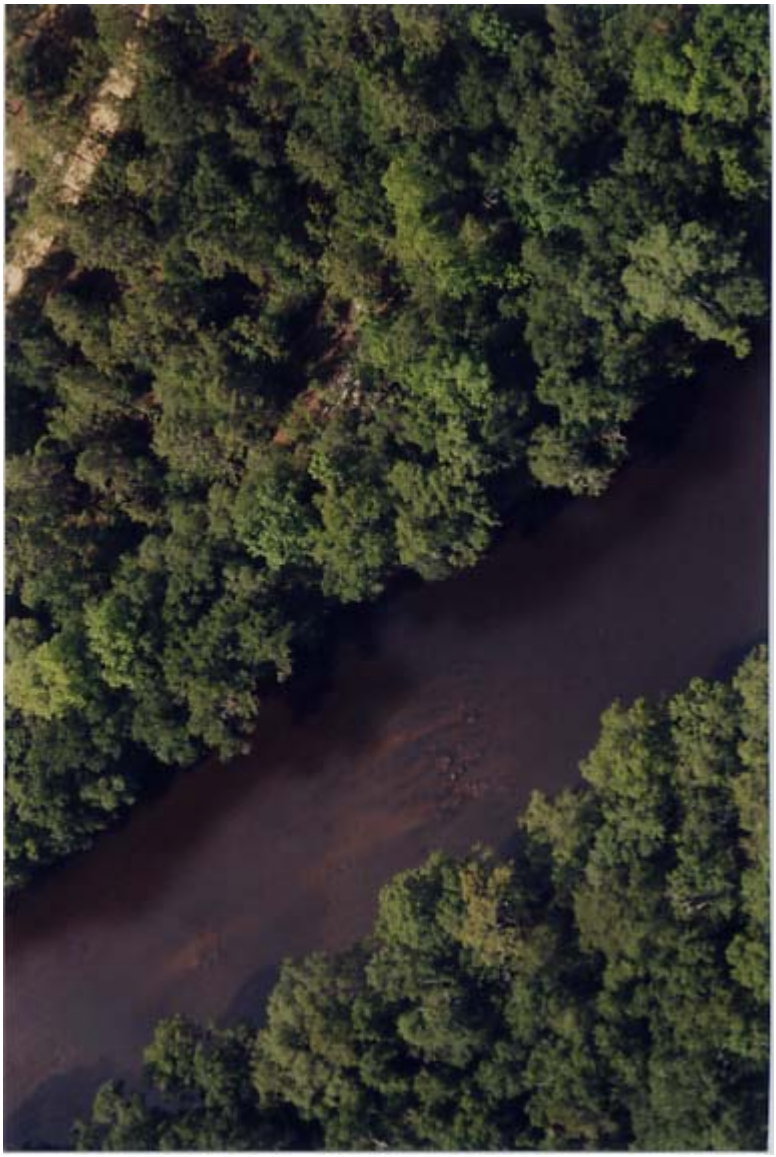
The SRWMD collected benthic biological data in the river near MBS using two methods: Hester-Dendy multi-plate samplers and dip nets, at the same four sites as the surface water quality samples (Figure 4-3). A total of 352 Hester-Dendy, and 18 dip net observations were available for analysis. Hester-Dendy samples were collected from March 1989 through December 2002. Each sampler was placed in the river and removed 28 days later. Dip net samples were conducted for 1.5 years, starting in February 1990 and ending in August 1991. All dip net samples were collected bankside. Based on the abbreviated sampling record for the dip net data, they were not included in the analysis. In the original data set, organisms were identified to genus and species where possible, and raw abundance was provided.

Pre-analysis data steps included updating taxonomic nomenclature changes and adding complete taxonomic information (Phylum, Class, Order, Family variables) based on the Integrated Taxonomy Information System (ITIS). The ITIS system is a standardized interagency system to provide universal access to scientifically credible taxonomic information (www.itis.usda.gov/info.html). Additionally, every species was assigned to a functional feeding group based on information obtained from the Florida Department of Environmental Protection (personal communication.. Russel Frydenborg, FDEP).

4.6.4 Shoal Cross-section Data

Detailed landscape level cross-section information was collected at the six shoals previously surveyed in the winter of 2004. Elevations of these habitat features were measured in the field, used to model a three-dimensional surface for each shoal, and the three-dimensional model surface for each shoal was systematically sampled in representative cross sections across the shoals (Figures 4-4 through 4-34) using a computer algorithm. Thus, the distribution of modeled elevation points is expected to be representative of the true distribution of elevations at each shoal. All elevations were standardized to a common vertical datum (NGVD, 1929). Shoal areas were projected to a standard horizontal measurement system (Florida State Plane, North, NAD 1983), and the total shoal areas measured from survey drawings as follows (personal communication, Jim Schneider, SDII, Inc.):

Shoal 1 - 0.45 miles from MBS - Withlacoochee River Mile Marker 11.31 (Photo date 5/22/03)



Shoal 2 - 0.68 miles from MBS - Withlacoochee River Mile Marker 11.08 (Photo date 5/14/04)

Shoal 3 - 1.92 miles from MBS - Withlacoochee River Mile Marker 9.84 (Photo date 5/14/04)

Shoal 4 - 6.25 miles from MBS - Withlacoochee River Mile Marker 5.51 (Photo date 5/14/04)

Shoal 5 - 6.6 miles from MBS - Withlacoochee River Mile Marker 5.13 (Photo date 5/14/04)

Shoal 6 – 9.02 miles from MBS - Withlacoochee River Mile Marker 2.74 (Photo date 5/14/04)

4.7 Data Analysis Methods

Quantitative and objective methods were applied to empirically define relationships to narrow the field of potential minimum flow candidates based on the “best available data” regarding how flows from MBS affect three components of ecological integrity.

4.7.1 Flow and Water Quality

The relationship between estimated flow at Lee and water quality parameters measured by the SRWMD were assessed through extensive review of bivariate plots. Based on the most useful relationship observed in these plots, a regression was developed for the relationship between the lowest dissolved oxygen (DO) values observed and flow in the Withlacoochee River.

Dissolved Oxygen Lower Quantile Relationship to Spring Discharge:

A quantitative relationship between the dissolved oxygen lower quantile (10th percentile) and the MBS discharge was defined as:

$$Y_{10\{w\},t} = \alpha + \beta Q_t$$

where $Y_{10\{w\},t}$ = the 10th percentile of the set, *{w},* of dissolved oxygen measurements at date *t*,

Q_t = the MBS discharge at time step *t,* and

α, and *β* = regression parameters.

The dissolved oxygen measurement sets were defined according to the MBSs discharge estimated for the date of each dissolved oxygen measurement and the sets were grouped by a moving window that was 400-cfs units wide and was incremented by 100-cfs units.

4.7.2 Flow and Benthic Biology

The relationships between flow and biological integrity were assessed using the best available data, which consisted of benthic biological data collected by the SRWMD in the Withlacoochee River.

In order to examine the relationships between flow and biological integrity, the following two biological expectations were identified to guide the empirical analyses:

- As habitat availability increases, positive responses in abundance and diversity are expected for the biological/ecological components of the system.

- This positive relationship is expected to occur up to an identifiable point, beyond which diminishing returns are seen for further flow increases (meaning further increases in habitat availability are no longer followed by further increases in the

stability, productivity, diversity, etc. of the biological components of the system; i.e. the first expectation no longer holds).

The relationships between the estimated flow at Lee and the benthic biological data were explored with a series of bivariate plots. All biological variables were plotted against the estimated flow at Lee (referred to as "flow"), 30 day geometric mean flow and 28 day lag flow, collectively referred to below as 'flow'. The series of bivariate plots include:

- Shannon-Weaver Diversity Index scores and flow,
- percent composition of Ephemeroptera Plecoptera and Trichoptera (EPT) taxa and flow,
- abundance of individual benthic species and flow,
- abundance and percent composition of taxonomic families and flow,
- abundance and percent composition of taxonomic orders and flow, and
- abundance and percent composition of functional feeding groups and flow.

Shannon-Weaver Diversity Index

The Shannon-Weaver Diversity Index was applied using the log base-2 version of the equation as defined by the Florida Department of Environmental Protection (FAC 62-302.200(25)):

$$-\sum_{i=1}^{s}\left(n_i / N\right)\log_2\left(n_i / N\right)$$

where s = the number of species in a sample,

N = the total number of individuals in a sample, and

N_i = the total number of individuals of species s.

For comparing Shannon-Weaver Diversity Index values from other monitoring programs to the data used for these minimum flow analyses the index values should be standardized to the same log base of 2.

EPT Taxa

Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) are taxonomic orders of invertebrates that are often combined into a single metric used to assess the environmental condition of aquatic habitats. EPT ratios or percentages are used because taxa within these orders predictably decline with increasing levels of disturbance and tend to be lowest in areas of impaired water quality. In using EPT as a metric in the Withlacoochee River data, the abundance of all organisms in Orders Ephemeroptera, Plecoptera and Trichoptera were summed for each sample and divided by the total abundance of all organisms found in each sample. This provided the percentage of taxa in each sample that were EPT taxa.

4.7.3 Flow and Physical Habitat Availability

In order to link specific flow levels to both habitat availability for benthos and depths sufficient for fish passage, a relationship between river stage at the shoal and MBS discharge for each of the six shoals was developed:

Stage at Shoal Relationship to Spring Discharge

The relationship between the stage at each shoal and the estimated MBS discharge was defined as:

$$Z_{s,t} = \alpha + \sum_{k=1}^{K} \left(\beta_{s,k} Q_t^k \right)$$

where $Z_{s,t}$ = the stage (ft) at Shoal s at model time step t predicted by the HEC-RAS model presented in the previous section,

Q_t = was the estimated MBS discharge at model time step t, and

α, and β = regression parameters.

The number of terms, K, was selected empirically for each Shoal by identifying the largest value of K for a least-square regression model solution that would result in all slope parameters being significantly different from zero at an alpha level of 0.05. A K value of 3 was selected for shoal 3, and a K value of 1 was selected for shoals 1, 2, 4, 5, and 6.

Based on the relationships between stage and spring discharge, the inundated shoal area (in total acres for all six shoals) was plotted against a domain of potential MBS discharge values. Biologically important water depths on the shoals were established based on fish passage (0.6 ft) (Hupalo et al., 1994) and benthic macroinvertebrate preference curves (18 cm=0.6 ft and 40 cm=1.31 ft) (Gore, 1989.). The target water depths were similar in value.

Inundated Shoal Area Relationship to MBS Discharge:

The relationship between the area of the shoals inundated to biologically important depths and MBS discharge was defined as:

$$A_{z^*} = \sum_{s=1}^{6}\left[\sum_{c=1}^{C_s}\left(\sum_{i=1}^{I_{s,c}}\left[\frac{1}{CI}\right]\delta[z_{s,c,i},Q_t]\right)A_s\right]$$

where A_{z^*} = the area (acres) of the combined shoals that is estimated to be inundated to at least depth z^*,

C_s = the number of cross-sections systematically sampled at shoal s,

$I_{s,c}$ = the number of systematic elevation measurements reported for cross section c at shoal s,

$\delta[Z_{s,c,i},Q_t]$ = a decision variable set to 1 if the estimated stage depth at shoal s for MBS discharge Qt was greater than cross section elevation $z_{s,c,I}$ by the target depth z^*; (otherwise 0), and

A_s = the total habitat surface area of shoal s.

This definition of the relationship was quantified using the statistical approach presented above in order to obtain an unbiased estimate of the habitat distribution that is representative of the actual shoal habitat in the river.

The shoal elevations observations used in this equation were sampled from the survey data in proportion to their probability of occurrence in the field. The frequency distributions of measured shoal elevations were presented with respect to alternative minimum flow values combined across the six representative shoals. In addition, habitat availability results for the shallowest cross section from all of the data collected was evaluated.

Analyses were also completed for each of the six shoals independently, and the results of these analyses indicated that the 70-cfs minimum flow value would not lead to a restrictive loss of inundated or passable habitat at any of the six shoals. Individual plots for these results are shown in figures 4-61 through 4-72. Note that the plots with y-axes labeled “Passable” present the percent of shoal area passable with depths of at least 0.6 feet. Hence, the individual variation of depths at each shoal is not masked by pooling the data. Rather all of the elevation observations are represented with respect to the estimated probability of their occurrence in the river shoal areas. The acres are assigned in proportion to the size and morphometry of each shoal in the river. Thus, a smaller shoal contributes less acreage to the total habitat passable at a given depth.

This approach recognizes that these six surveyed shoals are representative of shallow habitat in this region of the river, and that at any particular target depth these shoals are not uniformly passable. For example, if a particular population of fish requires a passage depth of 0.6 feet, then the percentage of area passable reported based on the equation presented above indicates the estimated area to be at least 0.6 feet. Most of the area indicated would be at depths greater than 0.6 feet as indicated by the estimated distribution of depths.

Additionally, based on the available elevation data, the most restrictive cross-section of all the shoals combined was determined (Shoal 2, Cross-section A). The percent area inundated for the most restrictive cross-section was plotted against a domain of potential MBS discharge minimum flow values. The percent area of the most restrictive cross-section was also plotted for the target water depths previously mentioned.

As a final comparison, the shoal acres inundated was plotted against the shoal acreage determined to be passable by fish, and classified according to potential MBS discharge minimum flow values.

4.7.4 Flow Duration Curve Analysis

A flow duration curve analysis, using concepts developed in Jacobs and Ripo (2002), was utilized to provide an assessment of a number of minimum flow values. A flow duration curve (FDC) is a cumulative frequency curve that quantifies the percentage of time that specified flows are equaled or exceeded. The flow duration curves presented were constructed from MBS discharge data simulated using the relationship in Figure 3-16. This relationship was chosen for the flow duration curve analysis because it allows for the simulation of a full period of record (the relationship in figure 3-14 is only valid for Lee discharge below 2500 cfs). The results of this analysis are presented in Section 4.8.3 along with the results of the physical habitat availability analyses described above.

In the first step of the flow duration curve analysis, a flow duration curve was constructed using the initial 20 years of the period of record (1932 to 1952) synthesized flows from Madison Blue Springs (Figure 4-60). This is the best estimate of the spring flow regime prior to any significant anthropogenic influences on flows. Inspection of this flow duration curve indicates that the 99th exceedance value of flow (i.e., the flow that is exceeded 99 percent of the time) is approximately 90 cfs. This flow is operationally defined as the historical minimum flow.

In the next step of the analysis, a FDC was constructed for a recent 20 year period (1982 to 2002). This is the best estimate of the current spring flow regime. Total impact to the spring under current withdrawal conditions can be estimated by comparing the historical FDC and current FDC.

In the final step of this analysis, a series of hypothetical FDCs were constructed by shifting the historical FDC downwards. Each shifted FDC defines a different flow regime while maintaining the form of the historical FDC.. The corresponding differences in available water, water used,

and expected areas of shoal habitat inundated and passable by fish were estimated by comparing the historical FDC to each hypothetical FDC. The results of this analysis provide an independent set of information to the empirical habitat availability analysis described above in Section 4.7.3.

4.8 Results

The results from the empirically defined relationships were used to narrow the field of potential minimum flow candidates based on the "best available data" regarding how flows from MBS affect the three previously cited components of ecological integrity.

4.8.1 Flow and Water Quality

A biologically meaningful relationship between low dissolved oxygen levels in the Withlacoochee River and flow in the Withlacoochee River was defined using the observed data. Low dissolved oxygen conditions were expected at low river flows due to increased residence time and the presence of biological and chemical oxygen demand processes. In line with this expectation, dissolved oxygen values less than 5 mg/L occurred only at flows less than 2500 cfs (Figure 4-35). The dissolved oxygen level of 5 mg/L is a biologically important level below which biological integrity is expected to be impaired (Florida State Surface Water Quality Standards). In particular, the Florida State Impaired Waters Rule defines impaired waters as waters in which the state standards are exceeded at a rate of greater than 10 percent of the time. The results of the regression analysis defined a statistically significant relationship (R^2=0.68, p-value <0.0001) between low dissolved oxygen conditions (10th percentile) and flow, and the results are presented graphically in Figure 4-36. Bivariate plots of additional water quality parameters and flow are contained in Appendix B.

This biologically meaningful relationship between low dissolved oxygen levels and flows in the Withlacoochee River may be most directly useful for establishing a flow for the relevant Withlacoochee River reach at a later time, and it is not recommended as an application to select candidate minimum flow levels for MBS.

4.8.2 Flow and Benthic Biology

Relationships to be used to narrow the field of minimum flow candidates for MBS were not identified from the flow and benthic biology data. A steady decrease in Shannon-Weaver Diversity scores was observed as flow increased (Figure 4-37). EPT taxa comprised a similar percentage of each sample throughout the majority of observed flow values, except for the highest flows, which were observed as having a reduced percentage of EPT taxa (Figure 4-38). A decreasing relationship with increasing flow was also observed for a number of species, families, orders and feeding groups, in terms of both raw abundances and percent composition (Appendix C). An increase in abundance was observed for Family Simuliidae (blackflies) and *Simulium* spp., as flow increased (Figures 4-42 and 4-43). Plots of the raw abundance of the two most abundant orders (Figures 4-39 and 4-40), families (Figures 4-41 and 4-42) and species (Figures 4-43 and 4-44) are presented, as well as two feeding groups (Figures 4-45 and 4-46).

The application of these benthic invertebrate relationships to defining candidate minimum flow levels is not recommended. These plots should not be interpreted as reflecting an accurate relationship between benthic invertebrate abundance and flow. While flow was observed to be a force of potential dislodgement for organisms inhabiting lotic environments, laboratory studies have been conducted that show organisms have the ability to withstand flows greater than typically occur in natural systems (Statzner et al., 1988). Additionally, it is necessary to note that the Hester-Dendy samplers use artificial substrate plates which do not replicate all the natural substrates found in the river, which provide numerous refuges from flow (e.g., rocks, interstitial spaces between sediments) that allow organisms to hold their position in the river under higher flow regimes (Giller and Malmqvist, 1998). Hester-Dendy samplers are said to imitate one type of natural substrate/habitat found in the river- snag (wood) habitat. Therefore, it is possible to conclude that the Hester-Dendy samples best serve in this instance as providing information on which species occur in the river, but that the abundance values may not accurately reflect benthic invertebrate responses to changes in flow on shoal or other natural habitat (substrate).

4.8.3 Flow and Physical Habitat Availability

Biologically meaningful relationships were observed between MBS flow and physical habitat availability at the six representative shoal habitats in the Withlacoochee River downstream of the spring. We recommend application of these relationships to narrow the field of potential minimum flow candidates for MBS.

Estimated river stage at the shoals was observed to increase with increasing estimated flow from MBS. As described in the methods sections above, regression analysis were used to quantify these relationships for each of the six shoals. Figures 4-47 through 4-52 present the results of these analyses. All of the regressions were highly significant ($P>F < 0.001$) and explained a significant portion of the variation in the shoal stage data (R^2 values ranged from 0.70 to 0.84).

The estimated total surface area of shoals inundated was also positively related to the estimated MBS discharge. Similar response curves were observed for the biologically important target water depths of >0-feet, > 0.6 feet, and >1.31 feet (Figures 4-53 - 4-55). Each inundation response curve has several inflection points that represent potential candidate minimum flow values.

Examination of the relationship between flow and conditions on the most restrictive (shallowest) cross section (Shoal 2, cross-section A) provides an alternative analytical approach. Results are provided for the previously applied water depths of >0 feet (Figure 4-56), > 0.6 feet (Figure 4-57), and >1.31 feet (Figure 4-58). Results from these analyses of the most restrictive cross-section indicated that there was a positive relationship between the availability of habitat along the cross-section with these various depths as a function of MBS discharge as expected.

In order to provide a tool for narrowing the selection of possible candidate minimum flow values for MBS, a final response curve was developed to present the relationship between the total surface area inundated and the area passable by fish at a water depth of 0.6 feet to a set of candidate MBS flow values (Figure 4-59). This curve ranges over the MBS flow values that define the domains of the regression models that were used to construct them; these model domains ranged from 52 cfs to 100 cfs. Based on inflection points observed in the relationships presented in this plot, three candidate minimum flow values were identified:

- 70 cfs (increases in spring discharge in this region of the curve will not result in significant increases in total inundated shoal area as evidenced by the near horizontal slope of the curve in the 70 cfs region of the curve),

- 85 cfs (increases in spring discharge in this region of the curve will not in increases in fish passable shoal area as evidenced by the near vertical slope of the curve in the 85 cfs to 90 cfs region of the curve),

- 100 cfs (this spring discharge was considered because it was the largest candidate value within the model domain).

These three candidate minimum flow values can be compared to historical flow conditions as described in Section 4.7.4. This allows an estimate of the potential loss of available habitat (i.e., percent of inundated shoal area) under these three candidate minimum flow values from historical flow conditions. The estimated losses are summarized in Table 4-4 and are based on the relationship seen in Figure 4-60.

For the 70 cfs candidate minimum flow value, the loss of shoal habitat availability during low water levels is 0.4 acres (7.7%) for fish passage and 0.3 acres (5.6%) for inundation from that available under historical flow conditions. The 0.4 acre loss is small within the context of the total available shoal habitat, and therefore we believe this does not constitute significant harm. Thus, the expected change in habitat for the 70 cfs minimum flow, over the range of flow conditions exhibited by MBS, was determined to be reasonable and it was determined to be an acceptable change barring potential future changes in shoal morphometry and further information from future data collection.

TABLE 4-4. Comparison of estimated differences in shoal habitat areas resulting from a shift from a historical flow regime (1932-1952) with a 90 cfs estimated low flow to potential future flow regimes for three candidate minimum flow values.

Minimum Flow Madison Blue Sp (cfs)	Shoal Area Passable by Fish (acres)	Shoal Area Wetted (acres)	Difference from Historical Shoal Area Passable by Fish (acres)(%)	Difference from Historical Shoal Area Wetted (acres)(%)
70 cfs	4.8	5.1	-0.4 (-7.7%)	-0.3 (-5.6%)
85 cfs	5.1	5.3	-0.1 (-1.9%)	-0.1 (-1.9%)
100 cfs	5.2	5.5	0	+0.1 (+1.8%)

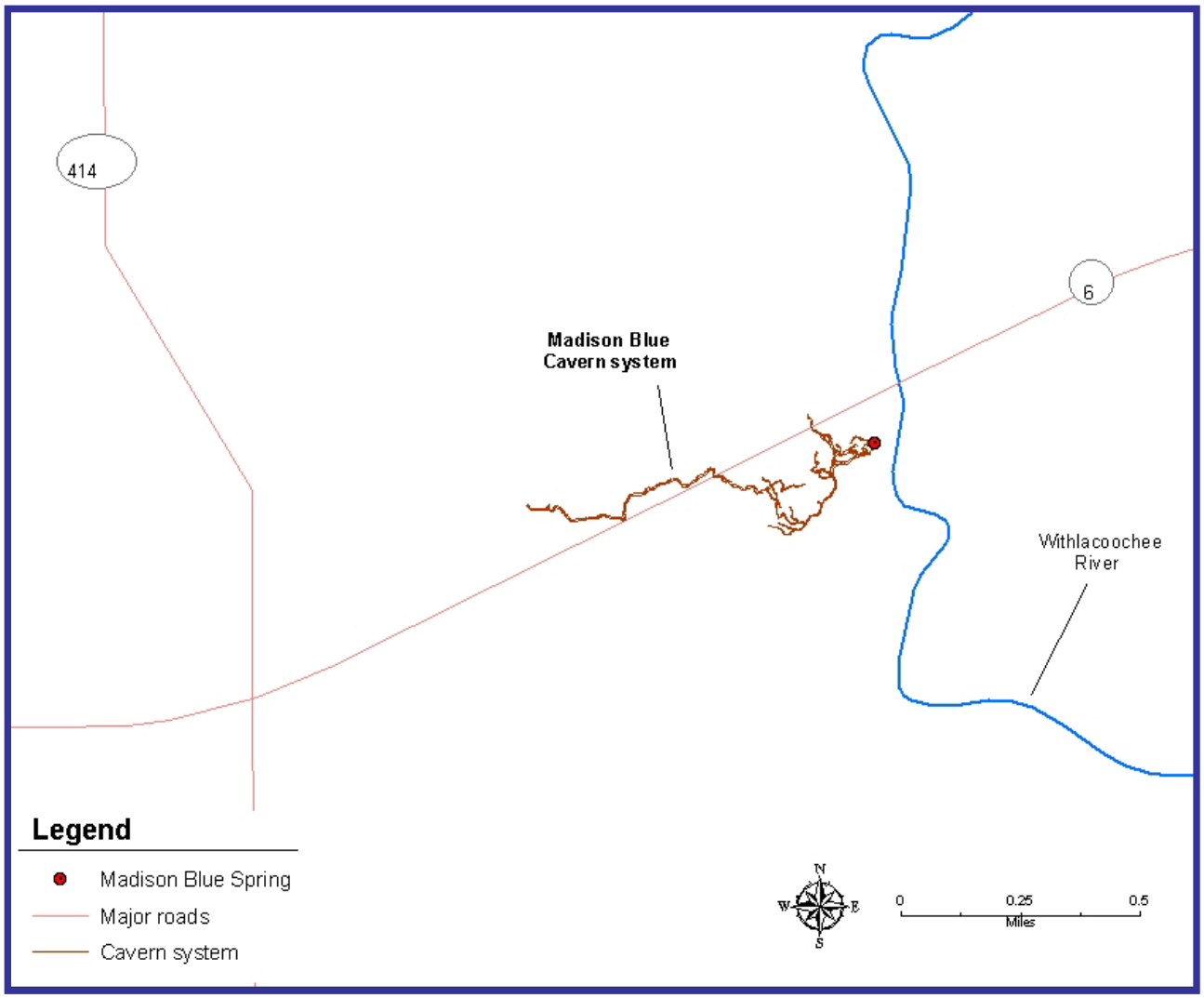


Figure 4-1. Map showing location of the underwater cave system associated with Madison Blue Spring.

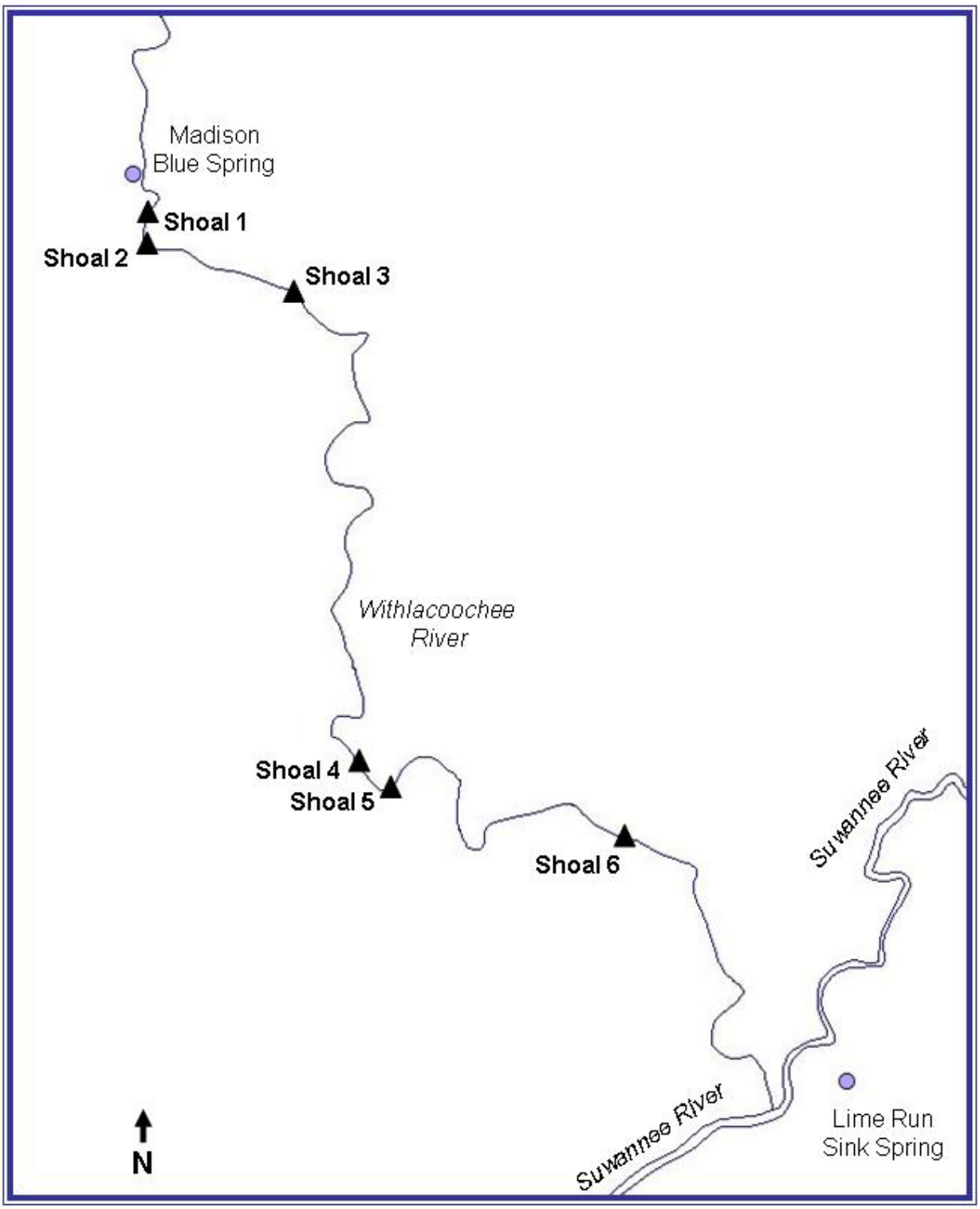


Figure 4-2. Locator map identifying the six shoals in the Withlacoochee River downstream of Madison Blue Springs.

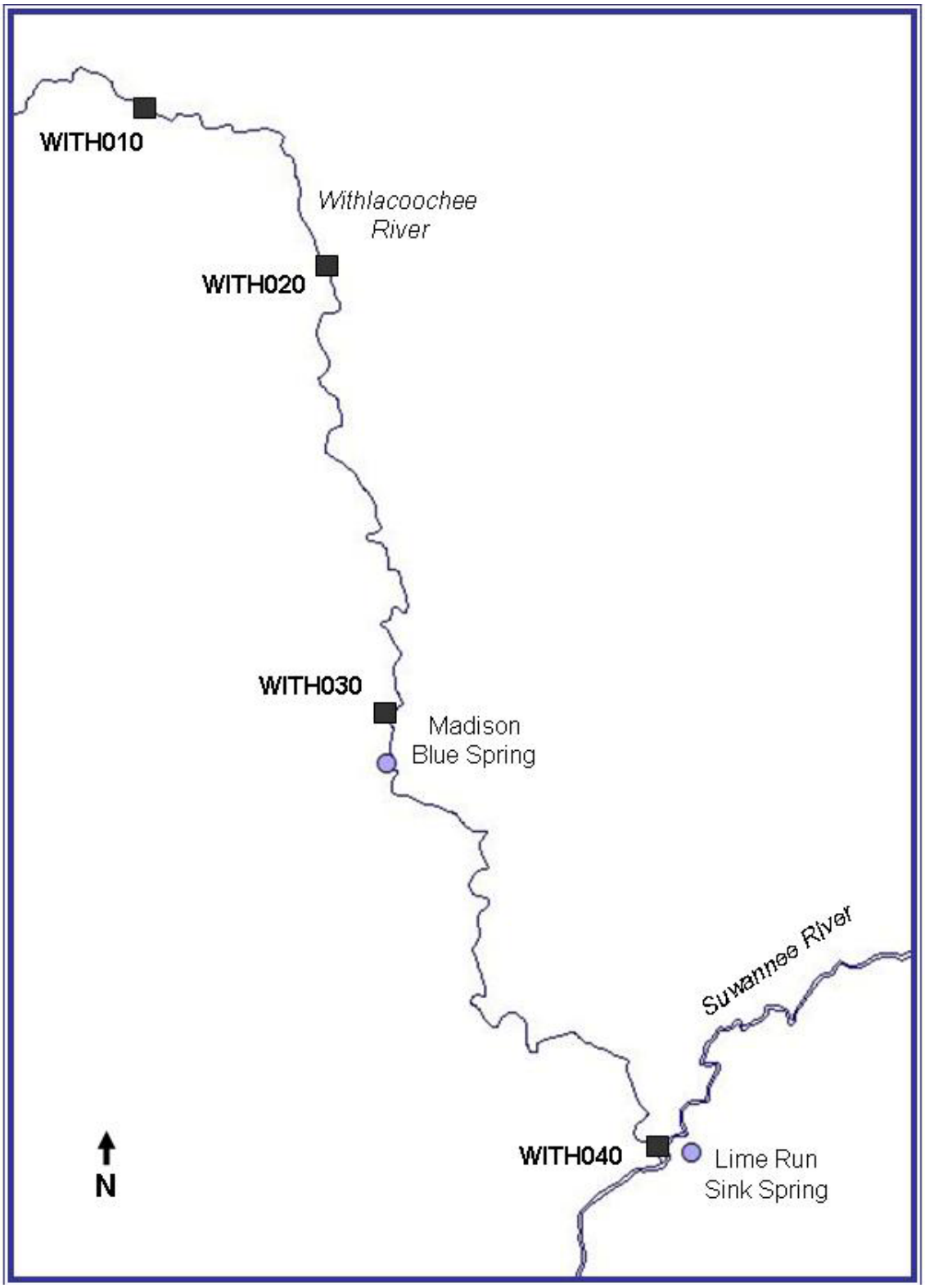


Figure 4-3. Locator map identifying the four Suwannee River Water Management Stations where water quality and biological data were collected.

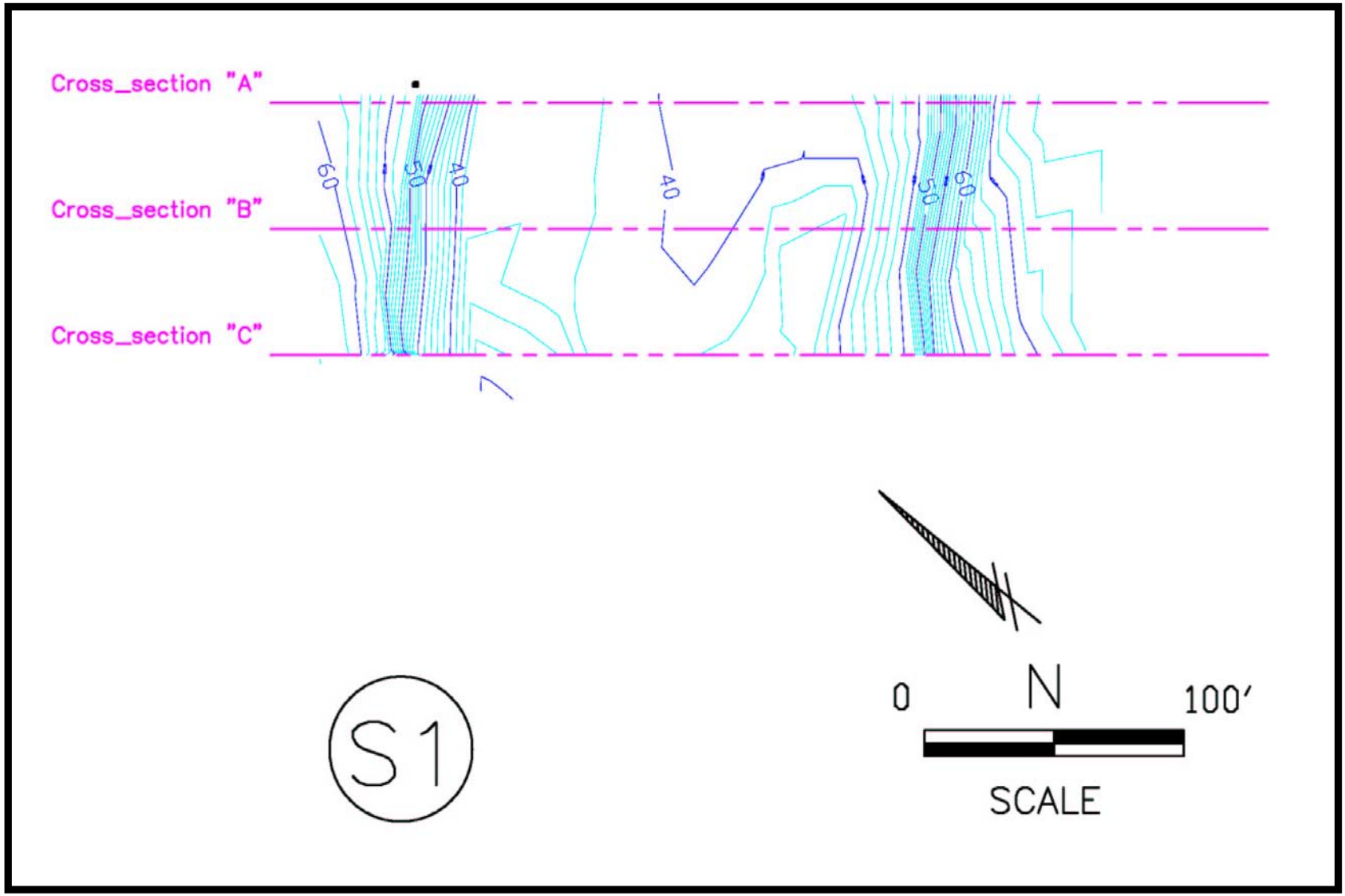


Figure 4-4. Map of Shoal 1 showing cross-section locations and elevation.

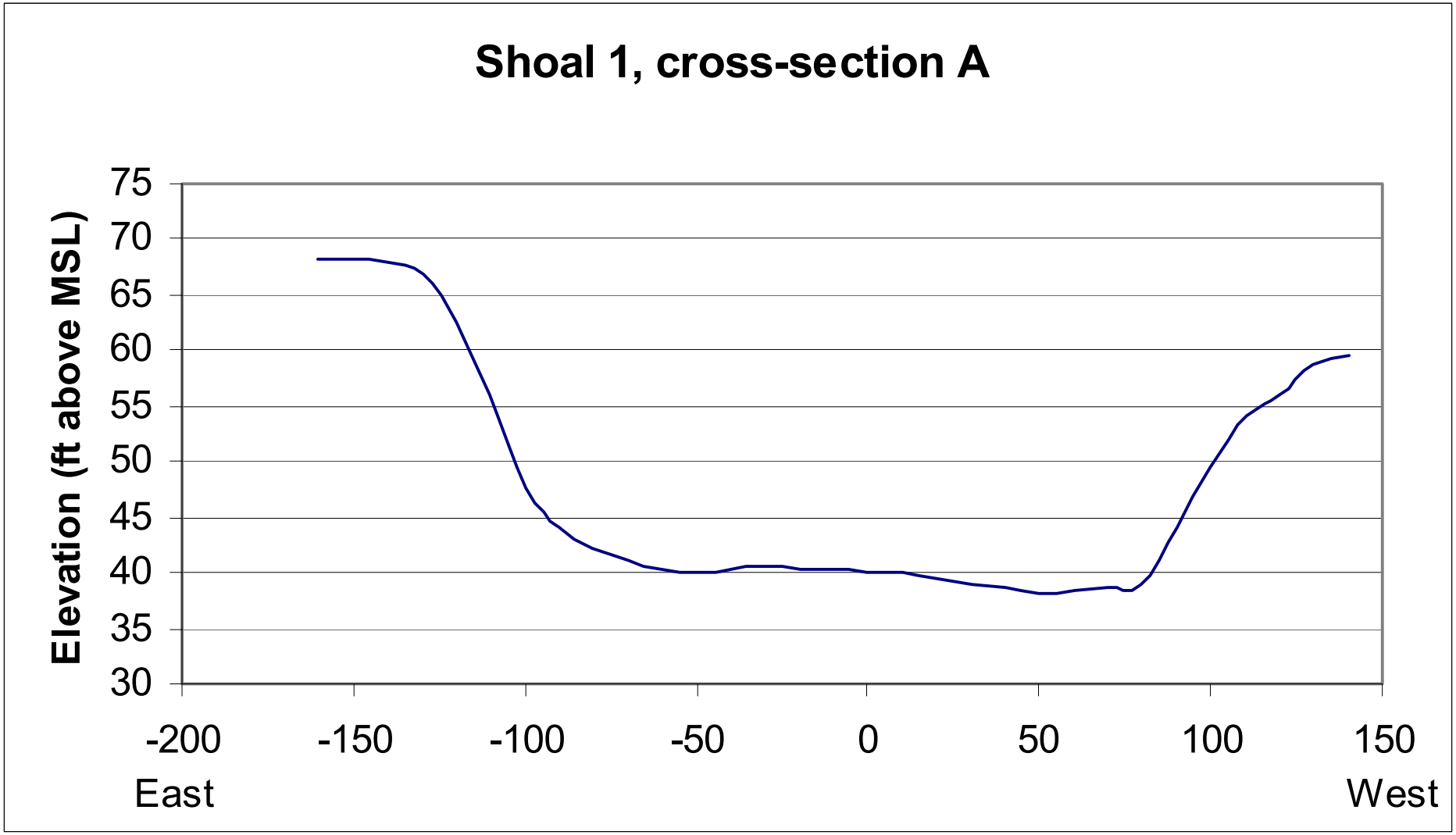


Figure 4-5. Elevation of Shoal 1, cross-section A.

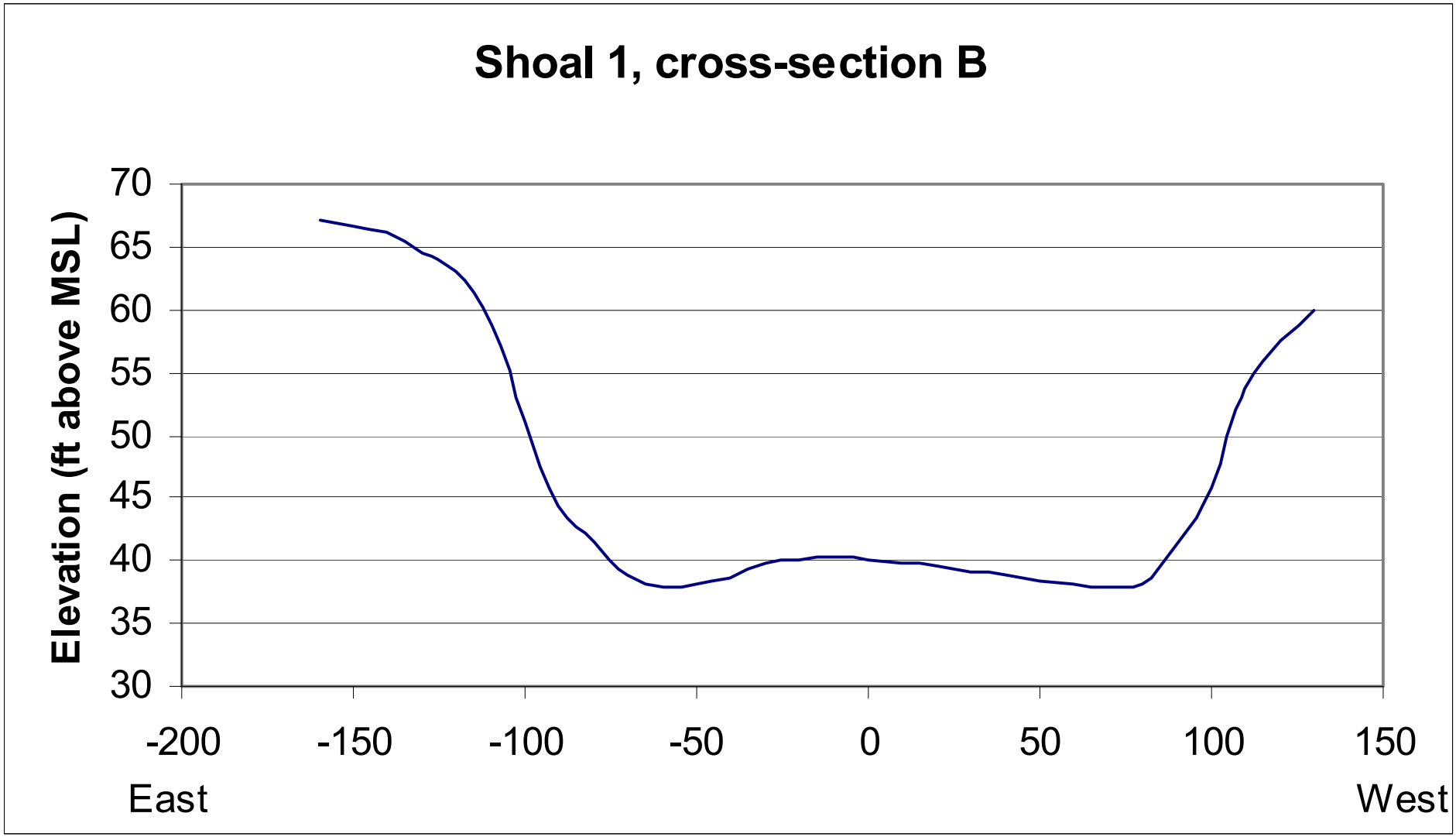


Figure 4-6. Elevation of Shoal 1, cross-section B.

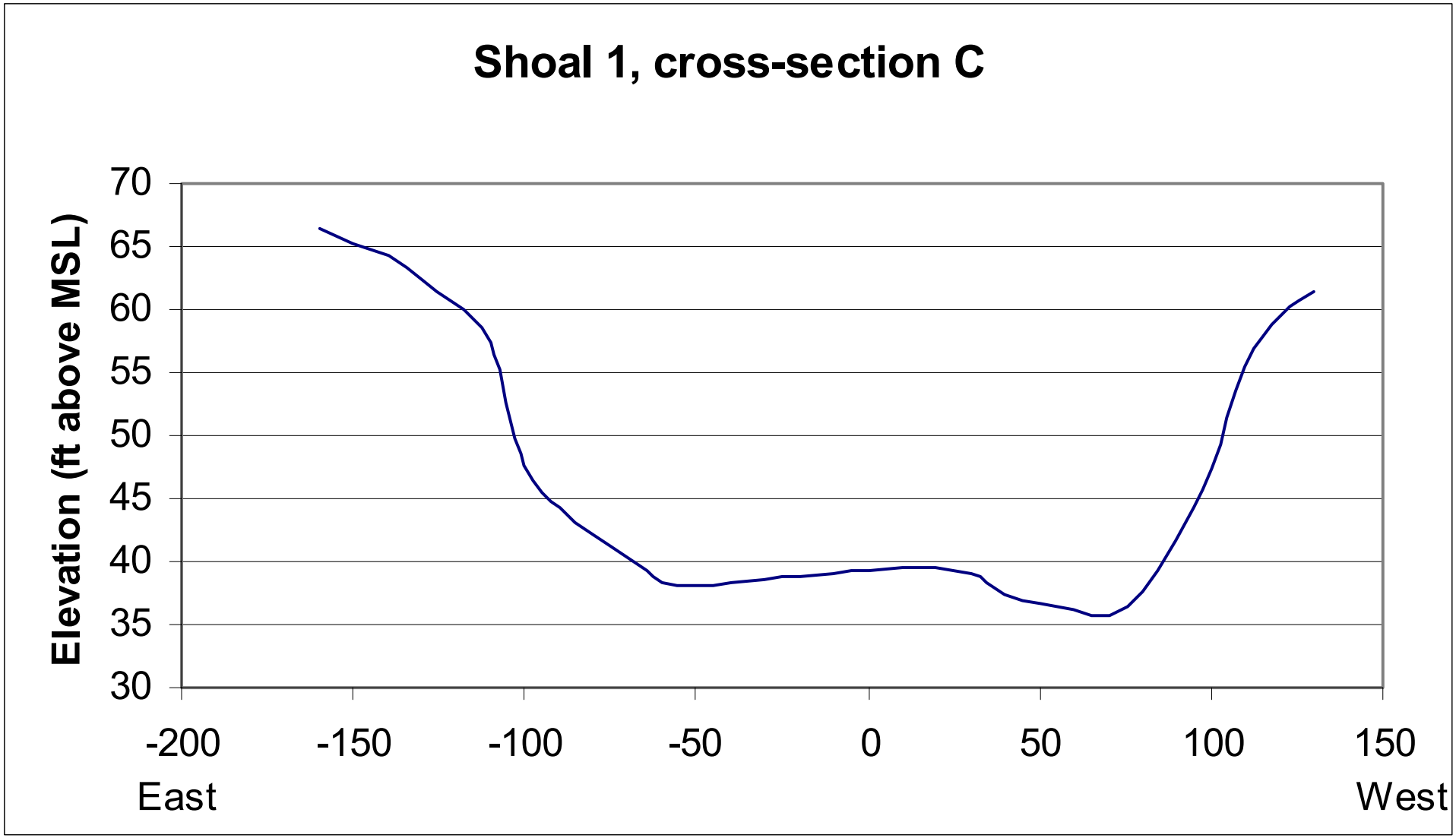


Figure 4-7. Elevation of Shoal 1, cross-section C.

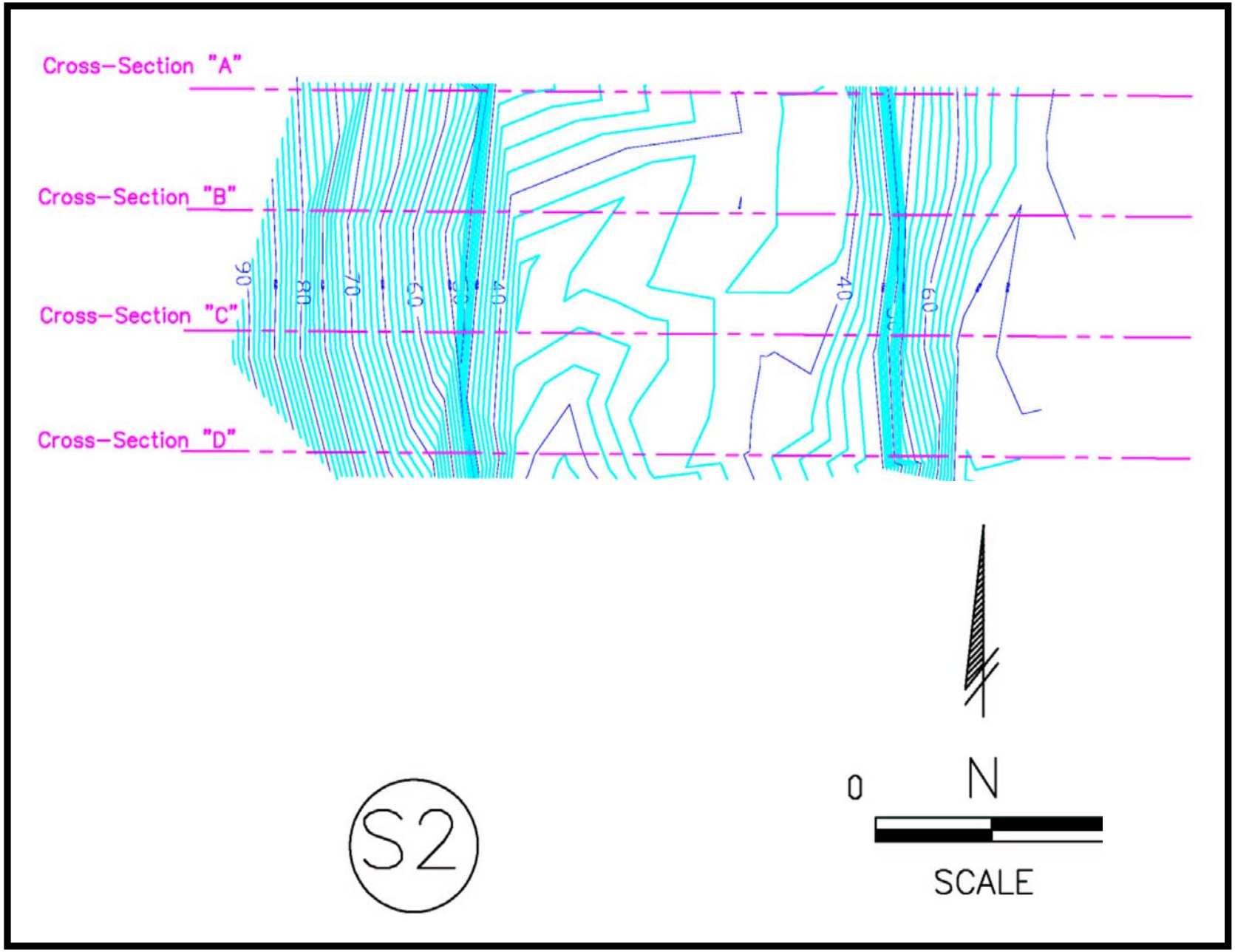


Figure 4-8. Map of Shoal 2 showing cross-section locations and elevation

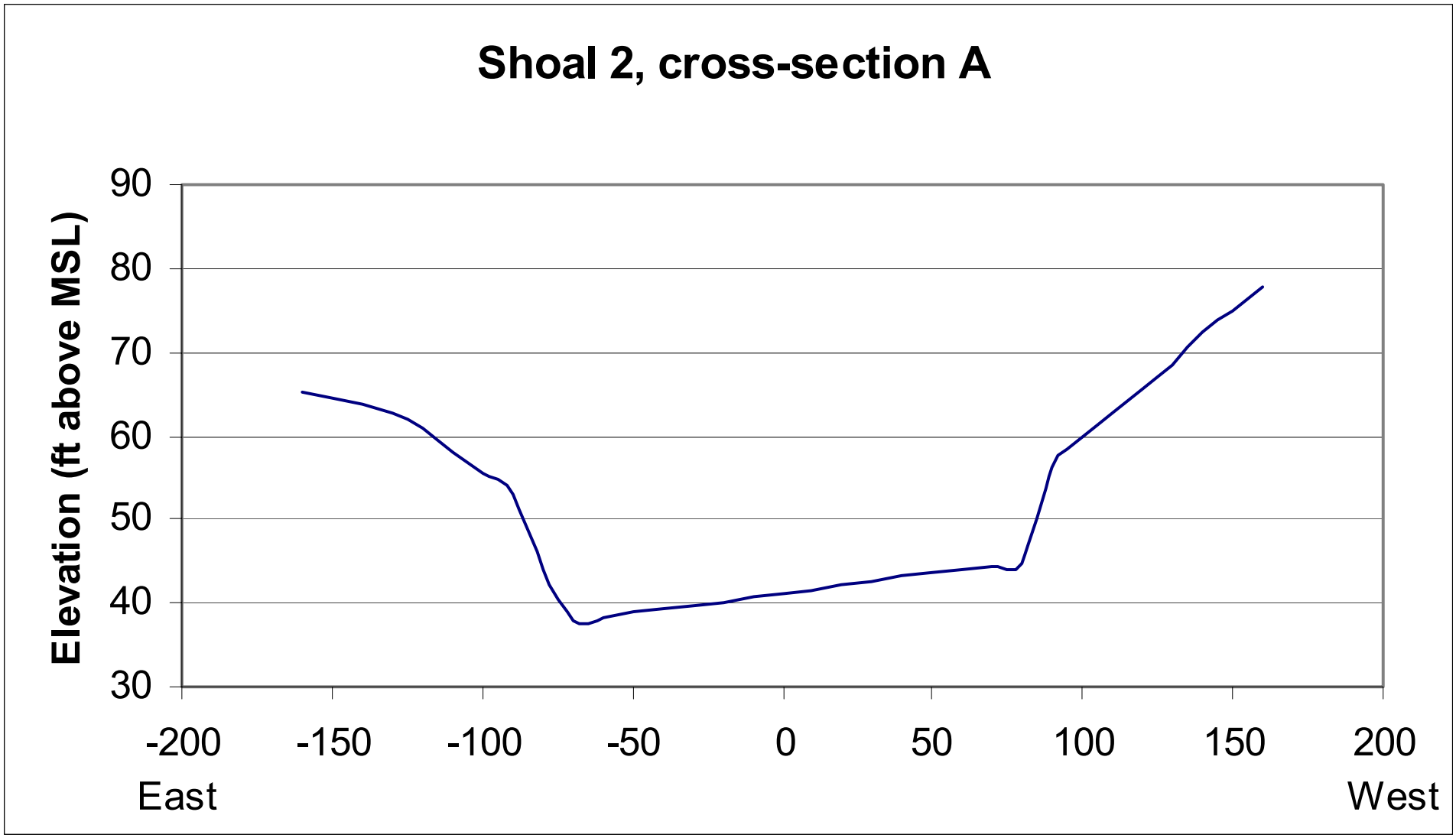


Figure 4-9. Elevation of Shoal 2, cross-section A.

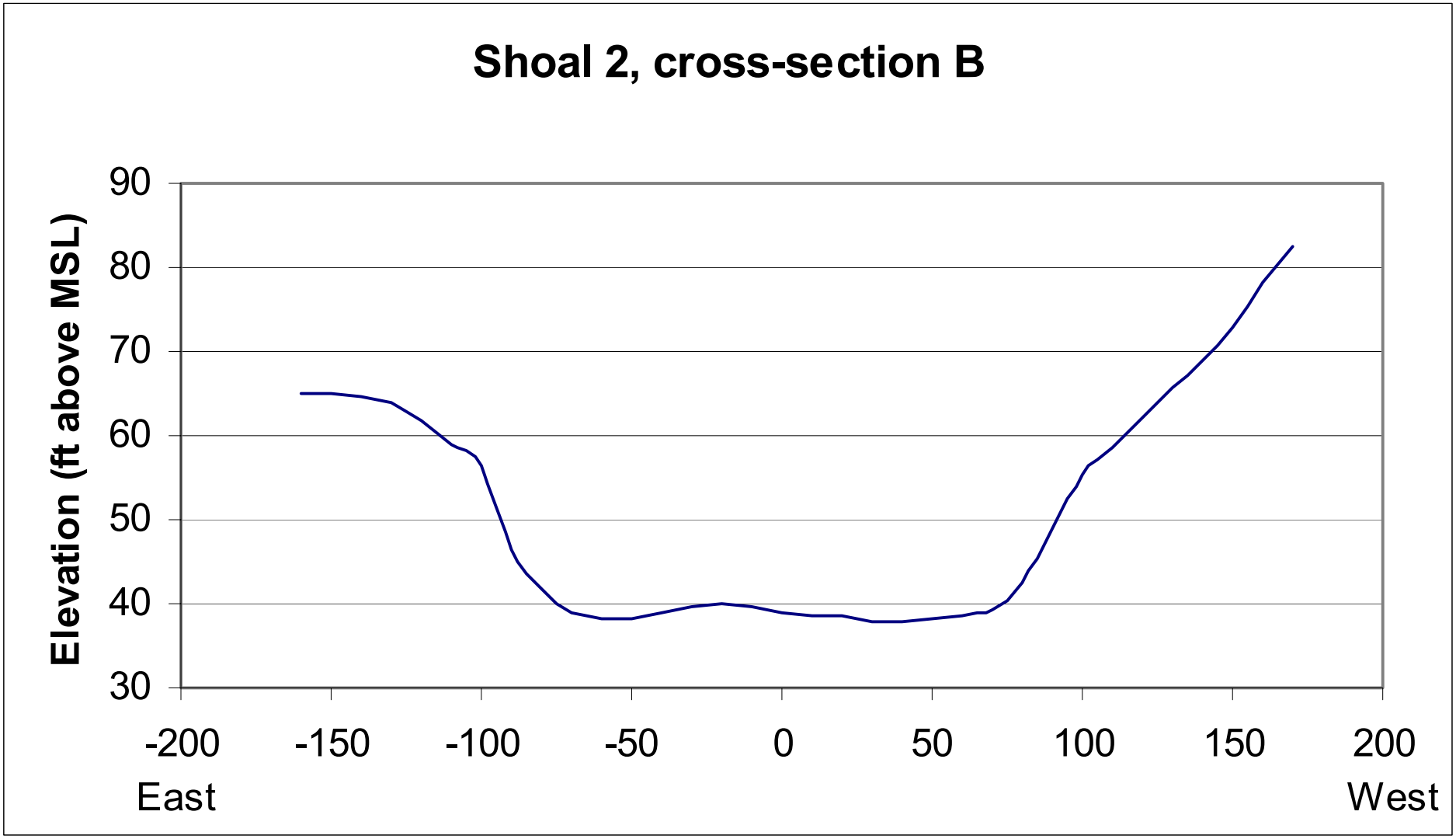


Figure 4-10. Elevation of Shoal 2, cross-section B.

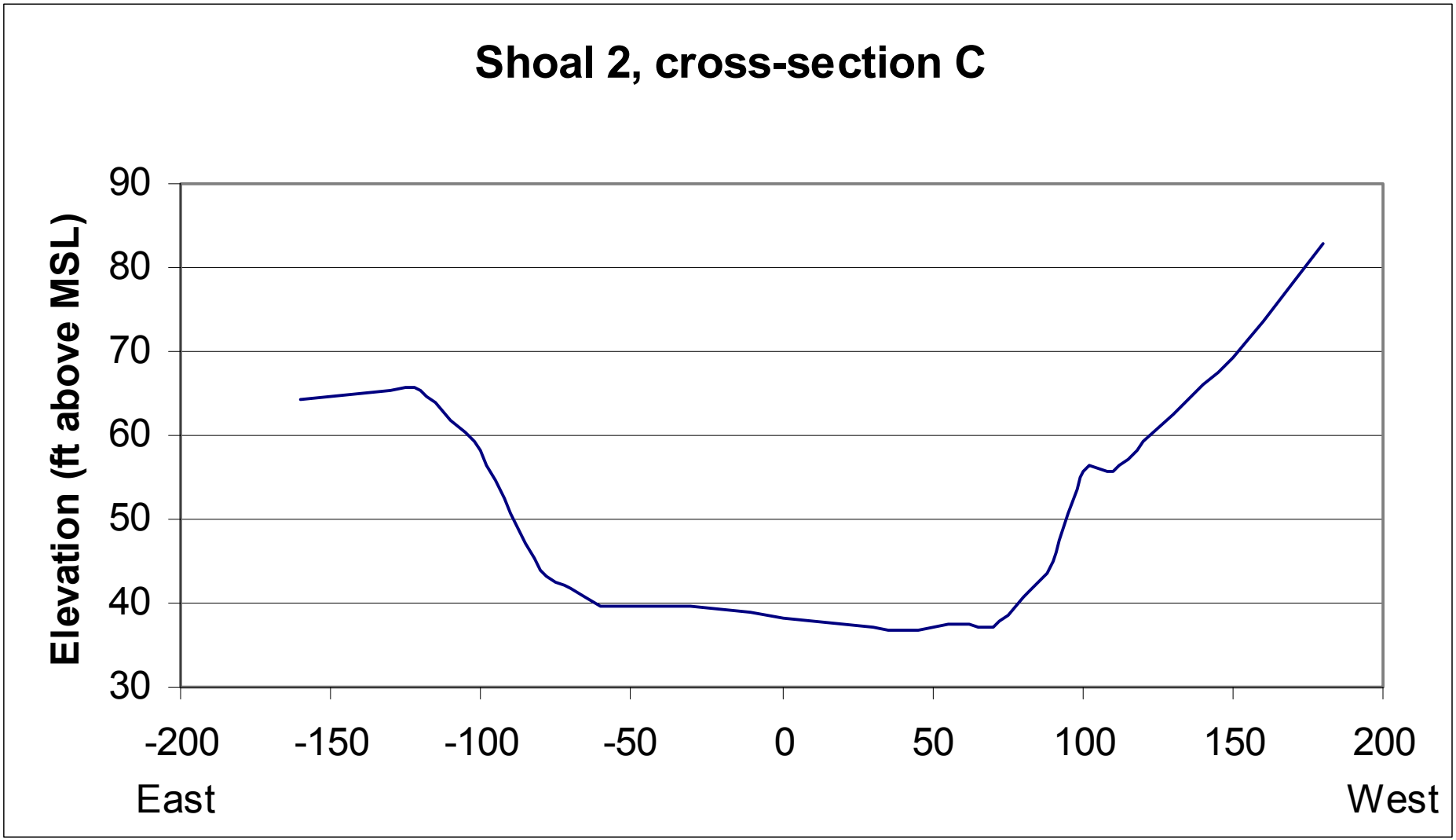


Figure 4-11. Elevation of Shoal 2, cross-section C.

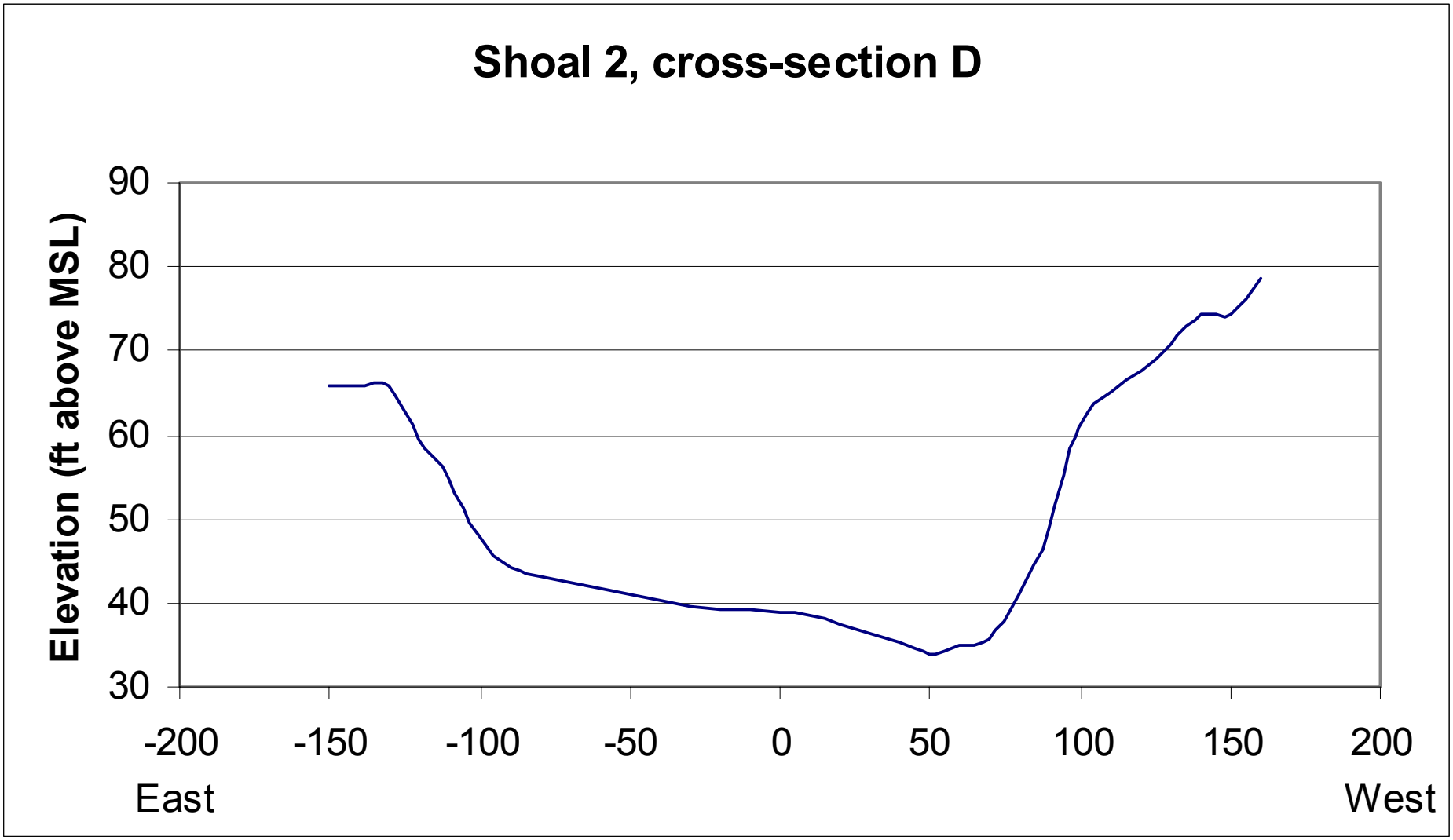


Figure 4-12. Elevation of Shoal 2, cross-section D.

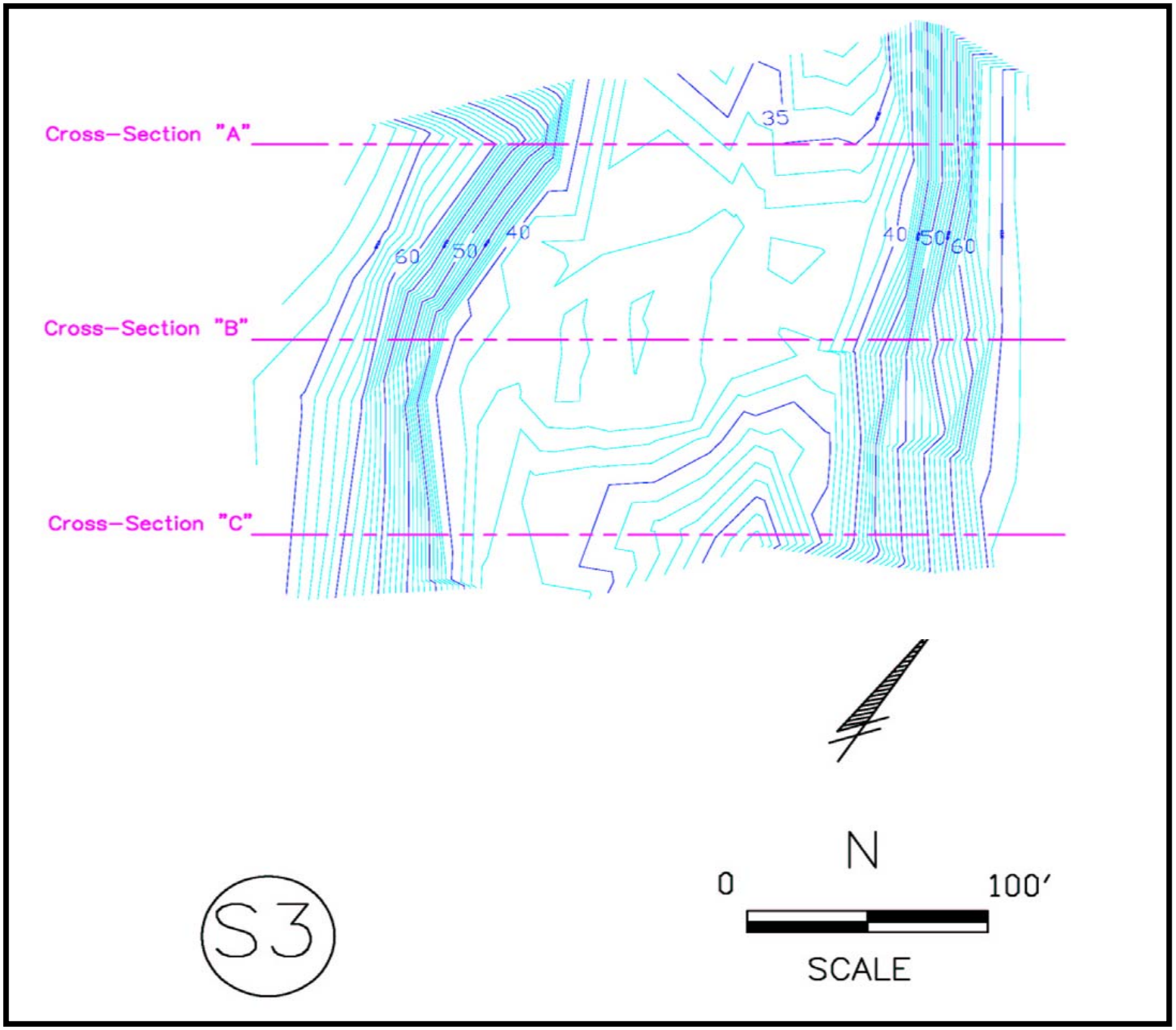


Figure 4-13. Map of Shoal 3 showing cross-section locations and elevation.

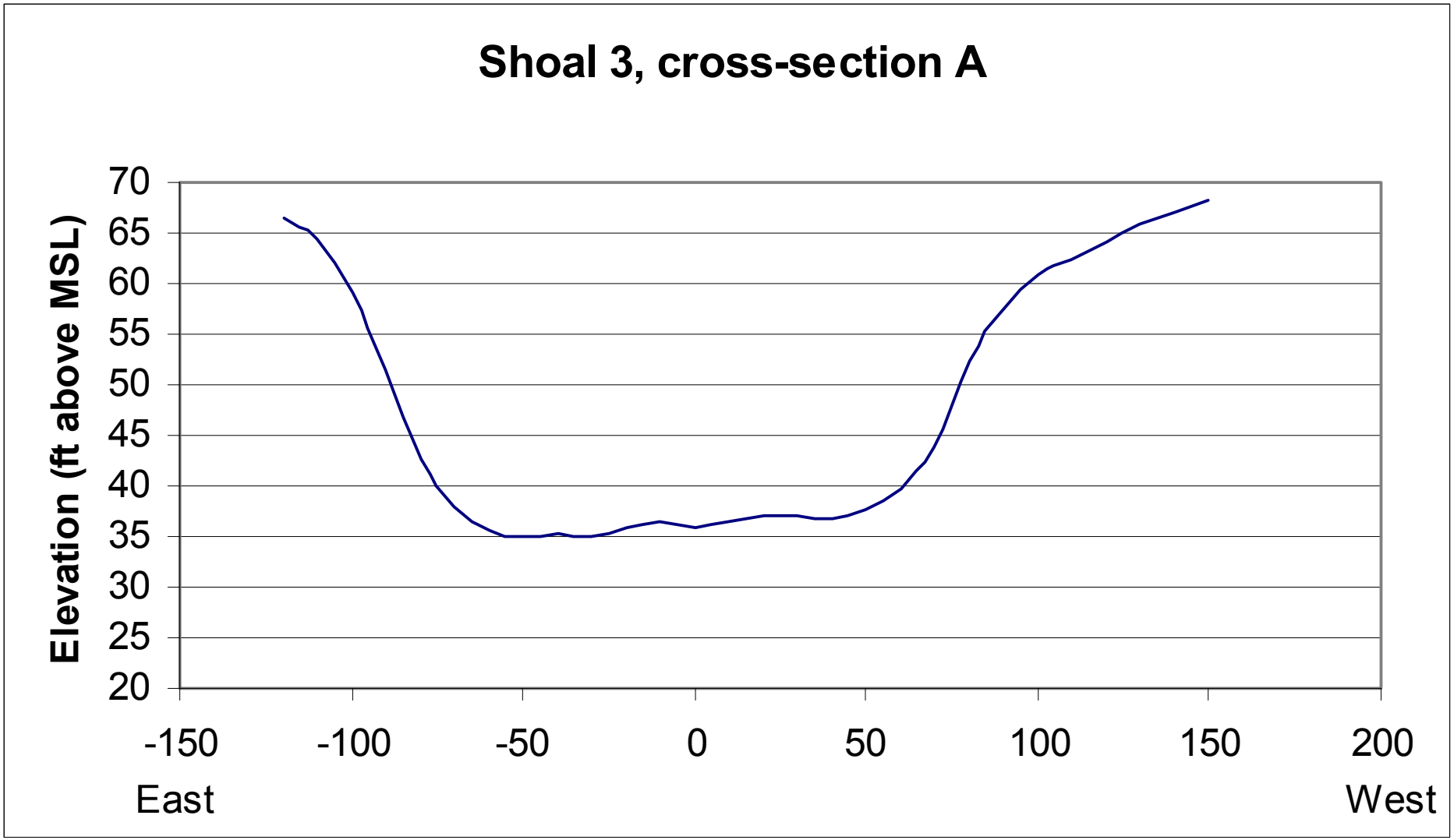


Figure 4-14. Elevation of Shoal 3, cross-section A.

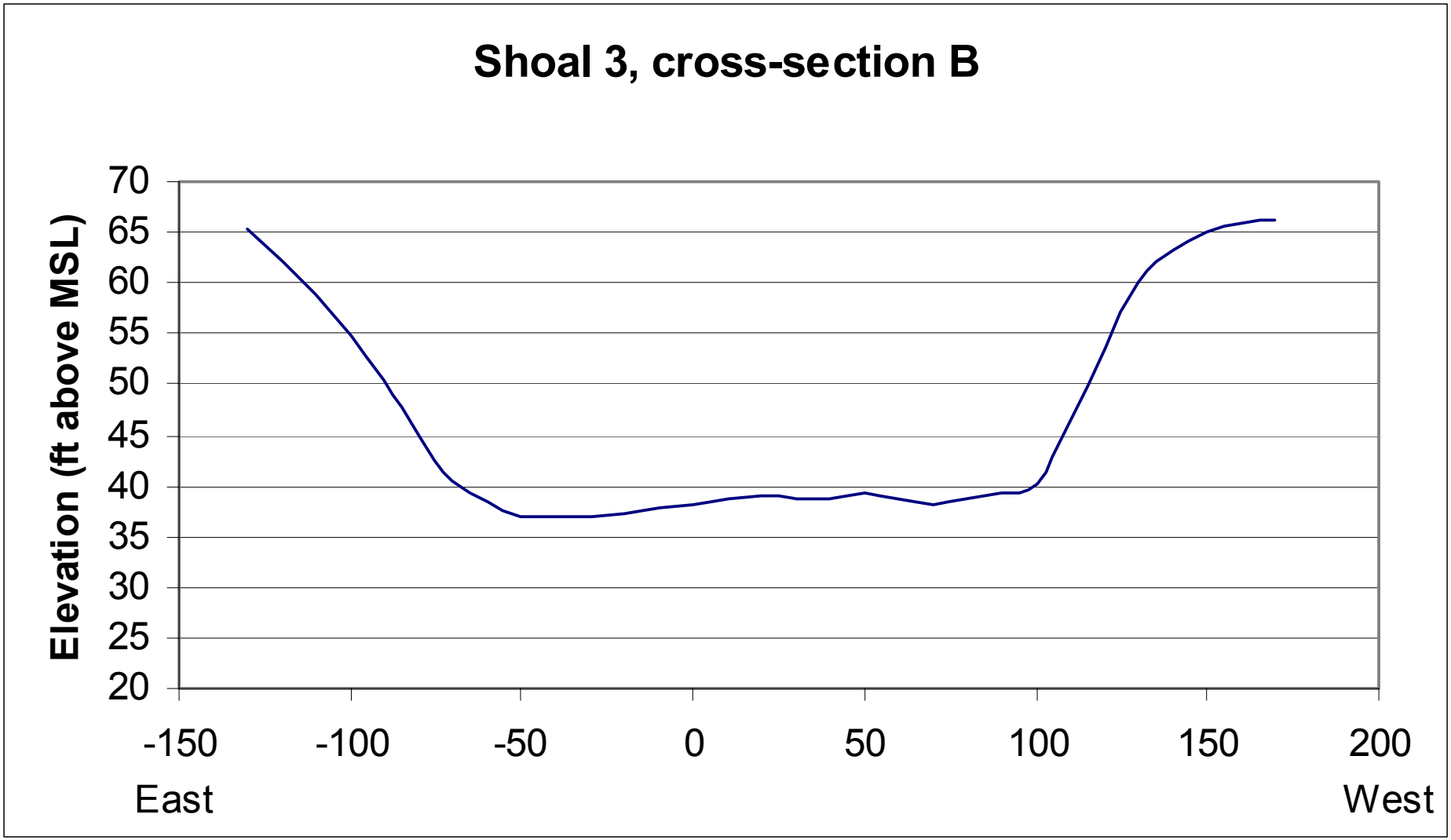


Figure 4-15. Elevation of Shoal 3, cross-section B.

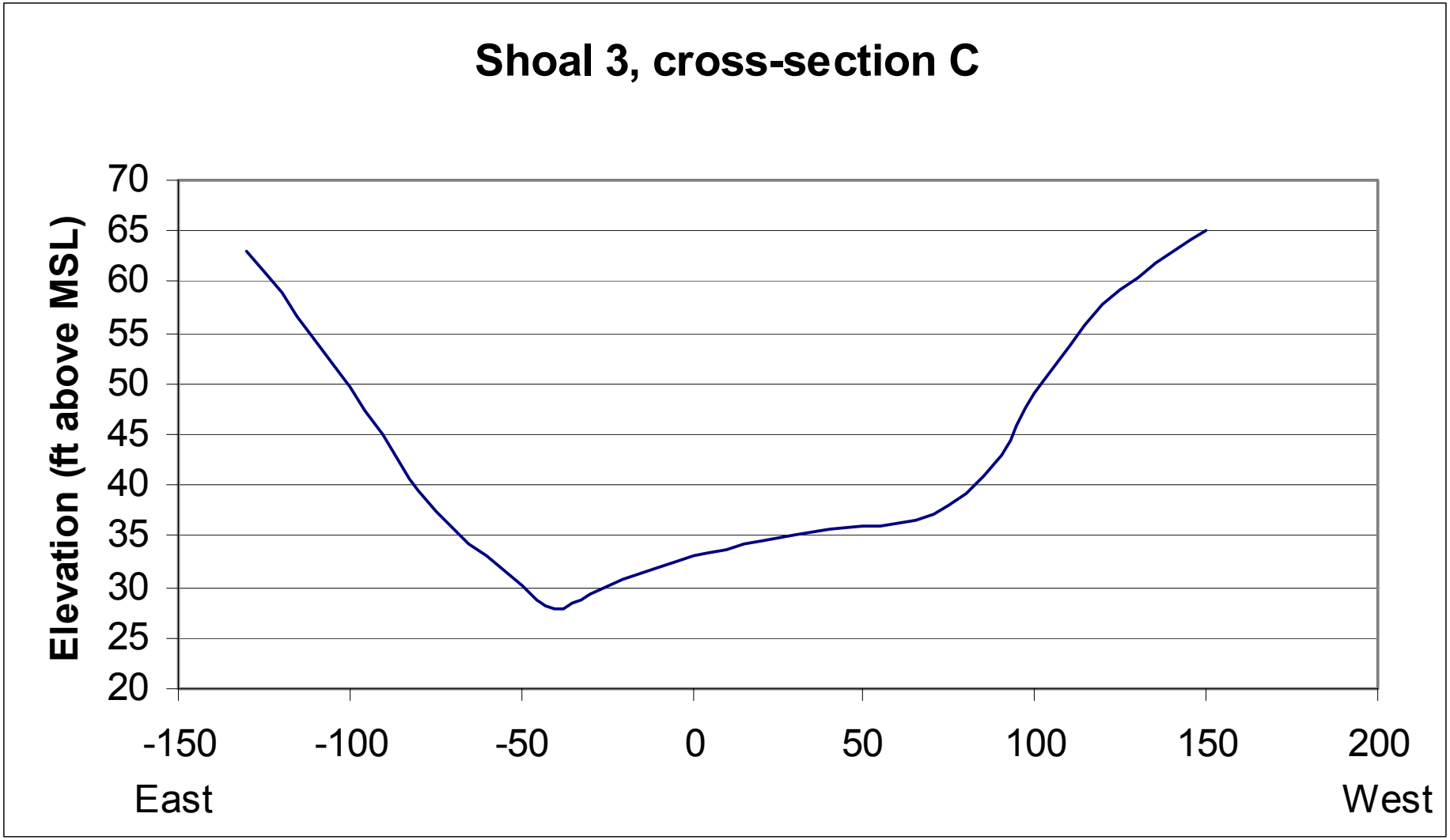


Figure 4-16. Elevation of Shoal 3, cross-section C.

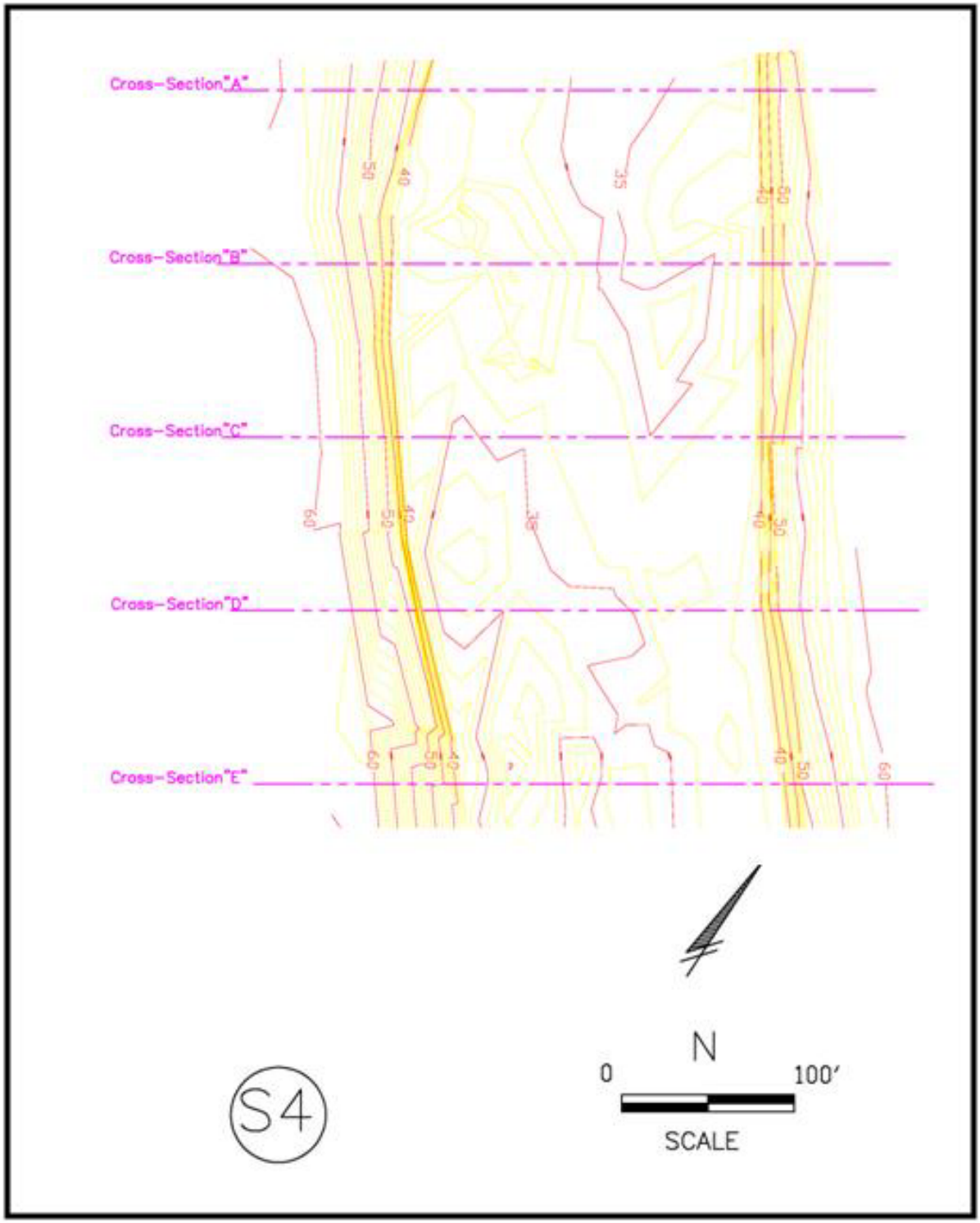


Figure 4-17. Map of Shoal 4 showing cross-section locations and elevation.

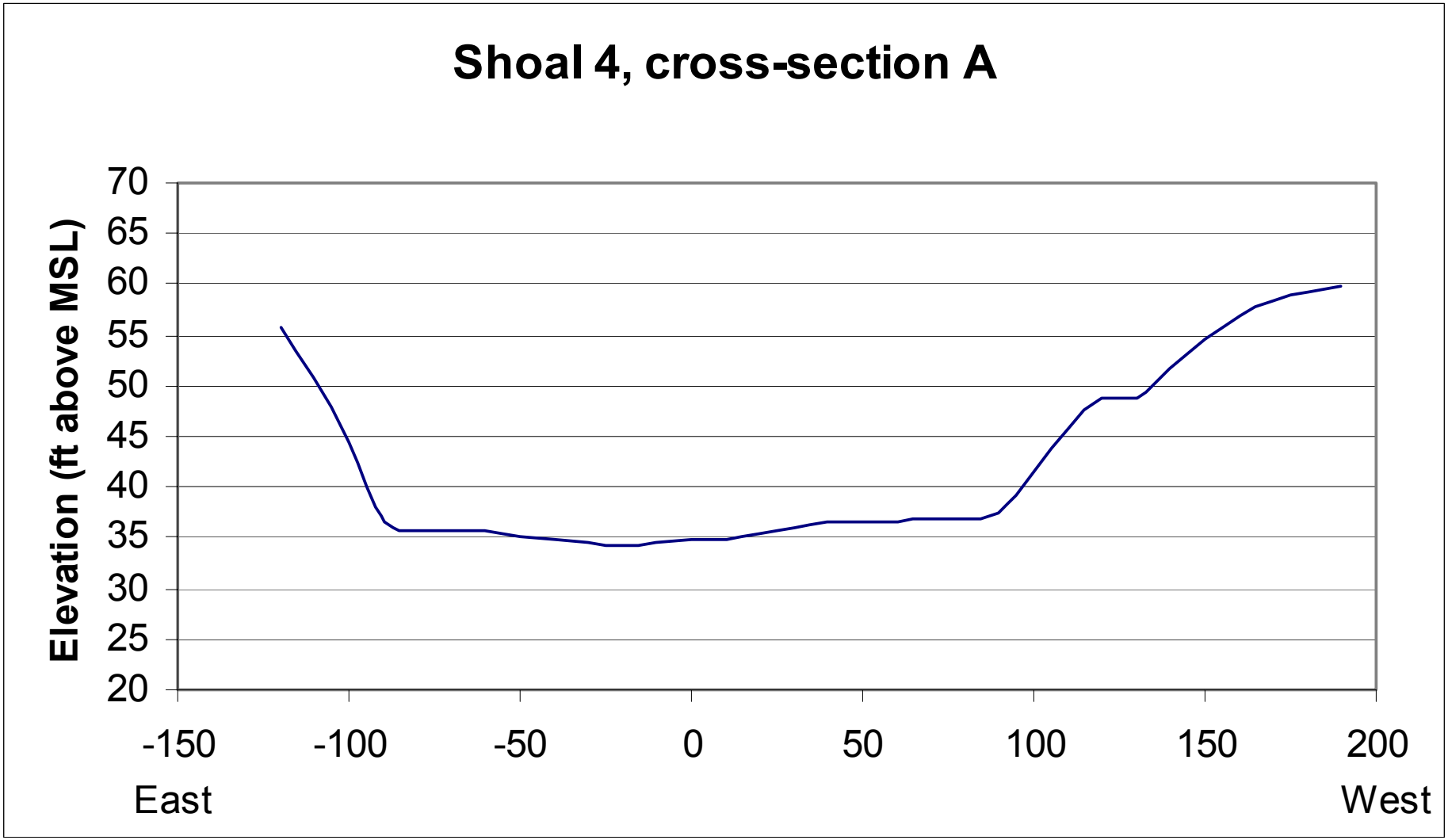


Figure 4-18. Elevation of Shoal 4, cross-section A.

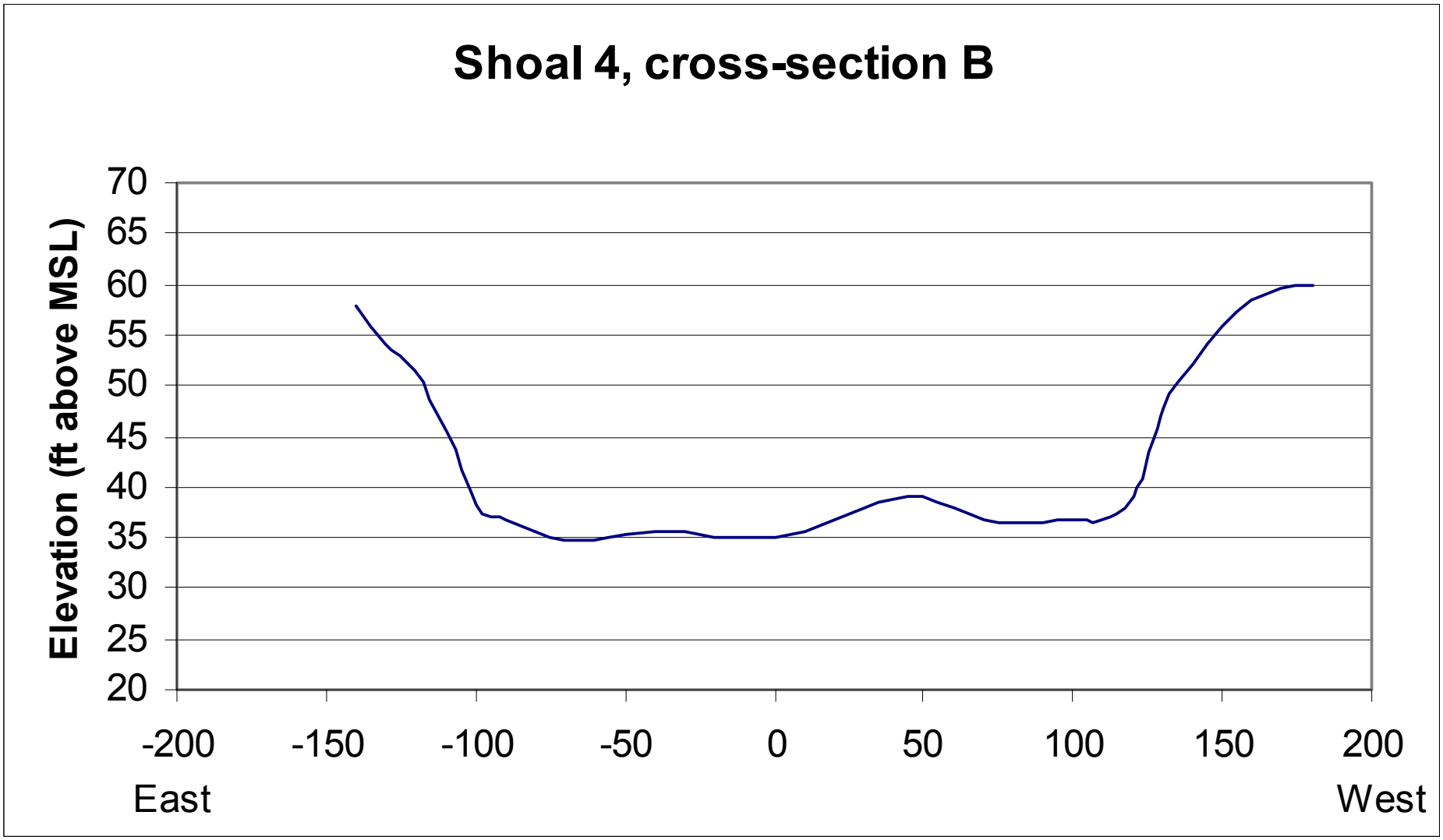


Figure 4-19. Elevation of Shoal 4, cross-section B.

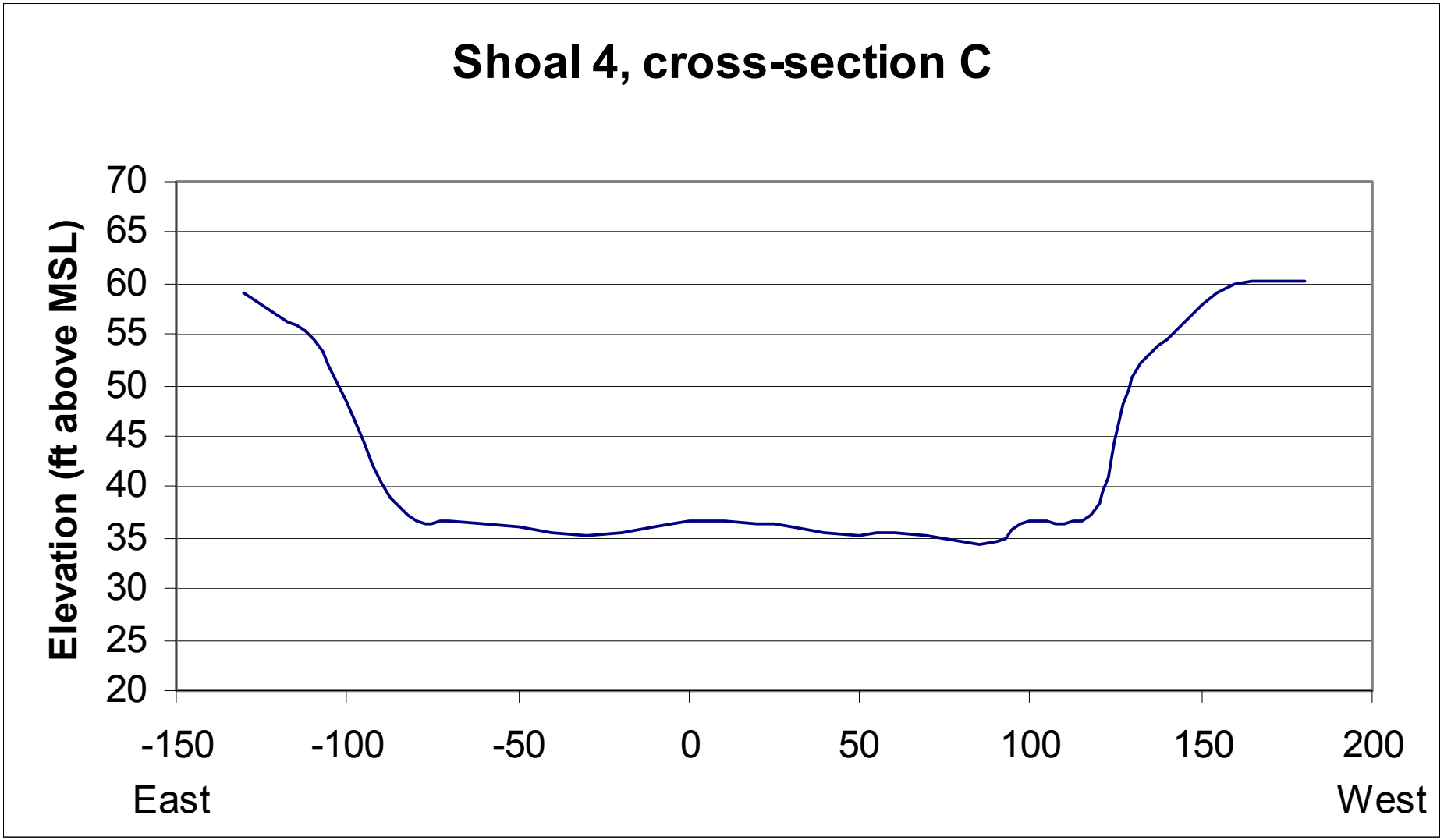


Figure 4-20. Elevation of Shoal 4, cross-section C.

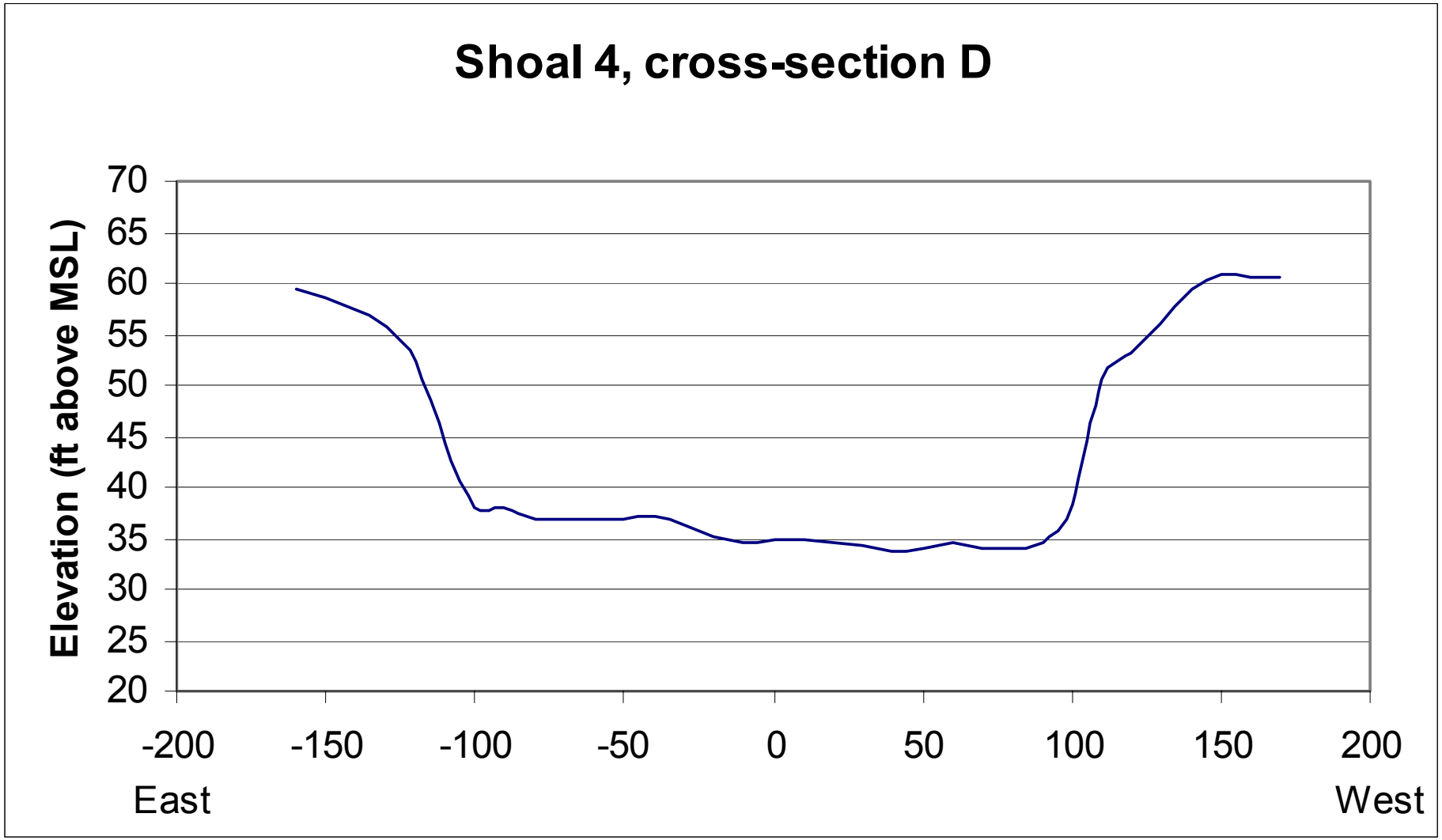


Figure 4-21. Elevation of Shoal 4, cross-section D.

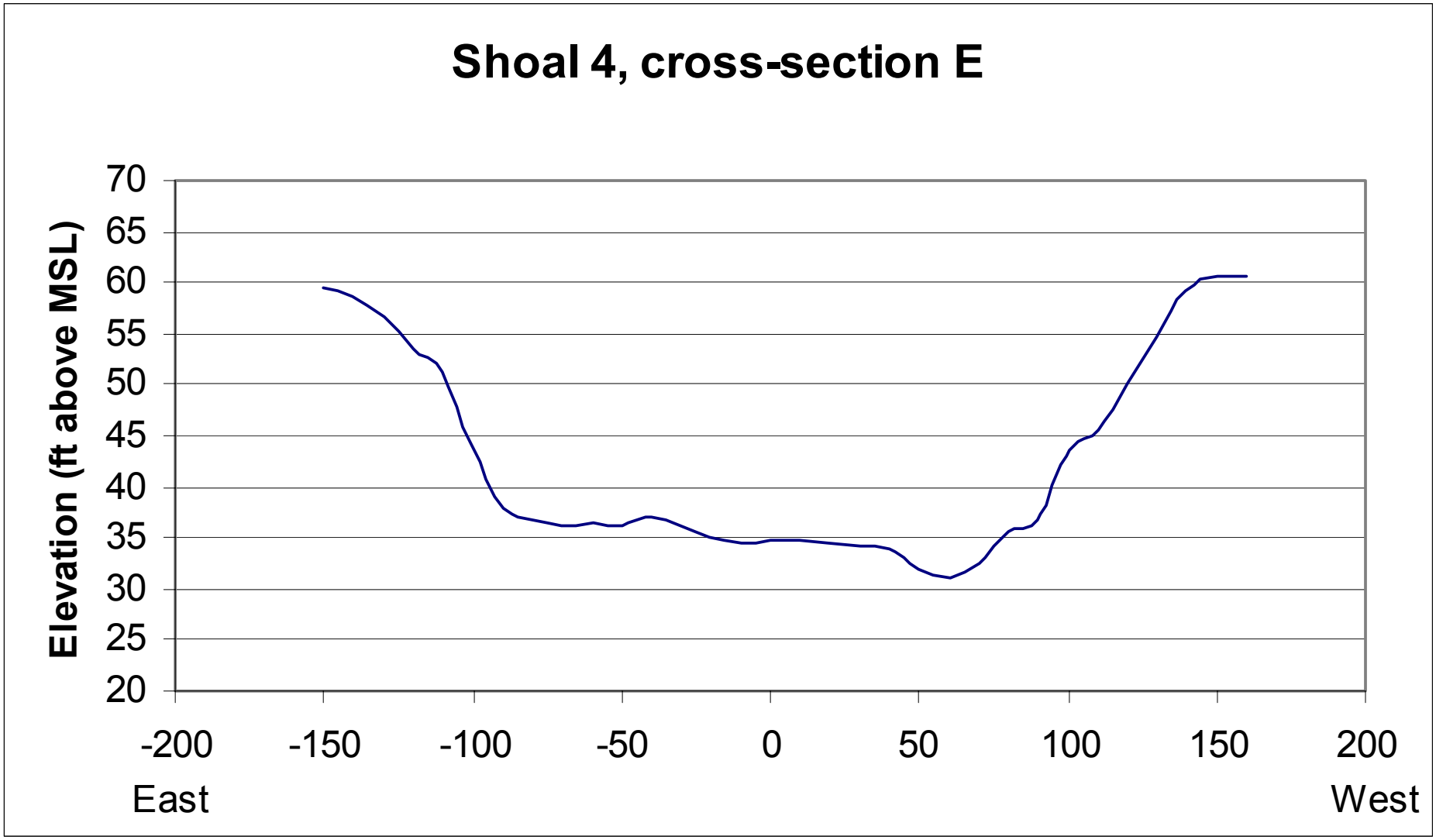


Figure 4-22. Elevation of Shoal 4, cross-section E.

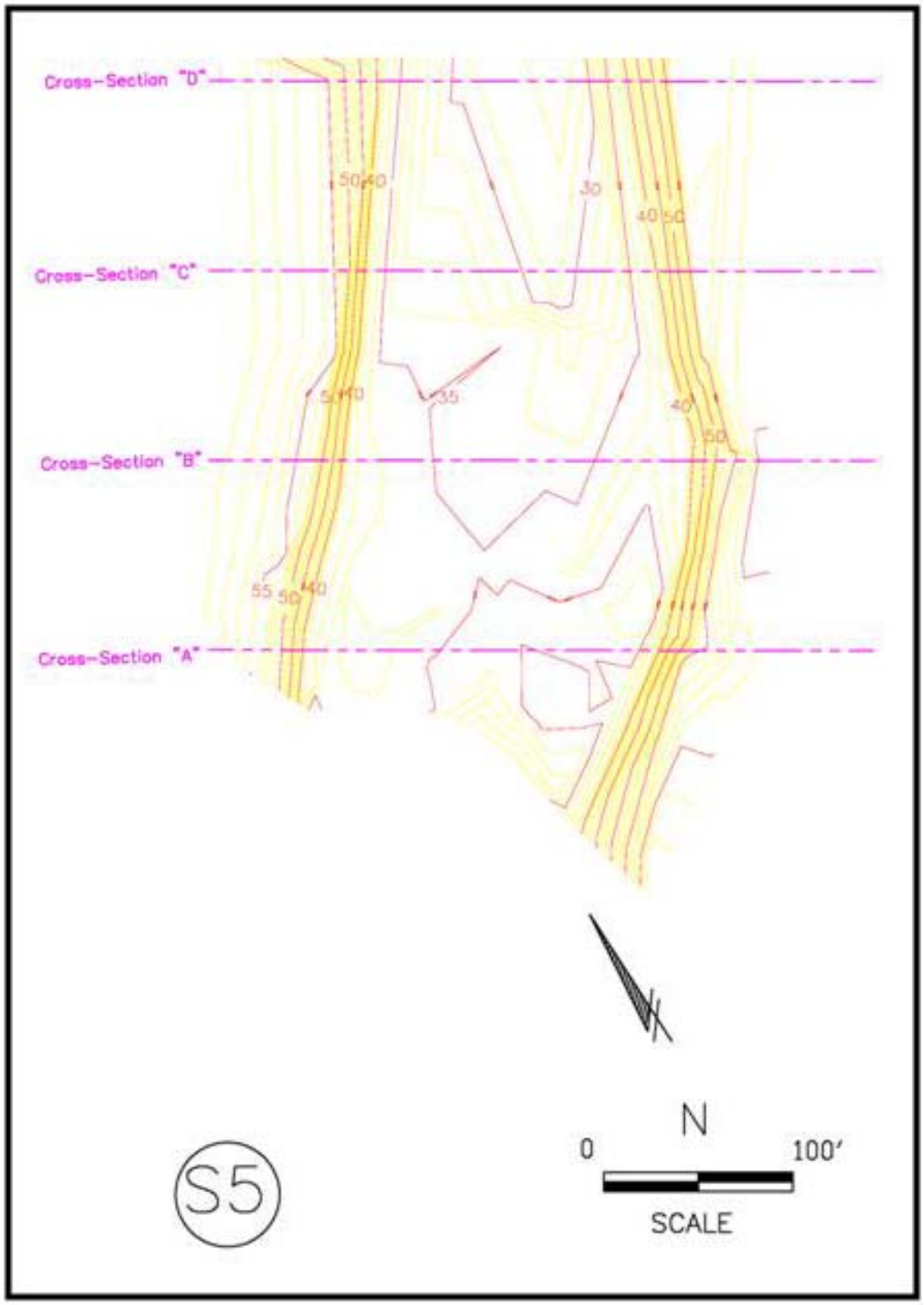


Figure 4-23 Map of Shoal 5 showing cross-section locations and elevation.

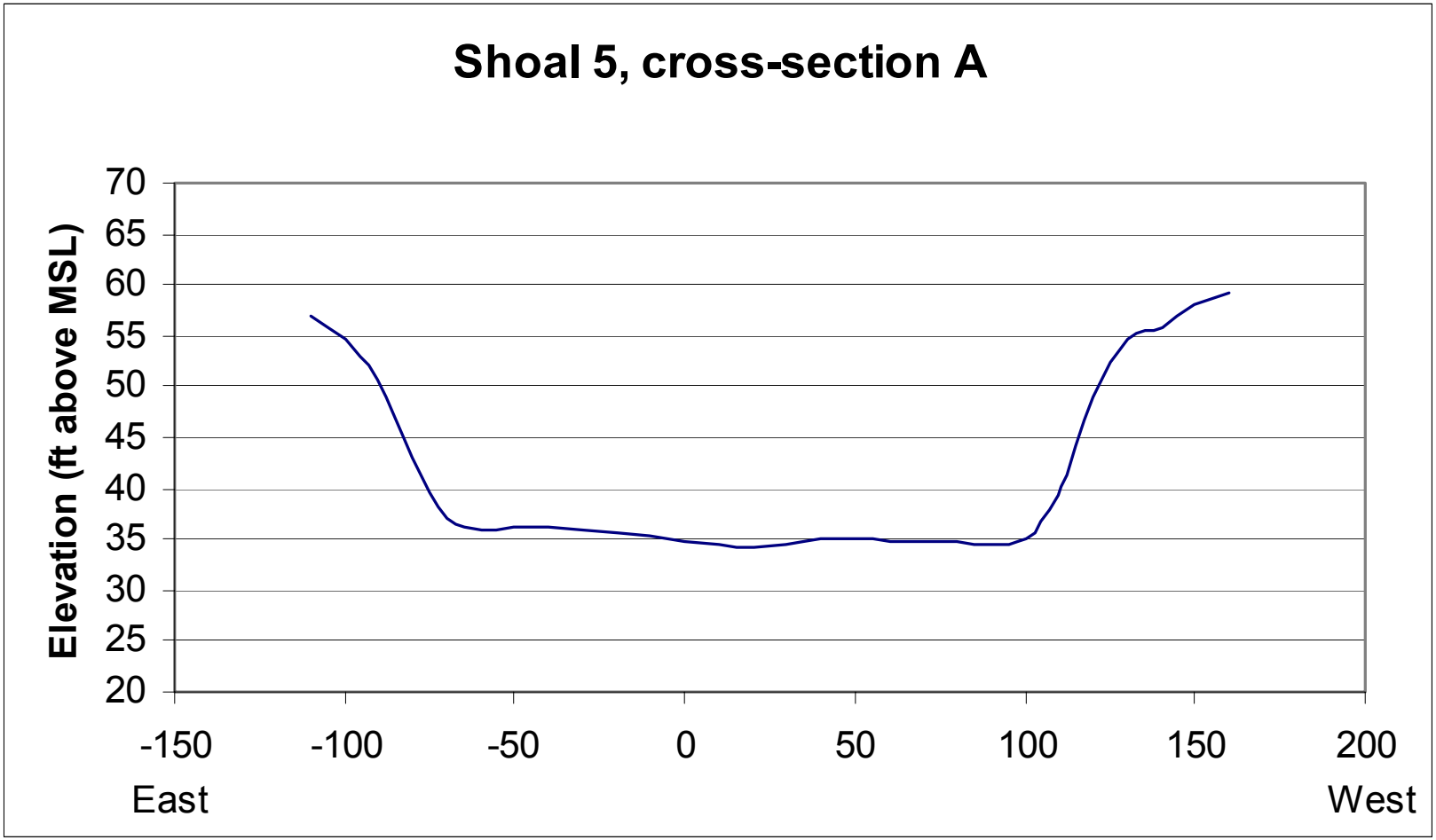


Figure 4-24. Elevation of Shoal 5, cross-section A.

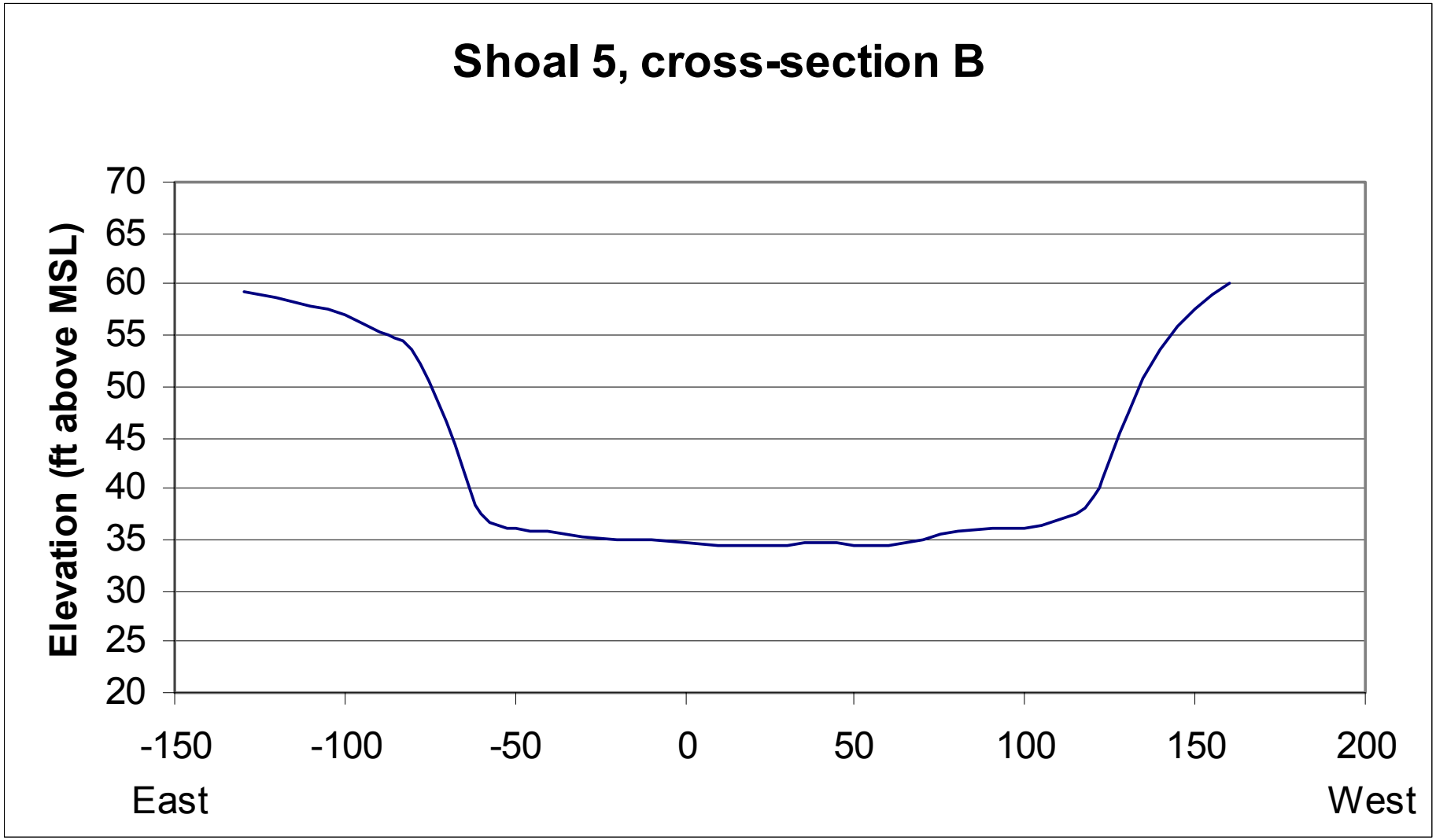


Figure 4-25. Elevation of Shoal 5, cross-section B.

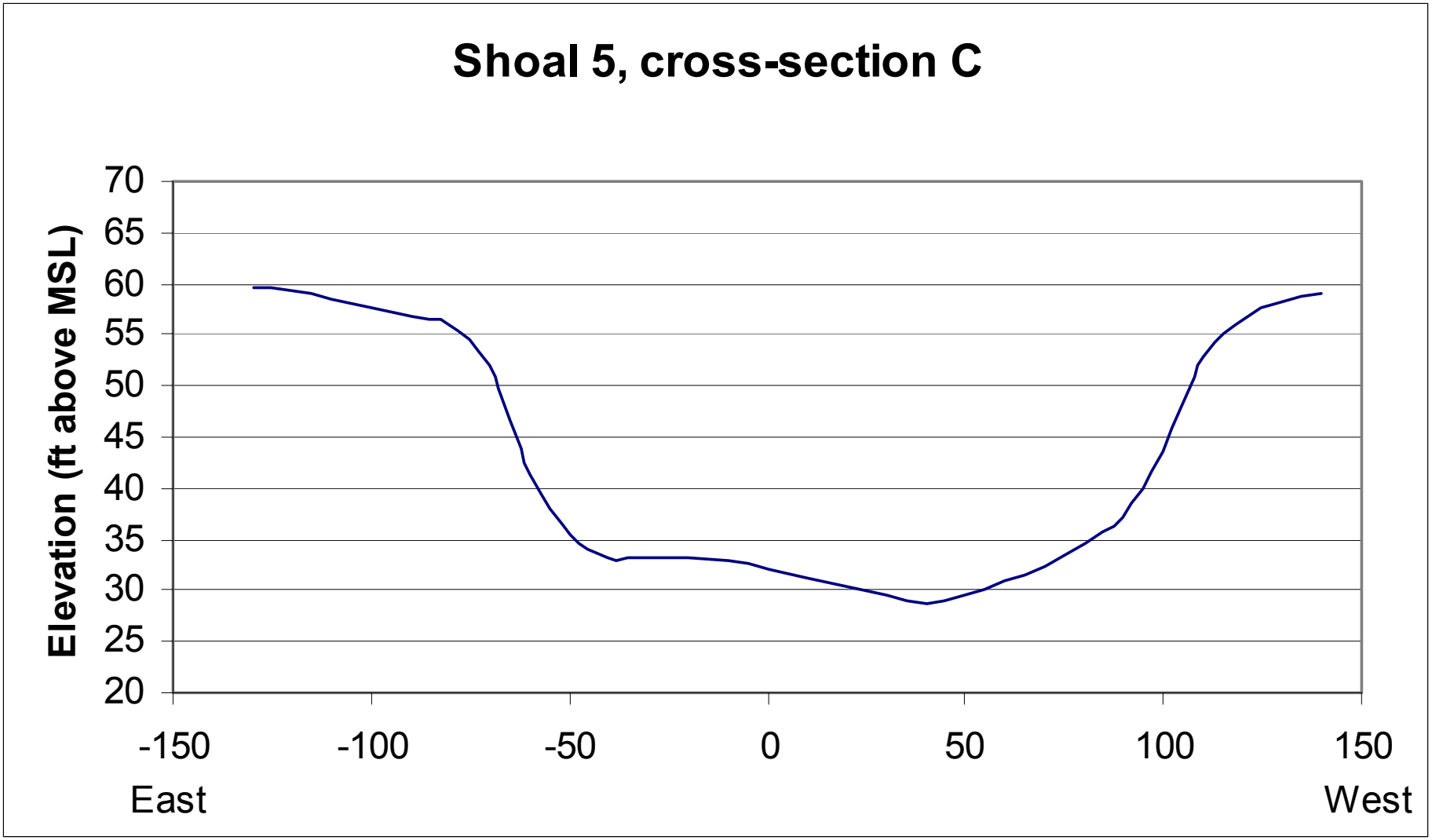


Figure 4-26. Elevation of Shoal 5, cross-section C.

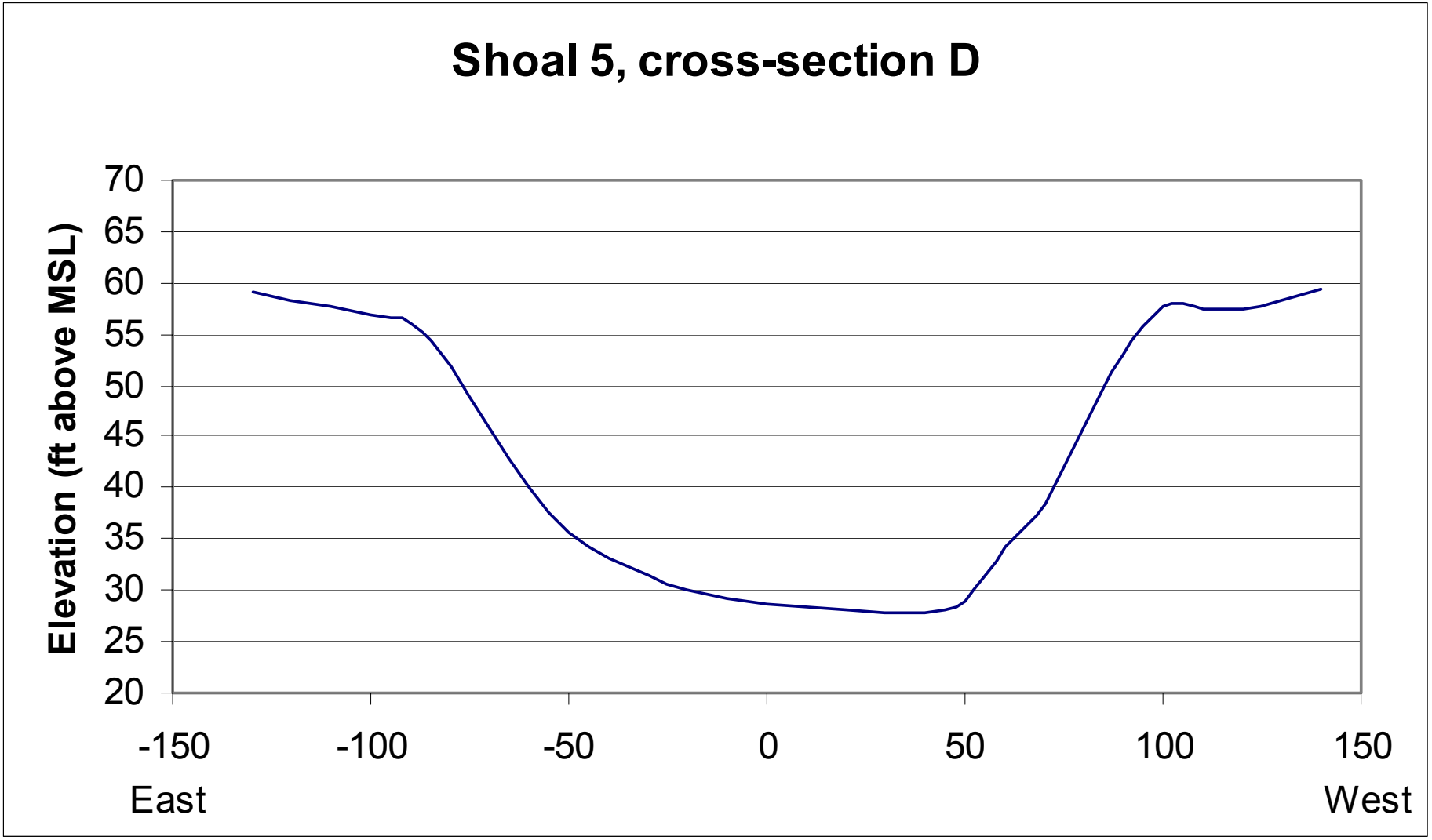


Figure 4-27. Elevation of Shoal 5, cross-section D.

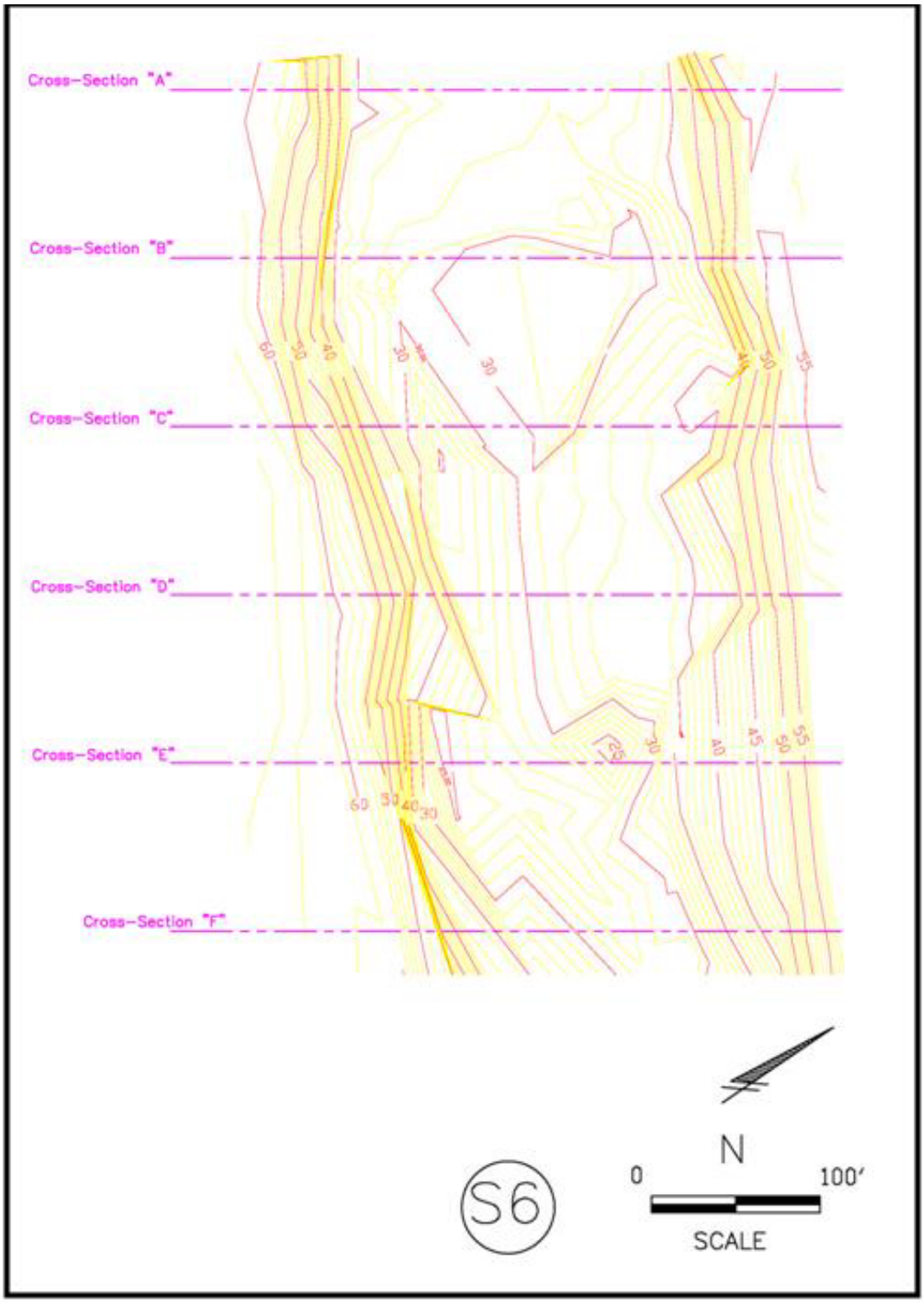


Figure 4-28. Map of Shoal 6 showing cross-section locations and elevation

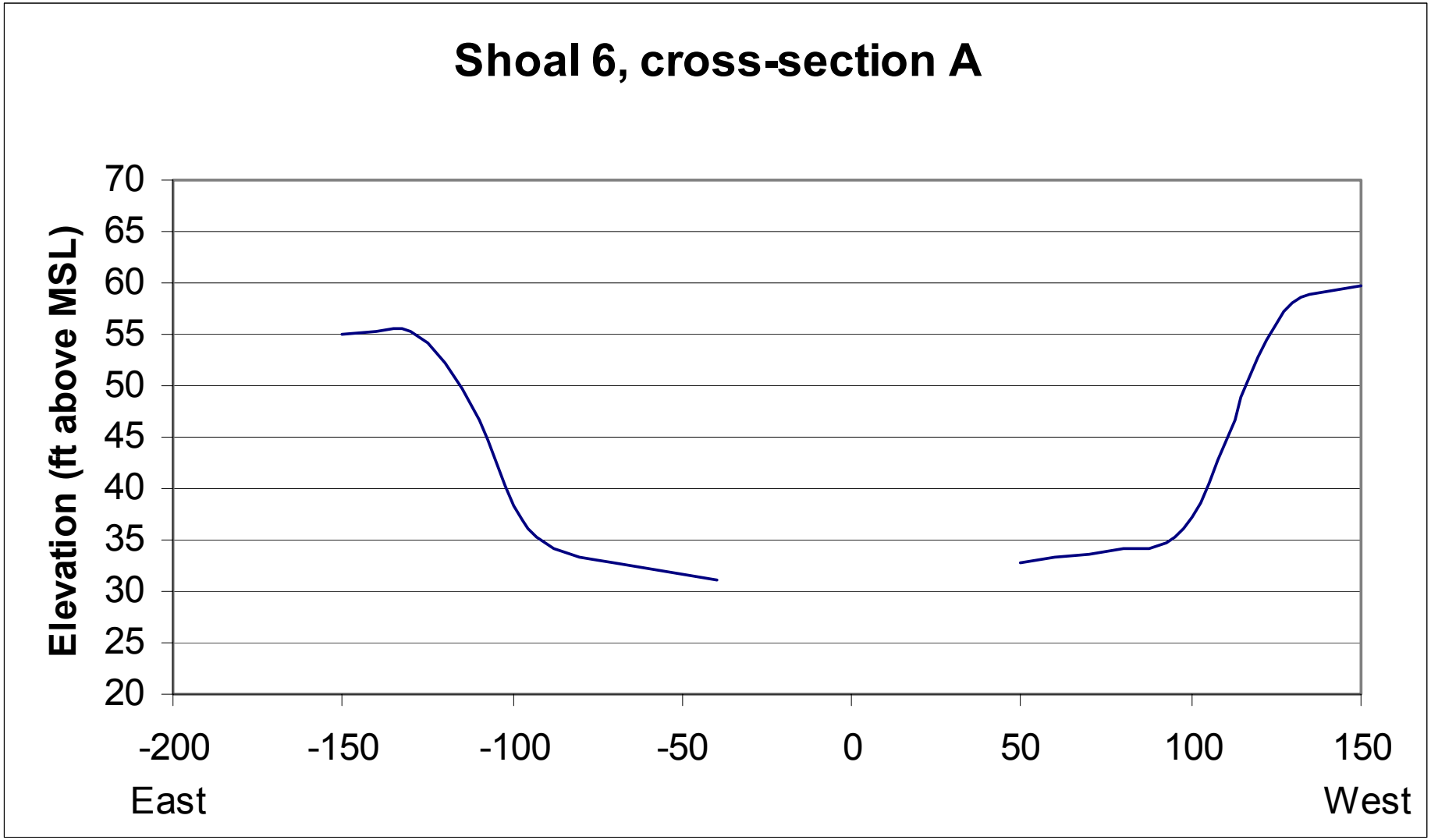


Figure 4-29. Elevation of Shoal 6, cross-section A. Data points in the middle reach of the cross-section, obtained from the survey of the shoals, were insufficient and correspond to the break in the line above.

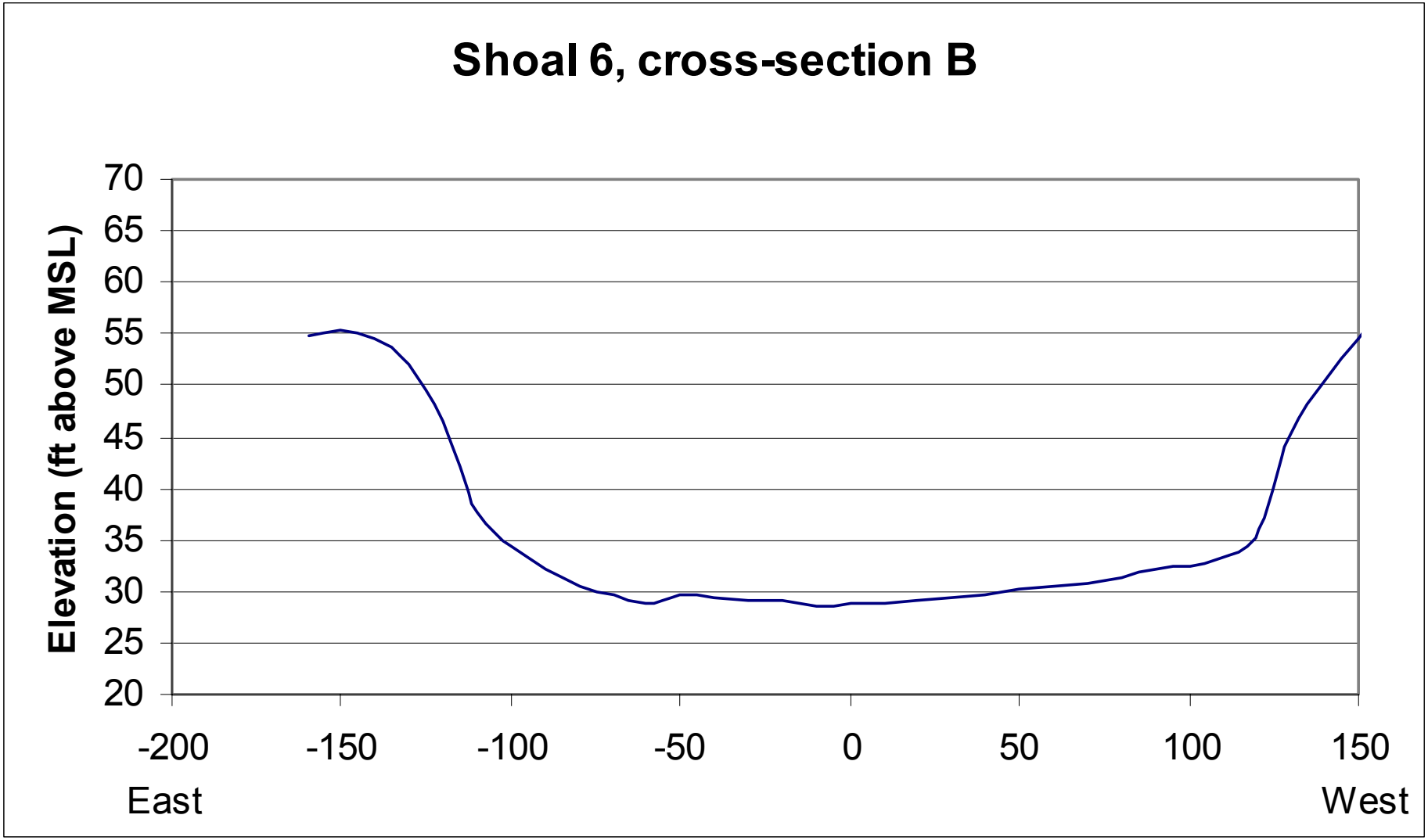


Figure 4-30. Elevation of Shoal 6, cross-section B.

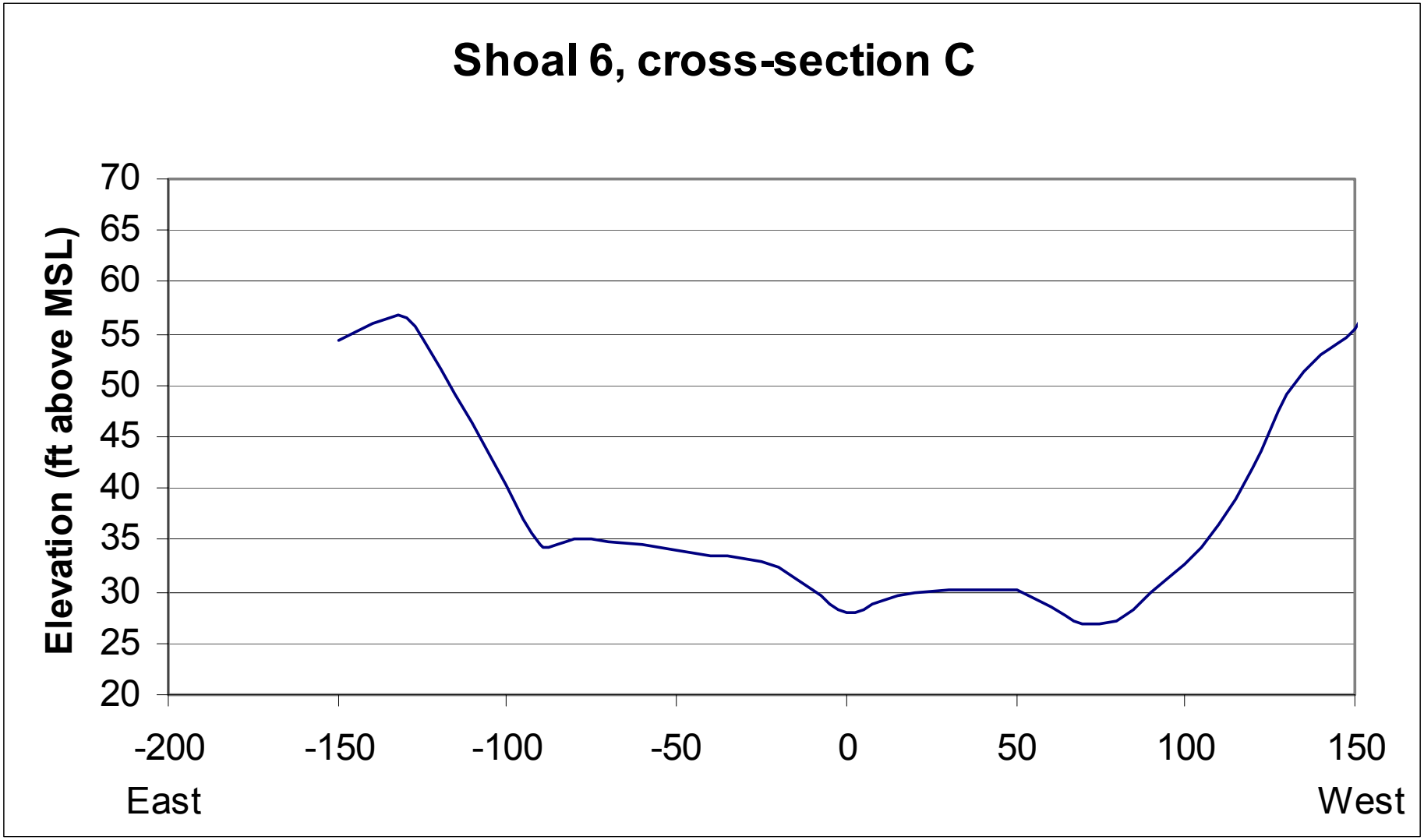


Figure 4-31. Elevation of Shoal 6, cross-section C.

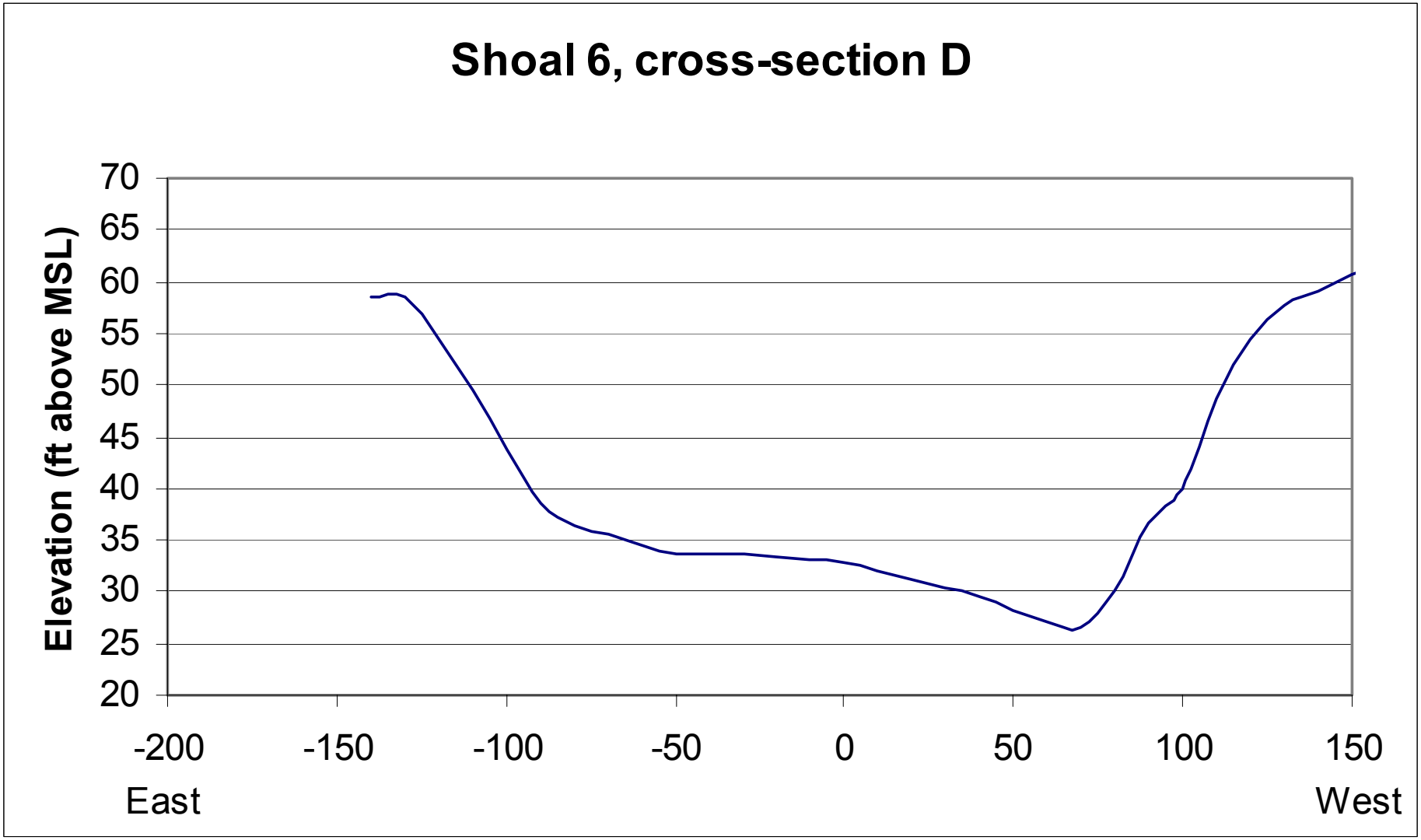


Figure 4-32. Elevation of Shoal 6, cross-section D.

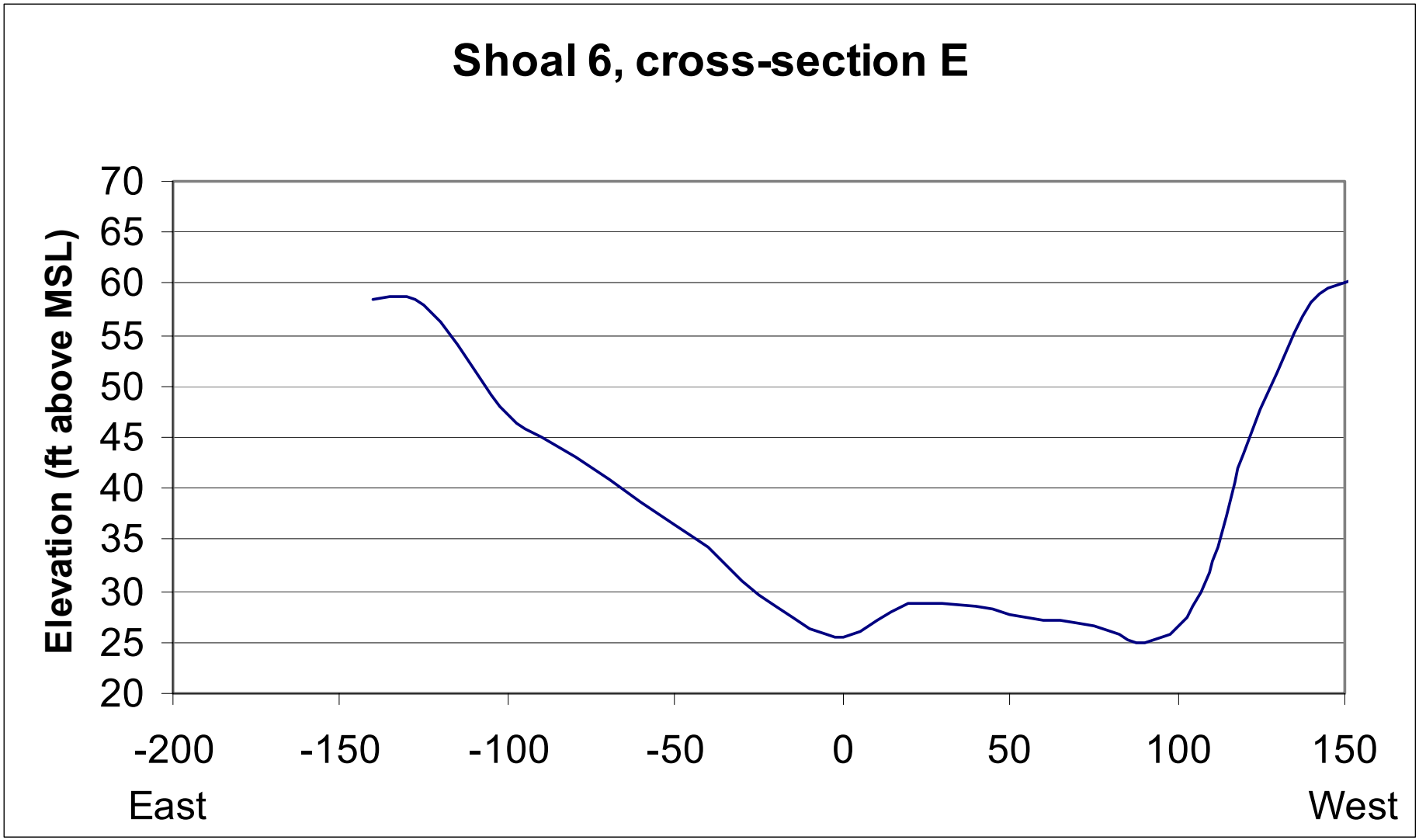


Figure 4-33. Elevation of Shoal 6, cross-section E.

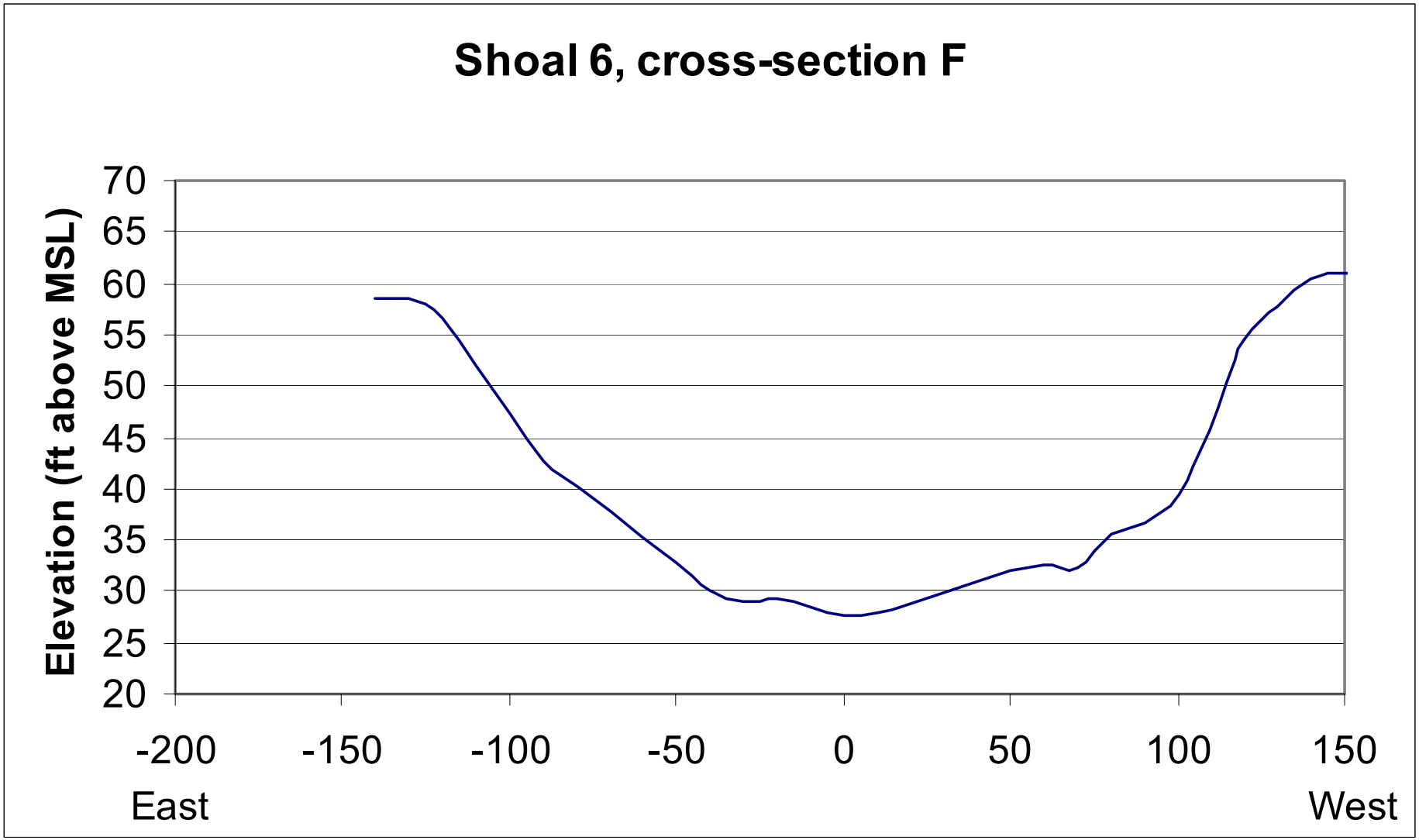


Figure 4-34. Elevation of Shoal 6, cross-section F.

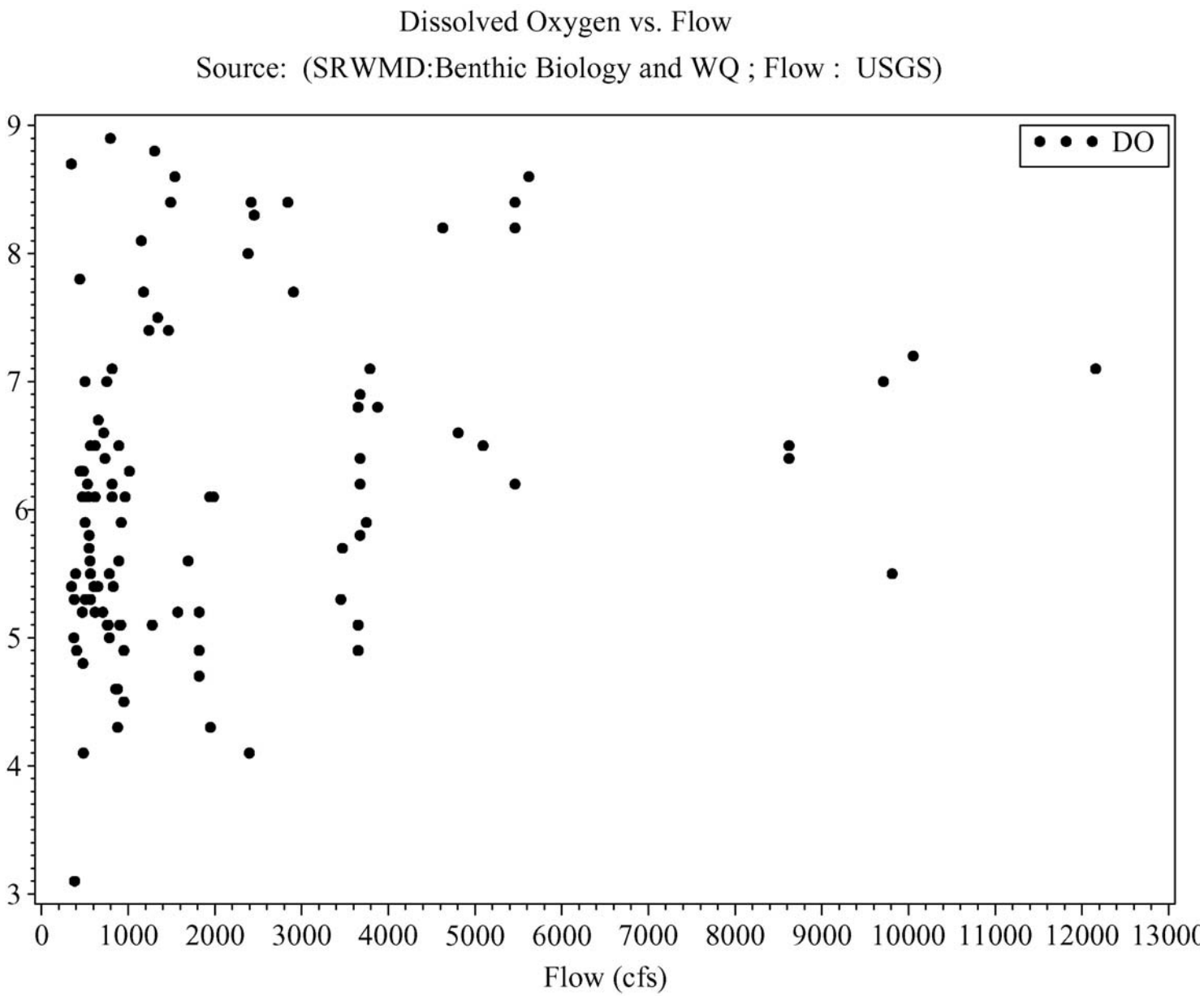


Figure 4-35. Relationship between dissolved oxygen and flow.

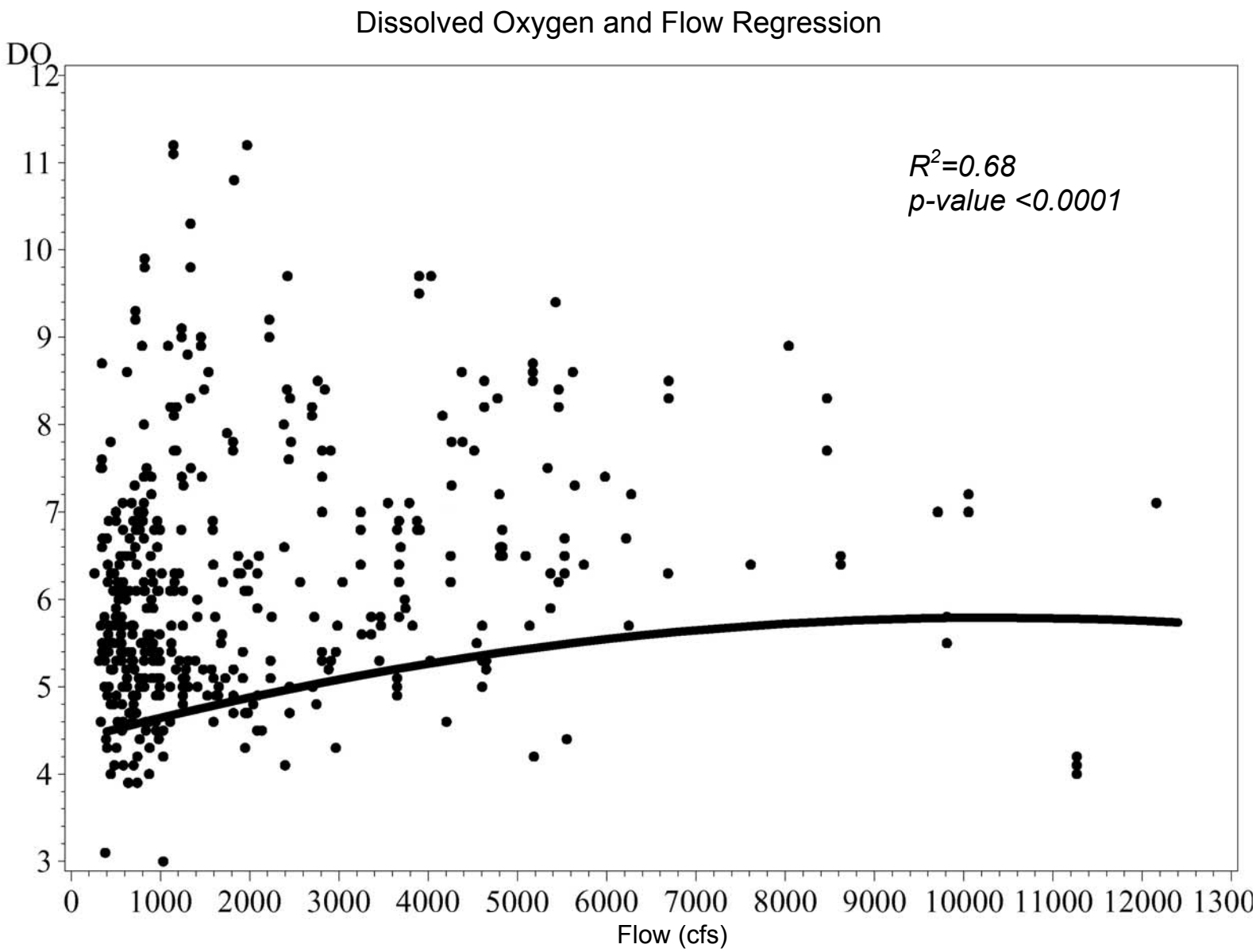


Figure 4-36. Regression output showing relationship between low dissolved oxygen (10th percentile) and flow

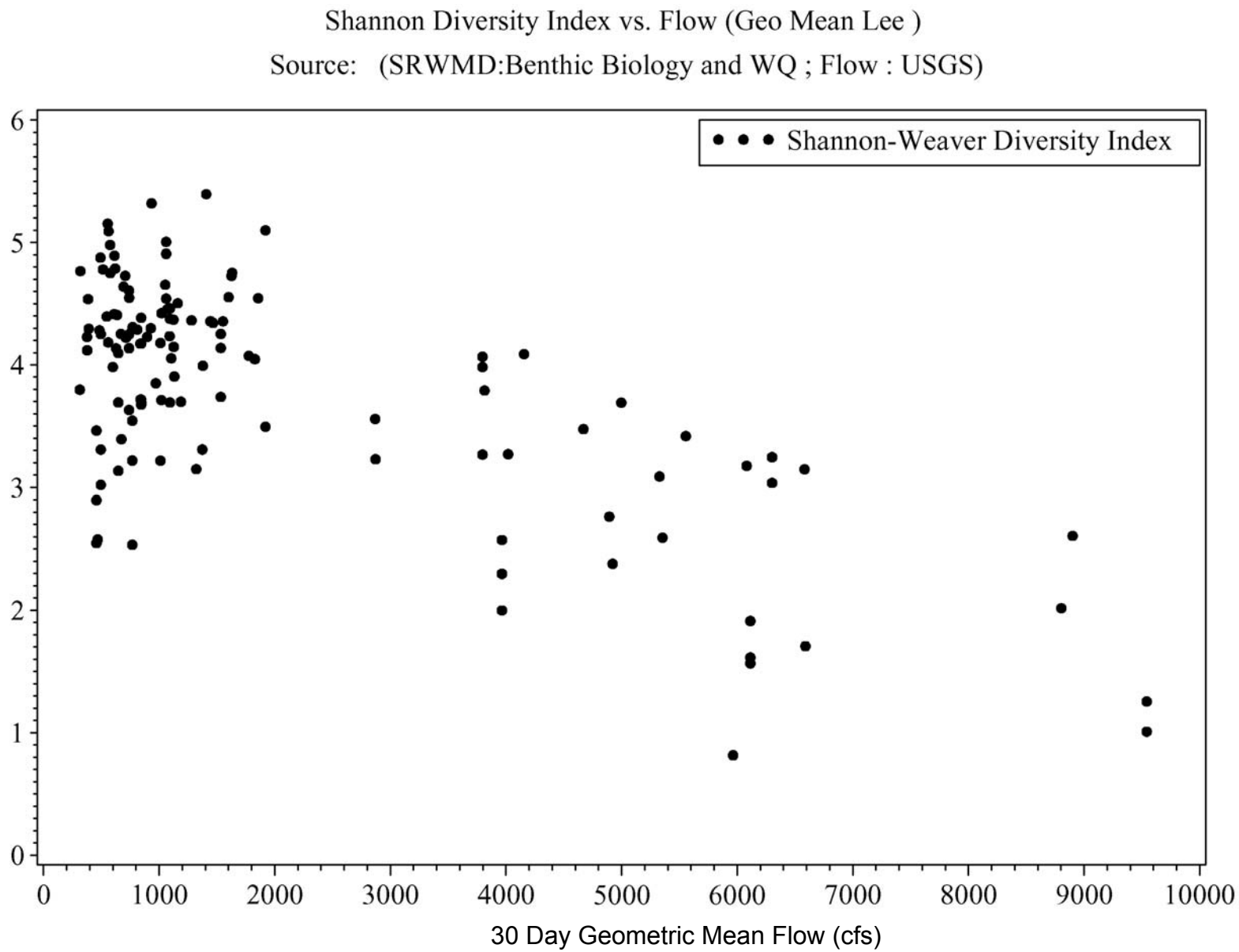


Figure 4-37. Relationship between Shannon Weaver Diversity Index Scores and 30 day geometric mean flow.

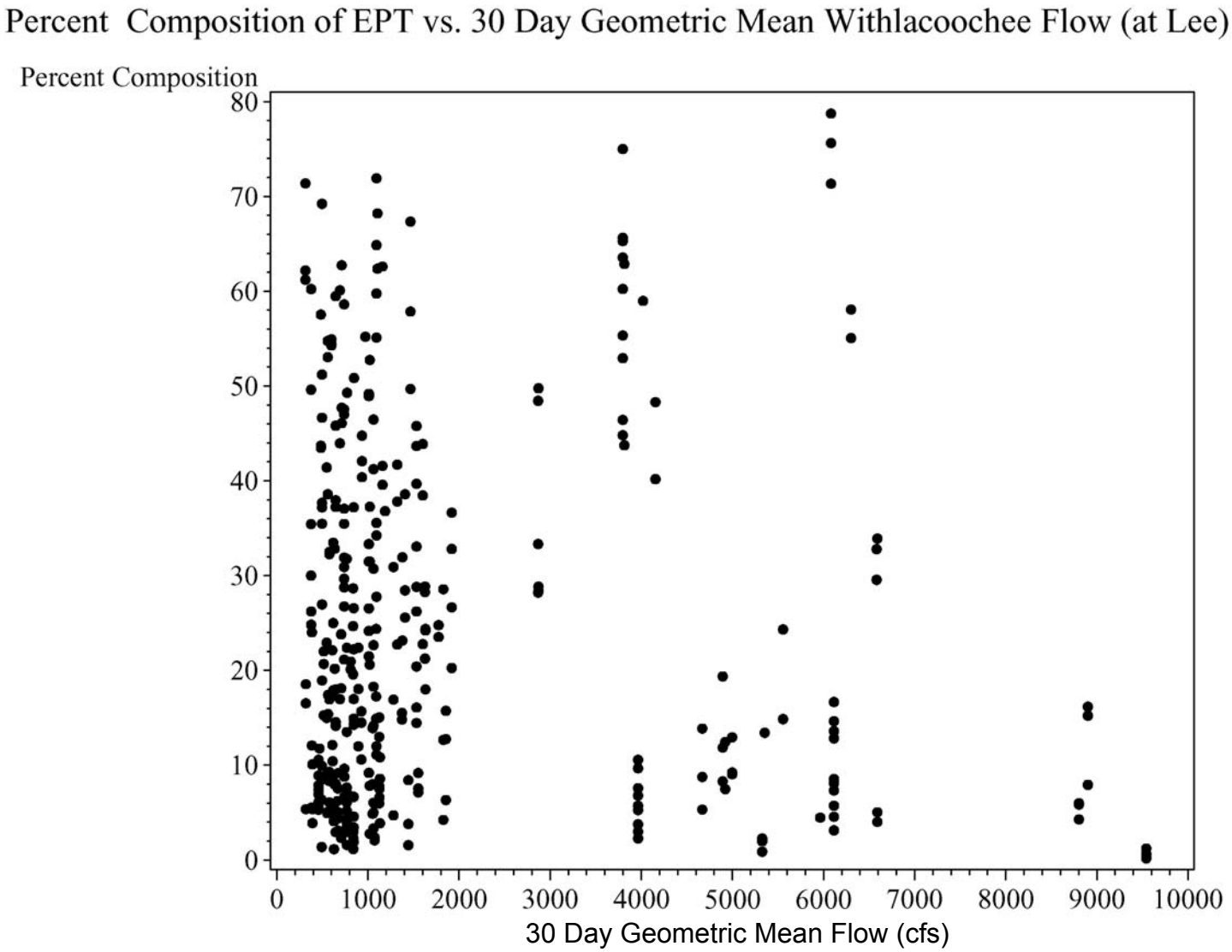


Figure 4-38. Relationship between Ephemeroptera, Plecoptera and Trichoptera and 30 day geometric mean flow.

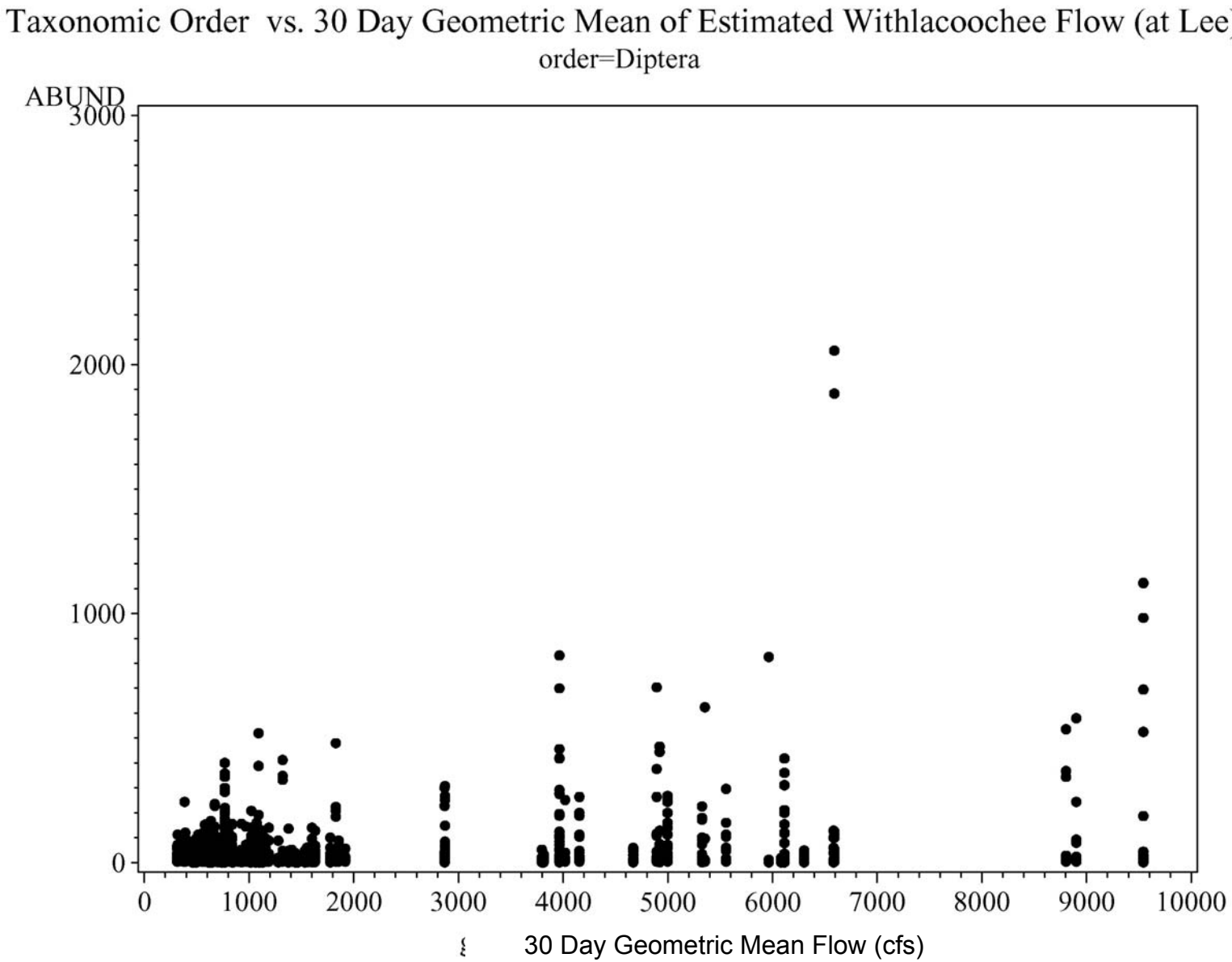


Figure 4-39 . Relationship between abundance of invertebrates in Order Diptera and 30 day geometric mean flow.

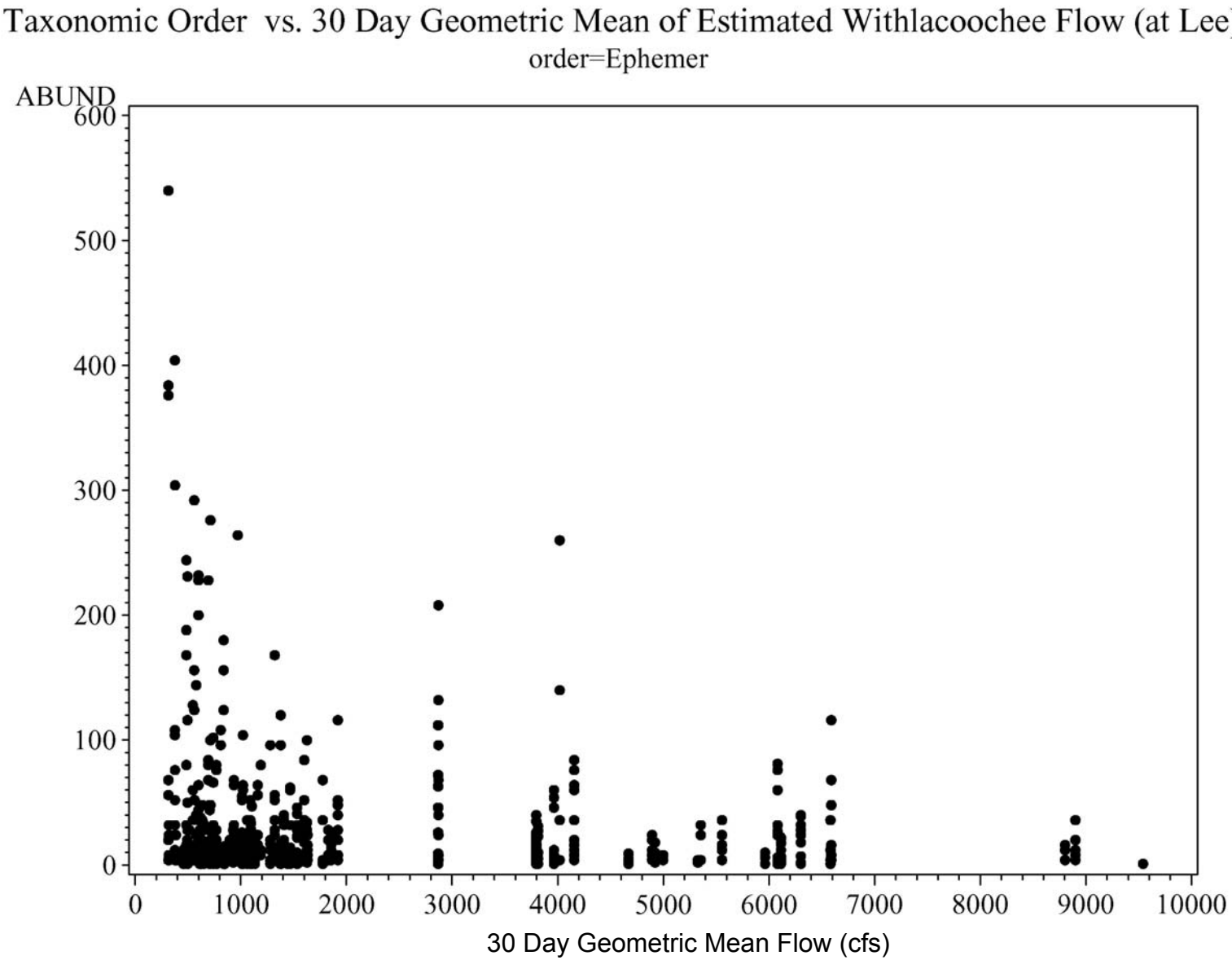


Figure 4-40. Relationship between abundance of Order Ephemeroptera and 30 day geometric mean flow.

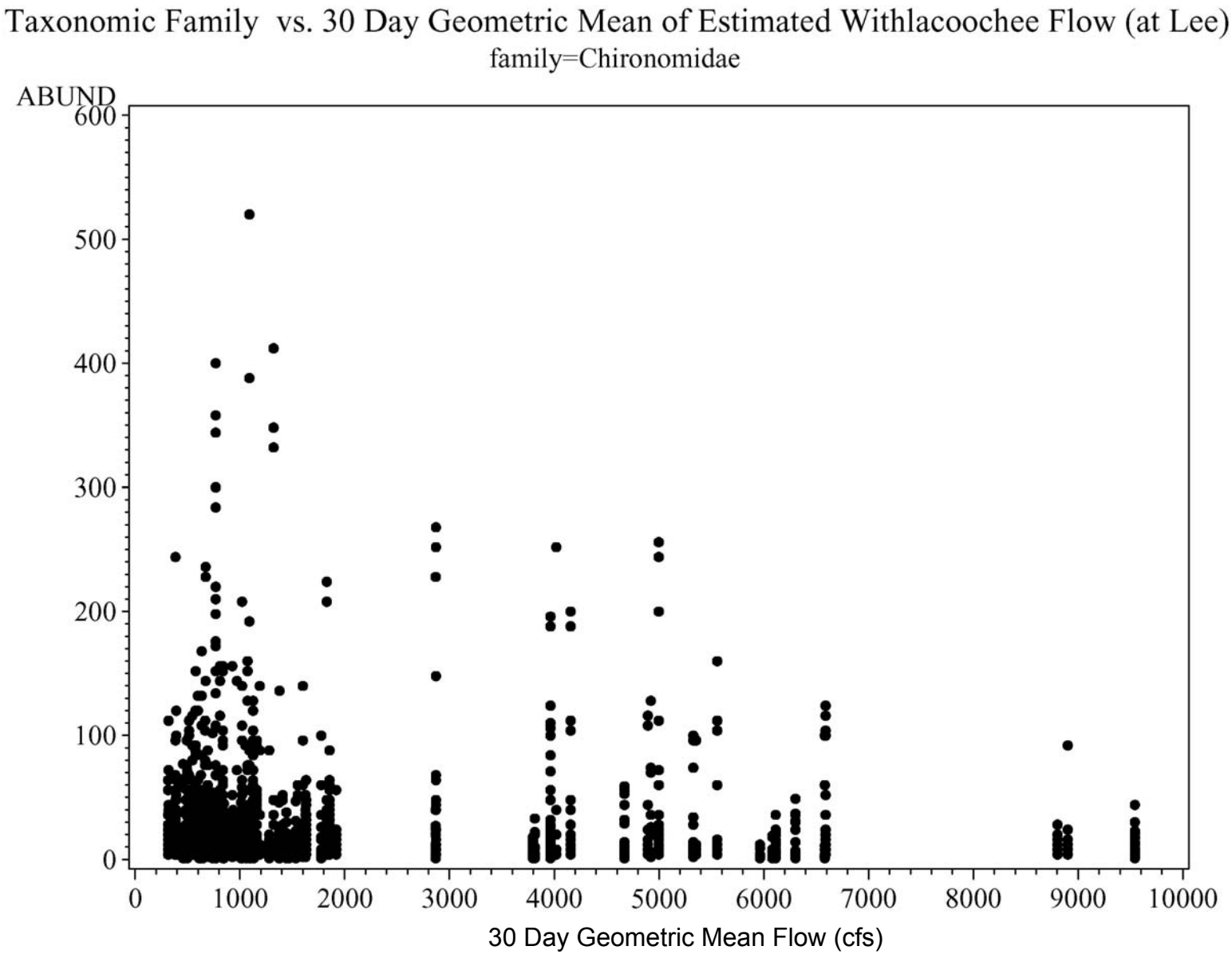


Figure 4-41. Relationship between abundance of organisms in Family Chironomidae and flow.

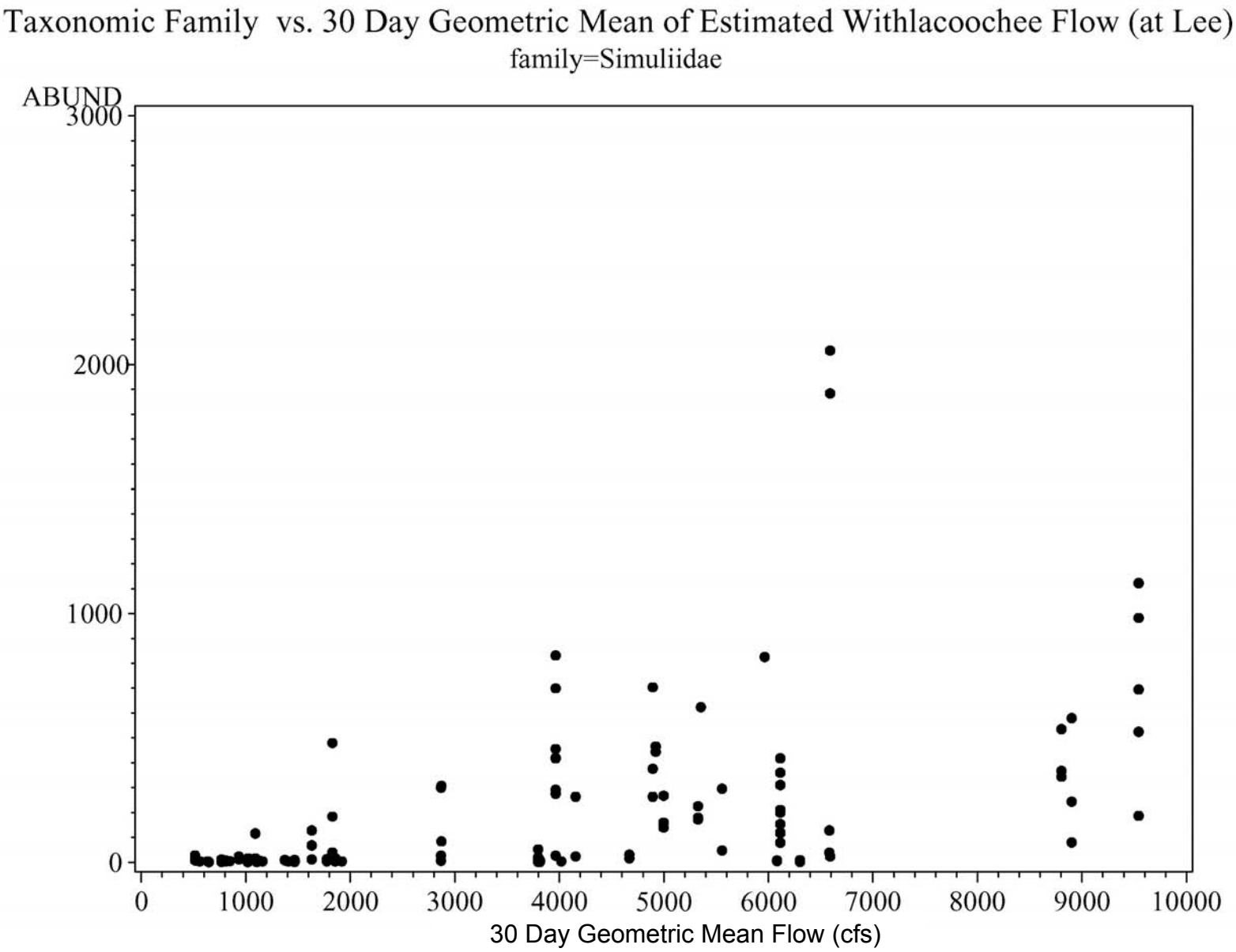


Figure 4-42. Relationship between abundance of organisms in Family Simuliidae and flow.

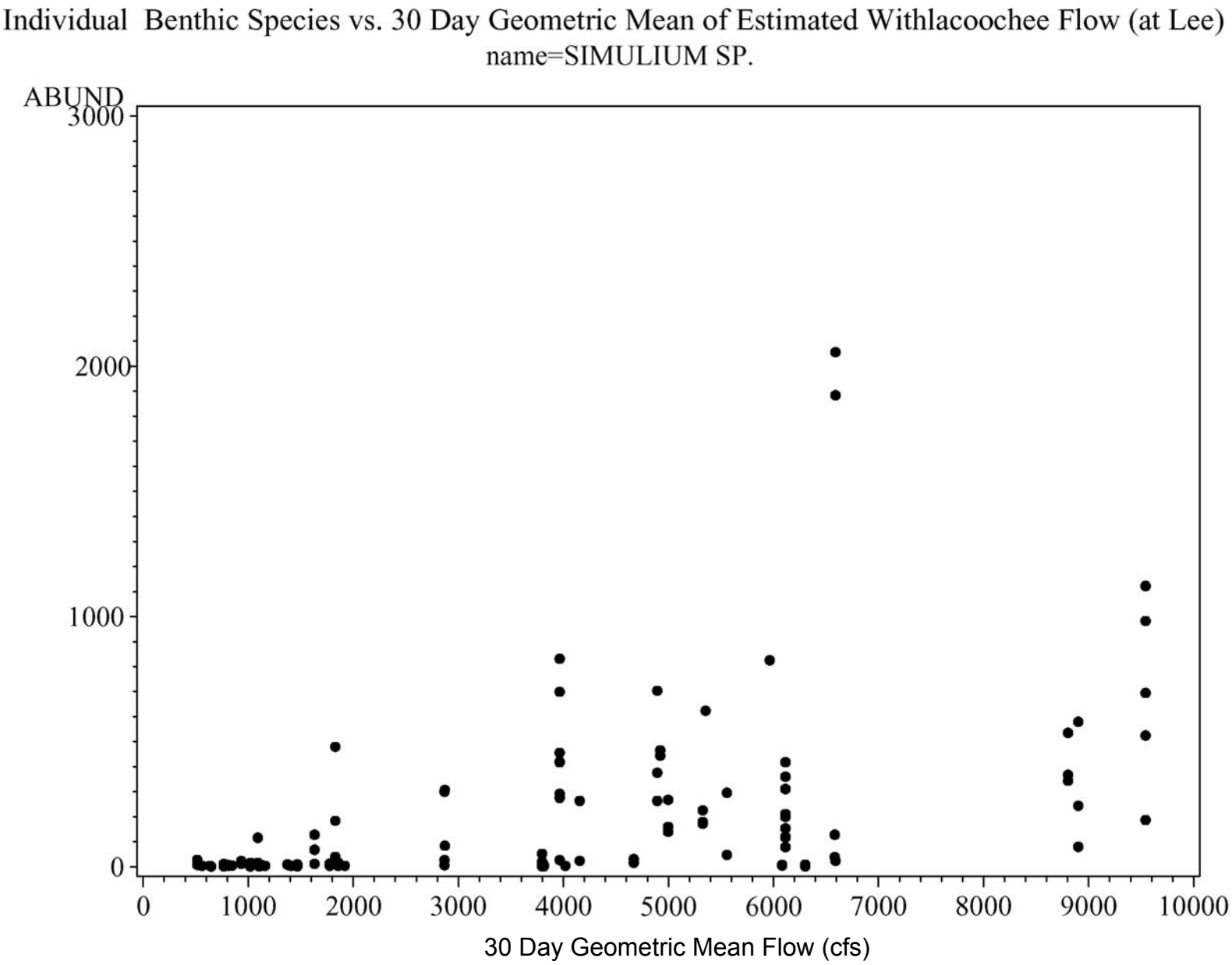


Figure 4-43. Relationship between abundance of *Simulium spp*, and flow.

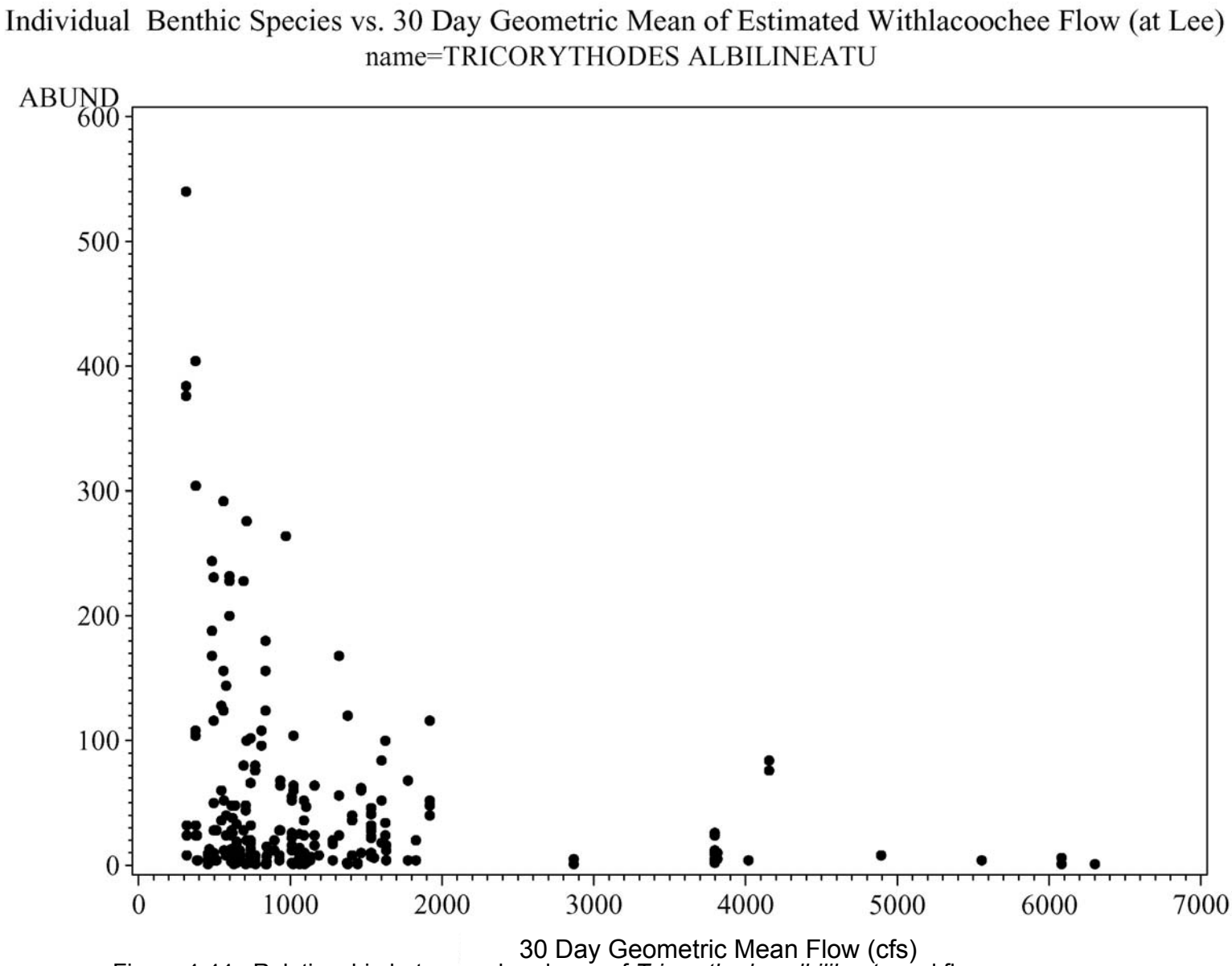


Figure 4-44. Relationship between abundance of *Tricorythodes albilibeatu* and flow.

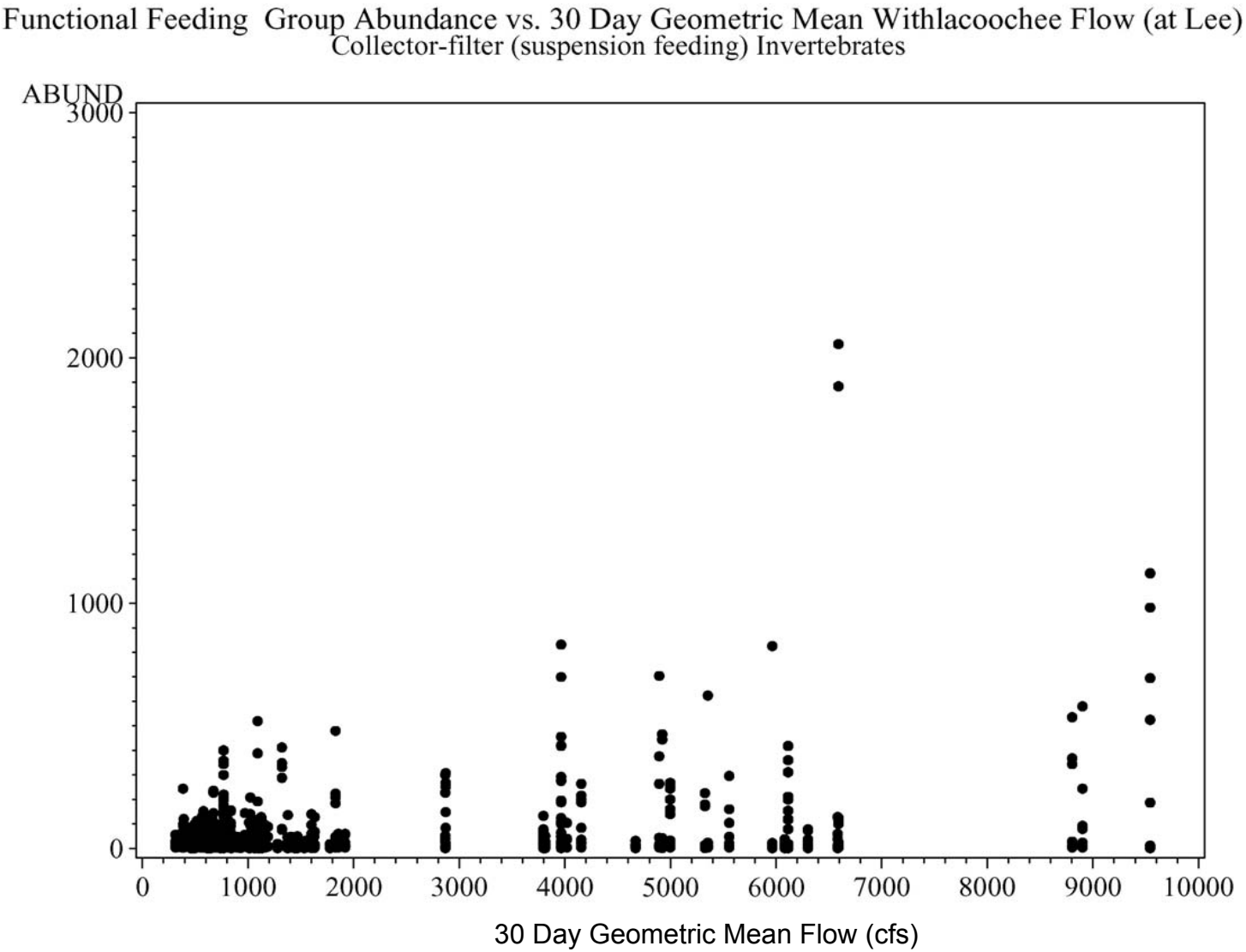


Figure 4-45. Relationship between functional feeding group abundance and flow.

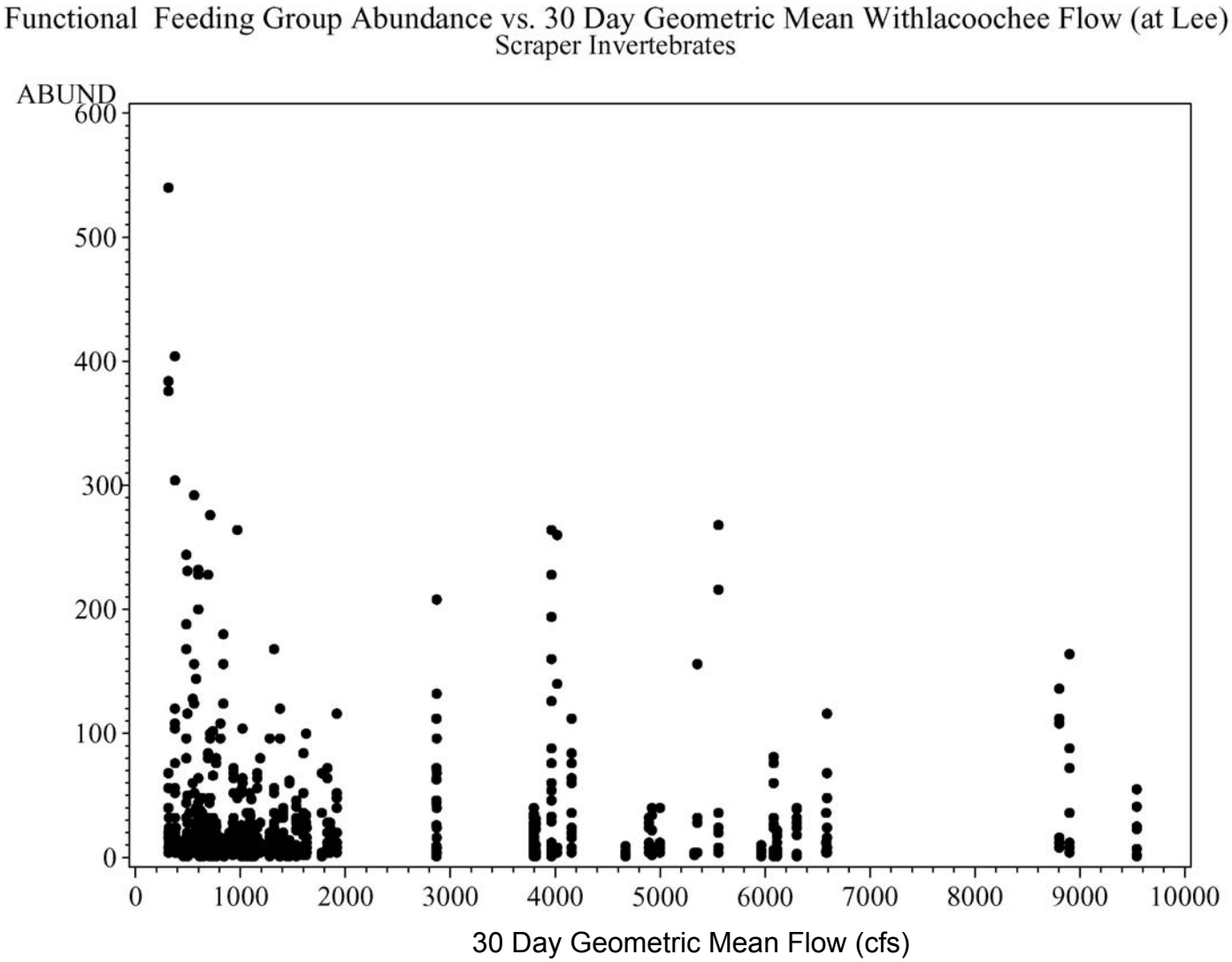


Figure 4-46. Relationship between functional feeding group abundance and flow.

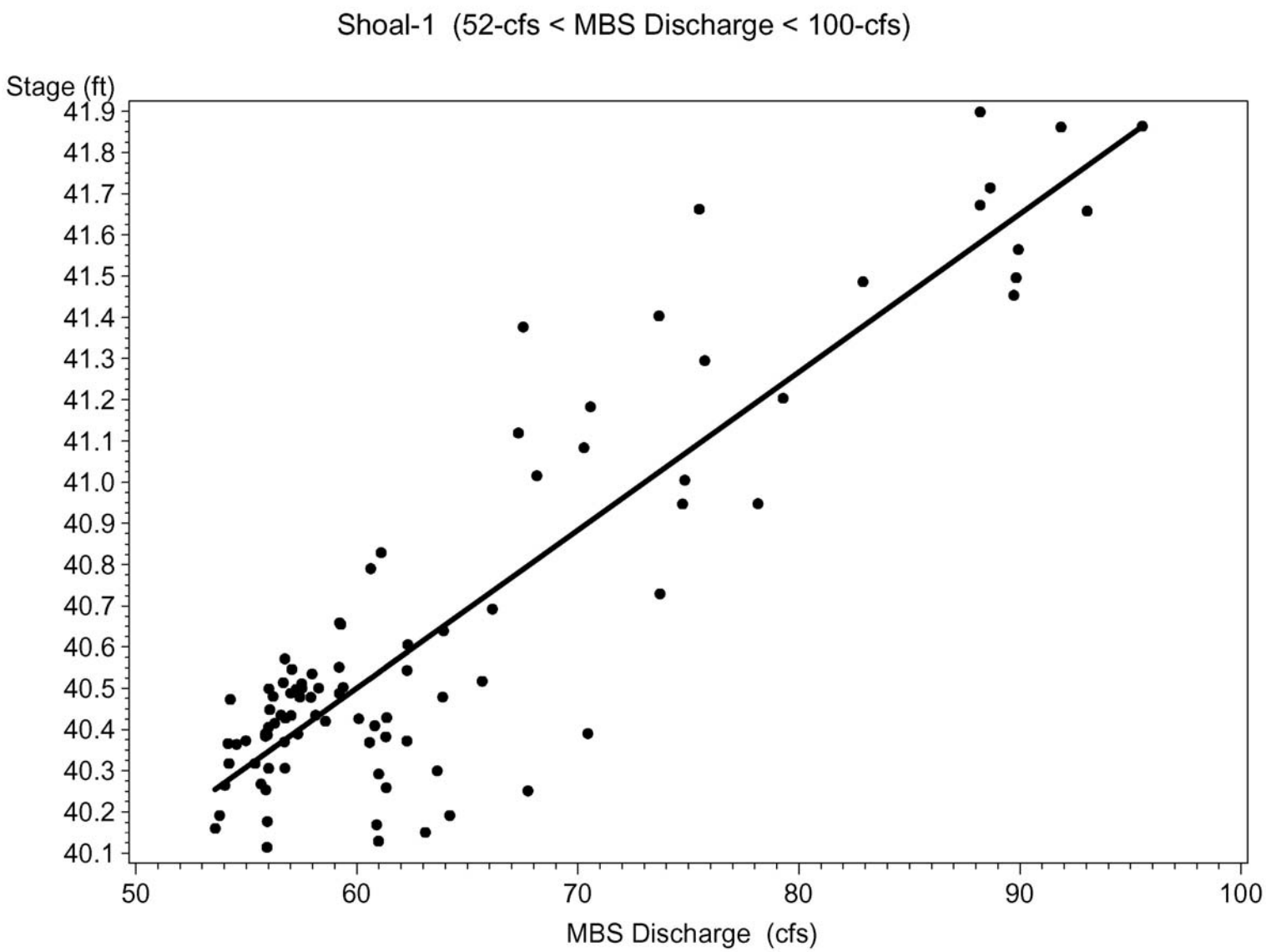


Figure 4-47. Relationship between stage at Shoal 1 and Madison Blue Spring discharge.

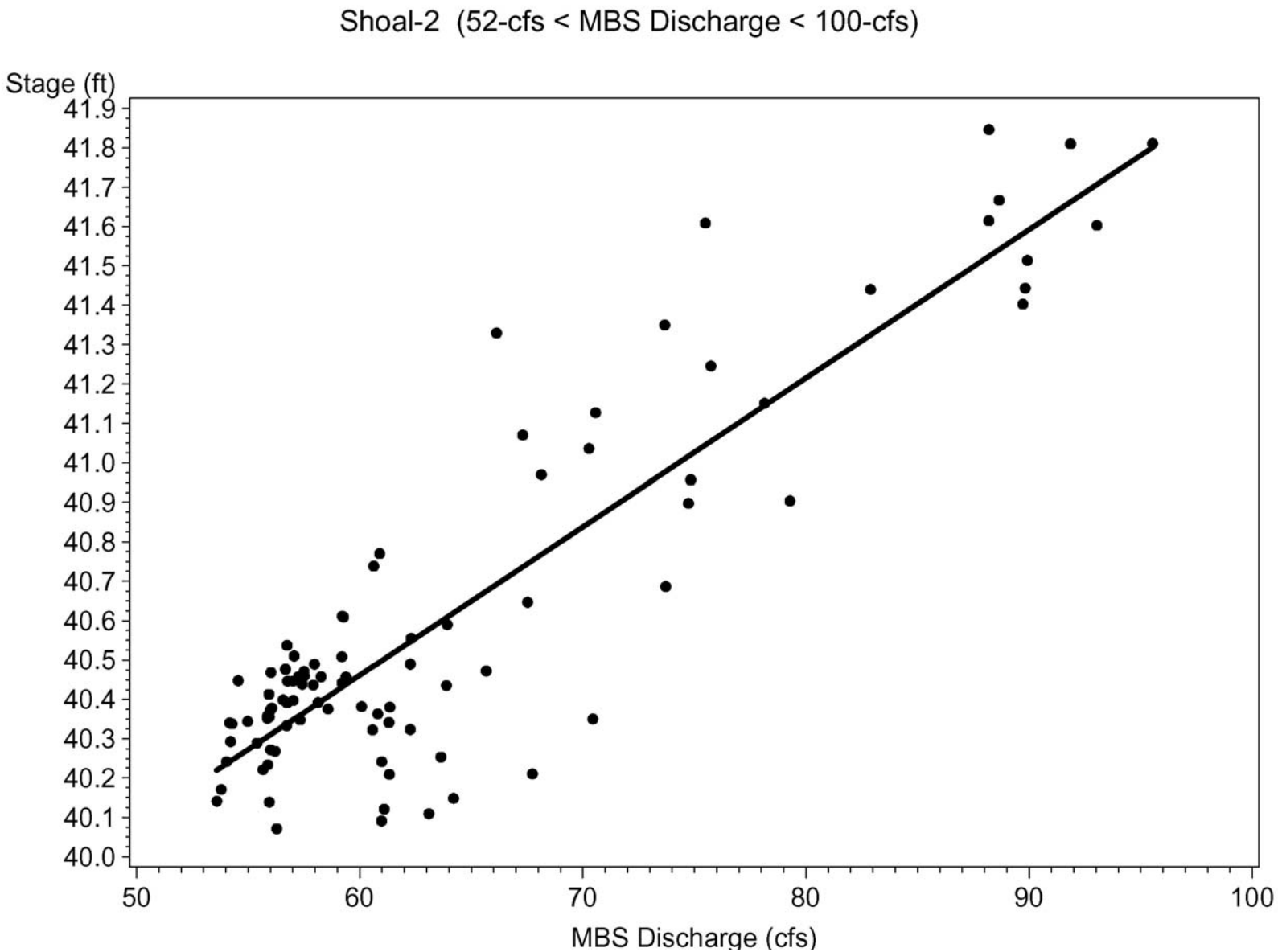


Figure 4-48. Relationship between stage at Shoal 2 and Madison Blue Spring discharge.

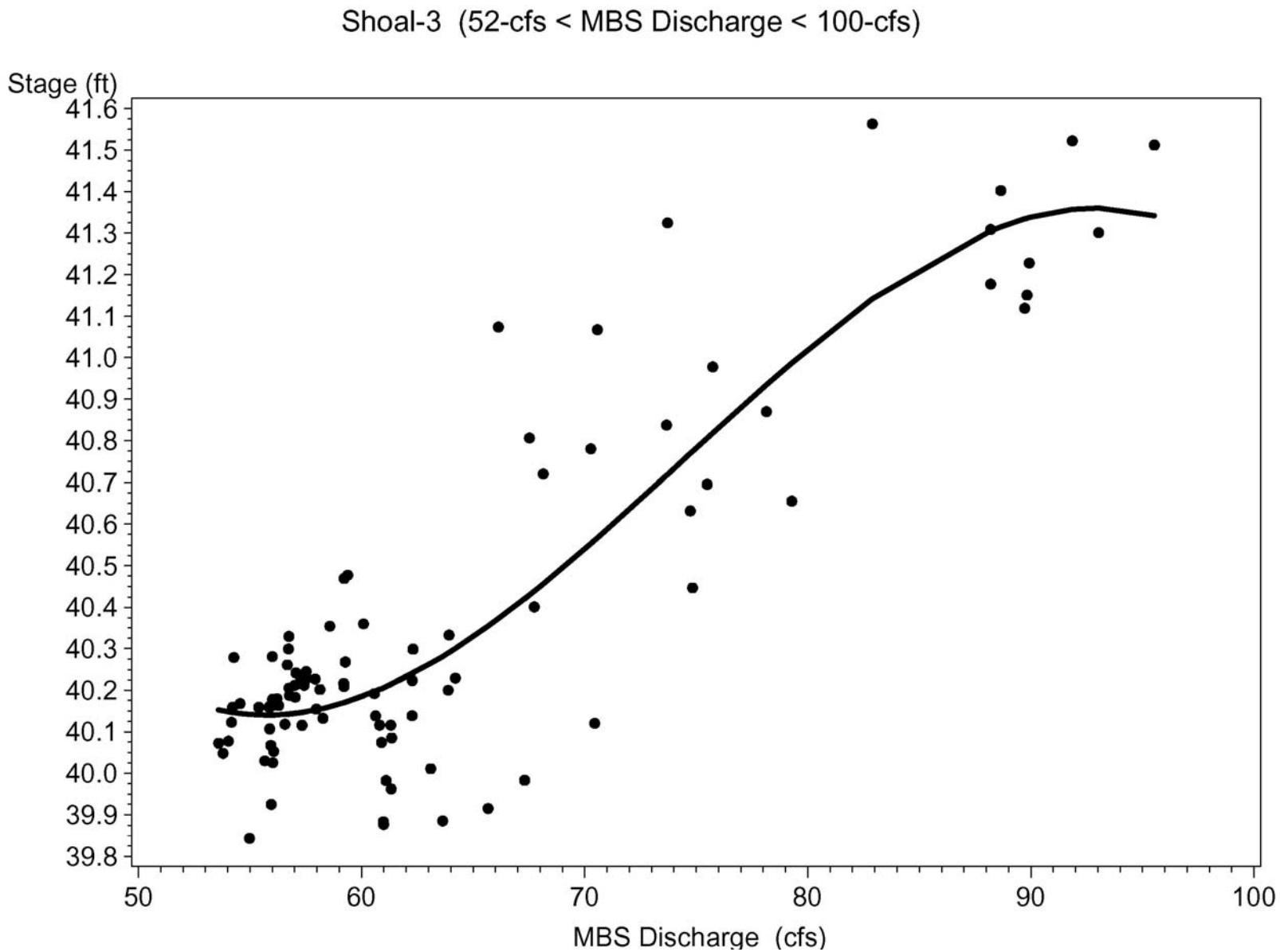


Figure 4-49. Relationship between stage at Shoal 3 and Madison Blue Spring discharge.

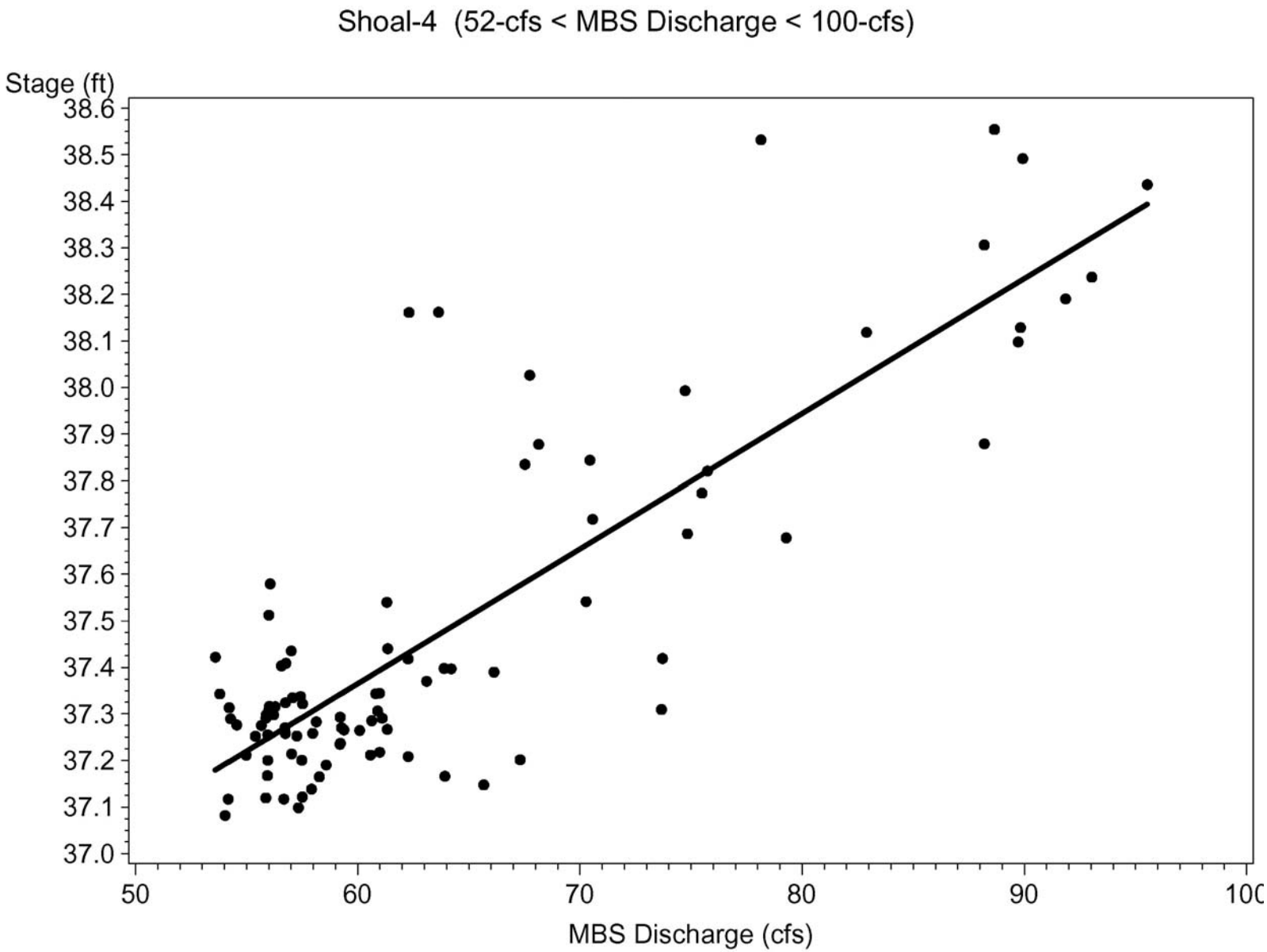


Figure 4-50. Relationship between stage at Shoal 4 and Madison Blue Spring discharge.

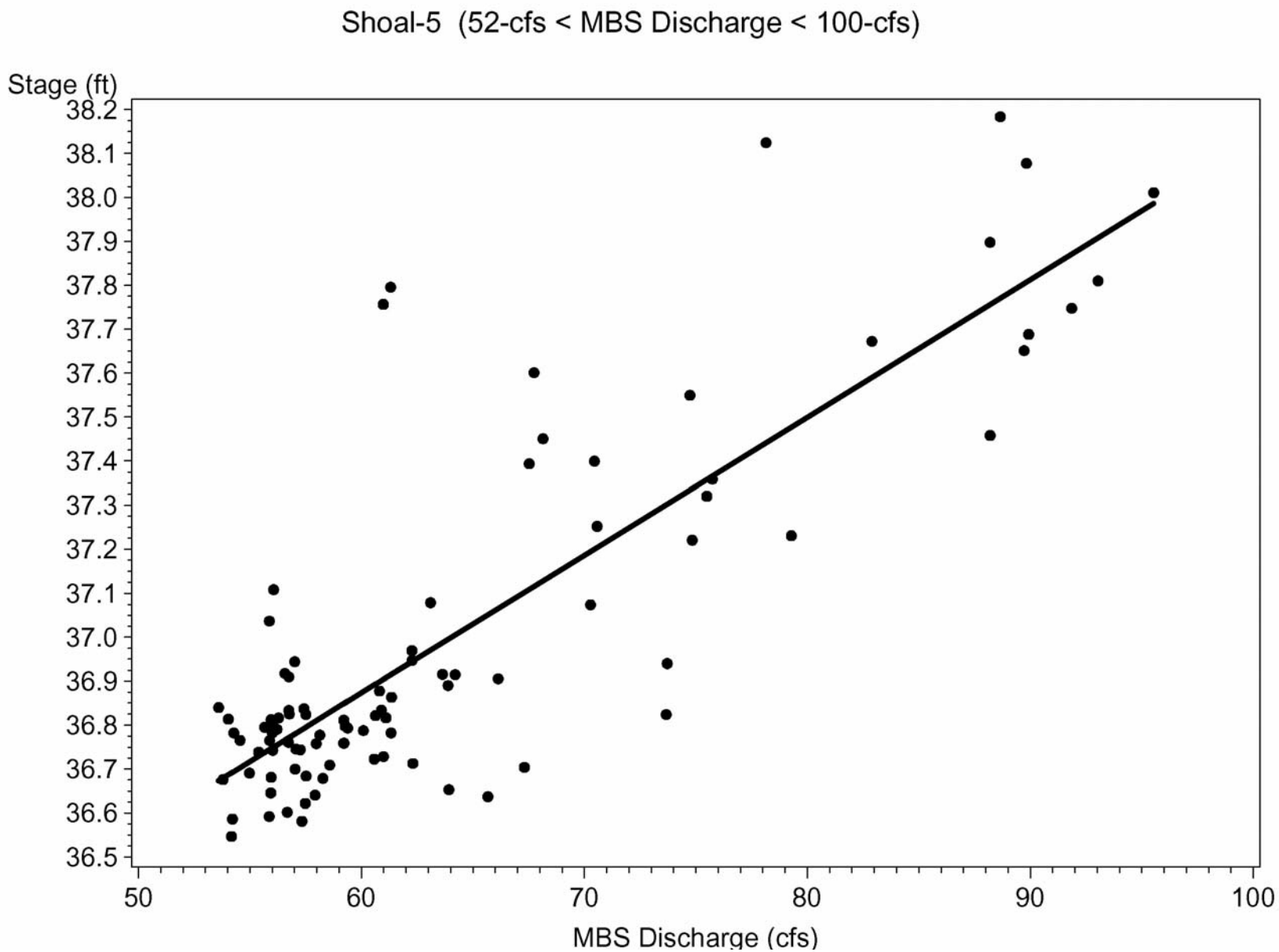


Figure 4-51. Relationship between stage at Shoal 5 and Madison Blue Springs discharge.

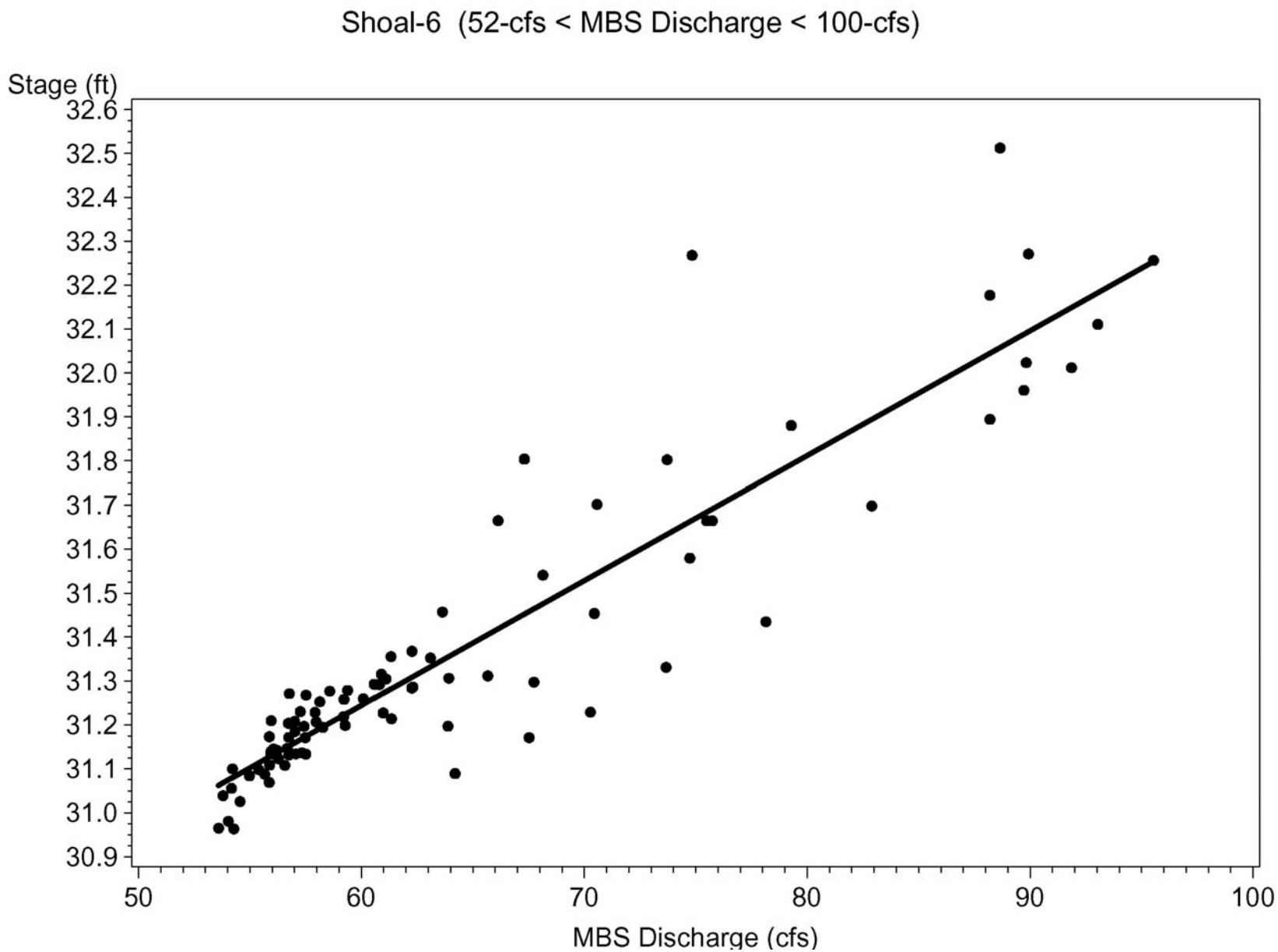


Figure 4-52. Relationship between stage at Shoal 6 and Madison Blue Springs discharge

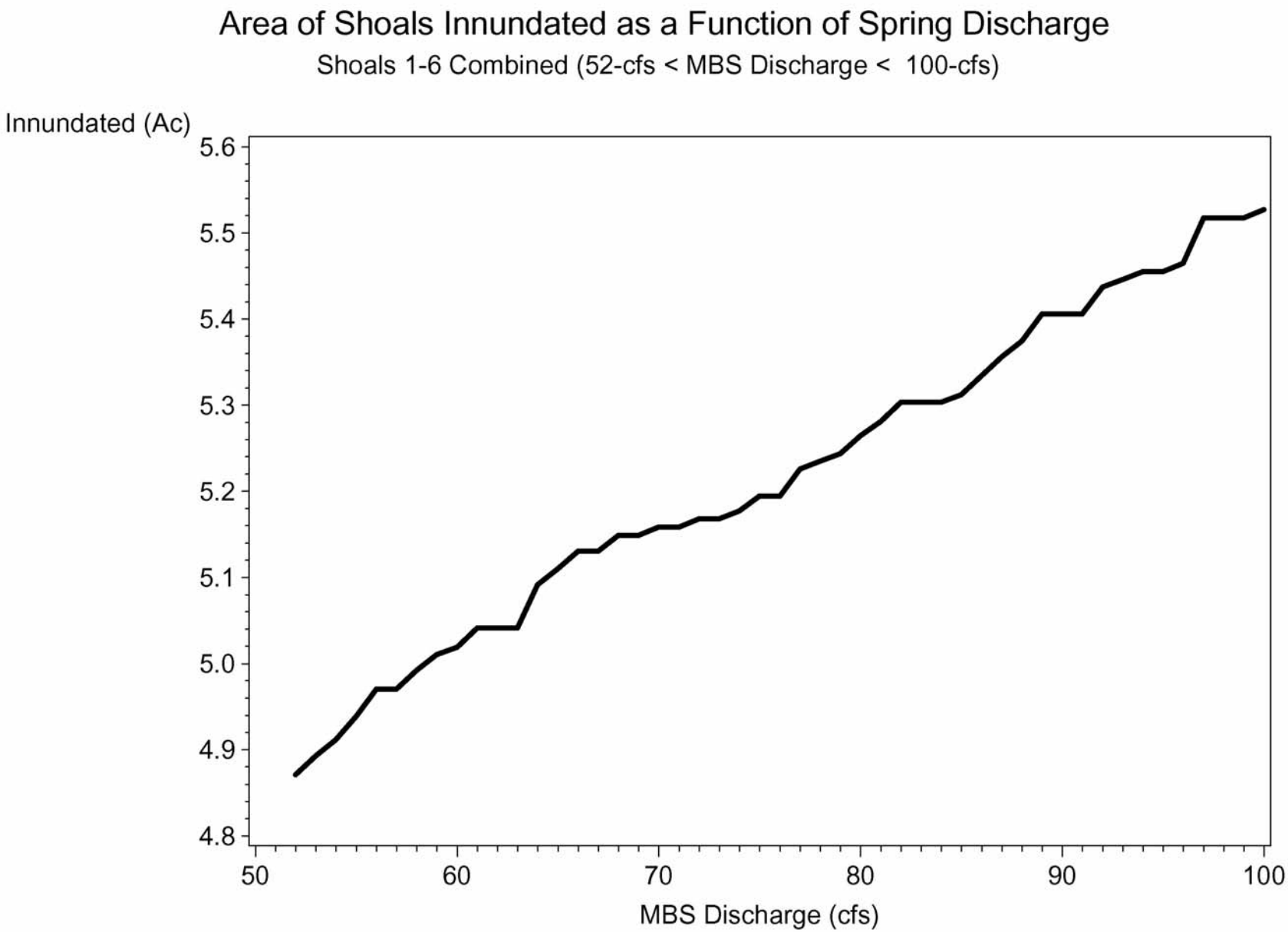


Figure 4-53. Relationship between area of shoal habitat inundated (any depth > 0 feet) as a function of Madison Blue Spring discharge.

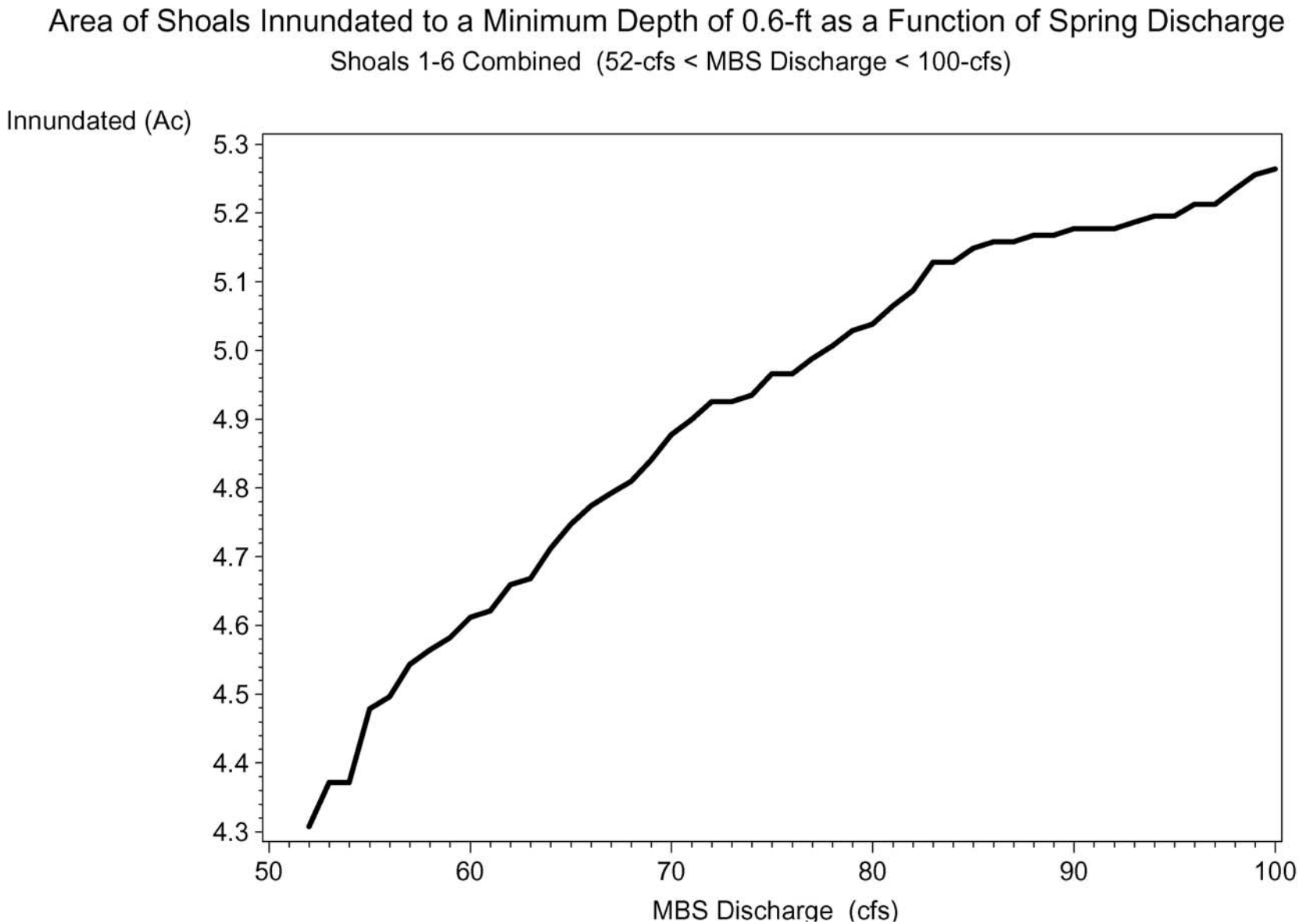


Figure 4-54. Relationship between area of shoal habitat inundated (to a minimum depth of 0.6 feet for fish passage) as a function of Madison Blue Spring discharge

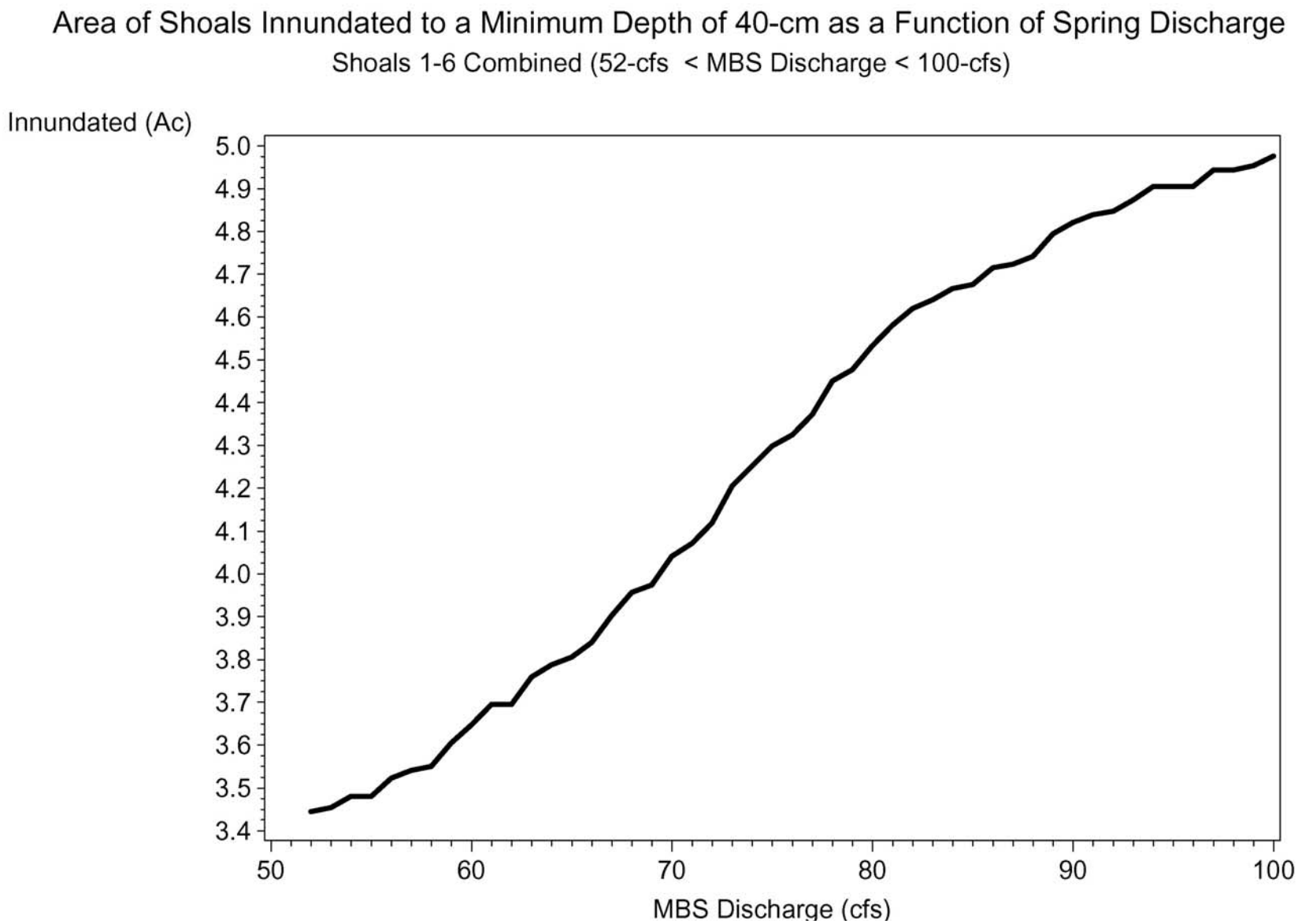


Figure 4-55. Relationship between area of shoal habitat inundated (to a minimum depth of 40 cm=1.31 feet) as a function of Madison Blue Spring discharge.

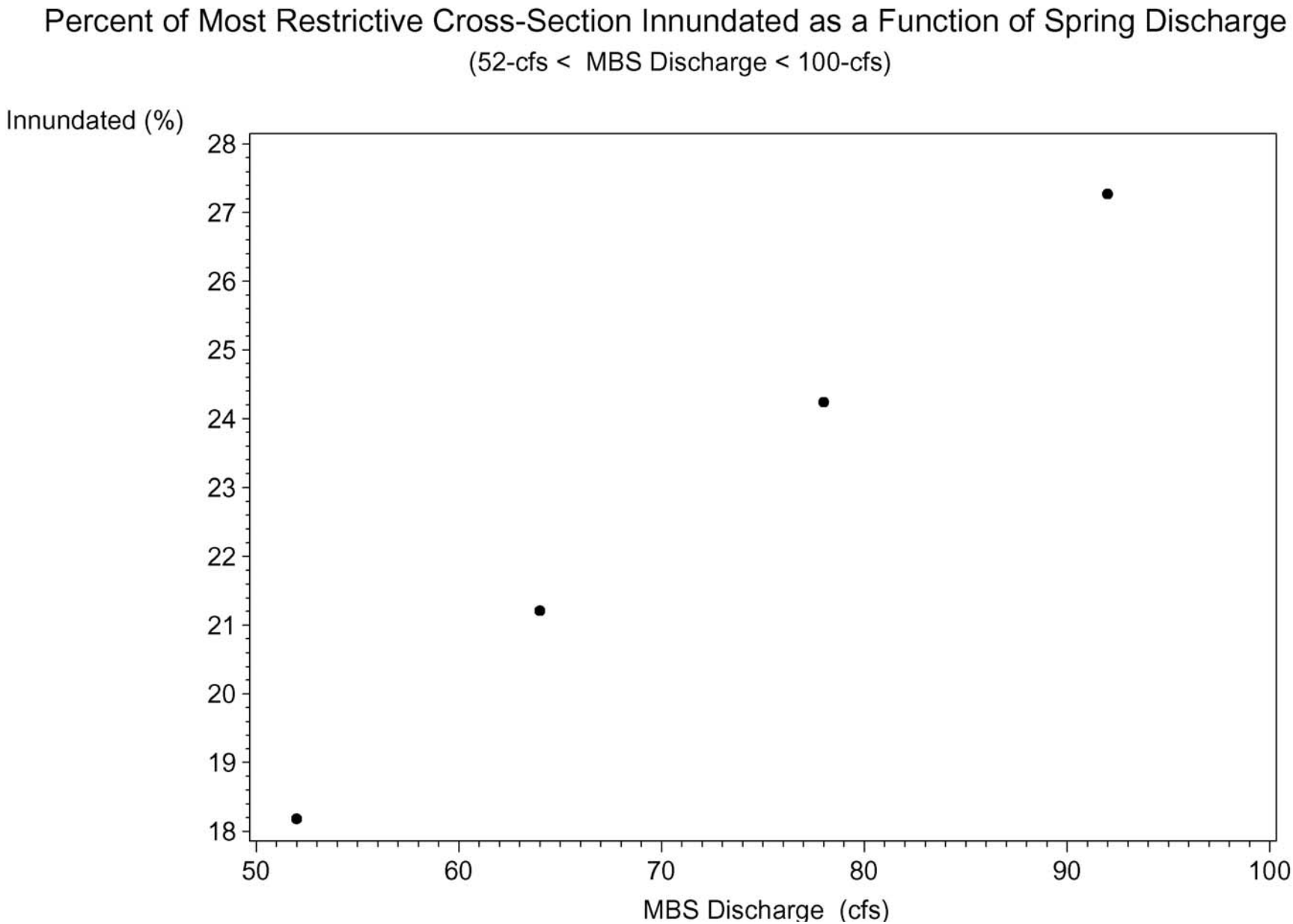


Figure 4-56. Relationship between the percent of the most restrictive cross-section inundated (any depth > 0 feet) and flow.

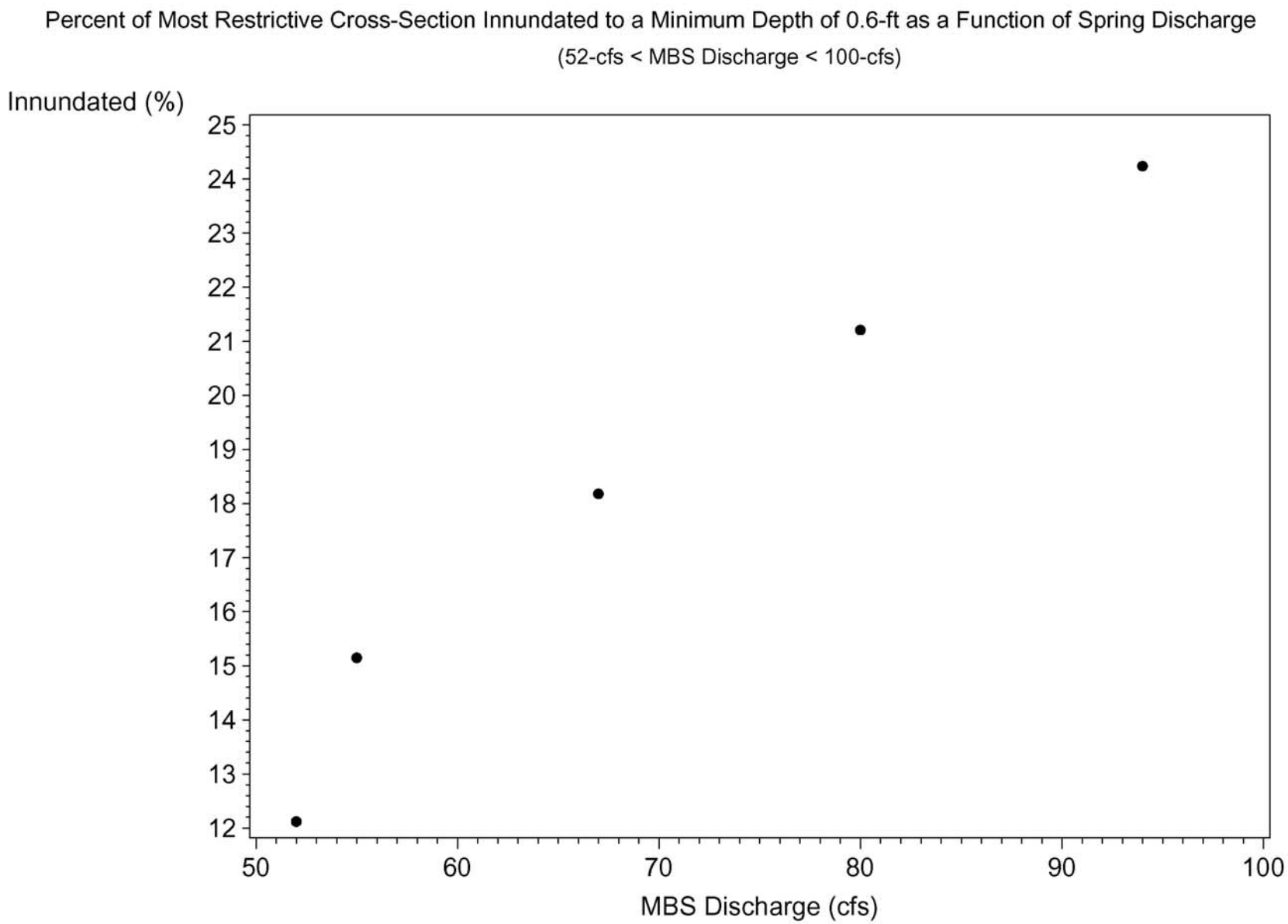


Figure 4-57. Relationship between the percent of the most restrictive cross-section inundated (to a minimum depth of 0.6 feet)

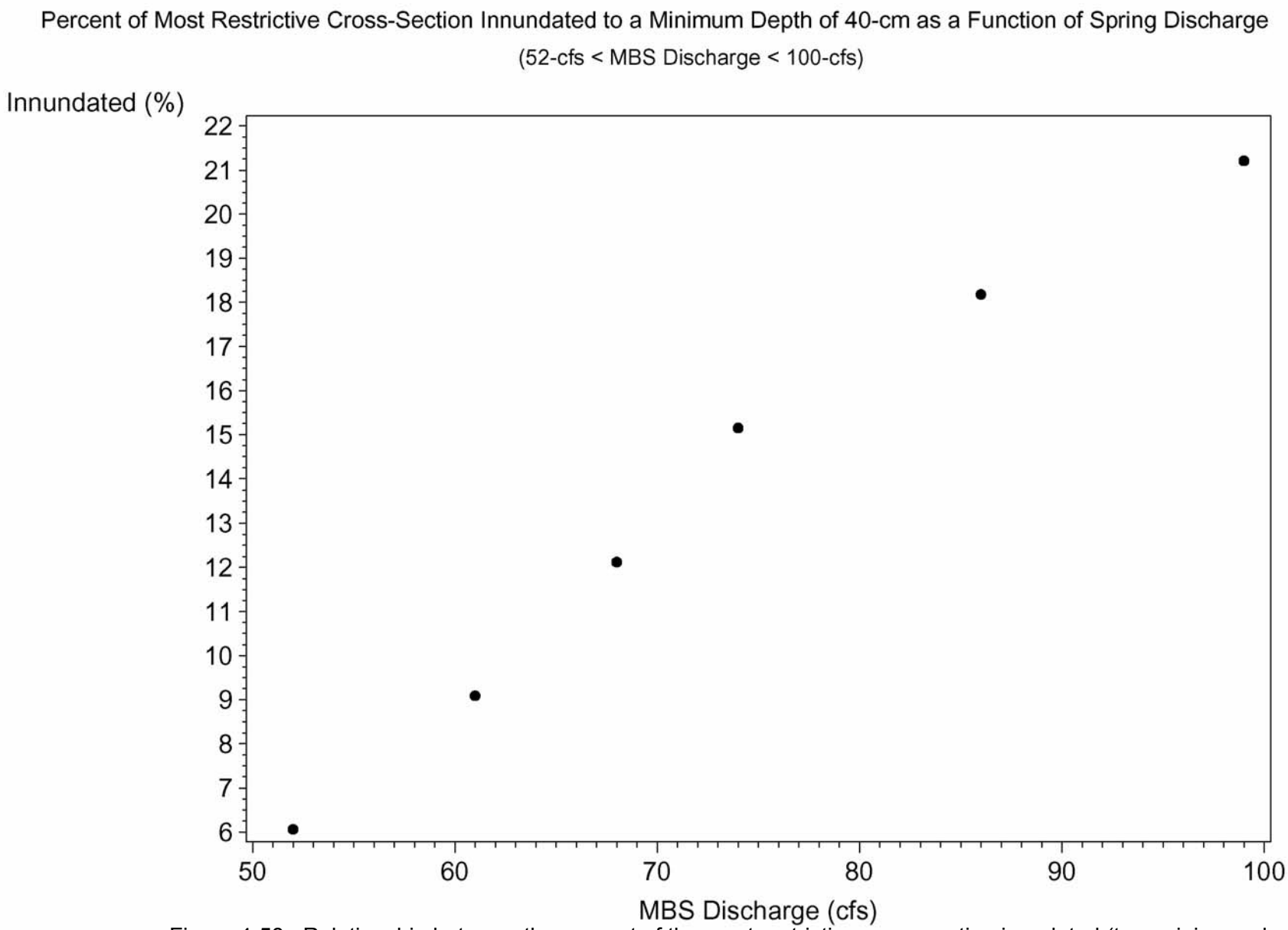


Figure 4-58. Relationship between the percent of the most restrictive cross-section inundated (to a minimum depth of 40cm=1.31 feet) and flow.

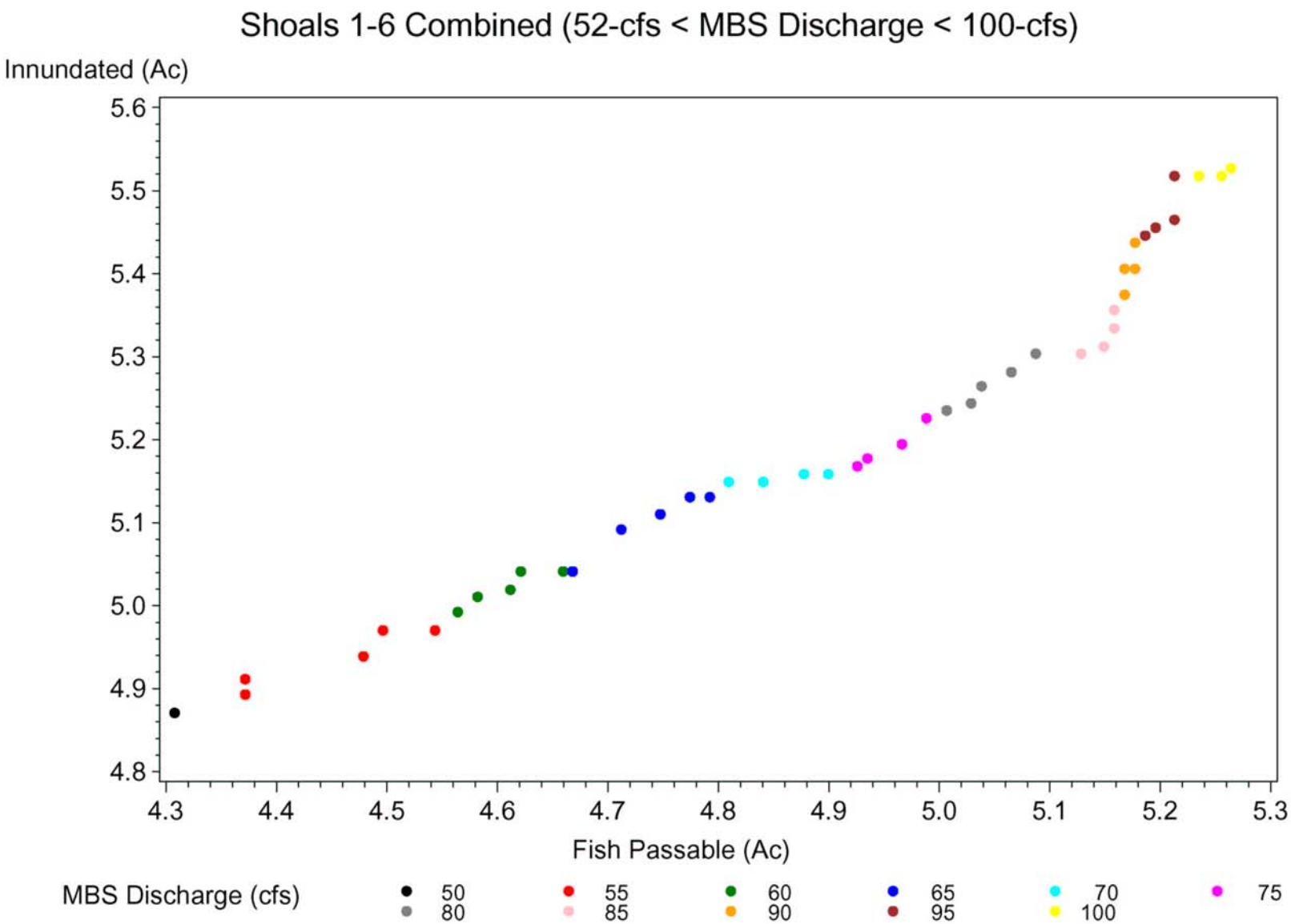


Figure 4-59. Response curve showing the relationship between total area inundated and the area of shoals passable by fish (minimum water depth of 0.6 feet).

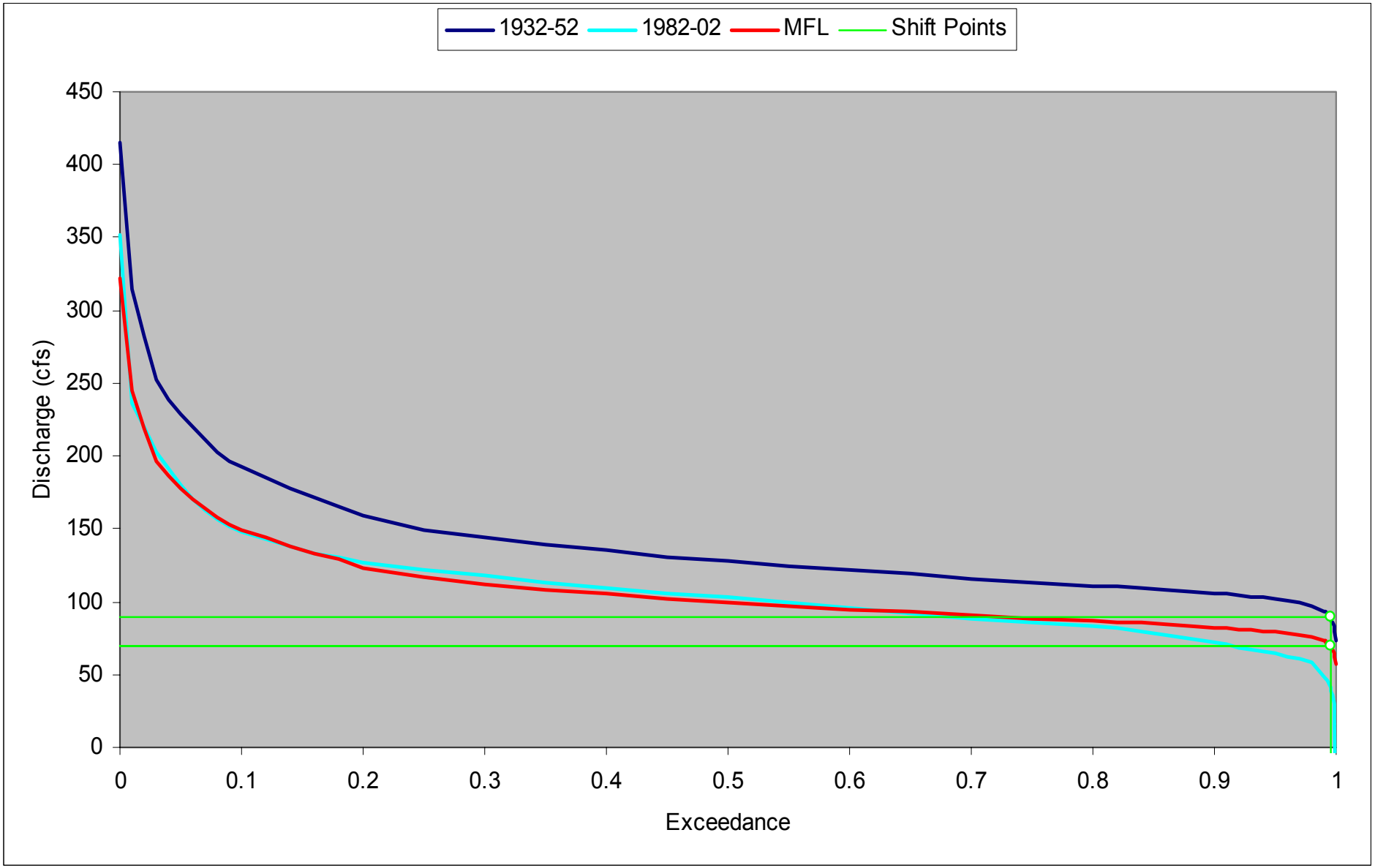


Figure 4-60. Flow duration curve analysis for historical (1932-1952), current (1982-2002) and MFL (70cs) conditions.

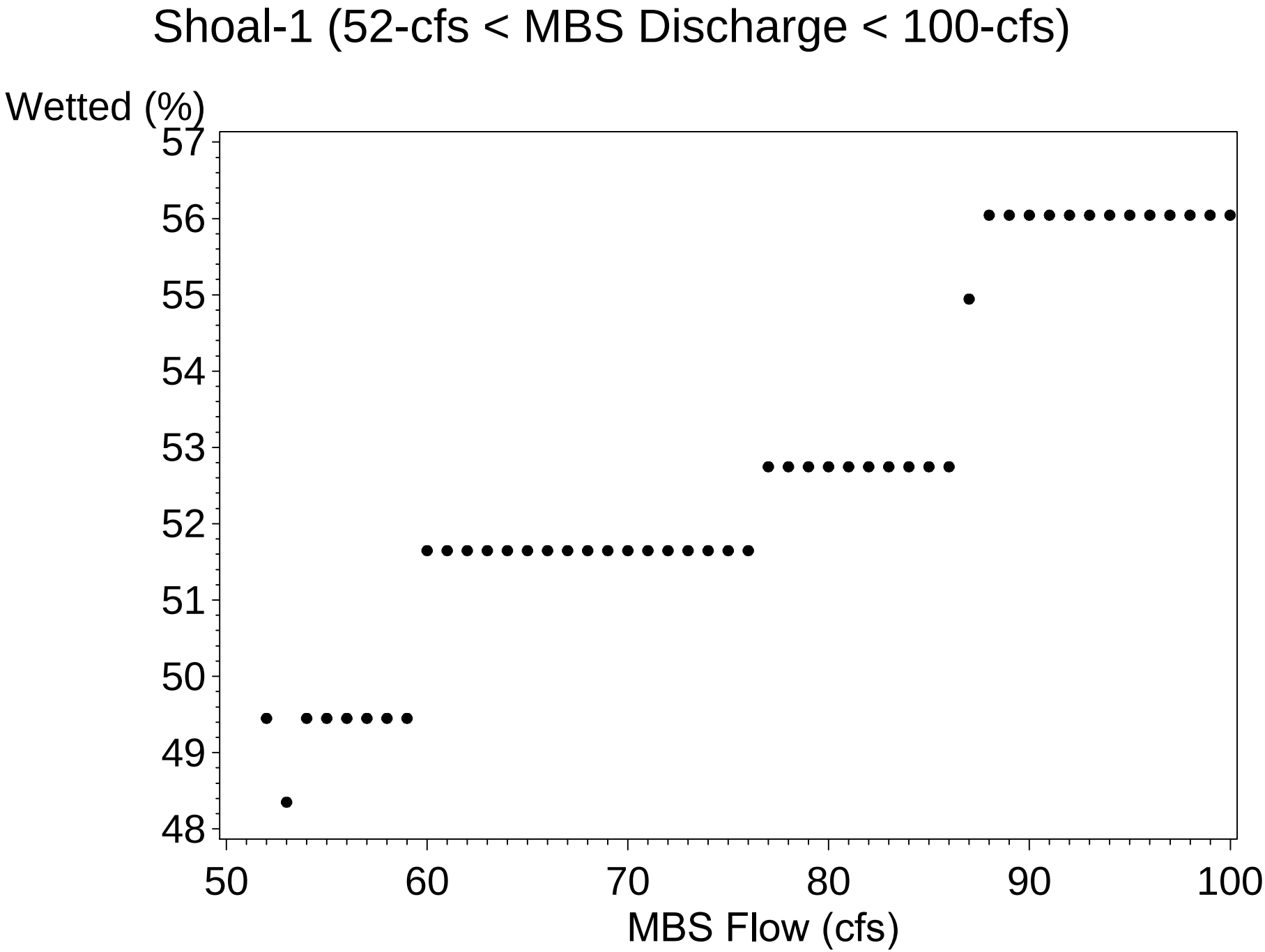

Shoal-1 (52-cfs < MBS Discharge < 100-cfs)
Wetted (%)
57
56
55
54
53
52
51
50
49
48
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-61

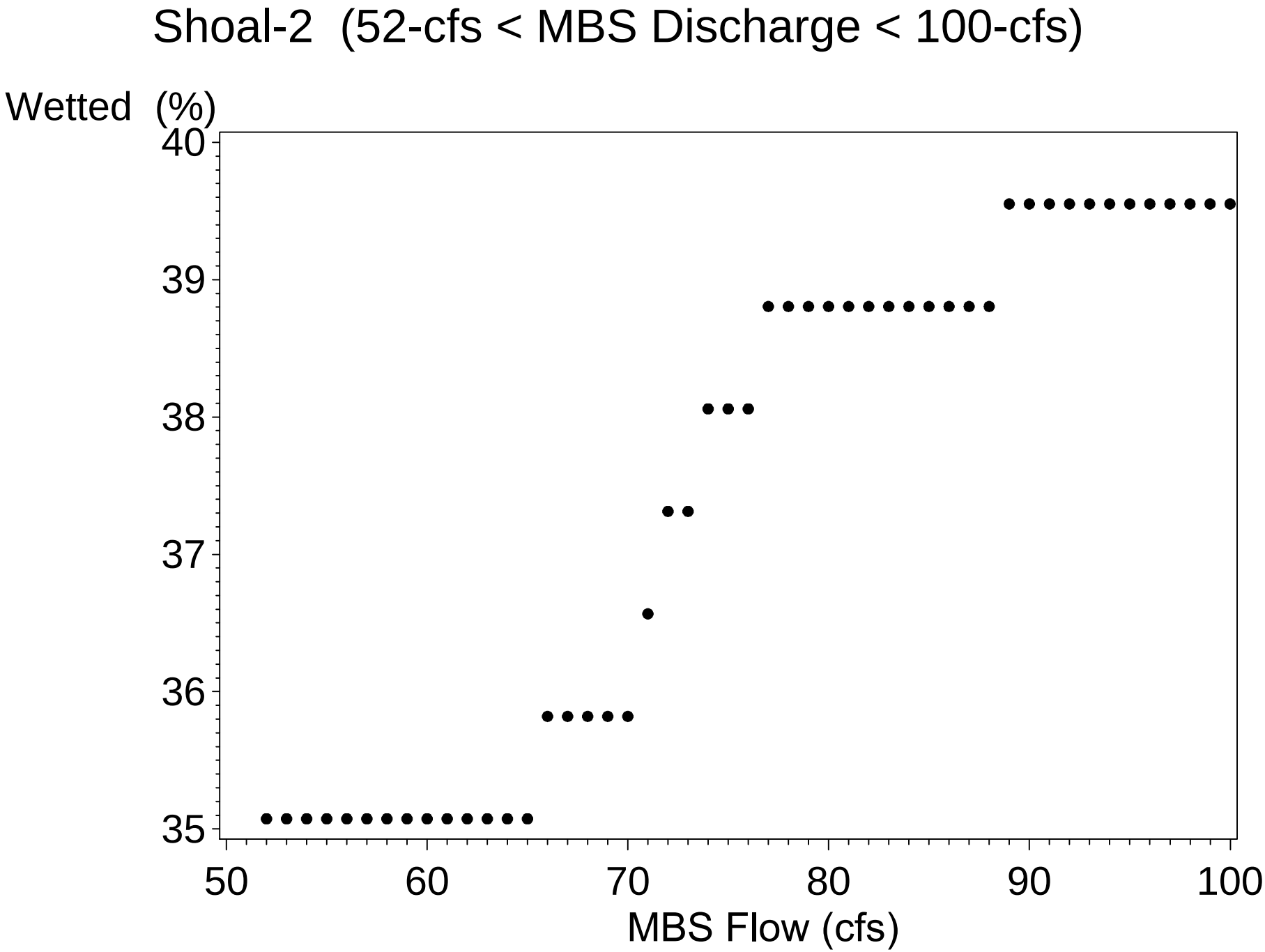

Shoal-2 (52-cfs < MBS Discharge < 100-cfs)
Wetted (%)
40
39
38
37
36
35
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-62

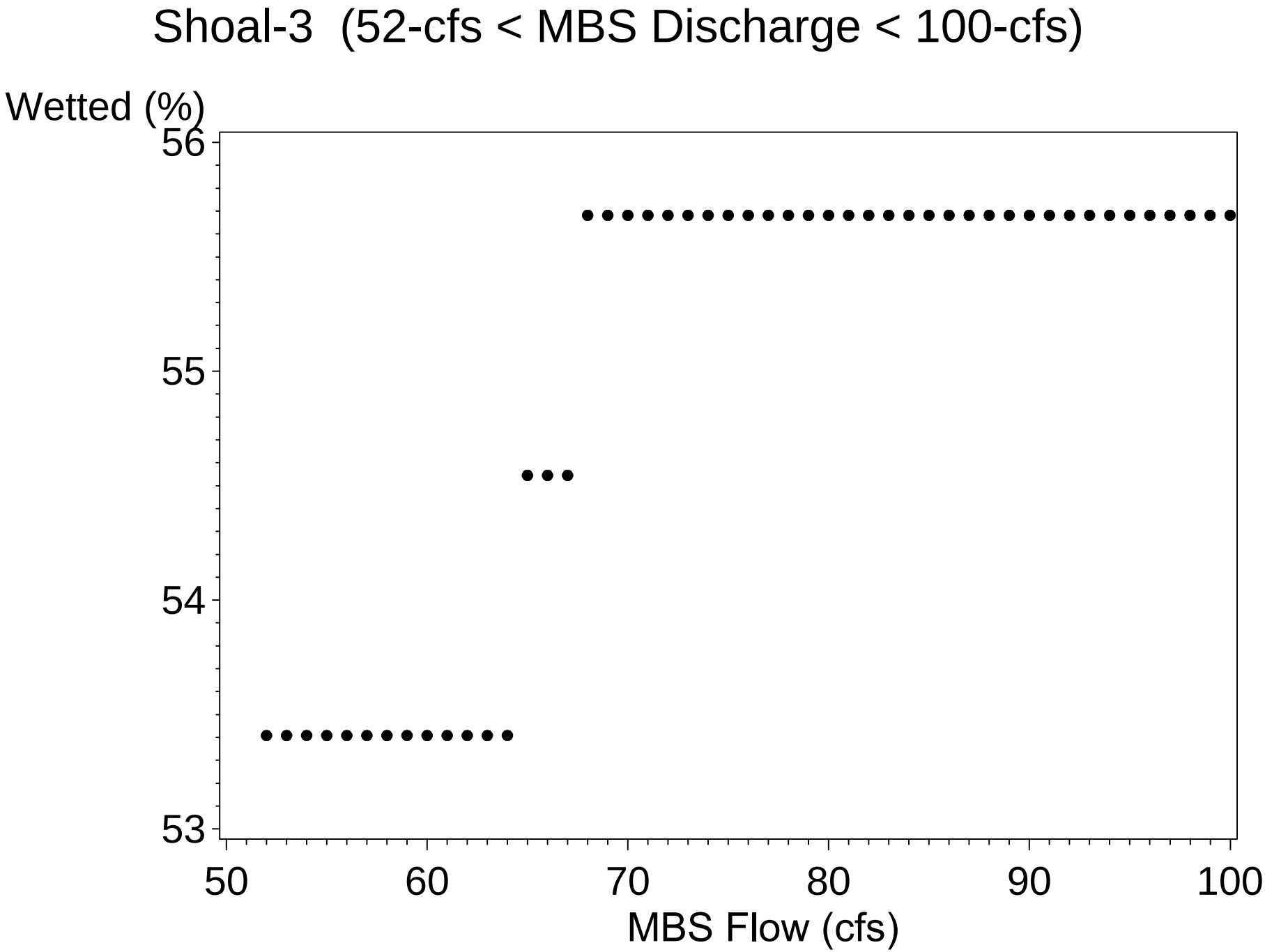

Shoal-3 (52-cfs < MBS Discharge < 100-cfs)
Wetted (%)
56
55
54
53
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-63

Shoal-4 (52-cfs < MBS Discharge < 100-cfs)

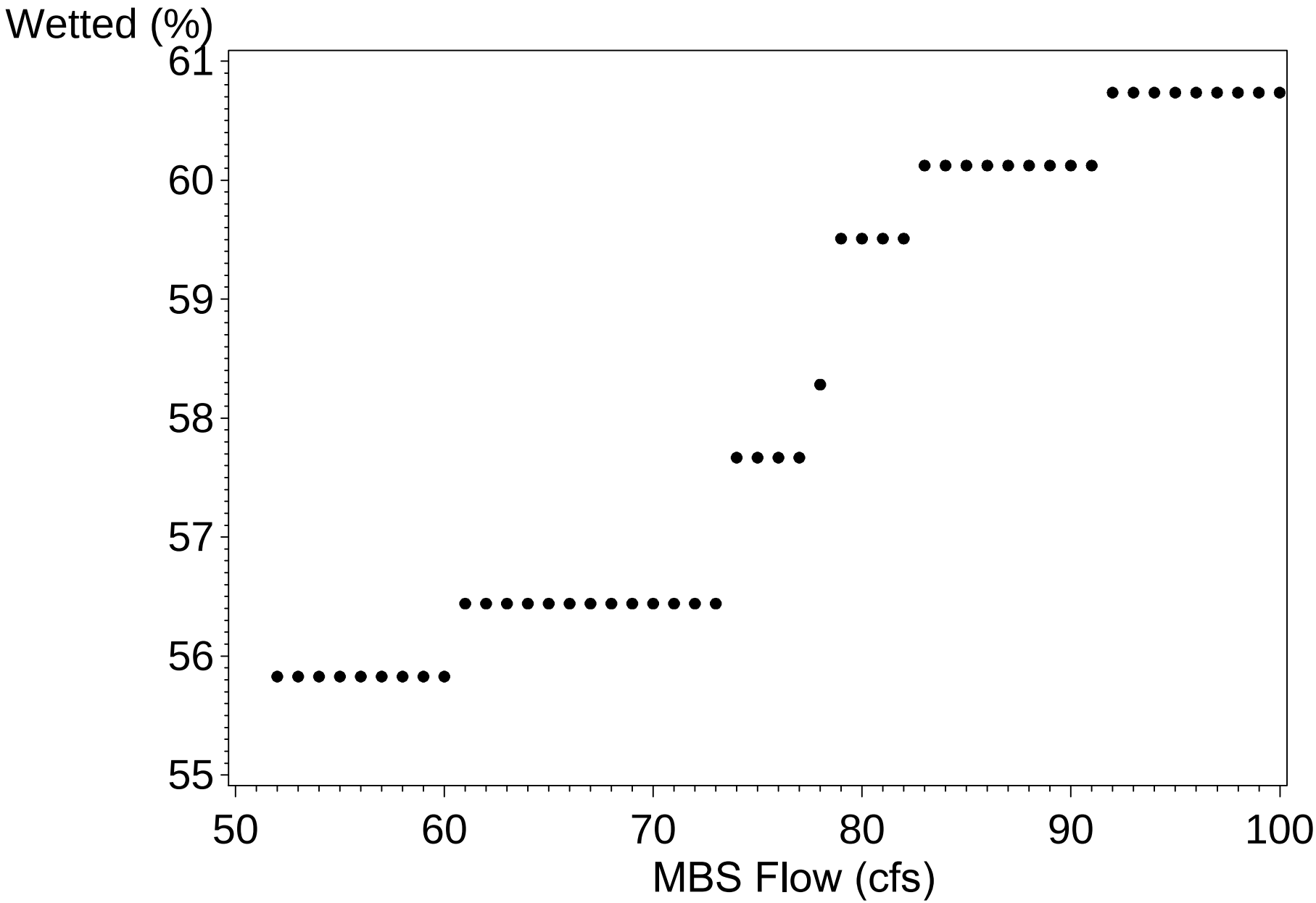


Figure 4-64

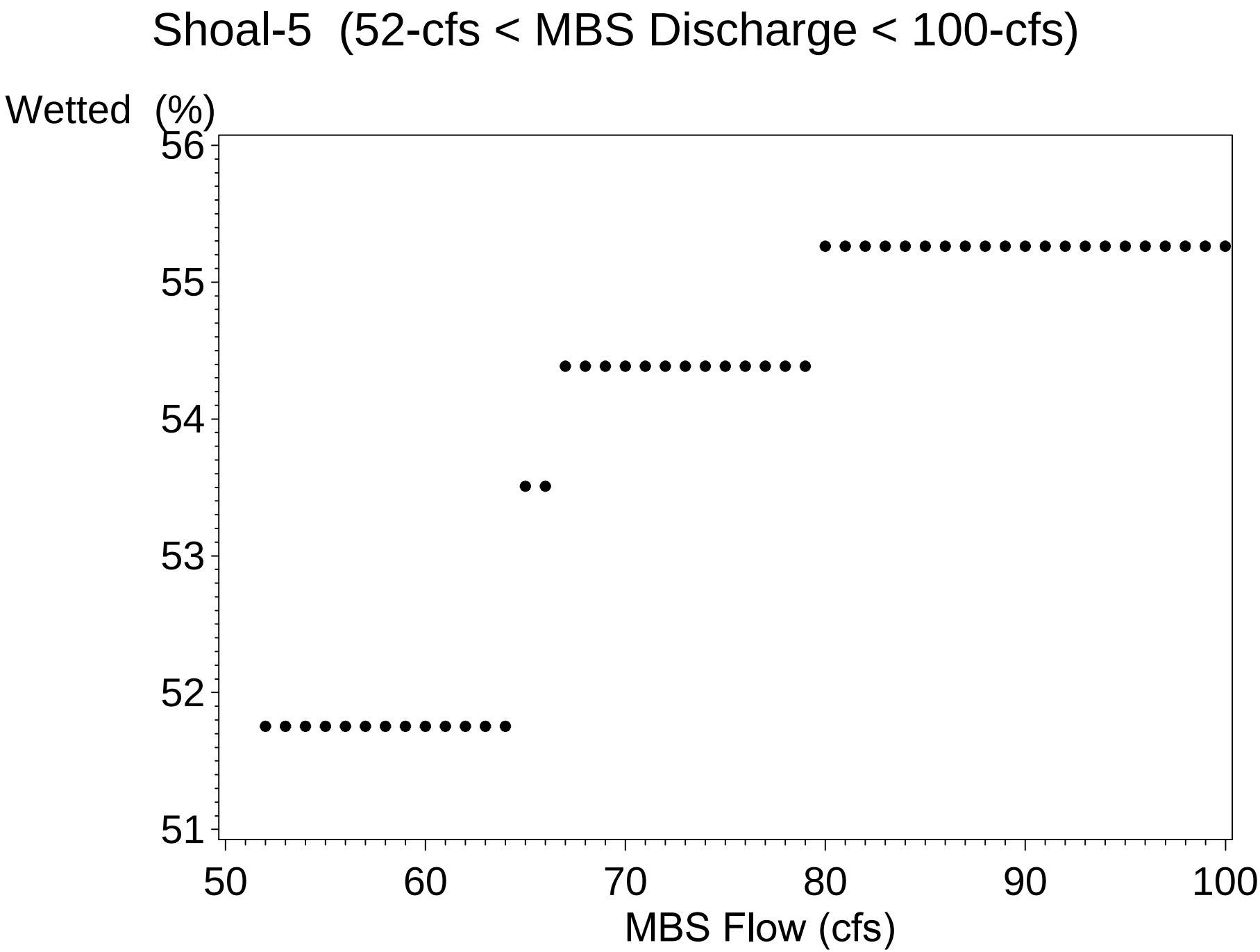

Shoal-5 (52-cfs < MBS Discharge < 100-cfs)
Wetted (%)
56
55
54
53
52
51
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-65

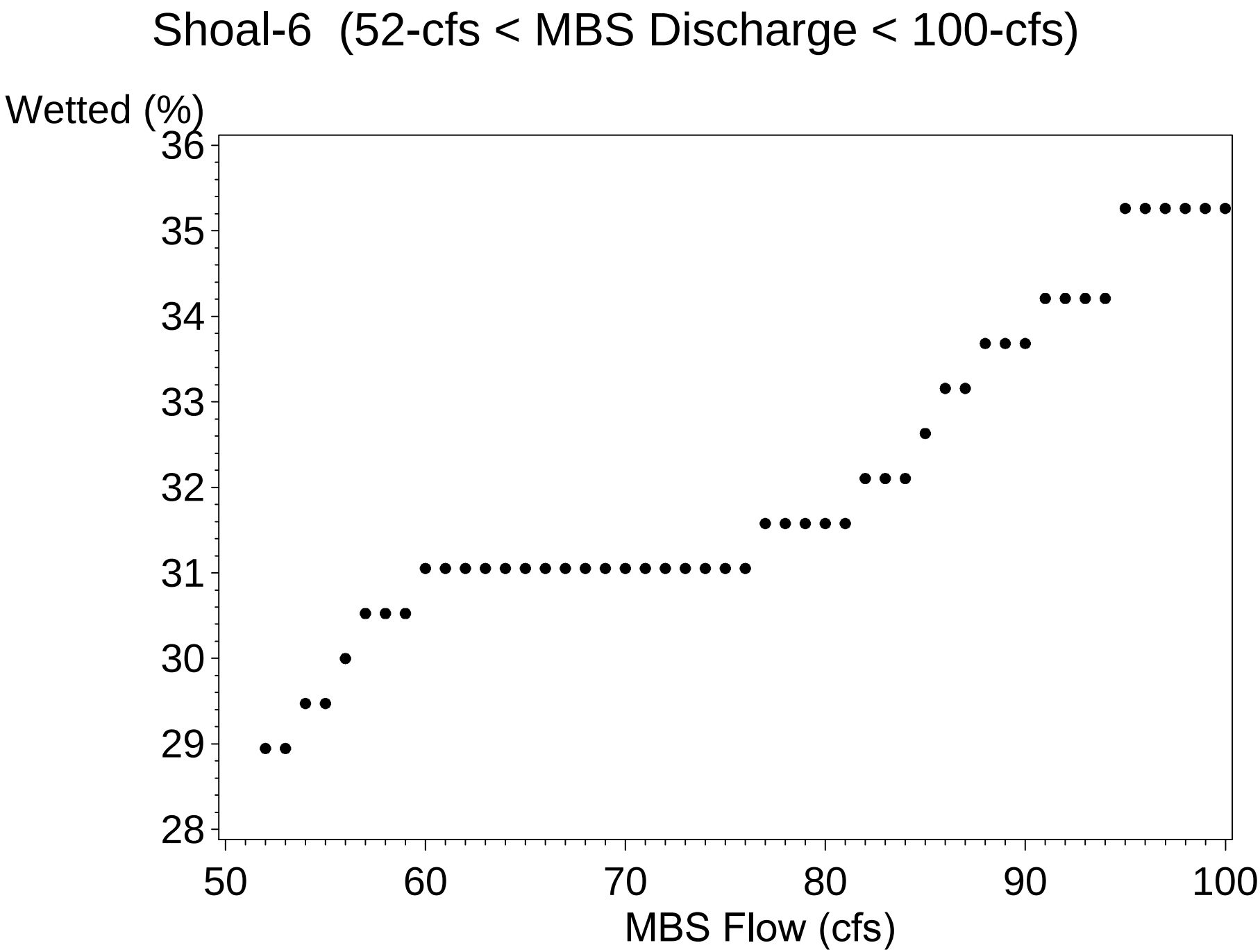

Shoal-6 (52-cfs < MBS Discharge < 100-cfs)
Wetted (%)
36
35
34
33
32
31
30
29
28
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-66

Shoal-1 (52-cfs < MBS Discharge < 100-cfs)

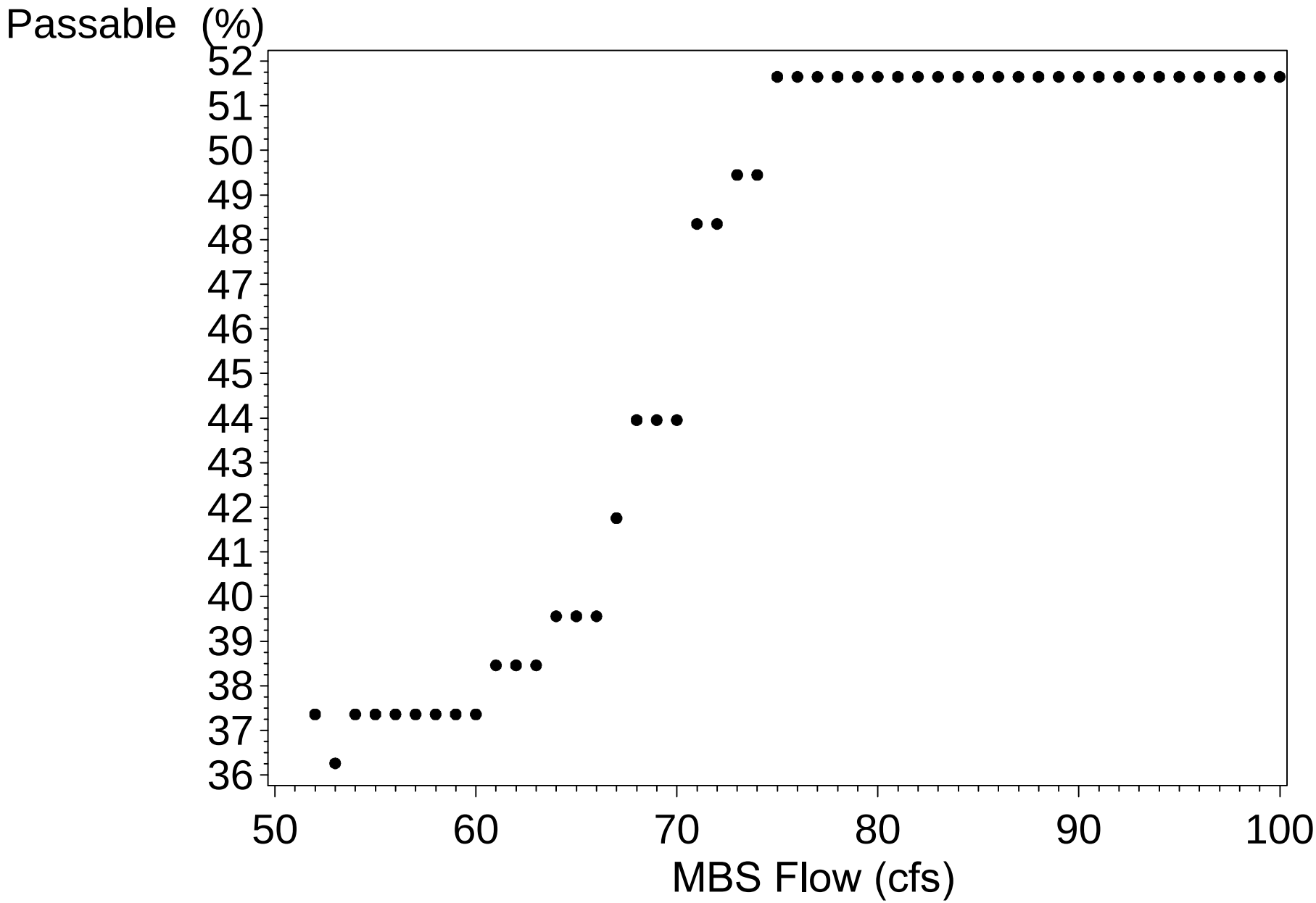


Figure 4-67

Shoal-2 (52-cfs < MBS Discharge < 100-cfs)

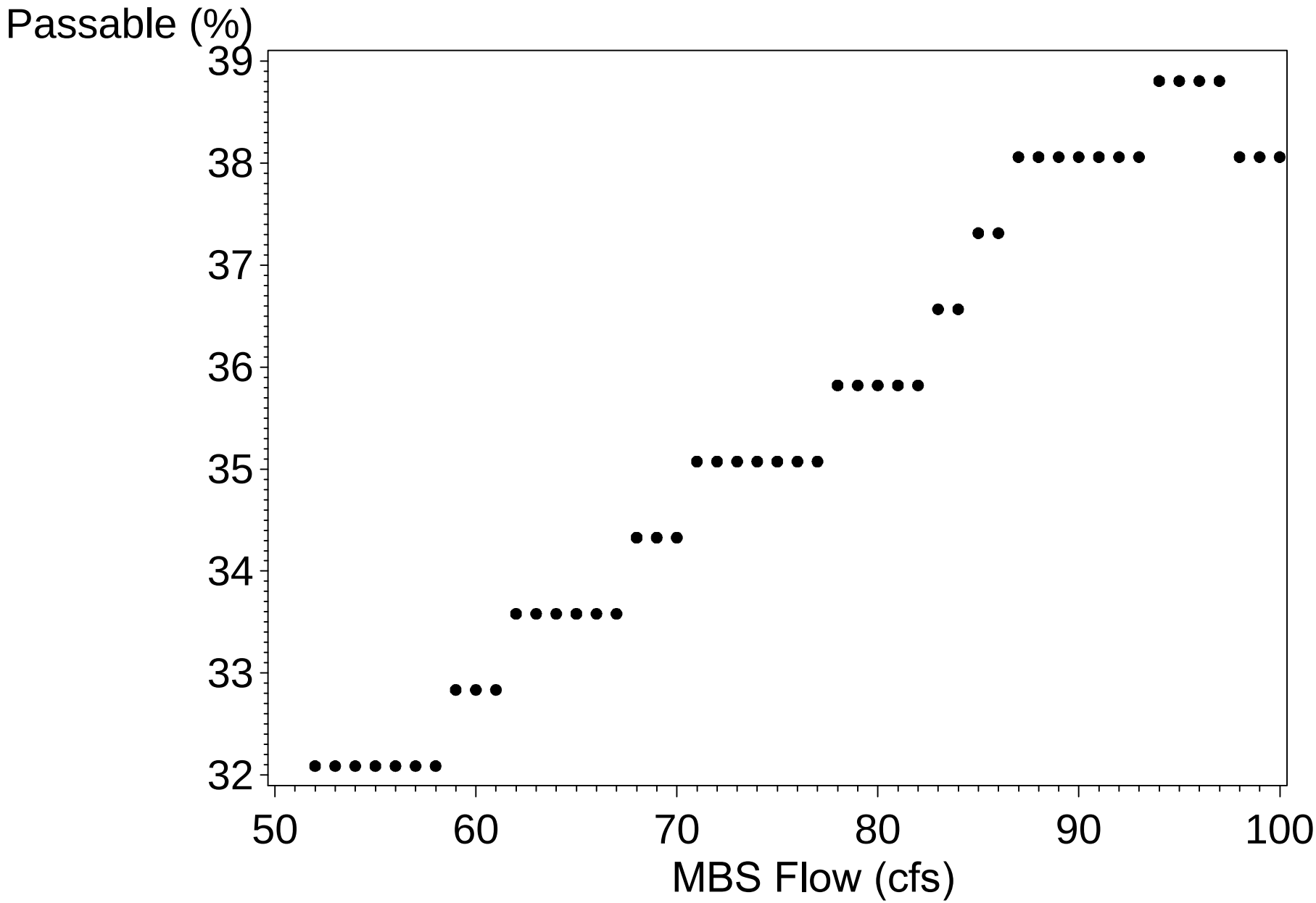


Figure 4-68

Shoal-3 (52-cfs < MBS Discharge < 100-cfs)

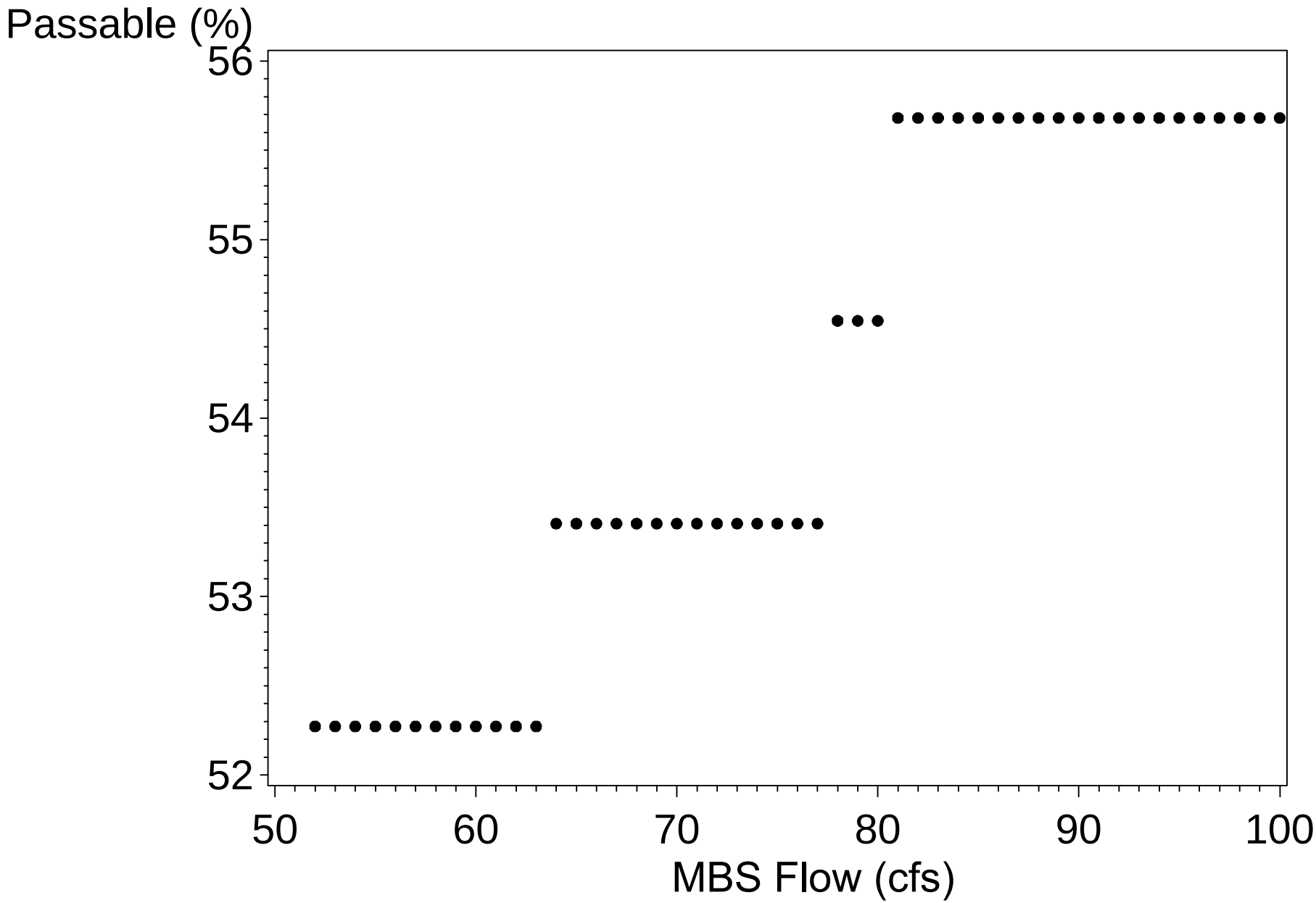


Figure 4-69

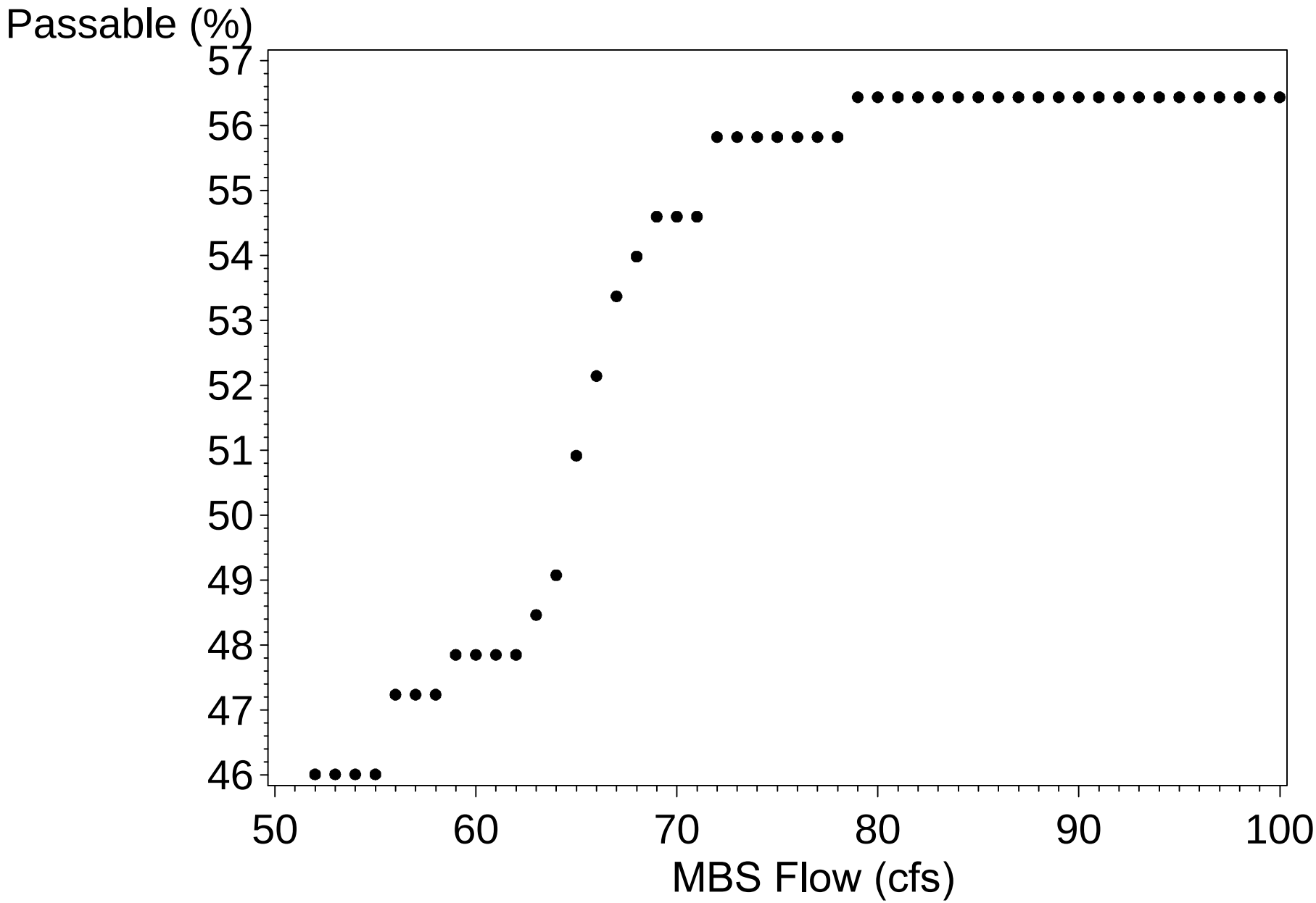

Shoal-4 (52-cfs < MBS Discharge < 100-cfs)
Passable (%)
57
56
55
54
53
52
51
50
49
48
47
46
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-70

Shoal-5 (52-cfs < MBS Discharge < 100-cfs)

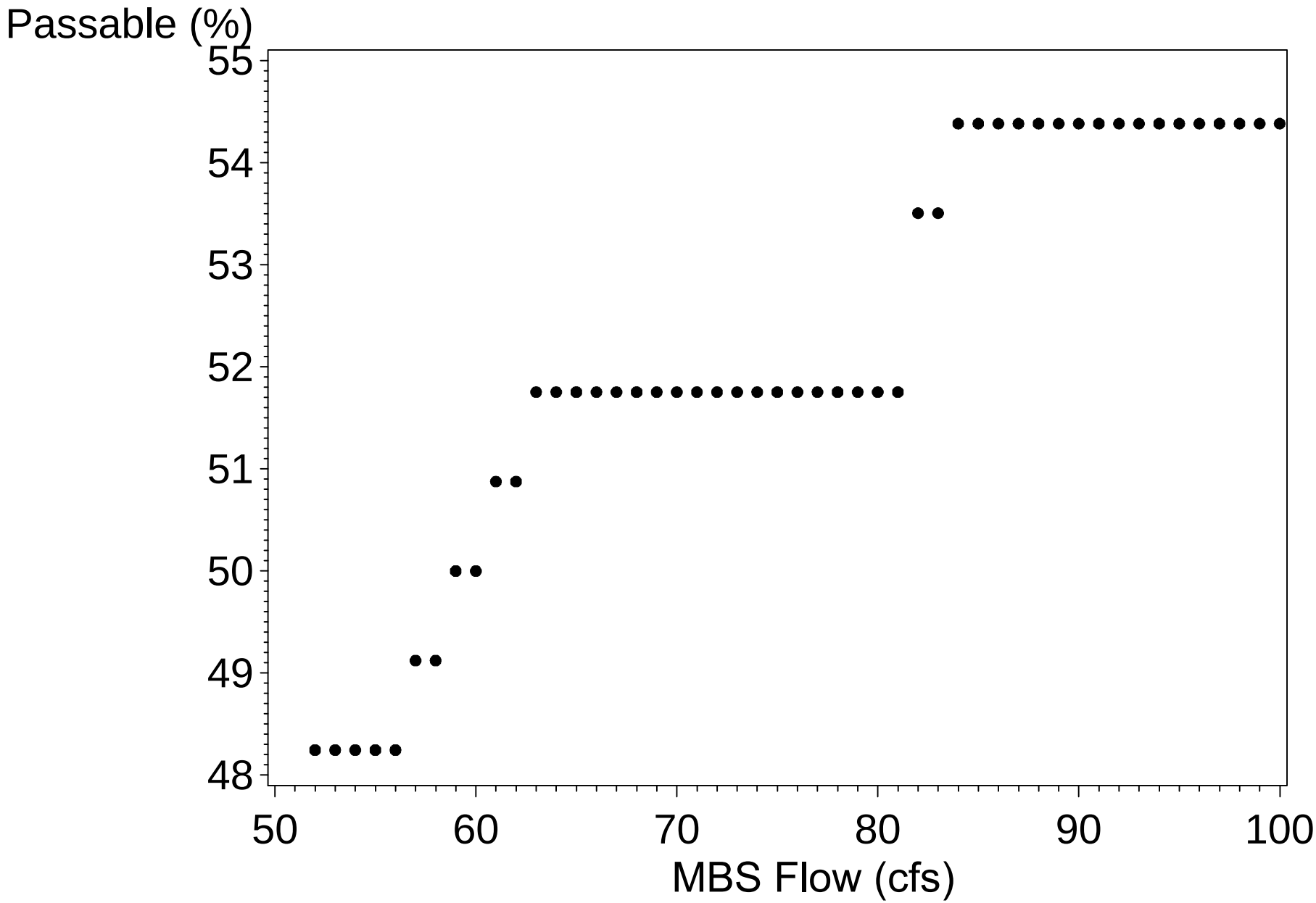


Figure 4-71

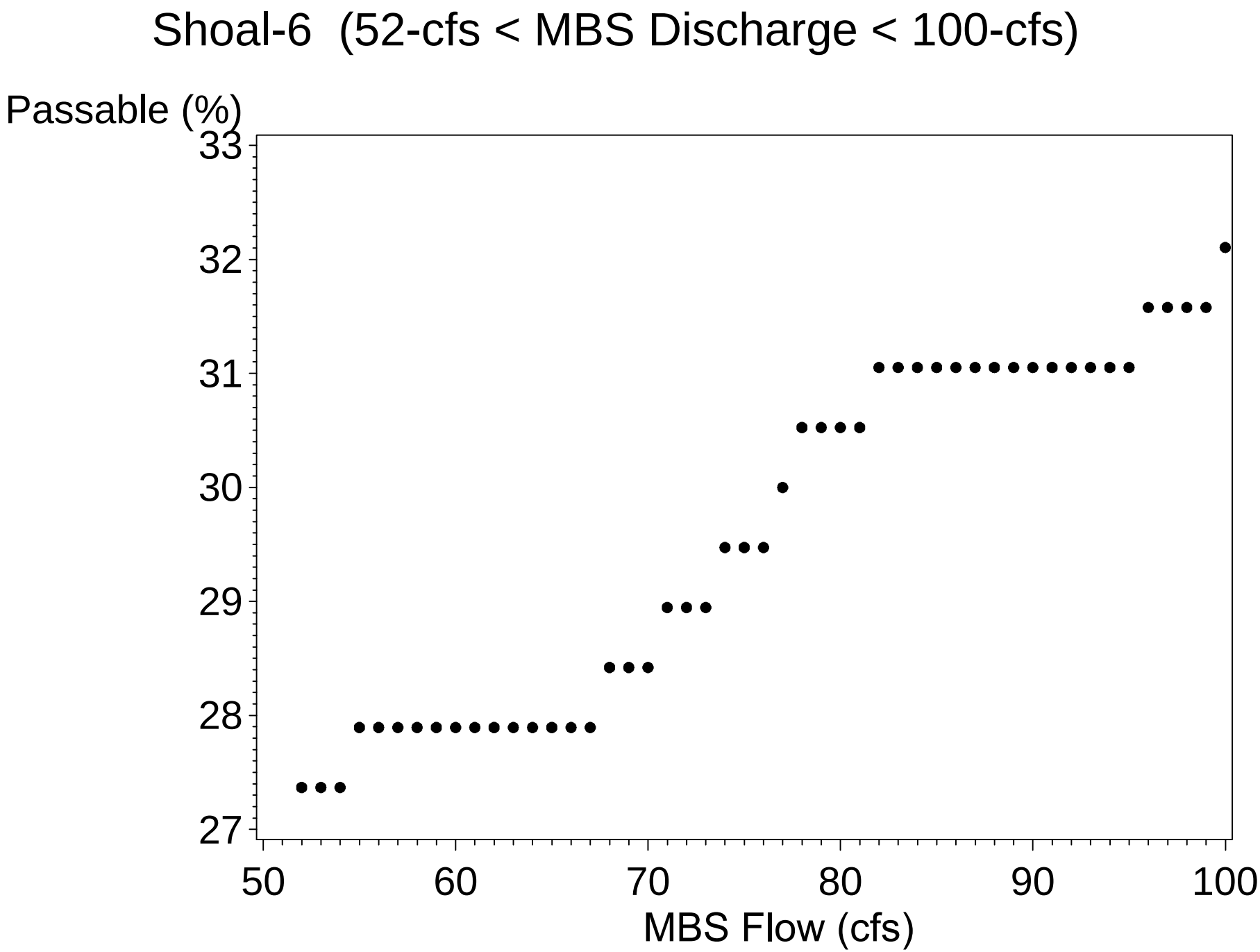

Shoal-6 (52-cfs < MBS Discharge < 100-cfs)
Passable (%)
33
32
31
30
29
28
27
50
60
70
80
90
100
MBS Flow (cfs)

Figure 4-72

5.0 MFL DEVELOPMENT

5.1 Background

Florida Statutes require each water management district to establish Minimum Flows and Levels (MFL) in accordance with the provisions contained in Chapter 373.042 F.S. More specifically, the Florida Department of Environmental Protection (FDEP) has adopted further ecological and resource values (62-40.473 F.A.C.) that should be considered when determining significant harm for adoption. The MFL should provide protection from "significant harm" for the following applicable ecological and resource values:

a. Recreation in and on the water;
b. Fish and wildlife habitats and the passage of fish;
c. Estuarine resources;
d. Transfer of detrital material;
e. Maintenance of freshwater storage and supply;
f. Aesthetic and scenic attributes;
g. Filtration and adsorption of nutrients and other pollutants;
h. Sediment loads;
i. Water quality; and
j. Navigation.

As the characteristics and best available data pertaining to a water body under consideration for a MFL are reviewed, some of the 62-40.473 F.A.C. values may be more applicable than others. The determination of significant harm to the water resource and/or the ecology of the area is determined by the SRWMD Governing Board after consideration of many scientific, legal, social, economic and other factors that result in a determination of "significant harm". The recommendations provided in this report are intended to assist the SRWMD Governing Board in making the determination of a minimum flow for MBS in consideration of applicable ecological and resource values.

5.2 MBS Specific MFL Values

The following five ecological and resource values were not considered to be applicable for the MFL developed for MBS:

- Estuarine Resources - MBS is a fresh water system that does not have an immediate connection to an estuary.
- Filtration and Adsorption of Nutrients and other Pollutants - MBS does not have a vegetative component that provides water quality improvement.
- Navigation - The spring is not a navigable waterway and the spring run, although technically navigable by small, non-motorized craft under infrequent stage conditions, would not be considered a navigable waterway in the context of the FDEP criteria.
- Transfer of Detrital Material – This criterion is not applicable to spring systems.
- Sediment Loads - This criterion is not applicable to spring systems.

The following values, in priority order, were potentially either directly or indirectly applicable as the available data were identified, collected and analyzed:

1. Fish and Wildlife Habitats and the Passage of Fish;
2. Maintenance of Freshwater Storage and Supply;
3. Recreation in and on the Water;
4. Aesthetic and Scenic Attributes; and
5. Water Quality.

5.3 Summary of 62-40.473 F.A.C. Value Evaluations

Fish and Wildlife Habitats and the Passage of Fish

In consideration of fish and habitat values, Section 4 – Ecological Analyses identified three potential MBS discharge levels that represent recognizable and notable environmental change

at representative shoal habitats in the Withlacoochee River for consideration in selecting a minimum flow for MBS.

In order to provide a tool for narrowing the selection of possible candidate minimum flow values for MBS, a final response curve was developed to present the relationship between the total surface area inundated and the area passable by fish at a water depth of 0.6 feet to a set of candidate MBS flow values (Figure 4-59). This curve ranges over the MBS flow values that define the domains of the regression models that were used to construct them; these model domains ranged from 52 cfs to 100 cfs. Based on inflection points observed in the relationships presented in this plot, three candidate minimum flow values were identified:

- 70 cfs (increases in spring discharge in this region of the curve will not result in significant increases in total inundated shoal area as evidenced by the near horizontal slope of the curve in the 70 cfs region of the curve),

- 85 cfs (increases in spring discharge in this region of the curve will not in increases in fish passable shoal area as evidenced by the near vertical slope of the curve in the 85 cfs to 90 cfs region of the curve),

- 100 cfs (this spring discharge was considered because it was the largest candidate value within the model domain).

These three candidate minimum flow values can be compared to historical flow conditions as described in Section 4.7.4. This allows an estimate of the potential loss of available habitat (i.e., percent of inundated shoal area) under these three candidate minimum flow values from historical flow conditions. The estimated losses are summarized in Table 5-1 (and Table 4-4) and are based on the relationship seen in Figure 4-60.

For the 70 cfs candidate minimum flow value, the loss of shoal habitat availability during low water levels is 0.4 acres (7.7%) for fish passage and 0.3 acres (5.6%) for inundation from that available under historical flow conditions. The 0.4 acre loss is small within the context of the total available shoal habitat, and therefore we believe this does not constitute significant harm. Thus, the expected change in habitat for the 70 cfs minimum flow, over the range of flow conditions exhibited by MBS, was determined to be reasonable and it was determined to be an

acceptable change barring potential future changes in shoal morphometry and further information from future data collection.

TABLE 5-1. Comparison of estimated differences in shoal habitat areas resulting from a shift from a historical flow regime (1932-1952) with a 90 cfs estimated low flow to potential future flow regimes for three candidate minimum flow values.				
Minimum Flow Madison Blue Sp (cfs)	Shoal Area Passable by Fish (acres)	Shoal Area Wetted (acres)	Difference from Historical Shoal Area Passable by Fish (acres)(%)	Difference from Historical Shoal Area Wetted (acres)(%)
70 cfs	4.8	5.1	-0.4 (-7.7%)	-0.3 (-5.6%)
85 cfs	5.1	5.3	-0.1 (-1.9%)	-0.1 (-1.9%)
100 cfs	5.2	5.5	0	+0.1 (+1.8%)

Maintenance of Freshwater Storage and Supply

The FAS, which discharges to MBS also serves as a water supply to a number of District-permitted water users. These water users have a vested interest in maintenance of the water supply since they have received approval for water use from the District. To assist in selecting a minimum flow that addresses maintenance of this freshwater supply, the effect that a range of minimum flows would have on the ability of existing legal users to maintain their water supplies and still prevent significant harm to the ecosystem was evaluated.

This consideration of maintaining existing water supplies does not supercede the District's right to manage permitted quantities for efficiency and reasonable use. Rather, it evaluates the potential for periodic disruption of existing legal uses based on a District-managed minimum flow for MBS. This evaluation is also necessary to determine if the water body is subject to a recovery strategy based upon the use of permitted quantities and the proposed MFL.

A series of graphs were created to look at the frequency and duration of time that flow from MBS falls below a certain value. The graphs provided information sufficient to understand how a particular minimum flow rate might be managed under current conditions and based on historic hydrologic conditions and withdrawals and current conditions.

When the Withlacoochee River stage is high, the river affects the flow in MBS. Based on an analysis of MBS flow at various river stages, the effect of the river on flow from MBS appears to be minimized for stages at the Pinetta gauge below 55 ft. The stage at Pinetta is below 55 feet approximately 50 percent of the time. Figures 5-1 through 5-6 show the frequency and total duration of time that flow in MBS falls below a given value each year, during the time when the stage at the Pinetta gauge is below 55 feet. Graphs were created for the frequency and total duration of events when spring flow does not exceed 70, 75, 80, 85, 90, 95, and 100 cfs. This range was selected to bracket the three candidate minimum flows to be considered based on ecological criteria. Table 5-2 summarizes the data in Figures 5-1 – 5-6.

Flow Level	70 cfs	75 cfs	80 cfs	85 cfs	90 cfs	95 cfs	100 cfs
Total Duration of Occurrences (days)	371	557	799	1226	1905	2540	3251
Total Frequency of Occurrences	42	58	94	130	139	155	200
Avg. Duration (days) /Yr)	5.3	8.0	11.4	17.5	27.2	36.3	46.4
Avg. Frequency (days)/Yr	0.60	0.8	1.3	1.9	2.0	2.2	2.9

Table 5-2: Flow Exceedance Summary Data for Period 1932-2002

Flow Trends in the simulated discharge data for MBS were analyzed by looking at the mean annual discharge of MBS for the period of record. Two sets of graphs were generated. (Figures 5-7 – 5-13). The first takes the mean annual discharge for the entire period of record and the second takes the mean annual discharge only for the days in each year with a stage at Pinetta below 55 feet (Figure 5-14). The results are similar. This is because the river creates low and negative flows when stage is high, but also high flows as stage falls and the built up pressure in the aquifer is released. An overall decreasing trend is seen for the entire period of record. When this is split up into the periods of 1934 -1971 and 1972-2002, a decreasing trend is seen in the later period and a slightly increasing trend is seen in the earlier period.

Flow Level	70 cfs	75 cfs	80 cfs	85 cfs	90 cfs	95 cfs	100 cfs
Total Duration of Occurrences (days)	344	499	665	945	1302	1550	1840
Total Frequency of Occurrences	32	41	55	71	72	67	78
Avg. Duration (days) /Yr	17.2	25.0	33.3	47.3	65.1	77.5	92.0
Avg. Frequency (days)/Yr	1.6	2.0	2.8	3.6	3.6	3.4	3.9

Table 5-3: Flow Exceedance Summary Data for Period 1982-2002

Table 5-3 compares the flow rate exceedance based on the 20-year period from 1982-2002. During this time interval, water-use activity in MBS springshed increased over earlier period and the region experienced cycles of record wet and dry periods. Additionally, flow data suggest there is a corresponding decreasing trend in discharge at MBS possibly due to cyclic hydrologic conditions and/or increased water use withdrawals.

Recreation in and on the Water

MBS is a first magnitude spring, owned by the State of Florida. Currently, Madison Blue Spring State Recreation Area is managed according to the Suwannee River State Park Plan that provides various recreation activities including picnicking, swimming and diving. There is no available information regarding the impact of lowered flows on the recreational aspects of MBS. However, it is intuitive that that a spring flow that maintains a full pool and flow in the spring run at minimum maintains most of the recreational activities of the water resource.

The proposed minimum flow for the Fish and Wildlife Habitats and the Passage of Fish value is 70 cfs which will provide a median flow of 100 cfs (Figure 5-15). This proposed minimum flow would prevent significant harm to recreational activities at the spring.

Aesthetic and Scenic Attributes

This value is also related to the previous discussion on recreation. The aesthetic and scenic value of MBS is related to a full MBS pool and clarity of the water. There is not a significant vegetative component in MBS pool and spring run that will be affected by a minimum flow from MBS.

Additionally, MBS is classified as a first magnitude spring, meaning the median flow from the spring exceeds 100 cfs or 64.6 million gallons per day. Maintenance of this flow is significant to the aesthetic and scenic nature of the park which provides a tourism attraction for Madison County and the State of Florida.

Additionally, a flowing spring run provides aesthetic and scenic value to the water resource. However, there does not exist definitive data to assess the flow necessary to maintain these attributes.

The recommended minimum flow based upon the Fish and Wildlife Habitats and the Passage of Fish criteria is 70 cfs. This minimum flow also provides a median flow of 100 cfs through the spring run which classifies the spring a first magnitude spring. Absent more definitive data, this flow is assumed to provide protection from significant harm to the aesthetic and scenic attributes of the MBS.

Water Quality

As discussed in Section 4.6.1, a biologically meaningful relationship between low dissolved oxygen levels in the Withlacoochee River and flow in the Withlacoochee River was defined using the observed data. However, due to lack of water quality data for the spring, there was no such relationship found between the MBS discharge and the river. It is recommended that the water quality value not be used as a MFL target criteria until such time data is collected to provide the basis for a relationship between flow and water quality, if applicable, in the spring or river.

The water quality relationship based upon dissolved oxygen levels, would be a more appropriate a target criterion to be used in establishing an MFL for the Withlacoochee River.

5.4 Determination of a Recommended Minimum Flow

In determination of a recommended MFL for Madison Blue Spring, the following items identified in this report, are significant for consideration:

1. At the present time, there is limited data available to definitively characterize the hydrologic and ecologic system that defines the spring. Further data collection will provide a more comprehensive understanding of the hydrologic and ecologic system that characterizes MBS.
2. The spring provides a major contribution of flow to the Withlacoochee River when the river stage is at or below 55 feet NGVD as measured at the Pinetta Gauge.
3. The designation of MBS as a first magnitude spring has significant importance to the region as a recreational and tourism resource and the spring's aesthetic attributes.
4. Protection of shoal habitat is a critical element for the protection of the ecological value of the Withlacoochee River.

5. Without available data to provide a contrary opinion, it is assumed that the proposed 70 cfs minimum flow (which also yields a 100 cfs median flow) that provides protection from significant harm to the aquatic habitat and fish passage in the Withlacoochee River will also provide adequate flow to prevent significant harm to the recreational and scenic/aesthetic attributes for the MBS.
6. The 70 cfs minimum flow will provide for the maintenance of existing permitted water use quantities within the springshed of MBS.

Applicable Ecological and Water Resource Values	Value Flow Requirements	Benefits Provided by Flow Requirements	Does 70 cfs MFL Meet or Exceed Value Flow Requirements?
Fish and Wildlife Habitats and the Passage of Fish	>70 cfs	Provides protection from significant harm to shoal habitat and fish passage in the Withlacoochee River	YES
Maintenance of Freshwater Storage and Supply	>70 cfs	Provides maintenance of existing permitted water use	YES
Recreation in and on the Water	>70 cfs minimum	Provides a full spring pool and flow in the spring run	YES
Aesthetic and Scenic Attributes	>70 cfs >100 cfs median	Provides a full spring pool and flow in the spring run and classification as a first magnitude spring	YES
Water Quality	NA	NA	NA

Table 5-4 Summary of 70 cfs MFL Effectiveness to Address Applicable Ecological and Water Resource Values

5.5 Recommendations

In consideration of meeting the Chapter 373.042 F.S. requirements for establishing a Minimum Flow and Level for MBS and addressing the applicable water-resource values provided in 62-40.473 F.A.C., the following are recommended:

1. Adopt a minimum flow of 70 cfs for MBS applicable when the stage of the Withlacoochee River measured at the Pinetta gauge is 55 feet (NGVD) or less and which maintains a 100 cfs median flow for the MBS spring discharge.

2. Re-evaluate the MBS minimum flow five years after MFL adoption by incorporating additional data collected for related surface water, groundwater, ecological systems and water use within the springshed.

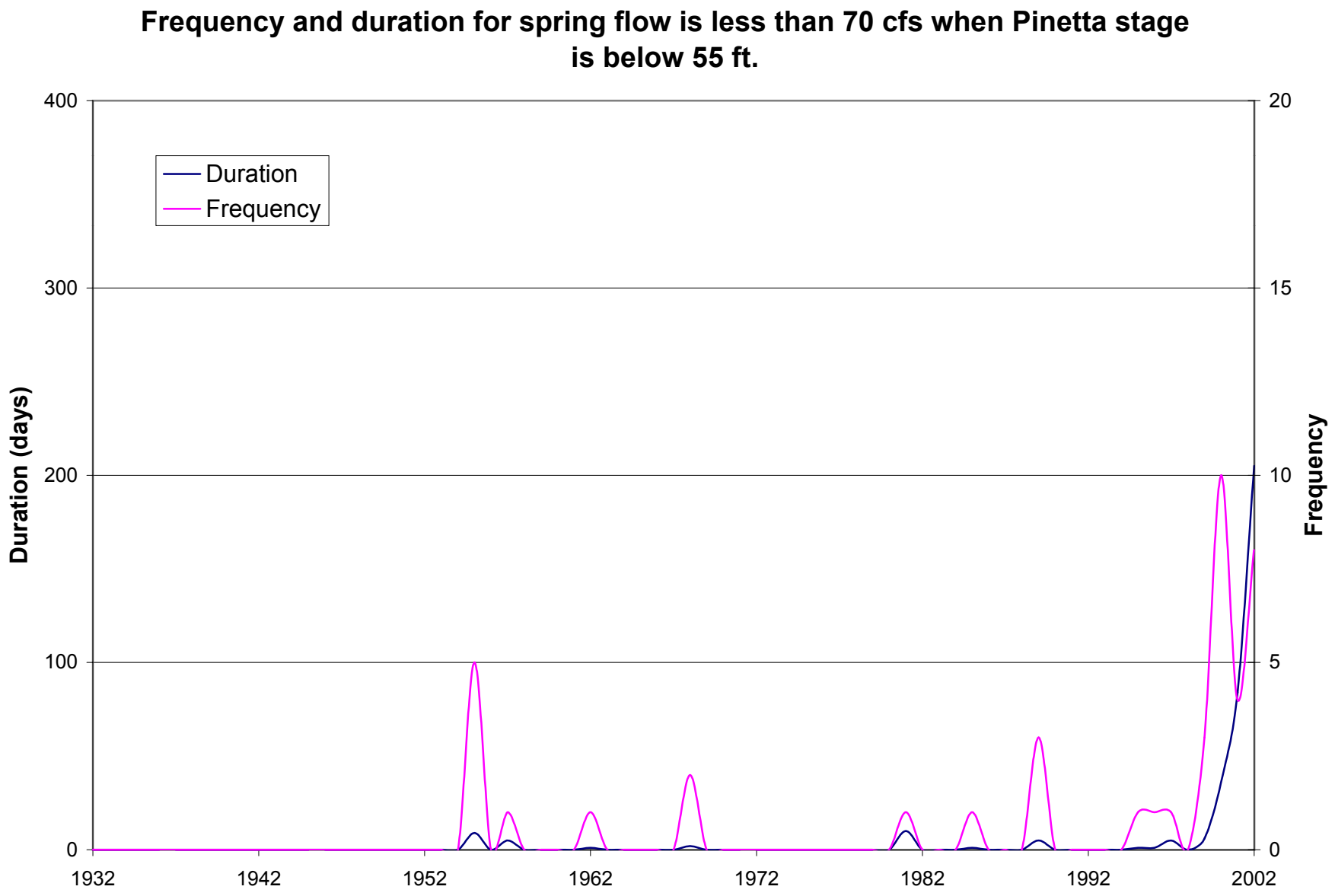

Frequency and duration for spring flow is less than 70 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-1

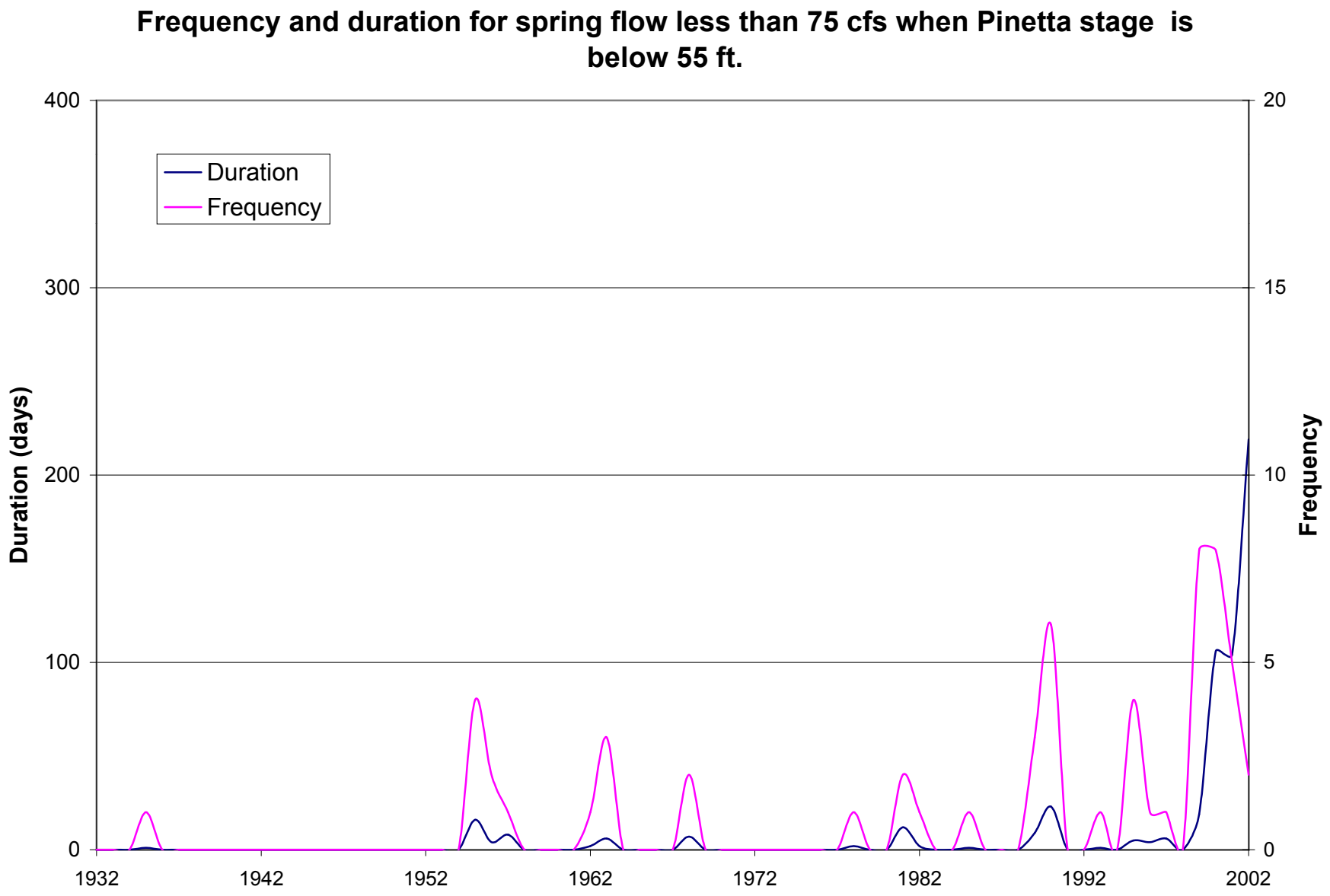

Frequency and duration for spring flow less than 75 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-2

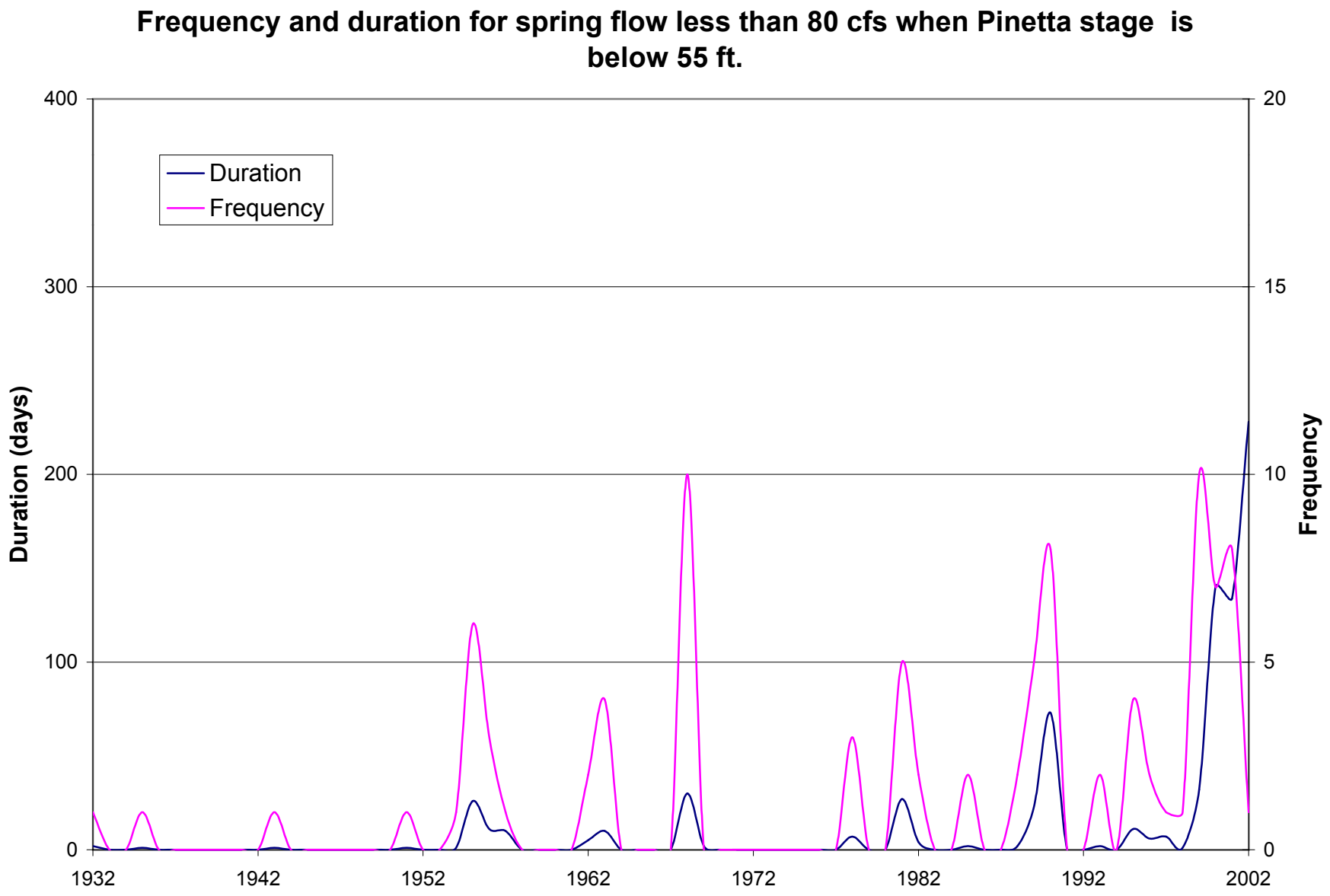

Frequency and duration for spring flow less than 80 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-3

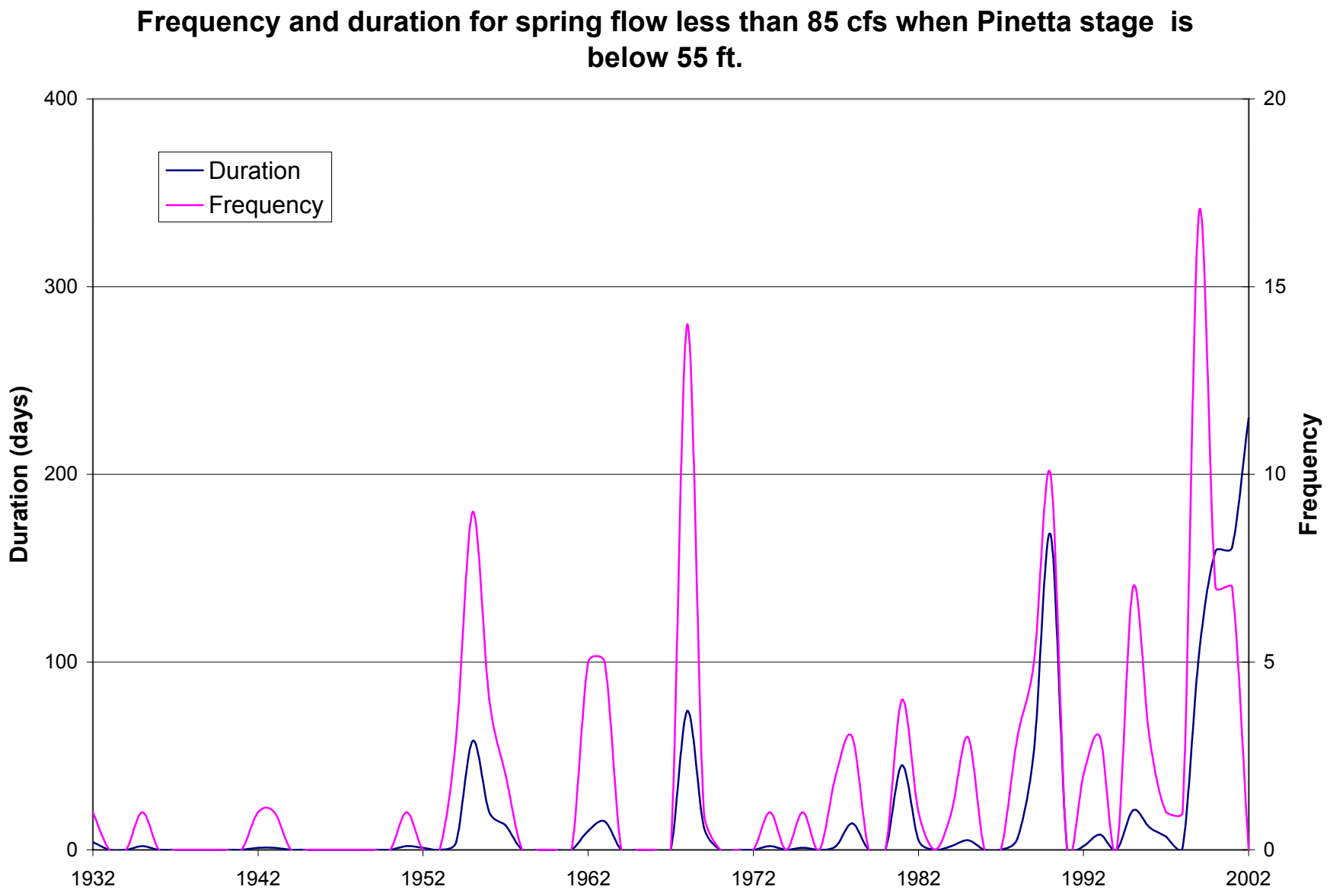

Frequency and duration for spring flow less than 85 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-4

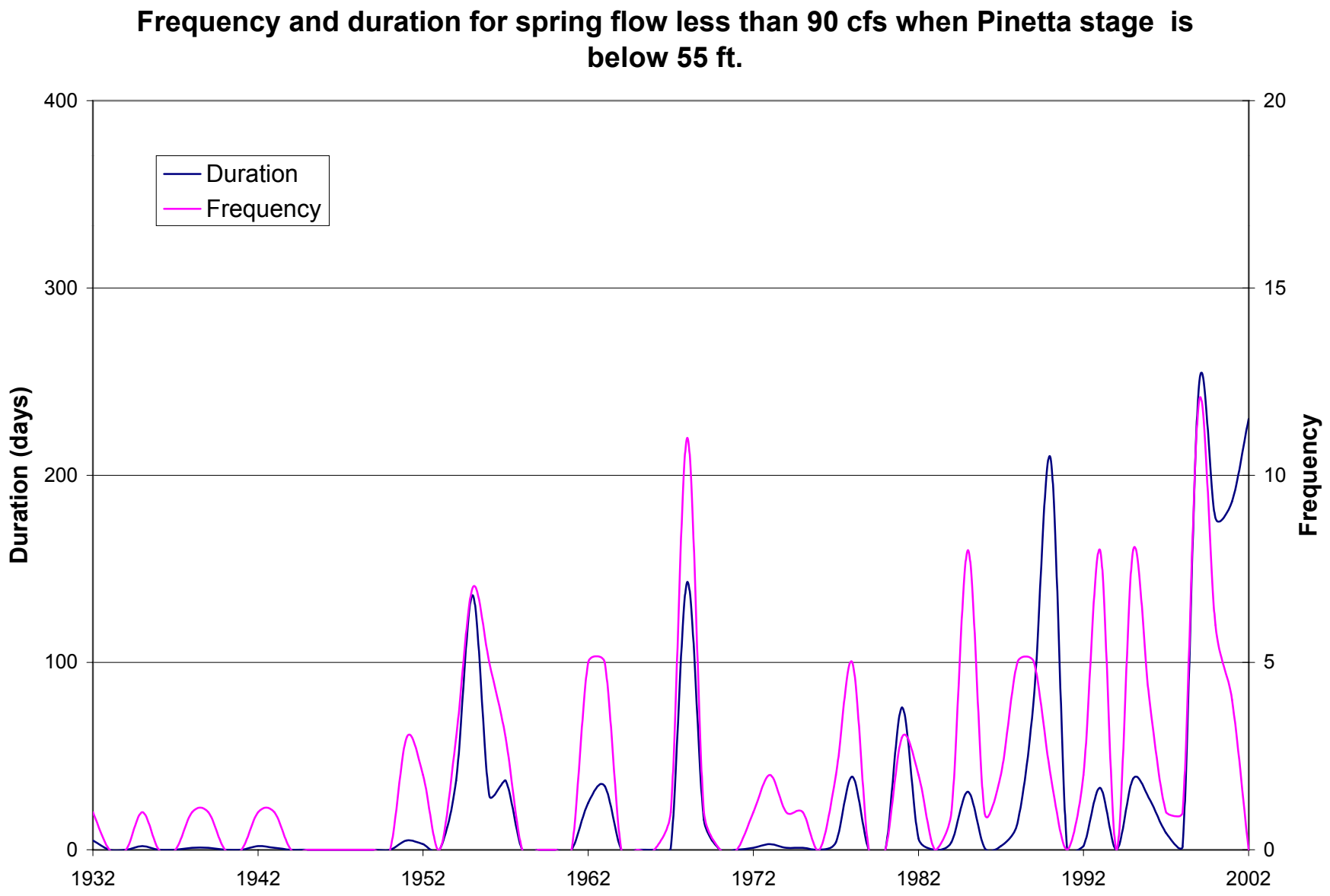

Frequency and duration for spring flow less than 90 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-5

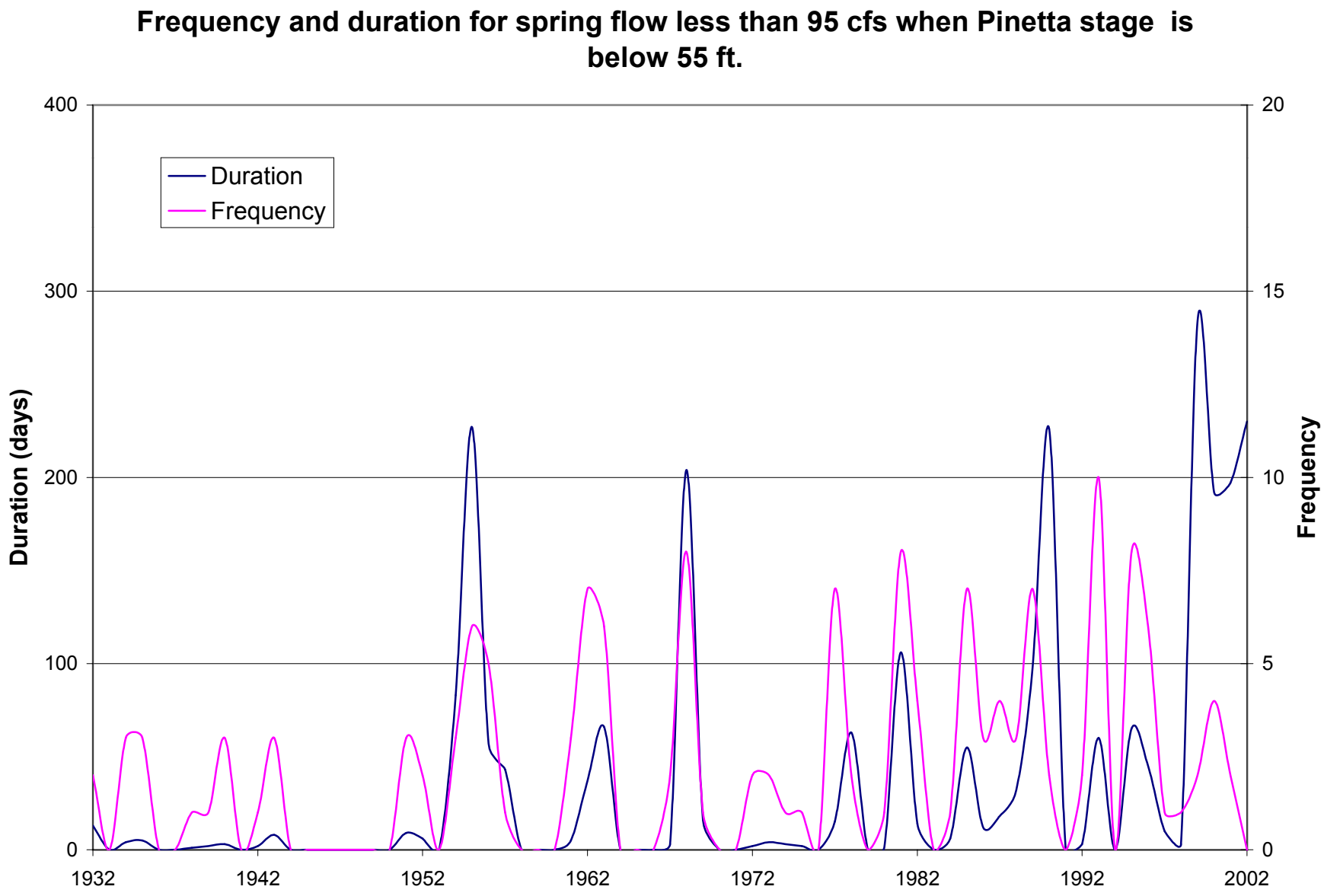

Frequency and duration for spring flow less than 95 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-6

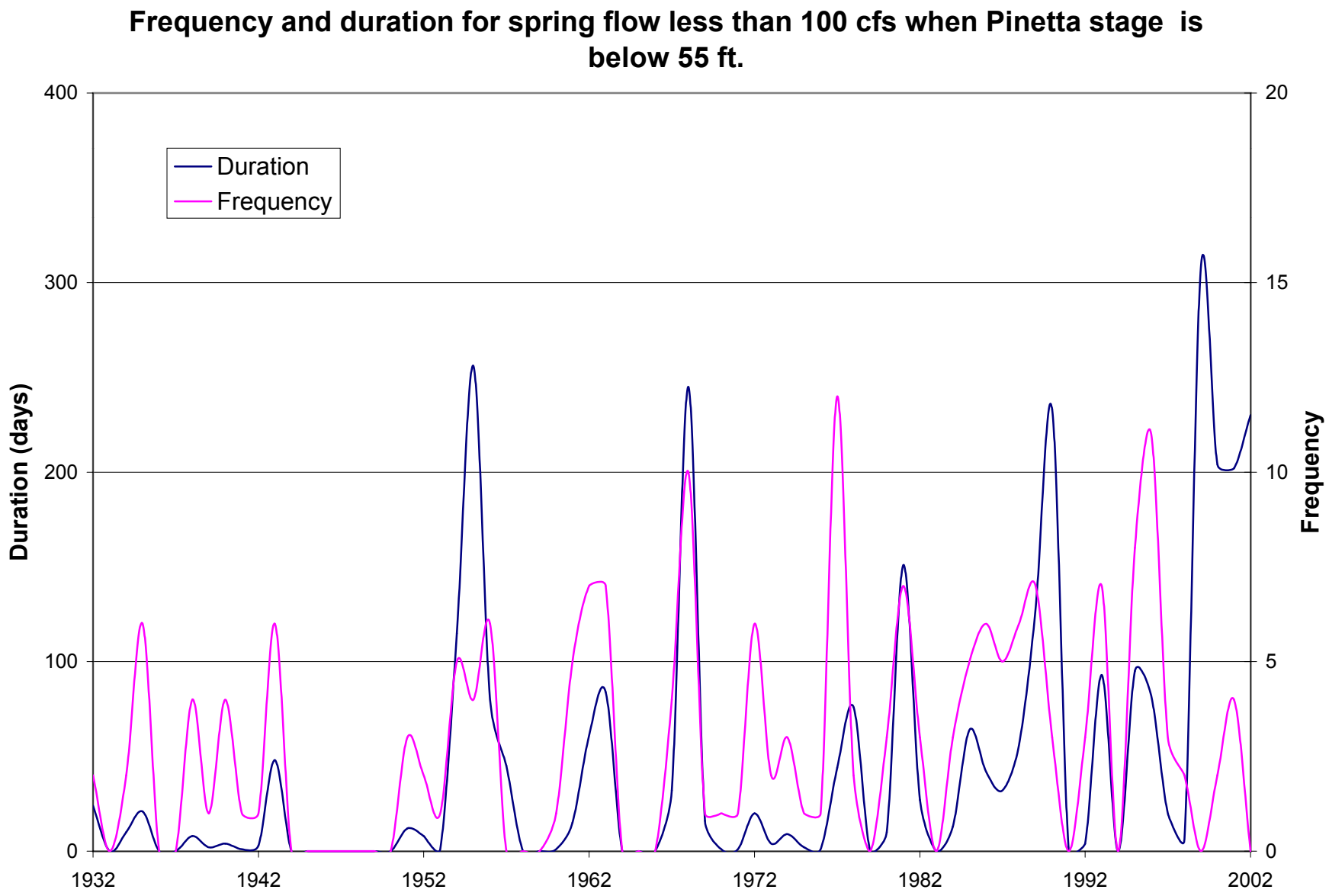

Frequency and duration for spring flow less than 100 cfs when Pinetta stage is below 55 ft.
Duration
Frequency
Duration (days)
Frequency
400
300
200
100
0
20
15
10
5
0
1932
1942
1952
1962
1972
1982
1992
2002

Figure 5-7

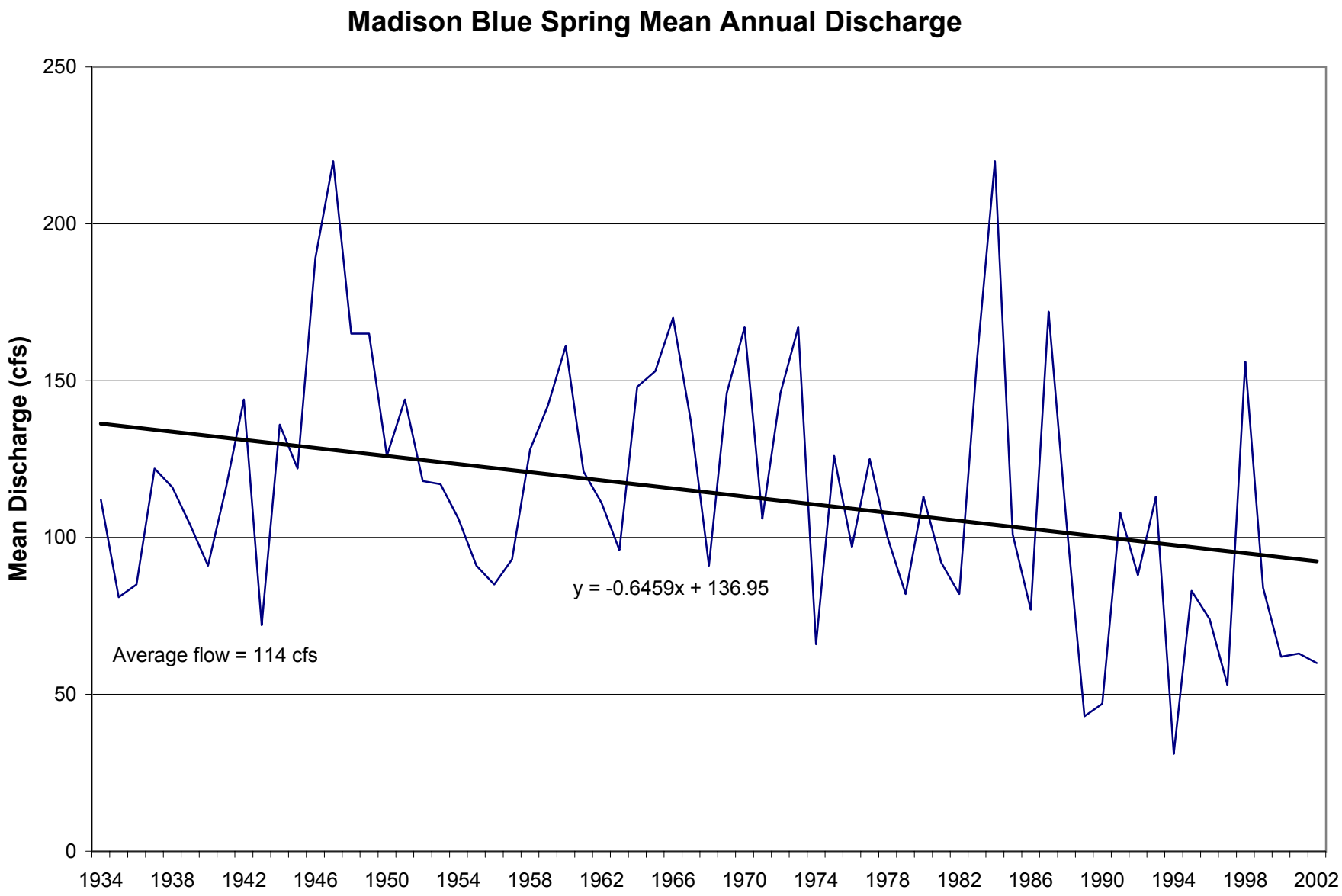

Madison Blue Spring Mean Annual Discharge
Mean Discharge (cfs)
250
200
150
100
50
0
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
y = -0.6459x + 136.95
Average flow = 114 cfs

Figure 5-8

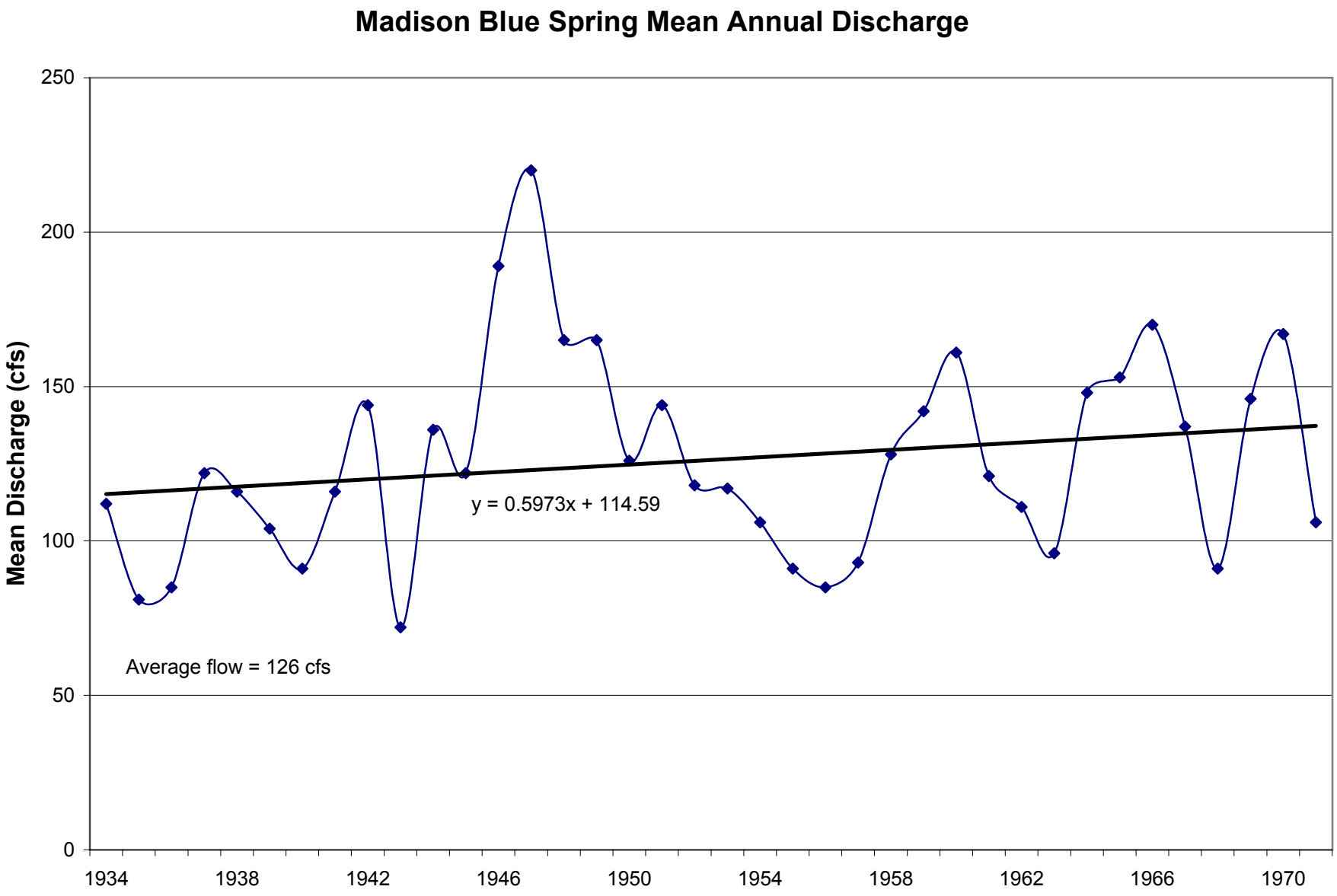

Madison Blue Spring Mean Annual Discharge
Mean Discharge (cfs)
250
200
150
100
50
0
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
y = 0.5973x + 114.59
Average flow = 126 cfs

Figure 5-9

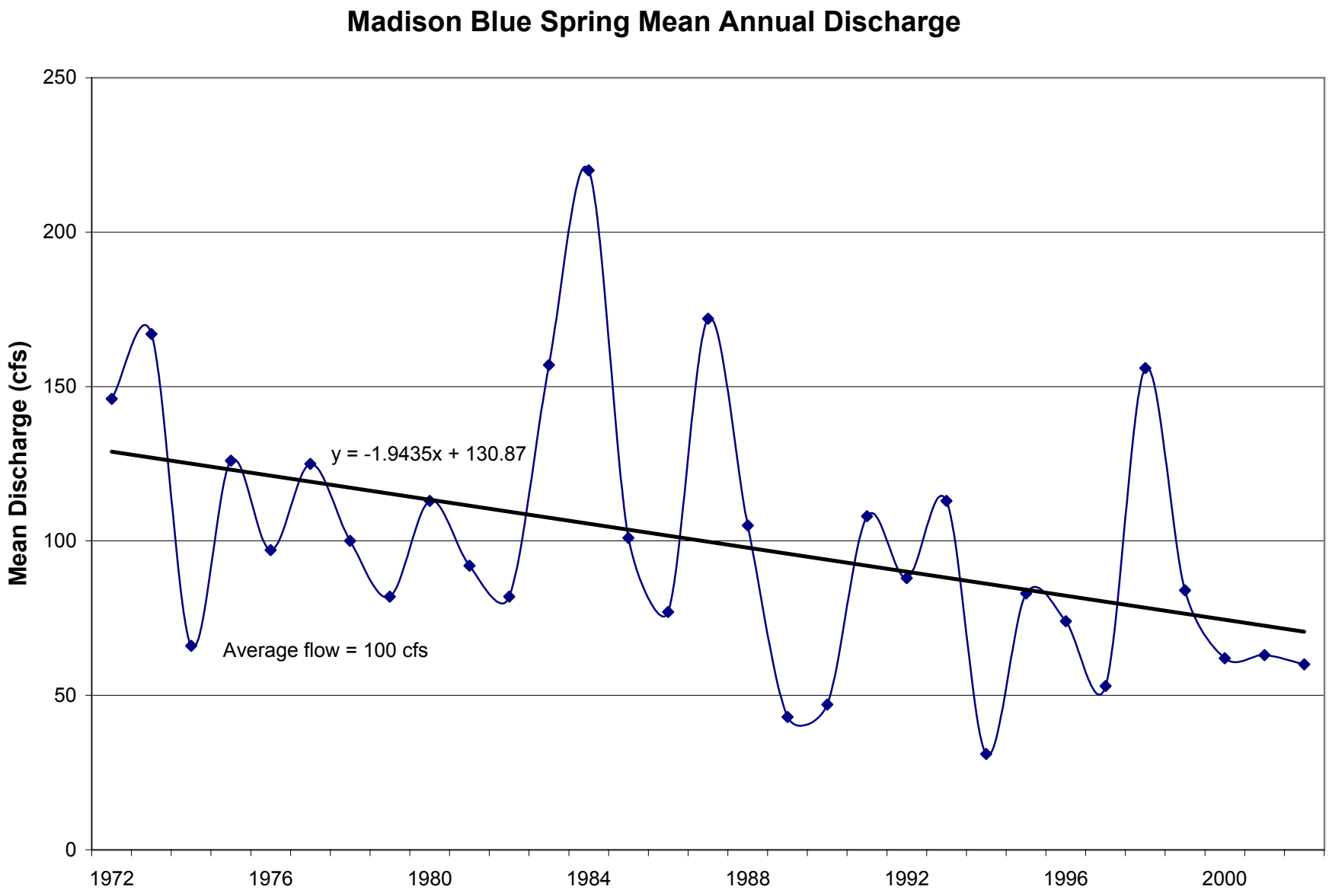

Madison Blue Spring Mean Annual Discharge
Mean Discharge (cfs)
250
200
150
100
50
0
1972
1976
1980
1984
1988
1992
1996
2000
y = -1.9435x + 130.87
Average flow = 100 cfs

Figure 5-10

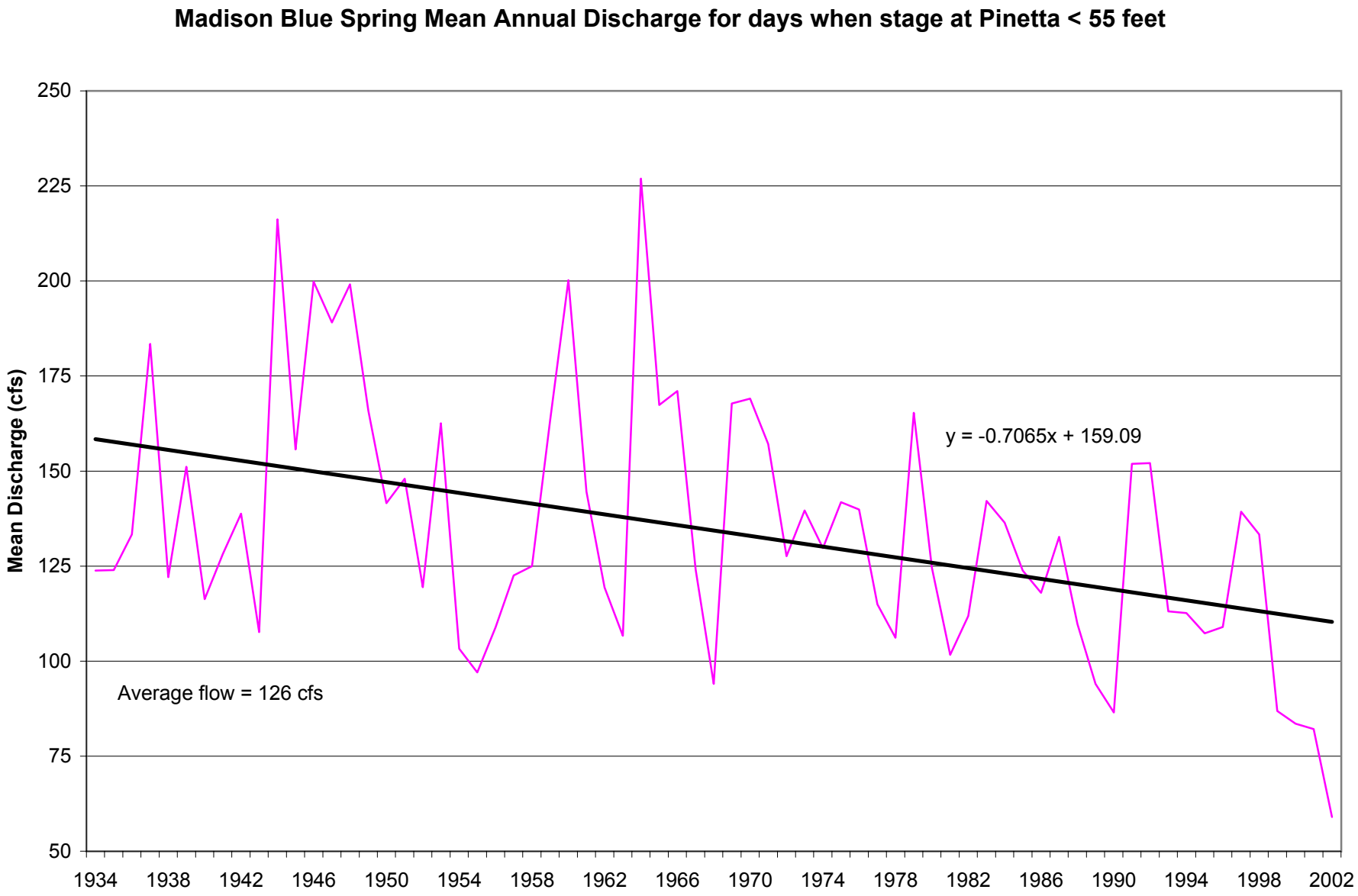

Madison Blue Spring Mean Annual Discharge for days when stage at Pinetta < 55 feet
Mean Discharge (cfs)
250
225
200
175
150
125
100
75
50
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
y = -0.7065x + 159.09
Average flow = 126 cfs

Figure 5-11

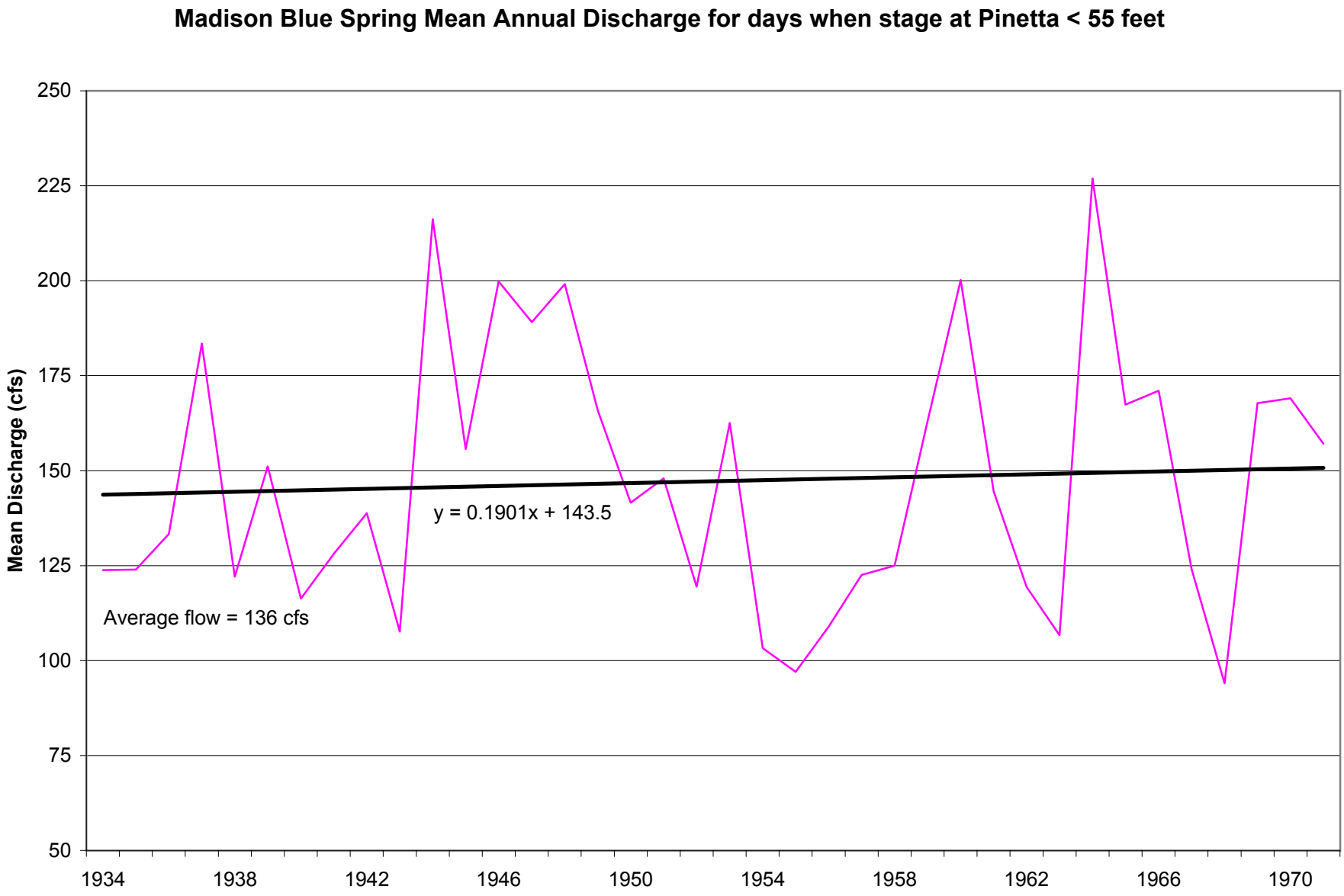

Madison Blue Spring Mean Annual Discharge for days when stage at Pinetta < 55 feet
Mean Discharge (cfs)
250
225
200
175
150
125
100
75
50
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
y = 0.1901x + 143.5
Average flow = 136 cfs

Figure 5-12

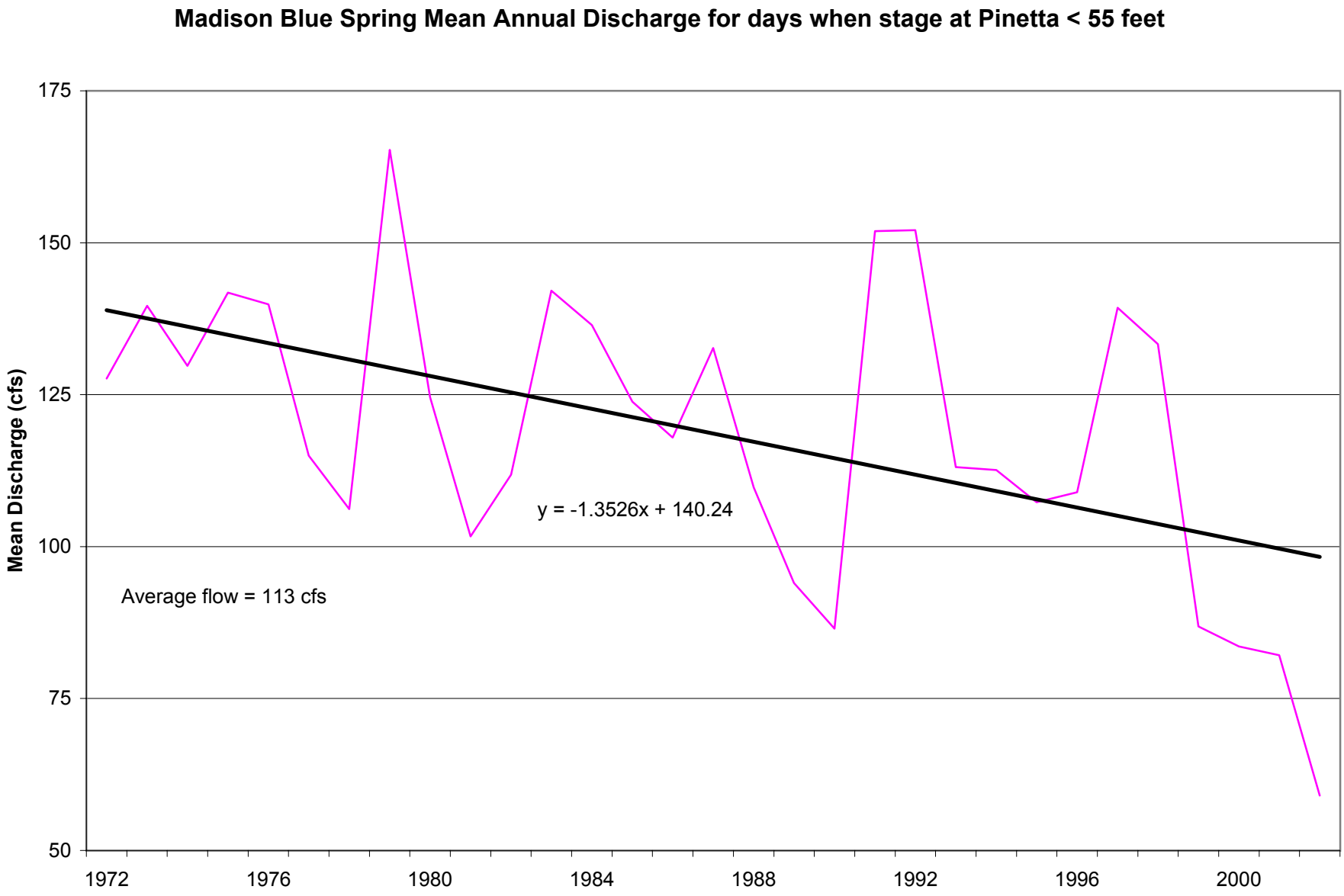

Madison Blue Spring Mean Annual Discharge for days when stage at Pinetta < 55 feet
Mean Discharge (cfs)
175
150
125
100
75
50
1972
1976
1980
1984
1988
1992
1996
2000
y = -1.3526x + 140.24
Average flow = 113 cfs

Figure 5-13

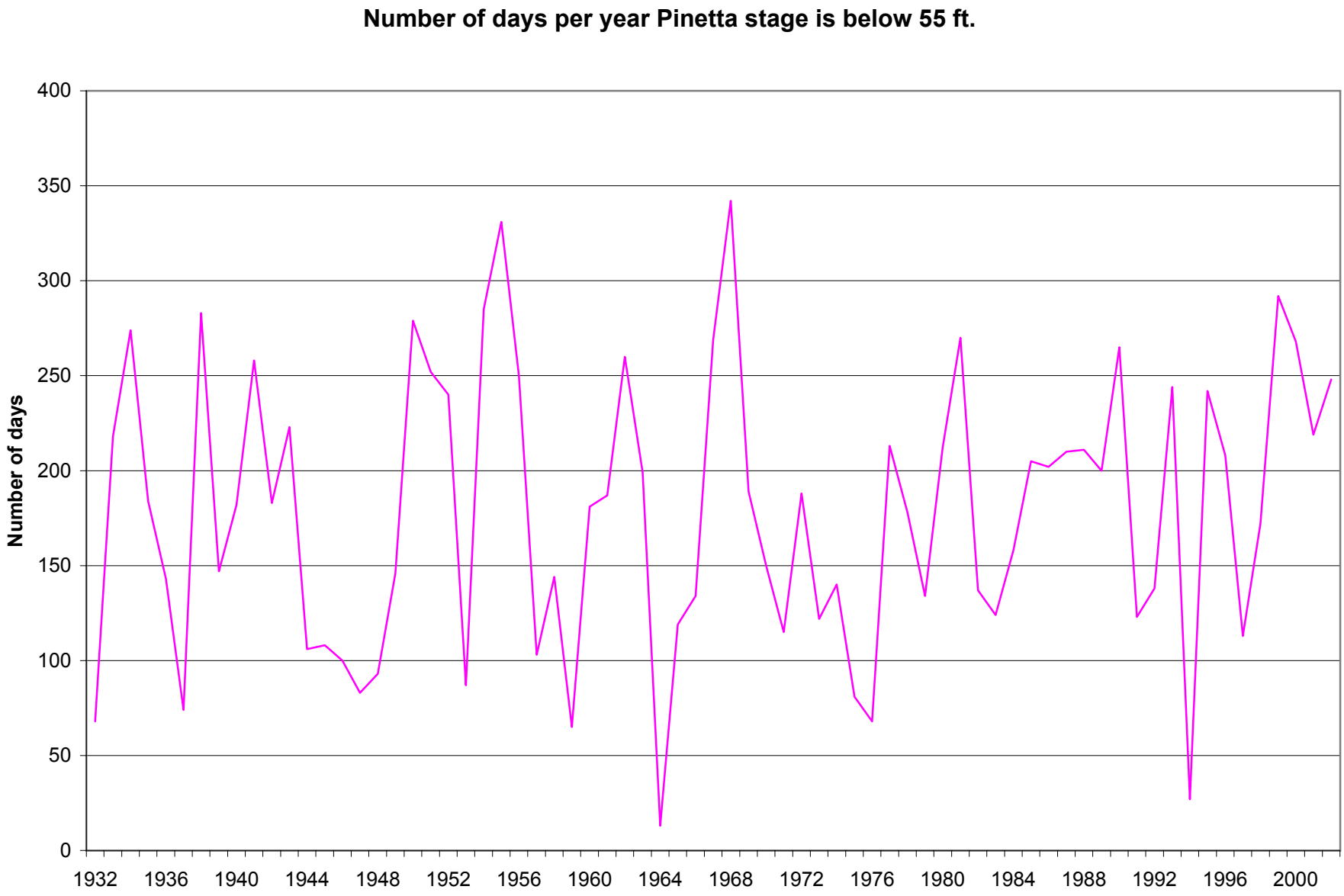

Number of days per year Pinetta stage is below 55 ft.
Number of days
400
350
300
250
200
150
100
50
0
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000

Figure 5-14

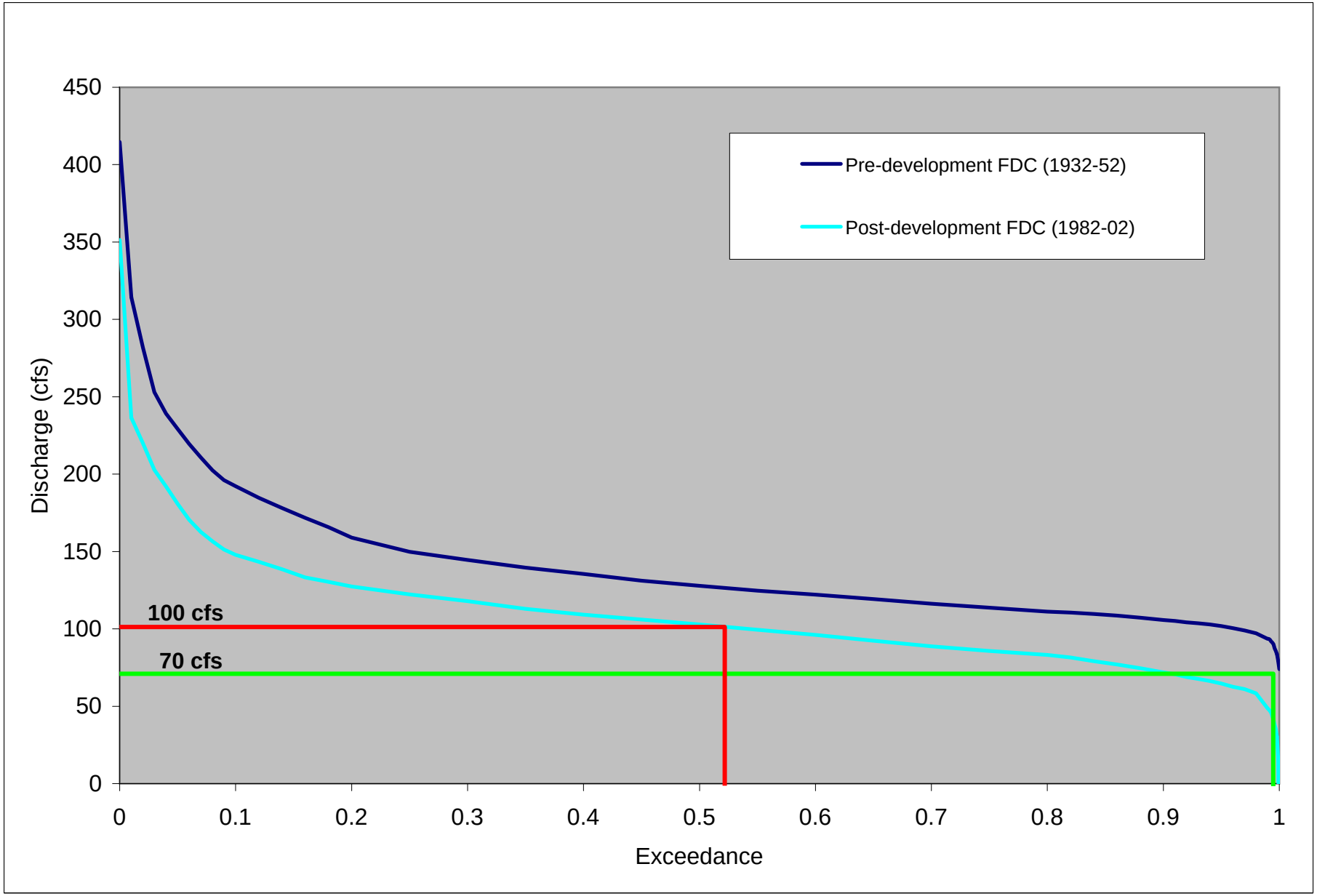


Figure 5-15 - Flow Duration Curve for MBS with Proposed MFL @ 70 cfs

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