SPECIAL PUBLICATION SJ2007-SP19

HUMAN USE AND ECOLOGICAL EVALUATION OF THE RECOMMENDED MINIMUM FLOW REGIME FOR BLUE SPRING AND BLUE SPRING RUN, VOLUSIA COUNTY, FLORIDA

Final Report

Human Use and Ecological Evaluation of the Recommended Minimum Flow Regime for Blue Spring and Blue Spring Run, Volusia County, Florida

Prepared for

St. Johns River Water Management District

September 2006

Wetland Solutions, Inc.

Executive Summary

The St. Johns River Water Management District (District) establishes Minimum Flows and Levels (MFLs) for lakes, wetlands, streams, and springs. The minimum flow for a surface water course defines the limit at which further water withdrawals would be significantly harmful to the water resources or ecology of the area. MFLs shall be determined using the best available information and shall also consider nonconsumptive uses of water (Section 373.042, Florida Statutes (*FS*)).

The District is in the process of establishing a minimum flow regime (MFR) for Blue Spring located in Volusia County, Florida. Blue Spring and Blue Spring Run are located in Blue Spring State Park which encompasses 2,483 acres (1,002 hectares) of land with a variety of habitats. The estimated long term average discharge of Blue Spring is 157 cubic feet per second (cfs) or 101 million gallons per day (mgd) (Rouhani *et al.* 2006).

Blue Spring and Blue Spring Run are internationally famous as a winter warm-water refuge for the endangered West Indian manatee (*Trichechus manatus latirostris*), a large aquatic mammal that requires winter warm-water refuges to survive near the northern extreme of its range. Blue Spring is the only naturally occurring large winter warm-water refuge for manatees on the eastern coast of Florida and specifically for the St. Johns River population. Manatee use of Blue Spring and Blue Spring Run as a warm-water refuge has increased since 1977 when the spring and spring run were designated as critical habitat for the Florida Manatee under the federal Endangered Species Act (ESA) (Rouhani *et al.* 2006). Blue Spring Run also provides the only known habitat for two endemic snail species (FDEP 1999).

Due to the unique relationship between Blue Spring and Blue Spring Run and the survival and expansion of the manatee population in Florida, a minimum flow regime that would be sufficient to protect manatees' use of Blue Spring as a winter warm-water refuge under catastrophic conditions was developed, hereafter referred to as the "Blue Spring MFR" (Rouhani *et al.* 2006). Additionally, Section 62-40.473, *Florida Administrative Code* (*FAC*), requires the consideration of 10 human use and ecological Water Resource Values (WRVs) when establishing MFLs including:

- Recreation in and on the water (62-40.473 (1) (a), *FAC*)

- Fish and wildlife habitats and the passage of fish (62-40.473 (1) (b), *FAC*)
- Estuarine resources (62-40.473 (1) (c), *FAC*)
- Transfer of detrital material (62-40.473 (1) (d), FAC)
- Maintenance of freshwater storage and supply (62-40.473 (1) (e), *FAC*)
- Aesthetic and scenic attributes (62-40.473 (1) (f), *FAC*)
- Filtration and absorption of nutrients and other pollutants (62-40.473 (1) (g), *FAC*)
- Sediment loads (62-40.473 (1) (h), *FAC*)
- Water quality (62-40.473 (1) (i), *FAC*)
- Navigation (62-40.473 (1) (j), *FAC*)

The purpose of this report is to present an evaluation, within the constraints of existing data, concerning whether consideration of any of these WRVs warrants adoption of a minimum flow regime more stringent than that developed to protect manatees' use of Blue Spring as a winter warm-water refuge under catastrophic conditions. In some cases existing data are inadequate or of the wrong type to be used for full quantitative evaluation of these WRVs. In those cases, this report provides suggestions for additional data collection. A total of 46 individual, quantitative metrics are proposed for the evaluation of these WRVs. This report also provides example methodologies for data analysis to allow detection of ecological changes compared to baseline conditions.

Rouhani *et al.* (2006) have recommended a Blue Spring MFR based on the criterion of providing winter manatee habitat during catastrophic cold-weather conditions for an expanding population of manatees utilizing Blue Spring. A recommended flow regime was developed that defines the minimum long term mean flow for five-year increments in a phased program of increasing minimum long term mean flows. The first increment would allow a temporary reduction in the long term mean flow from 157 cfs to 133 cfs for the period of time from the date of rule adoption to March 31, 2009. This 15% decrease in flow represents the maximum allowable reduction in the Blue Spring long term mean flow. This minimum long term mean flow would be raised during each of five subsequent five-year intervals to 137, 142, 148, and finally 157 cfs (no allowable long term mean flow reduction) by March 2024.

Based on this review of existing and new information, it was concluded that almost all of these ecological and human use WRVs have the potential to be affected by changes in spring flow. Some metrics are likely to decrease, others to increase, and some to remain unchanged in response to flows less than current levels.

However, it was also concluded that based on the best available information and best professional judgment that all of these values would be protected by the Blue Spring MFR developed to protect manatees' use of Blue Spring as a winter warm-water refuge. This conclusion is based on the observed range of variability of much of the existing environmental data collected from Blue Spring Run (coefficient of variation for water quality parameters from <1 to >200%) compared to the relatively smaller temporary change in flows allowed by the Blue Spring MFR (maximum long term mean flow reduction of 15%).

This report recommends that a database of WRV metrics be assembled through continuing and expanded monitoring at Blue Spring and Blue Spring Run for the purpose of future re-evaluation of minimum flows. New monitoring efforts are recommended only for the purpose of defining existing data ranges. New long-term monitoring programs may be recommended after preliminary data are evaluated and the relevance of particular parameters to the protection of existing WRVs is verified.

Table of Contents

Section Page

List of Figures

List of Tables

List of Appendices

1.0 Introduction

1.1 Background

Blue Spring and Blue Spring Run in Volusia County, Florida are internationally famous as a winter warm-water refuge for the endangered West Indian manatee (*Trichechus manatus latirostris*), a large aquatic mammal that requires warm-water winter refuges to survive near the northern extreme of its range. Blue Spring is the only naturally occurring large manatee winter warm-water refuge on Florida's east coast and specifically for the St. Johns River manatee population. Manatee use of Blue Spring Run as a winter warm-water refuge has increased since 1978, when routine manatee counts were begun in the spring run (Rouhani *et al.* 2006). In addition to their importance to manatee populations, Blue Spring and Blue Spring Run provide numerous other environmental and societal functions including habitat for numerous other plant and animal species, water quality maintenance, and human recreation in Blue Spring State Park. Protection of these Water Resource Values (WRVs) from excessive reductions in water flows and levels is an important goal for the St. Johns River Water Management District (District).

The District is currently implementing the Minimum Flows and Levels (MFLs) program mandated by Florida law (Section 373.042, *Florida Statutes* [*FS*]). The MFLs Program establishes MFLs for surface water and ground water systems. Under this statute, the minimum flow for a surface water course shall be the limit at which further withdrawals would be significantly harmful to the water resources or the ecology of the area. Once an MFL is established, an applicant for a consumptive use permit (CUP) or environmental resource permit (ERP), pursuant to Chapters 40C-2, 40C-20, 40C-4, or 40C-40, F.A.C., would be required to provide reasonable assurance that the minimum flow would not be violated by a proposed water withdrawal or the construction or operation of a proposed surface water management system.

Due to the unique relationship between Blue Spring and Blue Spring Run and the survival and expansion of the manatee population in Florida, a minimum flow regime (MFR) that would be sufficient to protect manatees' use of Blue Spring as a winter warm-water refuge under catastrophic conditions was developed, hereafter referred to as the "Blue Spring MFR" (Rouhani *et al.* 2006). Additionally, Section 62-40.473, *Florida Administrative Code* (*FAC*), requires the consideration of 10 human use and ecological Water Resource Values (WRVs) when establishing MFLs including:

- Recreation in and on the water (62-40.473 (1) (a), *FAC*)
- Fish and wildlife habitats and the passage of fish (62-40.473 (1) (b), *FAC*)
- Estuarine resources (62-40.473 (1) (c), *FAC*)
- Transfer of detrital material (62-40.473 (1) (d), *FAC*)
- Maintenance of freshwater storage and supply (62-40.473 (1) (e), *FAC*)
- Aesthetic and scenic attributes (62-40.473 (1) (f), *FAC*)
- Filtration and absorption of nutrients and other pollutants (62-40.473 (1) (g), *FAC*)
- Sediment loads (62-40.473 (1) (h), *FAC*)
- Water quality (62-40.473 (1) (i), *FAC*)
- Navigation (62-40.473 (1) (j), *FAC*)

Wetland Solutions, Inc. was contracted by the District to assess whether the recommended Blue Spring MFR, determined to be sufficient to protect manatees' use of Blue Spring as a winter warm-water refuge under catastrophic conditions, will protect these WRVs.

1.2 District's Recommended Blue Spring MFR

Rouhani *et al.* (2006) have recommended a Blue Spring MFR based on the criterion of providing winter manatee habitat during critical cold-weather periods for an expanding population of manatees utilizing Blue Spring. This evaluation determined that under the current (linear) rate of expansion of manatee use, a minimum long term mean flow of 133 cfs for Blue Spring could be permitted until March 31, 2009. This represents approximately a 15 % reduction in the long term mean spring flow. This permitted minimum long term mean flow would be raised during each of five subsequent five-year intervals to 137, 142, 148, and finally 157 cfs (no allowable long term mean flow reduction). Rouhani *et al.* 2006 recommended that data collection and analysis continue, and that these recommended minimum flows be reassessed at least once every five years.

1.3 Water Resource Values Considered and Metrics

While the recommended Blue Spring MFR is likely to be conservative (15% maximum allowed temporary long term mean flow reduction and no long term mean flow reduction ultimately) it is important to evaluate the possible effects of this temporary allowable long term mean flow reduction on the 10 specific WRVs listed in Section 62-40.473, *FAC*. A field examination and literature review were conducted to ascertain which of the 10 WRVs are applicable to Blue Spring. Metrics for quantification of each of the applicable WRVs are proposed and methods are described for their evaluation. These quantitative metrics are based, where possible, on widely used standard methods. Only existing data collected for other purposes were available for this evaluation.

2.0 Description of the Study Area, Existing Flows and Levels, and Conceptual Ecosystem Model

2.1 Site Location

Blue Spring State Park is located in Volusia County, Florida, 2 miles west of Orange City and adjacent to the St. Johns River (**Figure 2-1**). Blue Spring State Park encompasses 2,483 acres (1,002 hectares) of land with a variety of habitats (FDEP, 1999), including Blue Spring and Blue Spring Run (**Figure 2-2**). The spring and run have an estimated area of 4.1 acres (1.7 hectares) and a length from the upper edge of the spring basin to the point of confluence with the St. Johns River of about 2,336 feet (712 m). Blue Spring and Blue Spring Run are classified as Class III waters by the State of Florida, indicating the following designated uses: "recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife." Blue Spring and Blue Spring Run are also designated as "Outstanding Florida Waters" since they are located within a state park.

Water quality in Blue Spring and Blue Spring Run is characteristic of the Florida Aquifer, with high clarity, high dissolved solids, and generally low pollutant concentrations. The mean temperature of the spring is 23.0 ^{o}C and the recorded temperature range is only from 21.5 to 24.5 ^{o}C at the downstream water quality station (Station 4 in **Figure 2-2**). Dissolved oxygen is typically quite low in Blue Spring (average 0.6 mg/L) and increases downstream in the run to an average of 1.4 mg/L. Specific conductance averages 1,474 µmhos/cm at the downstream station in the spring run. Color in the spring run is very low and averages 3.2 platinum cobalt units (PCU).

Where Blue Spring Run mixes with the St. Johns River, water clarity drops due to relatively high dissolved color in the river. Temperature and salinity gradients are likely to occur at the confluence of the spring run and the river. Mean temperature in the St. Johns River near Deland is more variable than in the spring run, with an average of 23.8 ^{o}C and a recorded range from 11.6 to 31.2 ^{o}C. Average dissolved oxygen levels are higher in the St. Johns River (5.7 mg/L) than in the spring run. Specific conductance is typically lower in the St. Johns River, with an average of 950 µmhos/cm at this station. Average color in the St. Johns River at Deland is 133 PCU with a range from 95 to 500 PCU.

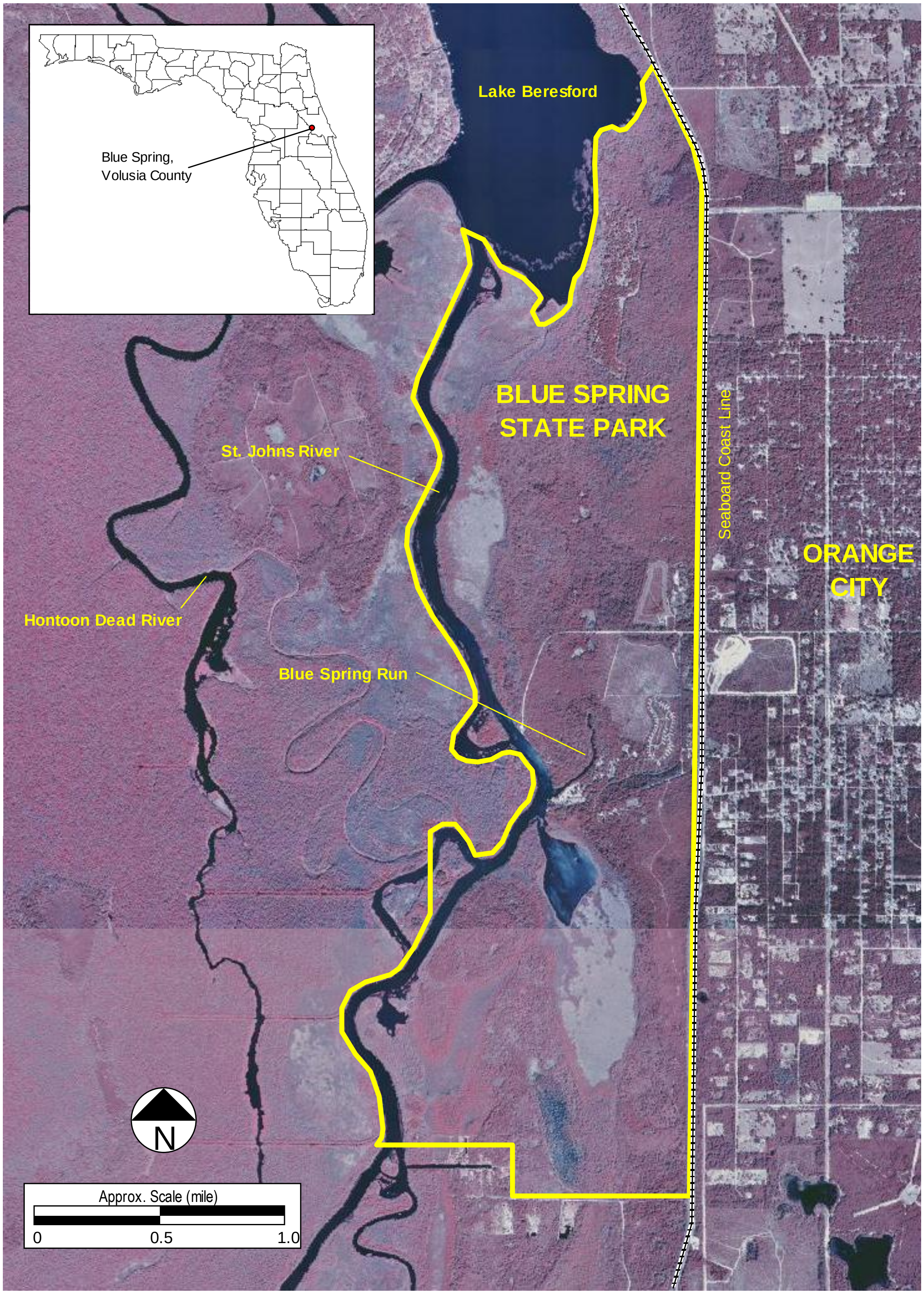


FIGURE 2-1
Location Map of Blue Spring Run and Blue Spring State Park, Volusia County (USGS aerial photo)

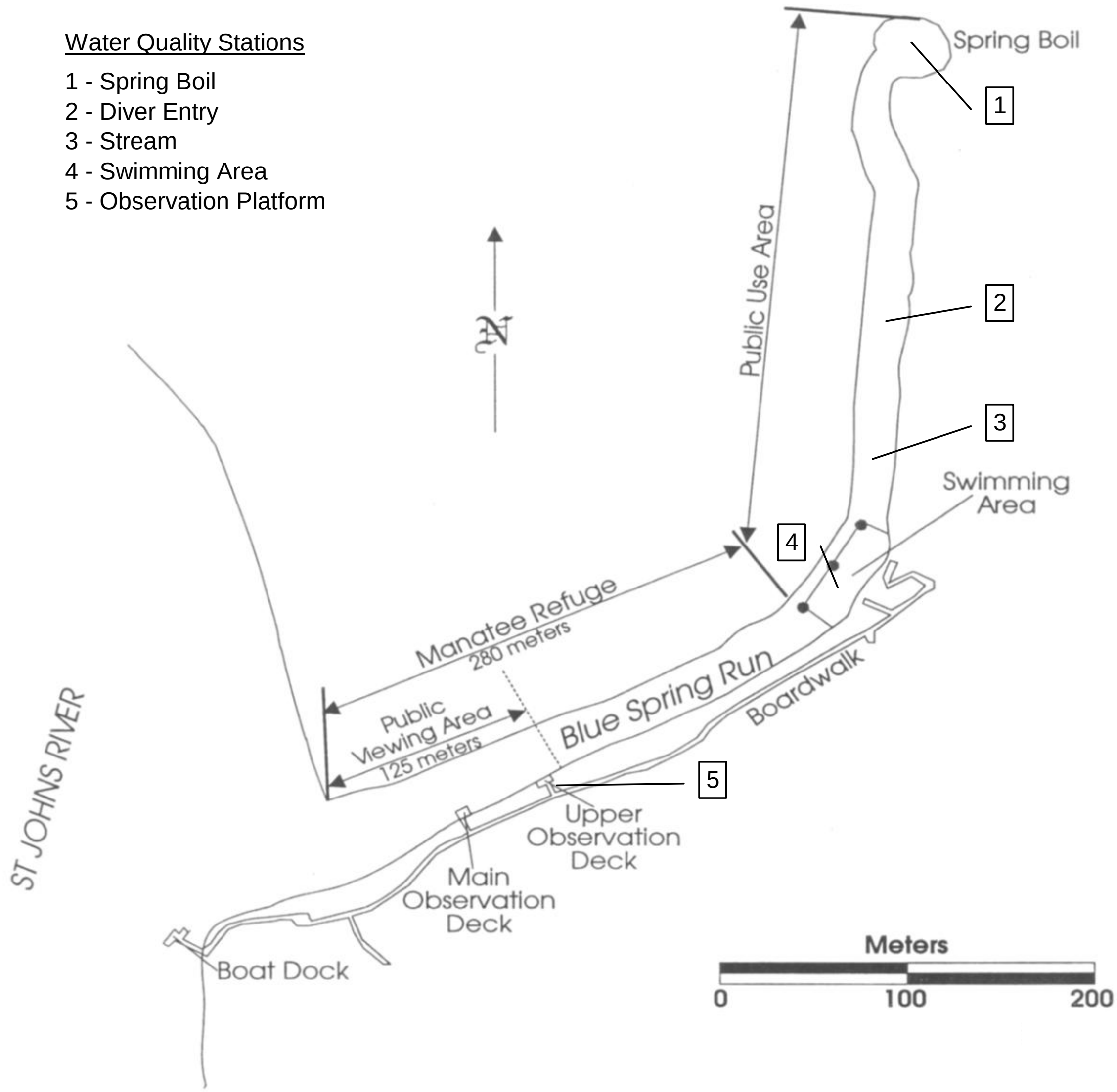


FIGURE 2-2
Map of Blue Spring Run, Located in Blue Spring State Park, Volusia County (base map from Sucsy, 2002)

Detailed water quality conditions in Blue Spring and Blue Spring Run are described below in Section 3.11.3 while water quality conditions in the adjacent St. Johns River are described in detail by ECT (2002).

2.2 Flow and Level Data

Flow in Blue Spring and Blue Spring Run is largely controlled by the difference in stage between the Floridan aquifer and the level of water in the St. Johns River (Rouhani *et al.* 2006). Water levels in Blue Spring Run are primarily controlled by the level of water in the St. Johns River and not by the spring discharge rate (Sucsy 2005).

Flow and water level data for Blue Spring Run are summarized in **Figure 2-3a** for the period 1932 to 2006. These data are based on discrete water level records and a stage/discharge relationship for the spring run. The long term mean flow over the period-of-record evaluated for this report was 384,100 m^3/d (157 cfs). Minimum and maximum recorded flows were 154,100 and 533,400 m^3/d (63 and 218 cfs), respectively. Average stage was 0.47 m above National Geodetic Vertical Datum 1929 (1.55 ft NGVD29). Minimum and maximum recorded stages were -0.12 and 1.99 m (-0.41 and 6.54 ft NGVD29), respectively.

Hydraulic residence time (HRT) and mean flow velocity for Blue Spring Run were estimated based on bathymetric data (PBS&J 1995) and a stage/volume relationship was developed by the District (Sucsy *et al.* 1998). Bottom elevations measured along the centerline of the spring run ranged from -0.49 to -3.44 m (-1.6 to -11.3 ft NGVD29). Channel widths at the water surface ranged from about 18.3 to 38.1 m (60 to 125 ft). The estimated water volume in Blue Spring Run at average water stage was 27,000 m^3 (952,000 cubic feet [cf]).

Figure 2-3b illustrates the time series estimates for HRT and velocity for Blue Spring Run. The estimated average HRT was 1.7 hrs with a range of 0.9 to 4.4 hrs. Estimated average velocity in the spring run was 0.12 m/s (0.41 ft/s) with a range from 0.045 to 0.22 m/s (0.15 to 0.72 ft/s).

Linear regression analysis showed no apparent relationship between water stage and spring discharge during this period (R^2 = 0.0002 in **Figure 2-4**). This analysis reconfirms

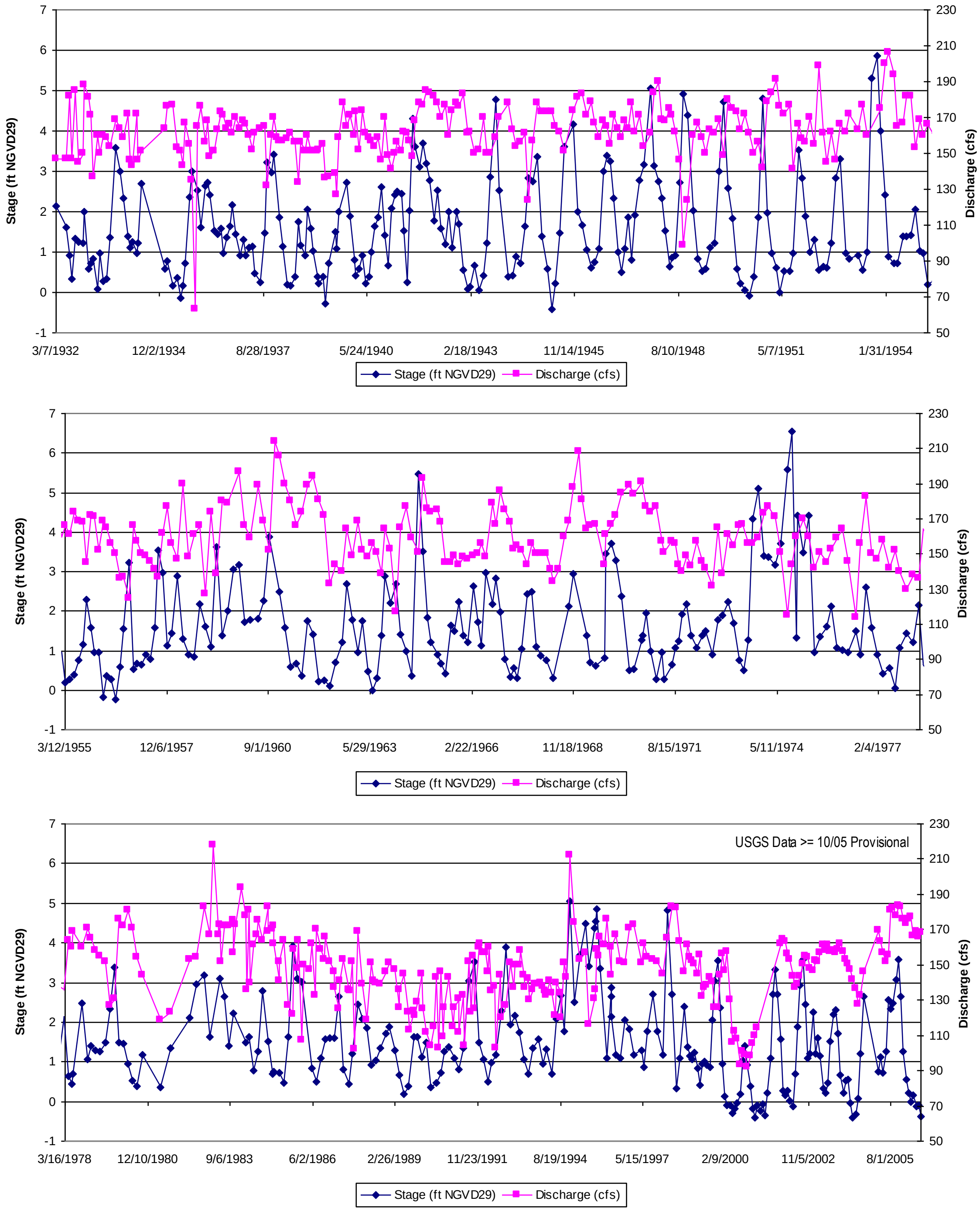


FIGURE 2-3a
Blue Spring Stage / Discharge Time Series Plots

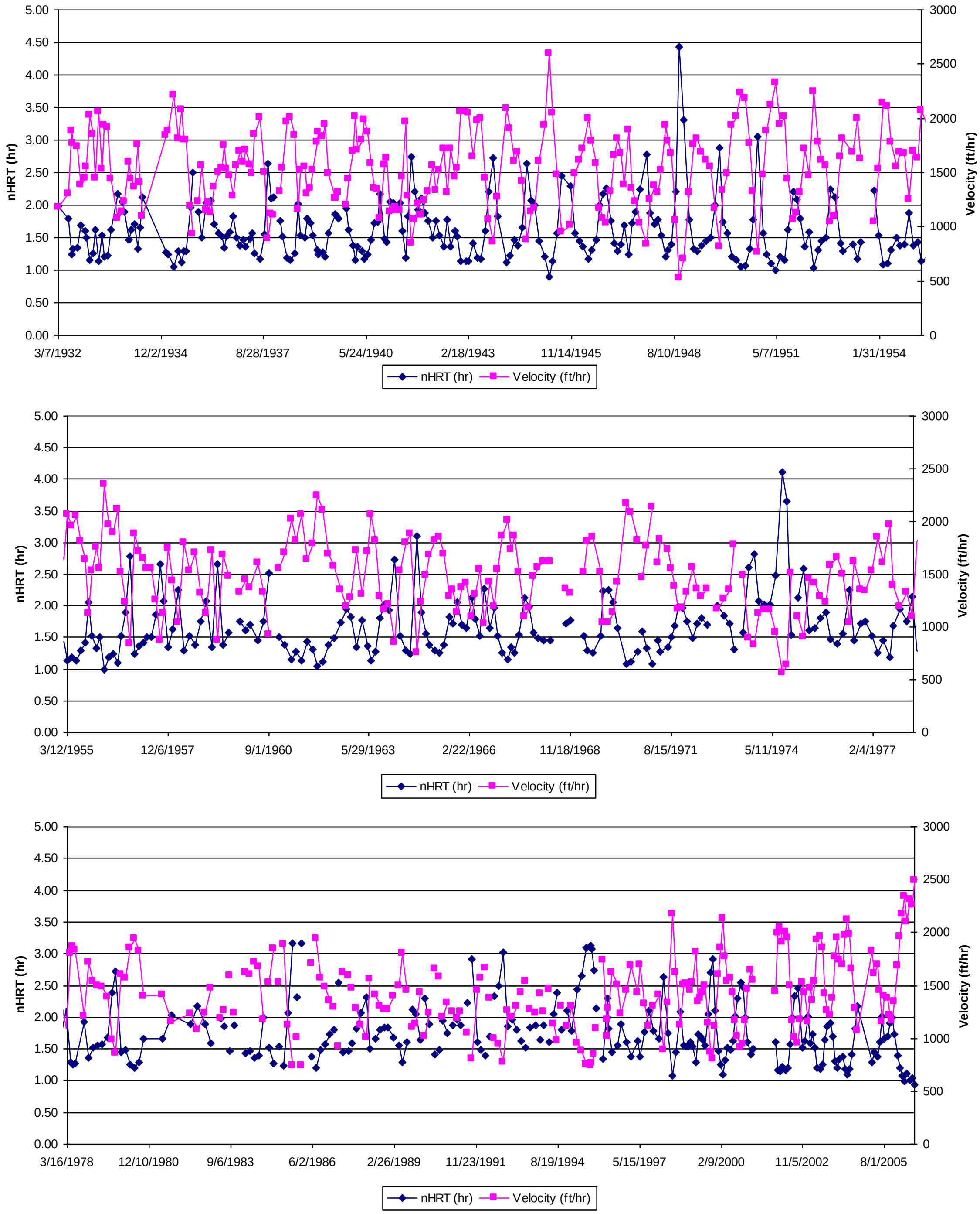


FIGURE 2-3b
Blue Spring Estimated Nominal Hydraulic Residence Time (nHRT) and Velocity Time Series Plots

the conclusion by Rouhani *et al.* (2006) and Sucsy (2005) that water stage in Blue Spring Run is not controlled by Blue Spring flow but rather by water levels in the contiguous reach of the St. Johns River.

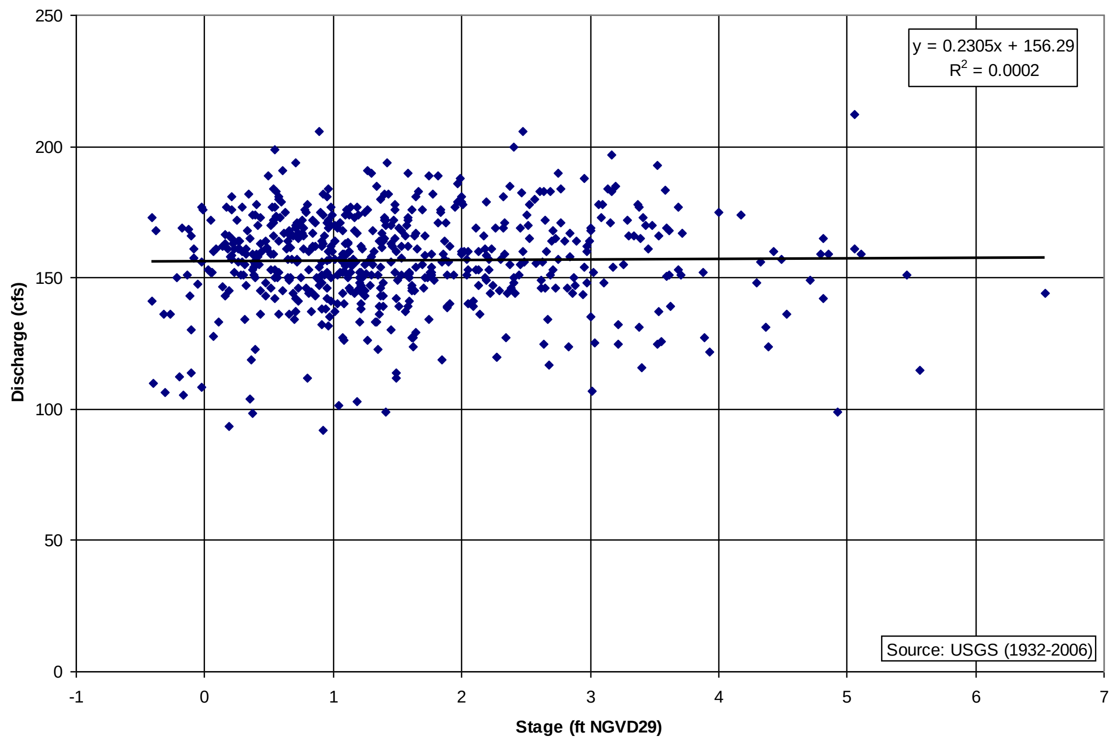


FIGURE 2-4
Blue Spring Discharge vs. Stage Relationship

2.3 Flow and Level under the Blue Spring MFR

Figure 2-5 presents the existing flow and stage data for Blue Spring and Blue Spring Run in the form of probability distributions. Use of this figure allows estimation of flow and stage at any probability based on the existing period-of-record (about 74 years). The recommended Blue Spring MFR (middle curve, Figure 2-5) is 25 cfs less than the existing flow (top curve, Figure 2-5). This is an assumed probability distribution of flows under the recommended Blue Spring MFR allowed through March 2009 and illustrates one possible distribution of future flows during the first phase of the proposed rule. This assumed distribution not only lowers the average flow by 25 cfs but also the minimum and maximum flows by the same amount (**Figure 2-5**).

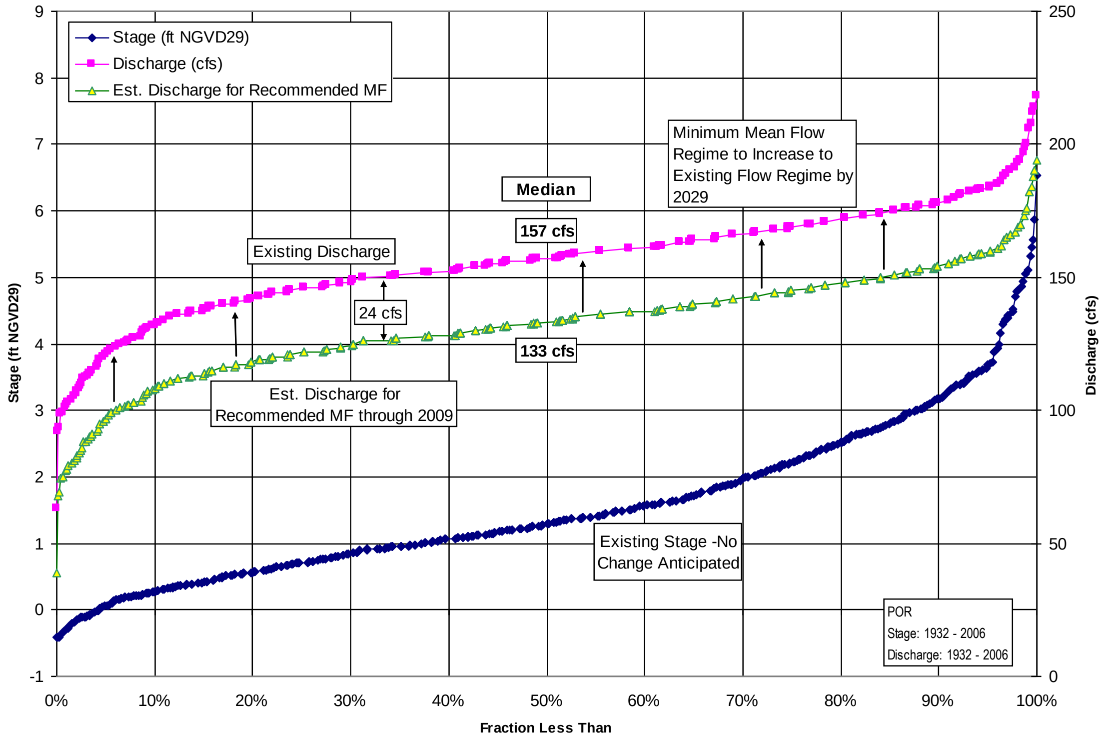


FIGURE 2-5
Cumulative frequency curves for stage and flow in Blue Spring and Blue Spring Run based on the District's recommended minimum flows and levels.

The probability distribution of stages in Blue Spring and Blue Spring Run was not expected to measurably change under the District's recommended Blue Spring MFR (Rouhani *et al.* 2006). As noted earlier, there is no significant correlation between existing flow and stage data for Blue Spring and Blue Spring Run (Sucsy 2005). For the purposes of the current study, we have adopted the District's assumption of no significant net change in stages in Blue Spring and Blue Spring Run as a result of the recommended Blue Spring MFR.

2.4 Blue Spring/Blue Spring Run Conceptual Ecosystem Model

An ecosystem model provides a tool for summarizing the most important components of the Blue Spring ecosystem (energy and matter storages) and their inter-relationships. Preparation of an ecosystem model allows definition of boundaries with external influences clearly identified as well as quantification of the internal energy and matter flows and their hypothesized interactions. A model can also be used to aggregate or expand the view of the system to help focus attention on an optimal level of detail to best answer a given question.

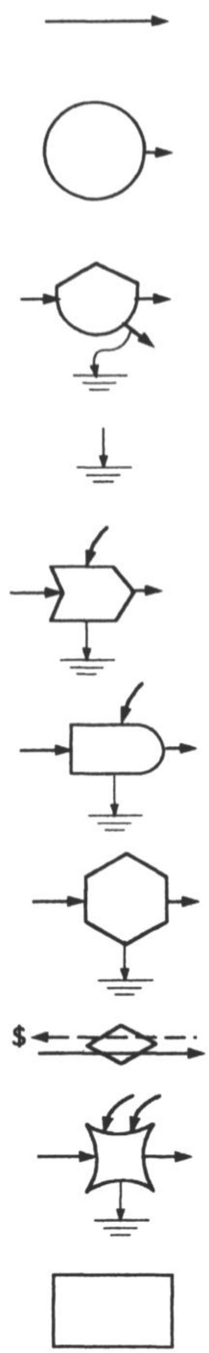
The Blue Spring Run Conceptual Ecosystem Model was prepared as a method for illustrating the most important interactions between the WRVs identified for this aquatic resource. The model presented in the "Energese" model language of Odum (see **Figure 2-6** and Odum 1983 for a description of symbols used in these models) does not need to be so complex that it becomes unwieldy for illustration purposes but must be complex enough to avoid omission of important ecosystem components.

With this balance between simplicity and complexity in mind, the following state variables and energy fluxes are illustrated in the Blue Spring Run Conceptual Ecosystem Model:

- External Forcing Functions
    - Sunlight
    - Rainfall with dissolved and particulate nutrients
    - Groundwater inputs of water and dissolved nutrients
    - Atmospheric gas connections
    - Temperature
    - Watershed interactions
    - St. Johns River
    - Human goods and services
- Downstream Exchanges
    - Manatees moving in and out from the St. Johns River
    - Fish, amphibians, reptiles, birds moving in and out from the St. Johns River and surrounding uplands
    - Aesthetic benefits to humans both within and outside the aquatic environment

- Internal State Variables (Storages)
    - Water
    - Nutrients and suspended solids
    - Detritus/microbes
    - Periphyton/aquatic macrophytes
    - Aquatic herbivores (other than manatees, such as mullet, tilapia, turtles, aquatic insects, etc.)
    - Manatees
    - Aquatic carnivores (catfish, bream, bass, aquatic insects, etc.)
    - Aquatic top carnivores (e.g., alligators and otters)
- Humans and aesthetics

Figure 2-7 illustrates the conceptual ecological model for Blue Spring Run. The conceptual spring model was used to illustrate the most likely linkages between each WRV and spring flows as a method for suggesting additional analyses, assuming more complete data become available. Groups of state variables and energy flows representing each of the WRVs discussed in this report are circled with dashed lines. Temperature is shown as an important influence on manatee movements between the run and the St. Johns River, and has been described in detail by others (Rouhani *et al.* 2006). The model also shows the importance of the interaction between humans and the manatees and other wildlife in the spring run. The presence of the wildlife and the beauty of the spring and spring run (aesthetics) attract people to the park. These people spend money at the park (by convention shown flowing opposite to energy flows) that is used for a variety of activities that influence the ecology of the spring run (e.g., trails, boardwalks, picnic areas, parking lots, cabins, office staff, water and sewer systems, etc.).



ENERGY PATHWAY — a flow of energy, often with a flow of materials.

ENERGY SOURCE — energy that accompanies each of the resources used by ecosystems, such as sun, winds, tidal exchanges, waves on the beaches, rains, seeds brought in by wind and birds.

STORAGE — a place where energy is stored. Examples are resources such as forest biomass, soil, organic matter, groundwater, and sands in beach dunes.

HEAT SINK — energy that is dispersed and no longer usable, such as the energy in sunlight after it is used in photosynthesis, or the metabolic heat passing out of animals. Heat sinks are attached to storage tanks, interactions, producers, consumers, and switching symbols.

INTERACTION — process that combines different types of energy flows or flows of material. In photosynthesis, sunlight, water, and nutrients interact to produce organic matter.

PRODUCER — unit that makes products from energy and raw materials. Examples include trees, grass, crops, and factories.

CONSUMER — unit that uses the products from producers. Examples include insects, cattle, microorganisms, humans, and cities.

TRANSACTION — business exchange of money for energy, materials, or services.

SWITCH — process that turns on and off, such as starting and stopping fire and the pollination of flowers.

BOX — miscellaneous symbol for subsystems such as the soil subsystem found in a diagram of a forest, or fishing business found in a diagram of an estuary. A rounded rectangle is also used for the system boundary that is selected.

FIGURE 2-6
Energy Symbols in the “Energese” Model Language

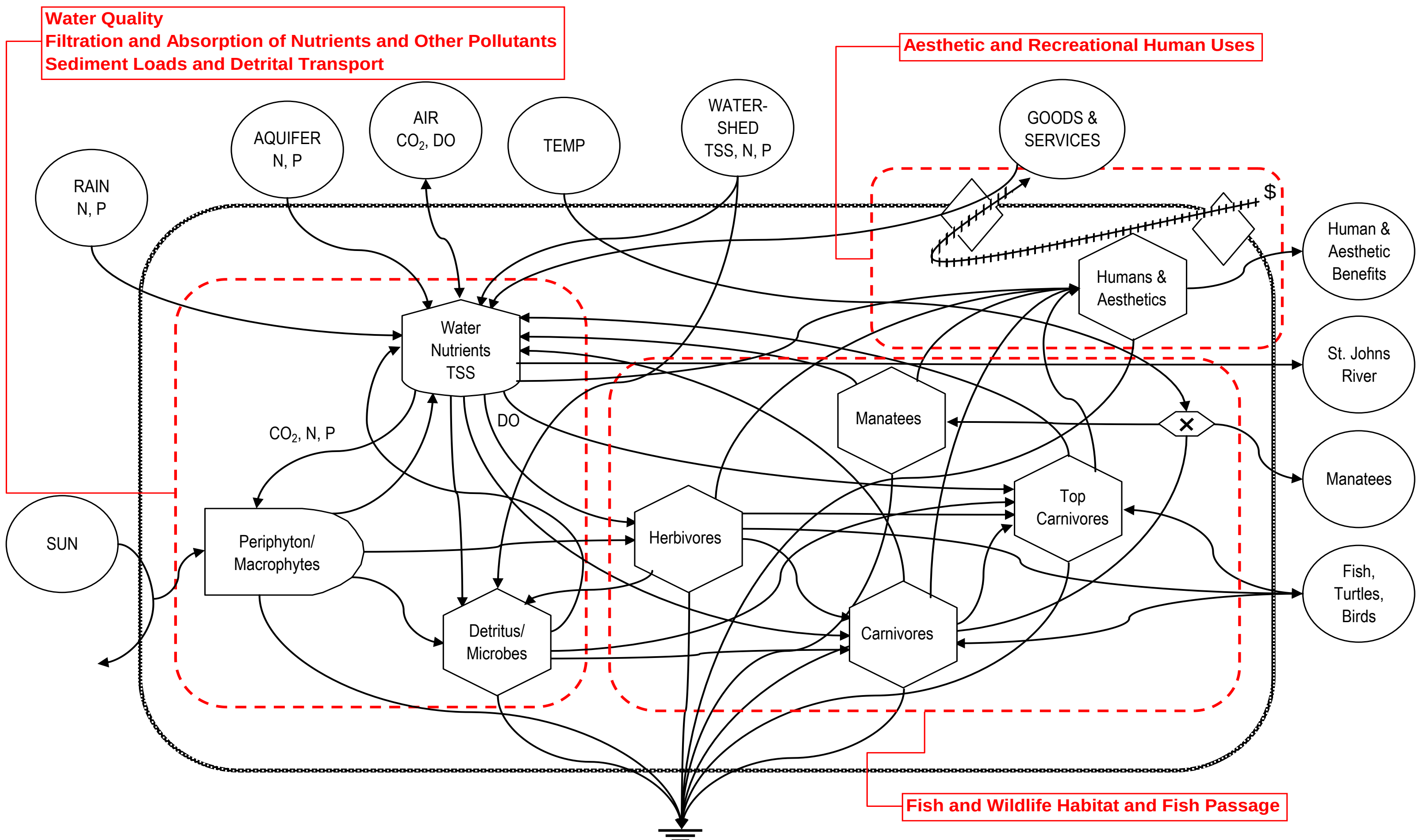


FIGURE 2-7
Conceptual Ecological Model for Blue Spring Run Illustrating All of the Ecological and Human Use Water Resource Values Described in the Report

3.0 Environmental and Resource Evaluation

3.1 Introduction

Not all aquatic habitats provide all possible environmental functions or WRVs. For example, many aquatic areas do not provide useable habitat for manatees, some are not used by humans for recreation, etc. An important step in the process of evaluating how the Blue Spring MFR determined to be sufficient to protect manatees under catastrophic conditions will protect the WRVs of Blue Spring and Blue Spring Run was to confirm what values should be evaluated.

Following confirmation of existing WRVs, a list of possible metrics was prepared for each of the applicable values. Metrics were selected based on their relevance for estimating impacts due to flow reductions and their ease of measurement.

The third step in this analysis consisted of a search of existing information relevant to the confirmed WRVs and the selected metrics for Blue Spring and Blue Spring Run. For those metrics with available data, analyses were conducted to determine if there might be measurable effects of spring flows on the particular WRV. These analyses consisted of quantification of the metric and correlation analysis with spring flows.

This report section provides estimates of the possible effects of the Blue Spring MFR on each of the applicable WRVs. These estimates are made on the basis of the identified metrics and quantifiable data, when available. In those cases where data are insufficient to provide a quantitative assessment, professional judgment is the basis of the estimate and additional desirable data needs are identified.

3.2 Confirmation of Existing WRVs and Quantitative Metrics

3.2.1 Inventory of Existing WRVs

Existing WRVs were inventoried for Blue Spring and Blue Spring Run using the following methods:

- Field trip to project site (February 26, 2002)
    - Visit and interview site managers
    - View public use areas

    - Reconnaissance of project area (canoeing and snorkeling)
    - Field water quality measurements (representative vertical and upstream/downstream profiles of temperature, dissolved oxygen, conductivity, pH, and depth)
- Interview off-site resource managers
    - SJRWMD
    - Florida Fish and Wildlife Conservation Commission
    - FDEP
    - Local governments (Volusia County Environmental Health Department)
- Collect and review existing information on Blue Spring and Blue Spring Run WRVs
    - Published and unpublished reports/articles/maps
    - Water resource data
    - Water quality data
    - Aerial photographs

Seven of the 10 WRVs described in Section 62-40.473, *FAC* were found applicable for Blue Spring and Blue Spring Run as listed in **Table 3-1** and described below.

3.2.2 Identify Appropriate Quantitative Metrics for Each WRV

Whenever possible, standardized, reproducible methods should be used to quantify existing WRVs. The first step in the quantification process is to identify appropriate sampling methods for each metric. The next step is to ascertain if data have previously been collected for each metric. In many cases, these specific data are not available. In those instances, it is sometimes possible to look at other related data sets to infer or estimate what the quantitative WRVs may be. In all cases where the necessary data are not available, specific recommendations are made for additional data gathering activities. While there are many possible parameters that could be measured, a focused suite of metrics is recommended that may best define the effects of the Blue Spring MFR on each

WRV (**Table 3-2**). This section identifies and describes the proposed representative ecological and human use WRV metrics and summarizes current knowledge about their magnitudes.

3.2.3 Correlation Analysis of Effects of Blue Spring MFR on WRV Metrics

The Blue Spring/Blue Spring Run ecosystem is so complex that it cannot be easily visualized. Relationships between specific WRV metrics and the flow rate of Blue Spring may be direct and indirect at the same time, and both positive and negative effects of flow on a single metric are possible. Correlation analysis provides a starting point to look for positive and negative interactions between WRV metrics and spring flows. However, correlation analysis alone typically does not confirm a cause-and-effect relationship (McBride *et al.* 1993). Therefore, a more detailed flow chart of possible cause and effect relationships must be developed to go beyond the preliminary examination of effects of the Blue Spring MFR on the WRV metrics described in this report. A useful method for organizing information related to the processes affecting each metric is the development of a conceptual ecosystem model described above.

3.3 Recreation In and On the Water

3.3.1 Introduction

State parks are a focal point for recreation. Parks with aquatic features such as spring boils, clear spring runs, mixed deciduous forest, and access to large rivers such as the St. Johns, are very attractive to humans for a variety of recreational activities and for their aesthetic attributes. The opportunity to watch West Indian manatees makes Blue Spring State Park especially attractive for scenic and active recreational uses.

Typical recreational uses focused on aquatic resources (other than aesthetic attributes described below in Section 3.8) include: swimming, fishing, education, canoeing, kayaking, bird watching, manatee watching, snorkeling, scuba diving, boating, water skiing, and use of personal water craft. These activities can be directly quantified through activity counts and through measurement of associated economic expenditures.

Due to widespread trends of increasing human population in Florida, recreational use of Blue Spring State Park can be expected to increase with time. Temporal changes in recreational uses should be viewed within the perspective of this expected population increase, and human use data can be normalized by dividing by the total human population to help correct for this possible bias.

Changes in flows and levels in an aquatic system can result in changes in recreational uses. For example, spring flows have declined in some areas due to natural and anthropogenic changes in aquifer levels (Florida Springs Task Force 2000), resulting in degraded water clarity and higher water temperatures, and declines in recreational uses. Consequently, it is assumed that quantification of the human recreational use WRV requires a historic perspective, as well as an understanding of the baseline human population.

The Blue Spring conceptual ecosystem model (**Figure 2-7**) depicts the human interactions with Blue Spring Run as additional pollutant loads entering the water column from the import of Goods and Services. This lumped category of external inputs includes building and landscaping materials (including fill, gravel, limerock, fertilizers, lumber, concrete, etc.), people and their accoutrements (sunscreen, Band-Aids, hair, candy wrappers, etc.), and vehicles and their discharges of oil and exhaust. The system exports aesthetic benefits (no measurable energy content) in the form of memories and word-of-mouth advice to friends to visit the park. By convention in the Energese visual modeling language, money is shown running counter-current to the import of Goods and Services and the export of Aesthetic Benefits.

3.3.2 Recreational Human Use Metrics

Human recreational uses are some of the easiest functions to quantify. Aesthetic values are more difficult to measure accurately. Possible units for quantifying human uses are the Human Use Day (HUD), which refers to any daily use of a resource by a human regardless of how much time is spent during the day, and dollars ($) spent on or for the activity.

Five recommended human use metrics are listed in **Table 3-2.** These include the following metrics:

- Human-use days (HUDs) by category:

- Total human use
- Manatee watching
- Swimming/Snorkeling/Scuba diving
- Fishing

- Economic benefits ($/day)
  - Park fees

Measurement of these metrics can be made through direct observation, interviews with users, or by counts and exit surveys.

3.3.3 Human Use at Blue Spring State Park

One category of human use data obtained for Blue Spring State Park was the total number of visitors per day and the number of overnight visitors (**Table 3-3**). The number of people visiting the park averaged 907 per day (825 day visitors and 82 overnight visitors) and has ranged from 0 to 6,140 per day over the 16-year period of data collection (1990 to 2006) (Webb 2005, Schockin 2006). Human use is seasonal with two apparent peaks of activity (**Figure 3-1**): the colder winter months during high periods of manatee use of the spring run (especially over Thanksgiving and Christmas holidays) and the early summer period when the spring and adjacent river are most popular for swimming and boating activities.

TABLE 3-3

Summary of Overnight and Daily Visitors to Blue Spring Park, Volusia County

Statistics	Overnight Visitors (#)	Day Visitors (#)	Total (#)
Average	82	825	907
Median	63	661	752
Maximum	673	6,107	6,140
Minimum	0	0	0
Std Dev	64	635	659
Count	6,091	6,091	6,091
Std Err	0.82	8.14	8.44

Period of Record: 1/1/90 - 9/4/06

Source: Webb 2005; Schockin 2006

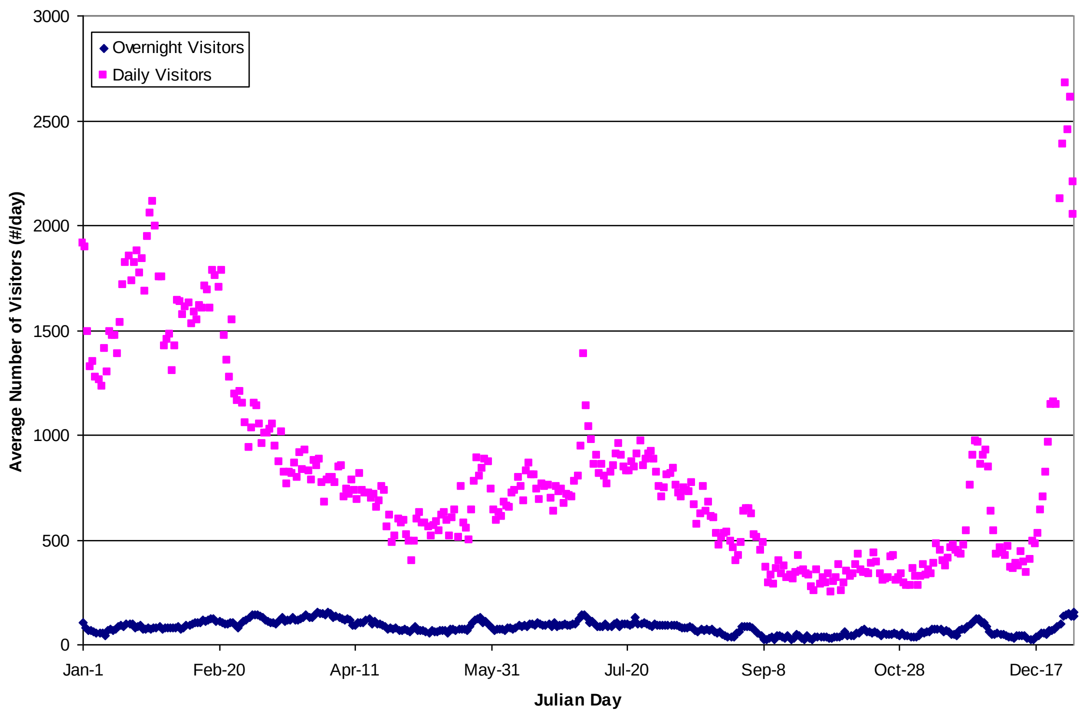


FIGURE 3-1
Average Number of Overnight and Daily Visitors to Blue Spring Park, Volusia County (January 1, 1990 - September 4, 2006)

Bonn and Bell (2003) prepared a detailed economic assessment of four Florida state parks with major artesian springs. Volusia Blue Spring was one of the systems evaluated by user surveys in late 2002. In fiscal year 2002, there were 337,356 visitors to the park. About 65% of these individuals were estimated to be from outside of Volusia County. These tourists injected money into the local economy as a result of day use fees and food costs as well as in money spent for over-night accommodations. Average daily spending at Blue Spring State Park was $19/person for a total estimated annual spending rate of about $10 million. This level of spending generated an estimated $2.4 million in wages and 174 local jobs. The authors made no quantitative estimates of the relationship between economic impact and spring flows. However, they did conclude that flows have been declining in Blue Spring since the mid-1980's and that this flow reduction "threatens the future of Blue Spring as a manatee refuge and recreation area" (Bonn and

Bell 2003, p. 70). The authors also hypothesized that increased nitrates in the spring discharge "… increase the growth of algae and lead to ecological decline" and state that recreational visitors to Blue Spring will be deterred due to diminished water quality and appearance of the ecosystem.

3.3.4 Relationship between Recreational Human Uses and Spring Flows

Average monthly human use at Blue Spring State park is not significantly correlated with spring discharge within the range of existing data (**Figure 3-2**). Human use is correlated with average air temperature (**Figure 3-3**), with greatest park use at the lowest temperatures. This is likely a response to the main attraction of the park – namely manatee watching during the winter months. There is a positive correlation between average manatee use and average human use of the park (**Figure 3-4**). Since overall human use of the park is tied to manatee use and manatee use is dependent upon spring flows (Rouhani *et al.* 2006), then human use is indirectly tied to spring flow. Based on the Blue Spring MFR developed to allow for increasing manatee usage in the future (Rouhani *et al.* 2006), it can be deduced that overall recreational use of the park will also be protected by the recommended Blue Spring MFR.

Other human uses are also likely to be correlated with flows but there are no quantitative data available to define this relationship. For example, it is intuitive that scuba diving, snorkeling, and swimming are tied to the clarity and temperature of the water, which may be affected by reduced spring flow. However, within the range of the maximum allowed temporary reduction in the long term mean flow of 15 percent, it is considered to be unlikely that water clarity or temperature will vary enough to result in a reduced use of the spring and spring run for these water-dependent recreational uses. This conclusion is based on the observation that swimming and scuba diving are limited to the middle and upper reaches of the spring and spring run, above the area possibly affected by intrusions of colored or colder waters from the St. Johns River.

Since no change in the stage of Blue Spring or Blue Spring Run is anticipated based on the District's recommended Blue Spring MFR, there is no anticipated effect of stage on any human uses at Blue Spring State Park.

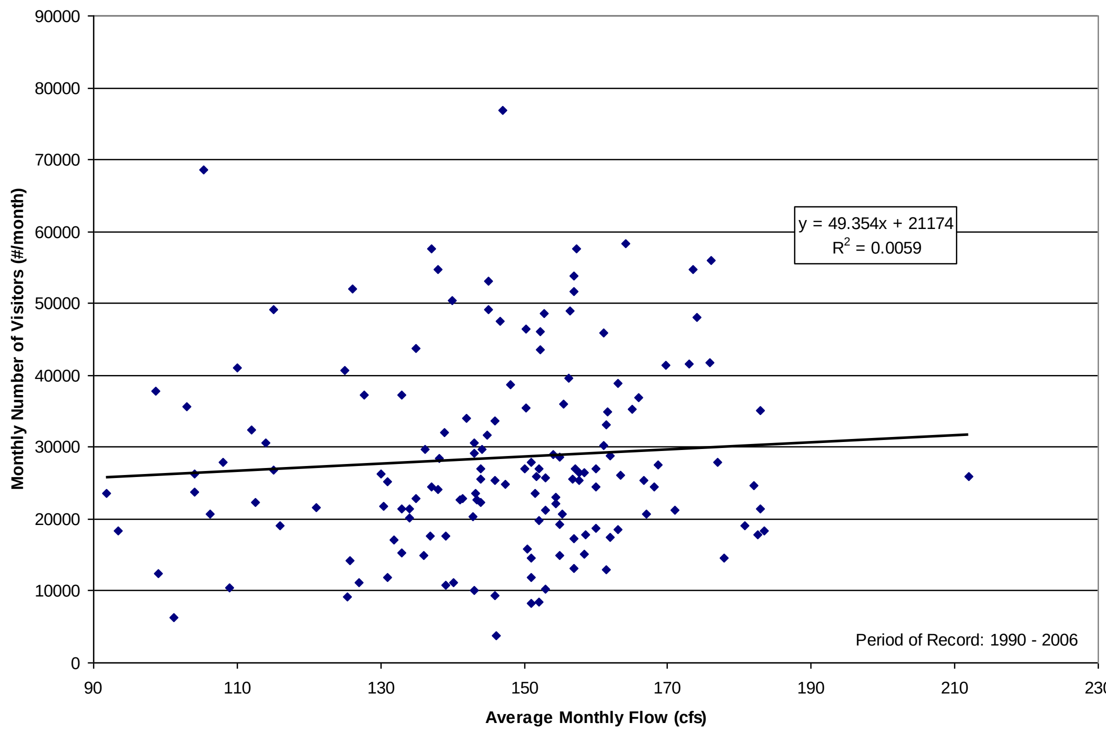


FIGURE 3-2
Blue Spring Monthly Number of Visitors vs. Average Monthly Flow

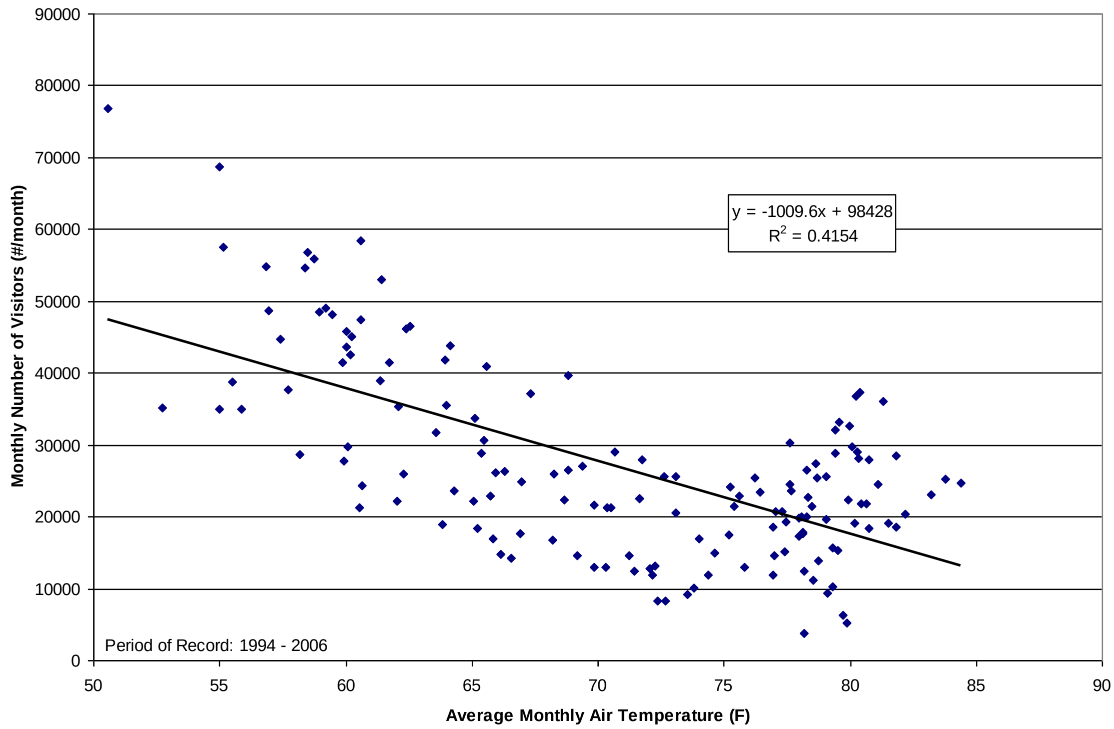


FIGURE 3-3
Blue Spring Monthly Number of Visitors vs. Average Monthly Air Temperature

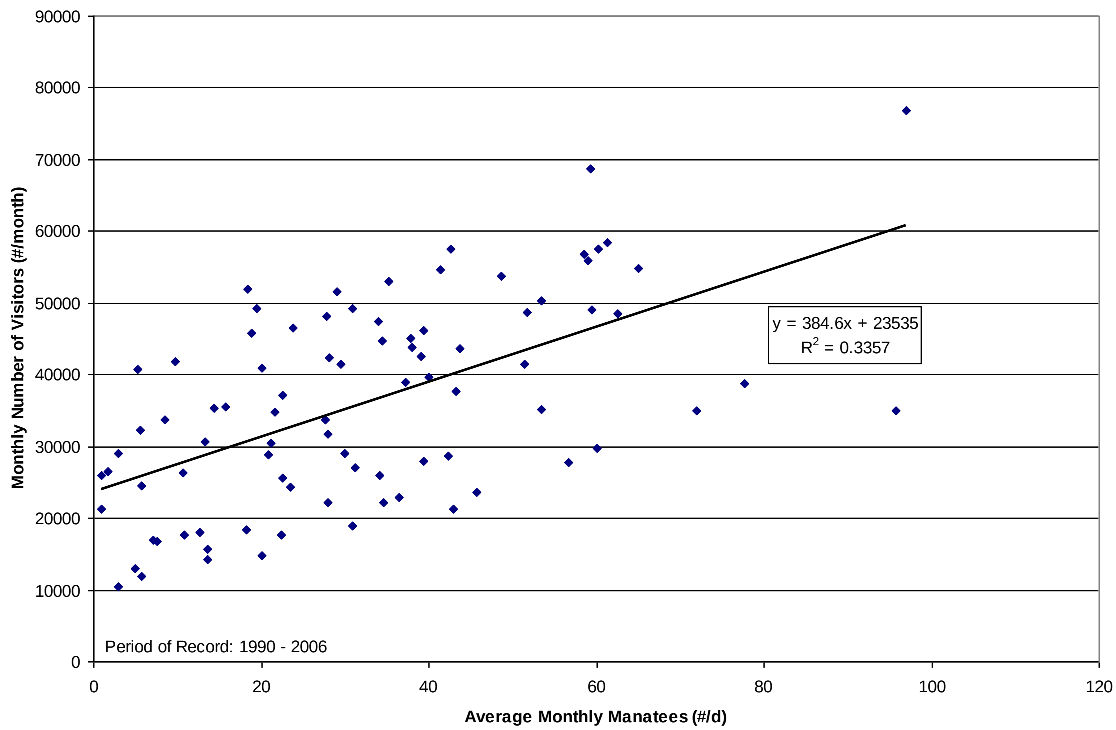


FIGURE 3-4
Blue Spring Monthly Number of Visitors vs. Average Monthly Manatee Count

3.3.5 Summary

Based on the available information, it is concluded that the recommended Blue Spring MFR will also protect recreation in and on the water. This conclusion is based on the observed indirect relationship between manatee and human use at Blue Spring State Park. Actual quantitative data to assess the effects of minimum flows on other human uses such as swimming and scuba diving are not available. Monitoring of these human uses is recommended to better assess the effects of spring flows on these water contact recreational uses. However, based on the magnitude of the temporary flow reduction allowed by the recommended Blue Spring MFR, and the dominant effect of river stage on water levels and depth in Blue Spring Run (Sucsy 2005), it is considered unlikely that the extent of these water-contact activities will be measurably affected.

3.4 Fish and Wildlife Habitats and the Passage of Fish

3.4.1 Introduction

Aquatic ecosystems provide critical habitat for a variety of animals, including larger organisms such as fish and other wildlife species. Major faunal groups of interest in the category of fish and wildlife include: fish, reptiles, amphibians, birds, and mammals. Aquatic ecosystems such as Blue Spring and Blue Spring Run provide habitat for many aquatic and terrestrial animal species. Some of the animals are obligate aquatic species (e.g., fish, turtles, and manatees) while others only use the aquatic system as one component of an upland-aquatic habitat continuum. For example, fish-eating birds are absolutely dependent upon the production of fish, while many passerine birds, such as cardinals and warblers, are indirectly dependent upon the aquatic resource for certain food and prey organisms and for drinking and bathing.

The Blue Spring conceptual ecosystem model (**Figure 2-7**) places this WRV into a number of trophic levels including Periphyton/Macrophytes, Detritus/Microbes, Herbivores, Carnivores, Manatees, and Top Carnivores. These living components of Blue Spring and Blue Spring Run form a food web of linkages of energy and matter flows. Many of these organisms interact with adjacent ecosystems, including the uplands in Blue Spring State Park and the adjacent St. Johns River and associated floodplain. Every one of the many thousands of species combined in these few model symbols has life history requirements of similar complexity to the manatee. All of them are to some extent dependent upon flows and water levels in Blue Spring.

Aquatic wildlife habitat is a function of the volume and areal extent of the aquatic resource. Decreased flows may result in a reduction in the amount or a change in the value of wildlife habitat. The effects of flow reductions on wildlife may be direct and/or indirect.

Fish and wildlife habitat must also be evaluated within a "historical" context. Habitat functions vary from year to year due to natural conditions. They may also be expanded or contracted due to human activities. A loss of habitat resources for one species is generally an increase in habitat for some other species. Changes in habitat resources should generally be evaluated within the context of historical variations and should include quantification of both beneficial and detrimental effects for the whole ecosystem. However, where habitat for an endangered or threatened species is concerned, a more narrow perspective may be appropriate.

Limited historical data exists on fish and wildlife populations in Blue Spring and Blue Spring Run. The Florida Department of Environmental Protection (FDEP) has initiated more extensive monitoring of some animal populations (snails) in Blue Spring Run. It is recommended that preliminary monitoring be conducted for the metrics listed in **Table 3-2** to quantitatively assess fish and wildlife populations at Blue Spring and to serve as a baseline for comparison of future conditions.

3.4.2 Fish and Wildlife Habitats and Fish Passage Metrics

Fish and wildlife habitat resources can be assessed at the species population level or at the ecosystem level. Population metrics include total population density and living biomass by species and the rate of change of these individual populations (secondary productivity). However, there are too many species to effectively track them all. The single most important species, in terms of public recognition, is the manatee, which is being assessed in a related effort (Rouhani *et al.* 2006). Additional focused interest is centered on two species of endemic operculate snails that inhabit Blue Spring Run, the Blue Spring hydrobe (*Aphaostracon asthenes*) and the Blue Spring siltsnail (*Cincinnatia parva*) (FDEP 1999).

A total of 14 possible metrics are recommended for this WRV (**Table 3-2**). Of the many possible plant and animal species other than manatees, the following species are considered representative of the spring's major trophic levels and are recommended for preliminary assessments:

- Primary Producers
    - Periphyton
    - Aquatic macrophytes
- Herbivores
    - Snails

  - Benthic insects
  - Mullet
  - Turtles
- Primary Consumers
  - Mosquitofish
  - Sunfish
- Secondary Consumers
  - River otter
  - Double-crested cormorant

Qualitative evaluation of the continuing presence or absence for these species can provide a preliminary indication of major ecosystem changes. However, quantitative metrics are important to detect trends and to react in time to avert species extirpation. Possible quantitative measures for each of these metrics are: the average annual population density expressed as areal biomass (grams dry weight per square meter – g dw/m^2) and the net secondary productivity (g dw/m^2/yr). Biomass estimates for periphyton, plants, and macroinvertebrates would be based on field sampling using cores or grid devices. Biomass estimates for the larger faunal species (fish, reptiles, amphibians, birds, and mammals) would be based on counted numbers of individuals in the whole spring run and published live body weights. Length:weight relationships can be used where available from the literature to improve biomass estimates. Net secondary productivity can be estimated as the change in biomass for each species from season to season or from year to year. These biomass and secondary productivity measures could then be evaluated to determine if they are correlated to spring flows. Limited resources for monitoring dictate that following preliminary, range-finding monitoring efforts, a few key species can be used for continuing assessments.

There are fewer ecosystem-level measurements and, therefore, data collection may be more affordable. On the other hand, interpretation of ecosystem data is more difficult because the resource manager does not always know what portion of the observed ecological function should be assigned to which part of the ecosystem. Representative ecosystem measurements that could be applicable to Blue Spring include:

- Ecosystem Metabolism
    - Gross primary productivity
    - Net primary productivity
    - Community respiration
    - Primary productivity to respiration ratio (P/R ratio)

All of these possible metrics can be measured within Blue Spring Run. For example, ecosystem metabolism can be measured using upstream/downstream dissolved oxygen and percent saturation data collected hourly over a 24-hour period (Odum 1957; Knight 1980). Upstream water quality would be measured in the spring boil and downstream water quality would be measured above any influence of the St. Johns River incursions. Previous work has shown that assumptions concerning near steady-state conditions at the spring boil inflow are met in large springs and that upstream-downstream water quality changes reflect the net effect of all of the production and removal processes occurring in the aquatic ecosystem. This metabolism can be fractionated into gross primary productivity and community respiration by analyzing daylight and nighttime data patterns. The P/R ratio provides a convenient index of the autotrophic/heterotrophic nature of the spring run.

3.4.3 Existing Blue Spring and Blue Spring Run Biological Data

Quantitative biological data are summarized for benthic macroinvertebrates, fish, and manatee populations at Blue Spring Run. Qualitative data are available for snails, turtles, and birds.

Table 3-4 summarizes results from an "EcoSummary" for Blue Spring prepared by FDEP (Bennett, 2002; http://www.dep.state.fl.us/labs/library/springs.htm). FDEP conducted field sampling on eleven dates from 2000 to 2005. Slightly different measurements were made on each sampling trip. The Stream Condition Index (SCI) ranged from 11 to 17. The SCI is a composite macroinverterbrate metric for use in Florida flowing streams (see Barbour et al. 1996 for a description of the components and

TABLE 3-4

Blue Spring Florida Department of Environmental Protection 'EcoSummary'

	Oct-00	Mar-01	Oct-01	Nov-01	Apr-02	Oct-02	May-03	Oct-03	Apr-04	Nov-04	Apr-05
Macroinvertebrate Parameters											
Stream Condition Index (SCI)	15	17	15	---	17	15	17	11	11	---	17
SCI Evaluation	poor	poor	poor	---	poor	poor	poor	very poor	very poor	---	very poor
SCI Region	peninsula	peninsula	peninsula	---	peninsula	peninsula	peninsula	peninsula	peninsula	---	---
Number of Individuals	---	---	104	---	---	---	---	---	---	---	---
Number of Taxa	18	18	18	---	18	22	12	15	9	---	---
Number of Ephemeroptera	0	0	1	---	---	---	---	---	---	---	---
Number of Plecoptera	0	0	0	---	---	---	---	---	---	---	---
Number of Trichoptera	0	0	0	---	---	---	---	---	---	---	---
EPT Index	0	0	1	---	1	2	1	0	0	---	---
Dominant Taxon	---	---	Pyrgophorus platyrachis	---	---	---	---	---	---	---	---
% Dominant Taxon	27.01	27.11	26.92	---	26.67	70.41	43.4	69	29.5	---	---
Florida Index	1	4	0	---	1	1	4	1	2	---	---
% Diptera	15.33	31.93	25.96	---	45	12.24	17	4.3	6.7	---	---
Number of Chironomidae	1	1	---	---	---	---	---	---	---	---	---
Number of Orthocladiinae	3	4	---	---	---	---	---	---	---	---	---
Total Number of Chironomidae	4	5	3	---	5	4	5	1	2	---	---
% Filter-Feeders	2.92	1.81	0	---	13.33	2.55	6.6	0	4.3	---	---
Periphyton Parameters											
Number of Individuals	---	---	411	689	---	---	---	---	---	---	---
Number of Taxa	28	29	---	---	---	---	---	---	---	---	---
Dominant Taxon	---	---	Fragilariaceae	Fragilariaceae	Fragilariaceae	Diatomaceae/ Fragilariaceae	Fragilariaceae	Diadesmis confervacea	---	---	---
% Bacillariophyceae	94.16	93.38	63.5	74.17	83.44	68.09	84.7	57.3	92.3	---	---
% Chlorophyceae	0.94	0.92	34.31	25.25	1.95	2.43	0	0	0.6	---	---
% Cyanophyceae	4.9	5.7	2.19	0.58	11.69	29.48	3	2.2	7	---	---
% Dinophyceae	0	---	---	---	---	---	---	---	---	---	---
% Dominant Taxon	38.23	17.65	22.38	28.16	30.52	17.93	39.2	19.4	27.2	---	---
Bacteria Parameters*											
Enterococci (col/100 mL)	26	20	---	40	32	6	6 B	10 B	40	6 B	---
Escherichia coli (col/100 mL)	2	4	---	8	12	1 K	4 B	2 B	23 B	2 K	---
Fecal Coliforms (col/100 mL)	10	1	---	2	2	1 K	1 K	2 B	8 B	4 B	---
Total Coliforms (col/100 mL)	40	10	---	2	90	40	20 B	50 B	54	16 B	---
Physical-Chemical Data											
Habitat Assessment	111	89	---	---	97	114	105	104	113	129	105
Sample Depth (m)	0.8	0.4	---	---	---	---	---	---	---	---	---
Specific Conductivity (umho/cm)	198	2019	---	1365	1381	878	878	1396	1705	861	1280
Dissolved Oxygen (mg/L)	2.3	2.2	---	1.5	2.6	1.43	1.43	3.3	3.33	1.9	2.5
pH (SU)	7.6	7.5	---	6.4	7.1	7.07	7.07	7.3	7.5	7.3	8
Temperature (deg. C)	22.8	23	---	22.9	23.2	23.2	23.2	23.1	23.4	22.9	23
Chemistry Data											
Ammonia (mg/L)	0.093	---	---	0.01	0.018 I	0.022	0.01 U	0.01 U	0.041	0.015 I	0.011 I
Nitrate-Nitrite (mg/L)	0.11	---	---	0.64	0.58 J	0.9	0.78	0.5	0.39	1.1	0.57
TKN (mg/L)	0.3	---	---	0.14	0.25	0.21	0.13 I	0.24	0.2	0.2 I	0.19 I
Total Phosphorus (mg/L)	0.093	---	---	0.069	0.072	0.067 J	0.069 A	0.076	0.098	0.059 I	0.076
Color (PCU)	5	---	---	---	5 U	5 UQ	5 U	5 UQ	5 Q	5 UQ	5 Q
Turbidity (NTU)	0.15	---	---	0.1	0.1	0.15 Q	0.35 A	0.2 Q	0.7 Q	0.1 Q	0.15 Q

**Bacteria samples were all outside of holding time (October 2000; March, October 2001; April, October 2002; May, October 2003; April, November 2004; April 2005)*

A = Value reported is the mean of two or more determinations

B = Results based on colony counts outside the acceptable range

U = Below Detection Limit

I = Below Quantitation Limit

K = Actual value is known to be less than value given

Q = Information Only

J = Estimated Value

Source: (Bennett 2002; http://www.dep.state.fl.us/labs/library/springs.htm) development of the SCI). SCI values in this range are considered "Very Poor" to "Poor." Low values of the SCI are typically found in aquatic systems with low dissolved oxygen concentrations. Therefore, since dissolved oxygen is low in Blue Spring due to natural conditions, the low SCI for this site is probably a natural condition and not related to human influences. Macroinvertebrate taxa numbers ranged from 9 to 22 during the events when measurements were made. A large portion of this macroinvertebrate population was comprised of organisms tolerant of low-dissolved oxygen concentrations (e.g., chironomids). From 28 to 29 algal taxa were recorded in the FDEP sampling and most of these species were diatoms (**Table 3-4**).

As shown in the water quality section below (Section 3.11), bacteriological sampling in Blue Spring Run has indicated the periodic presence of fecal coliforms at the swim area (average fecal coliforms were 13.4 and total coliforms were 47 col/100 ml). Bacteria populations recorded by FDEP (**Table 3-4**) were similar. These coliform populations are relatively low compared to most natural waters (FDEP 1989) and may be derived from either natural or human sources, or both.

No quantitative data were located for populations of amphibians, reptiles, or birds in and around Blue Spring Run. However, FDEP has prepared a qualitative list of species observed in the spring (see **Appendix A** from FDEP 1999). This list includes the following species totals:

- Mollusks 2
- Fish 34
- Amphibians 8
- Turtles 12
- Snakes 6
- Birds 56
- Mammals 2

Population levels for most of these faunal groups are expected to vary over a fairly wide range due to seasonal and annual climatic events. Thus, the Blue Spring MFR is not expected to result in a measurable (statistically detectable) change in the population of any of these organisms. Additional data collection and analysis of key taxonomic groups is recommended to improve the available information upon which this conclusion is based. Since no stage change is anticipated, there is not expected to be any effect of water depth on any of these populations as a result of the Blue Spring MFR.

3.4.4 Fish Populations

Fish populations in Blue Spring Run have been surveyed on 72 occasions by researchers from Stetson University (Work 2006). Quantitative fish data from Blue Spring are provided in **Tables 3-5 and 3-6** and **Figure 3-5** (Work 2006; http://www.stetson.edu/department/biology/amb/florida). A total of 32 fish species were observed in the spring run during a 4 year period. Snorkel counts observed 28 species and seine hauls captured 23 species. Fish counts were generally somewhat higher in the winter months than in the summer. Highest fish counts in the spring boil and in the upper portion of the spring run occurred in March 2004.

Dominant fish species in terms of numbers were: mosquitofish (*Gambusia holbrooki*), bluegill (*Lepomis macrochirus*), sailfin molly (*Poecillia latipinna*), rainwater killifish (*Lucania parva*), and least killifish (*Heterandria formosa*), These are generally small fish and their total biomass may be relatively low; however, due to their relatively short life histories and high turnover rates, they may contribute significantly to secondary productivity in the spring run. Larger fish that were present at significant densities were warmouth (*Lepomis gulosis*), golden shiner (*Notemigonis crysoleucas*), suckermouth catfish (*Pterygoplichthys disjunctivus*), redear sunfish (*Lepomis microlophis*), spotted sunfish (*Lepomis punctatus*), striped mullet (*Mugil cephalus*), largemouth bass (*Micropterus salmoides*), longnose gar (*Lepistosteus osseus*), and tarpon (*Megalops atlanticus*). Some of these fish are very large (tarpon over 40 inches in length were observed during the February 26, 2002 field trip) and their biomass, if quantified, might be much larger than the smaller fish species. While these larger fish are generally not feeding in the spring run, their presence may be important as prey species for other carnivores (e.g., otters and piscivorous birds) or may

TABLE 3-5

Blue Spring Average Fish Densities (#/m2) - Snorkel Count Method

Common Name	Genus Species	Location					
		1	2	3	4	5	Mean
Bluegill	*Lepomis macrochirus*	0.8516	2.7660	2.0388	1.7989	0.2291	1.5369
Warmouth	*Lepomis gulosis*	0.3074	0.8931	0.5832	0.6186	0.0437	0.4892
Golden shiner	*Notemigonis crysoleucas*	0.0845	0.6542	0.0998	0.0047	0.0018	0.1690
Suckermouth catfish	*Pterygoplichthys disjunctivus*	0.2017	0.0142	0.0120	0.3664	0.1832	0.1555
Redear sunfish	*Lepomis microlophis*	0.0336	0.2161	0.0724	0.2532	0.0103	0.1171
Seminole killifish	*Fundulus seminolis*	0.0672	0.2457	0.0858	0.0510	0.0026	0.0905
Spotted sunfish	*Lepomis punctatus*	0.0204	0.1553	0.1367	0.1208	0.0112	0.0889
Inland silverside	*Menidia beryllina*	0.0000	0.0306	0.1960	0.0340	0.0000	0.0521
Striped mullet	*Mugil cephalus*	0.0000	0.0060	0.0652	0.1030	0.0493	0.0447
Redbreast sunfish	*Lepomis auritus*	0.0010	0.0955	0.0301	0.0518	0.0209	0.0399
Largemouth	*Micropterus salmoides*	0.0031	0.0216	0.0664	0.0292	0.0106	0.0262
Longnose gar	*Lepistosteus osseus*	0.0011	0.0002	0.0034	0.0171	0.0902	0.0224
Coastal/Ironcolor	*Notropis petersoni/chalybaeus*	0.0020	0.0372	0.0144	0.0060	0.0002	0.0120
Mosquitofish	*Gambusia holbrooki*	0.0042	0.0135	0.0036	0.0029	0.0063	0.0061
Blue tilapia	*Oreochromis aureus*	0.0000	0.0000	0.0002	0.0130	0.0055	0.0037
Tarpon	*Megalops atlanticus*	0.0000	0.0000	0.0000	0.0050	0.0053	0.0021
Black crappie	*Pomoxis nigromaculatus*	0.0000	0.0035	0.0000	0.0034	0.0005	0.0015
Pacu	*Collosoma sp.*	0.0000	0.0000	0.0005	0.0002	0.0040	0.0009
Channel catfish	*Ictalurus punctatus*	0.0012	0.0000	0.0000	0.0013	0.0021	0.0009
Sailfin molly	*Poecilia latipinna*	0.0024	0.0016	0.0002	0.0000	0.0000	0.0009
Bluefin killifish	*Lucania goodei*	0.0000	0.0012	0.0002	0.0002	0.0011	0.0005
Rainwater killifish	*Lucania parva*	0.0000	0.0005	0.0007	0.0004	0.0007	0.0005
White mullet	*Mugil curema*	0.0000	0.0000	0.0003	0.0001	0.0018	0.0004
Bluespotted sunfish	*Enneacanthus gloriosus*	0.0000	0.0000	0.0010	0.0001	0.0000	0.0002
Least killifish	*Heterandria formosa*	0.0000	0.0005	0.0005	0.0001	0.0000	0.0002
Longear	*Lepomis megalotis*	0.0000	0.0000	0.0000	0.0002	0.0009	0.0002
Florida gar	*Lepistosteus platyrhincus*	0.0000	0.0000	0.0001	0.0001	0.0003	0.0001
Brown hoplo	*Hoplosternum littorale*	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
TOTAL		1.581	5.157	3.412	3.482	0.682	2.863

Source: Stetson University Department of Biology

Average from 72 sample events (10/20/00 - 7/22/04)

Location: 1 - boil, 2 - diver entry, 3 - stream, 4 - swimming area, 5 - observation platform (upstream)

TABLE 3-6

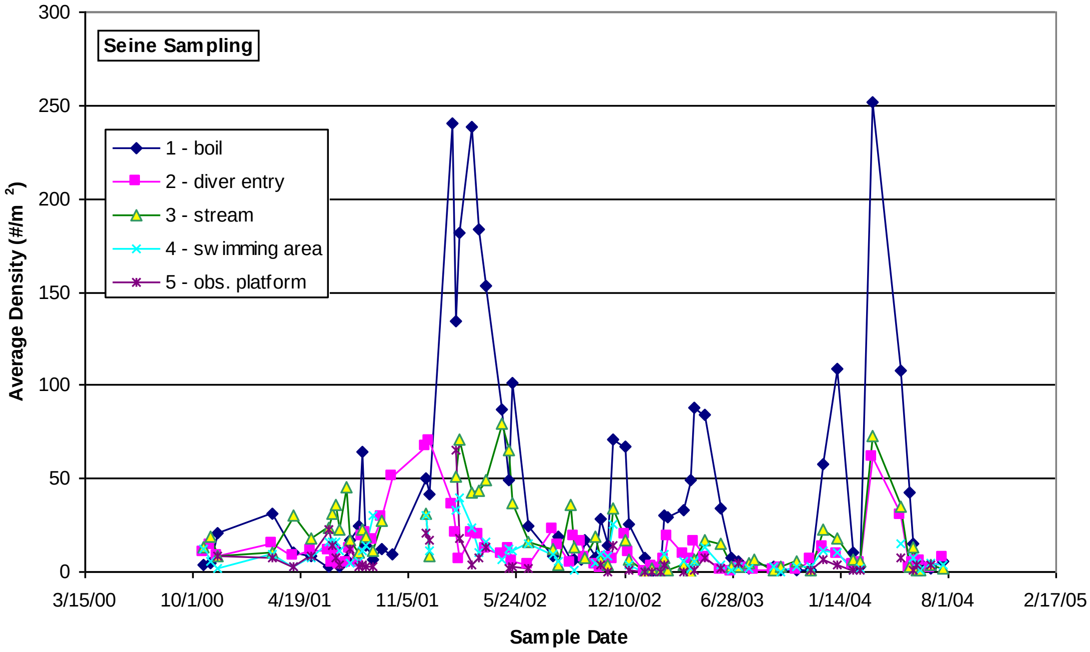
Blue Spring Average Fish Densities (# /m^2) - Seine Method

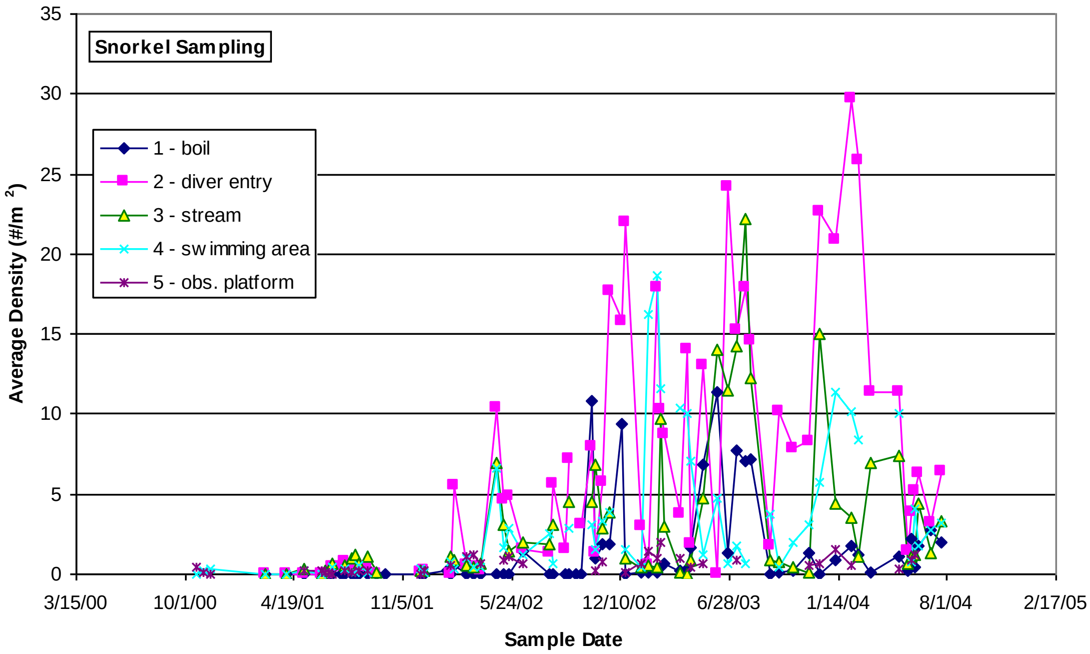
		Location					
Common Name	Genus Species	1	2	3	4	5	Mean
Mosquitofish	*Gambusia holbrooki*	38.5	9.44	11.2	6.30	4.91	14.1
Sailfin molly	*Poecilia latipinna*	3.08	1.05	2.40	0.440	0.284	1.45
Rainwater killifish	*Lucania parva*	0.005	0.476	1.515	1.024	1.182	0.840
Least killifish	*Heterandria formosa*	0.213	0.548	1.279	0.334	0.303	0.535
Bluefin killifish	*Lucania goodei*	0.057	0.698	0.763	0.292	0.177	0.397
Bluegill	*Lepomis macrochirus*	0.008	0.120	0.326	0.208	0.218	0.176
Inland silverside	*Menidia beryllina*	0.000	0.002	0.295	0.367	0.000	0.133
Seminole killifish	*Fundulus seminolis*	0.001	0.070	0.149	0.122	0.031	0.075
Golden shiner	*Notemigonis crysoleucas*	0.000	0.133	0.116	0.039	0.008	0.059
Warmouth	*Lepomis gulosis*	0.030	0.070	0.096	0.054	0.039	0.058
Golden topminnow	*Fundulus chrysotus*	0.034	0.046	0.101	0.028	0.007	0.043
Redear sunfish	*Lepomis microlophis*	0.001	0.003	0.005	0.088	0.003	0.020
Redbreast sunfish	*Lepomis auritus*	0.000	0.000	0.025	0.029	0.001	0.011
Spotted sunfish	*Lepomis punctatus*	0.000	0.008	0.011	0.027	0.004	0.010
Coastal/Ironcolor	*Notropis petersoni/chalybaeus*	0.000	0.007	0.020	0.004	0.005	0.007
Striped mullet	*Mugil cephalus*	0.000	0.000	0.025	0.000	0.000	0.005
Longnose gar	*Lepistosteus osseus*	0.001	0.001	0.000	0.012	0.001	0.003
Coastal shiner	*Notropis petersoni*	0.000	0.009	0.001	0.000	0.000	0.002
Largemouth	*Micropterus salmoides*	0.001	0.000	0.002	0.002	0.001	0.001
Suckermouth catfish	*Pterygoplichthys disjunctivus*	0.000	0.002	0.000	0.001	0.003	0.001
Tarpon	*Megalops atlanticus*	0.000	0.000	0.000	0.000	0.003	0.001
Blackbanded darter	*Percina nigrofasciata*	0.000	0.001	0.000	0.001	0.000	0.000
Flagfish	*Jordanella floridae*	0.000	0.001	0.000	0.000	0.000	0.000
TOTAL		41.9	12.7	18.3	9.4	7.2	17.9

Source: Stetson University Department of Biology

Average from 72 sample events (10/20/00 - 7/22/04)

Location: 1 - boil, 2 - diver entry, 3 - stream, 4 - swimming area, 5 - observation platform (upstream)





Source: Stetson University Department of Biology

FIGURE 3-5
Blue Spring Average Fish Density Time Series Plots

be indicative of other life history needs (e.g., osmotic regulation in the relatively salty spring water).

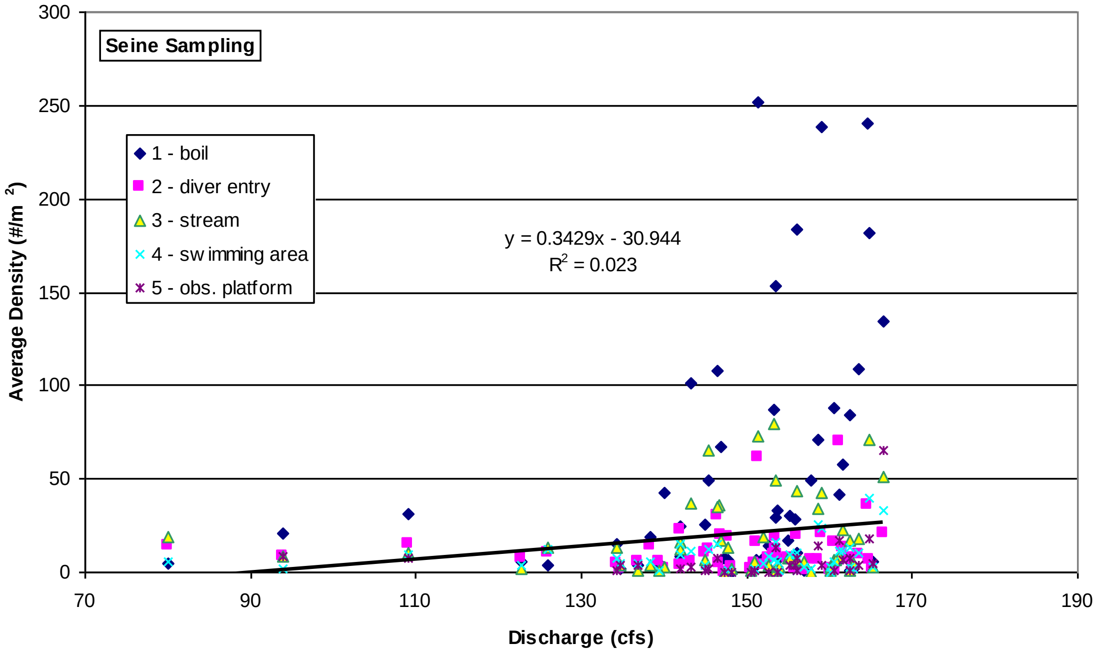
All of the fish species listed for Blue Spring and Blue Spring Run are also known to occur in the St. Johns River. Thus, they are all expected to be able to live in the spring run even without the spring flow. However, it can also be surmised that due to the combination of water quality, clarity, relatively constant temperature and higher salt content, the spring run habitat provides a different combination of life support functions for these fish species than the St. Johns River. Detailed life history studies for each fish species would probably be needed to fully understand the subtle dependence or independence of these fish species on spring flows.

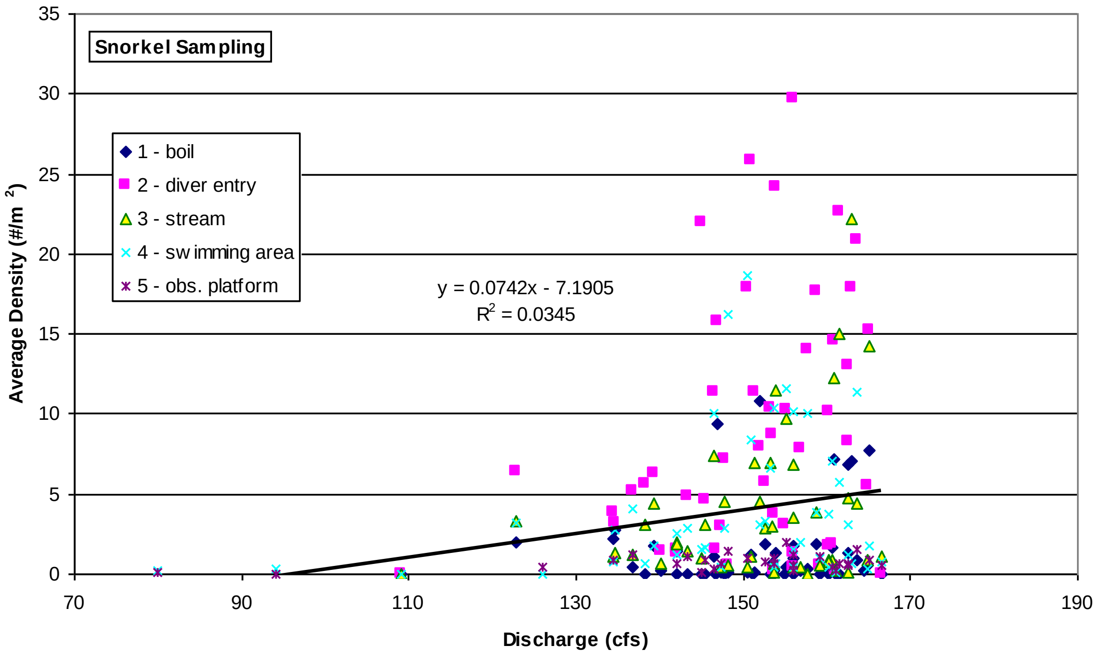
The existing fish population data are fairly detailed and can be used to provide a preliminary assessment of the effects, if any, of minimum flows on fish habitat. **Figure 3-6** illustrates the observed relationship between measured spring discharge rates and fish density estimates using the available data. A positive correlation between flow and fish density was observed at all stations; however, correlation coefficients were low indicating that factors other than flow are possibly more important in determining fish density in Blue Spring and Blue Spring Run.

Based on the observed variability of fish population numbers observed in Blue Spring Run, and the permissible change in flows under the Blue Spring MFR, no measurable (statistically detectable) changes to fish populations are anticipated. Since stage is not expected to change as a result of the Blue Spring MFR, there is no anticipated effect on fish passage.

3.4.5 Manatees

Manatee use has been documented at Blue Spring State Park and constitutes one of the only fairly complete wildlife datasets that can be applied to the analysis at hand. Although these manatee data are reviewed and analyzed elsewhere (Rouhani *et al.* 2006), the following summary illustrates an analysis method that could be applied to other key wildlife species (such as fish, reptiles, amphibians, mammals, and birds) if adequate data were available.





Source: Stetson University Department of Biology

FIGURE 3-6
Blue Spring Discharge and Average Fish Density Relationship (12/2000 - 3/2002)

Figure 3-7 summarizes monthly average manatee counts in Blue Spring Run for the period from 1979 through 2006. Average annual manatee counts have increased throughout this period of record. As illustrated in **Figure 3-8**, average monthly manatee numbers in Blue Spring Run are inversely correlated with air temperature ($R^2 = 0.40$) and can be predicted quite well based on Julian day (**Figure 3-9**). Average monthly manatee numbers are poorly correlated with spring discharge (**Figure 3-10**). This correlation indicates that under current conditions, other factors (such as temperature and cold water intrusion length) are controlling manatee use of Blue Spring Run.

It is intuitively clear that winter manatee use would decline precipitously if spring discharge were decreased dramatically below existing ranges. Decreased discharge will result in greater cold water intrusions in the downstream portion of the Blue Spring Run, potentially reducing warm-water habitat (Rouhani *et al.* 2006). The warm-water length in the spring run in turn controls the availability of useful winter manatee habitat. However, the ability of manatees to pack more closely in the spring run during critical conditions further complicates the determination of minimum flows.

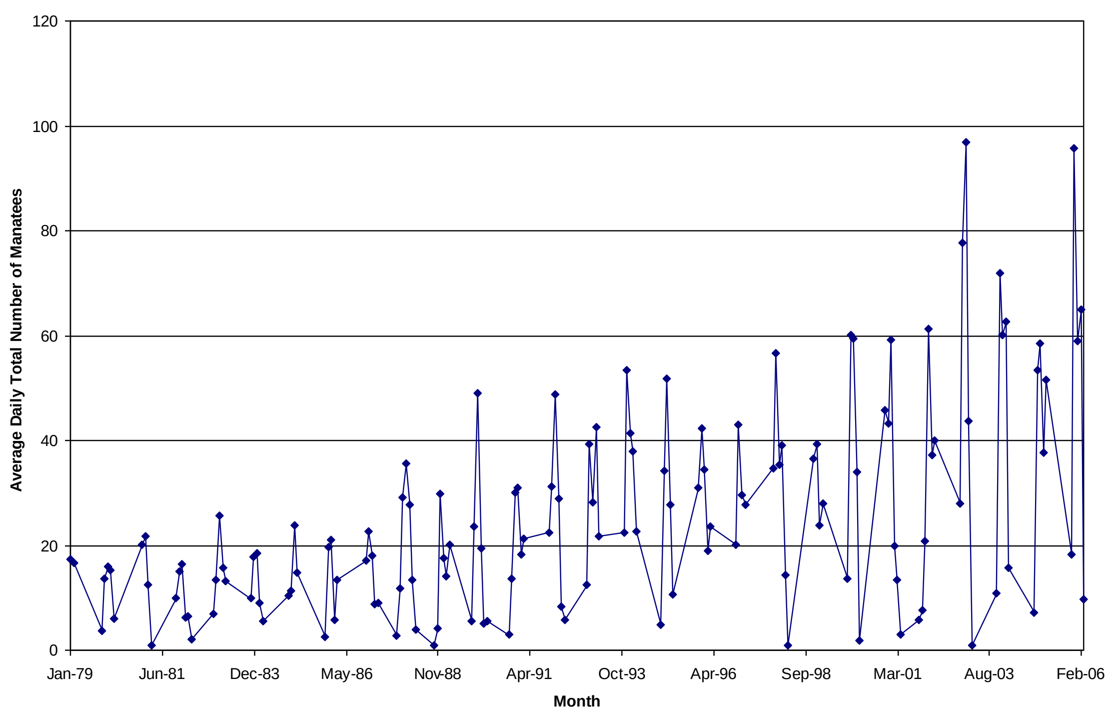


FIGURE 3-7

Monthly Average Daily Total Number of Manatees Surveyed in Blue Spring, Volusia County, Florida

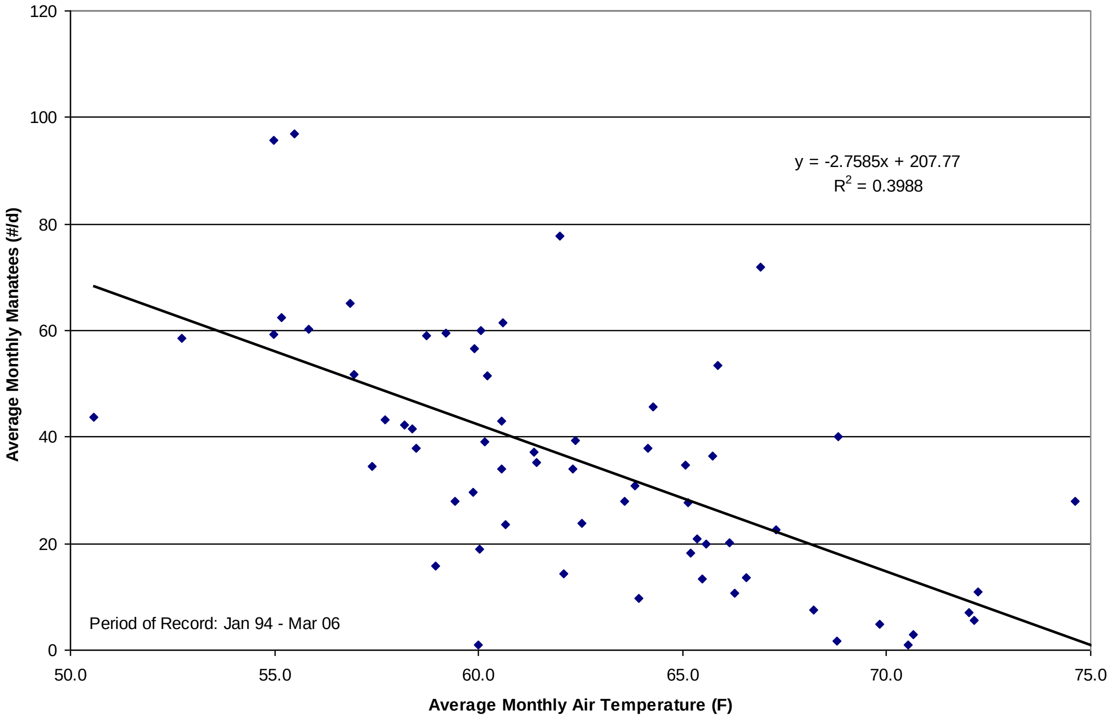


FIGURE 3-8
Blue Spring State Park Average Monthly Air Temperature vs. Average Monthly Manatee Count

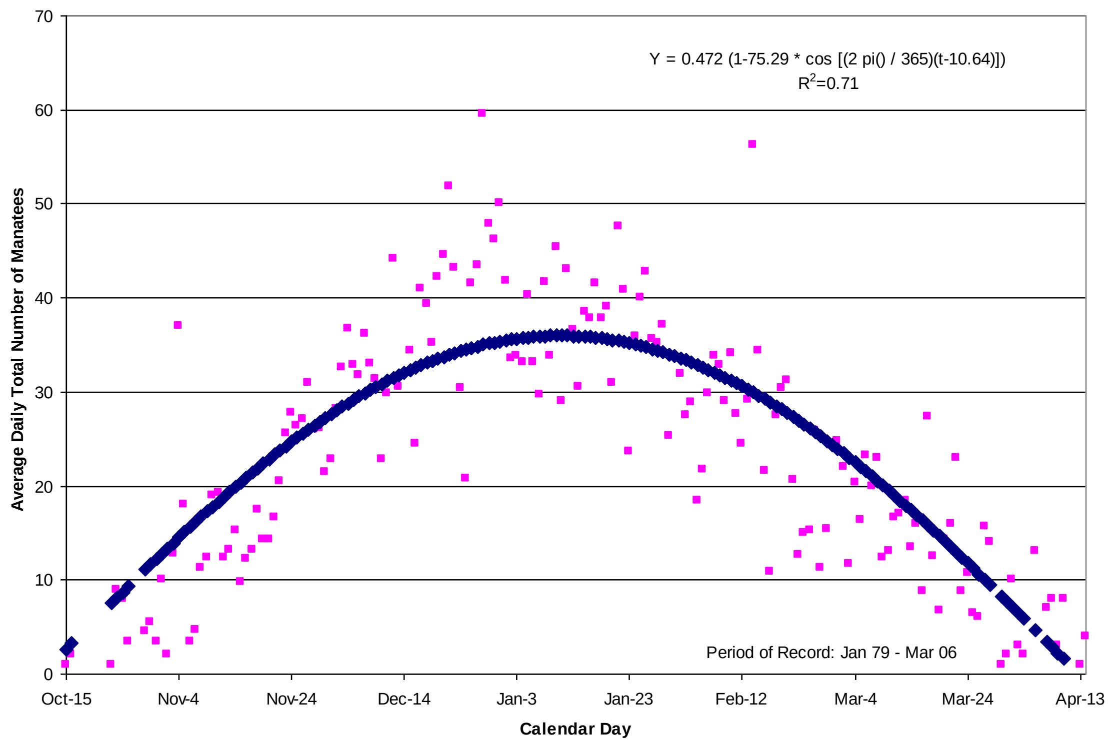


FIGURE 3-9
Daily Average Number of Manatees Surveyed in Blue Spring, Volusia County, Florida

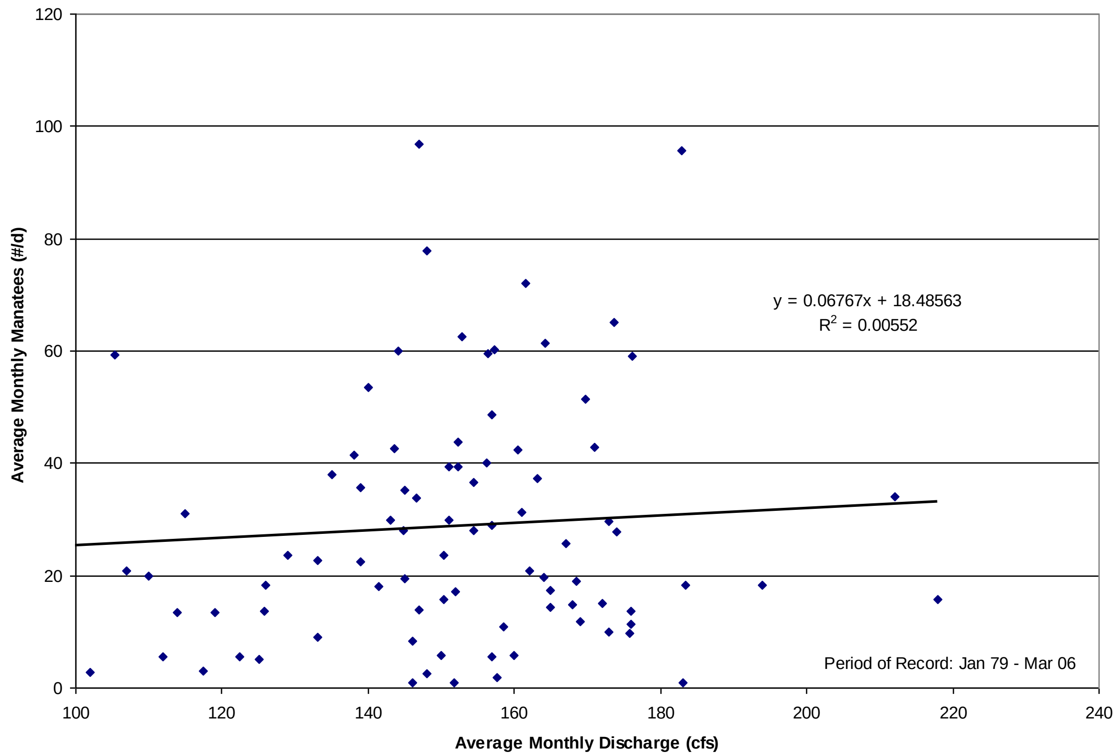


FIGURE 3-10
Blue Spring Average Monthly Discharge vs. Average Manatee Count

Rouhani *et al.* (2006) determined that: "Existing spring flow conditions provide adequate winter manatee refuge, even during extreme catastrophic events." A minimum long term mean flow of 132 cfs was predicted to accommodate the current manatee population using Blue Spring as a winter warm-water refuge. However, since manatee use is expected to continue to increase, the amount of available warm-water habitat will need to be larger. For this reason they concluded that a greater long term mean flow will be required over time. Additionally, Rouhani *et al*. (2006) showed conclusively that, water levels in Blue Spring Run are controlled by stages in the St. Johns River, and concluded that there will be no effect of water depth on manatee populations as a result of the recommended Blue Spring MFR.

3.4.6 Summary

These analyses illustrate how simple correlations can be used as a first step in searching for a relationship between wildlife populations and spring discharge. However, due to the complexity of wildlife environmental requirements, more complex models would likely be needed to more fully evaluate the possible effects of Blue Spring MFR on additional wildlife species. The relatively narrow range of existing flow data and wildlife population numbers limits the ability to make conclusions concerning the effects of very low flows on most wildlife species. A review of the best available information did not reveal any information that indicates that the recommended Blue Spring MFR would be unacceptable for other wildlife species.

Based on existing limited information it is concluded that existing populations of fish and wildlife using Blue Spring and Blue Spring Run will be protected by the Blue Spring MFR. This conclusion is made in light of the limited dependence of most of the wildlife species on the spring and spring run, their assumed ability to recolonize the run from the adjacent St. Johns River and surrounding wetlands and uplands if their populations were depleted for any reason, and the normal amount of actual variability expected in wildlife population numbers and occurrence. Given the 15% maximum temporary reduction in long term mean spring flow allowed by the Blue Spring MFR, it is considered unlikely that a detectable change in wildlife numbers and biomass could be documented. However, greater reductions in long term mean spring flows than those that would be permissible under this Blue Spring MFR could result in measurable changes in populations of dependent wildlife species in addition to manatees, and result in significant harm to this WRV. Since there is no change in stage anticipated as a result of the recommended Blue Spring MFR, there is no foreseeable impact of levels on the populations of any of the fish and wildlife species using Blue Spring and Blue Spring Run.

3.5 Estuarine Resources

The temporary reduction in Blue Spring discharge resulting from the Blue Spring MFR is expected to have negligible effects on downstream estuarine resources near the northern end of the St. Johns River. ECT (2002) concluded that a 320 cfs maximum surface water withdrawal from the St. Johns River near Deland would provide protection of the estuarine resources in the lower river. The temporary reduction of the long term mean flow by 25 cfs allowed by the Blue Spring MFR is accounted for in the 320 cfs maximum surface water withdrawal and, therefore, will not result in cumulative impacts downstream. Some fish and other wildlife species that are predominantly or partially dependent upon estuaries and saltwater for critical life history requirements are periodically found in Blue Spring Run (e.g., tarpon, American eel, striped mullet, etc.). Protection of these species from significant harm due to decreased flows was considered above in Section 3.4. For these reasons, the estuarine resources WRV was not considered further.

3.6 Transfer of Detrital Material

Detrital materials are organic solid materials resulting from the shedding of plant and animal tissues during normal growth and death processes. For example, freshwater and saltwater marshes lose large quantities of senescent plant leaves and stems that may be flushed out to adjacent water bodies by the tides (Mitsch and Gosselink 2002). Large populations of snails, fish, and birds produce wastes that may be transported and concentrated within an aquatic ecosystem. Streams and rivers adjacent to forested wetlands and uplands receive large amounts of plant detritus in the form of leaves and branches. All forms of detrital material may have value within an aquatic ecosystem. These organic materials retain nutritive value for populations of microbes and benthic insects and are the basis of a detrital food web.

Detritus entering a stream is often transported and re-distributed to adjacent waters where it may support additional community production. Relative to Blue Spring, the origins of detrital materials are primarily the leaves and twigs falling from trees and shrubs in the watershed and the internally produced wastes of the fish and manatee populations. The processing (physicochemical and biological) and transport of these materials is flow dependent. Flow reductions greater than those determined to be sufficient to protect manatees' use of Blue Spring as a winter warm-water refuge could limit the transport of detrital materials and thereby reduce productivity of adjacent aquatic ecosystems.

Detrital transport can be measured by quantifying the volatile fraction of total suspended solids (VSS). Upstream-downstream measurements for VSS are recommended (**Table 3-2**).

The Blue Spring conceptual ecosystem model (**Figure 2-7**) lumps detritus and microbial decomposers (bacteria, fungi, protozoans, etc.) into a single storage compartment (Detritus/Microbes). This compartment is important ecologically because of the function it plays in degrading dead materials and recycling critical chemical elements back to the aquatic ecosystem. In addition to recycling nutrients back to the water column, the Detritus/Microbe compartment serves as a food source for many of the spring's smaller consumer organisms such as aquatic insects and snails. The interactions between these living and non-living compartments could be illustrated at much greater detail in order to better define specific effects of flows and levels on this WRV. However, for the purposes of this report, the overall function of detrital transport is considered as a single lumped process.

There are no existing quantitative estimates for production and transport of detrital materials in Blue Spring Run. It can be expected that a predominance of detrital inputs to the spring run occurs during the autumn months through leaf fall. Based on existing observations in the spring run there are no apparent deposits of this material, indicating that existing flows are sufficient to transport the detritus that is not immediately consumed in the run out to the St. Johns River. These observations are supported by the low hydraulic residence time (HRT) estimated for the spring run (average about 1.7 hrs) and the high estimated average velocity (12 cm/s or 0.4 ft/s). Due to the expected relatively high variability in the amount of detrital material transported by Blue Spring Run and the maximum allowed temporary reduction in the long term mean flow, it is concluded that this WRV will be adequately protected by the Blue Spring MFR. Also, due to the lack of any estimated stage change as a result of the Blue Spring MFR, it is considered unlikely that detrital transport will be affected by stage. In an effort to further characterize the importance of this WRV, preliminary data collection on detrital inputs and transport to Blue Spring and Blue Spring Run are recommended in Section 4.

3.7 Maintenance of Freshwater Storage and Supply

Blue Spring does not provide freshwater storage or supply and, therefore, the WRV requiring maintenance of freshwater storage and supply was not further considered in this report.

3.8 Aesthetic and Scenic Attributes

Recreational use of Blue Spring State Park was described above under Section 3.3 (Recreation In and On the Water). Perhaps the major component of the park's use is for aesthetic and scenic purposes. Aesthetic and scenic attributes noted at Blue Spring State Park included: viewing scenery, watching wildlife (especially manatees but also fish and birds), breathing clean air, and swimming in clean water on a hot day. **Figure 2-7** illustrates how humans using the park interact passively with scenery and wildlife to derive aesthetic benefits. Detailed examination of each type of aesthetic benefit would require quantification of each wild organism (plant and animal) that people view when they use the park. Since the potential effects of the Blue Spring MFR on those biological components of Blue Spring and Blue Spring Run were discussed earlier, they are not repeated here.

Aesthetic uses are generally estimated through subjective surveys of resource users. A list of possible approaches for quantifying aesthetic and scenic attributes at Blue Spring includes the following:

- Park exit opinion survey
- Newspaper public service questionnaire
- Student essays on their favorite impressions from visiting the park
- Writing and art workshops to allow expression of subjective opinions about the park and its wildlife

Table 3-2 recommends that park exit surveys be conducted on a regular basis to assess aesthetic and scenic attributes of Blue Spring and Blue Spring Run.

Based on the available information, it is concluded that the Blue Spring MFR will also protect aesthetic and scenic attributes. This conclusion is based on the District's goal to protect manatee use and the observed relationship between manatee and human use at

Blue Spring State Park. Actual quantitative data to assess the effects of the recommended Blue Spring MFR on other aesthetic and scenic uses are not available. Monitoring of user's opinions is recommended to better assess the public's perception of the importance of spring flows on these subjective functions. Since it is estimated that the water level in Blue Spring and Blue Spring Run will not be affected by the Blue Spring MFR, then there is no effect of stage expected for aesthetic and scenic attributes.

3.9 Filtration and Absorption of Nutrients and other Pollutants

3.9.1 Introduction

Most aquatic ecosystems naturally assimilate water-borne pollutants (Metcalf and Eddy 1991; Kadlec and Knight 1996). This fact has been observed over the past few centuries as wastewater has been released to rivers and wetlands and astute observers have noticed that, as long as they are not over-loaded, most aquatic systems cleanse themselves downstream of the point of discharge. The reasons behind this assimilation potential of aquatic ecosystems are primarily related to the metabolic activity of microbes (i.e., bacteria, fungi, algae, and protozoa) in aquatic environments. These organisms assimilate many organic compounds, macro- and micro-nutrients, as well as trace elements, and other dissolved and particulate compounds. Microbes generally transform some of those pollutants to non-polluting forms through their normal metabolic processes. Similar pollutant assimilation and transformation processes occur in streams, lakes, wetlands, and in man-made wastewater treatment systems. **Figure 2-7** illustrates the multiple interactions between the water content of nutrients and other possible pollutants in Blue Spring Run. Detailed mini-models could be prepared for each individual water quality constituent to illustrate possible effects of flow rate and water depth (stage). A few examples provided below illustrate some of the complexity of these interactions.

The ability of aquatic systems to assimilate pollutants is tied to the volumetric flow of the water. Flow rate is especially important in streams and rivers because of the effect of current velocity on diffusion of atmospheric gases important in the pollutant assimilation process (e.g., oxygen) and the turbulent enhancement of transport of the pollutants throughout the water column to sites of metabolic activity. Flow rate also affects hydraulic residence time (HRT), and the resulting time available for microbial degradation of pollutants.

Several methods are available to estimate the potential of aquatic systems to transform and assimilate pollutants. One approach is to develop an estimated mass balance that incorporates the effects of all significant loads and removals for each relevant pollutant. Mass loads in the water column are computed based on knowledge of flows and concentrations at upstream and downstream stations. Flow-weighted mean concentrations can also be used for assessing load reduction. For the Blue Spring Run, inflow loads include the spring flow (typically the dominant inflow load), direct rainfall, and non-point and point-source runoff, and litterfall from the surrounding watershed. As long as flows are not very different between upstream and downstream stations (an assumption that is valid in Blue Spring Run), then concentration changes can be used in place of mass loads. Net pollutant load reductions may occur due to chemical transformations and degradation or through sedimentation and storage outside of the water column. Once a pollutant mass assimilation rate is known, then changes in this rate can be evaluated to see if they are correlated to environmental factors, including flows.

The historic record of pollutant assimilation rates in Blue Spring is incomplete. Some mass removals may be estimated from existing flow and concentration data. However, to better quantify this WRV, it will be necessary to develop a more complete water quality monitoring program as a benchmark for comparison of future rates and to assess the effects of the Blue Spring MFR on those rates.

3.9.2 Filtration and Absorption of Nutrients and Other Pollutants Metrics

The filtration and absorption of nutrients and other pollutants WRV can be assessed by preparing mass balances for the following representative nutrients and pollutants:

- Nitrogen forms (organic N, ammonium N, nitrate+nitrite N, total N)
- Phosphorus forms (particulate, dissolved organic, soluble reactive, total P)
- Trace metals (e.g., copper, iron, lead, mercury, zinc, etc.)

- Trace organics (e.g., pesticides, acid/base extractables, chlorinated hydrocarbons, etc.)

Nine specific mass balances are recommended in **Table 3-2**. Upstream and downstream loads are calculated by multiplying flow and concentration, and the difference is the net assimilation (or increase) in the pollutant's load. To be complete in this analysis, upstream loads should include the contribution of the spring boil, as well as atmospheric loads in wet and dry fall and non-point source runoff loads from the surrounding watershed. Once load reductions (or increases) are estimated over a period of record, they can be correlated to Blue Spring flows.

As mentioned earlier in Section 3.4.2, springs provide an excellent venue for estimation of mass load reductions. This advantage is due to their relatively constant inflow concentrations and flow rates (quasi steady-state). They are also close to constant-temperature environments, resulting in relatively constant constituent degradation rates over the annual climatic cycle. The main limitation to quantifying pollutant assimilation rates in a high-flow spring run is the relatively short HRT (average nominal HRT is about 1.7 hrs in Blue Spring Run) and resulting relatively small net changes in constituent concentrations between the upstream and downstream sampling stations. Very high turbulence in the spring run leads to a well-mixed water column and reduced need for replicate sampling. However, analytical techniques must be precise to detect relatively small concentration changes. Downstream samples must be collected above the point of influence of the backwaters from the St. Johns River.

3.9.3 Estimated Existing Pollutant Assimilation Rates

Some data are available to begin quantification of existing pollutant assimilation metrics for Blue Spring Run. Limited overlapping upstream/downstream water quality data are available for total nitrogen (TN) and total phosphorus (TP). However, some of these data sets were collected by different researchers and analyzed by different methods. Because of these differences, estimates of assimilation (or pollutant increases) are preliminary.

Upstream mass loading was calculated based on the product of the spring flow and the concentration of the constituent in the spring boil. The watershed and rainfall contribution was estimated based on the existing watershed landuse and runoff coefficients obtained from the District (Di 2002). The Blue Spring Run surface watershed above the downstream water quality station (150 m upstream from the mouth of Blue Spring Run) is approximately 63.4 acres in size. This watershed is comprised of 7 distinct landuse categories: forest regeneration areas (29%), mixed coniferous/hardwood forest (21%) residential, low density (17%), mixed wetland hardwoods (15%), pine flatwoods (13%), the spring run itself and other small feeder streams (4%), and other recreational areas (1%) (SJRWMD 2006). The "Marinas and Fish Camps" landuse shown on **Figure 3-11** is downstream of this water quality monitoring station and not included in this analysis. **Table 3-7** provides a summary of the seasonal runoff estimates, the seasonal runoff water quality coefficients, and the estimated annual mass runoff loading at the downstream water quality monitoring station.

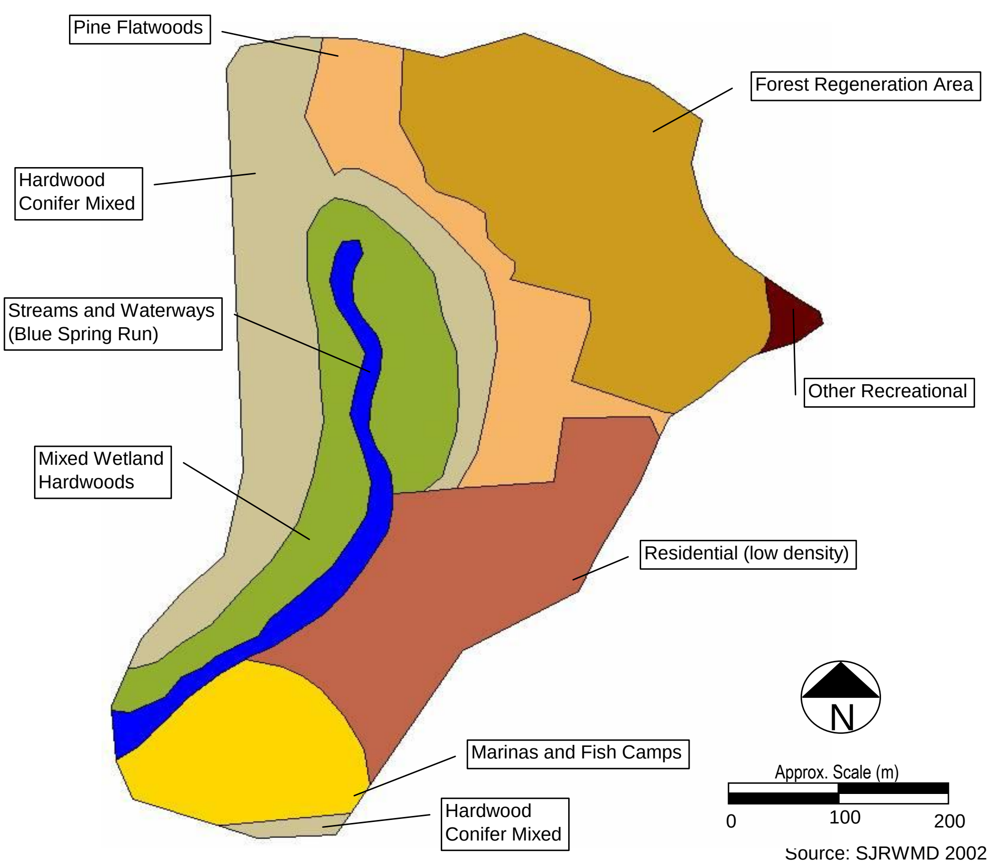


FIGURE 3-11
Land Use for the Blue Spring Watershed - 2000

TABLE 3-7

Blue Spring Run, Volusia County - 2000 Watershed Land Use and Estimated Mass Loadings

Land Use	LU Code	Area (ac) DS Stn 2000	EMC's TN (mg/L)	EMC's TP (mg/L)	Est. Runoff Coefficient (fraction)	Est. Runoff (m^3/yr)	Est. Loading to Blue Spring Run (kg/yr) TN	TP
Residential, low density	1100	10.9	2.29	0.30	0.40	24,290	55.6	7.29
Pine flatwoods	4110	8.3	1.25	0.05	0.05	2,439	3.05	0.122
Hardwood Conifer Mixed	4340	13.2	1.25	0.05	0.05	3,868	4.83	0.193
Mixed Wetland Hardwoods	6170	9.3	1.25	0.05	0.05	2,570	3.21	0.128
Streams and waterways	5100	2.5	1.25	0.11	0.75	10,324	12.9	1.14
Forest Regeneration Areas	4430	18.7	1.25	0.05	0.05	5,176	6.47	0.259
Other Recreational	1890	0.6	1.25	0.05	0.05	0,155	0.194	0.008
	Total	63.4					86.3	9.1

DS Stn - Land use (LU) area upgradient of downstream WQ station (150 yards from SJ River)

Average Rainfall (in) 54.0

Table 3-8 provides preliminary estimates of nutrient mass assimilation rates. Estimated loads from the watershed are small compared to loads in the spring flow (less than 0.1%). The estimated mass removal rate for TN was 22.5 kg/ha/d (20.1 lb/ac/d) with a removal efficiency of about 8.5%. Total phosphorus was assimilated at an estimated rate of 4.3 kg/ha/d (3.8 lb/ac/d) for an estimated removal efficiency of about 17.7%. It must be noted that the results in **Table 3-8** are preliminary and are included in this report to illustrate a methodology rather than to form the basis for final conclusions. These results need to be confirmed by synoptic upstream/downstream water quality measurements and a revised analysis when more complete data are available.

TABLE 3-8

Preliminary Estimates of Representative Pollutant Mass Assimilation Rates in Blue Spring

Parameter	Estimated Watershed Load (kg/yr)	Boil Conc. (mg/L)	Estimated Boil Load (kg/yr)	Downstream Conc. (mg/L)	Estimated Downstream Load (kg/yr)	Estimated Difference (kg/yr)	Estimated Mass Removed (kg/ha/d)
TN	86	0.79	107,207	0.72	98,215	9,079	22.5
TP	9	0.072	9,833	0.060	8,103	1,738	4.3
	Average Flow (cfs):		152				
	Spring Run Area (ha):		1.10				

Notes

4/23/02 outlier removed from average (TP = 0.84 mg/L)

POR = 9/01 - 7/04

3.9.4 Summary

Existing data from Blue Spring are not available to precisely determine the effects of spring discharge and stage on rates of pollutant assimilation. It is not necessarily intuitive how pollutant assimilation rate might be a function of flow rate. On one hand, HRT would increase as flow decreases and pollutant assimilation is known to be a direct function of HRT. However, the total pollutant load to Blue Spring Run would be lower at low flows and assimilation rates are known to be correlated with loading rates. While the second effect probably dominates, conflicting factors would be at work if average flows were reduced. An empirical data set that carefully quantifies pollutant assimilation rates under varying flow conditions would be useful to more accurately assess the impact of the Blue Spring MFR on this WRV metric.

Based on best available information from Blue Spring and based on the typical variability in estimated pollutant filtration and absorption rates, it is tentatively concluded that there will not be a measurable change in this WRV within the range of the temporary flow reduction allowed by the Blue Spring MFR. However, a larger flow reduction of undetermined magnitude would probably result in a significant reduction in this WRV. Also, because the Blue Spring MFR will not have any effect on spring run stages, there is not expected to be any affect of the future water level on filtration and absorption of nutrients and other pollutants.

3.10 Sediment Loads

3.10.1 Introduction

Sediments are mineral and organic solid materials that settle in aquatic systems. Relative to Blue Spring, the origins of these materials are: erosion of upland soils and over-hanging banks during heavy rains, leaves and twigs falling from trees and shrubs in the watershed, and mineral or organic based materials being transported through the spring vent. The processing (physicochemical and biological) and transport of these materials is flow dependent. The Blue Spring Run conceptual model illustrated in **Figure 2-7** incorporates this WRV within the water column as total suspended solids (TSS). The non-volatile component of TSS is of particular relevance and a metric for estimation of this WRV is described below.

Decreased flows will reduce velocity and result in greater sediment load reduction in Blue Spring Run. At the same time, flow reduction could conceivably result in a diminution of the sustainable sediment load reduction capacity of aquatic systems. While this WRV attempts to preserve the sediment load reduction capacity of aquatic systems, a high rate of sedimentation might be an ecological problem due to smothering of benthic habitat. For example, decreased flows will result in sediments settling out closer to the spring boil and increased rates of sediment accumulation above the sustainable rate that allows adaptation and maintenance of benthic biota. However, there does not appear to be an existing problem with creation of sediment loads to Blue Spring and Blue Spring Run, due to the limitations on human access and the highly vegetated watershed.

No historical data are available for mineral sediment loads in Blue Spring Run. It is recommended that preliminary monitoring be conducted to assess the level of this function at Blue Spring and to serve as a baseline for comparison of future conditions.

3.10.2 Sediment Load Metric

Sediment load may be quantified in the same way as other pollutants. Inflow loads can be estimated by documenting inflow water quality (non-volatile suspended solids) and flows from the spring boil and from the surrounding watershed. Outflow sediment loads can be determined from downstream mass balance estimates. The net difference is the sediment assimilation within the spring run. Based on repeated estimates of these upstream and downstream mass loads over time, this load reduction can be correlated with spring flows.

3.10.3 Estimated Existing Sediment Load Assimilation Rate

Limited upstream/downstream water quality data were available for TSS, one approximate measure of suspended sediments. A preliminary estimate of the watershed contribution of total suspended solids to Blue Spring using the same approach as described above for nutrients is 940 kg/yr (2,066 lb/yr). An estimated mass removal rate of TSS from the water column based on limited historic data was 87 kg/ha/d (77 lb/ac/d) over about 65% of the spring and spring run area. Mineral sediments cannot be decomposed or truly assimilated; they can only be removed by deposition. Since major sediment deposits were not observed in this area of the spring run, it is assumed that the estimated reduction of TSS is actually assimilation of volatile suspended solids (biological materials) rather than suspension and deposition of mineral solids. Additional monitoring is recommended to better quantify the respective fractions of TSS and VSS in Blue Spring and Blue Spring Run and the removal of mineral sediment loads in this aquatic system as a function of flow.

3.10.4 Summary

The mass removal of sediment loads in Blue Spring and Blue Spring Run is expected to be relatively variable due to the variability in measured concentrations of TSS at the upstream and downstream stations (92 to 120% coefficient of variation in the means based on historic data). For this reason it is concluded that the reductions in flow permissible under the Blue Spring MFR are not likely to measurably reduce the potential of this aquatic ecosystem to reduce sediment loads. However, this measurement variability could be reduced through more careful and frequent measurement. It is also concluded that the sediment load reduction of Blue Spring Run might be affected by flow, both as a consequence of total load reduction and conversely as a result of increasing residence time. Since stage is not affected by the Blue Spring MFR, it is concluded that assimilation of sediment loads will not be affected as a result of future water levels.

3.11 Water Quality

3.11.1 Introduction

The ambient water quality of Florida surface waters varies in response to environmental conditions such as geology, geography, surrounding land uses and vegetative cover, human uses, climate, atmospheric inputs, and seasonal and daily solar rhythms. Even in the absence of human influences, water quality is expected to vary due to the factors listed above. Additional variation may result from human-caused activities. **Figure 2-7** illustrates the complex interaction of water quality with all of the living and non-living components of the spring ecosystem. A few examples of these types of interactions are described below (Section 3.11.4) for dissolved oxygen and specific conductance.

There are many constituents that comprise water quality. These constituents can be quantified by physical, chemical, and biological measurements. Examples of physical measurements of water quality include: temperature, specific conductance, and secchi depth. Examples of measures of chemical water quality include: dissolved oxygen, total iron, TP, and salinity. Examples of biological water quality measures include: fecal coliforms, macroinvertebrate diversity, and algal growth potential. All of the many water quality measures vary within typical ranges characteristic of the water body. The range of these variations has been the subject of considerable research in Florida. FDEP has published a database on the ranges of major water quality measures in Florida surface waters (FDEP 1989).

Of all aquatic ecosystems in Florida, springs fed by deep artesian aquifers such as the Floridan aquifer, have the most constant water quality. While there may be large water quality differences among different springs that are fed from different regions of the Floridan aquifer, a single spring system typically has relatively less temporal water quality variation (Rosenau *et al.* 1977; Scott *et al.* 2002). This reduced susceptibility to water quality variation is reflected in long-term recording of water quality in a number of Florida's largest springs (Rosenau *et al.* 1977; Scott *et al.* 2002). For example, Scott *et al.* (2002) report Volusia Blue Spring water quality for the years 1946, 1960, 1972, and 2001. Although analytical methods have changed somewhat within this period and there are some diurnal and seasonal patterns in spring water quality, average temperature only varied between 23.0 and 23.1 degrees Celsius (°C), pH ranged from 7.2 to 7.8, calcium varied from 52 to 76 milligrams per liter (mg/L), and alkalinity from 105 to 142 mg/L as $CaCO_3$.

The largest reported change by Scott *et al.* (2002) for Volusia Blue Spring was an increase in nitrate and nitrite nitrogen (NO_x-N) from 50 to 640 µg/L (based on limited data). Nitrate contamination of springs has been documented in many areas of Florida due to human activities in the contributing watershed such as septic tank drainfields and intense livestock operations (especially dairies) (Scott *et al.* 2002). The apparent increased concentration of this parameter might be an indication of such pollution in the Blue Spring springshed (FDEP 2000).

Flows and levels in springs and in other aquatic ecosystems affect water quality maintenance directly through their effects on physical water quality, on chemical water quality because of increased HRT or lower dilution rates for allocthonous (external) inputs, or due to indirect effects, such as those described above in Section 3.9 (Filtration and Absorption of Nutrients and Other Pollutants).

3.11.2 Water Quality Metrics

There are too many water quality constituents in Blue Spring to allow use of all possible metrics for consideration during the establishment of the appropriate MFR. Therefore, it is helpful to identify subclasses of water quality metrics, and then choose metrics within those categories that are generally representative of all possible water quality constituents. **Table 3-2** provides a list of 15 recommended water quality metrics that should span the breadth of normal water quality considerations for evaluating this WRV with regard to Blue Spring and Blue Spring Run.

The simplest and most available metric for all of these water quality parameters is the time series measurement of concentration or intensity. The ideal metric would be a time series of measurements at multiple stations to allow integration of the concentration or intensity over the entire spring boil and run. This ideal data set is not available, but data for many water quality parameters do exist from two to three discrete stations within the system.

There are two uses that can be made of these water quality metrics. The first is development of correlation analyses between each water quality parameter and flow. If there is a significant correlation, then that relationship may be useful to estimate the effect of reducing flows on the specific water quality indicator. In some cases reducing flow may increase the concentration of a water quality constituent. In other cases reducing flow may result in a lower concentration.

The second use of the water quality metrics is to evaluate the effect of flow on the upstream-downstream concentration changes observed for each water quality parameter. This net change represents a functional aspect of the spring run. For example, the concentration of dissolved oxygen increases between the spring boil and the downstream reach of the run, in response to atmospheric inputs and primary productivity. Diffusion and primary productivity are both known from other studies to be directly correlated with flow rate. Temperature will change in response to flows and atmospheric conditions.

Concentrations of salts, alkalinity, and color will change in response to other ecological processes (e.g., weathering of parent rock and the leaching of tannins into the spring run from leaf litter) active within the spring run.

3.11.3 Existing Water Quality Data

Table 3-9 summarizes the existing water quality data obtained for Blue Spring and Blue Spring Run and Florida Class III water quality criteria for comparison (Chapter 62-302.530, *FAC*). These existing water quality data were gathered from numerous sources including:

- U.S. Environmental Protection Agency STORET database (http://oaspub.epa.gov/storpubl)
- Florida Department of Environmental Protection (Bennett 2002, http://www.dep.state.fl.us/labs/library/springs.htm)
- Florida Geological Survey (Scott *et al.* 2002)
- St. Johns River Water Management District (Hall 2002; Sucsy 2002)
- Stetson University Department of Biology (Work 2006)
- U.S. Geological Survey (Dickerson 2002; USGS 1995, http://waterdata.usgs.gov/nwis)
- Volusia County Environmental Health Department (Maday 2002; Rawlins 2002)

Based on this review, there is an incomplete water quality data record for Blue Spring. Many of the data summarized in **Table 3-9** are relatively old (more than 20 years) and may not be easily compared to more recent data, due to improvements in analytical techniques since that time. Where recent data are available they indicate that there has not been any apparent change in quality of the spring water, except for inorganic (NO_x) nitrogen concentrations.

As water exits the spring boil it is essentially groundwater with quality typical of the Floridan aquifer (Fernald and Patton 1984). Average water temperature at the spring boil was about 23.0 ^{o}C with a very narrow range from 22.6 to 24.0 ^{o}C (**Table 3-9**). Average temperature increased downstream (between Stations 4 and 5 in **Figure 2-2** to 23.0 ^{o}C with a wider range of recorded values (21.5 to 24.5 ^{o}C).

TABLE 3-9
Historic Summary of Water Quality in Blue Spring and Blue Spring Run, Volusia County, Florida and Applicable Florida Class III Criteria

Parameter	Units	Location	Class III Criterion	Average	Minimum	Maximum	Std Dev	CV (%)	Count	Period of Record	
Water Temperature	^{o}C	Upstream		23.0	22.6	24.0	0.21	0.92	40	6/20/00	7/20/04
		Swim Area	--	23.1	22.5	23.7	0.20	0.85	54	11/6/98	7/28/05
		Downstream		23.0	21.5	24.5	0.23	0.99	2,650	3/7/32	8/17/06
Turbidity	JTU	Upstream	<29 above	0.256	0.00	2.00	0.412	161	22	10/24/01	7/20/04
		Swim Area	natural	0.308	0.10	1.40	0.217	70.3	44	11/6/98	7/28/05
		Downstream	background	2.21	0.00	12.5	3.86	175	26	5/23/70	10/22/02
Color	PCU	Upstream	--	0.68	0.00	5.00	1.76	258	22	10/24/01	7/20/04
		Swim Area		6.59	5.00	20.00	3.54	53.7	44	11/6/98	7/28/05
		Downstream	--	3.18	0.00	30.0	4.25	134	64	11/1/60	9/6/05
Specific Conductance	umhos/cm	Upstream	< 50%	1,578	848	2,333	364	23.1	47	6/20/00	7/20/04
		Swim Area	increase	1,416	842	2,190	324	22.9	54	11/6/98	7/28/05
		Downstream		1,474	213	2,620	297	20.1	4,619	11/1/60	8/17/06
Dissolved Oxygen	mg/L	Upstream		0.65	0.05	6.70	1.02	156	41	6/20/00	7/20/04
		Swim Area	>5.0	1.32	0.44	4.30	0.60	45.1	54	11/6/98	7/28/05
		Downstream		1.39	0.20	3.30	0.66	47.8	56	5/9/67	9/6/05
BOD	mg/L	Upstream	--	0.235	0.170	0.300	0.092	39.1	2	1972	2001
		Downstream		0.420	0.00	1.00	0.282	67.2	10	5/23/70	10/22/02
COD	mg/L	Downstream	--	12.4	2.70	22.0	13.6	111	2	5/23/72	9/2/77
pH	SU	Upstream		7.21	6.77	7.80	0.187	2.59	41	6/20/00	7/20/04
		Swim Area	+/- 1 unit	7.34	7.00	7.66	0.136	1.86	54	11/6/98	7/28/05
		Downstream		7.51	3.30	8.40	0.559	7.44	99	11/1/60	9/6/05
Alkalinity	mg/L as CaCO3	Upstream	>20	135	130	139	3.01	2.23	10	3/18/02	10/22/02
		Swim Area		139	125	151	5.60	4.04	44	11/6/98	7/28/05
		Downstream		117	0.500	139	23.3	19.9	31	11/1/60	10/22/02
Total Dissolved Solids	mg/L	Upstream		846	449	1,162	178	21.0	32	6/20/00	7/20/04
		Swim Area	--	810	428	1,180	190	23.5	44	11/6/98	7/28/05
		Downstream		833	452	1,360	182	21.9	58	11/1/60	9/6/05
Total Suspended Solids	mg/L	Upstream		1.56	0.20	7.40	1.43	91.7	34	6/20/00	7/20/04
		Swim Area	--	3.41	0.50	16.00	3.13	92	44	11/6/98	7/28/05
		Downstream		1.25	0.00	3.00	1.50	120	4	2/10/71	10/22/02
Total Nitrogen	mg/L as N	Upstream		0.80	0.57	1.05	0.11	13.1	17	10/24/01	7/20/04
		Swim Area	note a	0.60	0.06	1.01	0.17	28.2	41	11/6/98	7/28/05
		Downstream		0.56	0.15	1.04	0.21	37.4	43	6/13/73	4/8/04
Total Organic Nitrogen	mg/L as N	Upstream		0.172	0.14	0.225	0.032	18.6	10	12/18/01	7/20/04
		Swim Area	--	0.105	-0.29	0.360	0.102	97.7	41	11/6/98	7/28/05
		Downstream		0.101	-0.08	0.310	0.090	89.3	49	5/23/70	4/8/04
Ammonia Nitrogen	mg/L as N	Upstream	note b	0.02	0.01	0.10	0.03	142	10	12/18/01	7/20/04
		Swim Area		0.05	0.00	0.14	0.04	85.8	44	11/6/98	7/28/05
		Downstream		0.08	0.01	0.18	0.05	60.8	45	2/10/71	4/8/04
Nitrate+Nitrite Nitrogen	mg/L as N	Upstream		0.48	0.13	0.90	0.22	44.9	43	6/20/00	7/20/04
		Swim Area	--	0.44	0.08	0.94	0.20	45.5	44	11/6/98	7/28/05
		Downstream		0.42	0.10	0.85	0.22	51.4	39	5/14/75	4/8/04
Total Phosphorus	mg/L as P	Upstream		0.073	0.061	0.083	0.006	7.99	21	10/24/01	7/20/04
		Swim Area	note a	0.069	0.056	0.084	0.008	11.4	44	11/6/98	7/28/05
		Downstream		0.083	0.010	0.840	0.108	130	53	5/2/72	9/6/05
Orthophosphate, Total	mg/L as P	Swim Area	--	0.057	0.037	0.075	0.011	20.2	44	11/6/98	7/28/05
		Downstream		0.069	0.010	0.100	0.015	21.3	44	5/2/72	4/8/04
Total Organic Carbon	mg/L as C	Upstream		1.75	1.20	2.40	0.345	19.7	12	10/24/01	7/20/04
		Swim Area	--	1.24	0.50	2.88	0.619	49.8	44	11/6/98	7/28/05
		Downstream		13.9	0.00	72.0	21.1	153	13	4/26/71	4/21/80
Hardness	mg/L as $CaCO_3$	Swim Area	--	267	205	358	37.2	13.9	44	11/6/98	7/28/05
		Downstream		249	190	320	30.8	12.4	23	11/1/60	5/20/81
Fecal Coliform	col/100 mL	Upstream		1.08	1.00	2.00	0.29	26.6	12	10/24/01	7/20/04
		Swim Area	<200	13.4	0.500	180	29.8	222	42	6/10/92	9/24/01
		Downstream		6.67	0.00	24.0	8.91	134	6	2/25/75	10/22/02
Total Coliform	col/100 mL	Upstream		4.40	1.00	30.0	7.66	174	15	10/24/01	7/20/04
		Swim Area	<1,000	47.0	5.00	192	60.6	129	8	10/17/94	9/18/96
		Downstream		318	10.0	1,800	659	207	7	2/25/75	10/22/02
Aluminum, Total	µg/L	Upstream		12.8	3.50	37.5	16.5	130	4	10/24/01	4/13/04
		Swim Area	--	15.8	12.5	45.6	7.8	49.4	44	11/6/98	7/28/05
		Downstream		46.2	0.00	130	39.8	86.1	11	5/23/70	5/20/81
Arsenic, Total	µg/L	Upstream		2.13	1.50	3.00	0.750	35.3	4	10/24/01	4/13/04
		Swim Area	<50	1.30	0.05	4.63	0.930	71	44	11/6/98	7/28/05
		Downstream		0.42	0.00	1.00	0.492	118	6	5/2/72	5/20/81

TABLE 3-9
Historic Summary of Water Quality in Blue Spring and Blue Spring Run, Volusia County, Florida and Applicable Florida Class III Criteria

Parameter	Units	Location	Class III Criterion	Average	Minimum	Maximum	Std Dev	CV (%)	Count	Period of Record	
Cadmium, Total	µg/L	Upstream	<2.32	0.34	0.25	0.38	0.06	18.2	4	10/24/01	4/13/04
		Downstream		1.17	0.00	2.00	0.75	64.5	6	5/2/72	2/5/85
Calcium, Dissolved	mg/L	Upstream	--	63.8	57.4	72.0	4.38	6.86	12	10/24/01	7/20/04
		Downstream		61.4	50.0	72.0	5.40	8.80	56	11/1/60	9/6/05
Chloride,Total	mg/L	Upstream	--	312	170	420	76.7	24.6	11	10/24/01	7/20/04
		Swim Area		354	161	553	101.0	28.5	44	11/6/98	7/28/05
		Downstream		404	110	1,000	116	28.7	198	11/1/60	9/6/05
Chromium, Total	µg/L	Upstream	<437	0.96	0.35	1.50	0.47	49.0	4	10/24/01	4/13/04
		Swim Area		1.13	1.00	2.06	0.25	22	44	11/6/98	7/28/05
		Downstream		6.00	0.00	10.0	4.90	82	4	5/23/70	2/5/85
Copper, Total	µg/L	Upstream	<25.9	2.19	1.25	3.00	0.747	34.1	4	10/24/01	4/13/04
		Swim Area		1.12	1.00	2.07	0.244	22	44	11/6/98	7/28/05
		Downstream		10.50	1.00	20.0	13.44	128	2	5/2/72	2/5/85
Iron, Total	µg/L	Upstream	<1,000	10.1	7.50	17.5	4.21	41.5	5	10/24/01	4/13/04
		Swim Area		30.5	25.0	98.3	16.34	53.6	44	11/6/98	7/28/05
		Downstream		90.0	5.00	670	185	206	12	5/2/72	5/20/81
Lead, Total	µg/L	Upstream	<10.2	2.50	2.50	2.50	0.00	0.00	4	10/24/01	4/13/04
		Swim Area		1.16	0.50	10.0	1.39	120	44	11/6/98	7/28/05
		Downstream		6.68	0.00	19.0	6.12	92	11	5/2/72	2/5/85
Magnesium, Dissolved	mg/L	Upstream	--	21.8	13.8	30.4	4.58	21.0	12	10/24/01	7/20/04
		Downstream		23.8	12.6	36.0	5.16	21.7	56	11/1/60	9/6/05
Manganese, Total	µg/L	Upstream	--	2.81	0.630	5.50	1.86	66.2	5	10/24/01	4/13/04
		Downstream		6.67	0.00	20.0	4.92	73.9	12	5/2/72	5/20/81
Nickel, Total	µg/L	Upstream	<342	1.13	0.75	1.50	0.32	28.7	4	10/24/01	4/13/04
		Swim Area		2.64	1.00	16.80	3.34	127	44	11/6/98	7/28/05
		Downstream		6.20	0.00	21.0	8.70	140	5	9/2/77	5/20/81
Silica, Dissolved	mg/L	Downstream	--	8.44	7.40	9.59	0.379	4.49	56	11/1/60	9/6/05
Sodium, Dissolved	mg/L	Upstream	--	166	93.1	234	39.1	23.6	12	10/24/01	7/20/04
		Downstream		193	81.9	301	52.7	27.4	56	11/1/60	9/6/05
Sulfate, Total	mg/L	Upstream	--	49.3	29.0	67.0	10.74	21.8	12	10/24/01	7/20/04
		Swim Area		54.5	28.7	79.3	13.33	24.5	44	11/6/98	7/28/05
		Downstream		52.9	28.1	79.0	12.5	23.7	58	11/1/60	9/6/05
Zinc, Total	µg/L	Upstream	<230	3.22	1.00	7.20	2.39	74.2	5	10/24/01	4/13/04
		Swim Area		5.65	5.00	13.15	2.08	36.8	44	11/6/98	7/28/05
		Downstream		15.0	10.00	20.0	7.1	47.1	2	5/2/72	9/2/77

Stations: Upstream = at spring boil (Stn 1 in Figure 2-2), Swim Area = 280 meters from St. Johns River (Stn 4 in Figure 2-2),
Downstream = 140 meters from St. Johns River (between Stn 4 and 5 in Figure 2-2)
Source: USGS, STORET, Volusia County Environmental Management, Florida Geological Survey, Class III criteria from 62-302.530, FAC
Note a: "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora and fauna"
Note b: un-ionized ammonia < 0.02 mg/L

The primary differentiating factors between this spring water and the average of other Florida springs is a very low dissolved oxygen concentration in the boil (average 0.65 mg/L) and relatively high salt content (total dissolved solids [TDS] = 846 and specific conductance = 1,578 µmhos/cm). Chlorides make up nearly one half of the dissolved salts (average = 312 mg/L) while sodium is present at a lower concentration (average = 166 mg/L).

Average dissolved oxygen increased markedly with distance downstream (average = 1.39 mg/L downstream of the swim area) in response to atmospheric diffusion and primary productivity of attached algae. Detailed dissolved oxygen data were also collected during a series of fish surveys conducted by Stetson University in 2000 – 2004 (Work 2006). These surveys documented dissolved oxygen and fish densities along the length of the run near the shore and in the main channel (**Table 3-10)**. Dissolved oxygen increased from about 0.36 to 0.45 mg/L near the boil to 1.76 to 2.14 mg/L downstream (between Stations 4 and 5 in Figure 2), with higher levels typically in the shallower water near the shore.

TABLE 3-10
Blue Spring Dissolved Oxygen Statistics Collected During Stetson University Fish Survey

		Location				
Statistic	**Units**	**1**	**2**	**3**	**4**	**5**
SHORE						
Average	mg/L	0.45	1.35	1.93	2.00	2.14
Median	mg/L	0.41	1.19	1.60	1.65	1.80
Maximum	mg/L	1.79	5.75	7.31	7.29	10.60
Minimum	mg/L	0.05	0.18	0.33	0.50	0.89
Std Dev	mg/L	0.28	0.87	1.26	1.20	1.25
Count		226	219	213	184	123
CHANNEL						
Average	mg/L	0.36	0.99	1.51	1.73	1.76
Median	mg/L	0.33	0.94	1.35	1.50	1.56
Maximum	mg/L	1.15	3.50	3.77	6.04	5.23
Minimum	mg/L	0.06	0.17	0.41	0.45	0.00
Std Dev	mg/L	0.17	0.46	0.66	0.93	0.76
Count		209	226	219	195	144

Source: Stetson University Department of Biology (Work, 2006)
Statistics from 72 sample events (10/20/00 - 7/22/04)
Station Locations: 1 - boil, 2 - diver entry, 3 - stream, 4 - swimming area, 5 - observation platform (upstream)
Stations Identfied in Figure 2

Particulate matter concentrations in the spring boil are very low as indicated by low turbidity (0.25 JTU) and total suspended solids (1.6 mg/L). Dissolved color is quite low (0.68 PCU) as is biochemical oxygen demand (0.24 mg/L). Alkalinity, hardness, and pH are relatively high due to dissolved calcium carbonate in this spring water (**Table 3-9**).

Nutrient levels are typical of Florida spring waters with an average TN concentration of 0.80 mg/L with 0.17 mg/L in the organic form, 0.02 mg/L as ammonium N, and 0.48 mg/L in the dissolved oxidized form (nitrate + nitrite N). Average TP was measured as 0.073 mg/L with 0.063 mg/L in the soluble reactive P form (**Table 3-9**).

Additional statistics are also listed in **Table 3-9**. The minimum, maximum, standard deviation, coefficient of variation (CV), and count are also listed for each parameter. The CV is relatively small (<10%) for a few parameters such as upstream temperature, pH, TP, calcium, and silica. However, most of the parameters have CVs greater than 20% at both stations with some CVs greater than 200%. Assuming that there may be a correlation with spring discharge, detection of statistically significant changes in the average concentrations for these parameters will be difficult with anything less than a 20% reduction in the long term mean spring flow.

3.11.4 Analysis of Possible Water Quality Changes as a Function of Spring Flow and Stage

Table 3-11 provides linear correlation coefficients for a number of the downstream water quality maintenance metrics and spring discharge and stage. Data scatter plots for these metrics are provided in **Appendix B**. It should be noted that some of these data sets are small and not sufficient to support strong conclusions concerning a relationship between flow and water quality. The following downstream water quality constituent concentrations were positively correlated with spring discharge (concentration increases as flow increases and concentration decreases as flow decreases): NO_x-N, TN, organic nitrogen, TP, copper, and zinc. Water quality metrics that increased with decreasing flow were: calcium, chloride, specific conductance, hardness, alkalinity, TDS, and NH_4-N.

The latter group includes water quality metrics that are most likely to show a possible increase in response to decreased flows in Blue Spring Run. Other metrics (temperature, dissolved oxygen, pH, color, PO_4, and mercury) had no measurable correlation to flow within the range of existing data.

As an illustration of how time-series water quality data could be used for consideration during establishment of minimum flow regimes, the inverse correlation between specific conductance and spring flow is used to estimate the effects of lowering flow on this Class III water quality criterion, which states that:

> *"specific conductance shall not be increased more than 50% above background or to 1,275 µmhos/cm, whichever is greater" [Florida Administrative Code 62-302.530]*

The average specific conductance value at the downstream station in Blue Spring Run was 1,474 µmhos/cm. The allowable increased specific conductance of 50% over the background is 2,211 µmhos/cm.

TABLE 3-11
Blue Spring Run Water Quality Metrics and Correlation with Discharge

	Discharge (cfs)	
Parameter	Correlation Coefficient (r)	Count
Water Temperature (^oC)	-0.034	2622
pH (SU)	0.018	66
Dissolved Oxygen (mg/L)	0.030	56
Specific Conductance (umhos/cm)	-0.610	2553
TDS (mg/L)	-0.664	58
Hardness (mg/L)	-0.573	23
Alkalinity (mg/L as $CaCO_3$)	-0.545	30
Ca, Dissolved (mg/L)	-0.574	56
Chloride (mg/L)	-0.495	198
Color (CPU)	-0.043	64
NH_4-N (mg/L)	-0.557	45
NO_X-N (mg/L)	0.514	39
TON (mg/L)	0.071	49
TN (mg/L)	0.411	43
PO_4 (mg/L)	-0.166	44
TP (mg/L)	0.086	53
Copper (µg/L)	0.508	10
Mercury (µg/L)	0.089	9
Zinc (µg/L)	1.000	2

The correlation between spring discharge and specific conductance is illustrated in **Figure 3-12** and the best-fit linear regression model can be summarized as:

Specific conductance (µmhos/cm) = -9.99 x Discharge (cfs) +2972

R^2 = 0.25 [Eqn. 1]

This correlation indicates that at a mean discharge of about 84 cfs, the Class III standard for specific conductance would be exceeded on a long-term average basis. An even smaller flow reduction (higher average flow than 84 cfs) might conceivably result in a higher rate of daily exceedances of this Class III standard. However, since this is an extrapolation outside the range of the regression data, such an interpretation is tentative.

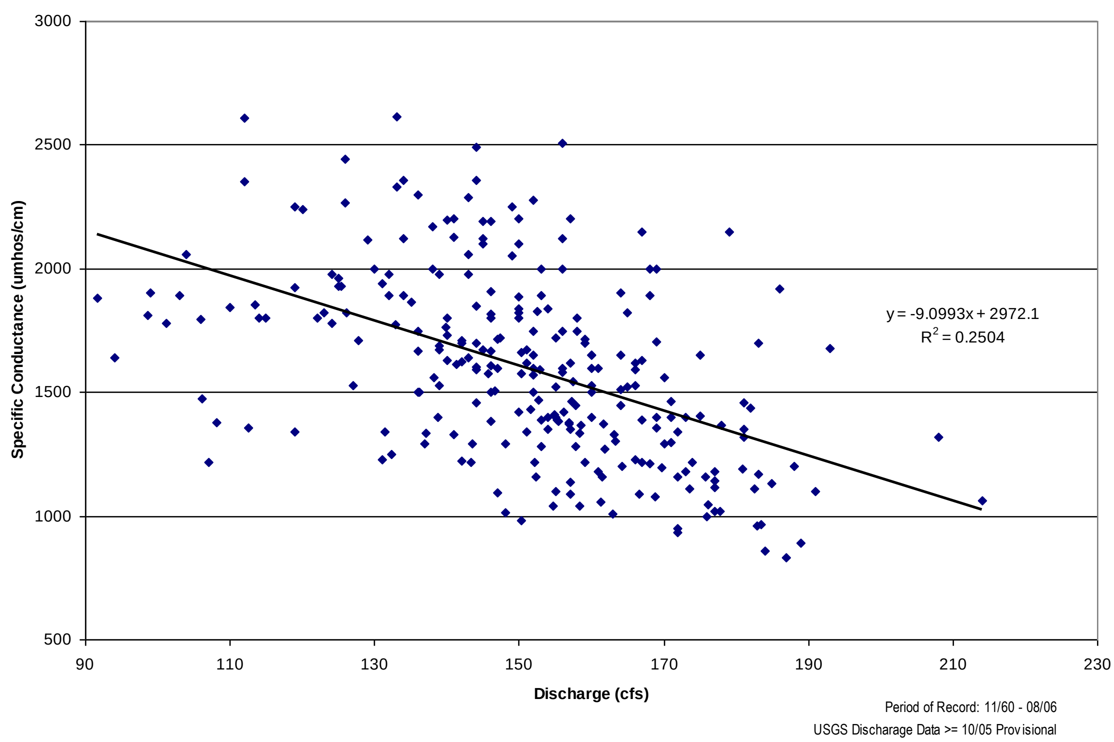


FIGURE 3-12
Relationship between Blue Spring Discharge and Downstream Specific Conductance

Average downstream specific conductance is not expected to be significantly affected within the range of the temporary flow reduction allowed by the Blue Spring MFR (minimum long term mean flow 132 cfs).

Another water quality parameter that is likely to be closely aligned to discharge is dissolved oxygen. Oxygen diffusion rates can be estimated based on flow velocity and water depth (Kadlec and Knight 1996). Knight (1980) showed that oxygen diffusion rates increased linearly with flow rate in the Silver River. One common formulation for estimating oxygen diffusion is the mass transfer equation:

$$Diff = K(C_{sat} - C) \qquad \text{[Eqn. 2]}$$

where:

Diff = diffusion of dissolved oxygen ($g/m^2/d$)

K = mass transfer coefficient (m/d)

C_{sat} = saturation dissolved oxygen concentration (mg/L)

C = actual dissolved oxygen concentration (mg/L)

The O'Connor and Dobbins (1958) correlation estimates the value of the mass transfer coefficient, K, based on water velocity (V in m/d) and water depth (H in m):

$$K = ((DV)/H)^{1/2} \qquad \text{[Eqn. 3]}$$

where:

D = molecular diffusivity of oxygen in water ($D = 1.76 \times 10^{-4}\ m^2/d$ @ 20 ^oC)

Based on the Blue Spring MFR, the average water velocity in Blue Spring Run would decrease from an estimated 10,368 m/d (34,000 ft/d) at an average flow of 156.6 cfs to a velocity of about 8,600 m/d (28,225 ft/d) if ground water withdrawals were permitted resulting in an interim long term mean flow of 132 cfs for the period 2006 – March 2009. This change in velocity would lower the estimated initial value of K from about 1.35 to 1.23 m/d at an assumed average depth of 1.0 m (3.3 ft). Assuming a spring boil dissolved oxygen concentration of 0.43 mg/L, and a saturated dissolved oxygen concentration of 8.5 mg/L at the spring run temperature of 23^oC, the estimated average diffusion rate for dissolved oxygen near the spring boil will be reduced from about 10.9 to 9.93 $g/m^2/d$ (an estimated 9% reduction). This level of change is not considered likely to be biologically significant.

On the other hand, reduced flow will increase the average residence time of the water in the spring run (from about 1.7 to 2.0 hrs), allowing a greater period of time for re-aeration at the assumed lower rate. The net effect of these opposing processes, increases and/or decreases in primary productivity and community respiration, and the effect of the resulting changed dissolved oxygen concentration on the quantity of fish and macroinvertebrate habitat could be assessed by correlating flows with a greater frequency of dissolved oxygen measurements. Based on existing data and this preliminary analysis, it is concluded that there will not be a significant effect of the Blue Spring MFR or water stage on dissolved oxygen concentrations.

3.11.5 Summary

The water quality WRV covers a broad spectrum of physical, chemical, and biological properties of Blue Spring and Blue Spring Run. Some of the metrics describing these properties are likely to increase with decreasing flow and some are likely to decrease in response to flow reductions. However, the existing data indicate that most chemical constituent concentrations are variable, due to a combination of actual variation and measurement error. As long as this normal variation is fairly wide (coefficient of variations around the mean greater than about 15%), then it is considered unlikely that there will be measurable water quality changes within the range of the temporary flow reductions allowed by the Blue Spring MFR.

For water quality parameters with existing data, this assessment holds for all parameters with the exception of temperature, pH, specific conductance, hardness, calcium, and silica. For each of these parameters, it is concluded that a measurable change from the existing constituent average may occur as a response to temporary flow reduction allowed by the Blue Spring MFR. In no case is that change considered likely to be large enough to exceed a Florida Class III water quality criterion or to cause measurable harm to the rest of the ecosystem.

3.12 Navigation

Recreational and commercial boating and navigation are not allowed in Blue Spring and Blue Spring Run. Therefore, this potential WRV is not realized at this location and is not considered further in this report.

4.0 Summary, Conclusions, and Recommendations

4.1 Inventory of Existing Uses

Section 62-40.473, *FAC* requires that a determination of minimum flows and levels must consider 10 WRVs including:

- Recreation in and on the water (62-40.473 (1) (a), *FAC*)
- Fish and wildlife habitats and the passage of fish (62-40.473 (1) (b), *FAC*)
- Estuarine resources (62-40.473 (1) (c), *FAC*)
- Transfer of detrital material (62-40.473 (1) (d), *FAC*)
- Maintenance of freshwater storage and supply (62-40.473 (1) (e), *FAC*)
- Aesthetic and scenic attributes (62-40.473 (1) (f), *FAC*)
- Filtration and absorption of nutrients and other pollutants (62-40.473 (1) (g), *FAC*)
- Sediment loads (62-40.473 (1) (h), *FAC*)
- Water quality (62-40.473 (1) (i), *FAC*)
- Navigation (62-40.473 (1) (j), *FAC*)

The purpose of this report was to determine, to the extent possible with existing information, whether the WRVs listed above would be protected under the recommended Blue Spring MFR that was determined to be sufficient to protect the manatee winter warm-water refuge under catastrophic conditions. The Blue Spring MFR allows an interim maximum reduction in the long term mean flows in Blue Spring of about 15% for the period 2006 – March 2009 with a subsequent return to existing long term mean flows by March 2024.

4.2 Summary of Estimated Changes to Water Resource Values for Blue Spring and Blue Spring Run

Data are presented in this report that describe the ecological resources in Blue Spring and Blue Spring Run. However, historic data collection has emphasized factors directly or indirectly affecting manatee use, with minor focus on general water quality, use by other wildlife groups, and human recreational and aesthetic uses. As a result, there are many data gaps that become apparent when trying to evaluate all of the applicable WRVs. Nevertheless, the best available information was used to consider these WRVs.

A total of 46 quantifiable metrics are suggested to assess water quality, pollutant assimilation, wildlife habitat, and human use WRVs at Blue Spring and Blue Spring Run in Volusia County, Florida. Existing data have been summarized and subjected to analyses to illustrate methodologies for evaluation of these WRVs. Existing quantitative data are available to assess the correlation between only 17 (~37%) of the WRV metrics and flows in Blue Spring Run. Since limited data are currently available to assess quantitative changes to these WRV metrics, estimates for the other metrics are based on best professional judgment.

A number of water quality characteristics (e.g., TN, zinc, specific conductance, hardness, and TP) of Blue Spring and Blue Spring Run were found to be correlated with spring flows and preliminary regressions indicate that excessive reduction in spring flow (greater than permissible under the recommended Blue Spring MFR) could lead to the exceedance of at least one Class III water quality standard (specific conductance) and statistically significant changes to a number of others. However, existing data ranges are limited and extrapolations outside the range of existing flows should be interpreted cautiously.

Table 4-1 provides a summary of estimated effects of the reduced flows on the 46 WRV metrics proposed in this report. There are generally not enough data to comprehensively address the precise relationship between spring flow and each WRV. However, based on the best available information and the best professional judgment of the author, it is concluded that the Blue Spring MFR should protect all of the WRVs from adverse impacts. Additional data collection is recommended in the future to develop better relationships between the WRVs and spring discharge.

Based on the analysis of the data available for this report and the observed variability of these data in response to the range of measured flows, it is concluded that only a few of these ecological and human use WRV metrics would be measurably affected within the range of temporary flow reduction allowed by the Blue Spring MFR. It is also concluded that any metrics that are affected will not change enough to measurably affect the spring's overall ecological functioning.

Based on the District's finding of no measurable change in water levels in Blue Spring and Blue Spring Run as a result of the Blue Spring MFR, it is concluded that none of the WRVs described above will be affected by a change in water levels as a result of the recommended Blue Spring MFR.

4.3 Data Collection and Analysis Recommendations

It is recommended that a variety of additional data be collected to evaluate and monitor WRV metrics for Blue Spring and Blue Spring Run. Any new data collection should be considered to be preliminary, and designed for the purpose of establishing a baseline and defining existing ranges for specific metrics. This report has described several possible techniques for analyzing these data. Based on this initial range-finding effort, long-term monitoring could be reduced to a more limited subset of water quality and biological parameters that best illustrate the effects of flows on each critical WRV.

Based on the findings of this report, the following recommendations are proposed:

- An enhanced water quality data collection program should be implemented to quantify upstream and downstream concentrations over a multi-year period for the parameters listed in **Table 4-1**. This data set would provide a baseline for comparison of future values.
- A water quality multi-probe could be installed upstream (near the boil) and downstream, near the mouth of Blue Spring Run (above the influence of the St. Johns River), to provide the data to estimate daily community metabolism (gross and net primary productivity and ecosystem respiration). This multi-probe sensor would need to record temperature, dissolved oxygen, and oxygen percent saturation hourly to provide the raw data needed for these estimates. Data for temperature would also be very useful for assessing the accuracy of the model developed by the District for manatee use in Blue Spring Run. Additional parameters including TDS, pH, and conductivity could also be included in this multi-probe and would be useful for assessing other aspects of the spring's

ecology. A second multi-probe located upstream at the spring boil, while not absolutely necessary for the analysis of community metabolism, would be useful to detect subtle changes in groundwater quality affecting Blue Spring and Blue Spring Run.

- Based on continuing and expanded data collection and analyses as illustrated in this report, the list of possible WRV metrics of interest in Blue Spring and Blue Spring Run could be further refined and possibly reduced in length to include only those metrics that are confirmed to be affected by spring flow.
- An historic record of pollutant assimilation rates in Blue Spring is not available. The upstream-downstream water quality data described above, in concert with continuous flow measurements can be used to quantify the existing assimilation rates as a benchmark for comparison of future rates and to assess the effects of the Blue Spring MFR on those rates.
- Future fish population studies in Blue Spring and Blue Spring Run should estimate or measure fish lengths and weights to allow development of biomass and productivity estimates for species that are found to be affected by flow rates.
- Changes in habitat resources should generally be evaluated within the context of historical variations and should include quantification of both beneficial and detrimental effects of flows in Blue Spring and Blue Spring Run.

TABLE 4-1

Estimated Effects of Reduced Flows on Blue Spring and Blue Spring Run Water Resource Value Metrics

Water Resource Value	Water Resource Value Metric Code	Metric	Expected Effect of Reduced Flow on Metric	Measurable Effect Estimated at 132 cfs?	Protected From Significant Harm at 132 cfs?
Recreation In and On the Water	1.1	total human use	-	no	yes
	1.2	manatee watching	-	no	yes
	1.3	fishing	-	no	yes
	1.4	snorkeling/scuba diving	-	no	yes
	1.5	park fees	-	no	yes
Fish and Wildlife Habitats and the Passage of Fish	2.1	periphyton biomass and productivity	-	no	yes
	2.2	aquatic macrophyte biomass and productivity	+	no	yes
	2.3	snail biomass and productivity	-	no	yes
	2.4	benthic insect biomass and productivity	-	no	yes
	2.5	striped mullet biomass and productivity	-	no	yes
	2.6	turtle biomass and productivity	+	no	yes
	2.7	mosquitofish biomass and productivity	-	no	yes
	2.8	sunfish biomass and productivity	-	no	yes
	2.9	river otter biomass and productivity	-	no	yes
	2.10	double-crested cormorant biomass and productivity	-	no	yes
	2.11	gross primary productivity	-	no	yes
	2.12	net primary productivity	-	no	yes
	2.13	community respiration	-	no	yes
	2.14	P/R ratio	-	no	yes
Transfer of Detrital Material	3.1	volatile suspended solids load reduction	+/-	no	yes
Aesthetic and Scenic Attributes	4.1	aesthetic and scenic survey	-	no	yes
Filtration and Absorption of Nutrients and Other Pollutants	5.1	total ammonia N load reduction	+/-	no	yes
	5.2	nitrate + nitrite N load reduction	+/-	no	yes
	5.3	organic N load reduction	+/-	no	yes
	5.4	total N load reduction	+/-	no	yes
	5.5	ortho P load reduction	+/-	no	yes
	5.6	total P load reduction	+/-	no	yes
	5.7	total copper load reduction	+/-	no	yes
	5.8	total iron load reduction	+/-	no	yes
	5.9	total zinc load reduction	+/-	no	yes
Sediment Loads	6.1	non-volatile suspended solids load reduction	+/-	no	yes
Water Quality	7.1	water temperature	+/-	yes	yes
	7.2	dissolved oxygen	+/-	no	yes
	7.3	conductivity	+	yes	yes
	7.4	pH	-	yes	yes
	7.5	hardness	+	yes	yes
	7.6	turbidity	+/-	no	yes
	7.7	total ammonia N	+	no	yes
	7.8	nitrate + nitrite N	-	no	yes
	7.9	organic N	-	no	yes
	7.10	total N	-	no	yes
	7.11	ortho P	-	no	yes
	7.12	total P	-	no	yes
	7.13	total copper	+	no	yes
	7.14	total iron	+	no	yes
	7.15	total zinc	+	no	yes

5.0 References Cited

Barbour, M.T., J. Gerritsen, and J.S. White. 1996. Development of the Stream Condition Index for Florida. Prepared for the Fla. Dept. Environ. Protection. 105 pp.

Bennett, Amy.2002. Department of Environmental Protection. Bureau of Laboratories - Environmental Assessment. 'EcoSummary' data for Blue Spring (personal communication 4/2/02)

Bonn, M.A. and F.W. Bell. 2003. Economic Impact of Selected Florida Springs on Surrounding Local Areas. Prepared for the Florida Department of Environmental Protection, Florida Springs Task Force. Tallahassee, Florida. 102 pp.

Brown, Steve. 2002. St. John River Water Management District, Palatka, Florida. GIS Land Use / Land Cover for Blue Spring Watershed. (personal communication 5/17/02)

Environmental Consulting & Technology, Inc. (ETC). 2002. Lower St. Johns River Salinity Regime Assessment: Effects of Upstream Flow Reduction near Deland. Prepared for the St. Johns River Water Management District. Gainesville, FL.

Di, Jian. 2002. St. John River Water Management District, Palatka, Florida. Pollutant Loading Rates for Different Land Use Groups for Blue Spring Park. (personal communication 5/16/02)

Fernald E. A. and D.J. Patton 1984. Water Resources Atlas of Florida. Florida State University, Tallahassee, FL, 291 pp.

Florida Department of Environmental Protection. 2000. Abstracts of Talks Presented at the Florida Springs Conference: Natural Gems-Troubled Waters, February 8-10, 2000, Sheraton Gainesville Hotel, Gainesville, Florida. Website, http://susdl.fcla.edu/related/springs.html. viewed 5/9/2002

Florida Department of Environmental Protection. 1999. Blue Spring State Park and Hontoon Island State Park Unit Management Plan. Tallahassee, FL.

Florida Department of Environmental Protection. 1989. Typical Water Quality Values for Florida’s Lakes, Streams and Estuaries. Tallahassee, FL.

Florida Springs Task Force. 2000. Florida's Springs – Strategies for Protection and Restoration. Prepared for Florida Department of Environmental Protection and the Citizens of the State of Florida.

Hall, Sonny. 2002. St. John River Water Management District, Palatka, Florida. Blue Spring Discharge, Stage, and Manatee Surveys. (personal communication 5/9/02)

Kadlec, R.H. and R.L. Knight. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, FL 893 pp.

Knight, R.L. 1980. Energy Basis of Control in Aquatic Ecosystems. Ph.D. Dissertation, University of Florida, Gainesville, FL. 200 pp.

Maday, Eric. 2002. Volusia County Health Department – Environmental Health, Orange City, Florida. Surface Water Quality Data from Blue Spring – Bacteria. (personal communication 5/10/02)

McBride, G.B., J.C. Loftis, and N.C. Adkins. 1993. What do significance tests really tell us about the environment? Environmental Management 17(4):423-432.

Metcalf and Eddy, Inc. 1991. Wastewater Engineering Treatment, Disposal, and Reuse. Third Edition. McGraw-Hill, Inc. NY.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. Third Edition. John Wiley & Sons, Inc. New Yourk, NY.920 pp.

O'Connor, D.J. and W.E. Dobbins. 1958. Mechanism of Reaeration in Natural Streams. ASCE Transactions Paper No. 2934:641-684.

Odum, H. T. 1983. Systems Ecology. Whiley-Interscience, NY.644 pp.

Odum, H.T. 1971. Environment, Power, and Society. Whiley-Interscience. NY. 336 pp.

Odum, H.T. 1957. Trophic structures and productivity of Silver Springs, Florida. Ecological Monographs 27:55-112.

Odum, H.T., E.C. Odum and M.T. Brown. 1998. Environment and Society in Florida. Lewis Publishers, Boca Raton, FL

Post, Buckley, Shuh & Jernigan. 1995. Special Purpose Survey of Crescent City Ridge Lakes Cross Sections & Profiles Blue Springs Outfall. Prepared for the St. Johns River Water Management District. 6 drawings.

Rawlins, Jack. 2002. Volusia County Environmental Management. Surface Water Quality Data from Blue Spring. (personal communication 4/8/02)

Rosenau, J.C., G.L. Faulkner, C.W. Hendry Jr., and R.W. Hull. 1977. Springs of Florida - Geological Bullentin No. 31, revised. Florida Geological Survey, Tallahassee, Florida.

Rouhani, S., P. Sucsy, G. Hall, W. Osburn, and M. Wild. 2006. Analysis of Blue Spring Discharge Data to Determine a Minimum Flow Regime. Prepared in cooperation with the Blue Spring Minimum Flow Interagency Working Group. Prepared for the St. Johns River Water Management District, Palatka, FL. Prepared by New Fields, Inc., Atlanta, Georgia. September 2006.

Schockin, Dianne. 2006. Department of Environmental Protection. District 3 - Florida Park Service. Blue Spring State Park Visitor Data (personal communication 9/8/2006)

Scott, T.M., G.H. Means, R.C. Means, and R.P. Meegan, 2002. First Magnitude Springs of Florida. Florida Geological Survey Open File Report No. 85.

St. John River Water Management District. 1998. Chapter 40C-8, F.A.C. Minimum Flow and Levels.

St. John River Water Management District Website, http://sjr.state.fl.us/programs/data.html . viewed 7/12/2006

Sucsy, P. 2002. St. John River Water Management District, Palatka, Florida. Maximum and Minimum Daily Air Temperature at DeLand for 1931-2000. (personal communication 5/9/02).

Sucsy, P. 2005. unpublished memorandum dated August 30, 2005.

Sucsy, P., R. Hupalo, and B. Freeman. 1998. Minimum Flow Determination for Blue Spring, Volusia County: the Relationship between Ground Water Discharge and Winter Refuge for Manatees. Draft Technical Report. Department of Water Resources, St. Johns River Water Management District, Palatka, FL.

U.S. Geological Survey. 1995. Springs of Florida. Fact Sheet FS-151-95. Tallahassee, Florida.

Webb, Kathy. 2005. Department of Environmental Protection. District 3 - Florida Park Service. Blue Spring State Park Visitor Data – Blue Spring.htm. (personal communication 11/22/05)

Website, http://oaspub.epa.gov/storpubl/legacy/proc_advanced_query (Organization Code 21FLA; Station ID: 20010148) viewed 5/7/2002

Website, http://iaspub.epa.gov/stormodb/DW_resultcriteria_geo (Lat/Long N=28.94840, S=28.94162, W=81.34485, E=81.33676) viewed 8/29/06

Website, http://waterdata.usgs.gov/nwis/inventory/?site_no=02235500. viewed 8/29/06

Website, http://waterdata.usgs.gov/fl/nwis/uv?02235500. viewed 5/10/2002

Website, http://www.abfla.com/parks/BlueSpring/bluespring.htm. viewed 2/21/2002

Website, http://www.dep.state.fl.us/labs/library/springs.htm viewed 7/17/2006

Website, http://www.floridadep.org/labs/reports/spring.htm. viewed 4/2/2002

Website, http://www.stetson.edu/departments/biology/amb/florida. viewed 3/18/2002

Website, http://www4.ncdc.noaa.gov/cgi-win/wwwcgi.dll?wwDI~StnSrch~StnID~20004479. viewed 5/9/2002

Work, Kirsten., 2006. Stetson University Department of Biology – Fish Survey Data from October 2000 to July 2004.

Appendix A

Plant and Animal List for Blue Spring State Park

APPENDIX A

Species List Observed in Blue Spring Run

COMMON NAME	SCIENTIFIC NAME
INVERTEBRATES	
Mollusks	
Blue Spring hydrobe	*Aphaostracon asthenes*
Blue Spring siltsnail	*Cincinnatia parva*
FISH	
Spotted gar	*Lepisosteus oculatus*
Longnose gar	*Lepisosteus osseus*
Florida gar	*Lepisosteus platyrhincus*
Ladyfish	*Elops saurus*
Tarpon	*Megalops atlanticus*
American eel	*Anguilla rostrata*
Hickory shad	*Alosa mediocris*
Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Dorosoma petenense*
Golden shiner	*Notemigonus crysoleucas*
Lake chubsucker	*Erimyzon sucetta*
White catfish	*Ameiurus catus*
Yellow bullhead	*Ameiurus natalis*
Brown bullhead	*Ameiurus nebulosus*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*Ictalurus punctatus*
Pirate perch	*Aphredoderus sayanus*
Needlefish	*Strongylura spp*
Seminole killifish	*Fundulus seminolis*
Bluefin killifish	*Lucania goodei*
Western mosquitofish	*Gambusia affinis*
Eastern mosquitofish	*Gambusia holbrooki*
Least killifish	*Heterandria formosa*
Sailfin molly	*Poecilia latipinna*
Bluespotted sunfish	*Enneacanthus gloriosus*
Redbreast	*Lepomis auritus*
Warmouth	*Lepomis gulosus*
Bluegill	*Lepomis macrochirus*
Longear sunfish	*Lepomis megalotis*
Redear sunfish	*Lepomis microlophus*
Spotted sunfish	*Lepomis punctatus*
Largemouth	*Micropterus salmoides*
Black crappie	*Pomoxis nigromaculatus*
Blue tilapia	*Tilapia aurea*
Striped mullet	*Mugil cephalus*
AMPHIBIANS	
Two-toed amphiuma	*Amphiuma means*
Greater siren	*Siren lacertina*

APPENDIX A CONT.

Species List Observed in Blue Spring Run

COMMON NAME	SCIENTIFIC NAME
AMPHIBIANS	
Green treefrog	*Hyla cinerea*
Squirrel treefrog	*Hyla squirella*
Bullfrog	*Rana catesbeiana*
Pig frog	*Rana grylio*
River frog	*Rana heckscheri*
Florida leopard	*Rana utricularia sphenocephala*
REPTILES	
Florida snapping turtle	*Chelydra serpentina osceola*
Striped mud turtle	*Kinosternon bauri*
Florida mud turtle	*Kinosternon subrubrum steindachneri*
Loggerhead musk turtle	*Sternotherus minor minor*
Common musk turtle	*Sternotherus odoratus*
Eastern chicken turtle	*Deirochelys reticularia reticularia*
Florida cooter	*Pseudemys floridana floridana*
Peninsula cooter	*Pseudemys floridana peninsularis*
Florida redbelly turtle	*Pseudemys nelsoni*
Florida box turtle	*Terrapene carolina bauri*
Florida softshell	*Apalone ferox*
American alligator	*Alligator mississippiensis*
Mississippi green water snake	*Nerodia cyclopion*
Banded water snake	*Nerodia fasciata fasciata*
Florida water snake	*Nerodia fasciata pictiventris*
Florida green water snake	*Nerodia floridana*
Brown water snake	*Nerodia taxispilota*
Florida cottonmouth	*Agkistrodon piscivorus conanti*
BIRDS	
Pied-billed Grebe	*Podilymbus podiceps*
Horned Grebe	*Podiceps auritus*
American White Pelican	*Pelecanus erythrorhynchos*
Brown Pelican	*Pelecanus occidentalis*
Double-crested Cormorant	*Phalacrocorax auritus*
Anhinga	*Anhinga anhinga*
American Bittern	*Botaurus lentiginosus*
Great Blue Heron	*Ardea herodias*
Great Egret	*Ardea alba*
Snowy Egret	*Egretta thula*
Little Blue Heron	*Egretta caerulea*
Tricolored Heron	*Egretta tricolor*
Cattle Egret	*Bubulcus ibis*
Green Heron	*Butorides virescens*
Black-crowned Night-heron	*Nycticorax nycticorax*
Yellow-crowned Night-heron	*Nyctanassa violacea*
White Ibis	*Eudocimus albus*
Glossy Ibis	*Plegadis falcinellus*
Wood Stork	*Mycteria americana*

APPENDIX A CONT.

Species List Observed in Blue Spring Run

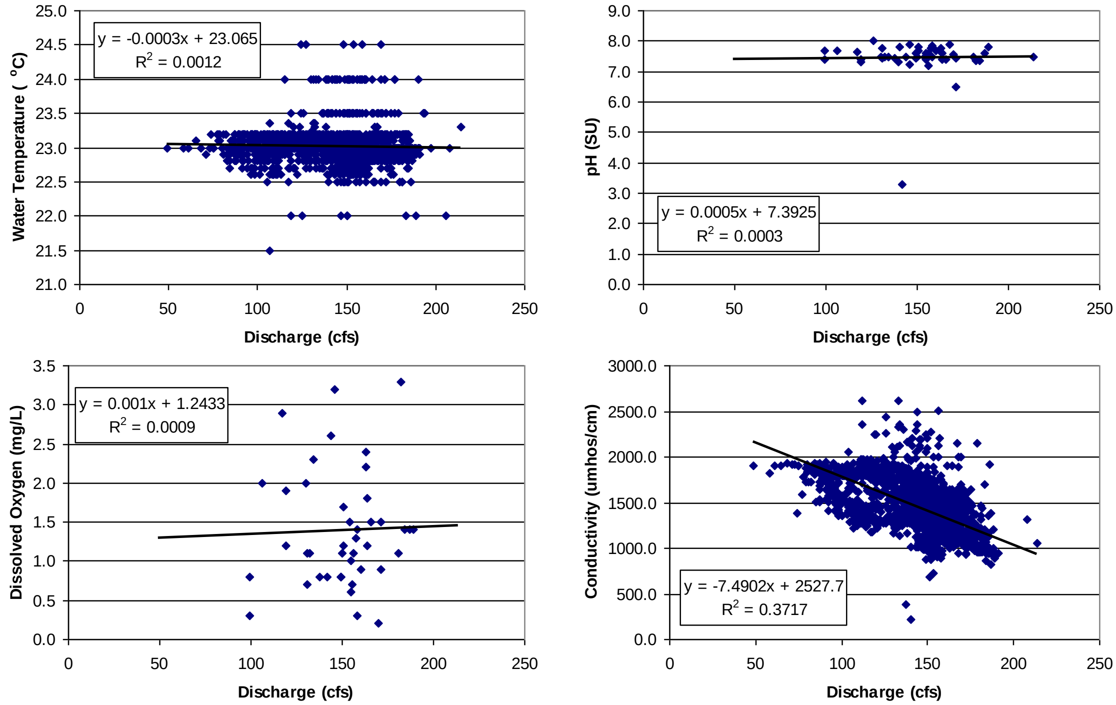
COMMON NAME	SCIENTIFIC NAME
BIRDS	
Black Vulture	*Coragyps atratus*
Turkey Vulture	*Cathartes aura*
Muscovy Duck	*Cairina moschata*
Wood Duck	*Aix sponsa*
Mottled Duck	*Anas fulvigula*
Mallard	*Anas platyrhynchos*
Blue-winged Teal	*Anas discors*
Northern Shoveler	*Anas clypeata*
American Wigeon	*Anas americana*
Lesser Scaup	*Aythya affinis*
Hooded Merganser	*Lophodytes cucullatus*
Red-breasted Merganser	*Mergus serrator*
Osprey	*Pandion haliaetus*
Swallow-tailed Kite	*Elanoides forficatus*
Bald Eagle	*Haliaeetus leucocephalus*
Northern Harrier	*Circus cyaneus*
Sharp-shinned Hawk	*Accipiter striatus*
Cooper's Hawk	*Accipiter cooperii*
Red-shouldered Hawk	*Buteo lineatus*
Broad-winged Hawk	*Buteo platypterus*
Red-tailed Hawk	*Buteo jamaicensis*
Purple Gallinule	*Porphyrula martinica*
Common Moorhen	*Gallinula chloropus*
American Coot	*Fulica americana*
Limpkin	*Aramus guarauna*
Killdeer	*Charadrius vociferus*
Solitary Sandpiper	*Tringa solitaria*
Spotted Sandpiper	*Actitis macularia*
Common Snipe	*Gallinago gallinago*
Ring-billed Gull	*Larus delawarensis*
Herring Gull	*Larus argentatus*
Caspian Tern	*Sterna caspia*
Forster's Tern	*Sterna forsteri*
Belted Kingfisher	*Ceryle alcyon*
Fish Crow	*Corvus ossifragus*
Boat-tailed Grackle	*Quiscalus major*
Common Grackle	*Quiscalus quiscula*
MAMMALS	
River otter	*Lutra canadensis*
West Indian manatee	*Trichechus manatus latirostris*

Source:
Blue Spring State Park and Hontoon Island State Park Unit Management Plan

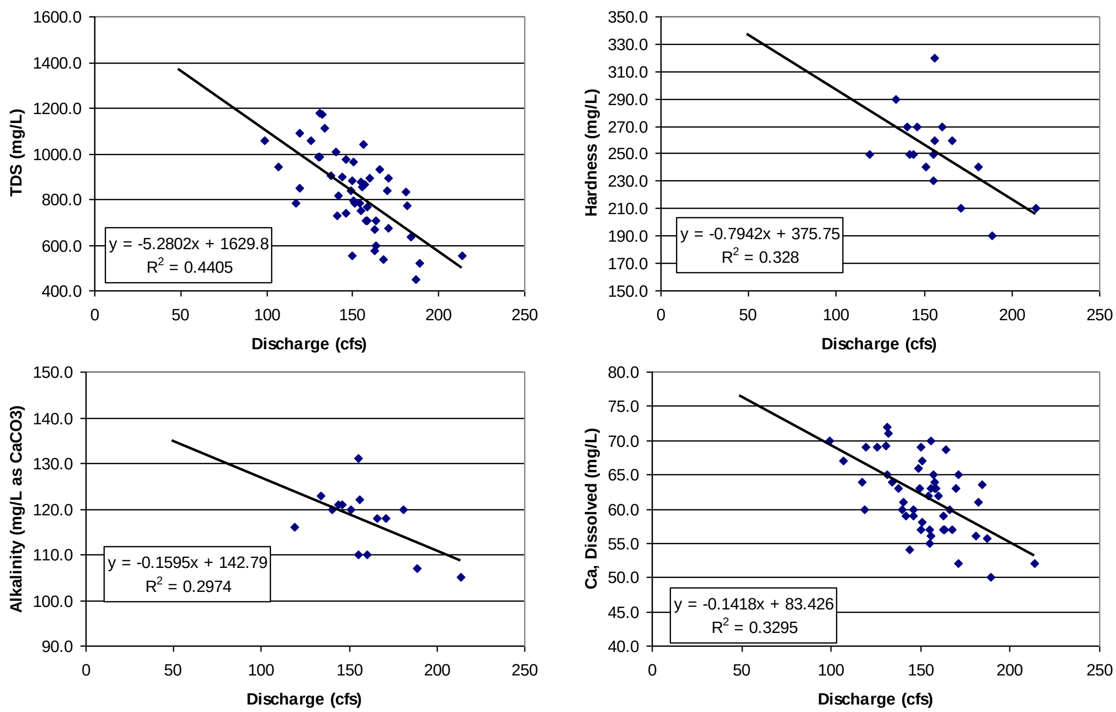
Appendix B

Scatter-Plots for Blue Spring Water Quality and Flows

APPENDIX B-1

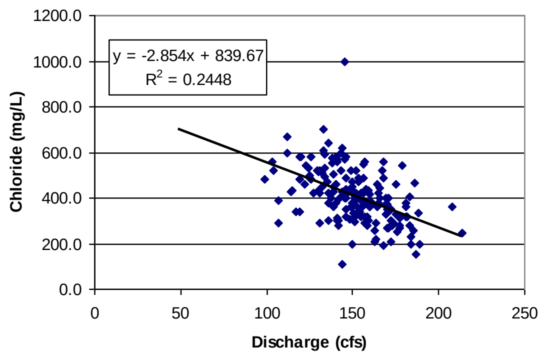


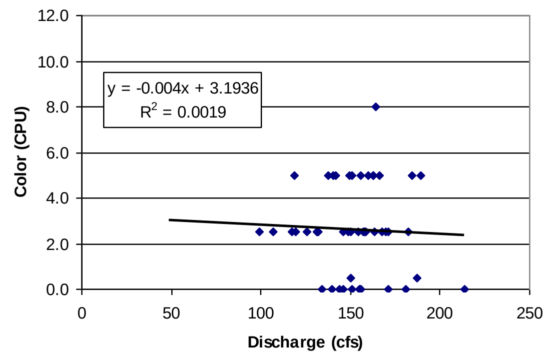
Scatter Plots for Blue Spring Water Quality and Flows

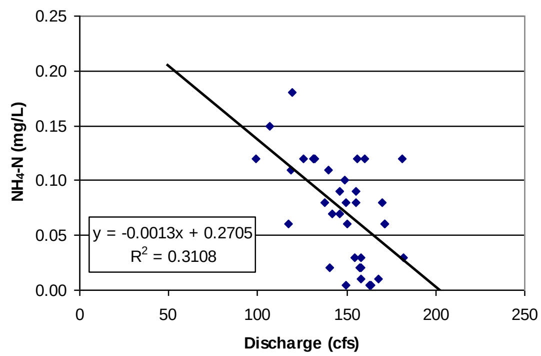


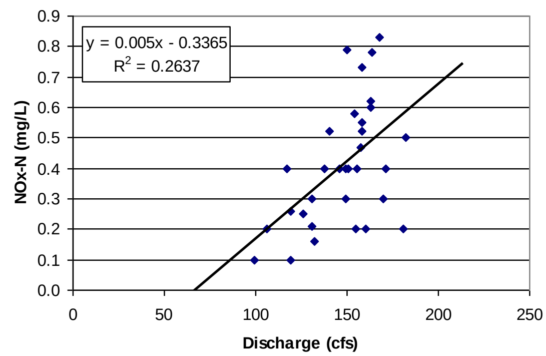
APPENDIX B-1

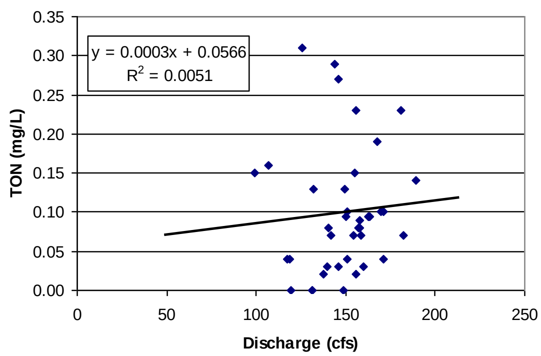
Scatter Plots for Blue Spring Water Quality and Flows

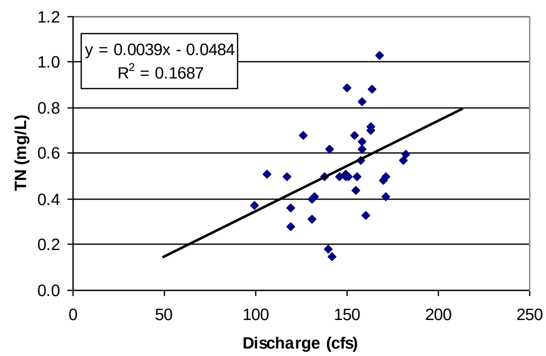


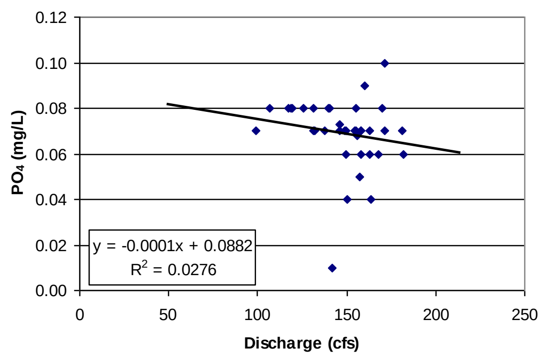


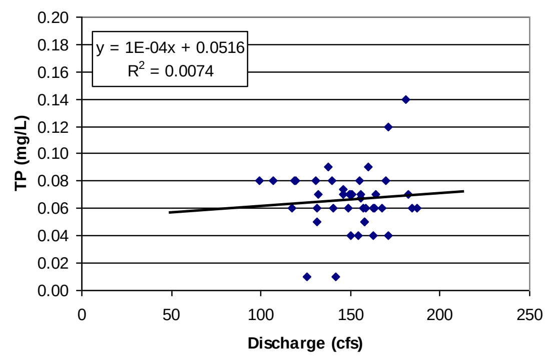












APPENDIX B-1

Scatter Plots for Blue Spring Water Quality and Flows