Final Report

Biological and Ecological Benefits from Chatfield Reallocation Environmental Pool Increased Releases (Chatfield Environmental Pool Project)

Submitted To:

Denver Trout Unlimited

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Executive Summary

The Chatfield Environmental Pool was created as part of the agreement between the Reallocation Project Partners and Colorado Parks and Wildlife (CPW), as outlined in the State's Fish and Wildlife Mitigation Plan, C.R.S. 37-60-122.2, approved in January 2014. The original environmental pool included 1000 acre-feet (AF) acquired by CPW and 600 AF acquired by the State. The environmental pool has now been expanded by 500 AF to 2,100 AF of the reallocated space because of the generosity of a partnership of 22 public and private, foundation and non-profit entities and individuals. These are:

Chatfield Storage Reallocation Project Environmental Pool Partnership		
Colorado Parks and Wildlife: 1000AF	Gates Family Foundation: 13 AF	Denver Trout Unlimited: 10 AF
Colorado Water Conservation Board: 600AF	City of Englewood: 10 AF	City of Sheridan: 3 AF
Denver Water: 250 AF	City of Littleton: 10 AF	Town of Columbine Valley: 1 AF
City and County of Denver: 50 AF	Urban Drainage and Flood Control District: 10 AF	Capitol Representatives (Marge Price and David Howlett): 1 AF
Walton Family Foundation: 45 AF	South Suburban Parks & Recreation District: 10 AF	South Metro Land Conservancy: 1 AF
Adams County: 25 AF	The Greenway Foundation: 10 AF	Evan and Kim Ela: 1 AF
Arapahoe County: 15 AF	The Colorado Parks Foundation: 10 AF	
Weld County: 15 AF	The Shoemaker Family: 10 AF	

The study area is the South Platte River corridor and extends from Chatfield Reservoir downstream to the east side of the Denver metropolitan area at approximately 104th Avenue. The study area is segmented into reaches associated with stream gage locations.

The objective of this project is to establish recommendations to maintain, protect and enhance the biological and ecological functions of the South Platte River from increased flow releases with water available through the Chatfield Reallocation Environmental Pool. CPW has control over the water stored in the Environmental Pool and has authority to make releases as deemed appropriate. The intent of this report is to provide additional analysis to assist in determining when the releases would be appropriate.

This analysis relied on readily available existing data from several sources. These sources include stream flow data from the State of Colorado and United States Geological Survey (USGS), hydrologic analysis from Denver Water, stream habitat data from previous Physical Habitat Simulation (PHABSIM) studies, stream cross section data from previous R2Cross studies (ERC 2014), biological data from CPW, South Platte Coalition for Urban River Evaluation (SPCURE) (Aquatics Associates 2011), South Adams County Water and Sanitation District (SACWSD), and Metro Sanitation District and water quality data from SACWSD, Trout Unlimited and USGS.

Variable flows are an important component of a healthy riverine ecosystem. Peak flows create and maintain habitats. Minimum flow values can be used to determine potential periods of stress during seasonal low water conditions for aquatic ecosystems.

The peak flow regime in the South Platte River through the metro Denver area is similar from Chatfield Reservoir downstream to the northeast portion of the Denver metro area. Both the three day and seven day maximum flows show a small increase longitudinally downstream for median values. The confined nature of the river channel due to urban infrastructure does not allow the channel to migrate at high flow, which would occur in an unconfined channel. The flows can modify in channel habitat features to benefit aquatic species.

The minimum flow regime for the South Platte River is distinctly different at the upper and lower sections of the study area when compared to the middle of the Denver metro area. The one day and seven day minimum flows at the Chatfield gage are at or close to zero for many days each year. Minimum flows in the middle reaches from Union to the Burlington Ditch range from approximately 12 cfs to 35 cfs due to tributary inflows. The minimum flows downstream of the Burlington Ditch are approximately 5 cfs or less. The months with the lowest minimum flows are November through February, August, and September. It is important to maintain minimum flows above specified thresholds for biological productivity and refuge habitat.

The PHABSIM analysis shows the greatest rate of increase in habitat abundance as flow increases from near zero to 20 cfs through 50 cfs depending on location within the study area. Wetted perimeter shows a similar response as PHABSIM results. The increase from extremely low flow to 20 cfs and greater also provide deeper areas in the channel as refugia during summer and winter when flows are typically lowest. Fish species present in the metro corridor include both cold water and warm water fish. Trout species are present through most of the South Platte from Chatfield downstream to approximately the Burlington ditch. The data from CPW and SACWSD showed that many species of warm water native and non-native fish are found within the study area..

The reaches with the lowest minimum flows are at the upstream and downstream end of the study area in South Platte Park and downstream of the Burlington Ditch, respectively. The days with the lowest flows occur in late summer (August and September) and through the winter months (November through February) based on the flow duration analysis. The limiting factors for aquatic species during these times are likely the lack of wetted area for primary and secondary producers during summer and winter and the lack of feeding and refuge habitat for fish. Habitat area increases as flows increase, however, there may be an additional limiting factor of elevated water temperatures at extremely low flows during late summer.

The recommended first steps and highest priorities for flow management include two critical time periods. The recommended flow management that would be most beneficial to the current conditions within the study area are:

- First - Eliminate days with zero or near zero flows. A minimum flow that would meet the criteria of the 50 % to 70 % wetted channel is 30 cfs in the Chatfield Reach and 10 cfs in the 64th Avenue Reach. Those reaches have the lowest flows in the study area.
- Second – Release water on low flow days in summer for additional refuge habitat. The release may provide some minor moderation of water temperature as well as additional depth in pools. Flows of 30 cfs to 40 cfs provide an additional 0.5 ft to 1.0 ft of depth compared to the depth at 10 cfs.

The ability to meet the release priorities will depend on the volume available from the environmental pool. The analysis of water rights and future operations is beyond the scope of this present report, however, water rights and operations should be considered in future studies. The environmental pool may not be refilled each year due to the junior nature of the water rights that are expected to fill the Environmental Pool and the relative priority of filling among the Reallocation other higher priority water users. The inability to refill the pool each year could impact the releases recommended for the environmental pool. The exact release value and the duration would need to be determined each year. There should also be an effort to shepherd the release downstream past the Burlington Ditch to the east side of the metro area, if possible. A potential component of the sheparding could be a reconfiguration of the Burlington Ditch return so it is immediately downstream of the diversion structure.

The number of days when additional flow could be released for environmental benefit varies with the volume of discharge. For example, a 5 cfs release could be made for 212 days at 2100 AF of water. A 20 cfs release could be made for 53 days with 2100 AF of water. The higher flow release of 30 cfs or 40 cfs for a shorter time may provide the better benefit to the aquatic organisms depending on the objectives of the release. There may be more refuge habitat in pools at those higher flows. The amount of productive wetted area is important through the winter. A lower magnitude release in winter that provides 70 % to 80% wetted channel would be beneficial to the reaches that are now less than 50% wetted channel or lower. It is important to note that even these lowest flows provide essential habitat that is not present with zero flows. The reaches that would most benefit from winter release are upstream in Littleton and downstream of the Burlington Ditch.

Next Steps and Future Studies

This report was an initial evaluation of some of the main factors impacting the South Platte River through Denver and how the environmental pool may be used to benefit the river. The report relied on readily available data, previous studies and input from stakeholders to develop the analysis and recommendations.

Next steps in the Environmental Pool project should include:

- Incorporation of institutional constraints such as water rights, projected future storage and release operations, and expected hydrologic changes in the South Platte and tributaries within the Denver metropolitan area.

- Formalize the decision structure between CPW and other stakeholders for the Environmental Pool.
- Formalize agreements for the Environmental Pool and its uses.
- Updated habitat evaluation in reaches that have had substantial restoration work completed.
- Updated habitat as a function of flow for species of interest that were not modeled in the earlier studies.
- Water temperature monitoring at least at the stream gage locations from Chatfield to 64th. Additional locations could be included at points of concern.
- Continued monitoring of biological and water quality data and providing that data in a timely manner to the stakeholder group.

Balancing the amount to release (cfs), the number of days to release, and seasonal timing of release (summer vs. winter, or both seasons) will likely need to be an ongoing process. An adaptive approach to the operation would be best, which would allow the operation to be refined as the years progress.

Additional considerations for the Environmental Pool management should include the potential to coordinate releases for downstream users that benefit the river ecosystem. How the coordination is accomplished is outside the scope of this current project but should be addressed during discussions with stakeholders.

Introduction

Background

The Chatfield Environmental Pool was created as part of the agreement between the Reallocation Project Partners and Colorado Parks and Wildlife (CPW), as outlined in the State's Fish and Wildlife Mitigation Plan, C.R.S. 37-60-122.2, approved in January 2014. The original environmental pool included 1000 acre-feet (AF) acquired by CPW and 600 AF acquired by the State. The environmental pool has now been expanded by 500 AF to 2,100 AF of the reallocated space because of the generosity of a partnership of 22 public and private, foundation and non-profit entities and individuals. These are:

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The environmental pool is being created to allow for strategic releases out of Chatfield Reservoir to enhance stream flows and water quality in the South Platte River below the reservoir. Environmental releases will not only provide water quantity and water quality benefits downstream of the reservoir but may be utilized downstream by the Central Colorado Water Conservancy District for agricultural purposes. The environmental pool is a great example of the type of project called for in the 2015 Colorado Water Plan for maximizing water resources through projects that provide multiple benefits for multiple users.

Objectives

The objective of this project is to establish recommendations to maintain, protect and enhance the biological and ecological functions of the South Platte River from increased flow releases with water available through the Chatfield Reallocation Environmental Pool. CPW has control over the water stored in the Environmental Pool and has authority to make releases as deemed

appropriate. The intent of this report is to provide additional analysis to assist in determining when the releases would be appropriate.

Study Area

The study area is the South Platte River corridor and extends from Chatfield Reservoir downstream to the east side of the Denver metropolitan area (Figure 1). The South Platte River in the study area has several hydrologic reaches based on USGS gage locations, tributary inflow and major diversions. The reaches are: 1) Chatfield Reservoir outflow to the USGS gage at Union Avenue (Figure 2); 2) Union Avenue gage to the USGS gage at Englewood (Figure 3); 3) Englewood gage to the USGS gage at 64th; and 4) downstream from South Platte at 64th gage (Figure 4). Tributary streams include Marcy Gulch, Bear Creek, and Cherry Creek. The largest diversion in the study area is the Burlington Ditch at approximately 64th Avenue.

Methods

This analysis relied on readily available existing data from several sources. These sources include stream flow data from the State of Colorado and USGS, hydrologic analysis from Denver Water, stream habitat data from previous Physical Habitat Simulation (PHABSIM) studies, stream cross section data from previous R2Cross studies (ERC 2014), biological data from SPCURE (Aquatics Associates 2011), Metropolitan Waste Water District and SACWSD, and water quality data from SACWSD, Denver Trout Unlimited and USGS.

Hydrology

This report is not an analysis of water rights and potential hydrologic regimes based on water right priorities. Rather it includes a hydrologic analysis of recent flows to assist in determining current limiting hydrologic conditions downstream from Chatfield Reservoir. Hydrologic data from the following gage locations was used to evaluate stream flow statistics for annual and monthly flows.

- PLACHACO-South Platte Downstream from Chatfield
- USGS 06710247- South Platte at Union Avenue
- USGS 06711565– South Platte at Englewood
- USGS 06714215 – South Platte at 64th

Denver Water provided the output from the Chatfield Release model of environmental flow releases from previous analysis and used during environmental pool discussions during the time the Chatfield Reallocation EIS was prepared. Those data included model output for the environmental pool for several stream release levels.

The hydrologic period of record from Water Years 2001 through 2017 was used for the analysis. This period of record was chosen to provide baseline data for recent years to coincide with the recent data for biological resources and water quality.

The hydrologic analysis was performed using Indicators of Hydrologic Alteration (IHA) available from The Nature Conservancy (TNC). The following analysis from IHA was completed:

- Maximum flow analysis
- Minimum flow analysis
- Flow duration analysis

Biological and Habitat Data

Biological data was acquired from four sources: CPW, Metro, SPCURE and SACWD. The biological data included information for benthic macroinvertebrates and fish species. These data were collected during monitoring projects supported by those entities.

Habitat data was taken from existing habitat studies for Physical Habitat Simulation (PHABSIM) and from R2Cross minimum flow studies. No new PHABSIM analysis was conducted for species currently present but not modeled in the original analysis. The PHABSIM data included an analysis of wetted perimeter and habitat area. The species used in the PHABSIM data were brown trout, channel catfish, and sand shiner. These species are present in the South Platte from Chatfield Reservoir downstream through Denver. These species represent species that include cold water, large bodied warm water and small bodied warm water fish. Trout habitat was only evaluated the upstream reach near Chatfield Reservoir. The warm water species were modeled at all river segments. The report is limited to these species to provide a concise example of change in habitat with flow. Additional PHABSIM data for several other species is listed in the Appendix.

Water Quality

Water quality data for standard parameters were available from SACWSD characterization of water quality characteristics in the South Platte from the foothills to east of Denver. Water temperature data was available from USGS gage data and from Trout Unlimited monitoring.

Results

Results from the existing data for hydrology, biological data, and water quality are compiled in the following sections. Hydrology data is discussed by reach. Biological data including habitat is discussed for the upper reaches near Chatfield Reservoir and for the lower reach near 64th Avenue. Water quality data is discussed by reach.

Hydrology

Daily hydrology data from four locations was analyzed for both peak flow regimes and minimum flow regimes. Peak flows create and maintain habitats. Minimum flow values can be used to determine potential periods of stress during seasonal low water conditions for aquatic ecosystems.

The current peak flow regime in the South Platte River through metro the Denver area is similar from Chatfield Reservoir downstream to the northeast portion of the Denver metro area. Both the three day and seven day maximum flows show a small increase longitudinally downstream for median values (Figure 5 through Figure 10). The median value for three day maximum flows approximately 700 cfs at Chatfield, approximately 700 cfs at Union, approximately 1000 cfs at Englewood, and approximately 1400 cfs at 64th. This increase in discharge for short term peak flows is to be expected given the increase in drainage area from the upstream to downstream locations. The median flows for seven day maximum flows have less difference from upstream to downstream. The median seven day peak flows are approximately 600 cfs at Chatfield Reservoir and Union, and approximately 700 cfs at Englewood and 64thAvenue.

The confined nature of the river channel, bank protection measures, and necessity for flood control to protect residents and infrastructure does not allow the river channel to migrate under peak flow regimes as would be the case with an unconfined channel. Any habitat creation and maintenance occurs within the current channel. The current peak flows approximate bank full (Urban Drainage HEC-RAS unpublished data). These peak flows are likely high enough to provide some measure of small sediment transport to provide clean substrates for algae, and benthic macroinvertebrates, the primary and secondary food web levels in the river.

The minimum flow regime for the South Platte River is distinctly different at the upper and lower sections of the study area when compared to the middle of the Denver metro area (Figure 11 through Figure 16). The one day and seven day minimum flows are lowest at Chatfield and at 64th. The one day and seven day minimum flows downstream from Chatfield Reservoir are close to zero. The median one day and seven day minimum flows are approximately 5 cfs at 64th Avenue. The median one day minimum flow at the USGS Union gage is approximately 12 cfs and approximately 30 cfs at the Englewood gage. The median seven day minimum flow is approximately 14 cfs at the Union gage and approximately 35 cfs at the Englewood gage. These higher minimum flows at the Union gage and at the Englewood gage are likely due to tributary inflows from Marcy Gulch and from Bear Creek. The lower minimum flows at the 64th Avenue gage are likely the result of the large diversion from the South Platte at the Burlington Ditch, which is upstream of that gage location.

The flow duration analysis also shows these same flow ranges and provides a means to determine when they occur during the year (Figure 17 through Figure 24). Months with the extremely low or zero flow days at Chatfield are November through February, August and September. The flow duration analysis shows that flow remains greater than 10 cfs greater

than 98% of the time at Union and greater than 30 cfs for over 98% of the time at Englewood. Flows are greater than 5 cfs all the time at 64th.

Biological and Instream Habitat

Physical habitat analysis for aquatic habitat was completed using existing river cross section data and Physical Habitat Simulation (PHABSIM) software. The existing data were from earlier analyses by Great Western Institute et al. (2008) and ERC (2014).

Data were available to evaluate the change in wetted perimeter at five individual study sites: Littleton at South Platte Park; near Union Avenue; near Evans Avenue; near Franklin Street; and downstream of the Burlington Ditch. These study sites are referred to in the tables and figures as: Littleton, Union, Evans, Franklin and Downstream. The Littleton, Union, Evans, and Downstream sites roughly correspond to the gage locations used in the hydrologic analysis.

Wetted perimeter analysis was completed for all sites at flows of 5, 10, 20, 30, 40 and 50 cfs to determine the change in wetted perimeter as flow increased from 5 cfs up to the other flow levels. The wetted perimeter analysis provides information on the width of the wetted channel and therefore the amount of stream cross section that is usable by aquatic species. The amount of wetted channel in riffles is used to determine the amount of habitat for benthic macroinvertebrates, a food source for higher trophic levels.

The greatest amount of increase at all sites is from the 5 cfs flow up to approximately 20 or 30 cfs (Table 1 through Table 4 , and Figure 25 through Figure 28). The Littleton site riffle wetted perimeter is approximately bank to bank at 40 cfs. The wetted perimeter at this site at 5 cfs is approximately 20% of the active channel, which limits the productive capability of the channel. The hydrology analysis showed that flows of 5 cfs and lower regularly occur in the late fall and winter at this section of the river. A 20 cfs flow at this site wets approximately 60 percent of the active channel, which is three times the amount of wetted channel as at 5 cfs.

A section of the Littleton area was restored to a narrower channel in one of the over wide sections to restore habitat function (ERC 2014). The comparison of the channel prior to restoration (Figure 29) with post restoration (Figure 30) shows that a much higher percentage of the channel is wet post restoration as at the same flow prior to restoration. The result is a better ecological function at lower flow levels.

The hydrologic analysis for the Union gage shows a median minimum flow of approximately 10 cfs at this location. The wetted perimeter analysis shows that the active channel is wet from bank to bank at approximately 20 cfs at this site. The 10 cfs base flow at this site provides approximately 90 percent of the total channel width as productive habitat.

The median minimum flow at the Evans site is approximately 30 cfs. The 30 cfs flow equates to nearly 95 percent wetted channel. Flow at this site has dropped as low as 12 cfs over the

period analyzed, however, the majority of time the flow is 20 cfs or greater. The 20 cfs provides approximately 80 percent of the channel width.

The median minimum flow at the downstream site is approximately 5 cfs which results in a wetted perimeter of approximately 40% of the active channel. A flow of 20 cfs provides wetted width of approximately 80% of the active channel in riffle habitat.

Wider wetted area provides more habitat for benthic invertebrates, which are an important food source for fish. The flows of 30 cfs and higher provide greater pool and riffle depths for refuge and feeding habitat.

Habitat area as a function of discharge increases most rapidly as flow increases from minimum up to flows in the range of 20 to 50 cfs (Table 5 through Table 10; Figure 31 through Figure 37). The change in habitat varies for each species, however, the magnitude of the habitat increase at flows of 20 cfs is approximately double or triple the amount available at the minimum flow.

Thirteen sites were sampled for benthic macroinvertebrates in the study are by SPCURE from 2007 through 2010 (Table 11). These were the most recent data available on the SPCURE website. The samples were evaluated using the MMI index from CDPHE. None of the sites were listed as "impaired", however, several were in the "gray area" between attainment and impaired.

All of the fish species collected in the downstream reach by Metro () also have been collected by CPW (). CPW has monitored fish at 51 locations from Chatfield Reservoir downstream to approximately 160th (Table 14, Figure 38 - Figure 41). CPW has collected a total of 40 fish species at these locations since the 1980s (Table 15). The species include cold water (trout) and warm water species. The species include both game species and non-game species.

Water Quality

The South Platte River downstream from Chatfield Dam through metro Denver is classified as Aquatic Life Warm 1. Readily available water quality data was acquired from several sources. Water temperature data was acquired from continuous monitoring conducted at the Englewood USGS gage and by Denver Trout Unlimited at Englewood. The continuous monitoring at Englewood shows average daily and maximum daily water temperatures highest during the period from late June through July (Figure 42). The long term USGS water temperature data show the same water temperature range as observed in 2016 (Figure 43). A comparison of water temperature, air temperature and discharge at Englewood shows that water temperature is influenced by air temperature more than discharge (Figure 44). The relationship seen at Englewood has been observed in the past at South Platte Park in Littleton (Miller Ecological unpublished field data).

Several water quality parameters were assessed by SACWD in fall of 2006 at three locations on the South Platte River from the foothills to the east side of the Denver Metro area. The parameters included Ammonia, Nitrite, Nitrite, Phosphorus, Dissolved Oxygen, and water temperature (Figure 45 , Figure 46). The nutrients increased on concentration from upstream to the downstream reach. The largest increase was between South Platte Park to 104th Avenue. This is likely due to the effect of the urban area on the South Platte River water quality. The SACWD data also show water temperature increasing from upstream to downstream as the South Platte transitions from a mountain river to plains river. Dissolved oxygen concentrations decrease from upstream to downstream, likely in response to the change in water temperature.

Additional more detailed water quality data may be available for future evaluations. Any future studies should make renewed contacts with Denver area Sanitation Districts and SPCURE to obtain updated information.

Discussion

The initial volume for environmental flows of 1600 AF (the initial environmental pool) was used as the starting point for the analysis. The previous analysis was documented in Miller (2016). The number of days at this water volume was compared to the number of days at 2,100 AF (Table 16). In addition, a range of release discharges were compared to determine the benefit of the additional flow.

The reaches with the lowest minimum flows are at the upstream and downstream end of the study area in South Platte Park and downstream of the Burlington Ditch, respectively. The number of days when additional flow could be released for environmental benefit varies with the volume of discharge. For example, a 5 cfs release could be made for 212 days at 2100 AF of water. A 20 cfs release could be made for 53 days with 2100 AF of water.

A previous analysis was completed in 2006 during previous environmental pool discussions. The analysis was completed by Denver Water using an assumed release of 10 cfs to evaluate the years when the environmental pool would be available. The analysis showed that the environmental pool is not available in all years (Figure 47) due to depletion of the downstream users pool in Chatfield Reservoir (Figure 48). This previous analysis used a period of record that coincided with other hydrologic studies at the time. The previous analysis is an example of how any future proposed released could be evaluated.

The days with the lowest flows generally occur in late summer (August and September) and through the winter months (November through February) based on the flow duration analysis. The limiting factors for aquatic species during these times are likely the lack of wetted area for primary and secondary producers during summer and winter and the lack of feeding and refuge habitat for fish. Habitat area increases as flows increase, however, there may be an additional limiting factor of elevated water temperatures at extremely low flows during late summer. The higher flow release of 30 cfs or 40 cfs for a shorter time may provide the better benefit to the

aquatic organisms since there could be a minor reduction in water temperature with a higher release. There also may be more refuge habitat in pools at those higher flows. Water temperature in winter may be an issue related to warmer water due to water treatment discharges. In the Chatfield reach it may not be as large a concern during the colder fall and winter months, however, the amount of productive wetted area is important through the winter. A lower magnitude release in winter that provides 70 % to 80% wetted channel would be beneficial to the reaches that are now less than 50% wetted channel or lower. The reaches that would most benefit from winter release are upstream in Littleton and downstream of the Burlington Ditch. It is important to note that even the lowest flows provide essential aquatic habitat at a level that is not present with zero flows.

There are numerous ways to release the stored water for environmental benefits. For example, it may be more beneficial to the river ecosystem to release at a higher discharge (e.g. 30 or 40 cfs) for a short period in late summer when both water temperature and wetted area are factors rather than a longer period at lower flow during that time of year. The higher storage volumes of 2100 AF provides more opportunity for environmental flows than the original 1600 AF volume. The 2100 AF storage volume also provide more flexibility in providing seasonally appropriate flow regimes than 1600 AF.

Conclusions and Recommendations

The recommended first steps and highest priorities for flow management include two critical time periods, November through February and August and September. The recommended flow management that would be most beneficial to the current conditions within the study area are:

- First - Eliminate days with zero or near zero flows. A minimum flow that would meet the criteria of the 50 % to 70 % wetted channel is 30 cfs in the Chatfield Reach and 10 cfs in the 64th Avenue Reach. Those reaches have the lowest flows in the study area. Even very low flow releases provide essential aquatic habitat that is not present when there is zero flow.
- Second – Release water on low flow days in summer for additional refuge habitat during times of elevated water temperature. Flows of 30 cfs to 40 cfs provide an additional 0.5 ft to 1.0 ft of depth compared to the depth at 10 cfs.

The ability to meet the release priorities will depend on the volume available from the environmental pool. The analysis of water rights and future operations is beyond the scope of this present report; however, water rights and operations should be considered in future studies. The environmental pool may not be refilled each year due to the junior nature of the water rights that are expected to fill the Environmental Pool and the relative priority of filling among the Reallocation other higher priority water users. The inability to refill the pool each year could impact the releases recommended for the environmental pool. The exact release value and the duration would need to be determined each year. There should also be an effort to shepherd the release downstream past the Burlington Ditch to the east side of the metro

area, if possible. A potential component of the sheparding could be a reconfiguration of the Burlington Ditch return so it is simmediately downstream of the diversion structure.

The best use of the additional volume may vary from year to year. To optimize the use of the water, there may be the need to make annual decisions on the operational release of the water, if possible. This could take place in late winter or early spring to evaluate the predicted snowpack/runoff and expected storage. The release could be set based on expected Environmental Pool volumes and past year's releases. A desired release regime could be designed prior to the initial release and then used as a reference for deciding how to release the water each year. The desired release regime could be a simple matrix of expected water year conditions and expected meteorological conditions (Table 17). An example of calculating these year types is shown for the Union and Englewood USGS gages. The hydrologic year types were derived from USGS gage records of average annual discharge to determine dry average and wet water years (Table 18, Table 19). The same type of analysis could be completed to determine meteorological year types. The year types could then be used to set thresholds for release triggers and release discharges.

For example, in years with warmer summer conditions, additional releases in late summer would likely help moderate water temperature in the upper section of the river in South Platte Park and increase wetted area for additional instream productivity through Denver. An increase from 10 cfs to 30 cfs would nearly triple the wetted area in riffles in South Platte Park and substantially increase riffle area in downstream reaches. Releases higher than 30 cfs provide even more wetted area at the cost of fewer days of release. The overall cost to the ecosystem may be the inability to make a winter release to raise the extreme low flows that occur.

Balancing the amount to release (cfs), the number of days to release, and seasonal timing of release (summer vs. winter, or both seasons) will likely need to be an ongoing process. An adaptive approach to the operation would be best, which would allow the operation to be refined as the years progress. An evaluation of the results of the release would also be beneficial. This should include a summary of the timing, release discharge and volume released. In addition, biological and physical data collection would be useful. This could include a summary of fish population or presence as summarized by CPW monitoring. Water temperature monitoring would provide data on the benefit of the release in late summer. This is available from USGS gages or collected with small data recorders as DTU has done in the past.

Additional considerations for the Environmental Pool management should include the potential to coordinate releases for downstream users that benefit the river ecosystem. How the coordination is accomplished is outside the scope of this current project but should be addressed during discussions with stakeholders. The change in Chatfield Reservoir pool elevations should be considered in the discussions regarding releases. Pool management in Chatfield and the potential effect to the upstream area from the releases or storage of the environmental pool should be evaluated as part of the management plan for the releases.

Next Steps and Future Studies

This report was an initial evaluation of some of the main factors impacting the South Platte River through Denver and how the environmental pool may be used to benefit the river. The report relied on readily available data, previous studies and input from stakeholders to develop the analysis and recommendations.

Next steps in the Environmental Pool project should include:

- Incorporation of institutional constraints such as water rights, projected future storage and release operations, and expected hydrologic changes in the South Platte and tributaries within the Denver metropolitan area.
- Formalize the decision structure between CPW and other stakeholders for the Environmental Pool.
- Formalize agreements for the Environmental Pool and its uses.
- Updated habitat evaluation in reaches that have had substantial restoration work completed.
- Updated habitat as a function of flow for species of interest that were not modeled in the earlier studies.
- Water temperature monitoring at least at the stream gage locations from Chatfield to 64th. Additional locations could be included at points of concern.
- Continued monitoring of biological and water quality data and providing that data in a timely manner to the stakeholder group.

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Tables

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Table 1. Wetted perimeter width and change in wetted perimeter as compared to 5 cfs at Chatfield reach.

	Riffle		Run	
Discharge (cfs)	**Wetted Perimeter (ft)**	**Percent Change**	**Wetted Perimeter (ft)**	**Percent Change**
5	15	0%	23	0%
10	21	47%	27	16%
20	45	206%	31	33%
30	61	317%	37	59%
40	73	402%	40	75%
50	74	409%	43	89%

Table 2. Wetted perimeter width and change in wetted perimeter as compared to 5 cfs at Union reach.

	Riffle		Run	
Discharge (cfs)	**Wetted Perimeter (ft)**	**Percent Change**	**Wetted Perimeter (ft)**	**Percent Change**
5	75	0%	34	0%
10	121	61%	37	9%
20	128	70%	48	41%
30	128	71%	66	94%
40	129	71%	93	173%
50	129	72%	97	185%

Table 3. Wetted perimeter width and change in wetted perimeter as compared to 5 cfs at the Englewood reach.

	Riffle		Run	
Discharge (cfs)	**Wetted Perimeter (ft)**	**Percent Change**	**Wetted Perimeter (ft)**	**Percent Change**
5	31	0%	52	0%
10	48	53%	59	13%
20	59	89%	83	58%
30	71	128%	86	65%
40	74	136%	89	70%
50	76	142%	91	73%

Table 4. Wetted perimeter width and change in wetted perimeter as compared to 5 cfs at the 64th Avenue reach.

	Riffle		Run	
Discharge (cfs)	**Wetted Perimeter (ft)**	**Percent Change**	**Wetted Perimeter (ft)**	**Percent Change**
5	53	0%	72	0%
10	69	30%	78	8%
20	113	115%	81	13%
30	127	141%	85	17%
40	139	164%	88	21%
50	149	182%	90	25%

Table 5. Total habitat available for adult and juvenile Brown Trout at each increment of flow. Note: trout habitat not simulated for Union, Englewood and 64th reaches.

Adult	Total Habitat Area (sq ft)				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	1,109,896	NA	NA	NA	1,109,896
10	2,771,713	NA	NA	NA	2,771,713
20	7,806,722	NA	NA	NA	7,806,722
30	14,864,592	NA	NA	NA	14,864,592
40	20,715,309	NA	NA	NA	20,715,309
50	26,342,203	NA	NA	NA	26,342,203
Juvenile	Total Habitat Area (sq ft)				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	7,590,482	NA	NA	NA	7,590,482
10	15,920,988	NA	NA	NA	15,920,988
20	31,460,453	NA	NA	NA	31,460,453
30	44,619,191	NA	NA	NA	44,619,191
40	51,311,665	NA	NA	NA	51,311,665
50	55,091,721	NA	NA	NA	55,091,721

Table 6. Total habitat available for adult and juvenile Channel Catfish at each increment of flow.

Adult	Total Habitat Area (sq ft)				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	14,017	8,802	1,688,809	1,307,311	3,018,939
10	96,290	61,645	2,378,614	5,758,410	8,294,959
20	227,306	136,186	2,528,668	8,905,400	11,797,560
30	312,123	185,562	2,564,145	10,987,830	14,049,660
40	369,338	268,429	2,584,218	12,013,400	15,235,385
50	422,584	335,520	2,605,075	12,578,370	15,941,550
Juvenile	Total Habitat Area (sq ft)				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	2,289,142	5,242,090	2,311,504	3,298,474	13,141,210
10	3,782,572	4,809,104	3,961,528	17,062,570	29,615,773
20	1,724,781	7,158,435	4,764,793	31,147,061	44,795,070
30	1,749,661	9,470,675	4,150,160	48,621,792	63,992,289
40	2,348,494	10,194,895	3,665,202	70,509,947	86,718,538
50	2,480,120	10,966,300	3,409,602	89,401,129	106,257,150

Table 7. Total habitat available for adult Sand Shiner at each increment of flow.

Adult	Total Habitat Area (sq ft)				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	19,432,929	38,673,559	10,645,297	126,113,258	194,865,043
10	22,858,223	47,385,587	9,233,533	188,476,955	267,954,298
20	25,728,133	54,513,174	7,544,631	242,832,734	330,618,672
30	29,480,153	63,387,617	6,924,613	250,827,719	350,620,101
40	31,862,532	74,801,474	6,542,883	260,068,758	373,275,646
50	32,631,913	80,772,279	6,306,640	258,103,645	377,814,477

Table 8. Percent change in total habitat available for adult and juvenile Brown Trout at each increment of flow.

Adult	Percent change in habitat from 5 cfs				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	0%	NA	NA	NA	0%
10	150%	NA	NA	NA	150%
20	603%	NA	NA	NA	603%
30	1239%	NA	NA	NA	1239%
40	1766%	NA	NA	NA	1766%
50	2273%	NA	NA	NA	2273%
Juvenile	Percent change in habitat from 5 cfs				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	0%	NA	NA	NA	0%
10	110%	NA	NA	NA	110%
20	314%	NA	NA	NA	314%
30	488%	NA	NA	NA	488%
40	576%	NA	NA	NA	576%
50	626%	NA	NA	NA	626%

Table 9. Percent change in total habitat available for adult and juvenile Channel Catfish at each increment of flow.

Adult	Percent change in habitat from 5 cfs				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	0%	0%	0%	0%	0%
10	587%	600%	41%	340%	175%
20	1522%	1447%	50%	581%	291%
30	2127%	2008%	52%	740%	365%
40	2535%	2950%	53%	819%	405%
50	2915%	3712%	54%	862%	428%
Juvenile	Percent change in habitat from 5 cfs				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	0%	0%	0%	0%	0%
10	65%	-8%	71%	417%	125%
20	-25%	37%	106%	844%	241%
30	-24%	81%	80%	1374%	387%
40	3%	94%	59%	2038%	560%
50	8%	109%	48%	2610%	709%

Table 10. Percent change in total habitat available for adult Sand Shiner at each increment of flow.

Adult	Percent change in habitat from 5 cfs				
Discharge	Site				
	Chatfield	Union	Englewood	64th	Total
5	0%	0%	0%	0%	0%
10	18%	23%	-13%	49%	38%
20	32%	41%	-29%	93%	70%
30	52%	64%	-35%	99%	80%
40	64%	93%	-39%	106%	92%
50	68%	109%	-41%	105%	94%

Table 11. Sampling sites for SPCURE macroinvertebrate sampling (Source: Aquatics Associates, 2011).

Site	Location
S84	u/s Marcy Gulch & Centennial WWTP, d/s Chatfield Reservoir
S76	d/s Mineral Ave. & Centennial WWTP oufall, at Carson Nature Center
S62	at Denver Seminary
S51	u/s Union Ave. & Bear Creek
S34	d/s Hampden Ave. & Bear Creek
S30	d/s Dartmouth St., u/s Littleton-Englewood WWTP & Arapahoe Plant
S21 22	u/s Evans Ave., d/s Littleton-Englewood WWTP & Arapahoe Plant outfalls
S7	d/s Mississippi Ave., u/s from Zuni Plant
N4	u/s 6th Ave. & Zuni Plant, d/s Great Western plume
N18	d/s I-25 at Elitch's, d/s Zuni Plant
N28	d/s Cherry Creek confluence
N34	d/s Park Ave. overpass
N45 46	d/s I-70

Table 12. South Platte River MMI results 2007 through 2010. Color key: white background = attainment, gray = gray area (Source: Aquatics Associates, 2011)

Site	2007	2008	2009	2010
S84	46.1	48.7	45.7	38.2
S76	54.3	52	52.4	48.5
S62	53.8	47.9	48.9	55.5
S51	53.7	52.8	55.8	60.5
S34	38.5	43	48.1	47.7
S30	45.8	46.5	31.7	58.9
S21 22	36.1	40.8	38.6	32.9
S76	33.2	37.8	26.5	47.6
N4	32.8	38.2	31.7	31.4
N18	49.2	42.7	46.2	41.9
N28	51.6	39.2	40.8	56.2
N34	39.7	50.1	39.6	49.5
N45 46	33.5	35.4	35.7	50.7

Table 13. Fish species present in South Platte River, 64th Reach (Source: Metro 2013).

Scientific Name	Common Name	Distribution	Total Number
Lepomis macrochirus	bluegill	Introduced	1
Culaea inconstans	brook stickleback	Native	7
Cyprinus carpio	common carp	Invasive	9
Semotilus atromaculatus	creek chub	Native	11
Pimephales promelas	fathead minnow	Native	107
Lepomis cyanellus	green sunfish	Native	19
Etheostoma exile	Iowa darter	Native	1
Etheostoma nigrum	johnny darter	Native	19
Micropterus salmoides	largemouth bass	Introduced	55
Rhinichthys cataractae	longnose dace	Native	53
Catostomus catostomus	longnose sucker	Native	8
Notropis stramineus	sand shiner	Native	155
Micropterus dolomieui	smallmouth bass	Introduced	1
Gambusia affinis	western mosquitofish	Invasive	31
Catostomus commersoni	white sucker	Native	47
Perca flavescens	yellow perch	Introduced	7

Table 14. CPW fish monitoring sites in South Platte River downstream from Chatfield Reservoir.

StationCode	Lat	Lon	SiteLastSurve
Chatfield to Union Reach			
SP1017	39.5674595	-105.04	13-Nov-2015
SP4038	39.5850416	-105.031	28-Sep-2012
SP1008	39.6001716	-105.025	28-Oct-2005
SP1019	39.6060825	-105.024	30-Sep-2009
SP1007	39.6128581	-105.025	11-Dec-2003
SP4211	39.627087	-105.017	28-Oct-2005
SP5754	39.6306915	-105.015	4-Oct-2012
Union To Englewood Reach			
SP1207	39.6355567	-105.018	12-Sep-1995
SP1022	39.6421166	-105.015	26-Sep-2013
SP1205	39.6503704	-105.012	12-Sep-1995
SP1240	39.65393	-105.006	24-Oct-2005
SP4891	39.6628143	-105.004	29-Sep-2012
SP4220	39.6664995	-105.004	24-Oct-2005
Englewood to 64th Reach			
SP4758	39.6763028	-104.998	7-Oct-2012
SP1512	39.6805106	-104.999	20-Oct-2016
SP1014	39.6888902	-105	12-Oct-2012
SP6836	39.6918454	-104.995	14-Sep-1995
SP6835	39.7034687	-104.996	14-Sep-1995
SP1201	39.7076766	-104.999	14-Sep-1995
SP4212	39.7147586	-105.002	27-Oct-2005
SP3325	39.7381928	-105.018	6-Sep-2017
SP4887	39.7472665	-105.015	3-Oct-2012
SP1009	39.7552683	-105.008	18-Sep-1995
SP1003	39.7596384	-105.004	20-Oct-1998
SP4888	39.7654678	-104.992	31-Aug-2015
SP0627	39.7698458	-104.983	1-Oct-2018
SP1232	39.775107	-104.979	28-Oct-2005
SP3324	39.7822786	-104.976	18-Jul-2002
SP1004	39.7879813	-104.973	1-Oct-2012
SP1241	39.7912689	-104.968	19-Sep-1995
SP4214	39.7954848	-104.965	3-Nov-2005
SP6262	39.8013665	-104.96	10-Sep-2018
SP1024	39.8069614	-104.959	19-Oct-2011
SP0628	39.8123846	-104.956	18-Sep-2012
64th to 160th Reach			
SP0629	39.8269958	-104.949	27-Aug-2018
SP4215	39.8581004	-104.934	18-Sep-2017
SP0630	39.8632238	-104.929	16-Oct-2018
SP6564	39.8786759	-104.904	8-Aug-2012
SP1002	39.8847925	-104.902	19-Oct-2011
SP3880	39.8986287	-104.899	11-Oct-2000
SP6765	39.9078197	-104.89	4-Sep-2018
SP4207	39.9118918	-104.889	18-Sep-2018
SP6255	39.9133413	-104.879	4-Sep-2014
SP0631	39.9197485	-104.872	20-Sep-2011
SP7821	39.9616486	-104.853	25-Sep-2018
SP7032	39.9616938	-104.853	20-Nov-2014
SP4208	39.9652928	-104.849	9-Nov-2005
SP7404	39.9820448	-104.838	22-Oct-1992
SP7879	39.9886381	-104.83	17-Oct-2016
SP0632	39.9888994	-104.83	5-Sep-2013
SP7822	39.9995147	-104.825	27-Sep-2018

Table 15. CPW fish species collected by reach.

Chatfield	Union	Englewood	64th
CommonName	CommonName	CommonName	CommonName
		BIGMOUTH SHINER	BIGMOUTH SHINER
BLACK BULLHEAD	BLACK BULLHEAD	BLACK BULLHEAD	BLACK BULLHEAD
BLACK CRAPPIE	BLACK CRAPPIE	BLACK CRAPPIE	BLACK CRAPPIE
BLUEGILL	BLUEGILL	BLUEGILL	BLUEGILL
BROOK STICKLEBACK	BROOK STICKLEBACK		BROOK STICKLEBACK
		BRASSY MINNOW	
		BROOK STICKLEBACK	
BROWN TROUT	BROWN TROUT	BROWN TROUT	BROWN TROUT
CHANNEL CATFISH	CHANNEL CATFISH	CHANNEL CATFISH	CHANNEL CATFISH
COMMON CARP	COMMON CARP	COMMON CARP	COMMON CARP
		COMMON SHINER	
CRAPPIE (S.U.)		CRAPPIE (S.U.)	CRAPPIE (S.U.)
CREEK CHUB	CREEK CHUB	CREEK CHUB	CREEK CHUB
FATHEAD MINNOW	FATHEAD MINNOW	FATHEAD MINNOW	FATHEAD MINNOW
		GIZZARD SHAD	GIZZARD SHAD
GOLDEN SHINER		GOLDEN SHINER	GOLDEN SHINER
		GOLDFISH	GOLDFISH
GREEN SUNFISH	GREEN SUNFISH	GREEN SUNFISH	GREEN SUNFISH
IOWA DARTER	IOWA DARTER	IOWA DARTER	IOWA DARTER
JOHNNY DARTER	JOHNNY DARTER	JOHNNY DARTER	JOHNNY DARTER
LARGEMOUTH BASS	LARGEMOUTH BASS	LARGEMOUTH BASS	LARGEMOUTH BASS
LONGNOSE DACE	LONGNOSE DACE	LONGNOSE DACE	LONGNOSE DACE
LONGNOSE SUCKER	LONGNOSE SUCKER	LONGNOSE SUCKER	LONGNOSE SUCKER
			MINNOWS
		NORTHERN PLAINS KILLIFISH	NORTHERN PLAINS KILLIFISH
		ORANGESPOTTED SUNFISH	ORANGESPOTTED SUNFISH
OTHER WARMWATER SPECIES	OTHER WARMWATER SPECIES	OTHER WARMWATER SPECIES	
PLAINS TOPMINNOW		PLAINS TOPMINNOW	PLAINS TOPMINNOW
		PUMPKINSEED	PUMPKINSEED
RAINBOW TROUT	RAINBOW TROUT	RAINBOW TROUT	RAINBOW TROUT
		RED SHINER	
SAND SHINER		SAND SHINER	SAND SHINER
	SAUGEYE (WALLEYE X SAUGER HYBRID)		SAUGER
			SAUGEYE (WALLEYE X SAUGER HYBRID)
SMALLMOUTH BASS	SMALLMOUTH BASS	SMALLMOUTH BASS	SMALLMOUTH BASS
		SPOTTAIL SHINER	SPOTTAIL SHINER
			SUNFISH (S.U.)
WALLEYE	WALLEYE		WALLEYE
WESTERN MOSQUITOFISH	WESTERN MOSQUITOFISH	WESTERN MOSQUITOFISH	WESTERN MOSQUITOFISH
WHITE CRAPPIE		WHITE CRAPPIE	WHITE CRAPPIE
WHITE SUCKER	WHITE SUCKER	WHITE SUCKER	WHITE SUCKER
YELLOW PERCH	YELLOW PERCH	YELLOW PERCH	YELLOW PERCH

Table 16. Potential days available with various increments of release for 1600 and 2100 acre-feet of water.

	Release (cfs)						
Volume	**5**	**10**	**15**	**20**	**30**	**40**	**50**
1600	162	81	54	40	27	20	16
2100	212	106	71	53	35	27	21

Table 17. Example potential release pattern based on water year type and meteorological year type.

	Late Summer Air Temperature		
Water Year Type	**Cool**	**Average**	**Warm**
Dry (25 percent exceedance flow)	Lower cfs release in summer (10 or greater) and low release in winter (10 cfs)	Moderate release in summer (20-30 cfs) and low release in winter (10 cfs)	Moderate to High release in summer (20-40 cfs) and low release in winter (10 cfs)
Average (50 percent exceedance flow)	Low to Moderate release (10 – 30 cfs) in summer and low to moderate in winter (10 – 20 cfs)	Moderate release (20-40 cfs) in summer and low to moderate (10-20 cfs) in winter	Moderate to high (20-50 cfs) in summer and low to moderate (10-20 cfs) in winter
Wet (85 percent exceedance flow)	Low to moderate (10-20 cfs) summer and moderate (20-30 cfs) in winter	Moderate (20-30 cfs) in summer and low to moderate (10-20 cfs) in winter	Moderate to high (20-50 cfs) in summer and low to moderate (10-20 cfs) in winter

Table 18. Union Ave USGS gage mean annual flow data – 2001 – 2017. Note: Highlighted values illustrate the approximate levels for wet, average and dry hydrology years.

Year	Mean annual discharge	Rank	Percentile
2015	551.5	1	94%
2007	412	2	88%
2016	244.8	3	82%
2009	187.4	4	76%
2010	180	5	71%
2008	161.8	6	65%
2014	161.1	7	59%
2005	139.8	8	53%
2017	121.4	9	47%
2011	110.4	10	41%
2003	107.7	11	35%
2006	105.2	12	29%
2001	93.8	13	24%
2004	92.7	14	18%
2013	49.3	15	12%
2012	40.7	16	6%
2002	29.3	17	0%

Table 19. Englewood USGS gage mean annual flow data – 2001 – 2017. Note: Highlighted values illustrate the approximate levels for wet, average and dry hydrology years.

Year	Mean annual Discharge	Rank	Percentile
2015	736.9	1	94%
2007	525.4	2	88%
2016	335.4	3	82%
2010	268.8	4	76%
2009	243.4	5	71%
2014	240.1	6	65%
2005	214.2	7	59%
2008	183.8	8	53%
2017	162	9	47%
2011	141.5	10	41%
2001	140.6	11	35%
2003	139.4	12	29%
2004	139.4	13	24%
2006	128.5	14	18%
2013	100.7	15	12%
2012	64.9	16	6%
2002	48.6	17	0%

Figures

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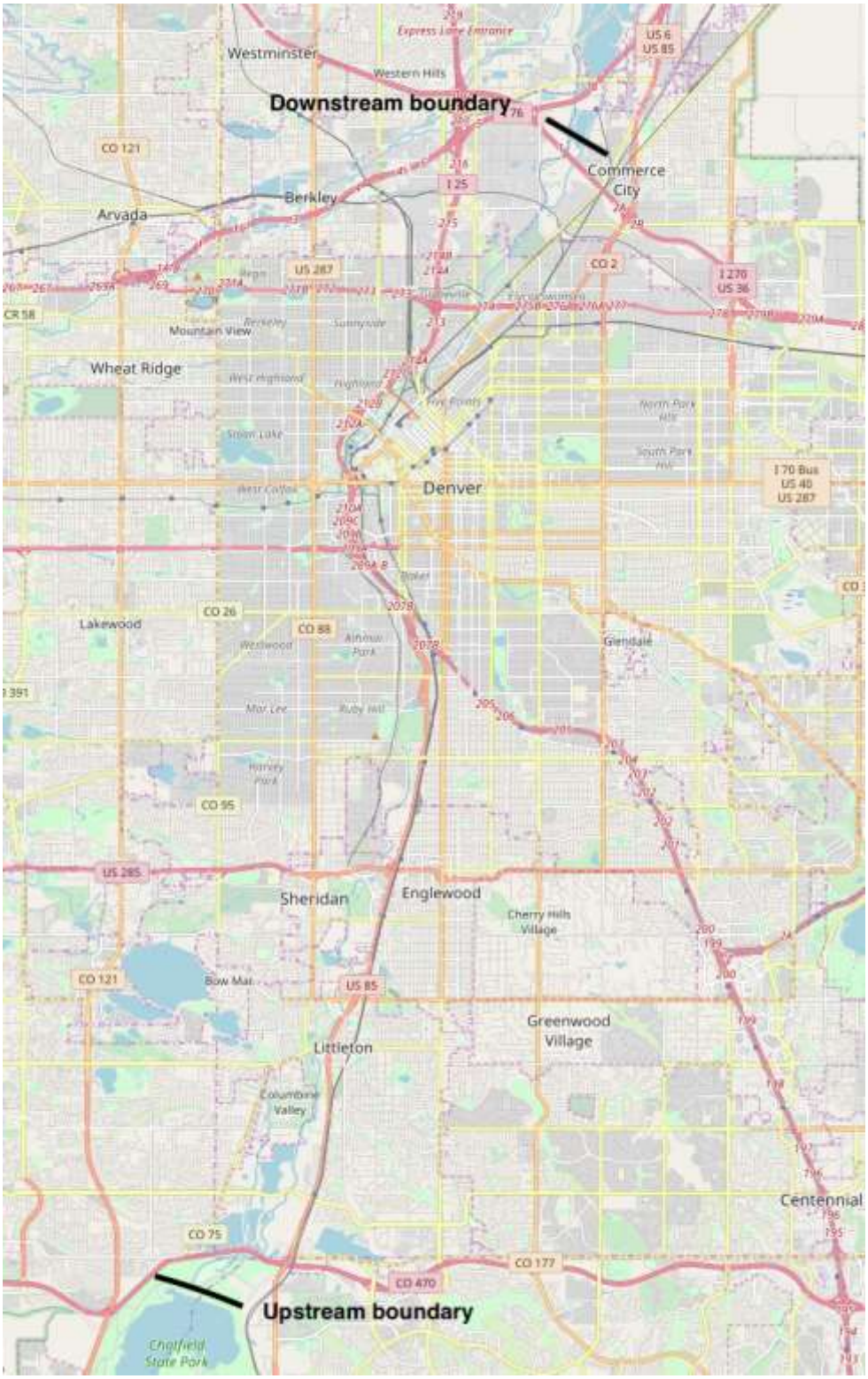


Figure 1. South Platte River study area from Chatfield Reservoir to Northeast Denver at 104th Avenue.

Figure 2. South Platte River from Chatfield Reservoir to USGS Union gage.

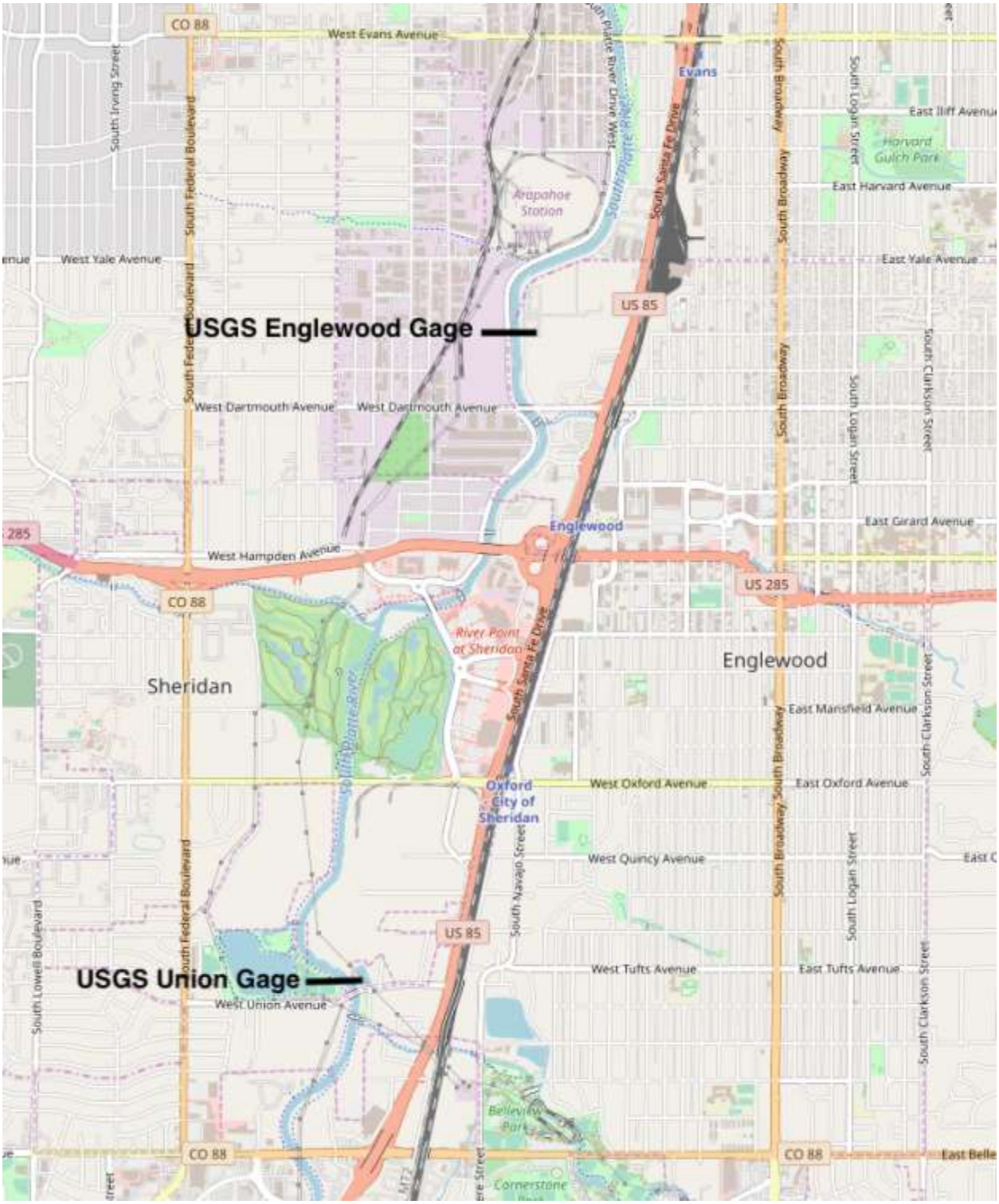


Figure 3. South Platte River from USGS Union gage to USGS Englewood gage.

Figure 4. South Platte River from USGS Englewood gage to USGS 64th Avenue gage.

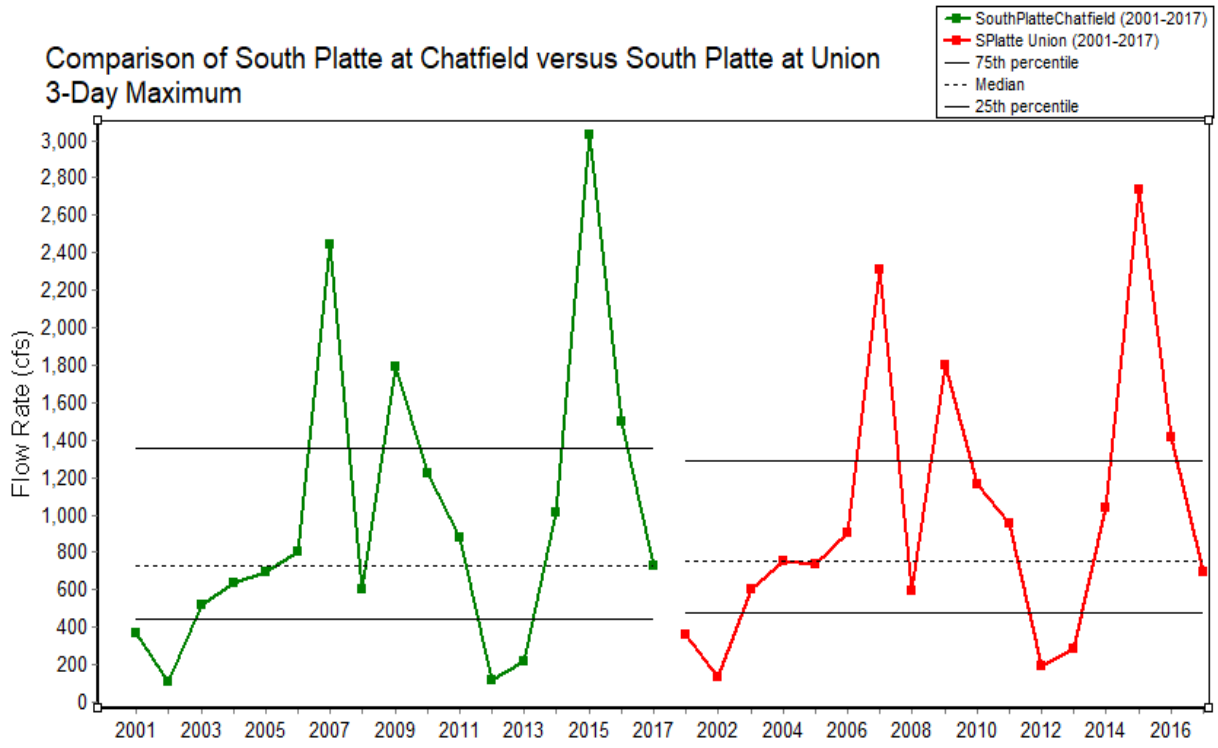


Figure 5. Comparison of three day maximum flows for the South Platte River at Chatfield versus South Platte at Union

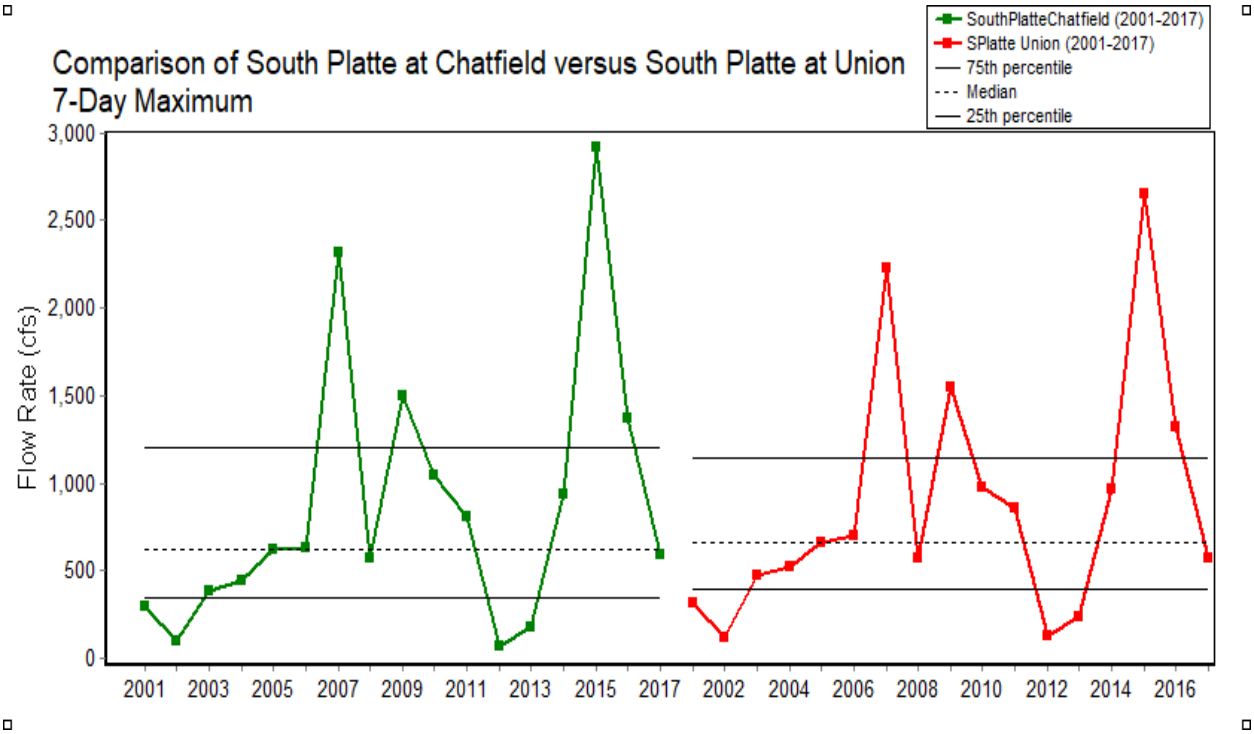


Figure 6. Comparison of seven day maximum flows for the South Platte River at Chatfield versus South Platte at Union

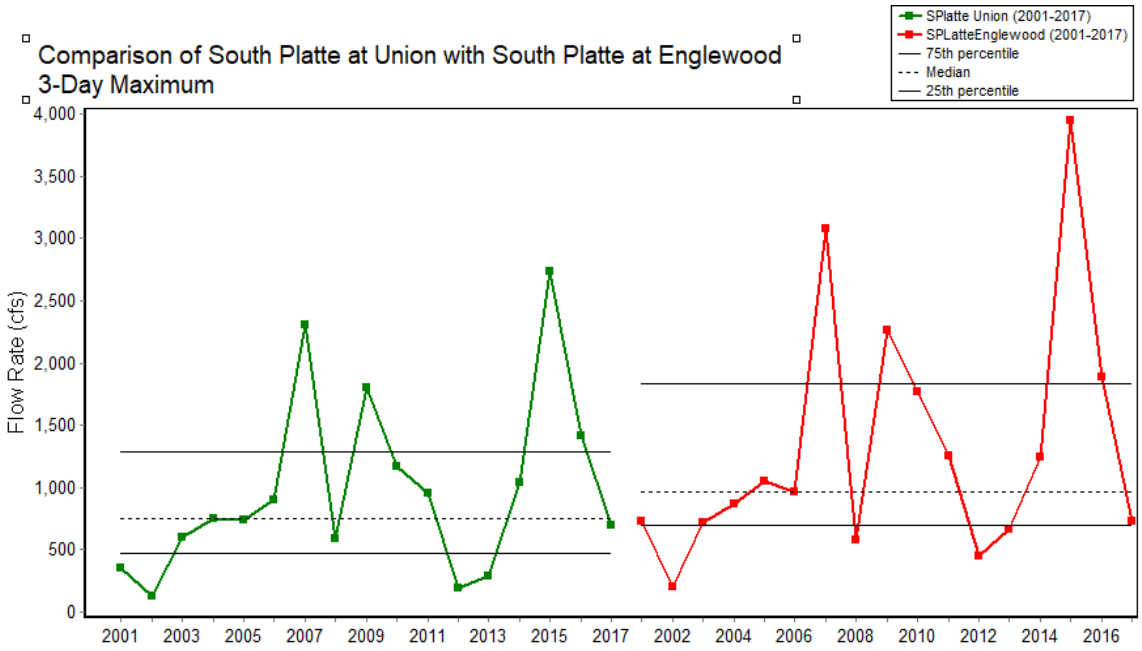


Figure 7. Comparison of three day maximum flows for the South Platte River at Union with South Platte at Englewood.

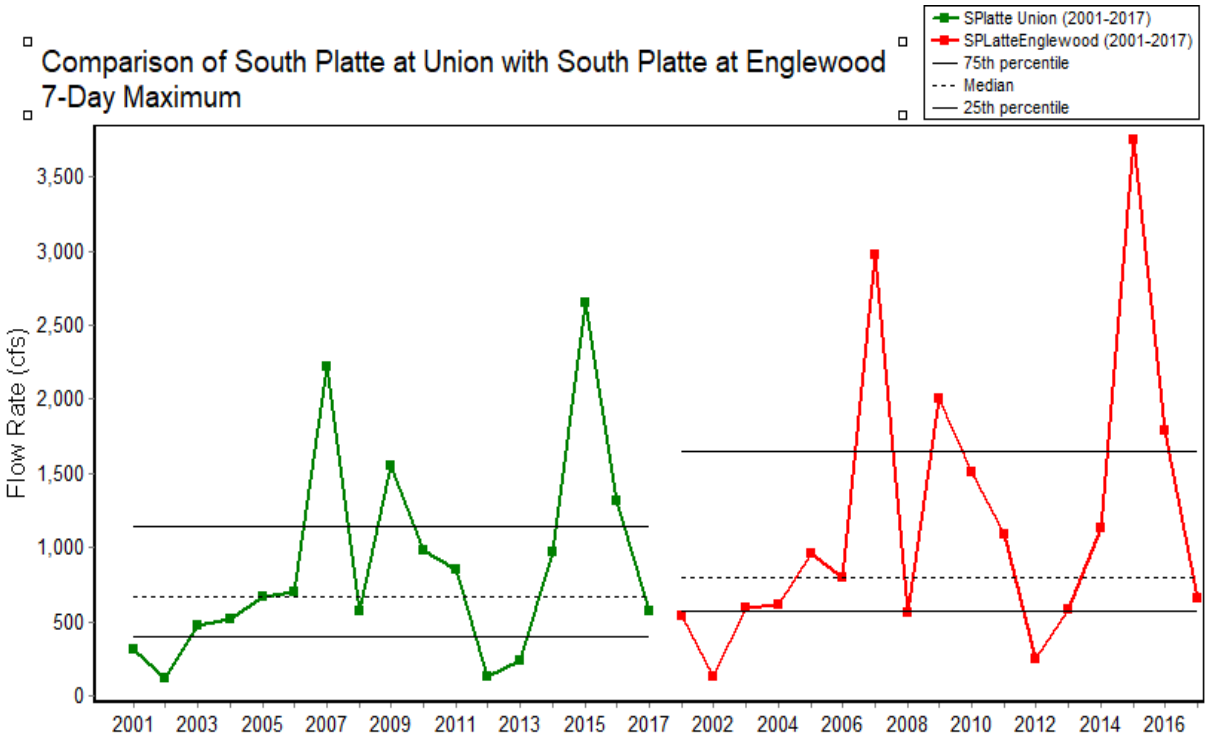


Figure 8. Comparison of seven day maximum flows for the South Platte River at Union with South Platte at Englewood.

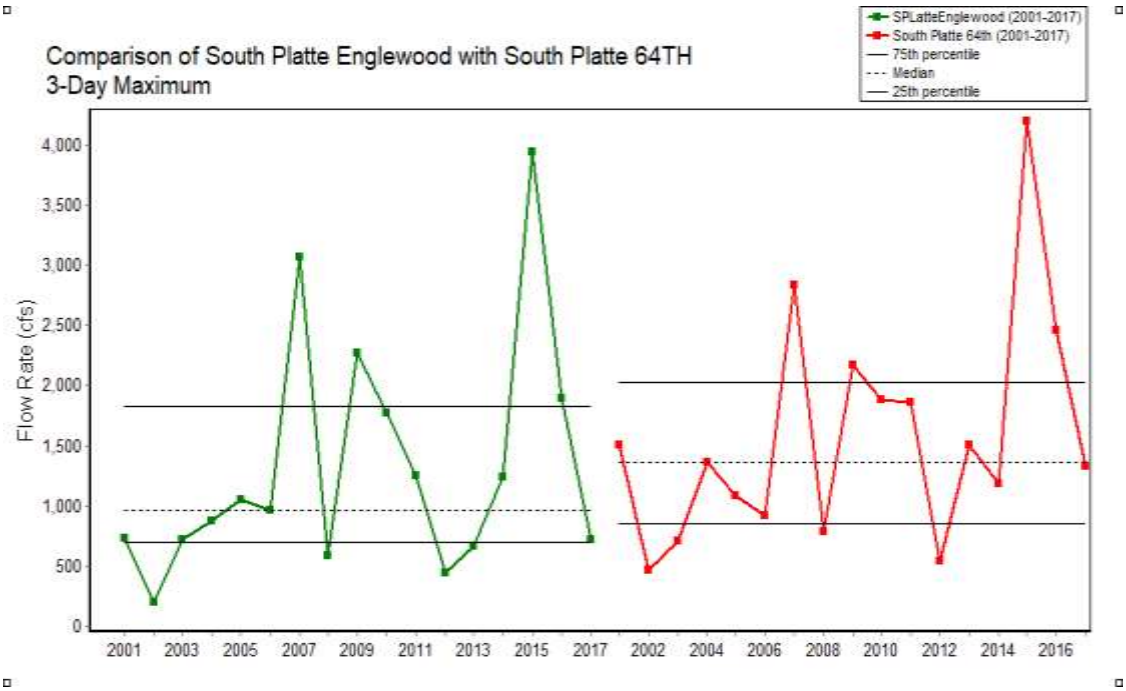


Figure 9. Comparison of three day maximum flows for the South Platte River at Englewood with South Platte at 64th.

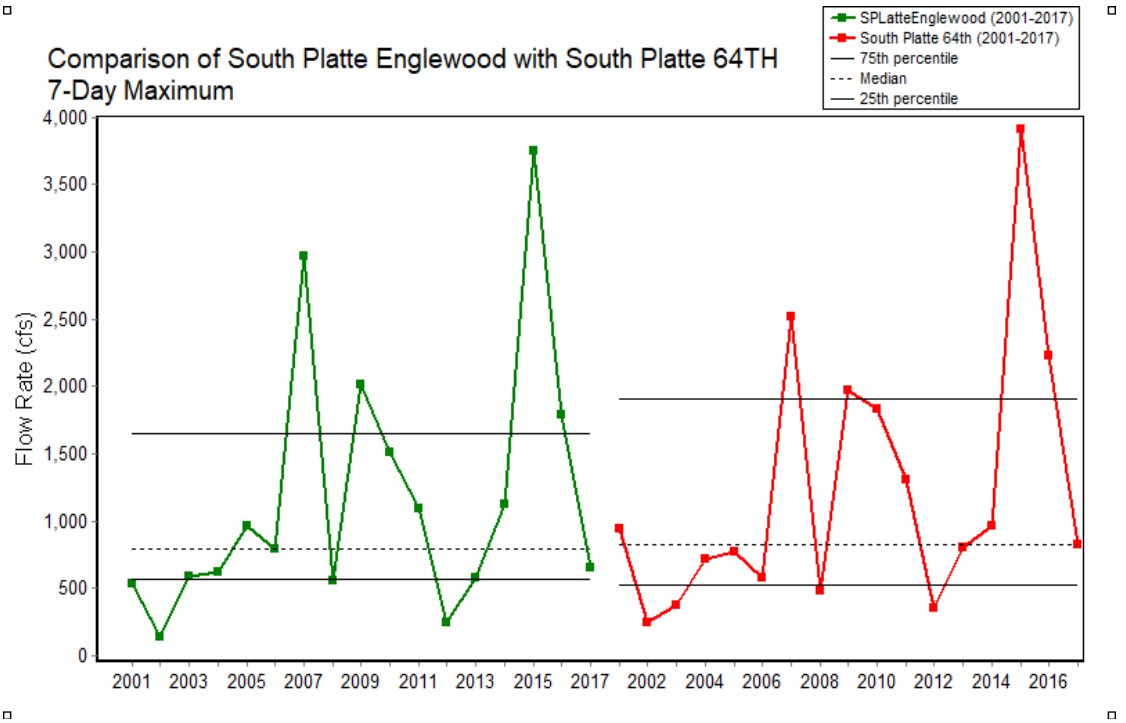


Figure 10. Comparison of seven day maximum flows for the South Platte River at Englewood with South Platte at 64th.

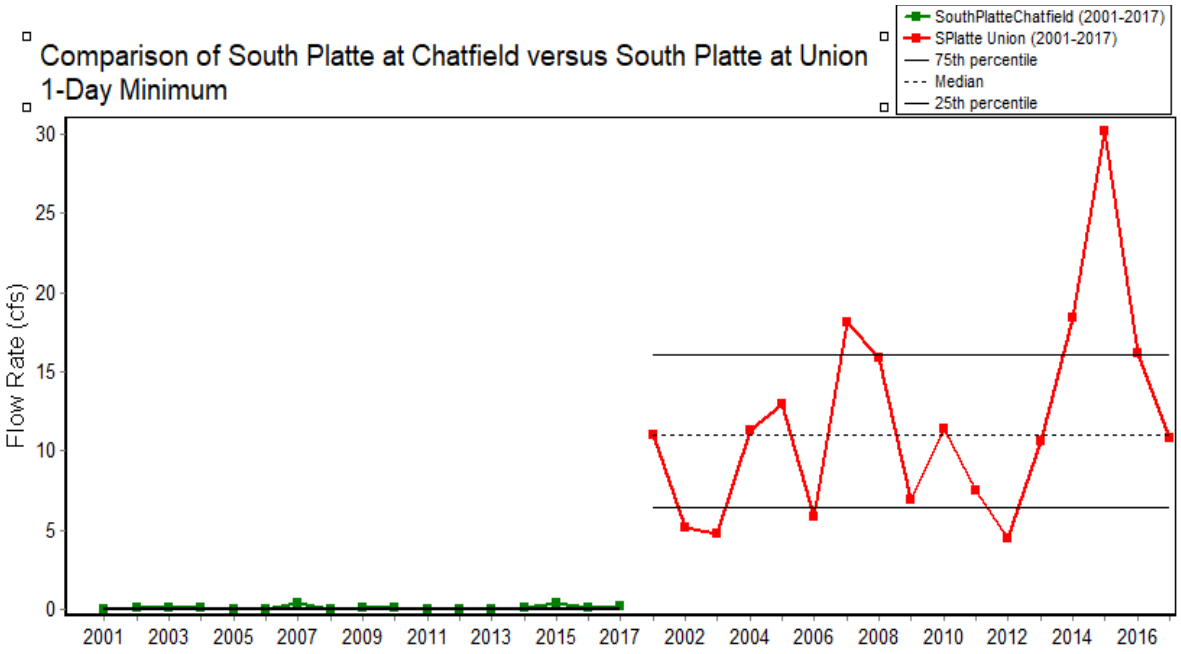


Figure 11. Comparison of one day minimum flows for the South Platte River at Chatfield with South Platte at Union.

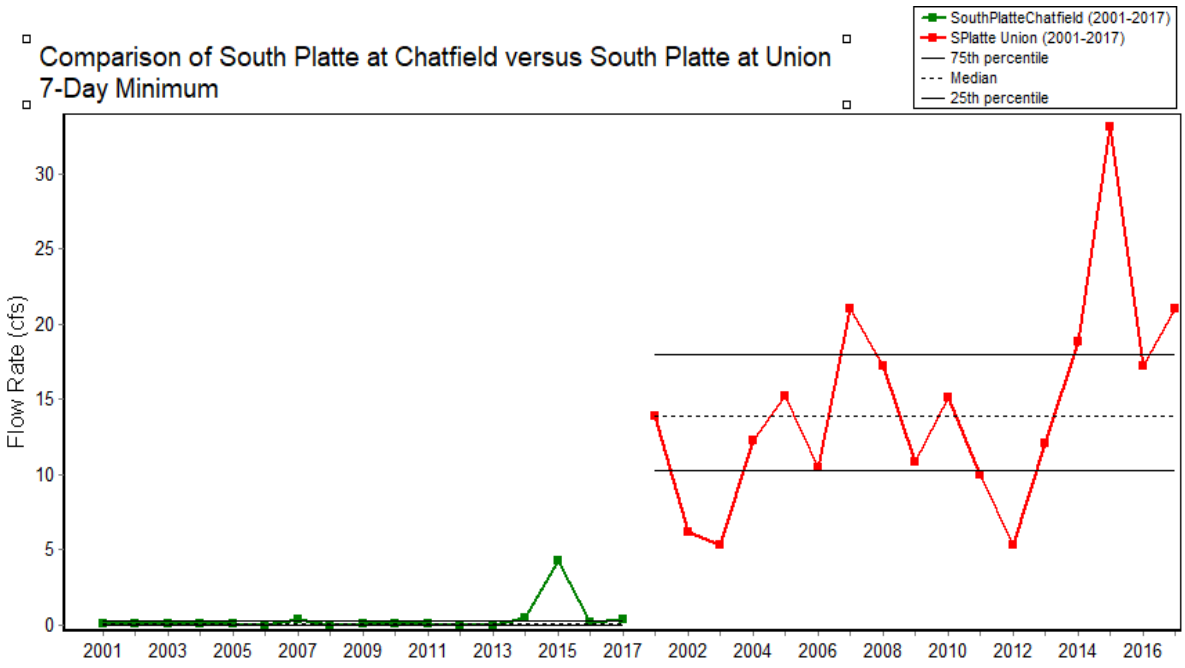


Figure 12. Comparison of seven day minimum flows for the South Platte River at Chatfield versus South Platte at Union.

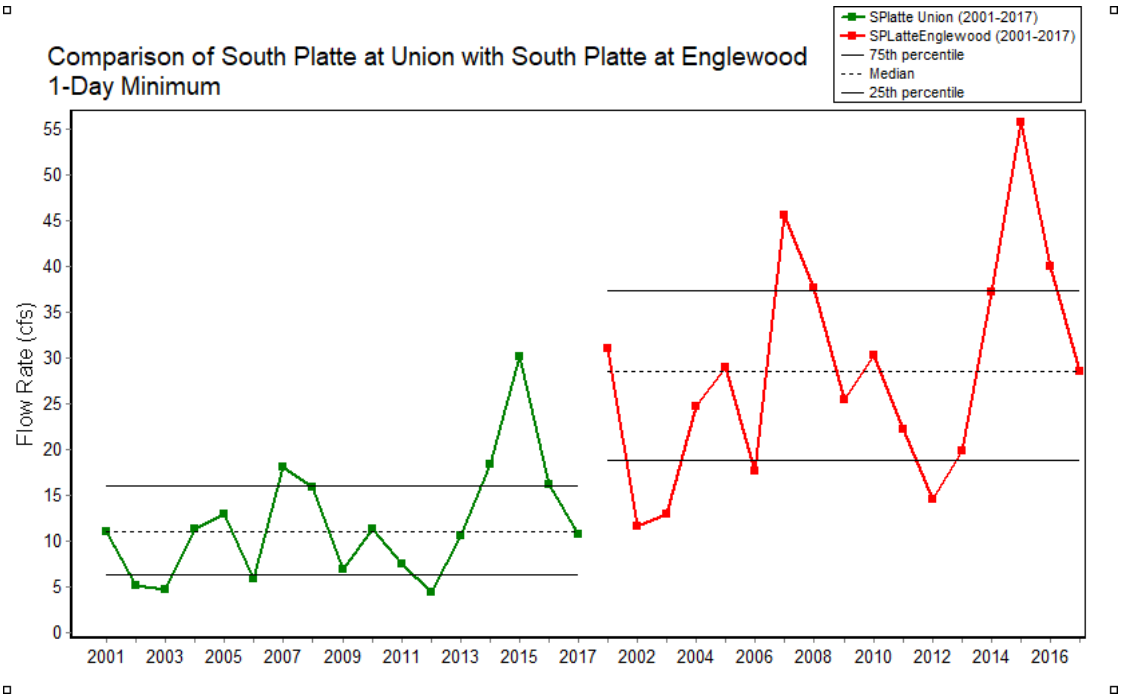


Figure 13. Comparison of one day minimum flows for the South Platte River at Union with South Platte at Englewood.

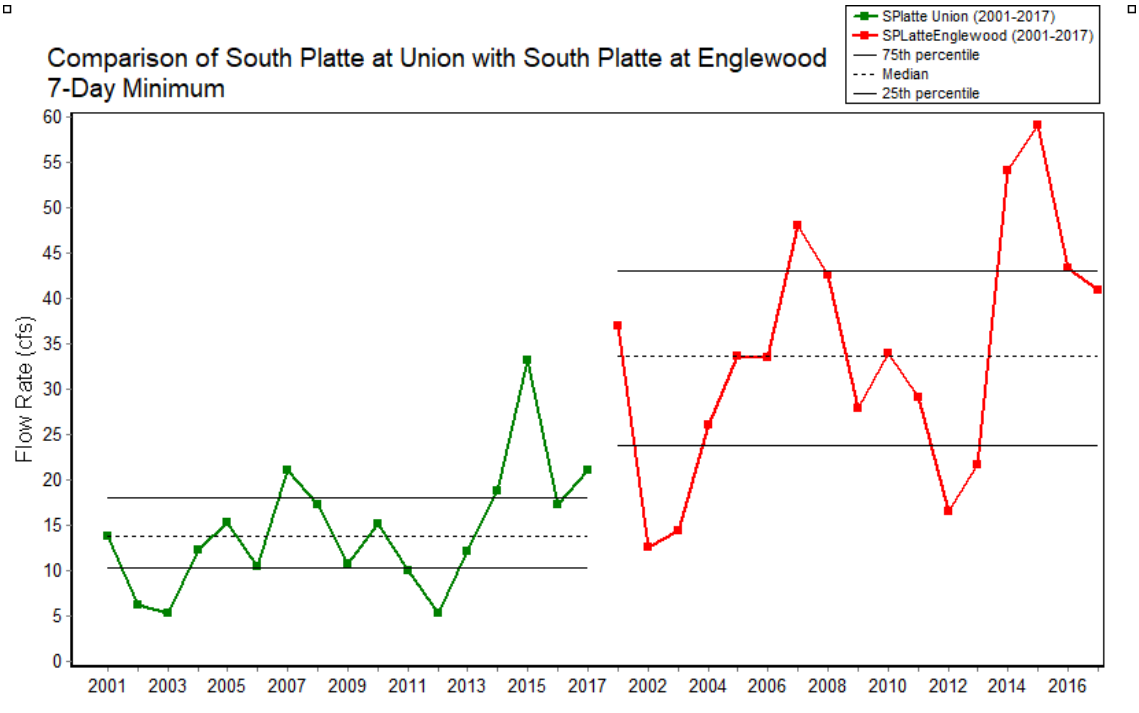


Figure 14. Comparison of seven day minimum flows for the South Platte River at Union with South Platte at Englewood.

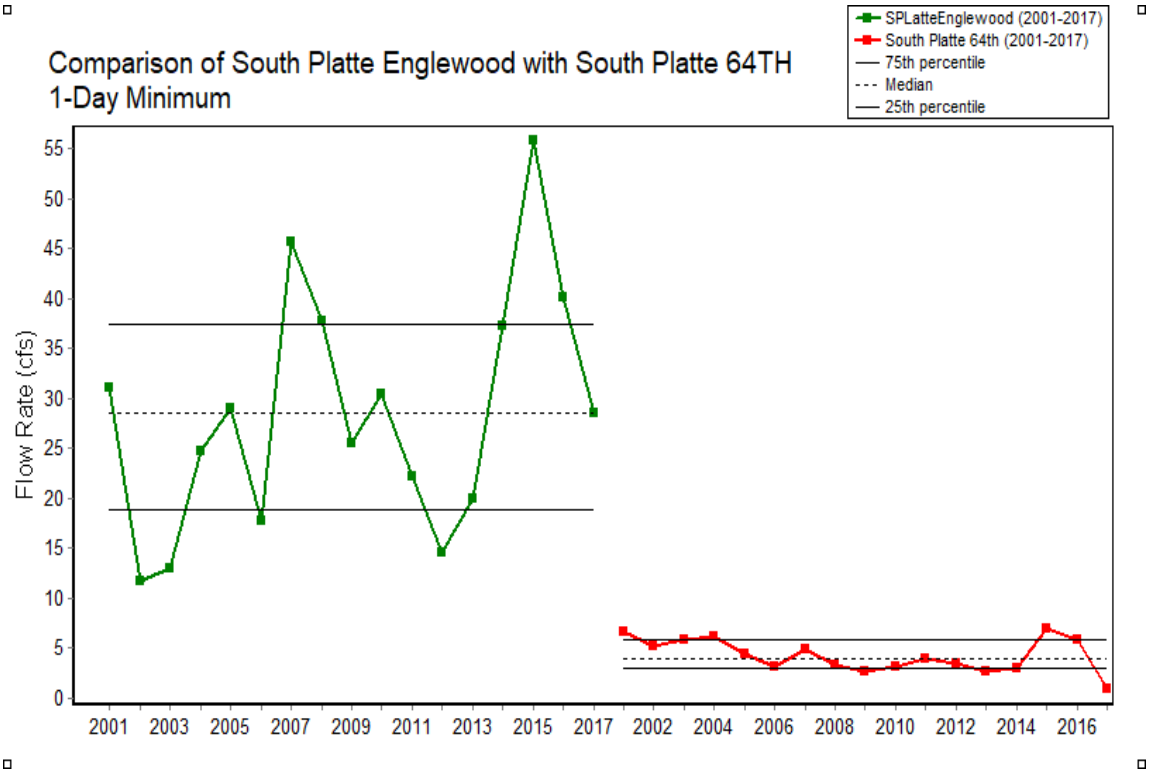


Figure 15. Comparison of one day minimum flows for the South Platte River at Englewood with South Platte at 64th.

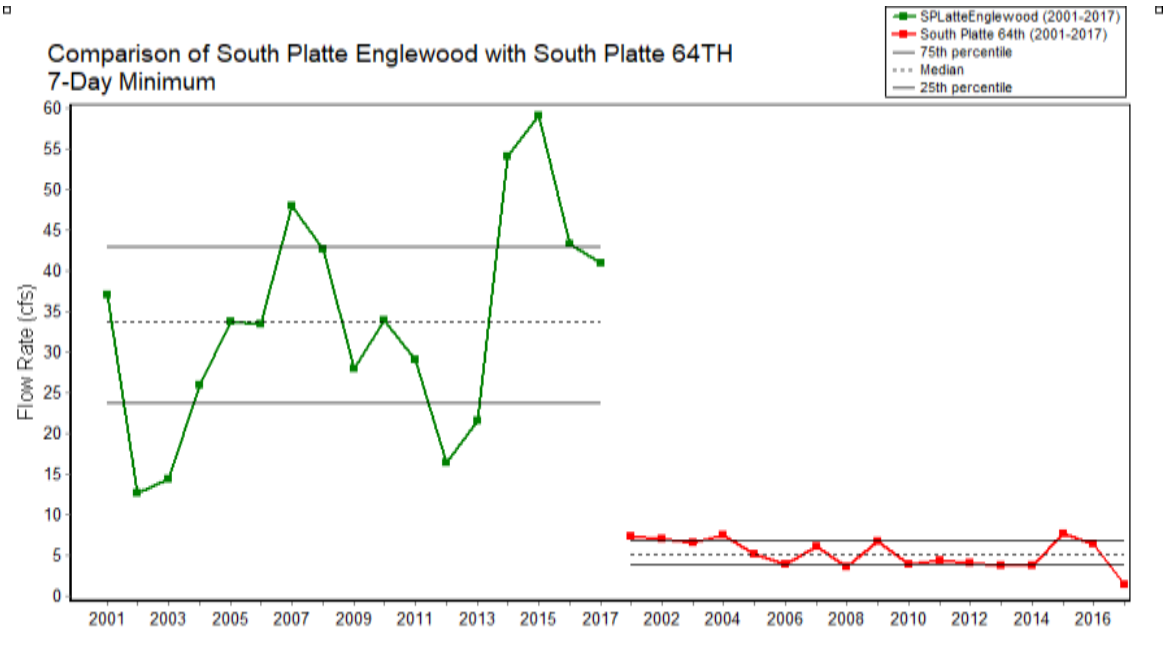


Figure 16. Comparison of seven day minimum flows for the South Platte River at Englewood with South Platte at 64th.

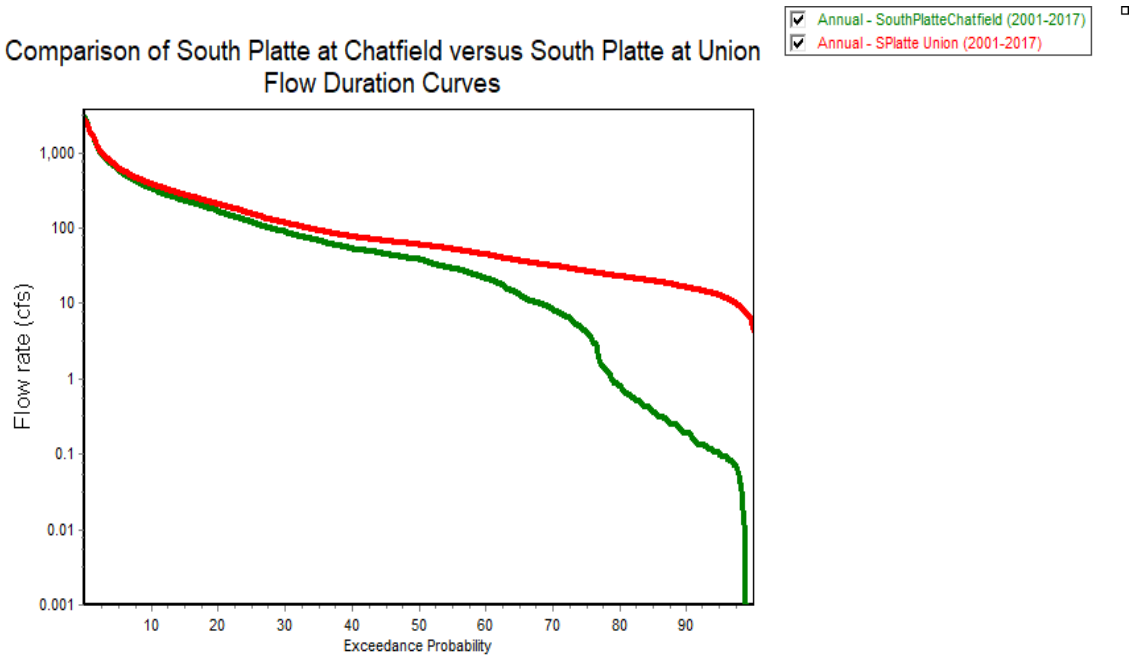


Figure 17. Annual flow duration curves for South Platte at Chatfield and South Platte at Union.

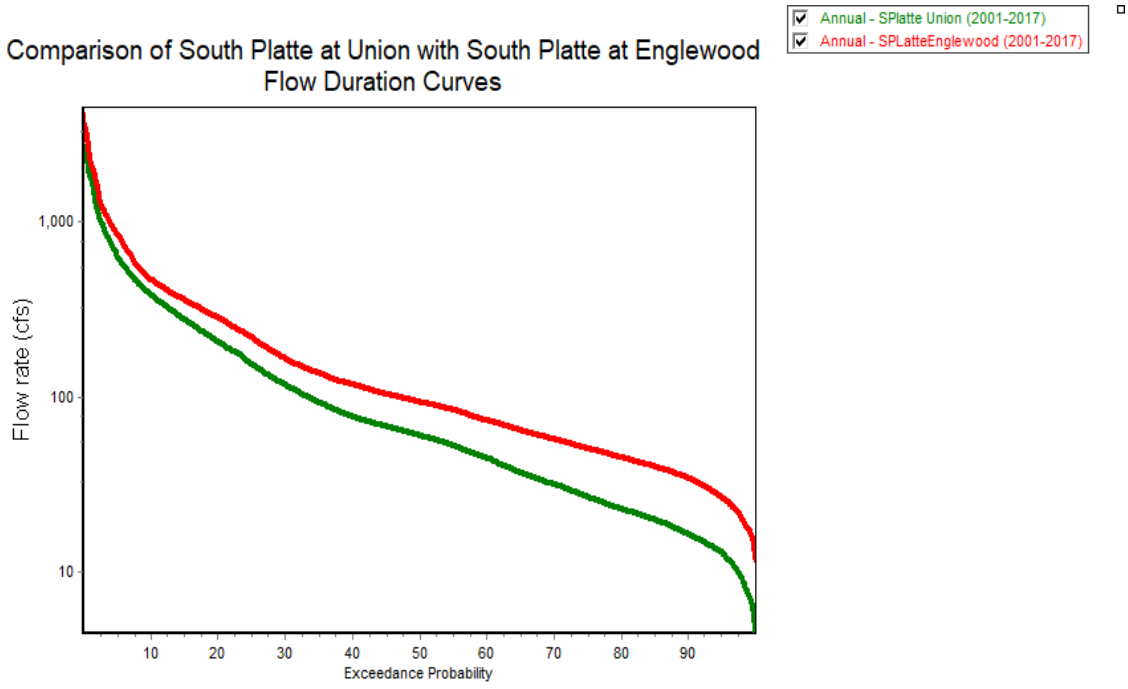


Figure 18. Annual flow duration curves for South Platte at Union and South Platte at Englewood.

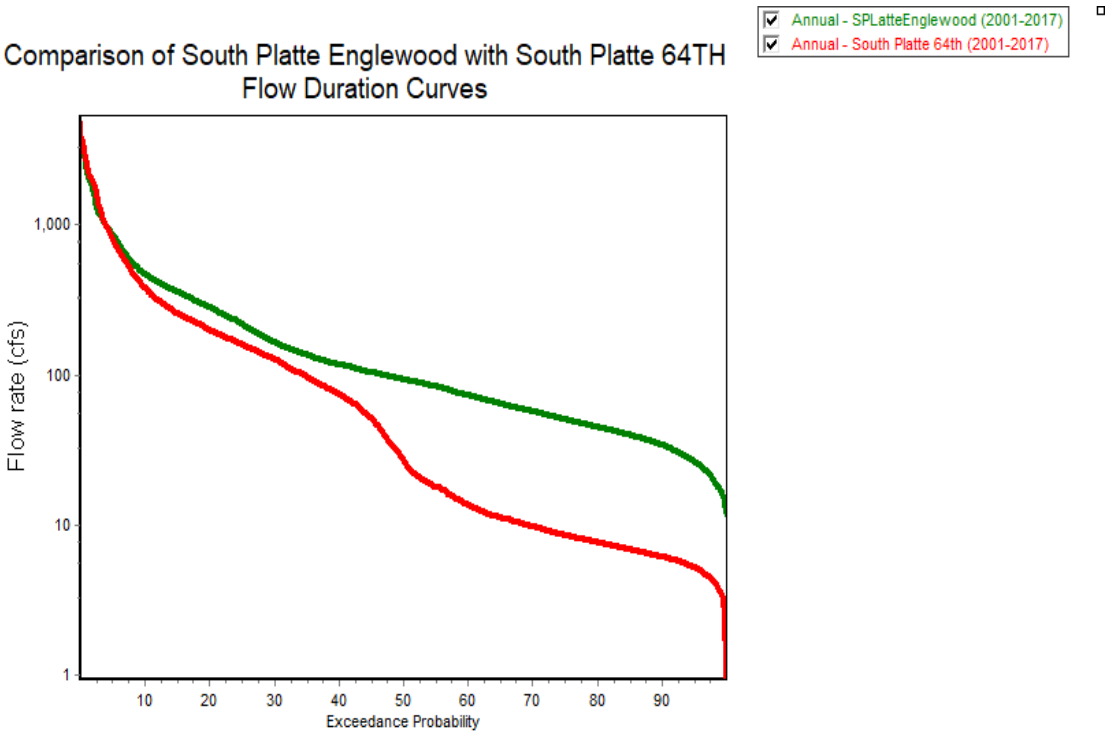


Figure 19. Annual flow duration curves for South Platte at Englewood and South Platte at 64th.

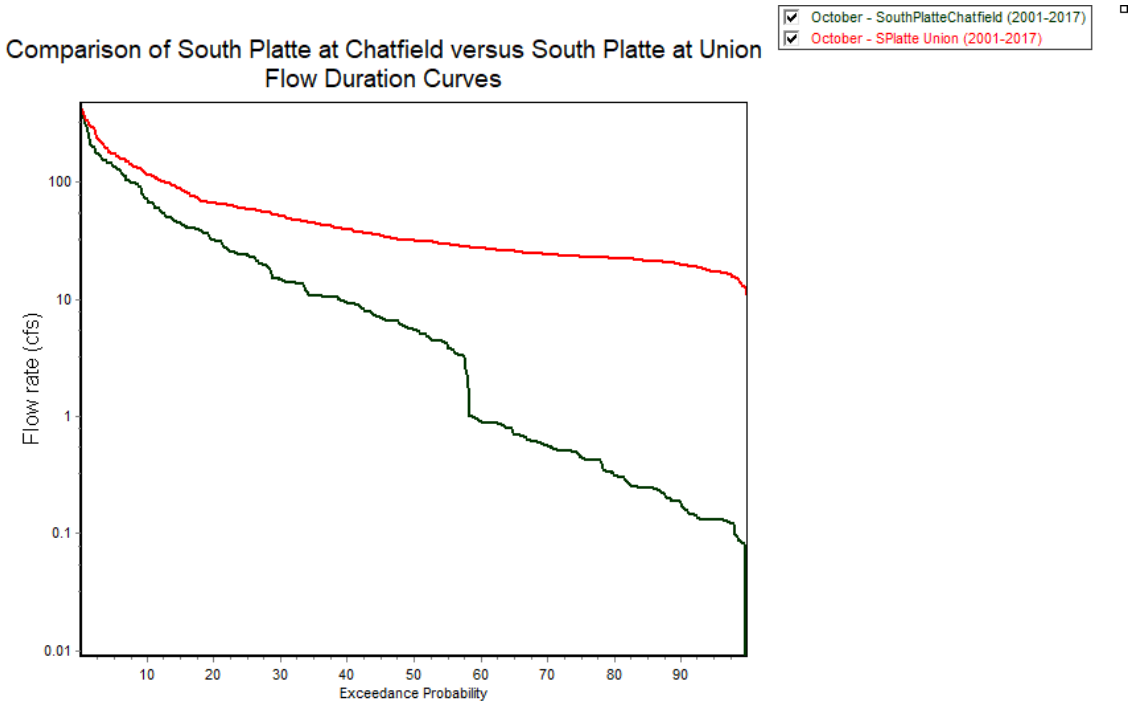


Figure 20. October flow duration curve for South Platte at Chatfield and South Platte at Union.

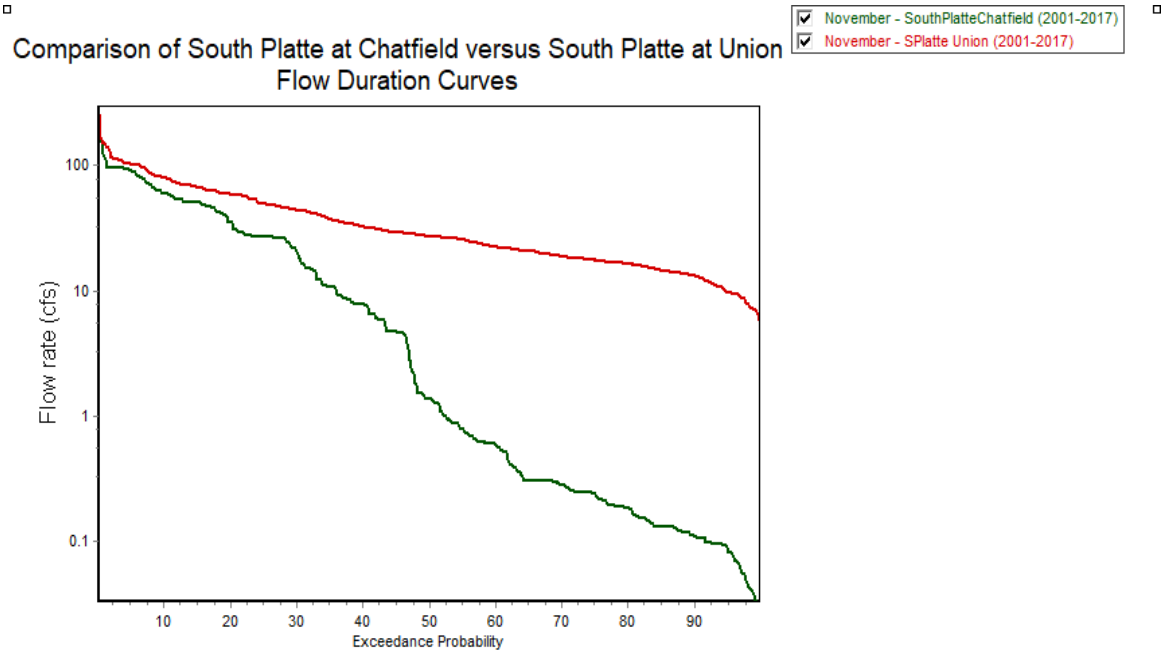


Figure 21. November flow duration curve for South Platte at Chatfield and South Platte at Union.

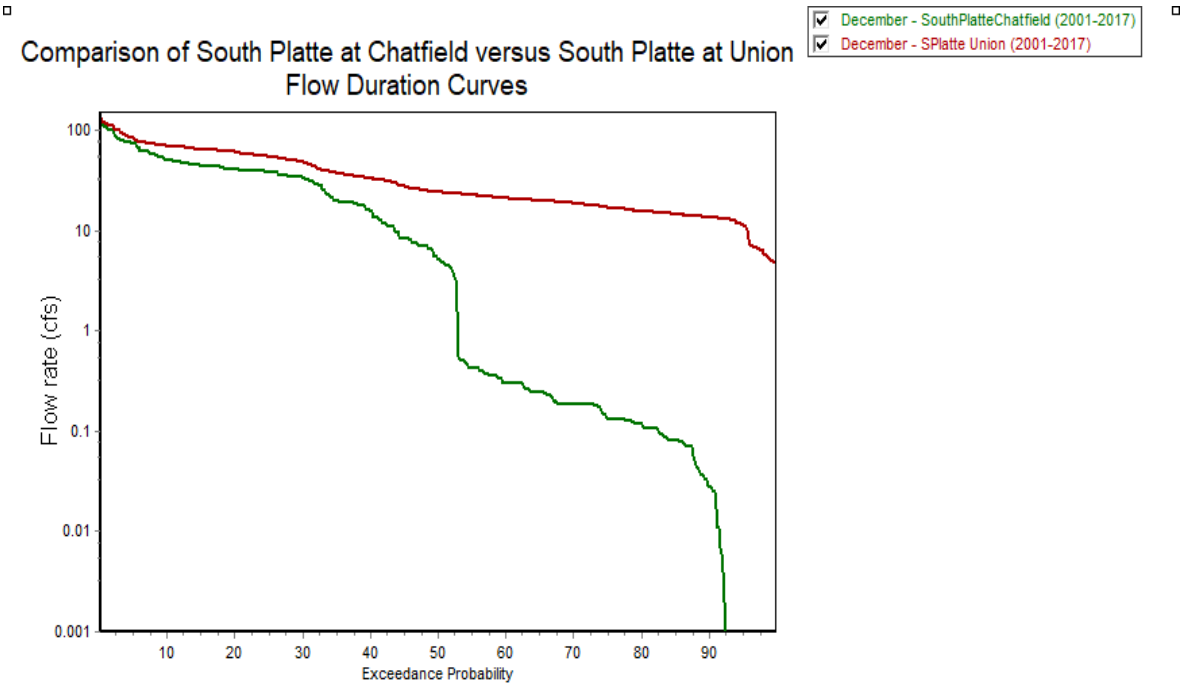


Figure 22. December flow duration curve for South Platte at Chatfield and South Platte at Union.

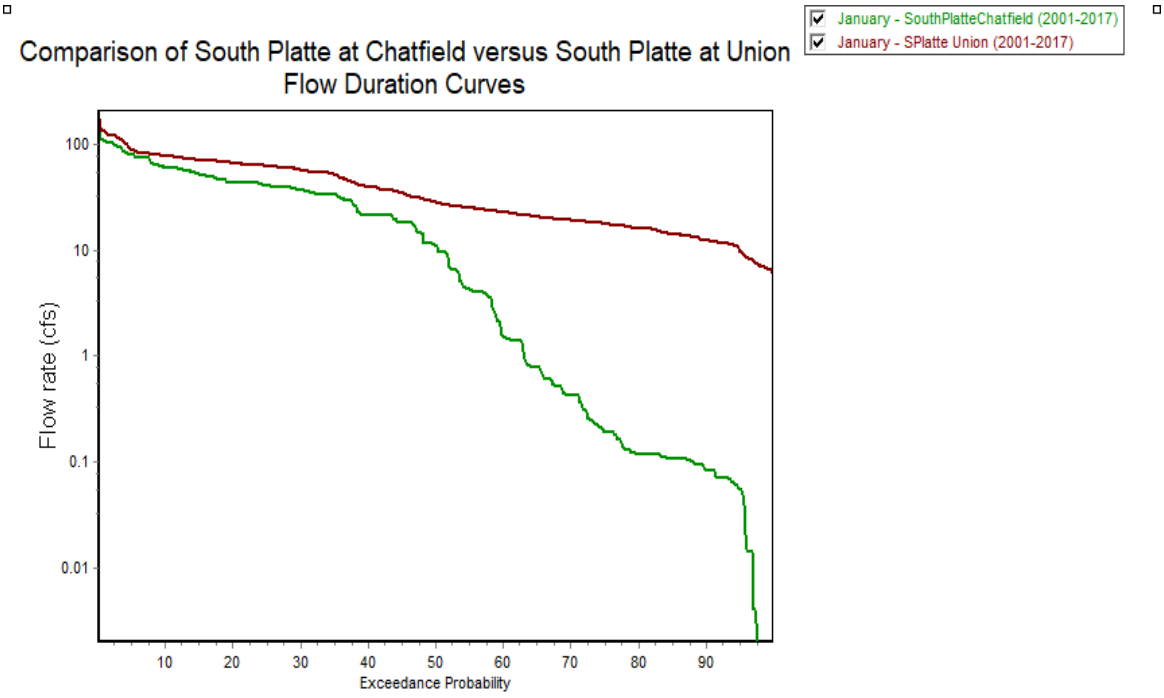


Figure 23. January flow duration curve for South Platte at Chatfield and South Platte at Union.

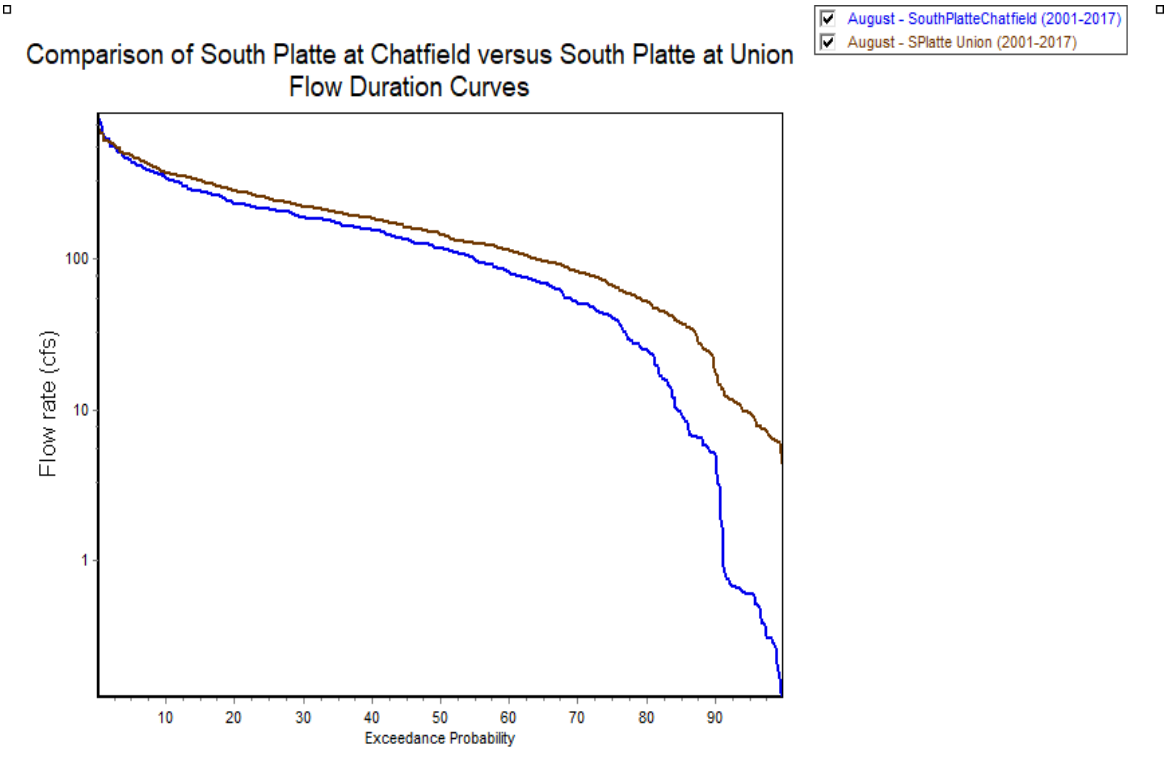
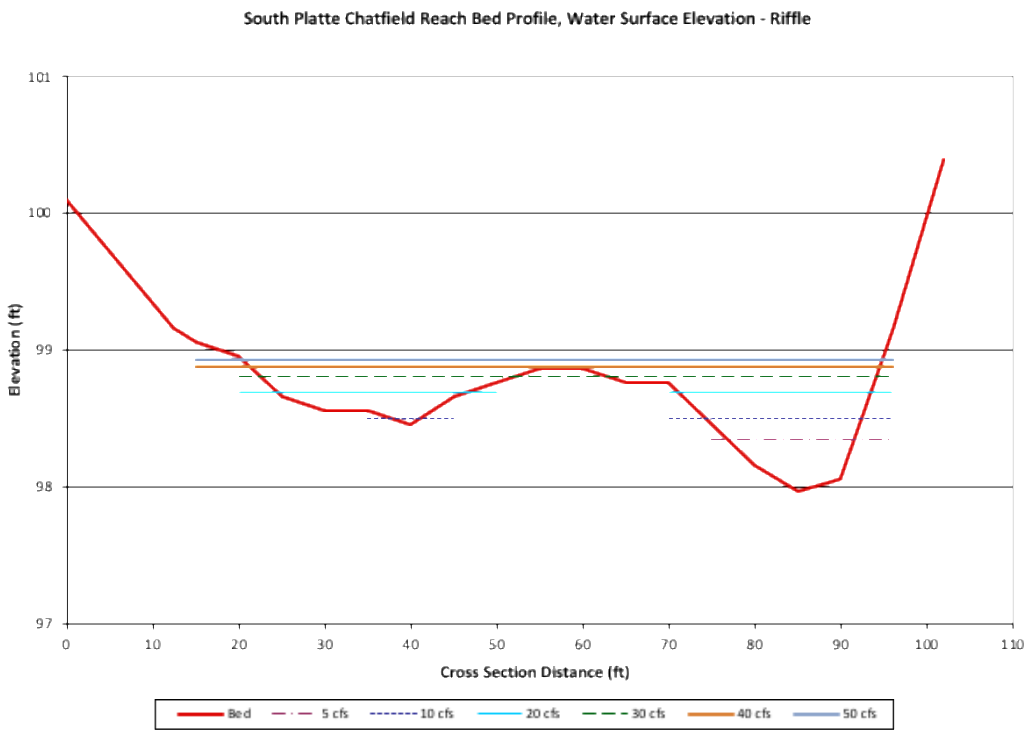


Figure 24. August flow duration curve for South Platte at Chatfield and South Platte at Union.



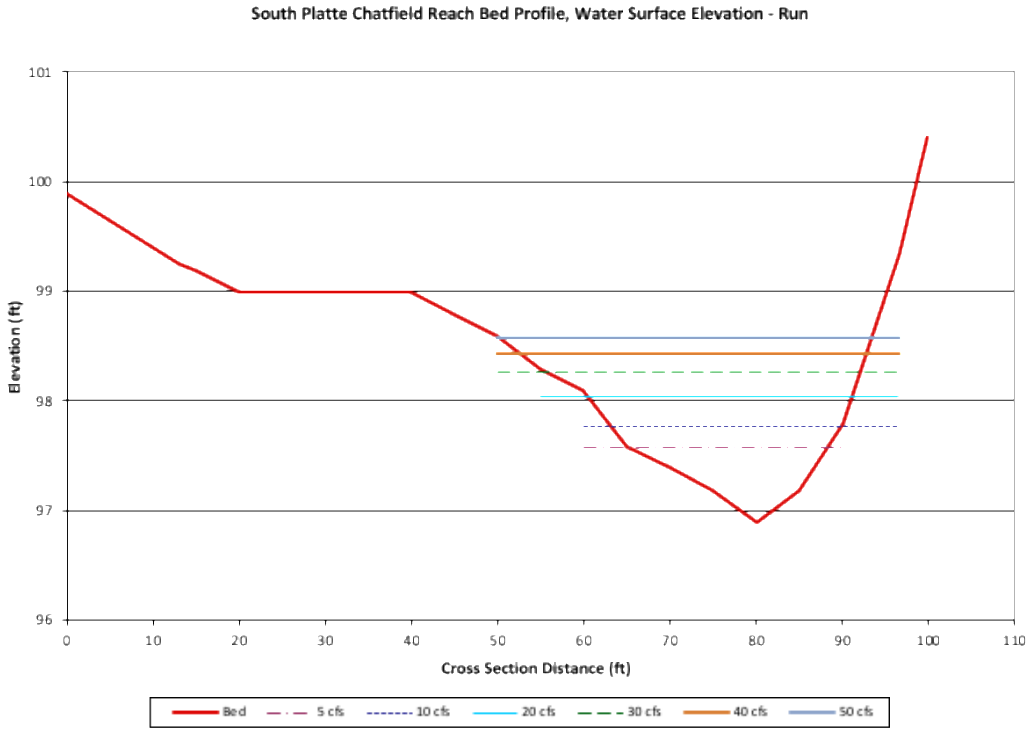


Figure 25. Wetted perimeter for riffle and run cross sections in the Chatfield Reach.

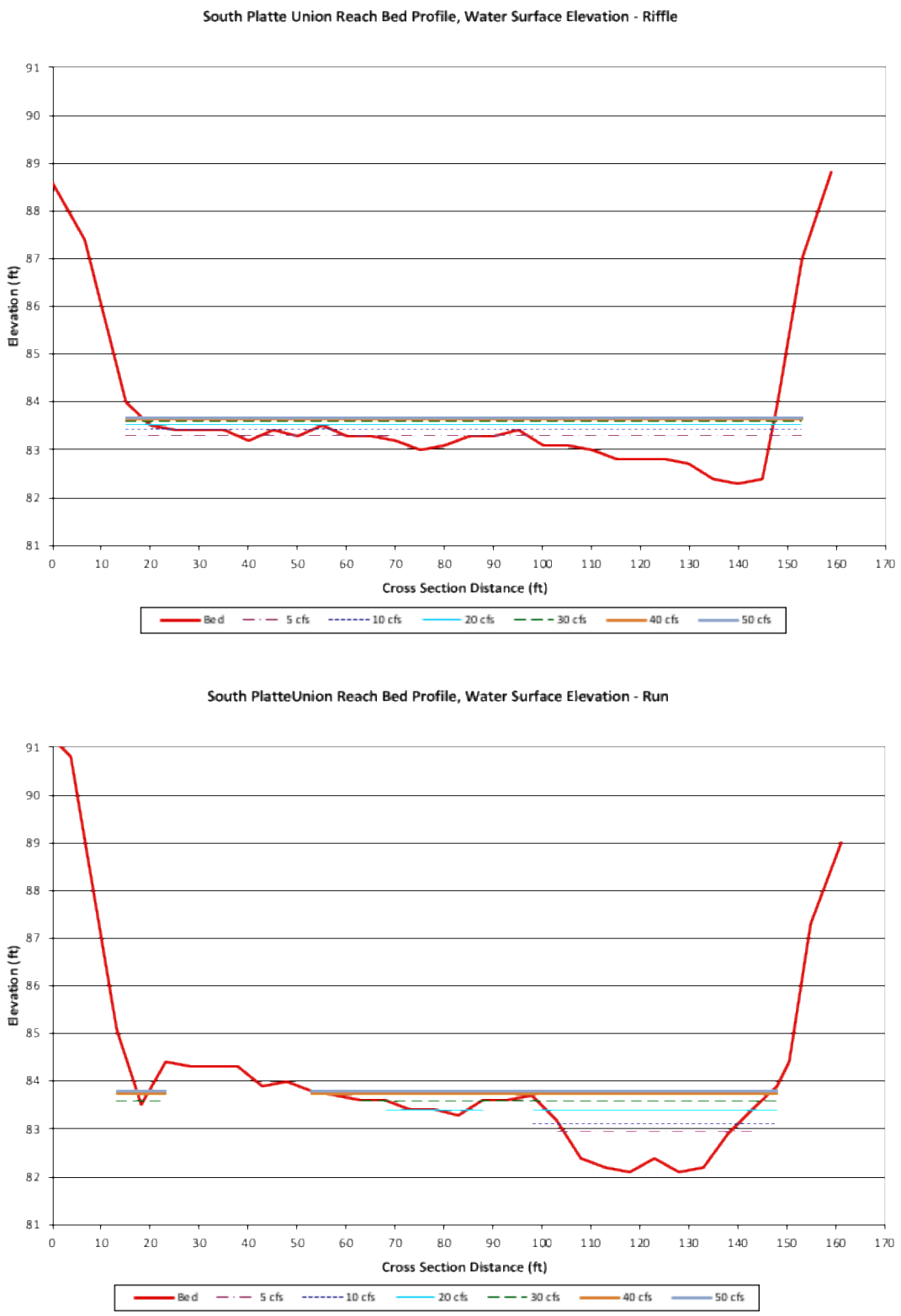
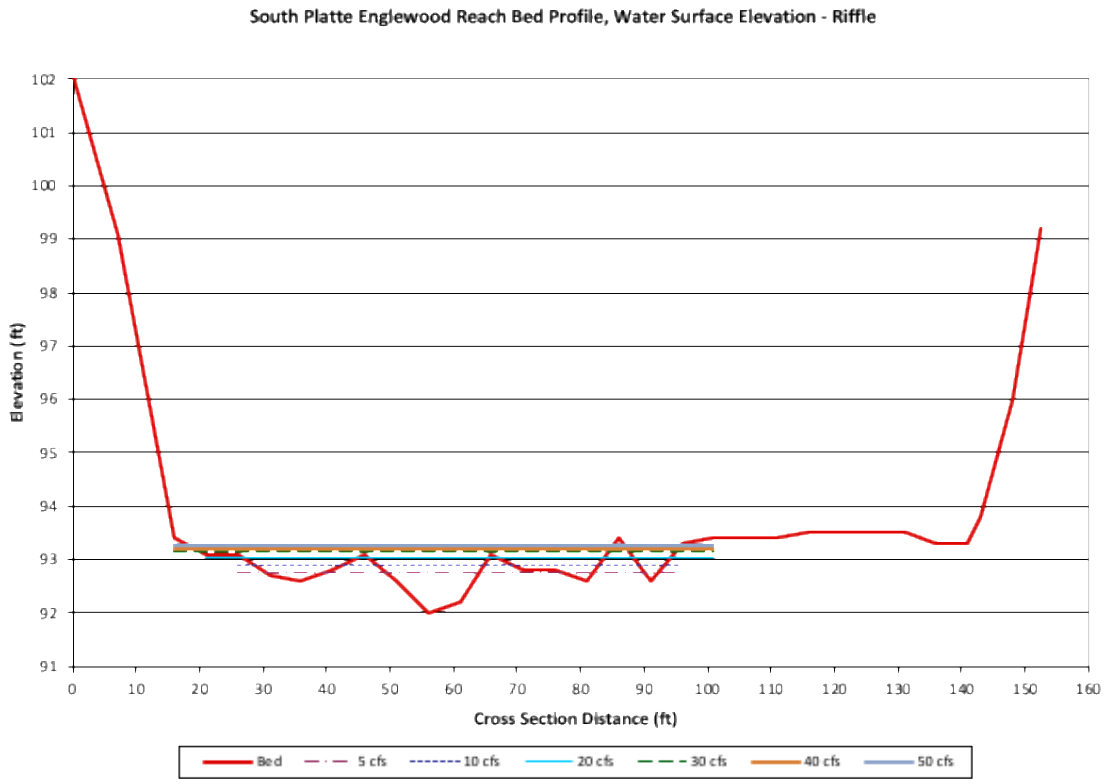


Figure 26. Wetted perimeter riffle and run cross sections in the Union Reach.



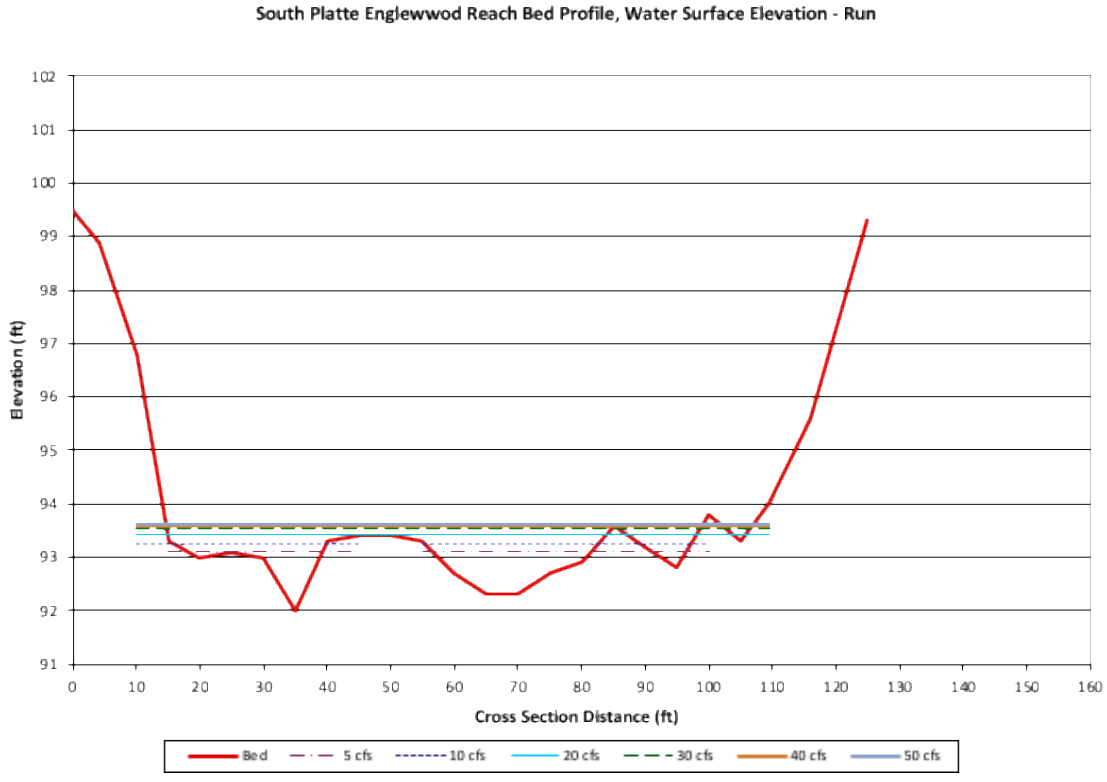


Figure 27. Wetted perimeter for riffle and run cross sections Englewood Reach

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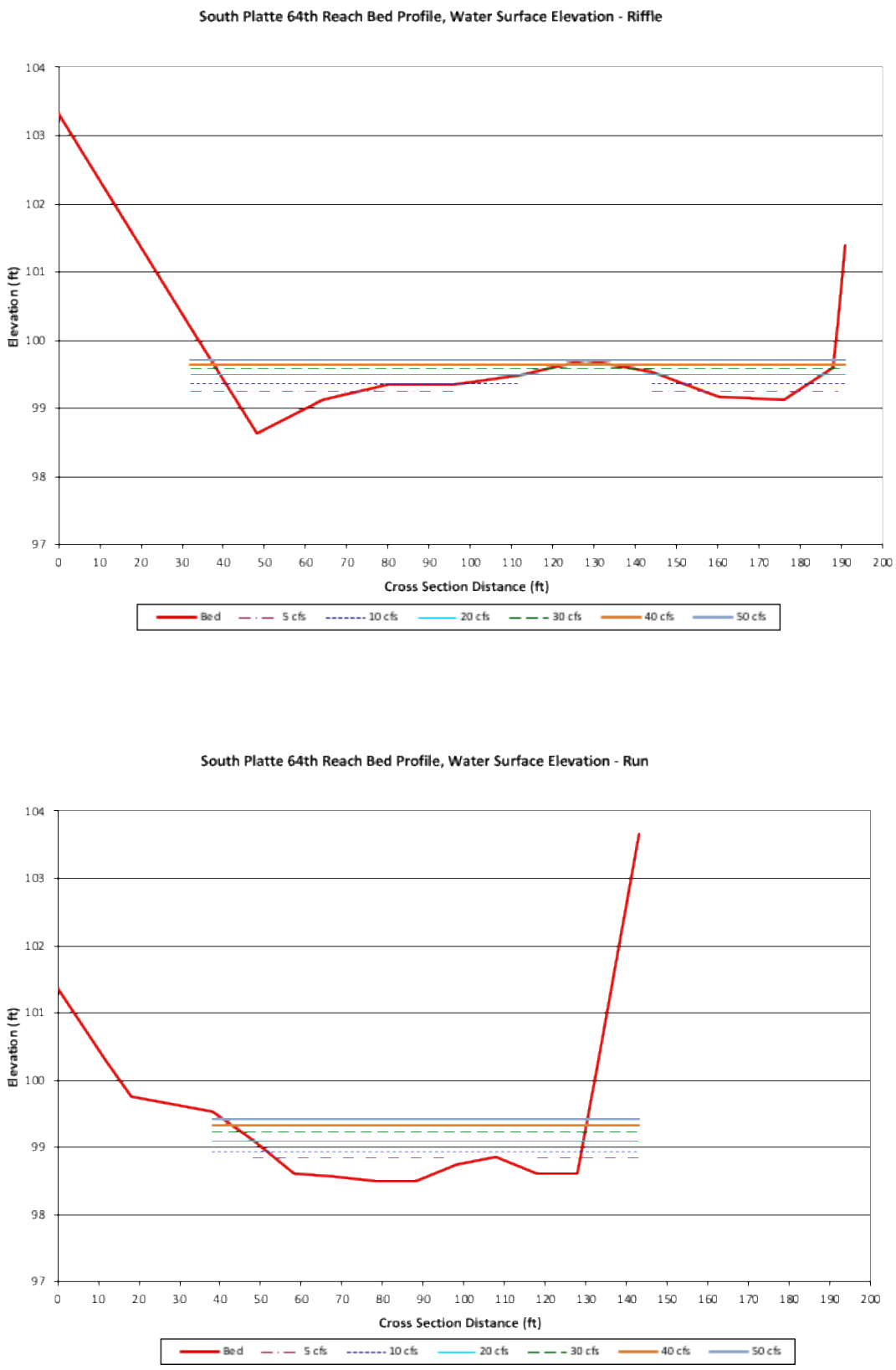

Figure 28. Wetted perimeter for riffle and run cross sections at Downstream data.

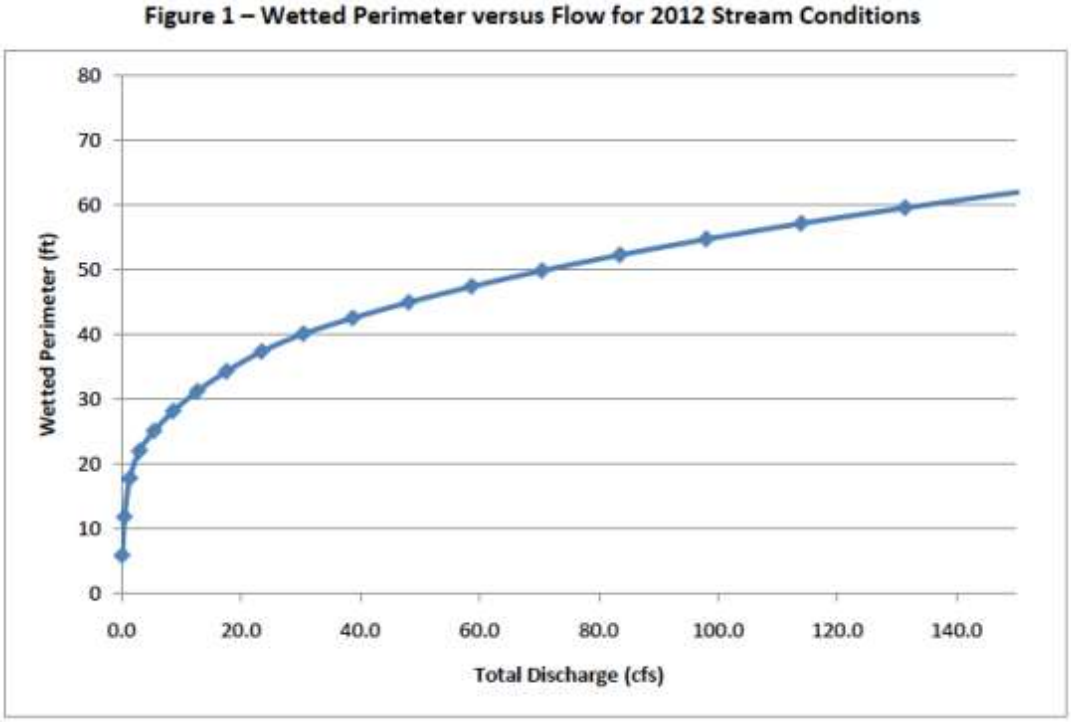

Figure 29. Wetted perimeter as a function of discharge for the South Platte River in Littleton for 2012 stream conditions (Source: ERC 2014, Figure 1 from report).

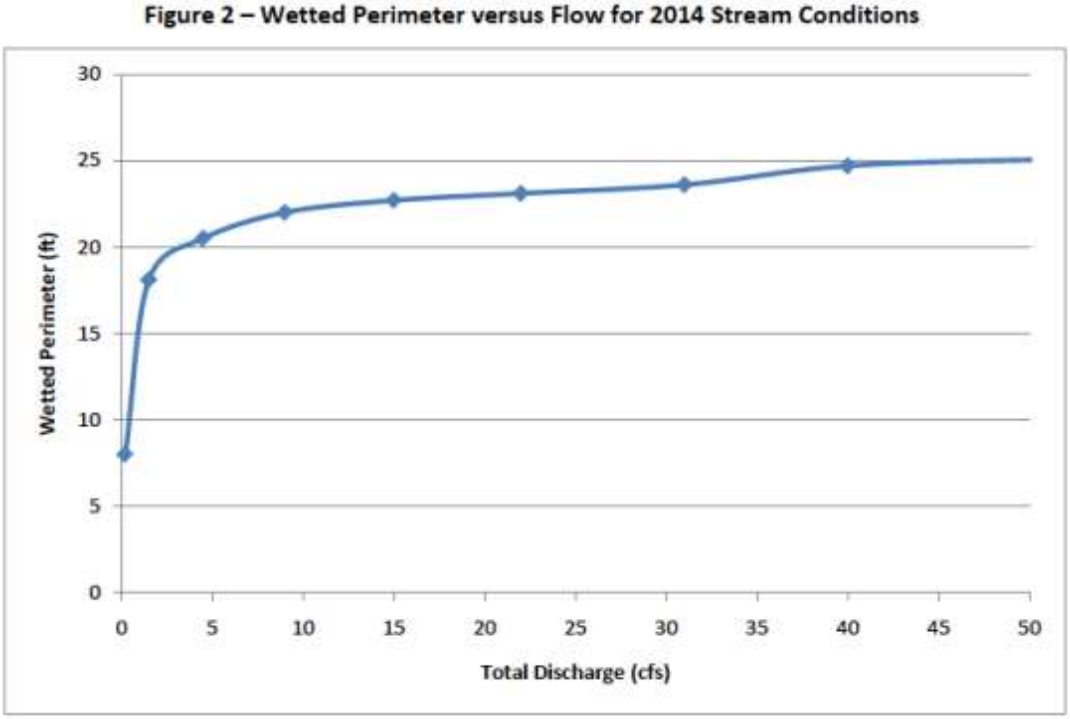

Figure 30. Wetted perimeter as a function of discharge for the South Platte River in Littleton for 2014 stream conditions (Source: ERC 2014, Figure 2 from report).

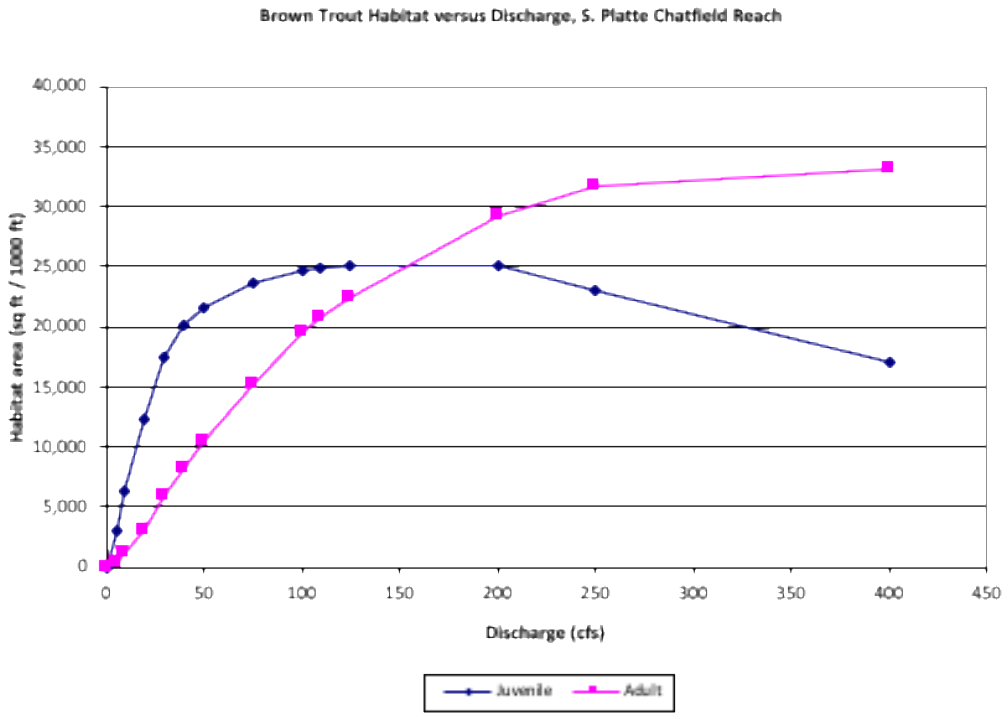

Figure 31. Brown Trout Habitat as a function of discharge at Chatfield Reach.

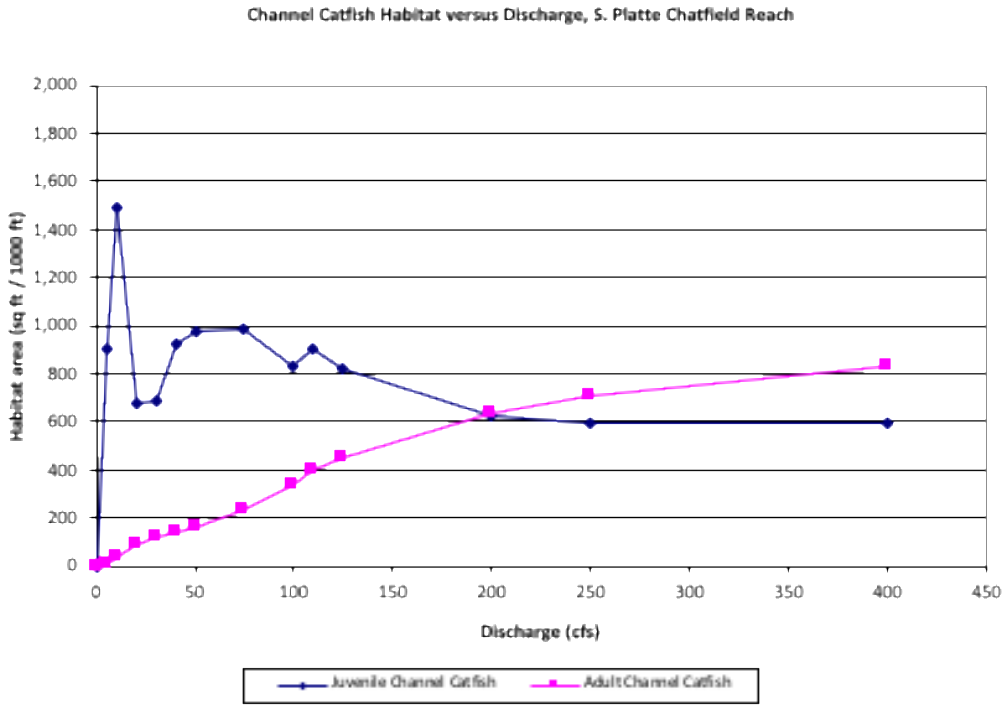

Figure 32. Channel Catfish Habitat as a function of discharge at Chatfield Reach.

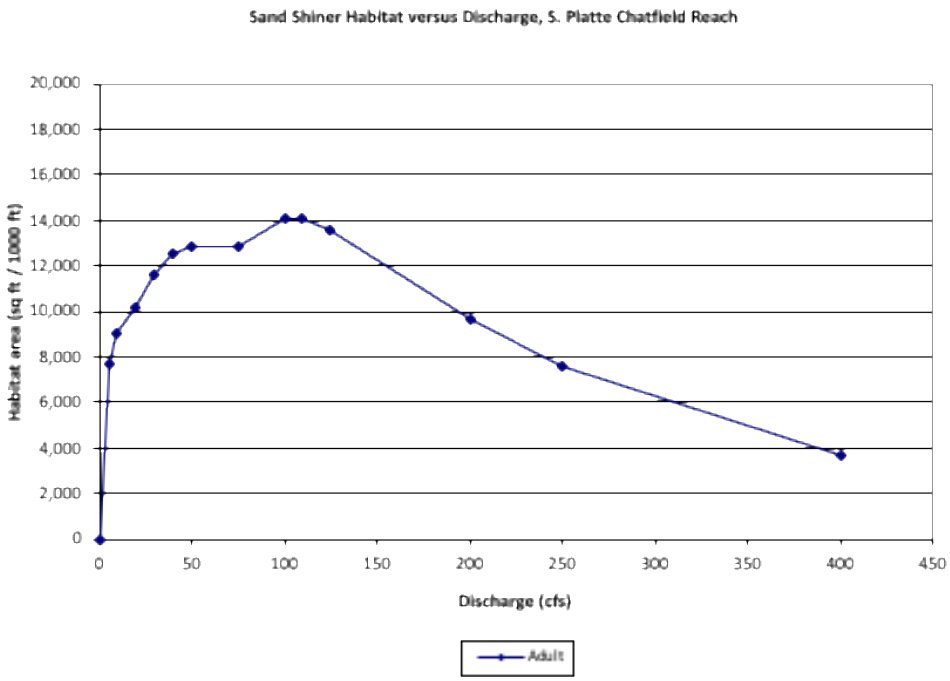

Figure 33. Sand Shiner Habitat as a function of discharge at Chatfield Reach.

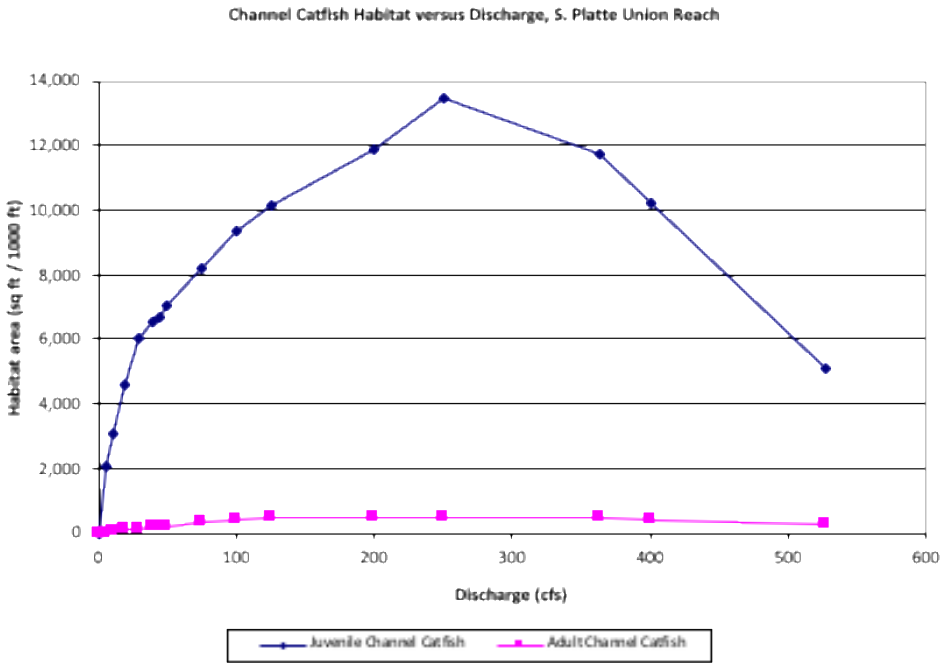

Figure 34. Channel Catfish Habitat as a function of discharge at Union Reach.

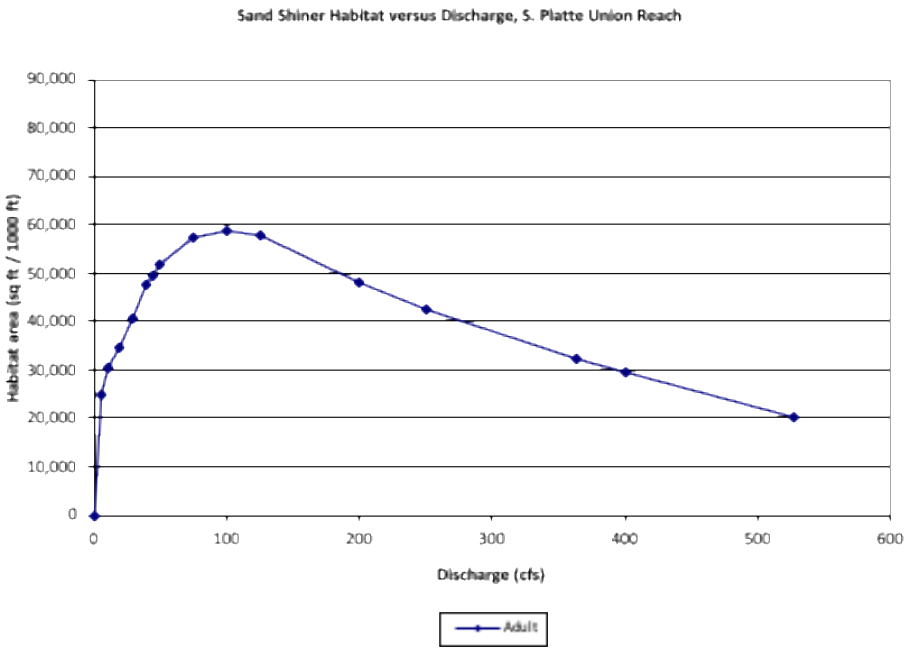

Figure 35. Sand Shiner Habitat as a function of discharge at Union Reach.

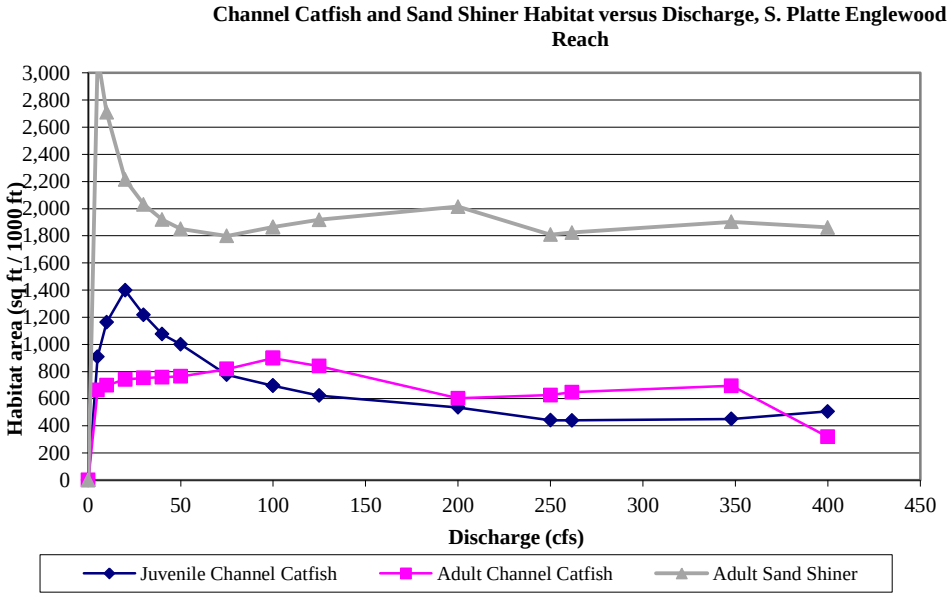

Figure 36. Channel Catfish and Sand Shiner Habitat as a function of discharge at Englewood Reach.

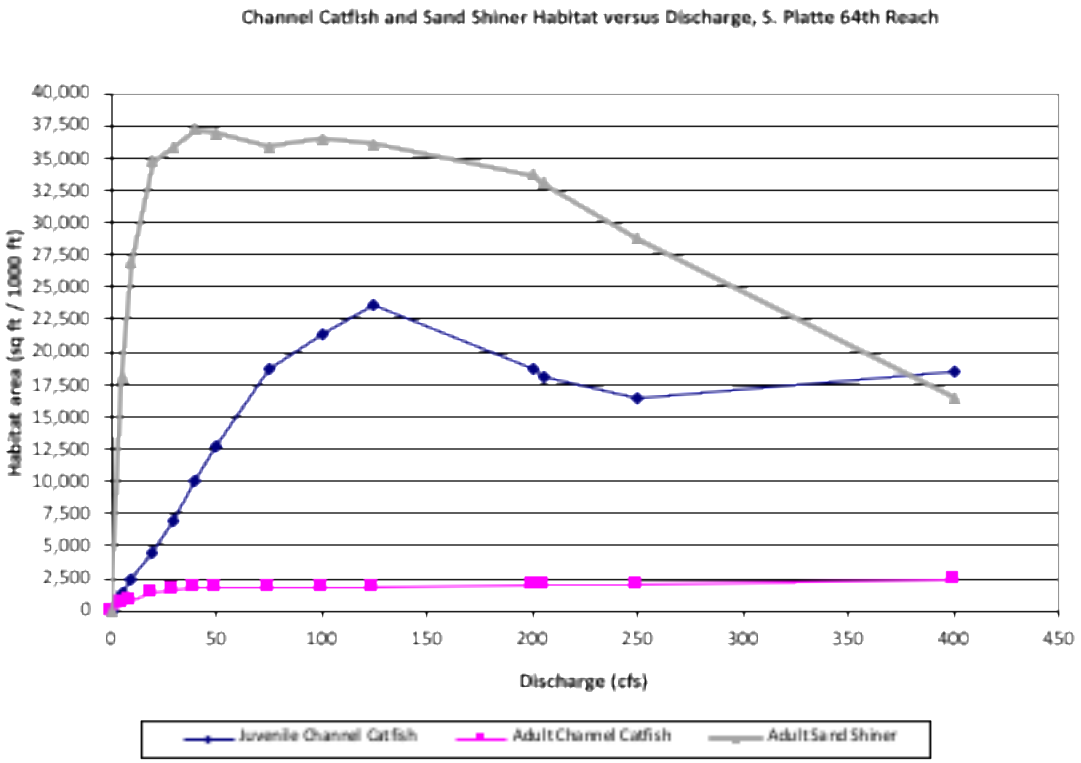

Figure 37. Channel Catfish and Sand Shiner Habitat as a function of discharge at Downstream site.

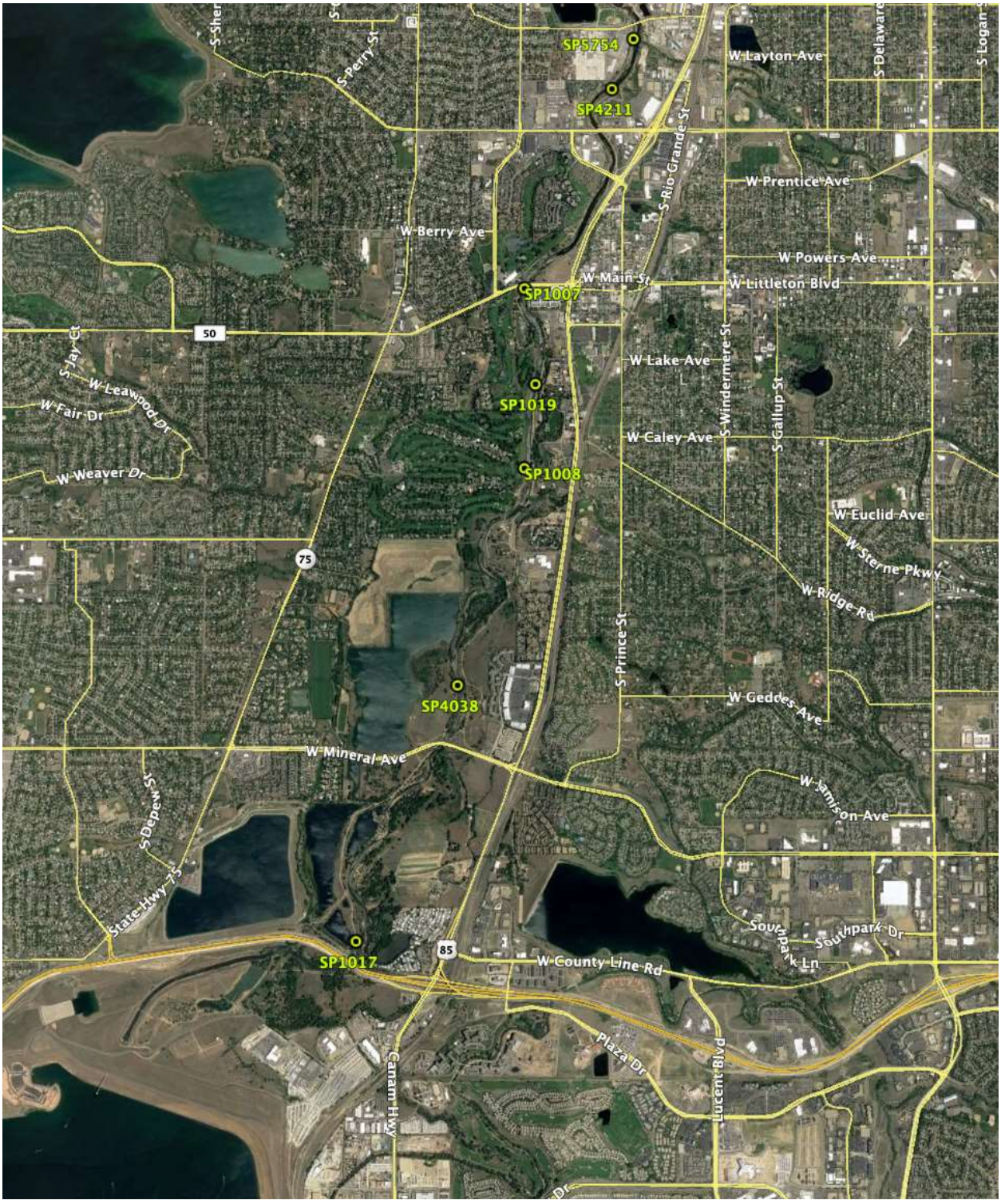

Figure 38. CPW fish monitoring sites, Chatfield reach.

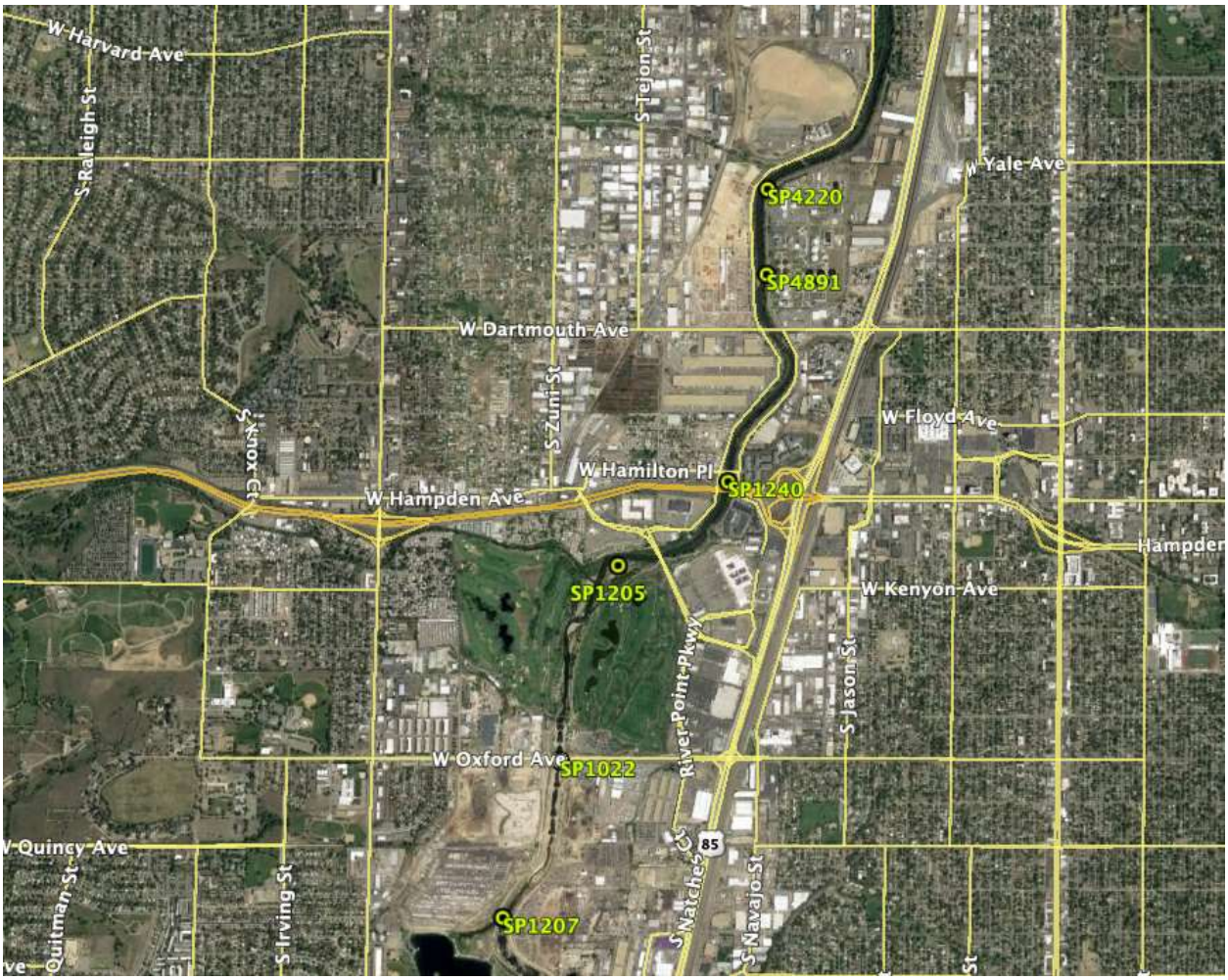

Figure 39. CPW fish monitoring sites, Union Reach.

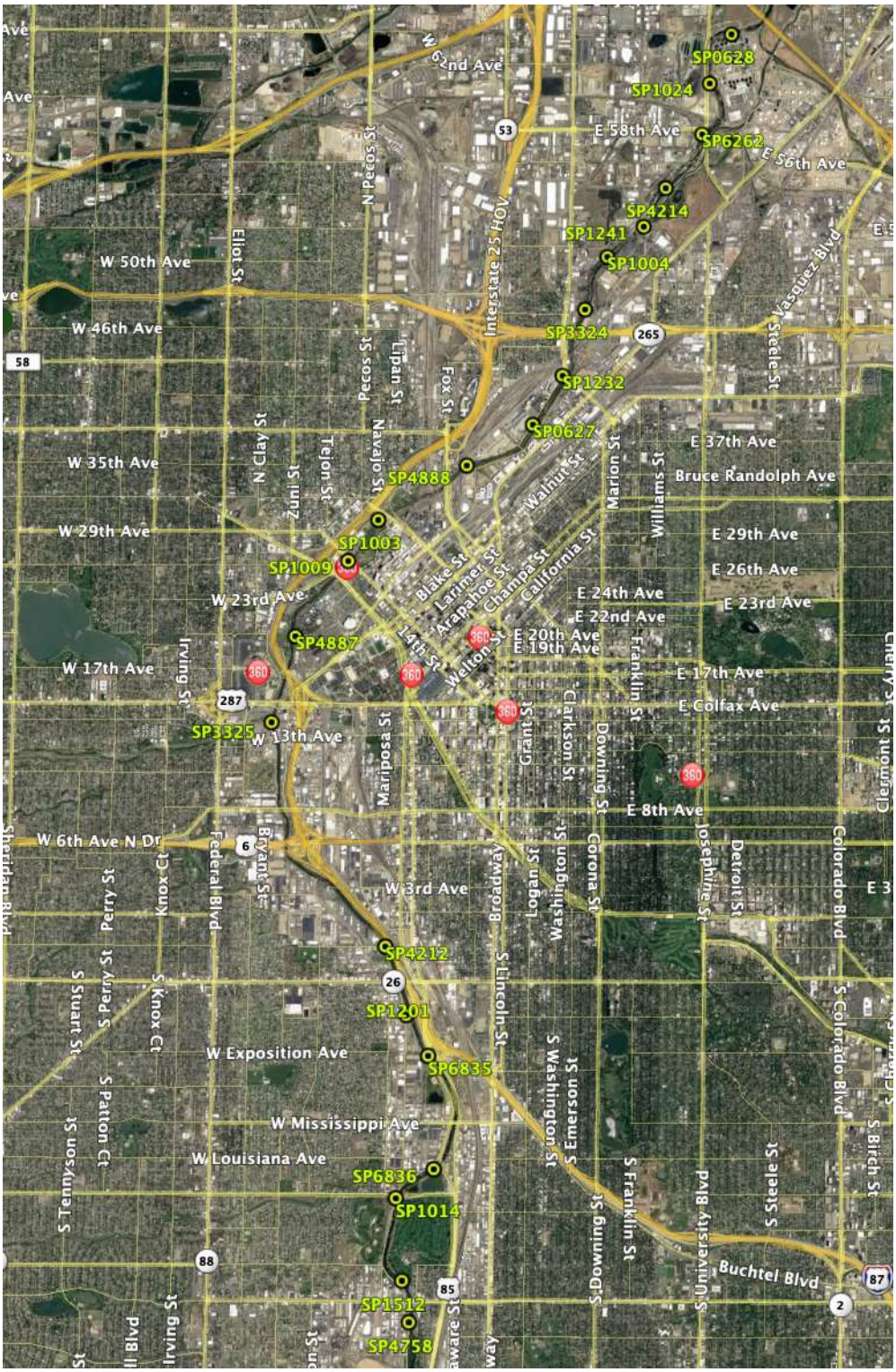

Figure 40.CPW fish monitoring sites, Englewood Reach.

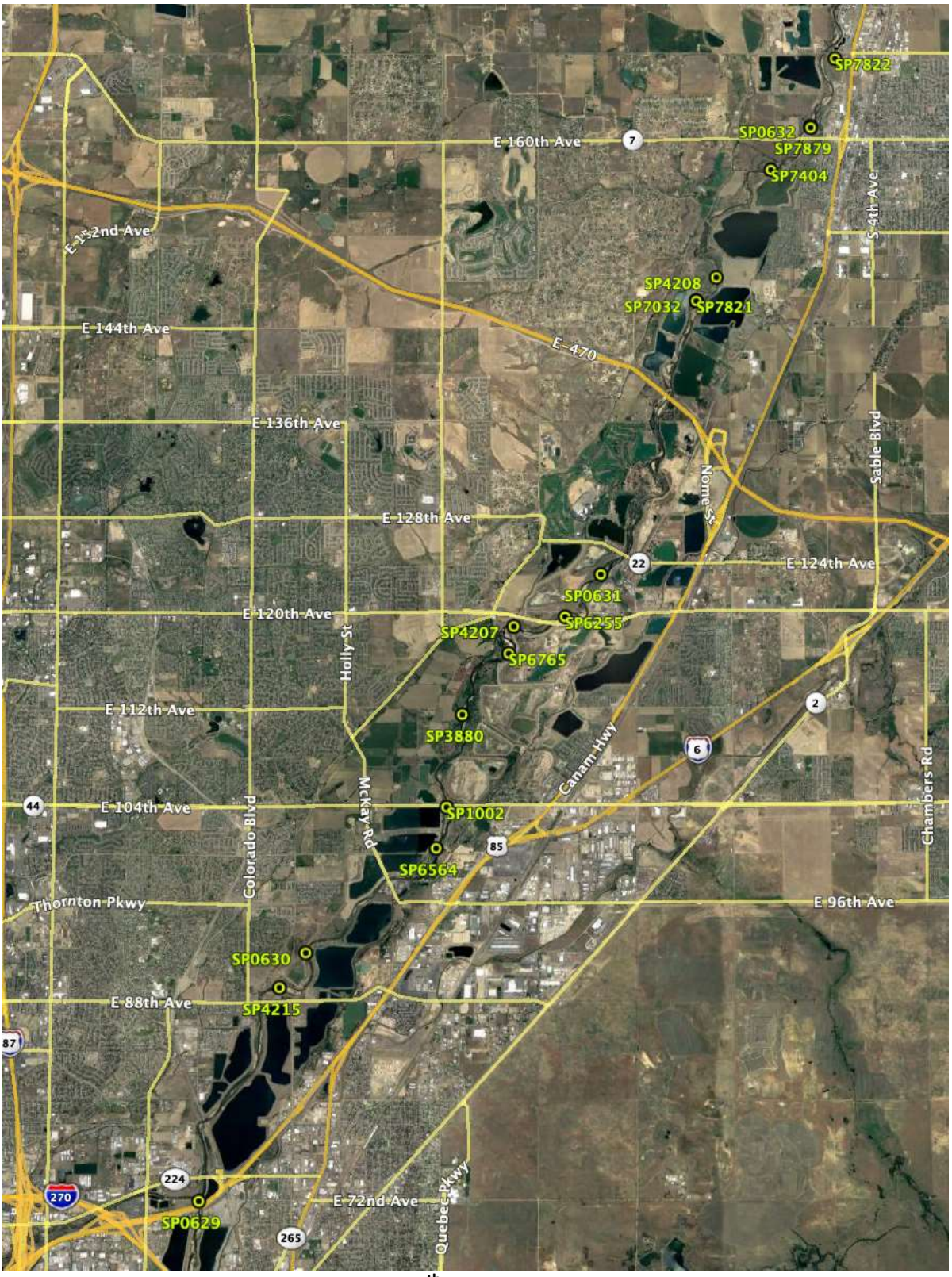

Figure 41. CPW fish monitoring sites, 64th Reach.

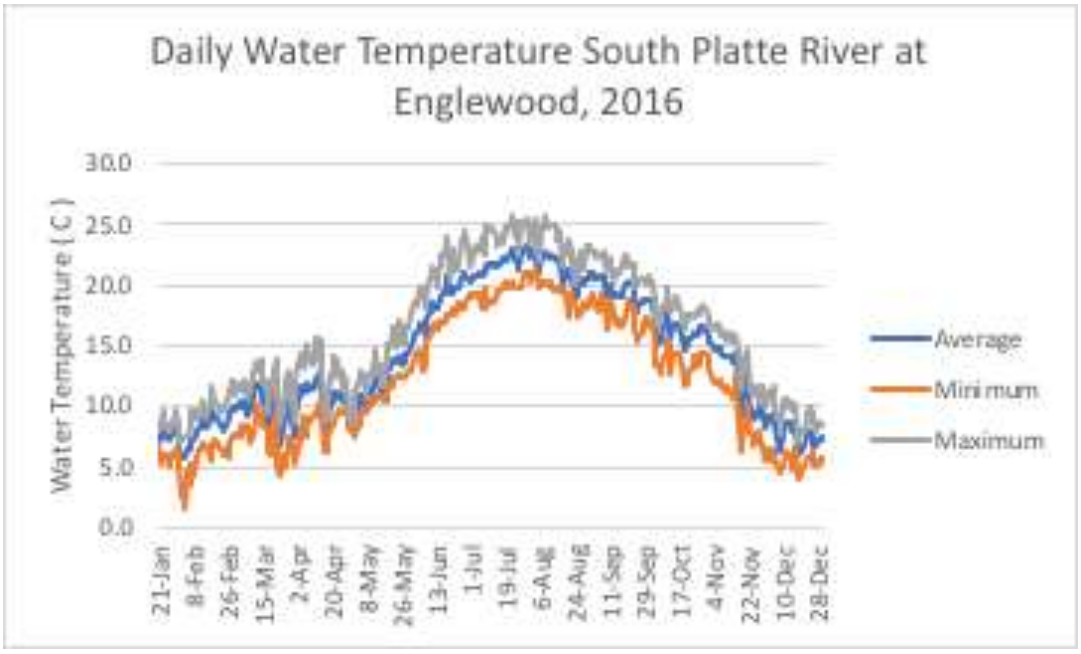

Figure 42. Daily water temperature for the South Platte River at Englewood in 2016 (Source: Denver Trout Unlimited monitoring data).

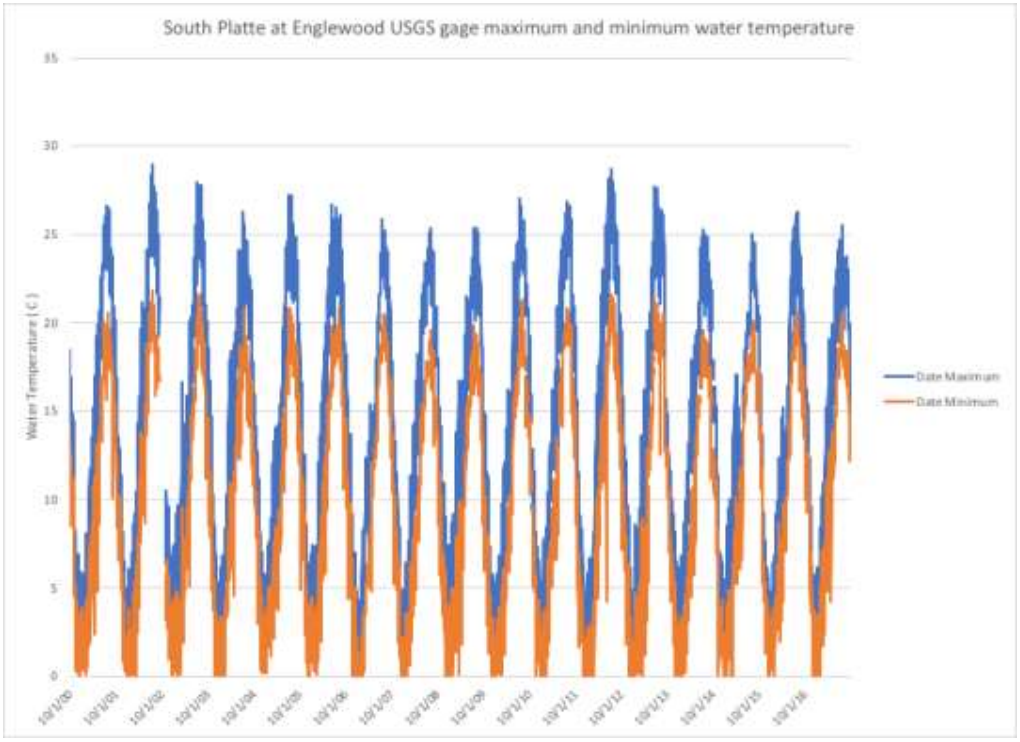

Figure 43. South Platte River daily water temperature at Englewood USGS gage, 2000 through 2016.

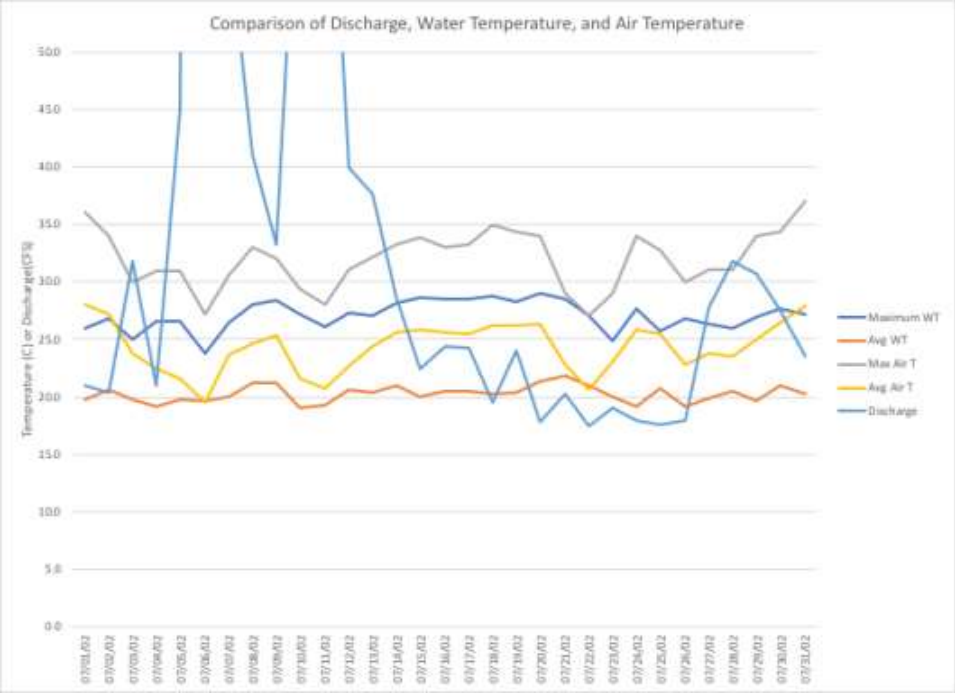

Figure 44. Comparison of discharge, water temperature and air temperature for South Platte River at Englewood USGS gage in July 2002.

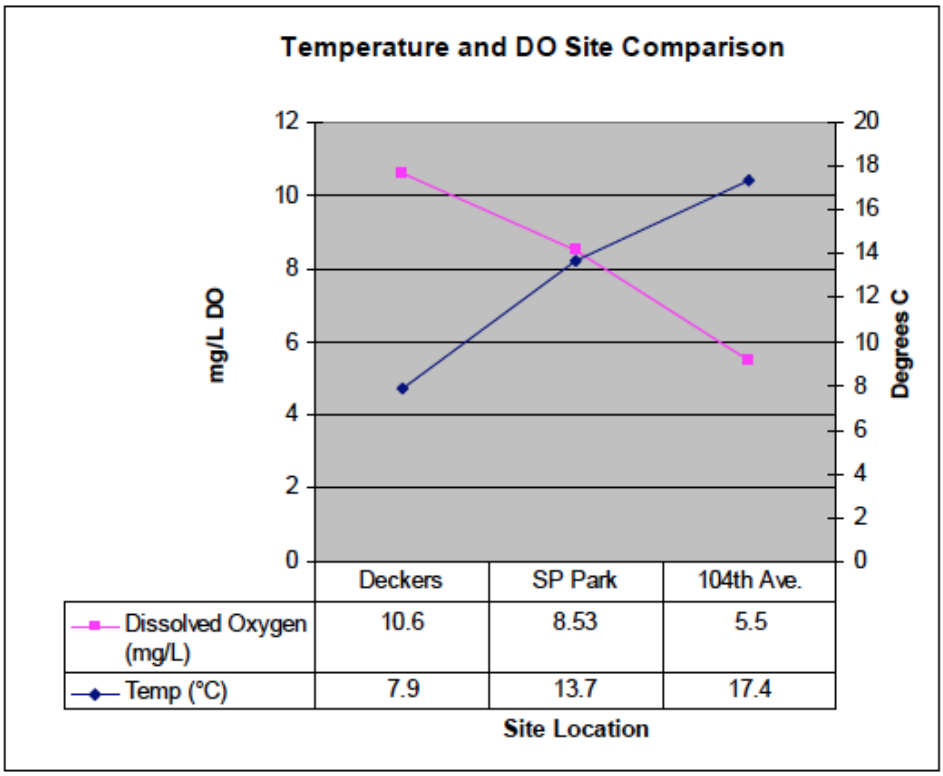

Figure 45. South Platte River dissolved oxygen and water temperature at three locations collected in September and October 2006. (Source: SACWSD 2007).

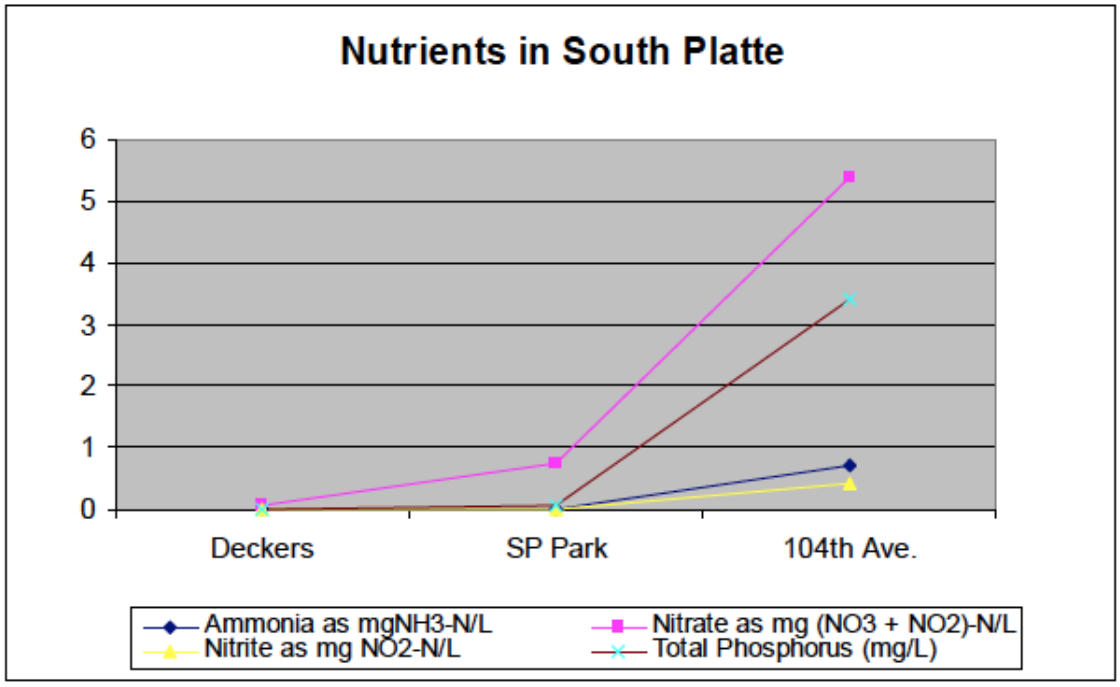

Figure 46. South Platte River nutrient levels at three locations collected in September and October 2006 (Source: SACWSD 2007).

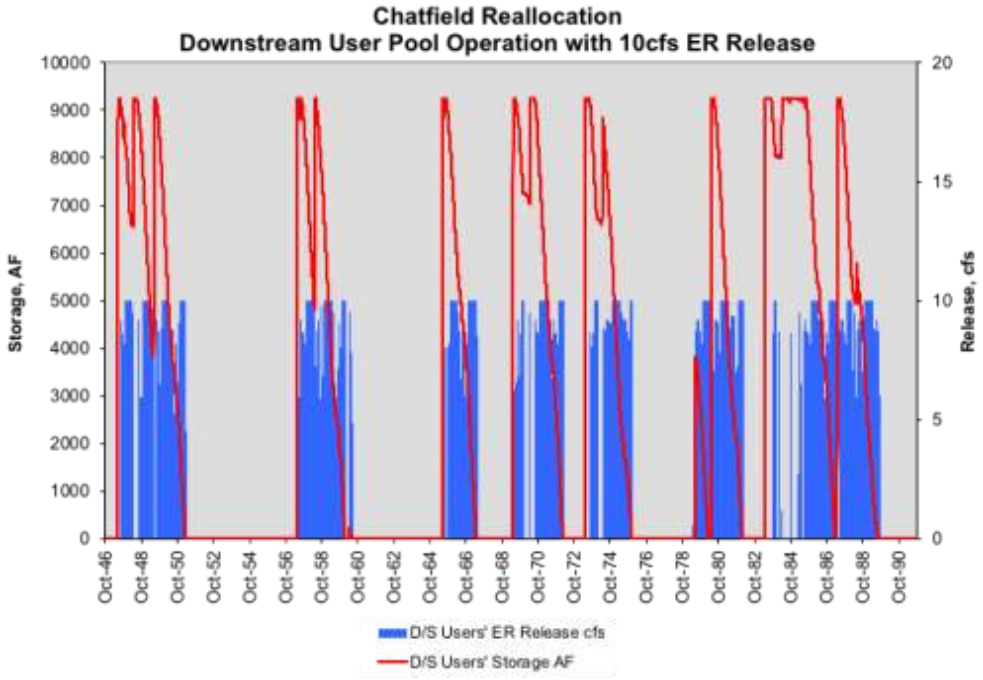

Figure 47. Simulation results for the downstream user pool operation with a 10 cfs Environmental Reallocation (ER) release. (Source: Denver Water)

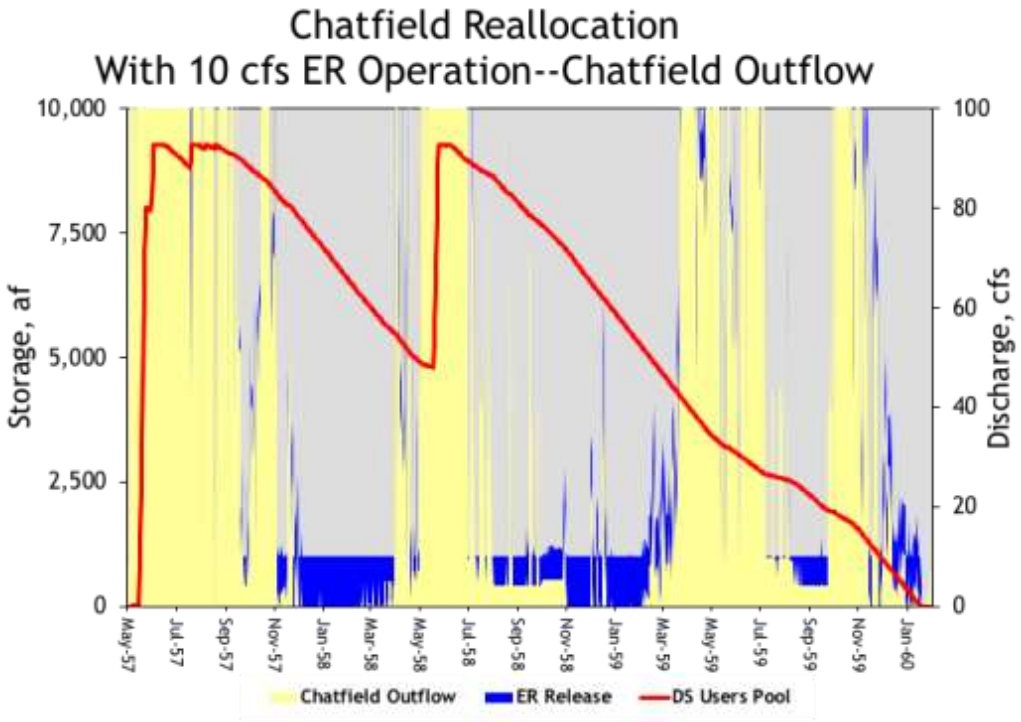

Figure 48. Simulation of Chatfield outflow, ER release and Downstream (DS) users pool. (Source: Denver Water)

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Appendix A – Habitat –Flow Relationships for various fish species in the South Platte River, Denver, Colorado. (Source: Appendix D: Environmental Flow Study 2006).

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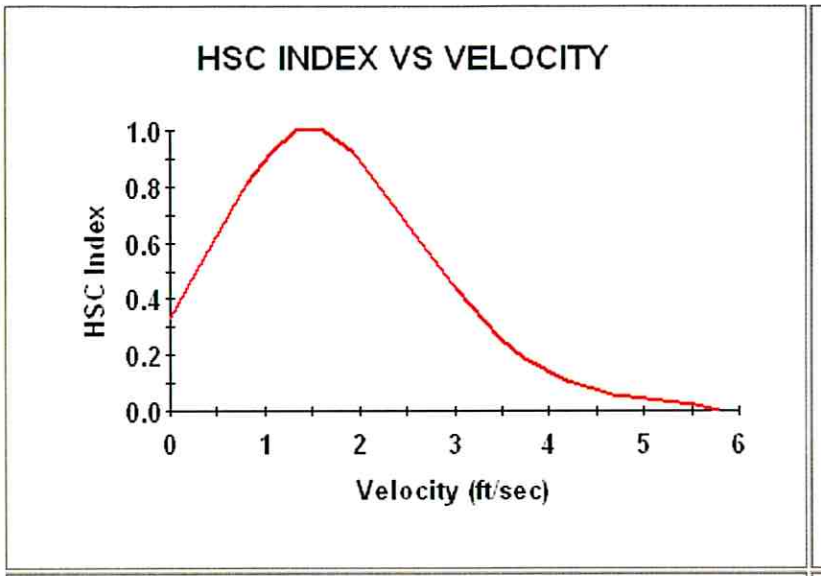
Attachment A

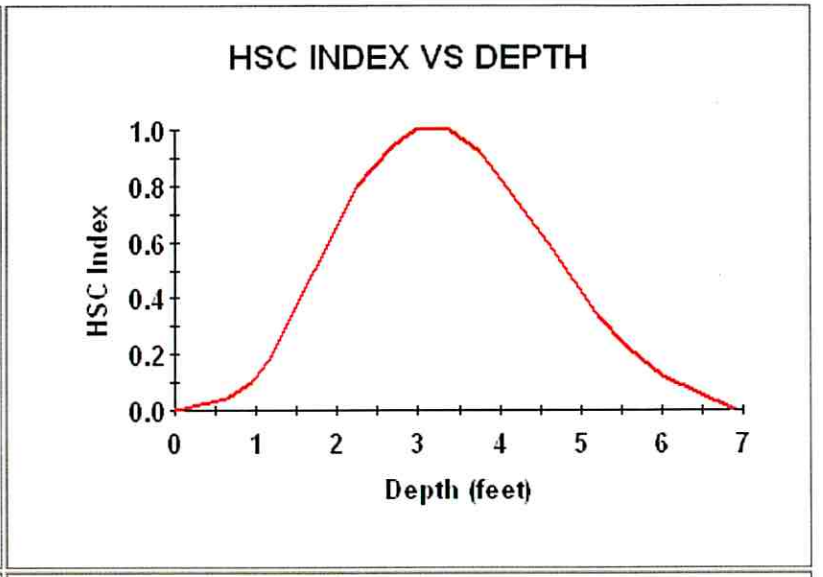
Habitat Suitability Data for Species of Interest

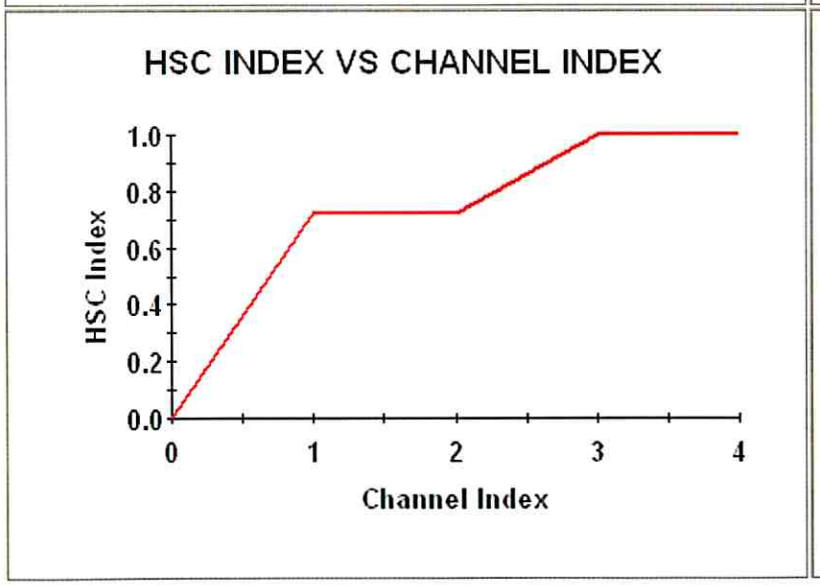
Habitat Suitability Criteria

- All data from published studies or Colorado studies
- Sources:
  - Brown and Rainbow Trout - CDOW South Platte River
  - Channel catfish, adult – Peters et al. 1989 – Platte River
  - Channel catfish juvenile – Chadwick Platte River
  - Common carp adult - Chadwick Platte River
  - Sand shiner - Chadwick Platte River
  - Longnose dace – USFWS HSI criteria
  - White sucker - USFWS HSI criteria

Brown Trout - Adult



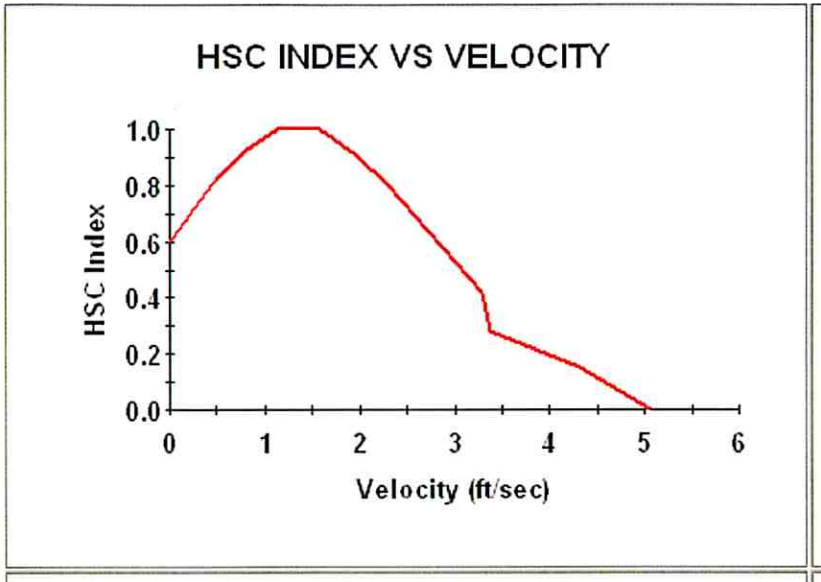


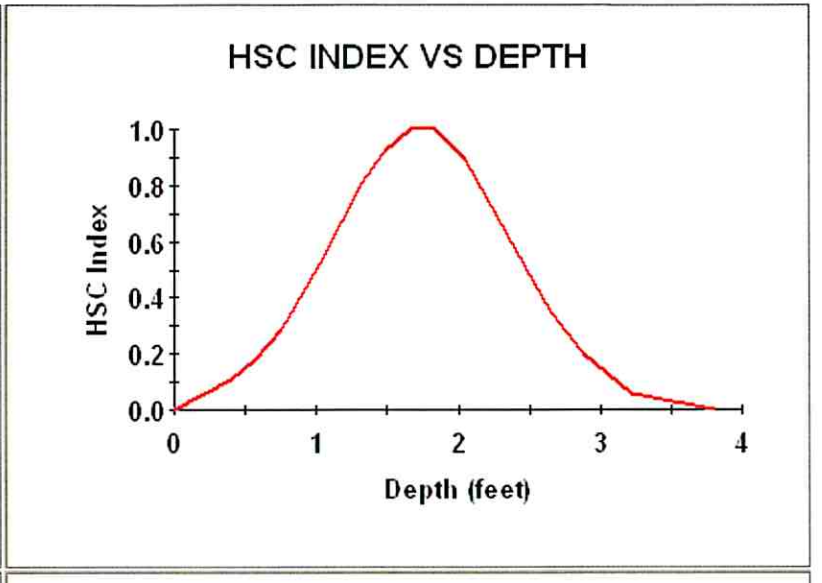


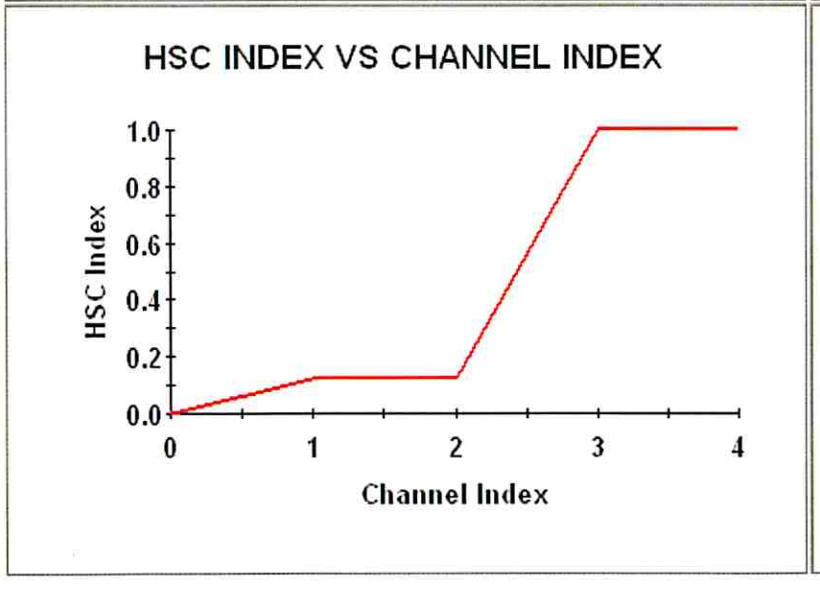
November 17, 2006

Preliminary Results – Subject to Revision

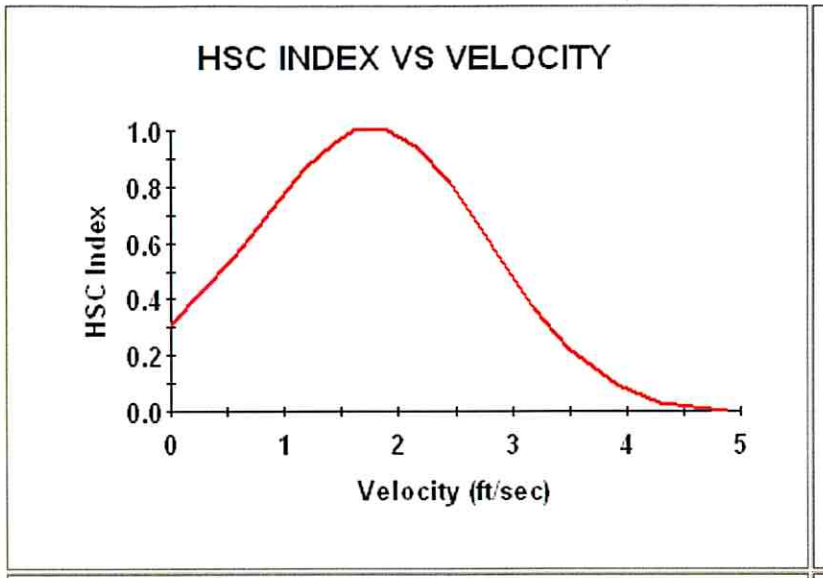
Brown Trout - Juvenile

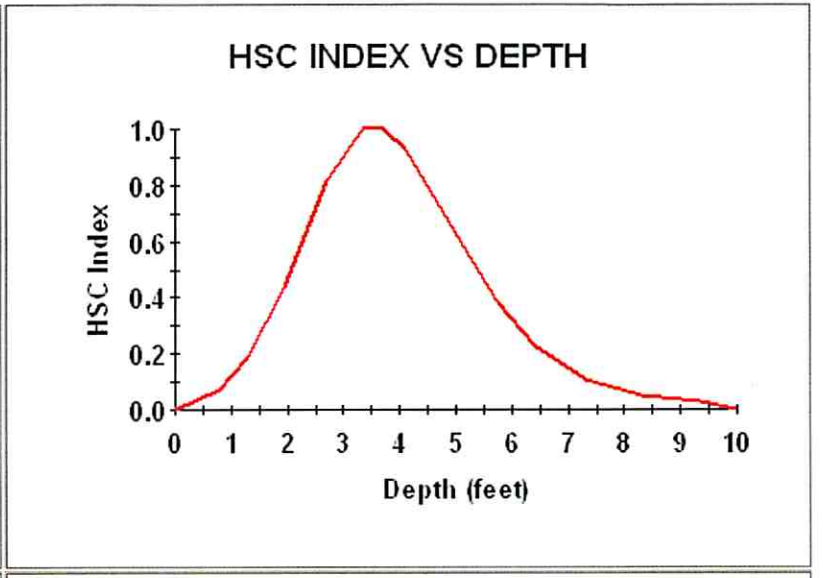


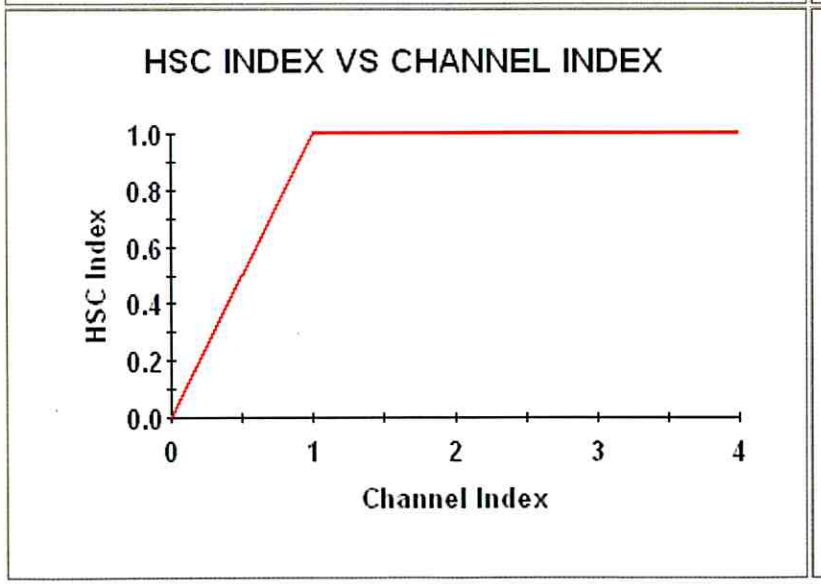




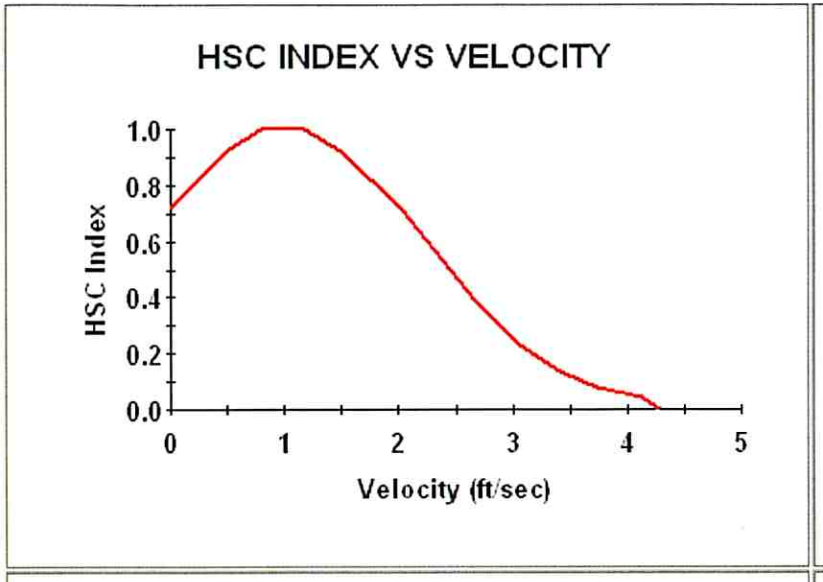
Rainbow Trout - Adult

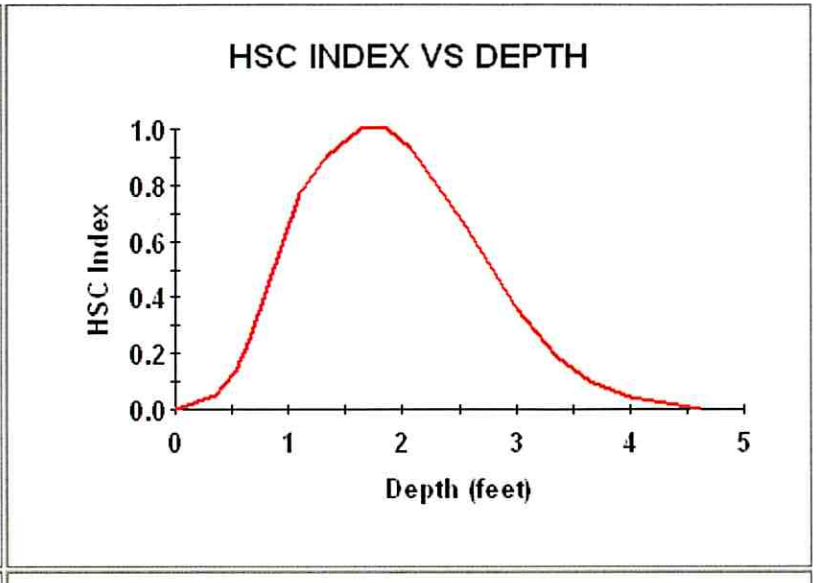


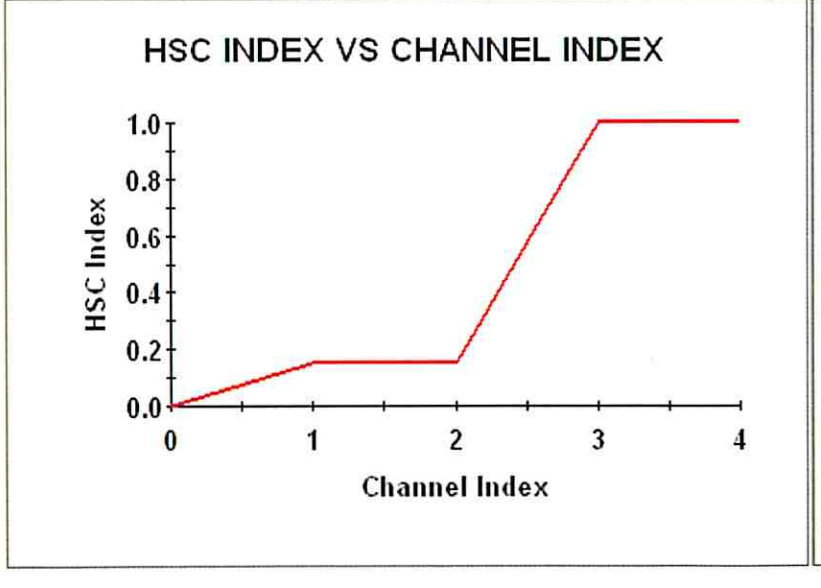




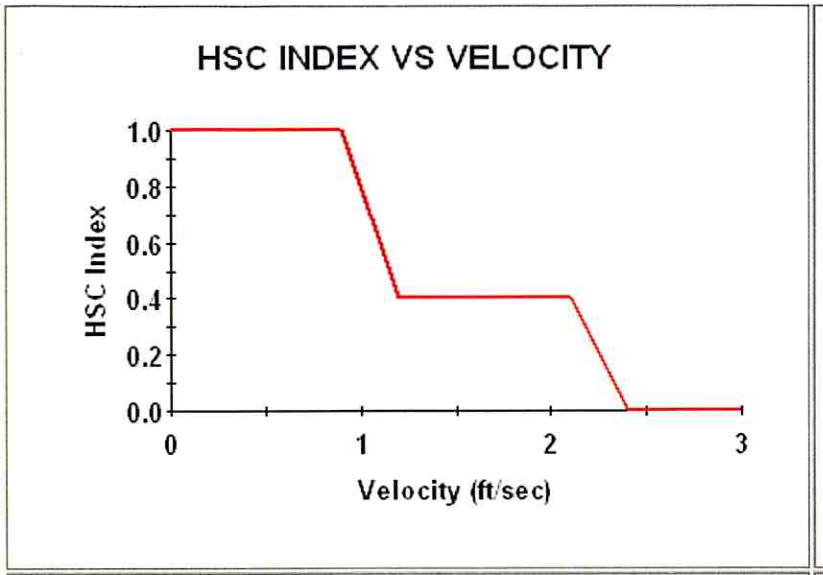
Rainbow Trout - Juvenile

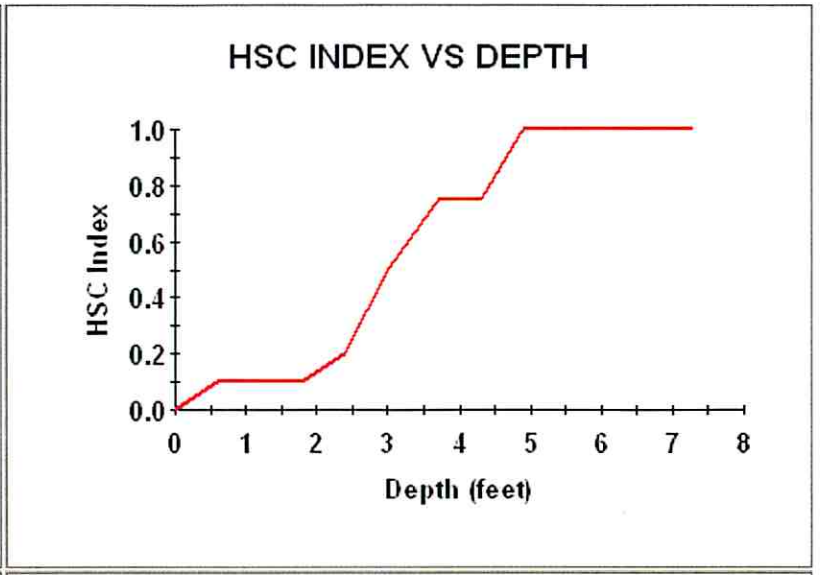


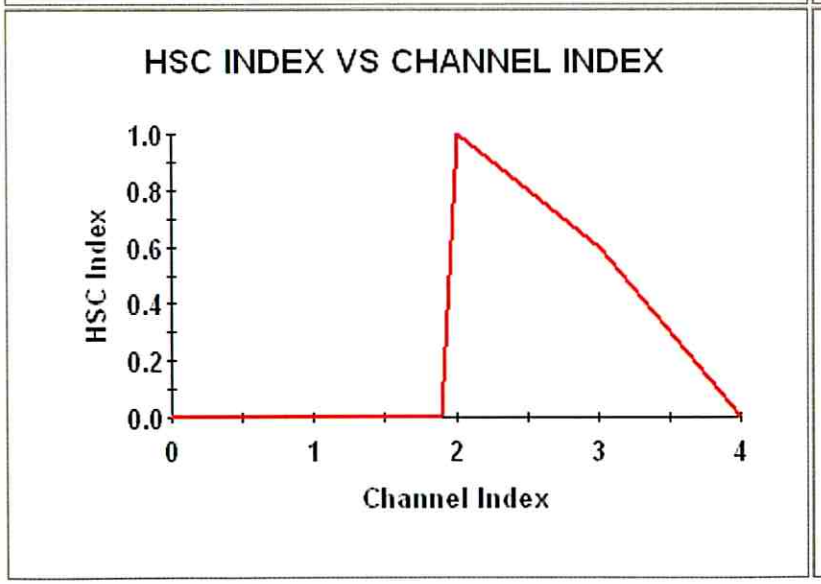




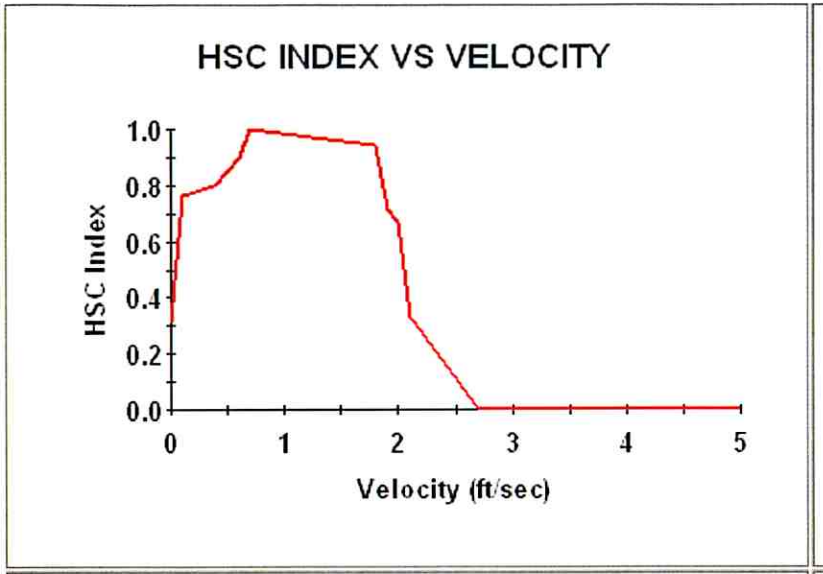
Channel Catfish - Adult

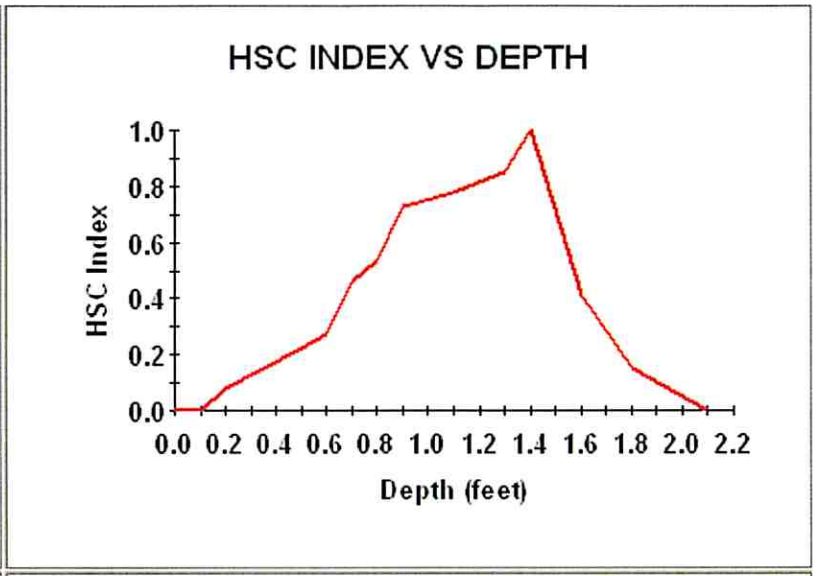


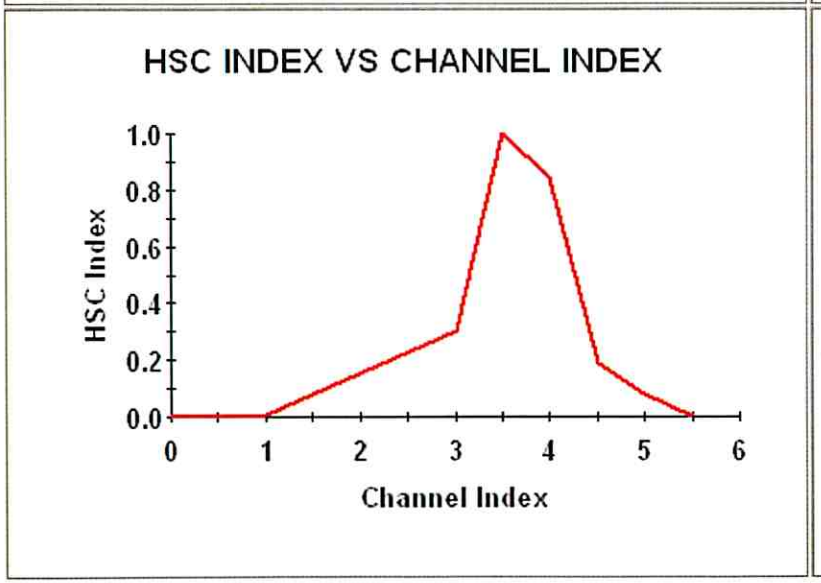




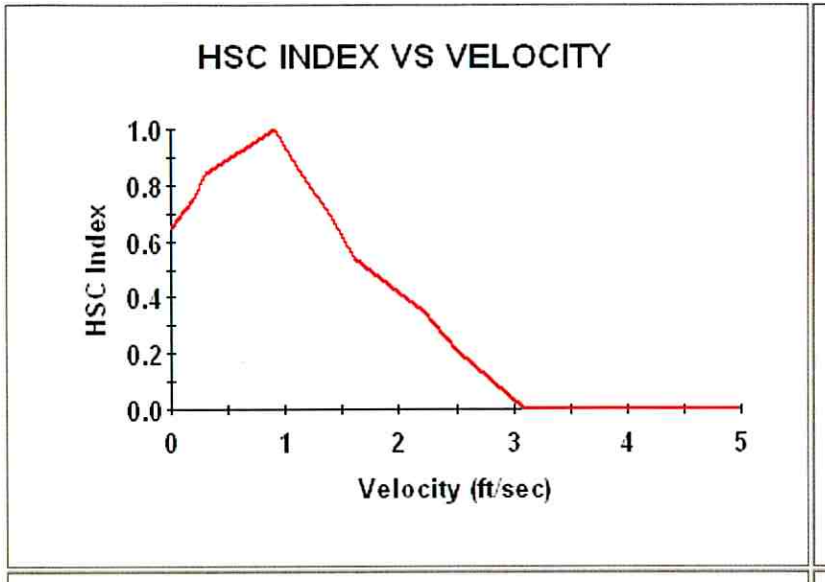
Channel Catfish - Juvenile

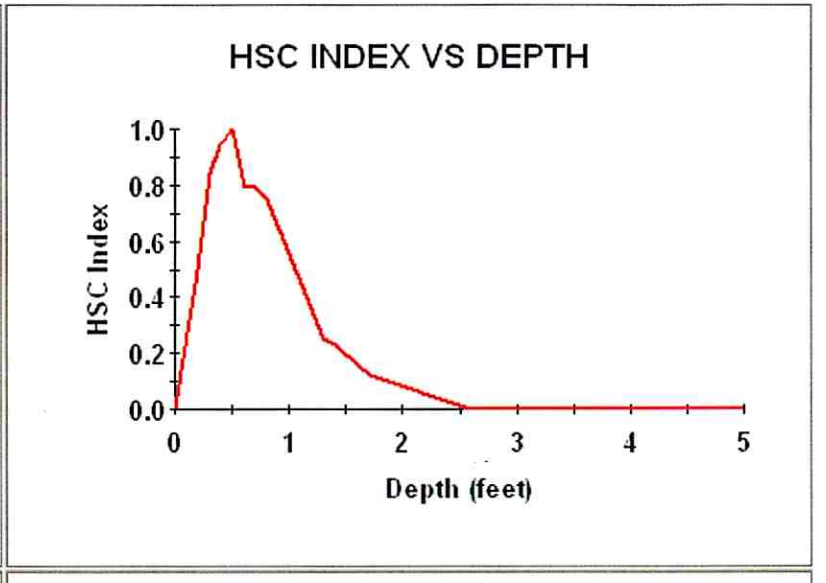


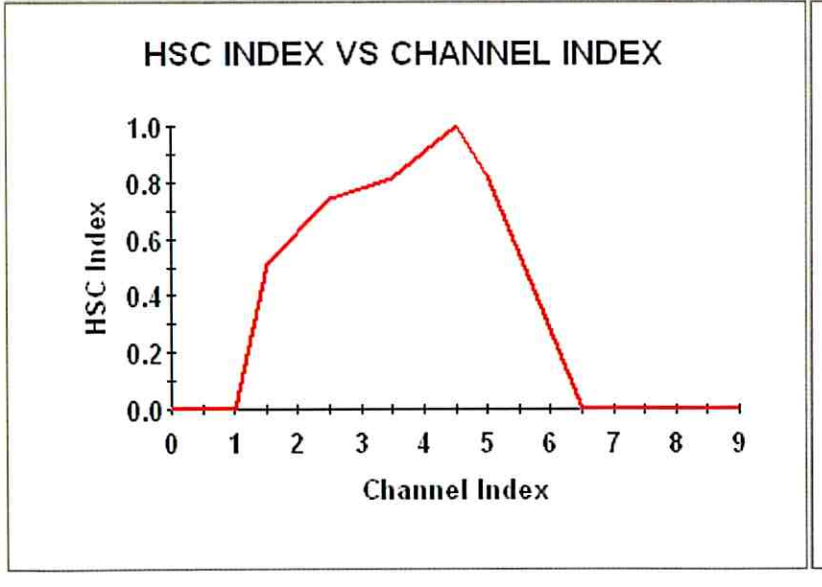




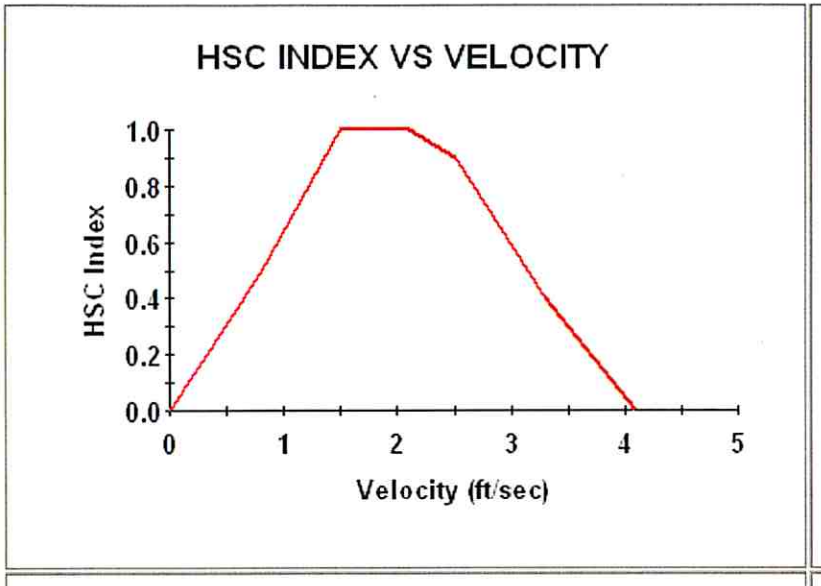
Sand Shiner - Adult

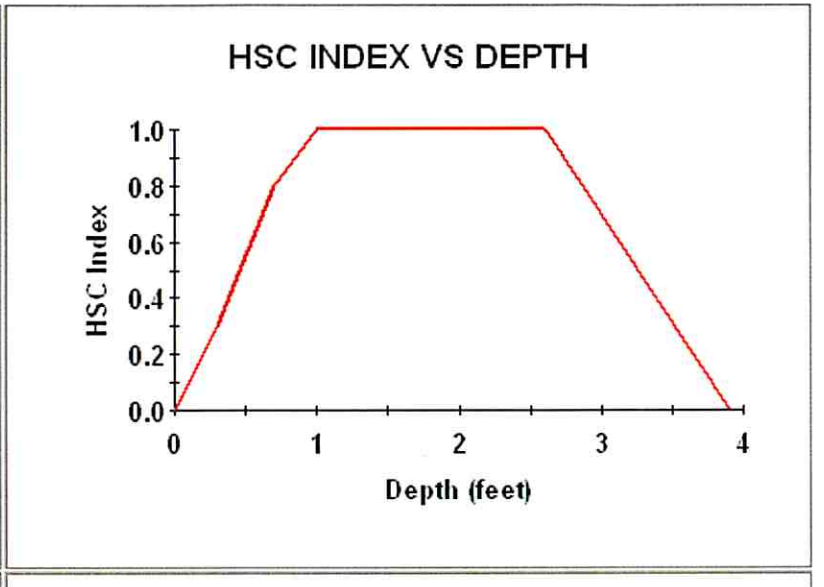


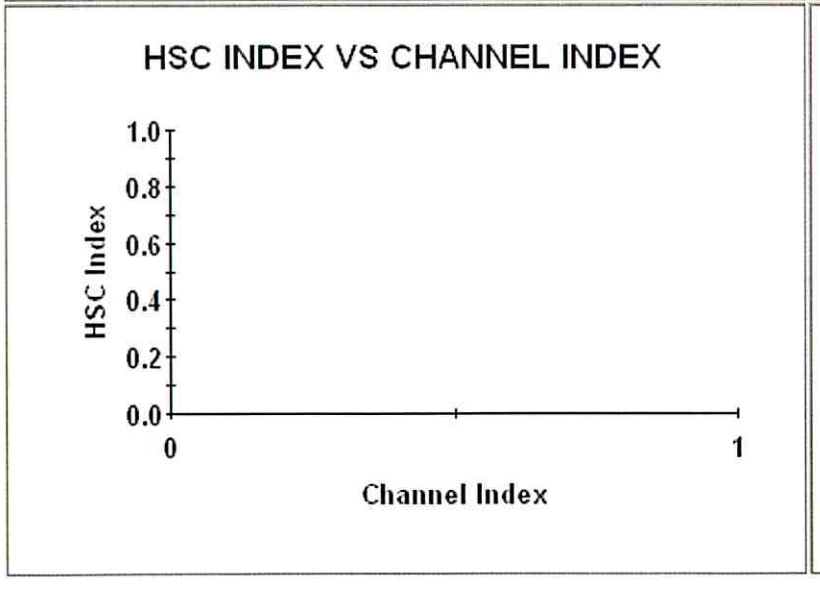




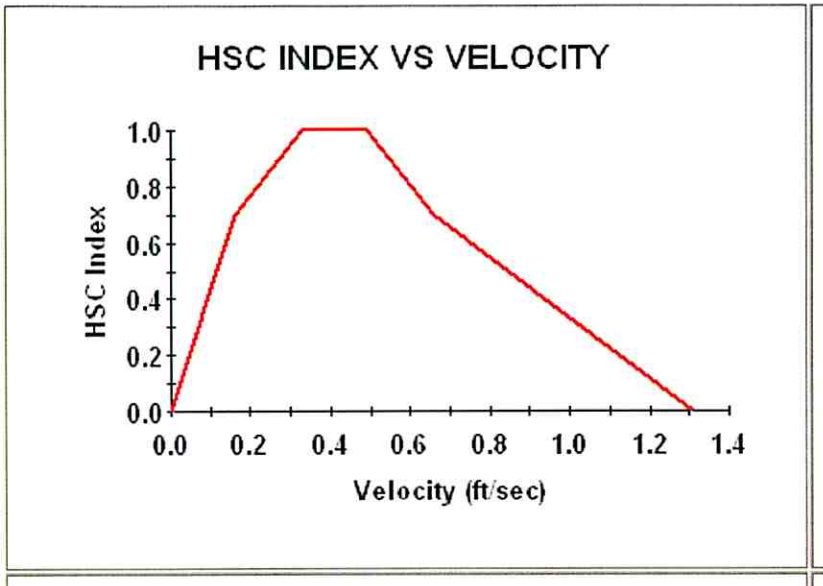
Longnose Dace - Adult

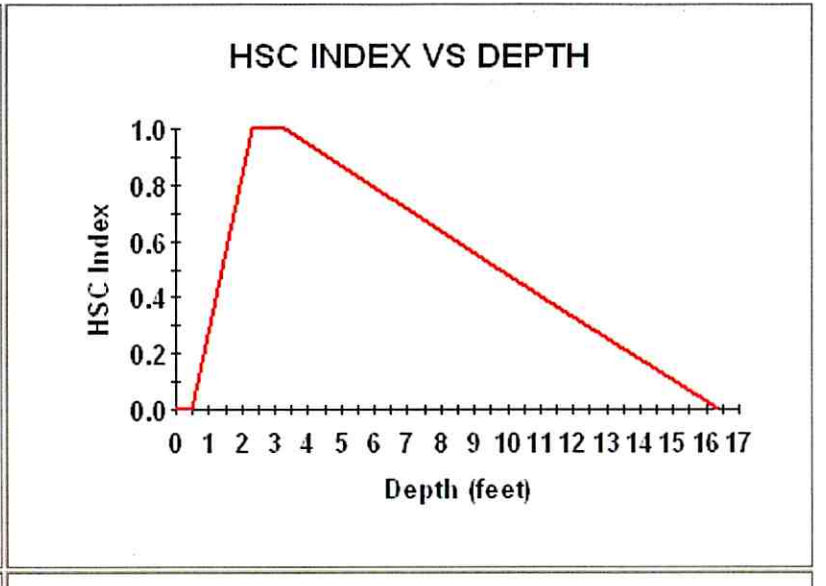


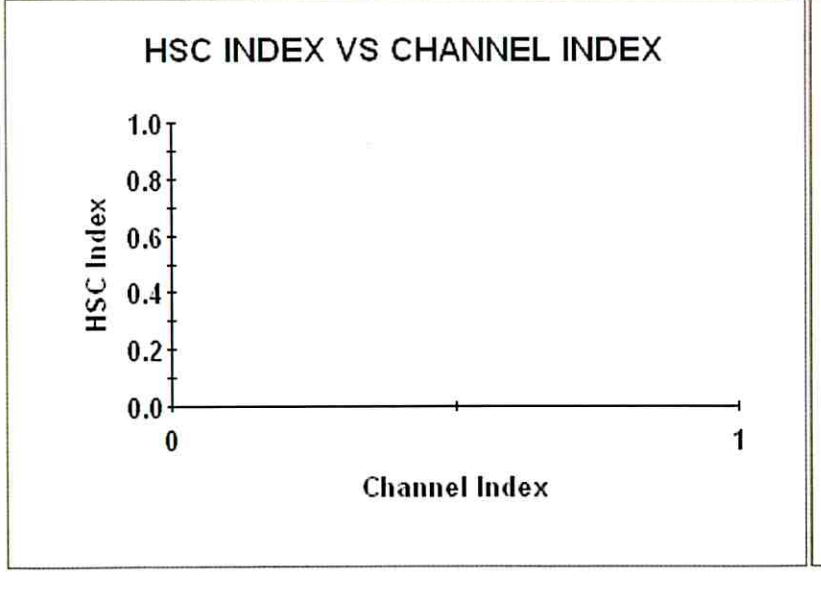




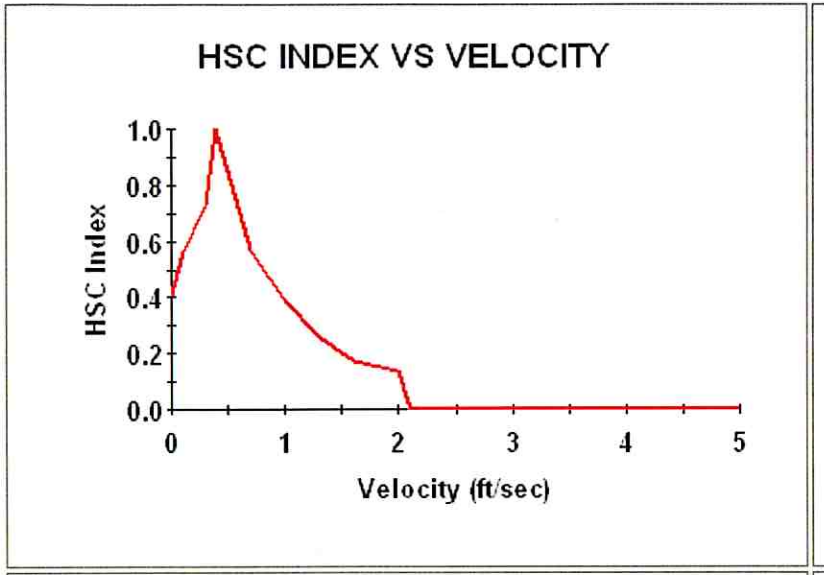
White Sucker – Juvenile/Adult

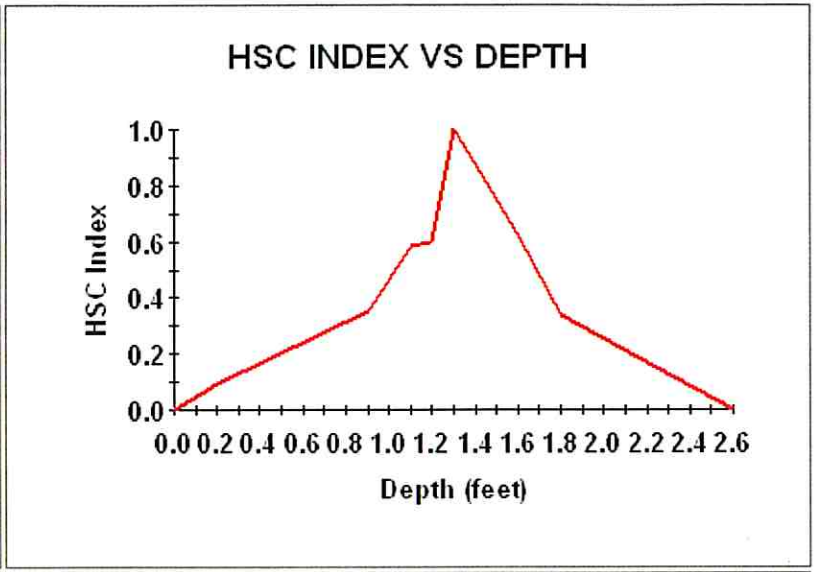


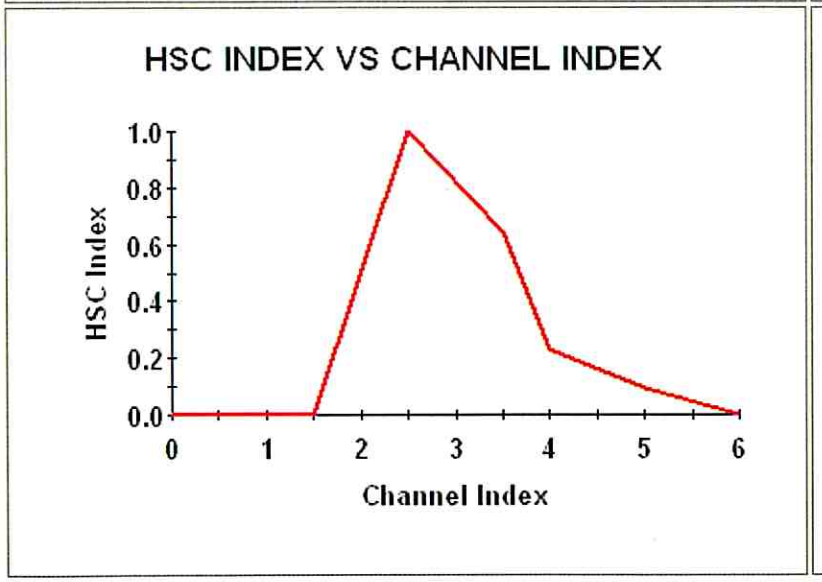




Common Carp - Adult







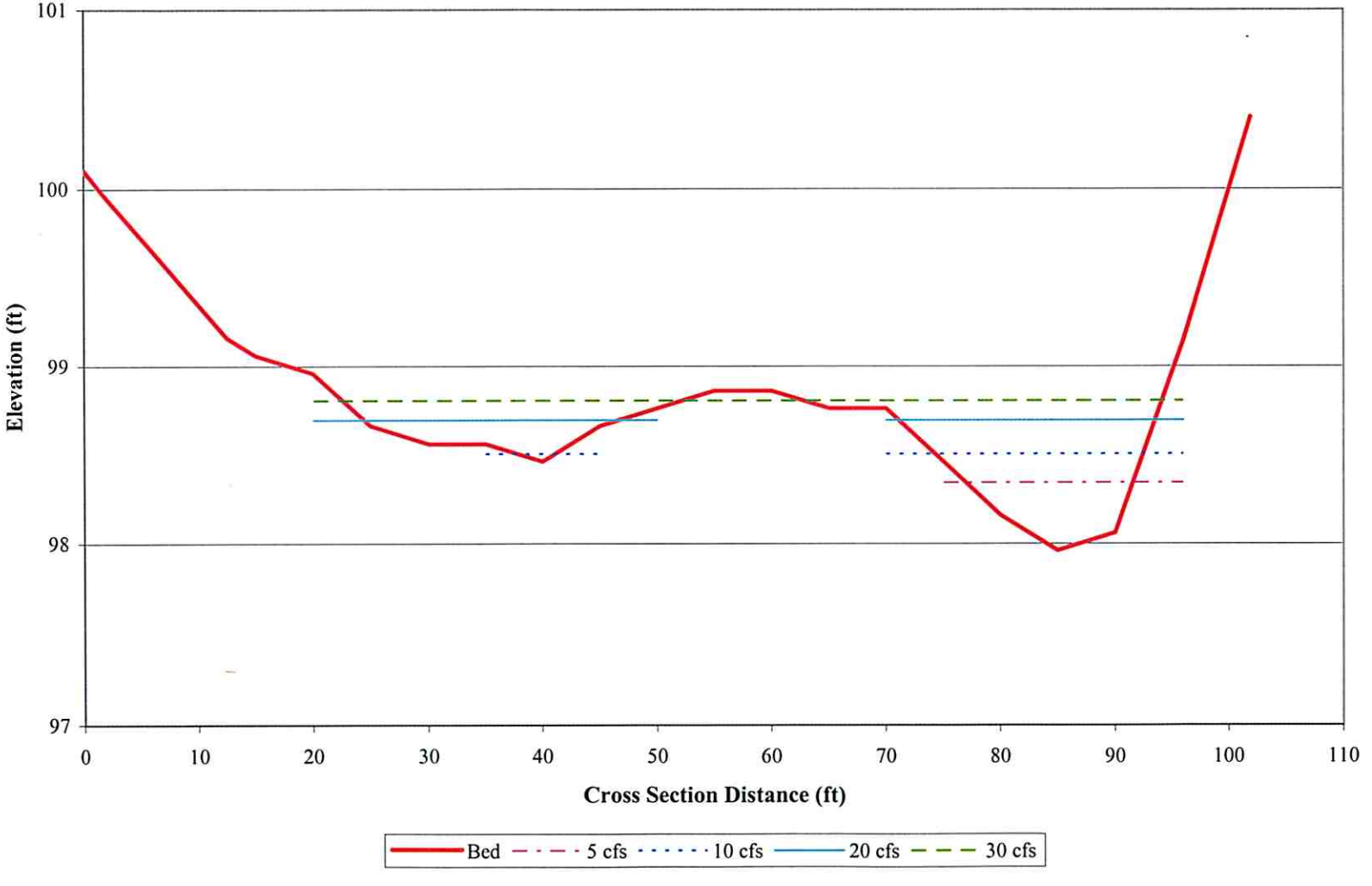
November 17, 2006

Preliminary Results – Subject to Revision

Attachment B

Cross Section Flow and Wetted Perimeter Analysis

South Platte Littleton Bed Profile, Water Surface Elevation - Riffle



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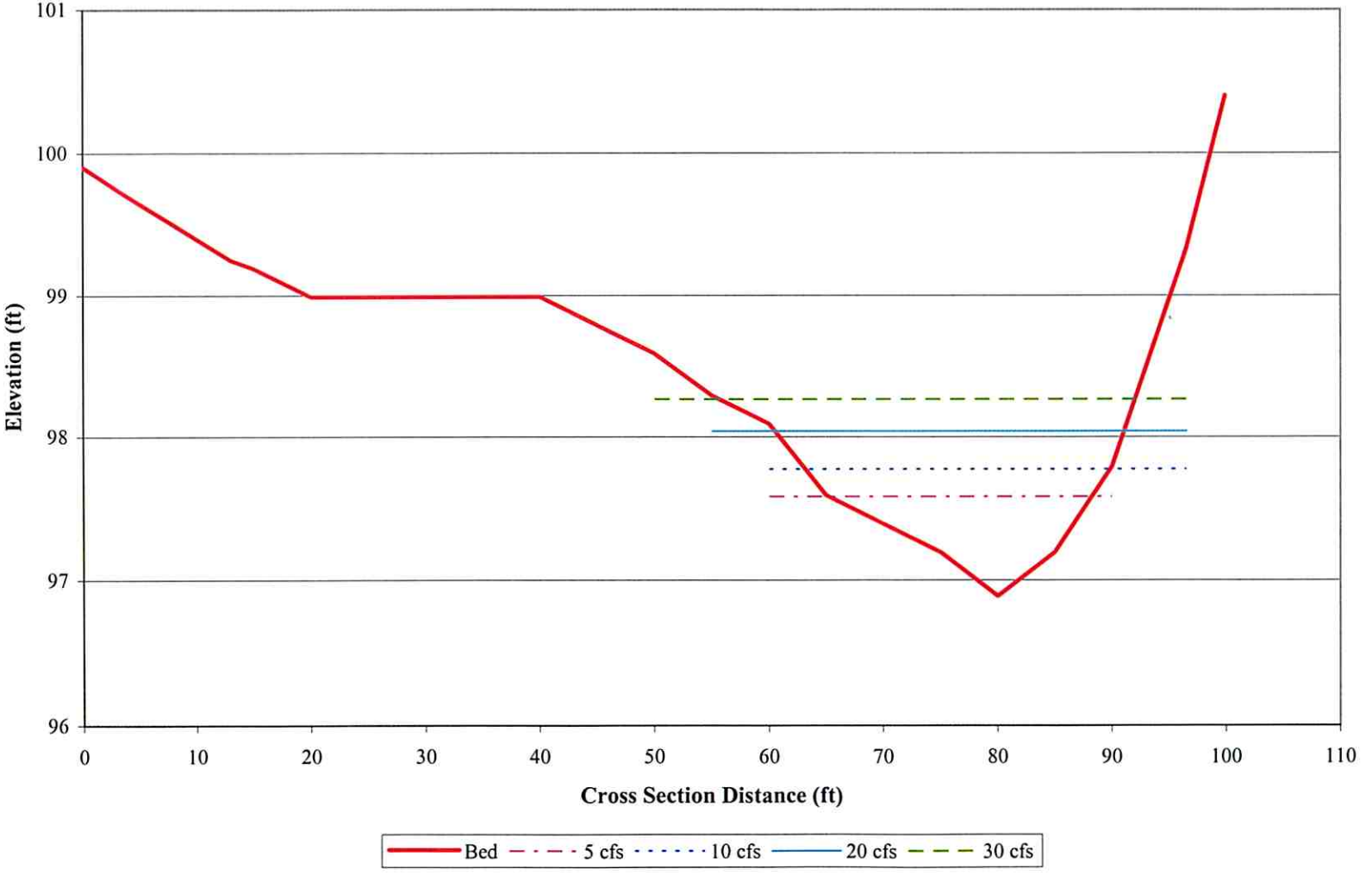
Preliminary Results – Subject to Revision

South Platte Littleton Bed Profile, Water Surface Elevation - Run



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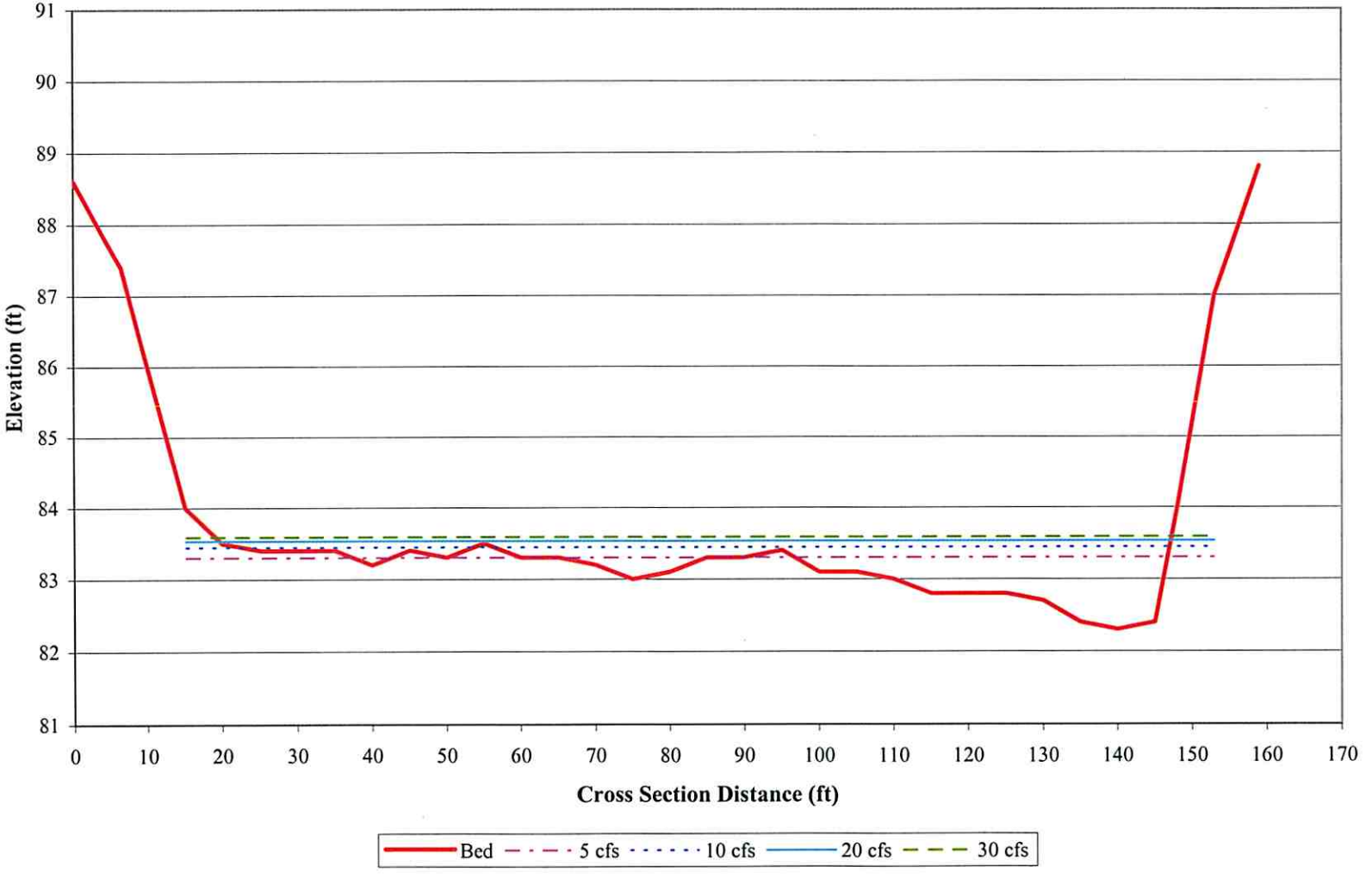
Preliminary Results – Subject to Revision

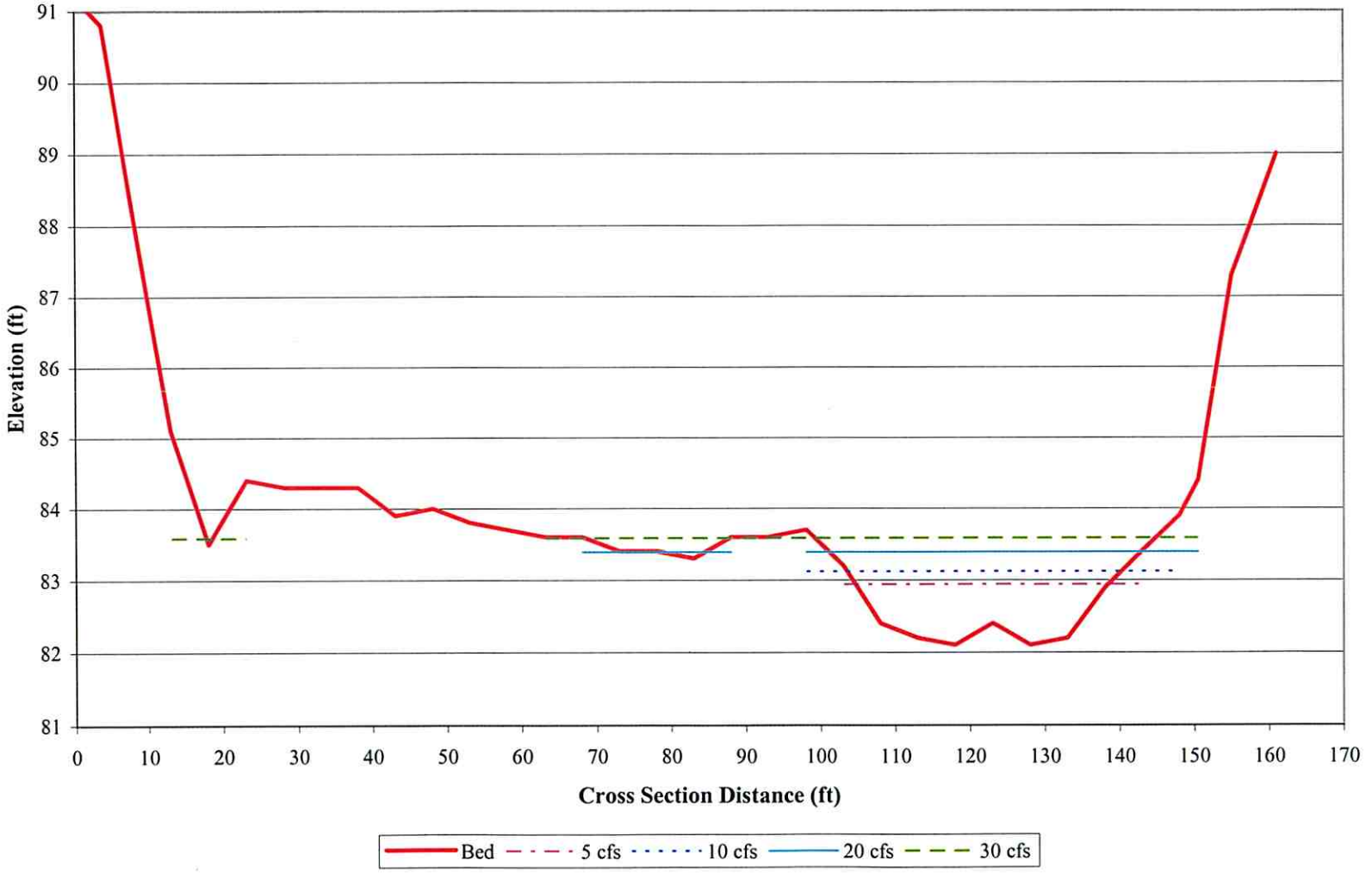
South Platte at Union St. Bed Profile, Water Surface Elevation - Riffle



November 17, 2006

Preliminary Results – Subject to Revision

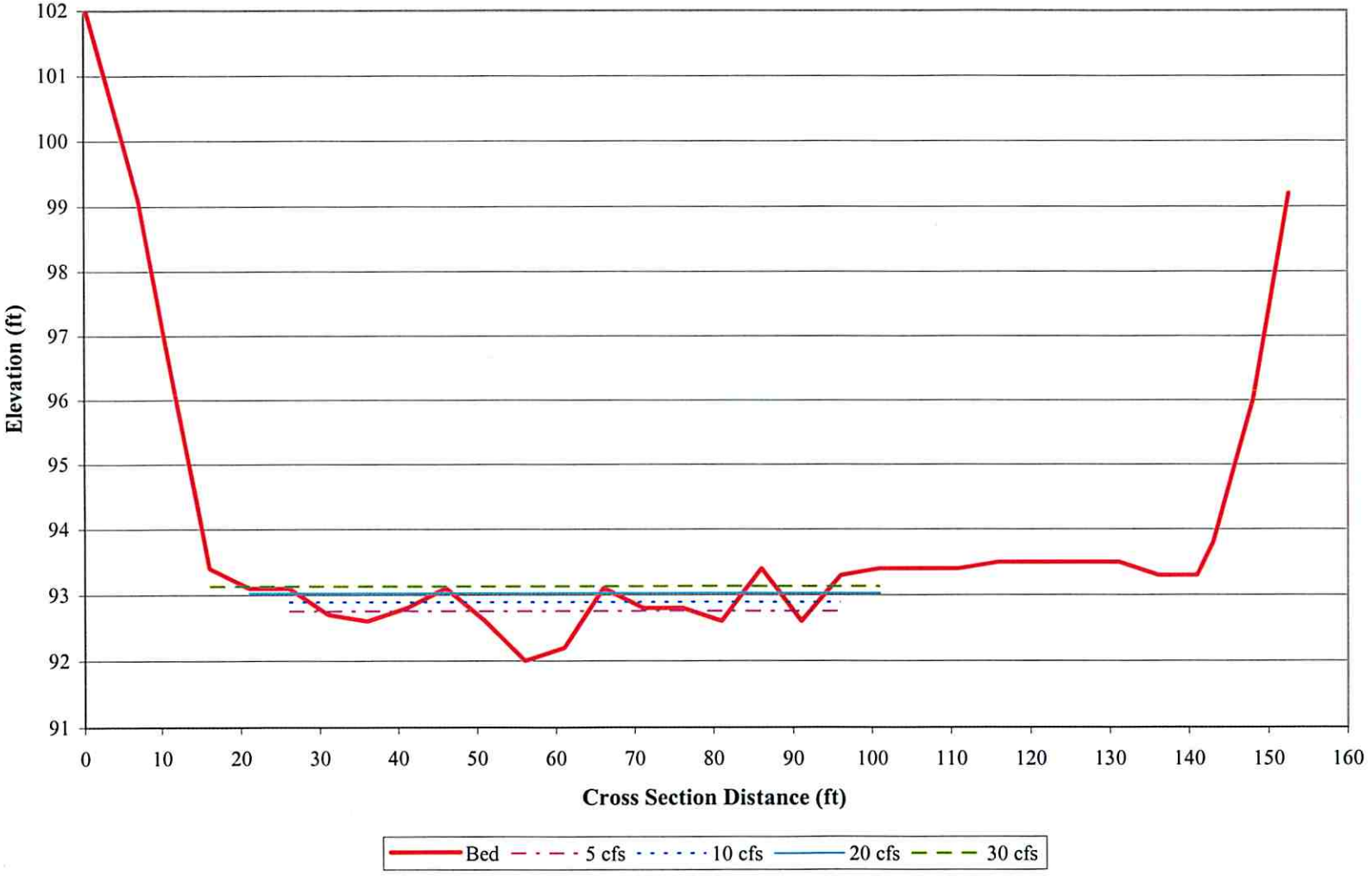
South Platte at Union St. Bed Profile, Water Surface Elevation - Run



November 17, 2006

Preliminary Results – Subject to Revision

South Platte at Evans St. Bed Profile, Water Surface Elevation - Riffle



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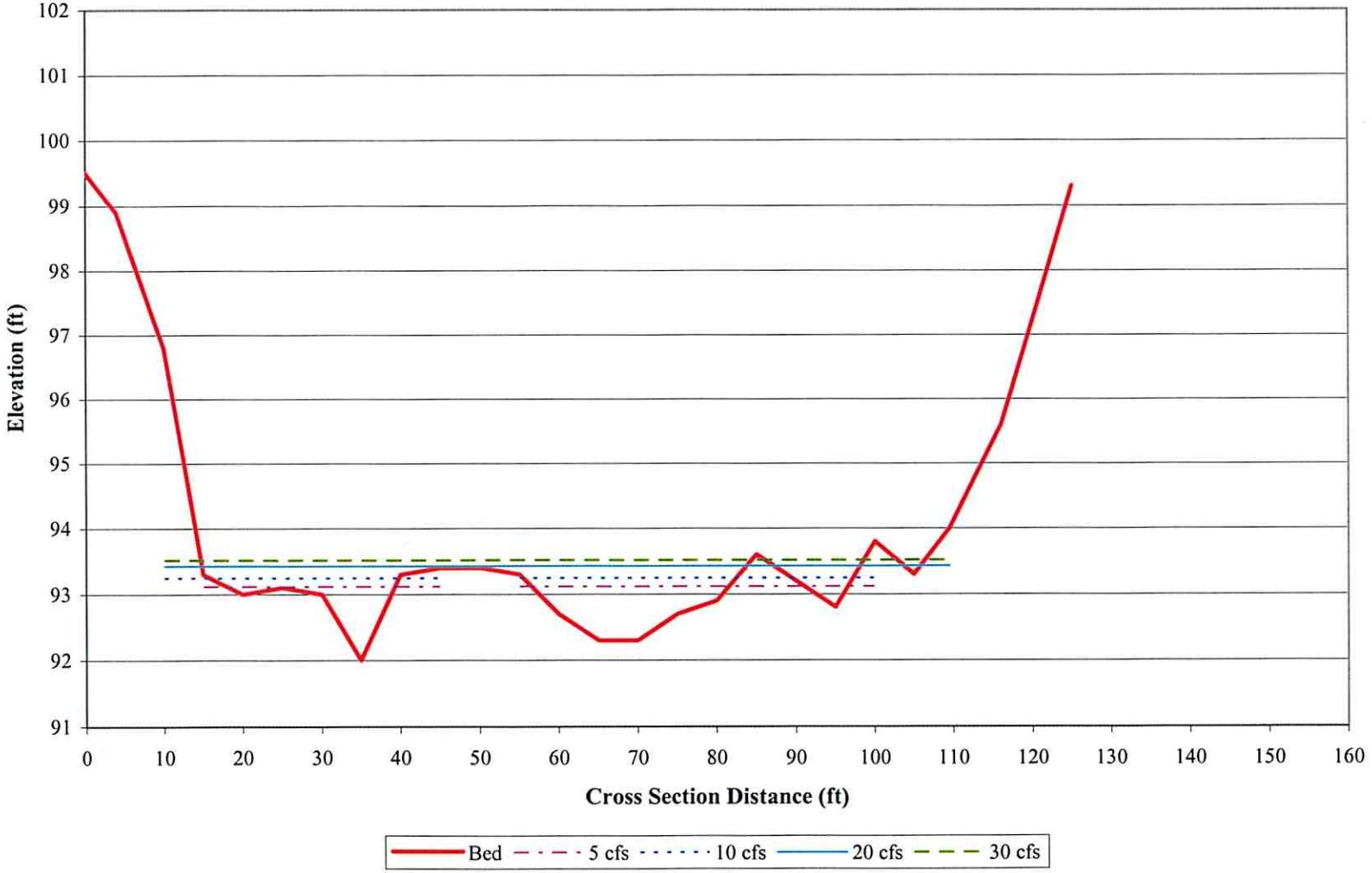
Preliminary Results – Subject to Revision

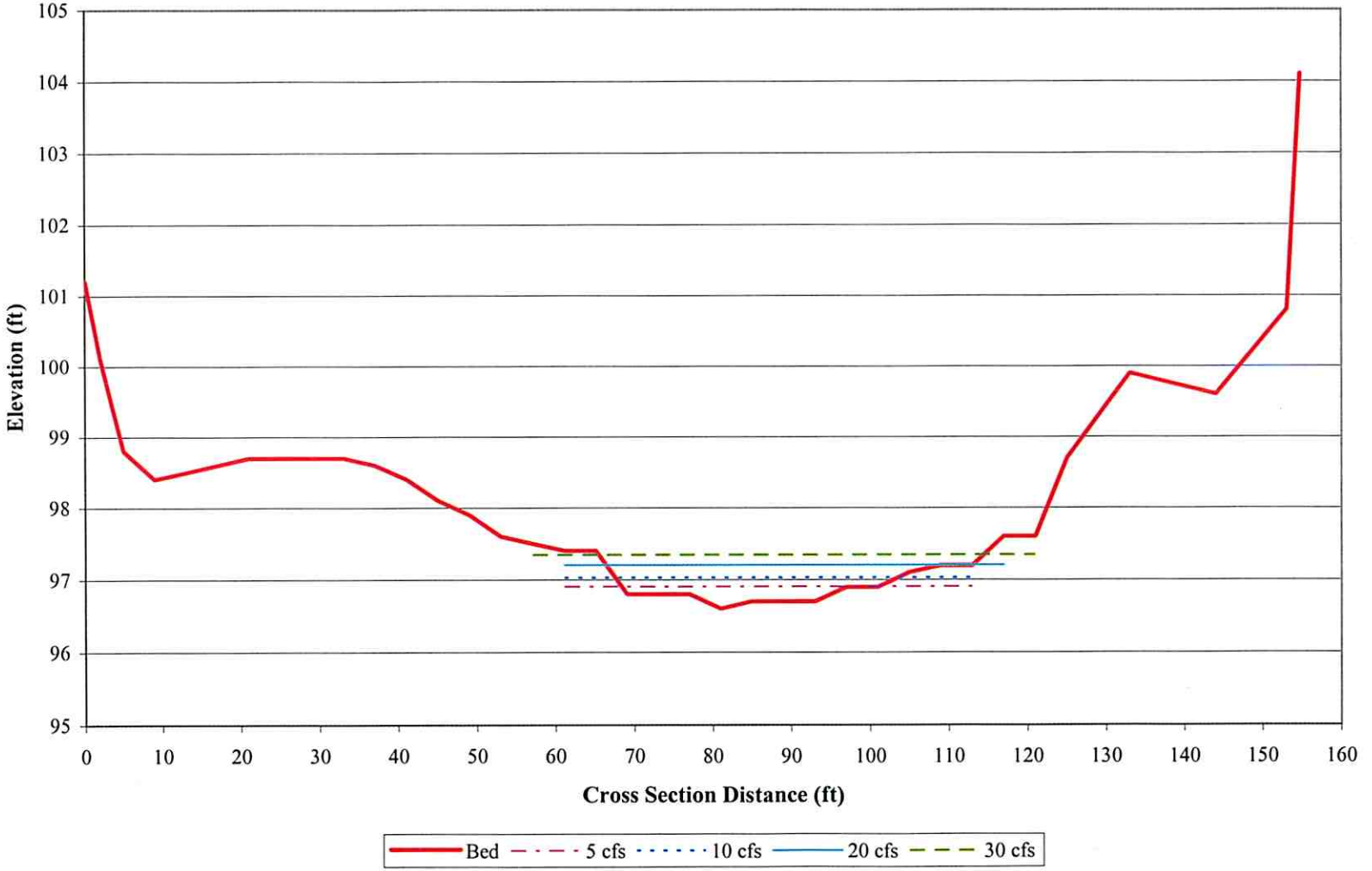
South Platte at Evans St. Bed Profile, Water Surface Elevation - Run



November 17, 2006

Preliminary Results – Subject to Revision

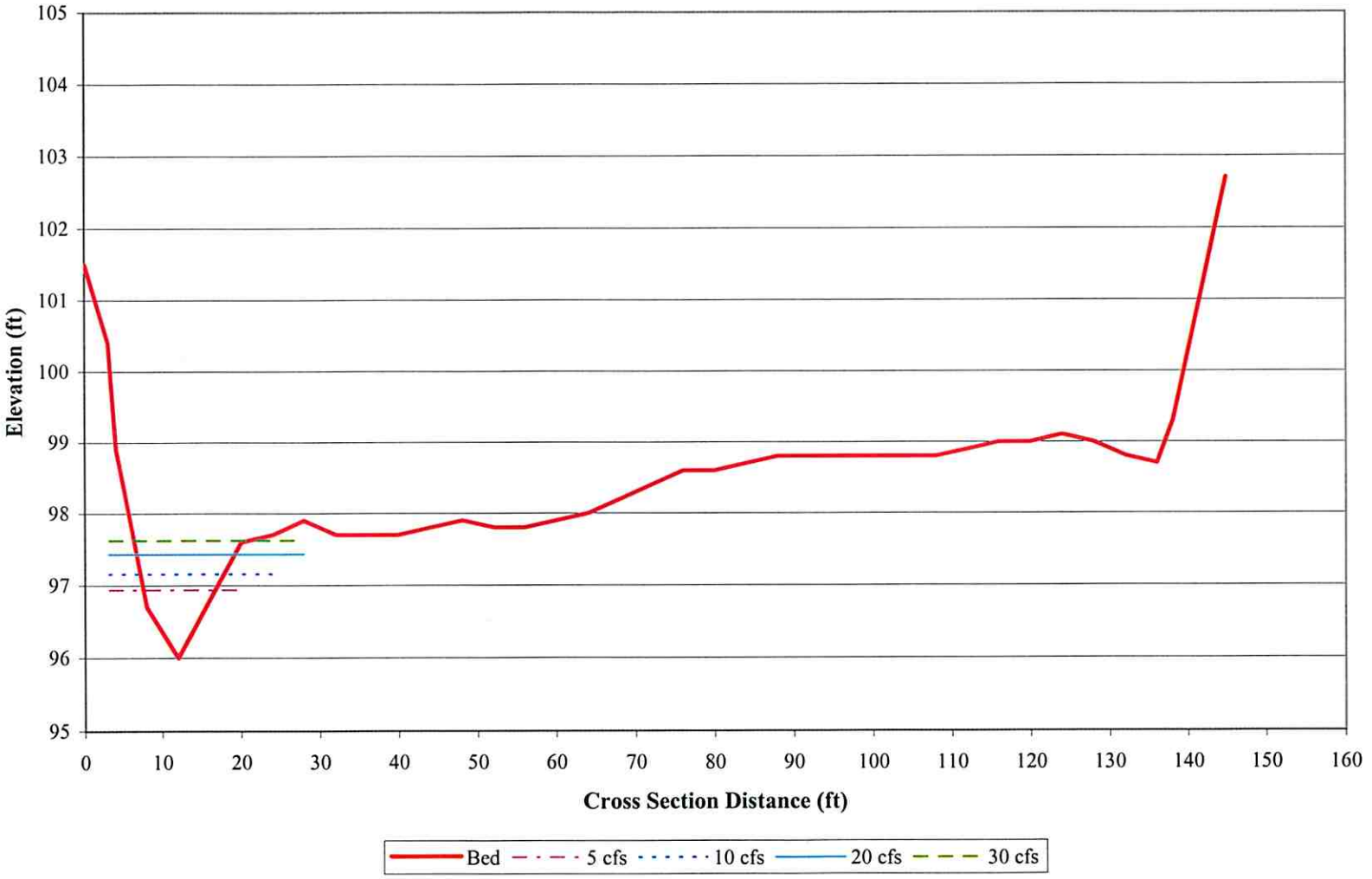
South Platte at Franklin St. Bed Profile, Water Surface Elevation - Riffle



November 17, 2006

Preliminary Results – Subject to Revision

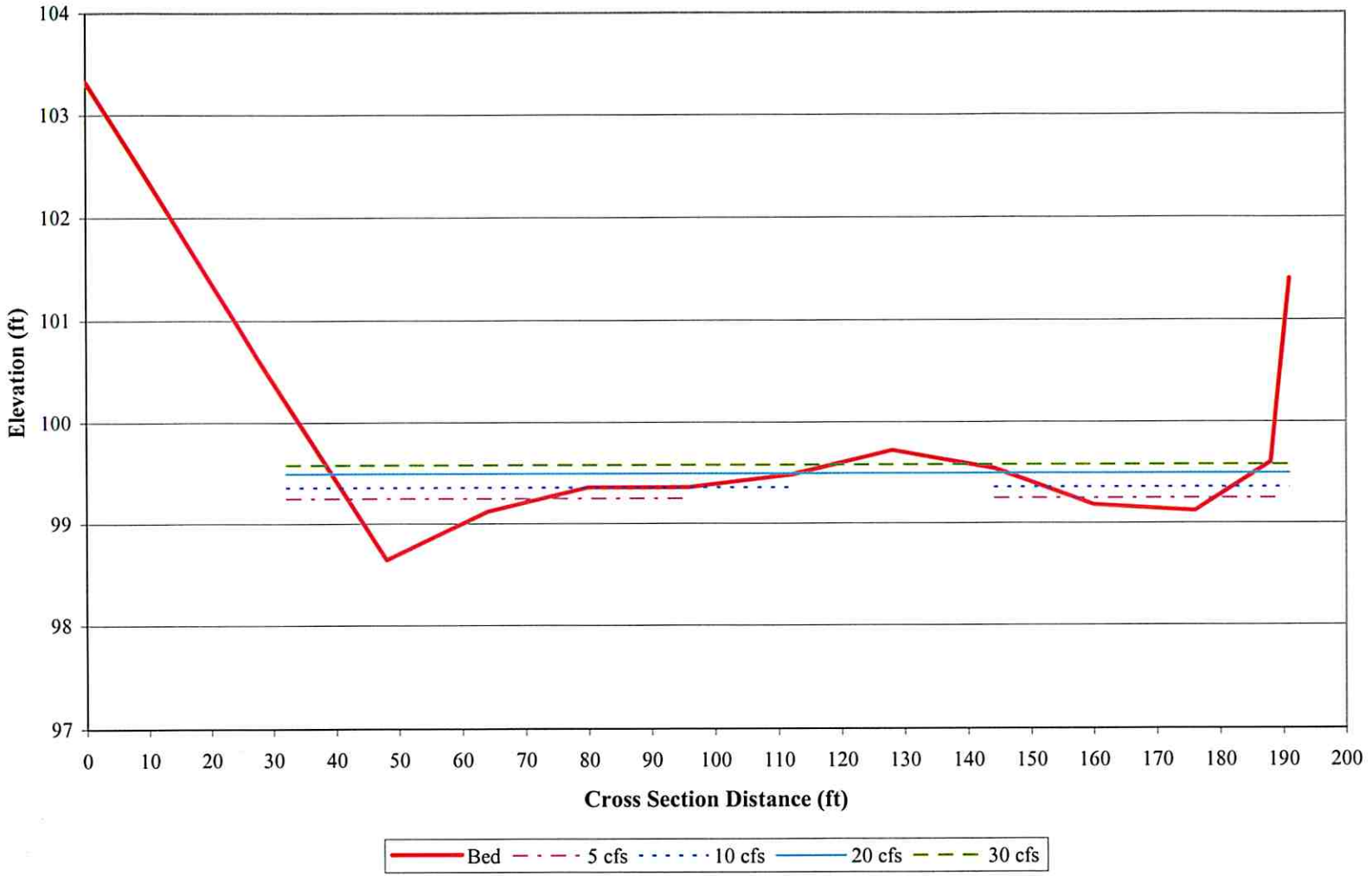
South Platte at Franklin St. Bed Profile, Water Surface Elevation - Run



November 17, 2006

Preliminary Results – Subject to Revision

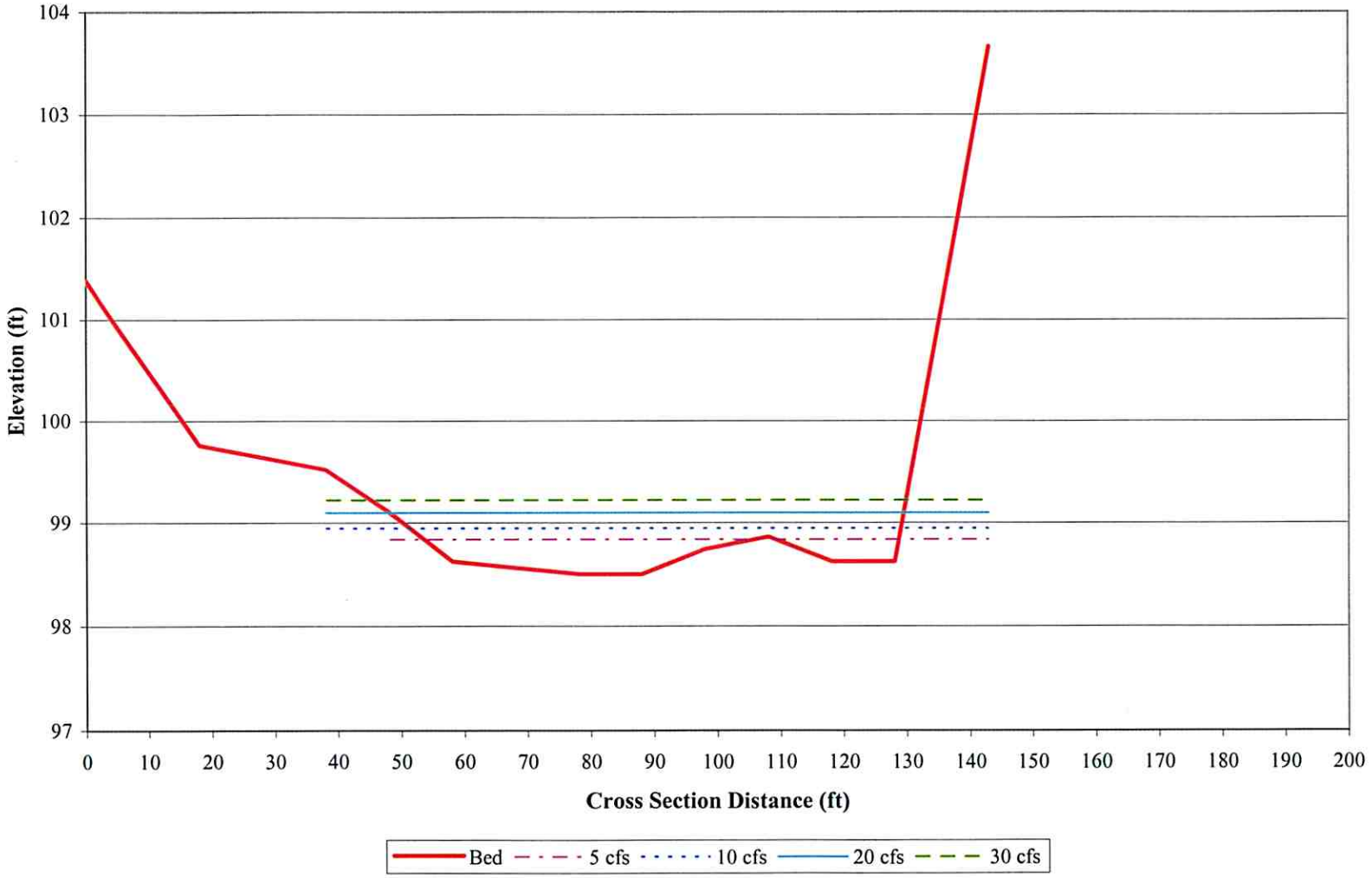
South Platte Downstream Bed Profile, Water Surface Elevation - Riffle



November 17, 2006

Preliminary Results – Subject to Revision

South Platte Downstream Bed Profile, Water Surface Elevation - Run



November 17, 2006

Preliminary Results – Subject to Revision

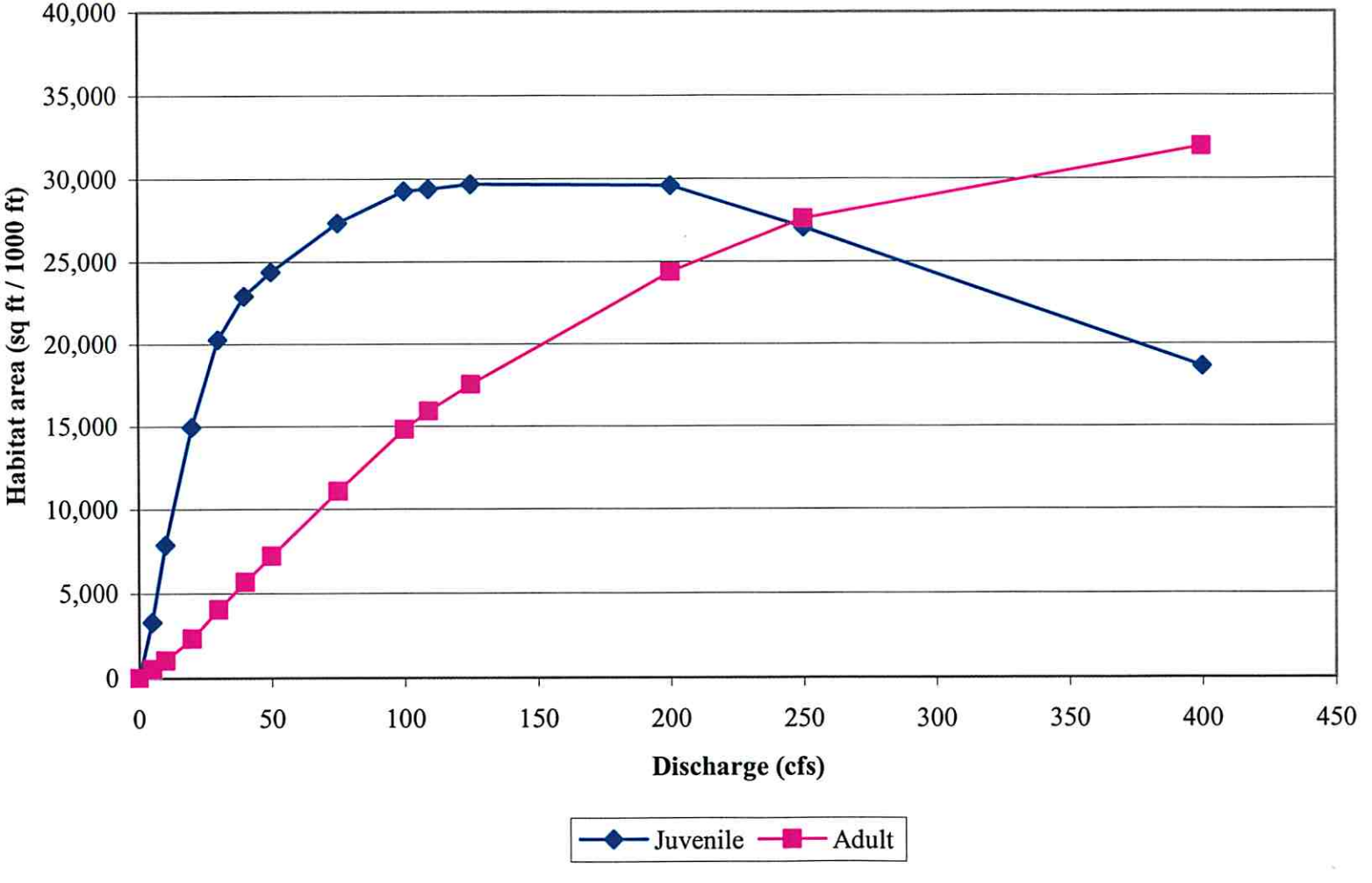
Attachment C

Habitat Flow Relationships

Habitat flow relationships

Southern reaches

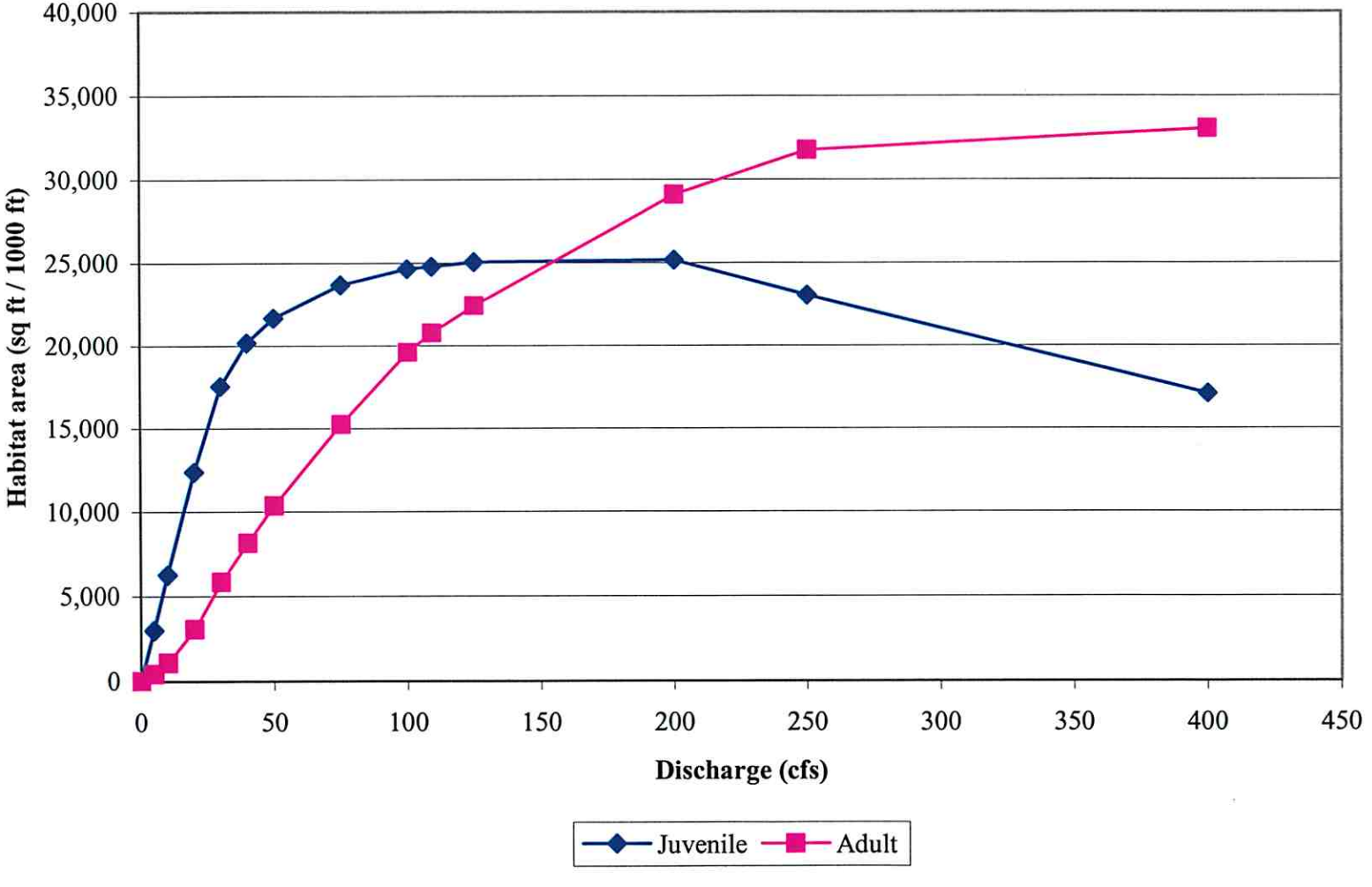
Rainbow Trout Habitat versus Discharge, S. Platte Littleton



November 17, 2006

Preliminary Results – Subject to Revision

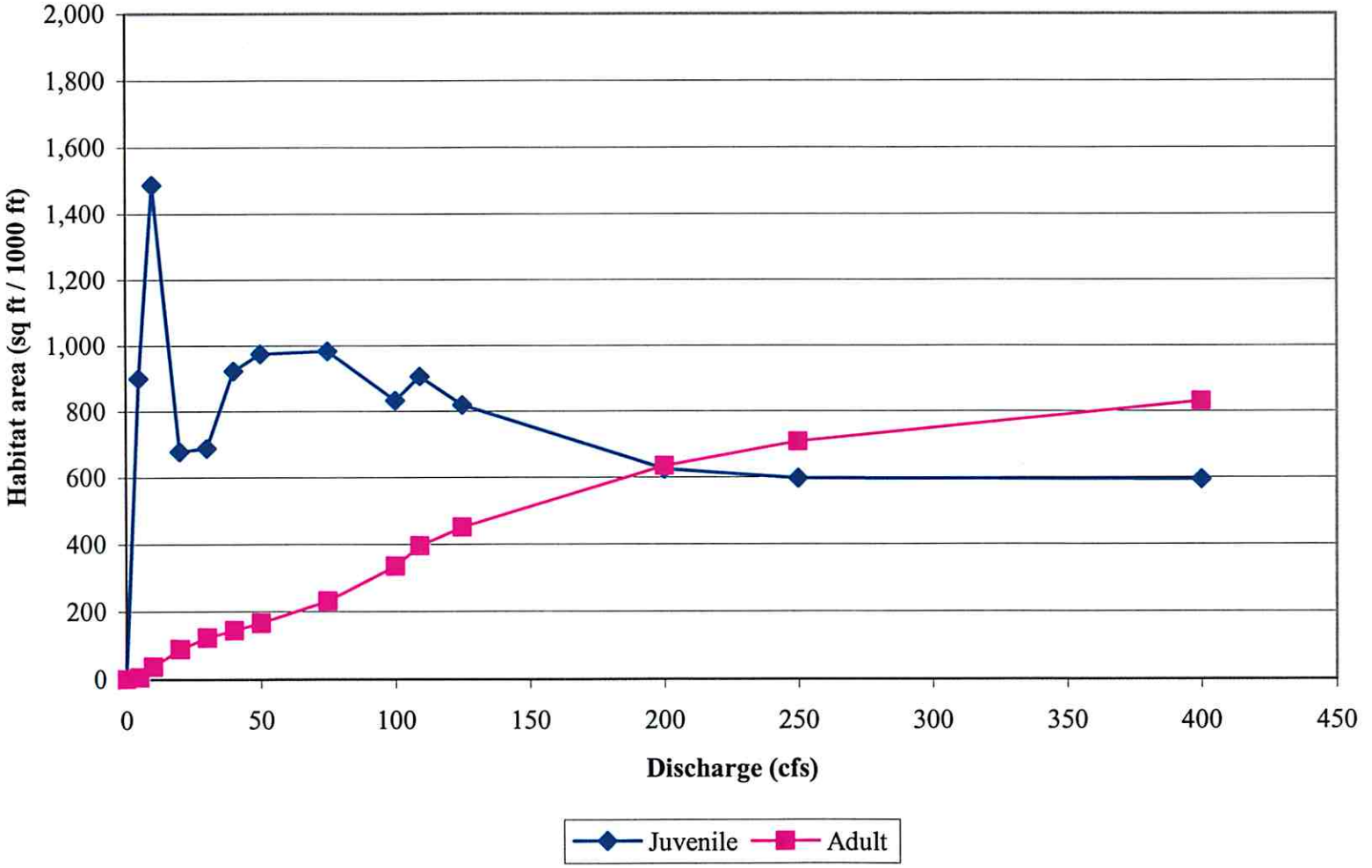
Brown Trout Habitat versus Discharge, S. Platte Littleton



November 17, 2006

Preliminary Results – Subject to Revision

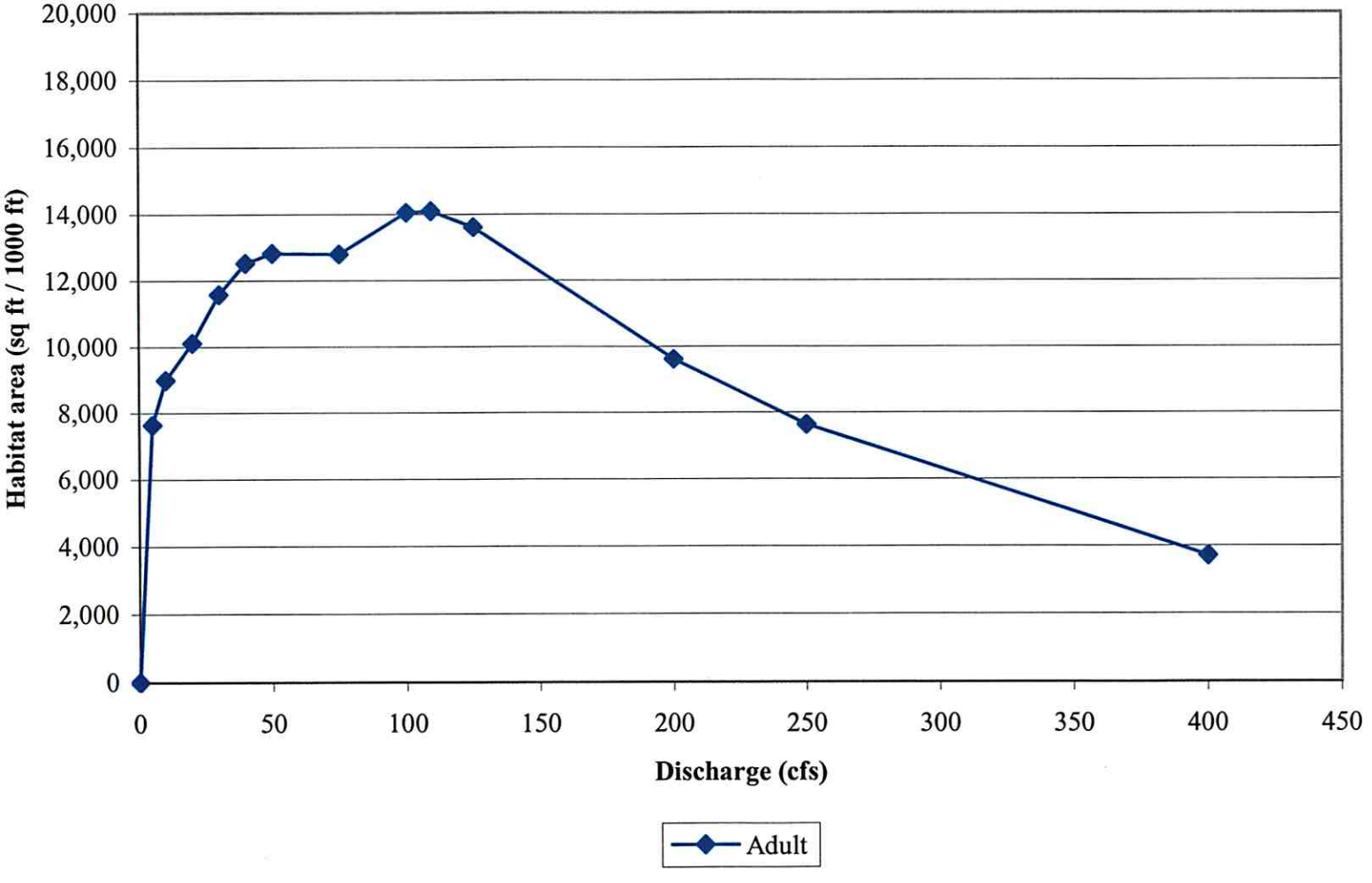
Channel Catfish Habitat versus Discharge, S. Platte Littleton



November 17, 2006

Preliminary Results – Subject to Revision

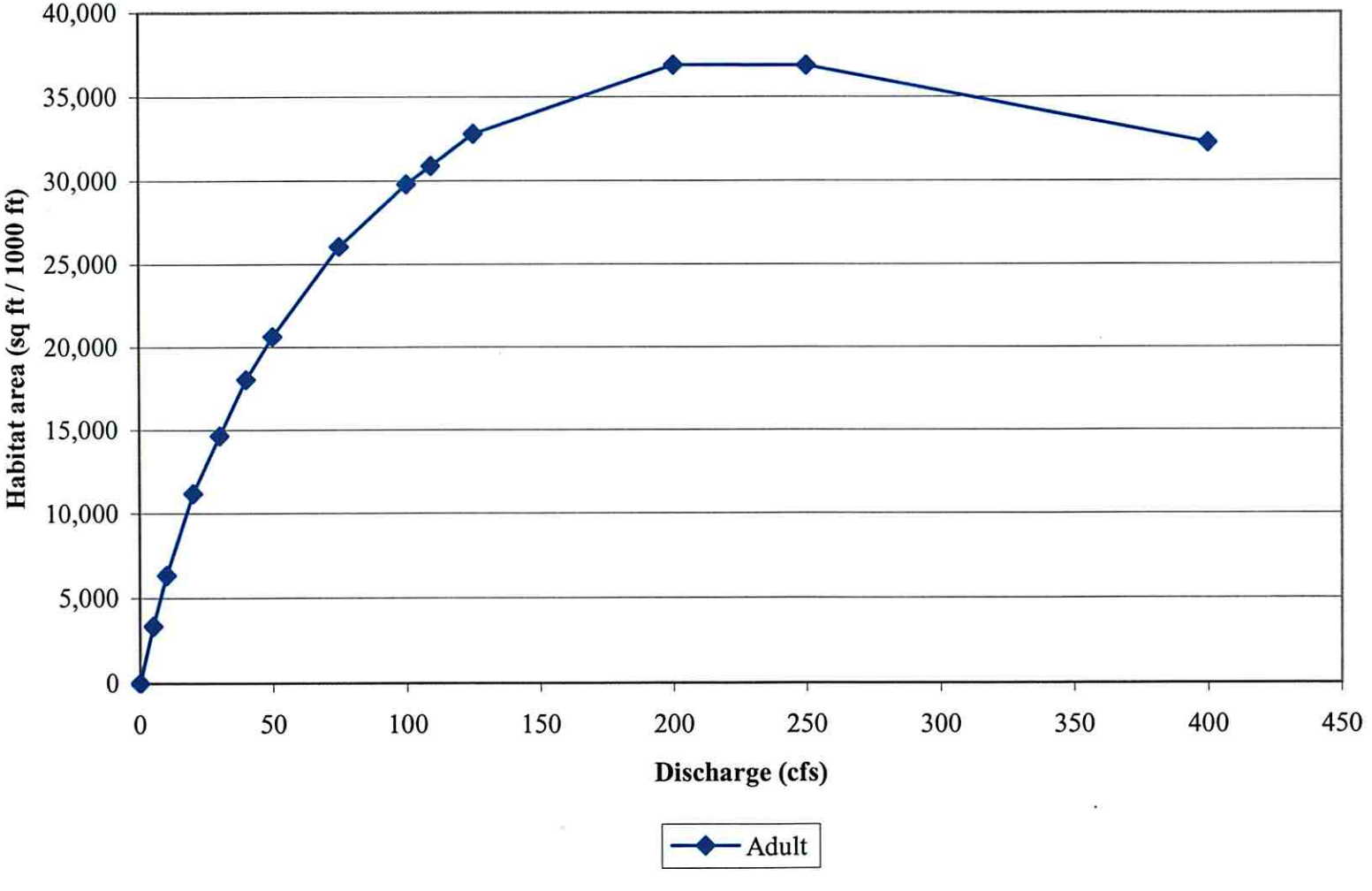
Sand Shiner Habitat versus Discharge, S. Platte Littleton



November 17, 2006

Preliminary Results – Subject to Revision

Longnose Dace Habitat versus Discharge, S. Platte Littleton



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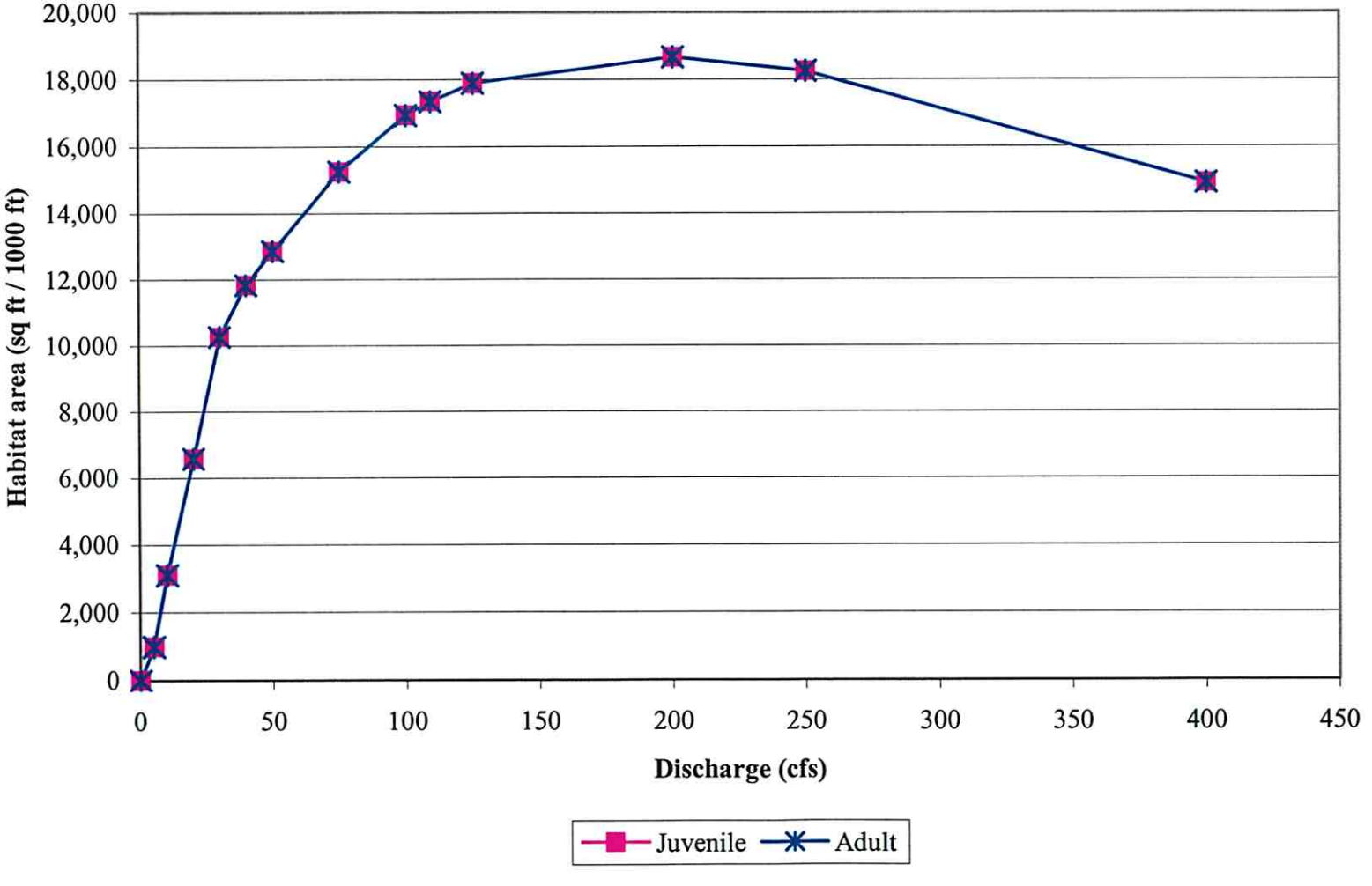
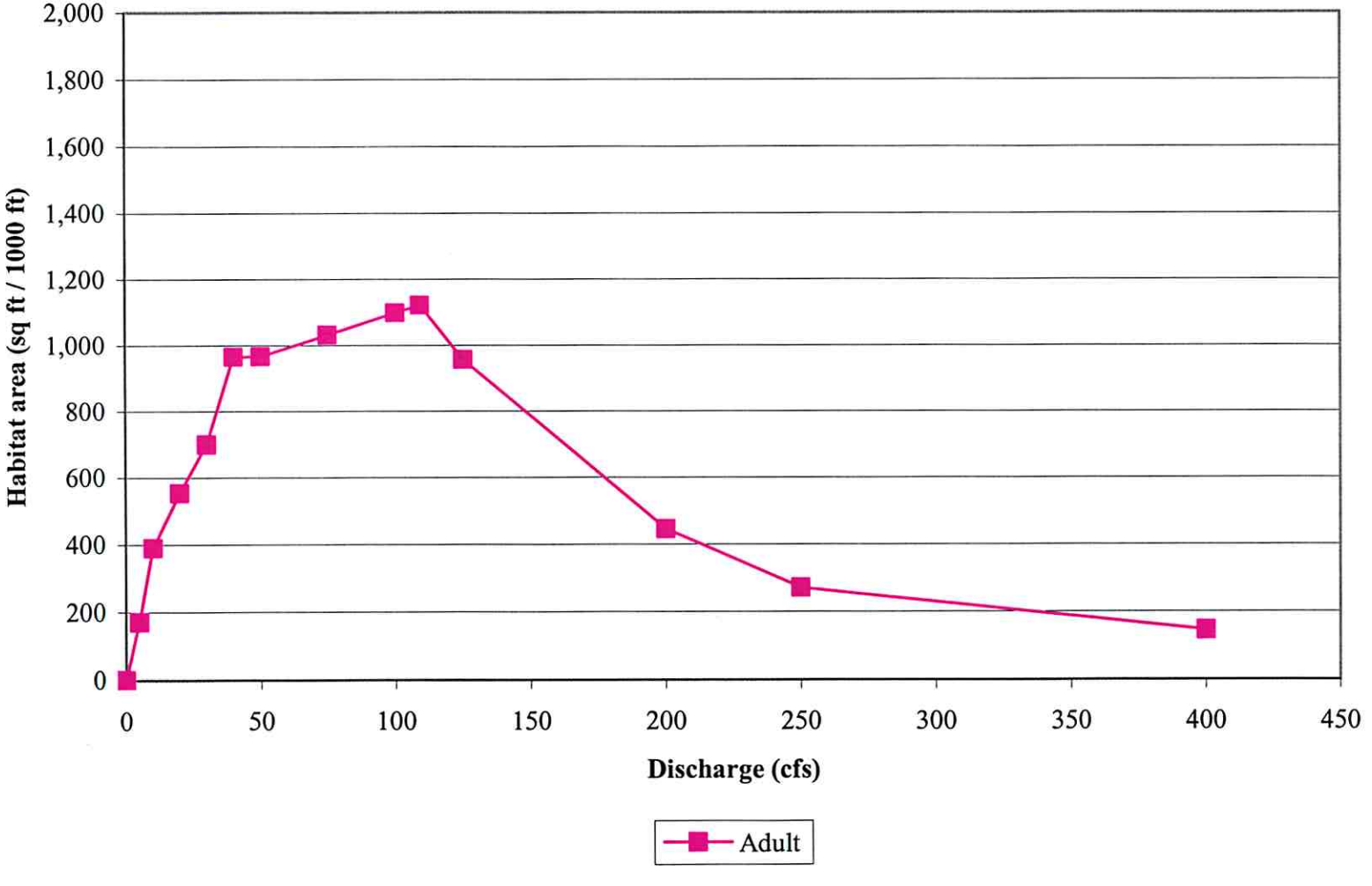
Preliminary Results – Subject to Revision

White Sucker Habitat versus Discharge, S. Platte Littleton



Common Carp Habitat versus Discharge, S. Platte Littleton



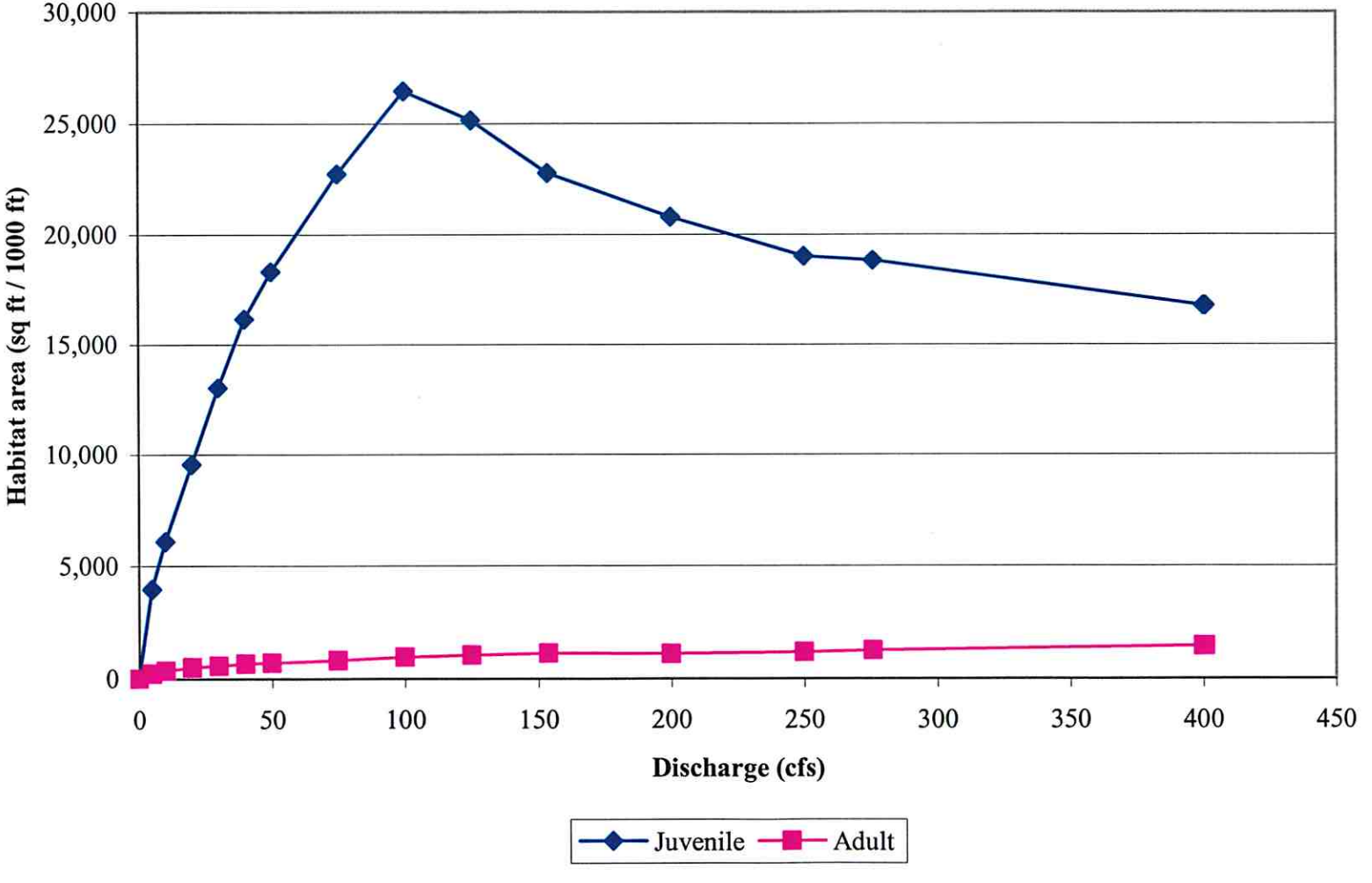
November 17, 2006

Preliminary Results – Subject to Revision

Habitat flow relationships

Middle reaches

Channel Catfish Habitat versus Discharge, S. Platte Franklin St.



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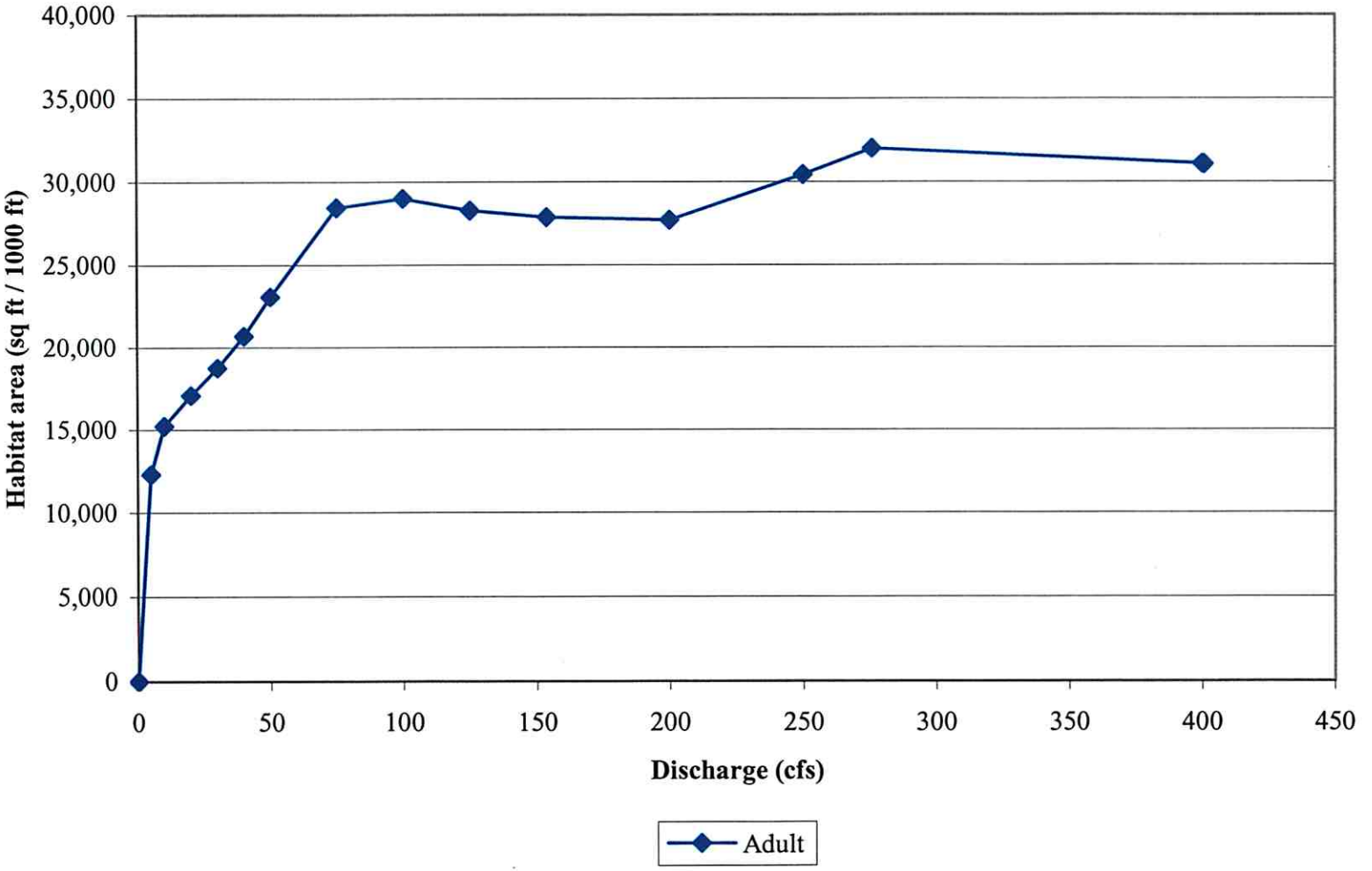
Preliminary Results – Subject to Revision

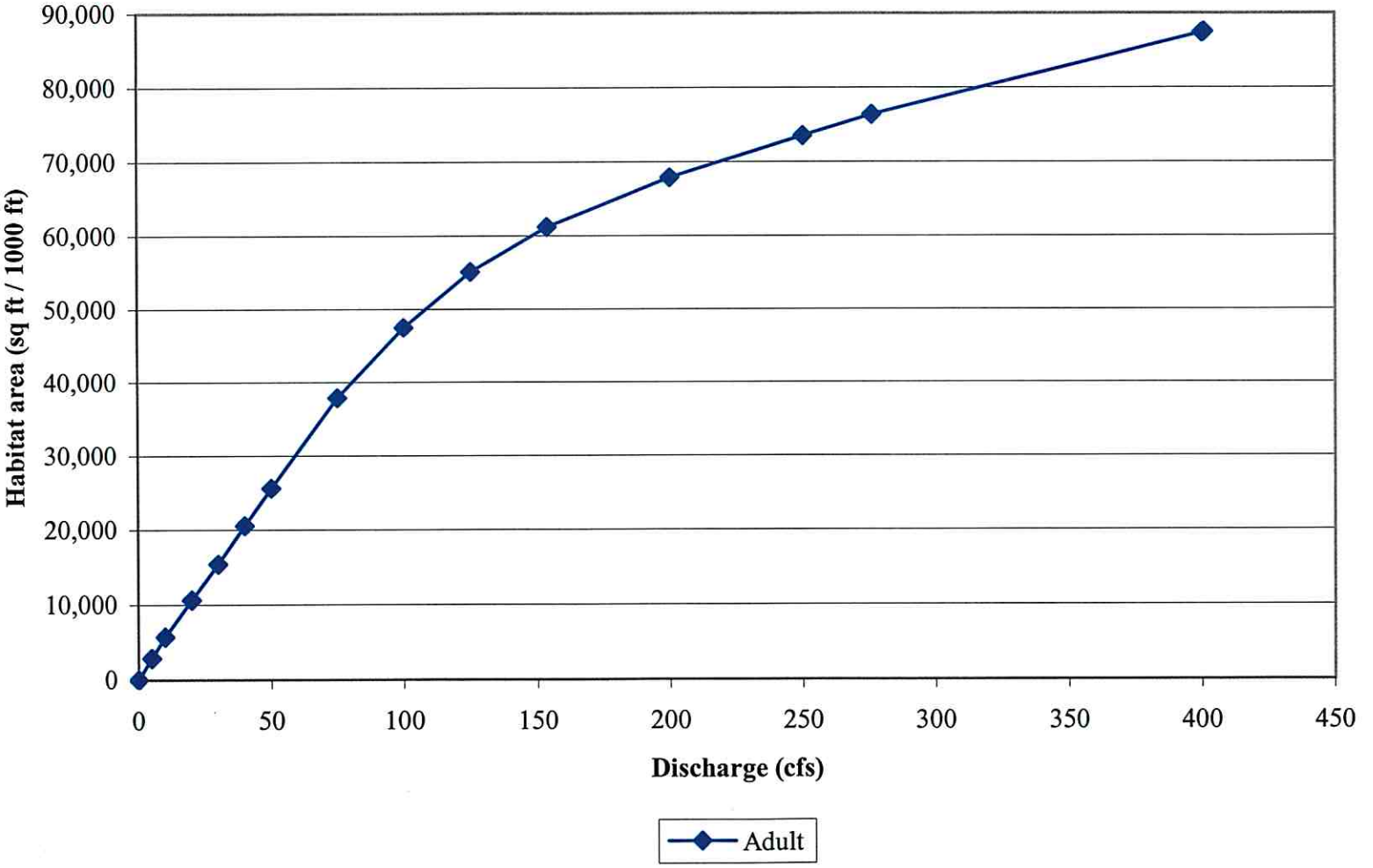
Sand Shiner Habitat versus Discharge, S. Platte Franklin St.



November 17, 2006

Preliminary Results – Subject to Revision

Longnose Dace Habitat versus Discharge, S. Platte Franklin St.



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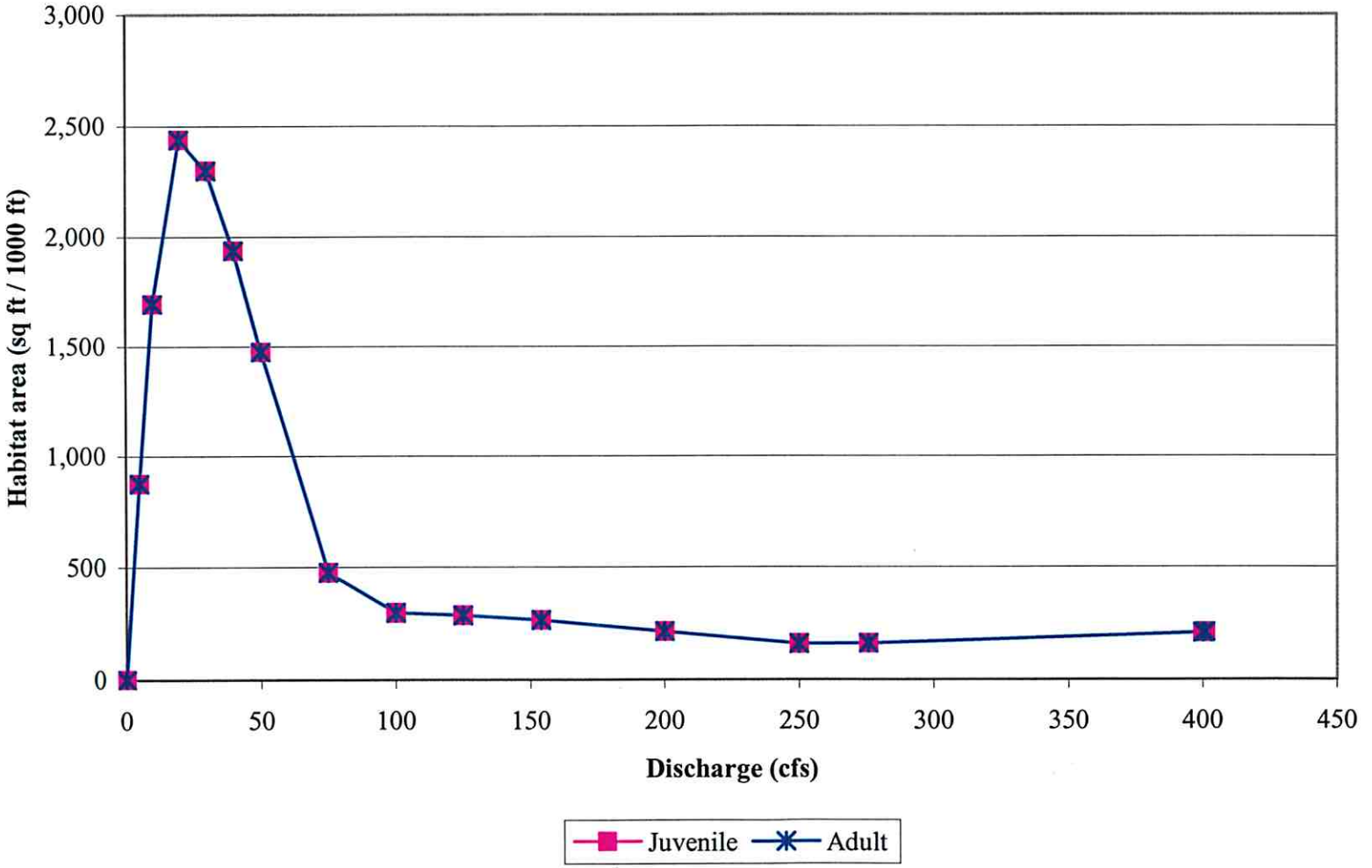
Preliminary Results – Subject to Revision

White Sucker Habitat versus Discharge, S. Platte Franklin St.



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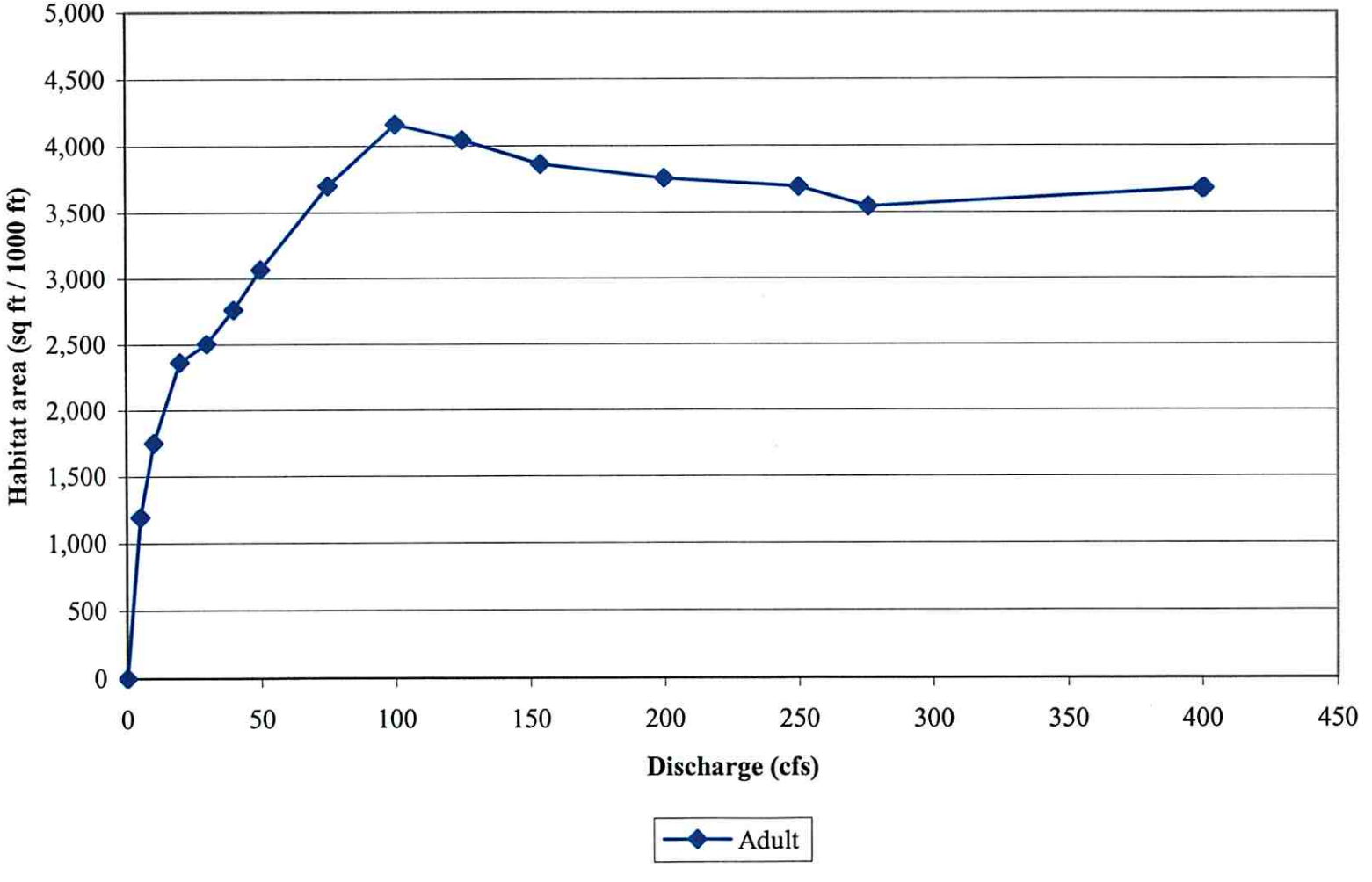
Preliminary Results – Subject to Revision

Common Carp Habitat versus Discharge, S. Platte Franklin St.



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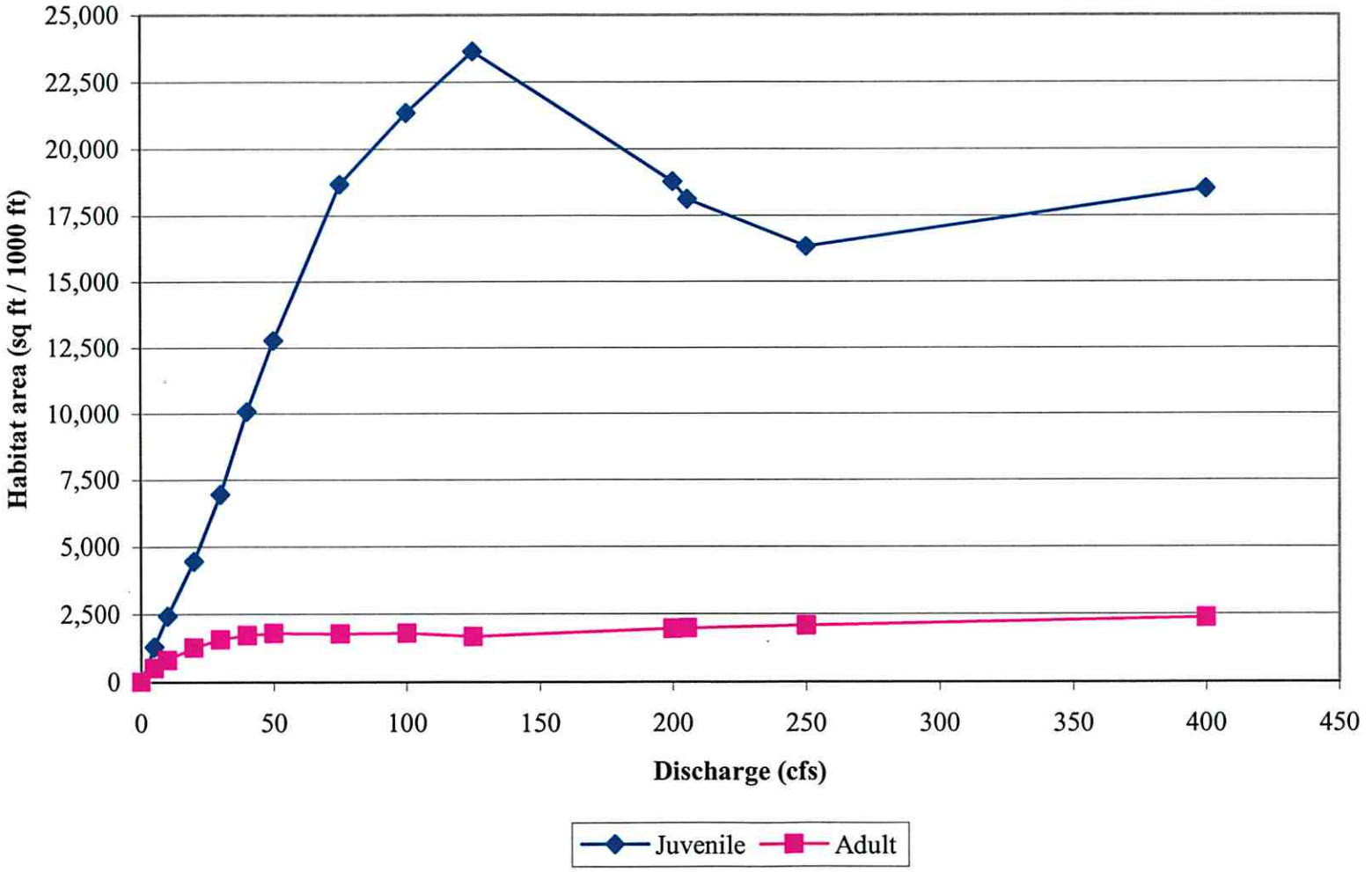
Preliminary Results – Subject to Revision

Habitat flow relationships

Northeastern reaches

Channel Catfish Habitat versus Discharge, S. Platte Downstream



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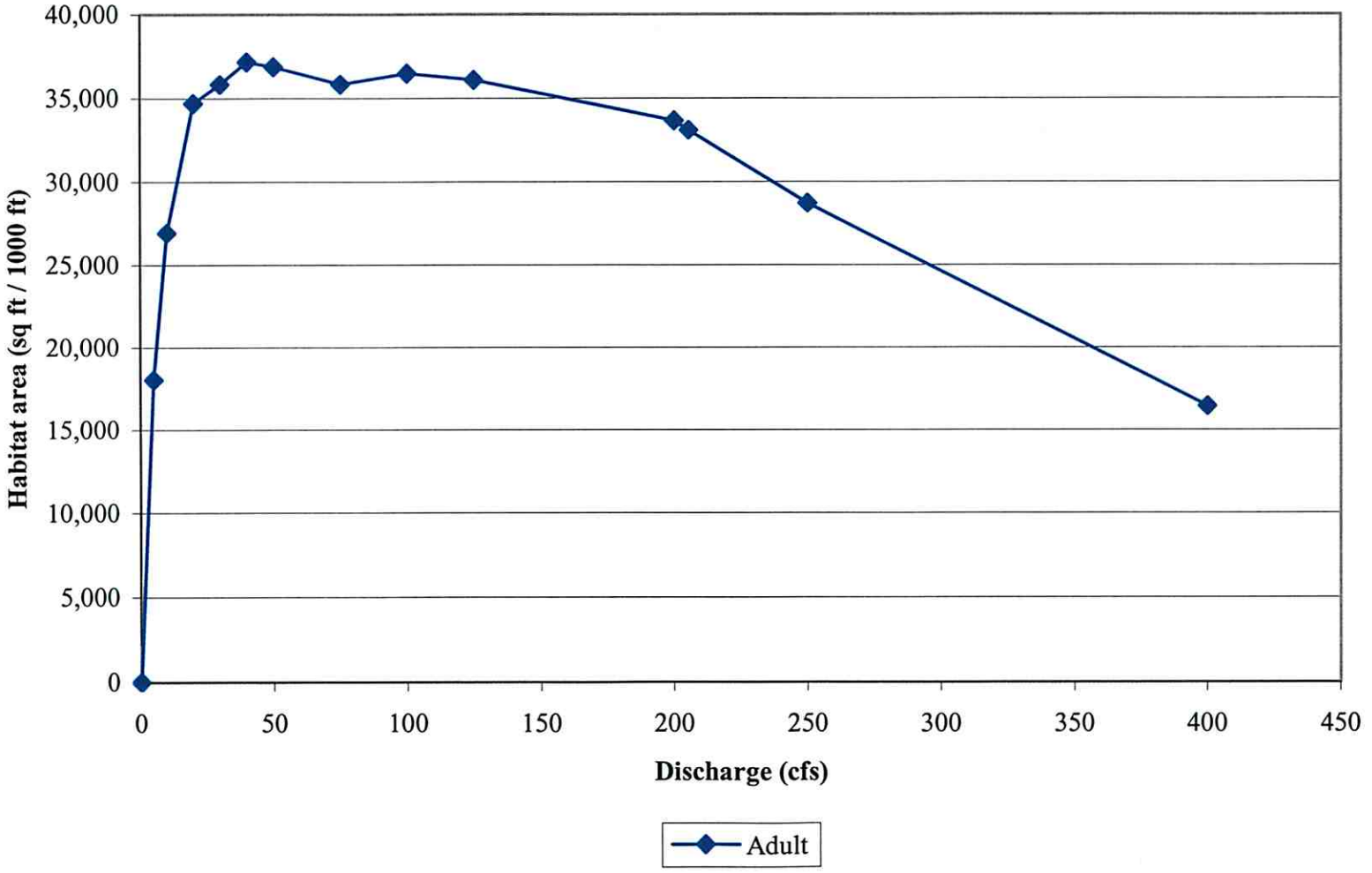
Preliminary Results – Subject to Revision

Sand Shiner Habitat versus Discharge, S. Platte Downstream



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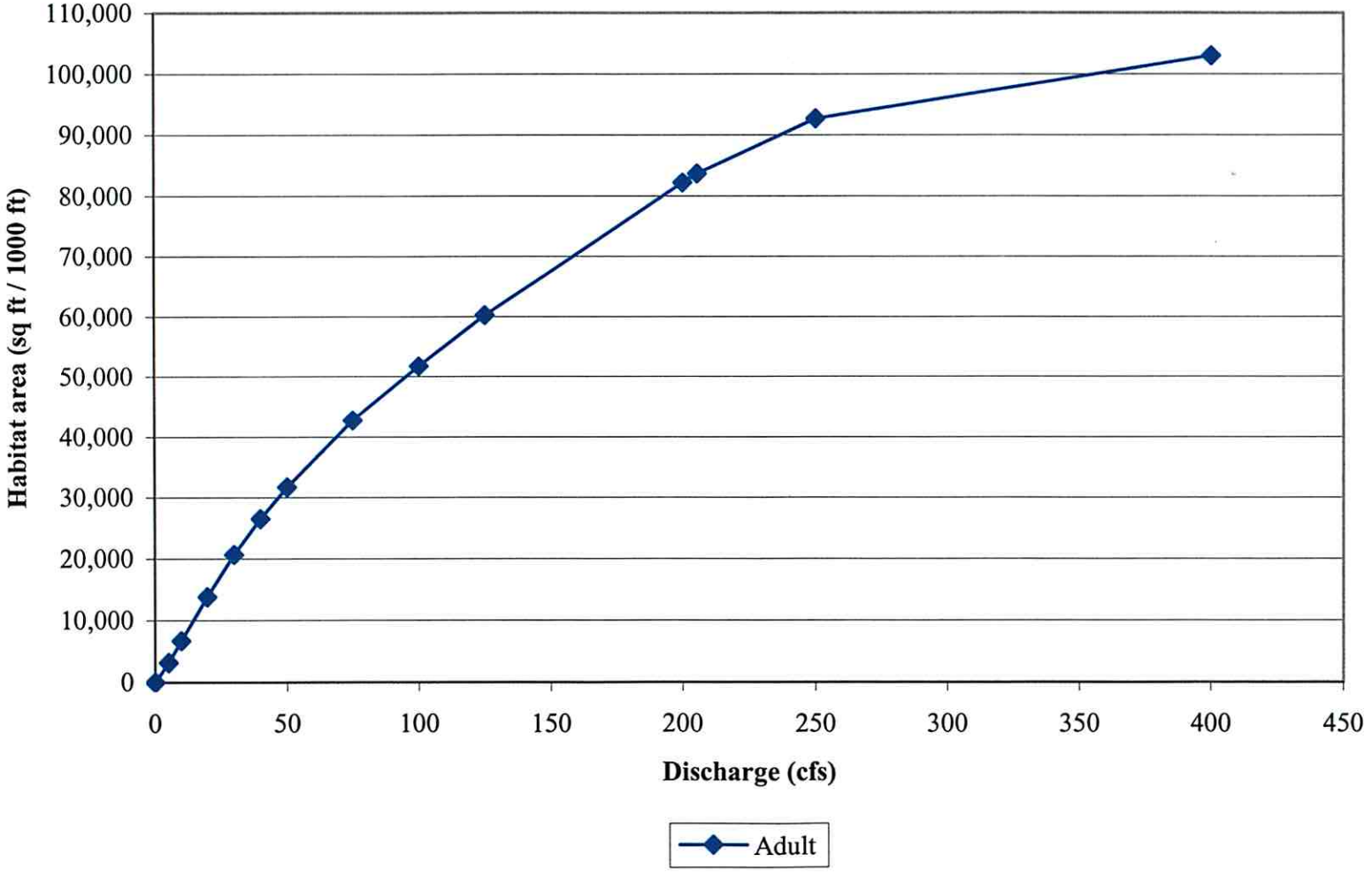
Preliminary Results – Subject to Revision

Longnose Dace Habitat versus Discharge, S. Platte Downstream



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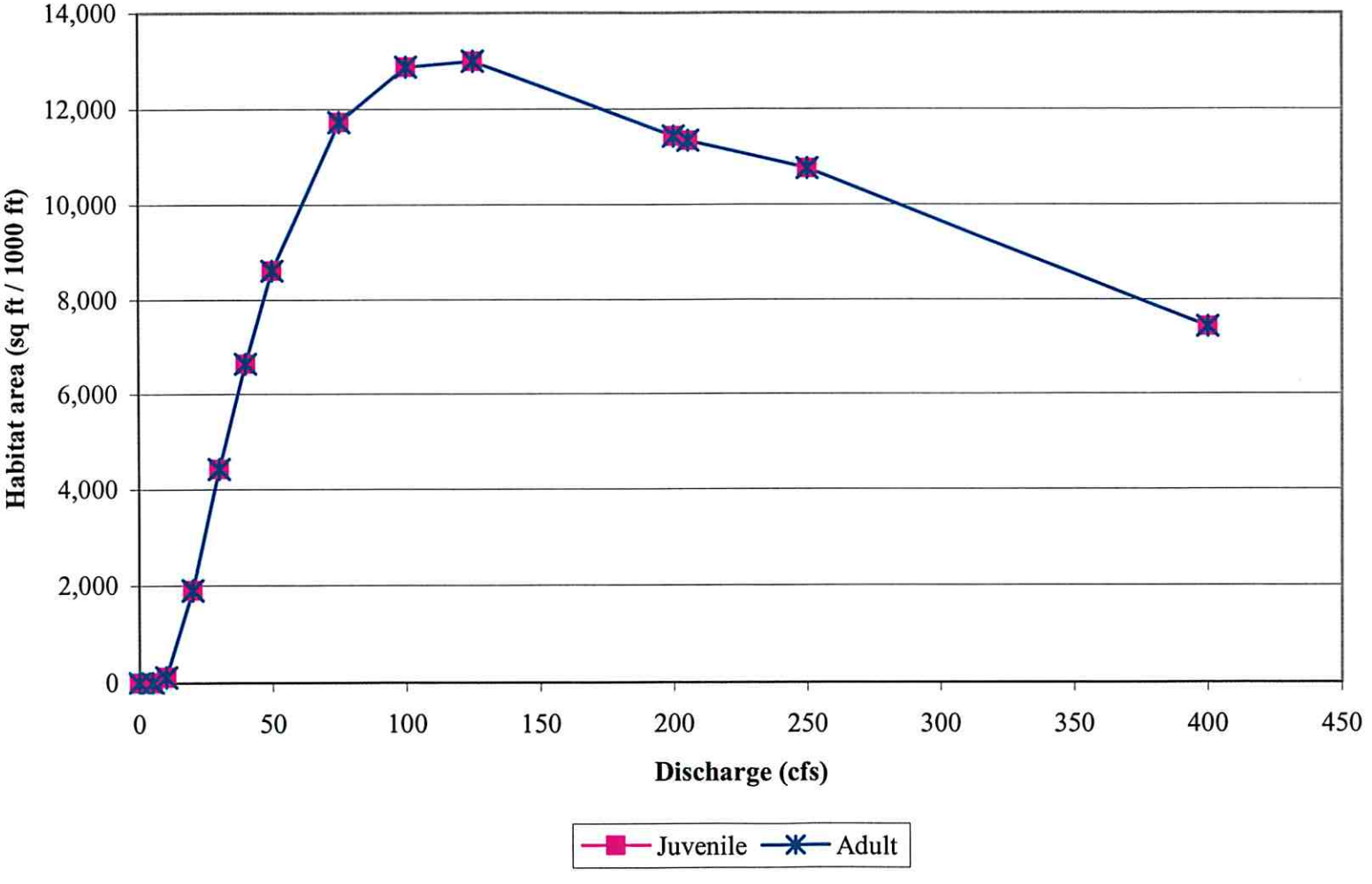
Preliminary Results – Subject to Revision

White Sucker Habitat versus Discharge, S. Platte Downstream



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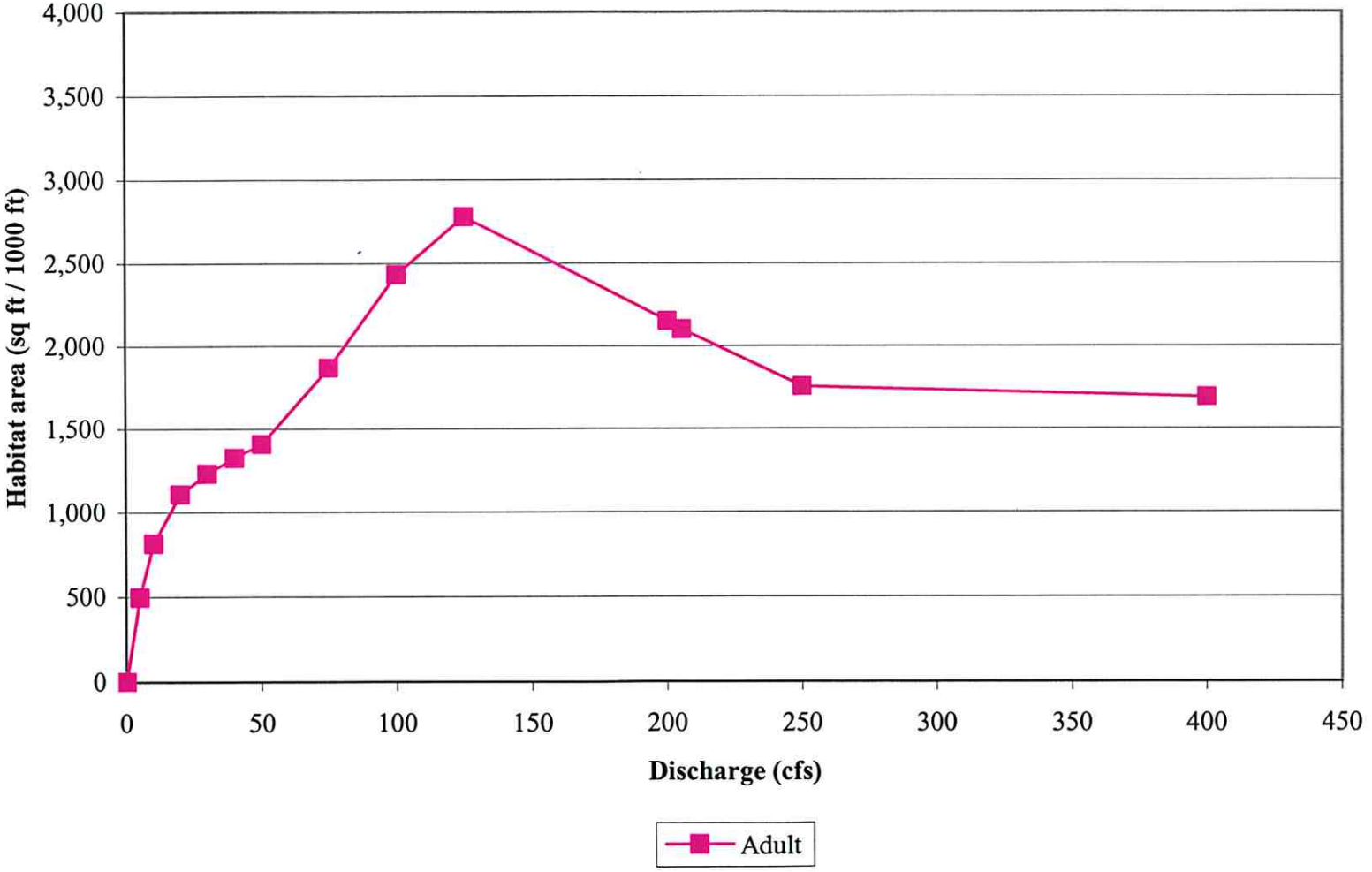
Preliminary Results – Subject to Revision

Common Carp Habitat versus Discharge, S. Platte Downstream



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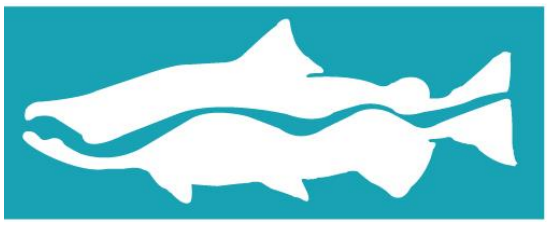

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