INDIAN CREEK/BLUE RIVER FATE AND TRANSPORT STUDY FINAL REPORT

Prepared for

U.S. Department of Energy

Kansas City Plant

Operated by Honeywell Federal Manufacturing & Technology

Prepared by

Anchor QEA, LLC

290 Elwood Davis Road, Suite 340

Liverpool, New York 13088

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	micrograms per liter
µm	micrometers
AICO	Abandoned Indian Creek Outfall
BFC	Bannister Federal Complex
BMP	best management practice
BSAF	biota-sediment accumulation factor
cfs	cubic feet per second
Cl/BP	chlorines per biphenyl
cm	centimeters
CSM	conceptual site model
D_{50}	median particle diameter
D_{90}	90^{th} percentile particle diameter
DEM	Digital Elevation Model
DOE	U.S. Department of Energy
DSR	Data Summary Report
EFDC	Environmental Fluid Dynamics Code
FEMA	Federal Emergency Management Agency
FIS	flood insurance study
f_{oc}	fraction organic carbon
g/cm^3	grams per cubic centimeter
g/d	grams per day
GBA	George Butler Associates
gpm	gallons per minute
GSA	General Services Administration
HSPF	Hydrologic Simulation Program-Fortran
k_f	porewater exchange mass transfer coefficient
km	kilometers
km^2	square kilometers
K_{oc}	organic carbon partition coefficient

K_{ow}	octanol-water partition coefficient
LID	Low-impact Development
LiDAR	Light Detection and Ranging
m	meters
m/km	meters per kilometer
MDNR	Missouri Department of Natural Resources
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MHWMF	Missouri Hazardous Waste Management Facility
MSOP	Missouri State Operating Permit
ng/L	nanograms per liter
NNSA	National Nuclear Security Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
POC	particulate organic carbon
POTW	Publicly Owned Treatment Work
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SAP	Sampling and Analysis Plan
SPMD	semipermeable membrane device
SWMM	Storm Water Management Model
TSS	total suspended solids
USDA	United States Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
Work Plan	*Fate and Transport Study Work Plan*

1 INTRODUCTION

This report pertains to the U.S. Department of Energy's (DOE's) Kansas City Plant, which is located at the Bannister Federal Complex (BFC) in Kansas City, Missouri, and managed by Honeywell Federal Manufacturing & Technologies, LLC. Anchor QEA, LLC, has developed this report on behalf of the BFC to document a polychlorinated biphenyl (PCB) Fate and Transport Study that was conducted within two surface water bodies in the vicinity of the BFC: Indian Creek and Blue River. This study was conducted in accordance with the *Fate and Transport Study Work Plan* (Work Plan; Anchor QEA 2013a), which describes a preliminary conceptual site model (CSM) of PCB fate, transport, and bioaccumulation at the site, and the approach to the second phase of the study, which included quantitative mathematical modeling and additional sampling/analysis to refine the CSM and support the modeling effort. The Work Plan was approved by the Missouri Department of Natural Resources (MDNR) in June 2013.

The PCB Fate and Transport Study was conducted as required under recent modifications to the BFC's Missouri Hazardous Waste Management Facility (MHWMF) Permit #MO 9890010524 between the DOE National Nuclear Security Administration (NNSA), the General Services Administration (GSA), and MDNR. The permit requires a study that identifies and, to the extent possible, quantifies, the origin, fate, and transport of PCBs into and through the Indian Creek and Blue River ecosystems. Moreover, the above permit requires that this study identify areas of expected PCB accumulation in sediment and fish tissue as well as other sinks within the system. Modifications to the MHWMF Permit were finalized August 24, 2012.

This report provides a brief history of PCB use and associated contamination of the BFC along with a summary of the myriad efforts to reduce PCB discharges from the facility's stormwater outfalls. In the Work Plan, a detailed analysis of the stormwater, water column, sediment, and fish PCB data collected prior to the Fate and Transport Study was conducted to inform the development of a preliminary CSM of the system. This report builds on that preliminary CSM by incorporating additional data collected during the Fate and Transport Study. Finally, this report summarizes the quantitative tools (i.e., models) and methodologies that were developed and applied to evaluate the significance of BFC stormwater inputs on sediment and fish PCB concentrations in Indian Creek and Blue River, and to evaluate changes in fish PCB concentrations resulting from potential PCB load reduction scenarios.

1.1 Background

1.1.1 Kansas City Plant Site Description and History

PCBs were used at the BFC as a heat transfer fluid from the mid-1960s until 1974. A number of documented spills occurred during this period; these historical spills have been investigated and corrective actions to remove or contain and prevent the off-site migration of PCB contamination have been implemented under previous versions of the MHWMF Permit and the BFC's Missouri State Operating Permit (MSOP; permit #MO 0004865). In 1982, the MDNR reissued the MSOP for the BFC limiting the discharge of PCBs from the plant stormwater outfalls to 1 microgram per liter (µg/L). In November 1999, the MSOP was reissued with an interim PCB discharge limit of 1.0 µg/L, and a final limit of 0.5 µg/L that became effective in November 2002. Compliance with the PCB discharge limit was determined based on weekly grab sampling as opposed to the monthly average approach that was implemented in previous versions of the MSOP. Over the last several years, weekly sampling of the BFC's four permitted stormwater outfalls (at the compliance locations specified in the State Operating Permit) has not detected PCBs above the analytical detection limit of 0.5 µg/L[1]; however, periodic bioaccumulation studies (conducted initially by the MDNR in the late 1980s, and regular fish monitoring conducted since 1991 by Oak Ridge National Laboratory [ORNL] on behalf of the BFC [Ashwood et. al 1993; Ashwood and Peterson 1994; Ashwood 1998; Peterson et. al. 2003; Peterson et. al. 2006; Peterson et. al.

[1] An additional monitoring location was added at the Outfall 002 flap gate under the MHWMF Permit at the request of MDNR MHWMF Permit program personnel. Even though there may be no discharge from Outfall 002, samples from the flap gate location are, nevertheless, collected twice per month (under certain creek flow conditions, surface water from Indian Creek backs up into the Outfall 002 raceway and, therefore, water is available for sampling at the flap gate location). Sample results from the Outfall 002 flap gate location have historically periodically detected PCBs. Between 2011 and 2015, 15 out of 122 samples (or 12%) collected at this location had detectable levels of PCBs exceeding 0.5 µg/L (ranging from 0.5 to 2.1 µg/L). However, sample results derived from the flap gate location are not representative of discharges from Outfall 002. During periods of no discharge, PCB results at the flap gate location are affected by sediment entrainment. The Outfall 002 raceway accumulates sediments discharged from the Outfall 002 system that contain low levels of PCBs—entraining even small amounts of these sediments in the sample can impact the aqueous PCB concentration measurements. The water is less than 1 foot deep in the raceway and the pickup tube on the sampler can be impacted by these sediments resulting in occasional detections of PCBs in the water sample collected at the flap gate location.

2008]) have identified the BFC as a source of PCB contamination to the local receiving streams (i.e., Indian Creek and Blue River). In addition, as evidenced by detectable levels of PCBs in biota upstream of the BFC, the presence of PCBs in fish near the BFC is at least partially due to other sources of PCBs in the watershed (DOE 2008). A number of best management practices (BMPs) designed to reduce the loading of PCBs conveyed within the plant stormwater have already been implemented (DOE 2003, 2012), as described in the following subsection.

1.1.2 Stormwater BMP Implementation History

A study conducted by George Butler Associates (GBA; 1989) provided detailed mapping, inspection results, and recommendations for repairs and improvements to the storm sewer system to reduce PCB loadings. This detailed analysis determined runoff curves and mapped the storm sewer piping system. Figure 1-1 provides a timeline of BMP implementation to date at the BFC. Many of the projects or practices were focused on: reducing infiltration and inflow of groundwater into the storm sewer system; resealing joints where storm sewers intersect catch basins, manholes, or other structures; adding continuous linings to existing storm sewers to seal pipe joints; and removing accumulated sediments (DOE 2003).

The MSOP re-issued in November 1999 contained a total residual chlorine limit. To comply with this limit, the BFC removed discharges of non-contact single pass cooling water (i.e., drinking water) that was historically used for equipment cooling purposes and discharged to the storm sewer system. Presently, the storm sewer system only receives storm event flow, limited flows associated with periodic testing of the fire protection system, and air conditioning condensate flows. As a result, base flow (i.e., non-storm event flow) decreased in the four regulated outfalls from approximately 100 gallons per minute (gpm) to 5 to 10 gpm. The significant decrease in base flow facilitated the installation of the Outfall 002 re-route system, which diverts approximately 3 to 5 gpm of base flow in Outfall 002 to the groundwater treatment system. As a result, Outfall 002 only discharges during precipitation events. Because the pump system has additional capacity, storm event-related flows of up to approximately 40 gpm are also captured and treated by the groundwater treatment system.

1.2 Fate and Transport Study Objectives

The principal objective of this study was to quantitatively assess the origin, fate, transport, and bioaccumulation of PCBs within the Indian Creek/Blue River system. Corollary objectives include the following:

- Evaluate the relative significance of the various sources of PCBs to the fish in Indian Creek and Blue River (i.e., how important are the ongoing loads from the permitted BFC outfalls relative to other sources of PCBs to fish?).
- Develop a means of estimating future concentrations in sediment and fish under current loading conditions (i.e., are PCB concentrations in fish anticipated to decline in the future if external PCB loads to the system continue at contemporary levels [which reflect numerous BMPs that have been implemented at the site]?).
- Evaluate whether additional BMPs can be reasonably implemented at the BFC to further reduce PCBs in stormwater.
- If additional BMPs can be implemented, predict whether these reductions will have any meaningful impact on sediments and fish.

1.3 Report Organization

The remainder of this report is organized as follows:

- Section 2 presents the refined CSM of PCB fate and transport and bioaccumulation for the system. This conceptual model builds on the preliminary CSM presented in Section 2 of the Work Plan using additional data collected and quantitative modeling performed as part of the Fate and Transport Study.
- Section 3 summarizes the mathematical modeling that was conducted to quantitatively assess the fate, transport, and bioaccumulation of PCBs within Indian Creek and Blue River. Specifically, this section provides a description of the models used and a summary of the work performed to develop, calibrate, and validate the models. This section also summarizes the results of diagnostic and prognostic (i.e., predictive) evaluations conducted using the calibrated model.
- Sections 4 and 5 present a summary of conclusions and recommendations, respectively, based on the results of the Fate and Transport Study.

Appendix A contains a Data Summary Report (DSR) that summarizes the data collected as part of the Fate and Transport Study. As described in the Work Plan and the Sampling and Analysis Plan (SAP; Anchor QEA 2013b), these data were collected to: 1) further the development of a conceptual understanding of PCB sources, fate, transport, and bioaccumulation within the system; 2) support mathematical model development and application; and 3) develop recommendations regarding additional BMPs that could be implemented to further reduce stormwater PCB loadings to the receiving waters (if determined to be necessary). Attachment 1 to Appendix A contains the laboratory data reports, Attachment 2 contains four Data Validation Reports summarizing the U.S. Environmental Protection Agency (USEPA) Stage 2A validation of the Fate and Transport Study data, and Attachment 3 contains electronic copies of the final project analytical database and field data files.

2 REFINED CONCEPTUAL SITE MODEL

Numerous environmental datasets have been collected by the BFC and others over the last several decades. These datasets, including stormwater, surface water, sediment, and fish tissue analytical data, were compiled and reviewed collectively in order to formulate a preliminary CSM of PCB fate and transport at the BFC and in Indian Creek and Blue River. This preliminary CSM was presented in the Work Plan (Anchor QEA 2013a). Additional site data, collected as part of the Fate and Transport Study, were used to refine the CSM as described below.

2.1 Site Setting

2.1.1 BFC

2.1.1.1 Drainage Area and Land Use

The BFC drainage area is approximately 320 acres (Figure 2-1). Site drainage to the Indian Creek/Blue River system is divided into eight major subbasins (numeric Outfalls 001, 002, 003, and 004 that drain the majority of the plant portion of the site, and alpha Outfalls B, C, D, and F that drain areas that exclude the building footprint; Figure 2-1). The area draining to the four numeric outfalls is predominantly impervious (ranging from 60% in Basin 001 to nearly 100% in Basins 003 and 004) and conveys stormwater runoff from roof and pavement areas—most of the remaining pervious area is grass cover within Basin 001. The area draining the four alpha outfalls ranges from 100% impervious in Basin B to 95% pervious in Basin F.

2.1.1.2 Storm Sewer System

Stormwater leading to the four numeric outfalls at the BFC is conveyed through an extensive network of storm sewer systems that discharge to Indian Creek (Outfalls 002, 003, and 004) and Boone Creek (Outfall 001). A comprehensive study of the water supply, sanitary sewer, and storm sewers at the BFC was conducted in the late 1980s (GBA 1989). The mapping and assessment of the storm sewer system presented in the GBA study report formed the basis for most of the subsequent storm sewer investigations and BMP projects that were implemented at the BFC to reduce stormwater PCB discharges. The sewershed delineation and stormwater runoff volume estimation methods developed as part of the GBA study are currently being used by the BFC as the basis for developing estimates of stormwater runoff flows and volumes. The storm sewer pipe network contains a series of laterals that generally are aligned in an east to west direction, and are lettered from south to north (A to Z); collector lines are generally aligned north to south and connect roof drains to the lateral system. Trunk storm sewer lines, located outside of building footprints, collect flows from the laterals and convey stormwater runoff to the four major outfalls (Figure VI-6 of GBA 1989).

There are approximately 50,000 linear feet of storm sewer at the BFC (GBA 1989). Approximately 15,500 linear feet (30%) of piping in the system is undersized and cannot adequately convey flow from a storm event corresponding to a 25-year return interval (Table VI-22 of GBA 1989).

2.1.1.3 Stormwater PCBs

PCB contamination in stormwater at the BFC is largely the result of spills that occurred in 1969 and 1971 in the area of Department 26, which is located at the southeast corner of the main manufacturing building, and was generally used to manufacture plastic products. PCB oils were used as a heat transfer fluid and were an integral part of the plastic injection molding process. A spill occurred in 1969 when a pipe joint failed and 1,500 gallons of PCB oil were released to the adjacent gravel area. Approximately 900 gallons entered the stormwater system and were presumably discharged to Indian Creek via Outfall 002. The 1969 spill is the source of the contamination found in the Abandoned Indian Creek Outfall (AICO) area and the 95th Terrace soil contamination area (DOE 1999). Additionally, in 1971, approximately 1,100 gallons of PCB oil were spilled on site soils, some of which entered the stormwater system and were discharged to Indian Creek through the new segment of Outfall 002, which extended the 002 system from AICO to the present day Outfall 002 raceway.

Sampling of stormwater, soils, and groundwater for PCBs at the BFC began in the early 1980s. These initial samples led to a number of different studies, including the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) reports that were developed in the late 1980s and early 1990s, which subsequently led to various cleanup activities. In 1982, MDNR issued a National Pollutant Discharge Elimination System (NPDES) stormwater permit to the BFC prohibiting discharge of PCBs; the BFC conducts regular stormwater monitoring as part of its stormwater permit requirements. Stormwater samples were generally collected twice per month until 2000; since 2000, sampling has been conducted weekly.

To support the Fate and Transport Study, additional PCB data were collected from various locations within the storm sewer system during two rainfall events in 2014. This included collection of composite water samples and samples of sediment being transported in stormwater at twelve locations within the system (see Section 2.2.1 for details).

2.1.2 Indian Creek/Blue River

2.1.2.1 Environmental Setting

The BFC is bordered by Indian Creek to the south, Blue River to the east, and Boone Creek to the north (Figure 2-2). Indian Creek joins with Blue River southeast of the BFC. BFC Outfalls 002 and 003/004 discharge into Indian Creek, and Outfall 001 discharges into Boone Creek, which enters Blue River northeast of the BFC (Figure 2-2). Blue River ultimately discharges into the Missouri River approximately 27 kilometers (km) downstream from its confluence with Indian Creek.

Detailed descriptions of the Blue River watershed, including channel characteristics, morphology, and sediment characteristics, have been documented in several reports, including AIMTech (2001) and DOE (2000). A brief summary from these reports, as they pertain to this study, is provided in this subsection.

Blue River is a fifth-order stream and forms by the confluence of Coffee Creek and Wolf Creek and flows in a north-northeast direction toward the Missouri River. The primary tributaries to Blue River downstream of its headwaters are Brush Creek and Indian Creek. Indian Creek's primary tributary is Tomahawk Creek. The Indian Creek watershed is the largest subbasin (approximately 80 square kilometers [km^2]) within the Blue River drainage basin (which drains a total area of approximately 700 km^2; nearly 150 km^2 of this drainage area is located upstream of the confluence with Indian Creek).

The Blue River watershed has been altered by urbanization and contains predominantly impervious land features. Such urbanization altered the natural hydrograph of the streams, increasing peak flow in response to storm events and changing sediment loading patterns. This, in turn, increases the degree of stream embeddedness, promotes the formation of central bars, and undercuts the banks. Moreover, channel reaches downstream of the confluence with Indian Creek adjacent to the BFC have been significantly modified by flood control measures, which further alter the natural stream hydrology and sediment transport characteristics.

The streambed within the stretch of Blue River upstream of the BFC is composed predominantly of bedrock and gravel and contains a network of riffles and pools. The banks of the upper portion of this reach are moderately steep, with bottomland hardwoods that extend to the water's edge. The gradient of this reach is moderate at approximately 1.7 meters per kilometer (m/km) and the stream water is clear during normal flow conditions. The river transitions to a wide and shallow channel with a bed that consists of fine organic substrate that then narrows just upstream of the Indian Creek confluence to form pools and riffles over areas of gravel, cobble, silt, and sand. Small quantities of aquatic emergent macrophytes are visible within the riffle zones. Steep, muddy banks and riparian vegetation (dominated by grasses, vines, and herbaceous vegetation) characterize the lower half of this reach.

The reach of Blue River adjacent to the BFC (i.e., downstream of its confluence with Indian Creek) was historically channelized through bottomland hardwoods. Bluff outcroppings form much of the east bank. Trees intermittently form a canopy overhanging the stream and other portions of the shoreline are colonized by short herbaceous vegetation. Channelized segments adjacent to the BFC are mostly devoid of tree canopy and the banks of the channelized sections have been stabilized with riprap. Large woody debris is found throughout this reach. The slope of this downstream reach is shallower as the water depth increases and current velocity decreases relative to upstream reaches; this downstream reach is also characterized by higher turbidity, and absence of macrophyte beds as compared to the upstream reach. The bottom substrate is generally composed of a gravel-sand-silt mixture, with erosion control riprap around the bridge abutments.

In Indian Creek, the stream gradient is higher than that of Blue River at 2.5 m/km. It is generally characterized as having steep banks that are reinforced with riprap in places, and undercut or bordered by gullies in unprotected areas. Parts of the stream rest on bedrock, but much of the stream shows evidence of erosion and widening of its bed. Just upstream of the confluence with Blue River, Indian Creek varies in makeup, consisting of pools with clay-silt substrate containing boulders and woody debris, and riffles with gravel and cobble substrate. The segment of Indian Creek immediately south of the BFC has been channelized and the streambank stabilized with riprap. Adjacent to Outfall 002, the streambed is dominated by large cobbles associated with bank stabilization efforts. During extended dry periods, Indian Creek flow would be reduced to near zero; however, discharges from two large Publicly Owned Treatment Works (POTWs) supplement flows (see Section 2.1.2.3). Indian Creek near Holmes Road (Figure 2-2) consists of pools and glides with clay-silt substrate that changes to a long, wide, and shallow riffle of gravel and cobble upstream. Some rooted emergent vegetation exists in the shallows of this reach. The riparian zone consists of grasses, weeds, and non-woody vegetation changing to bottomland hardwood. Several small concrete check dams are located in the portion of Indian Creek upstream of the BFC to Holmes Road.

2.1.2.2 Geology and Hydrogeology

Information regarding the hydrogeology of the BFC site was described in the Northeast Area/001 Outfall RFI Report (Department of Energy Albuquerque Operations Office Environment and Health Division Environmental Programs Branch 1993). A brief summary from that report is provided in this subsection.

The BFC is situated in the physiographic province of the Great Plains, which is along the southeastern edge of the Forrest City basin. Beneath the site, the strata are composed of approximately 14 meters (m) of unconsolidated Quaternary alluvium overlying more than 700 m of Paleozoic strata. The Blue River alluvium beneath the BFC is in direct contact with both the Knobtown Sandstone and unnamed shales of the Pennsylvanian Pleasanton Group. Upper Pennsylvanian rocks from the Kansas City Group form bluffs along the valley limits. Cycles of deposition and erosion and construction activities by the U.S. Army Corps of Engineers flood control program (i.e., placement of fill) have affected the distribution of materials within the alluvium. In the northeast area of the BFC site, the alluvium consists of two separate permeable zones: an upper sand/clay/silt unit and basal gravel. A clayey-silt aquitard separates the two layers in some areas. The basal gravel zone contains a considerable amount of eroded bedrock made of angular limestone and sandstone gravel, with a sand/silt/clay mixture.

Typical depths to groundwater in the vicinity of the BFC are approximately 10 feet. Shallow groundwater generally flows toward the surface water bodies, as expected; however, groundwater flow is altered in some areas by pumping wells that operate as part of the groundwater pump and treat system, which is used to prevent groundwater contaminated with volatile organic compounds from migrating off the BFC. In general, migration of PCBs in groundwater is limited by their strong adsorption to the soil matrix (e.g., Mackay et al. 1992). Consistent with this expectation, groundwater sampling conducted by the BFC has indicated that groundwater transport is not a significant source of PCB loading to the receiving streams (DOE 1999).

2.1.2.3 Hydrology

Flow rates in Indian Creek and Blue River are monitored by the U.S. Geological Survey (USGS) at four locations near the BFC—three in Indian Creek and one in Blue River (Figure 2-3). In Indian Creek, Gauge 06893300 (Indian Creek at Overland Park, Kansas) is located approximately 14 km upstream of the BFC, and has the longest period of record of the three Indian Creek gauges (March 1963 to present). Average flow in Indian Creek at this location is 37 cubic feet per second (cfs).

The next downstream gauge on Indian Creek, Gauge 06893390 (Indian Creek at State Line Road, Leawood, Kansas), is approximately 4.5 km upstream of the BFC. The period of record for this gauge is relatively short, from April 2003 to present. Annual average flow at this location over the period of record is approximately 100 cfs. The next downstream gauge on Indian Creek (located closest to the BFC) is Gauge 06893400 (Indian Creek at 103rd Street in Kansas City, Missouri), which is approximately 3.5 km upstream of the BFC. The period of record for this gauge extends from April 2002 to present, with more than a 2-year gap in record between October 2008 and February 2011. The annual average flow at this gauge is approximately 90 cfs; the lower average flow at this gauge relative to the next upstream gauge is likely due to the different and relatively short periods of record between the two gauges.

The USGS gauge along Blue River (06893500 Blue River at Kansas City, Missouri), is located between the Indian Creek/Blue River confluence and the mouth of Boone Creek, adjacent to the BFC. The period of record at this location is from May 1939 to present. The long-term average flow rate for the station is 175 cfs. The statistically derived return frequency of 2-, 10-, and 100-year flow events at this station were estimated at 10,600, 20,600, and 31,700 cfs, respectively.[2]

Section 3.2.2 provides a discussion of how upstream inflows for both Indian Creek and Blue River (upstream of the confluence) were calculated based on the historical long-term flow record at the Blue River USGS gauge (06893500).

For the last several decades, flows in Indian Creek and Blue River have been heavily influenced by three large POTWs upstream of the BFC (one on Indian Creek, one on Tomahawk Creek, and one on Blue River). Businesses and residences in Johnson County draw water from the Kansas River (outside of the Blue River Basin) that is then transferred to a wastewater treatment facility and discharged into tributaries of Blue River or Blue River itself. Since the addition of wastewater effluent to the Blue River Basin in approximately 1955, an increase in median daily streamflow of 28 cfs has been observed in Blue River (Wilkison et al. 2006). This increase is almost equivalent to the sum of the discharges of the three upstream facilities (29 cfs; Wilkison et al. 2006). This effect is magnified during periods of drought when the majority of Blue River flow in this portion of the stream is treated wastewater effluent (Wilkison et al. 2006).

Daily average flow rates for the four BFC stormwater outfalls from March 2005 to present ranged from 0.1 cfs in Outfalls 001 and 004 to 0.3 cfs in Outfall 001 (see Section 2.2.1.2 of the Work Plan). The daily average flow rates for days during active stormwater discharges were

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[2] These statistics were calculated using the Log-Pearson Type 3 method (Helsel and Hirsch 2002) and peak flow rates for the 75-year period of record at USGS Gauge 06893500.

1.0, 0.4, 0.5, and 0.3 cfs for Outfalls 001, 002, 003, and 004, respectively. These flow rates are less than 1% of the flow rates for Indian Creek and Blue River during the same periods.

2.1.2.4 Habitat Conditions and Biological Communities

The Blue River Basin is located within the Prairie Faunal Region, which is an area characterized by a low diversity in fish fauna, and subject to variable environmental conditions (DOE 2000). Benthic macroinvertebrate communities observed during a biological and habitat assessment study in Indian Creek and Blue River were found to be indicative of moderately impacted streams (DOE 2000). Species normally found in nutrient-rich environments, where siltation occurs and less stable, poorer habitat exists were found at both streams. Species of fish that were found included several different minnow, sucker, catfish, sunfish, and darter species. Fish species richness and composition were below the expected standard on a watershed basis; however, this was consistent with observations reported more than 40 years ago. Sensitive fish species were found to be low in numbers or were absent in the watershed, and species more tolerant of extreme conditions were plentiful. The results of the survey suggested that the impacts associated with urbanization and channelization resulting in lower water quality and reduced habitat diversity were contributors to the observed depression of biological communities.

2.1.2.5 PCBs

Numerous PCB datasets have been collected from the receiving waters by the BFC during the last 30 years, including surface water, sediment, fish tissue, and semipermeable membrane device (SPMD) samples[3] (summarized on Table 2-1 of Anchor QEA 2013a). Surface water samples have been collected routinely in the vicinity of the BFC from 1996 to present at three locations along Indian Creek, and at three locations along Blue River. Surface water samples were also collected at two locations in Boone Creek in 2004, 2007, and 2009 to present. Sediment samples were collected historically at a few locations along Indian Creek and Blue River during studies in 1985 and in 1998 to 1999. More recently (beginning in 2001), sediment samples have been routinely collected from Indian Creek at Holmes Road

[3] SPMDs are passive samplers that accumulate hydrophobic organic compounds (such as PCBs) from the water column. They are constructed of a low-density polyethylene (LDPE) membrane containing a thin film of a high-molecular weight lipid (triolein) (http://wwwaux.cerc.cr.usgs.gov/SPMD/spmd_overview.htm).

and in the vicinity of Outfall 002. Fish samples have been collected from three locations in Indian Creek, three locations in Blue River, and one location in Boone Creek over several years (1991, 1992, 1993, 1998, 2002, 2005, 2007, and 2012). SPMDs were also deployed in Indian Creek, Blue River, and Boone Creek in 2007 and 2008.

Additional PCB data were collected from the receiving waters in 2013 and 2014 to support the Fate and Transport Study. This included collection of water column, sediment, and bank soil PCB data from Indian Creek and Blue River, as described in the SAP, Appendix A, and the next subsection.

2.2 Evaluation of Site PCB Data

Section 2.2 of the Work Plan provided a preliminary CSM of PCB fate and transport at the BFC and in Indian Creek and Blue River that was developed based on an evaluation of the available site PCB data. This section provides a synopsis of that original evaluation, followed by an evaluation of the new data collected for the Fate and Transport Study in 2013 and 2014 that were used to augment the CSM.

2.2.1 Stormwater

Extensive sampling and analysis of PCBs have been conducted historically from within the stormwater collection system to identify and mitigate potential PCB sources. As a result of these source tracking efforts, the BFC has implemented numerous BMPs to minimize PCBs in stormwater (as described in Section 1.1.2 and in DOE [2003]). These BMPs have greatly reduced PCB concentrations in BFC stormwater discharged to Indian Creek and Blue River. Since 2008, routine permit compliance monitoring required by the MSOP has not detected the presence of PCBs in discharges from the BFC. However, non-routine monitoring of stormwater discharges indicates that low-level PCB concentrations persist, and are only detectable using a low detection limit method (USEPA Method 1668a; Figure 2-4). Moreover, these BMPs that have reduced PCB concentrations in stormwater combined with other BMP efforts to reduce outfall flow volume (e.g., Outfall 002 re-route system) have resulted in a considerable reduction in PCB load to Indian Creek and Blue River over time, particularly during the last decade. Figures 2-5 and 2-6 show time series of calculated mean annual outfall flows and total PCB loads, respectively.[4]

As noted in the Work Plan, additional stormwater sampling was conducted as part of the Fate and Transport Study to better quantify stormwater PCB sources and contemporary outfall PCB loadings. Phase 1 of the stormwater sampling program included the collection of particulate matter from paved surfaces and rooftops (prior to it entering the storm sewer system) and sediments that have accumulated within catch basins. As described in the SAP, two samples were collected from each of three zones: Zone A—areas where PCBs were detected previously; Zone B—transition zone between Zones A and C; and Zone C—areas where PCBs are not anticipated to be present. Pavement, rooftop, and catch basin sampling locations are shown on Figures 2-7a through 2-7c, respectively. In summary, the new data indicate that the distribution of PCBs among pavement and roof zones is consistent with the previous understanding of the site (i.e., the highest PCB concentrations were observed in Zone A and were on the order of 0.1 to 0.4 milligrams per kilogram (mg/kg); lower concentrations were observed in Zones B and C and were generally less than 0.05 mg/kg; Figure 2-8). Zone C samples were collected from un-impacted areas of the site and can be considered representative of site background PCB levels. These Zone C samples indicate that background PCB levels on solids entering storm sewers are 0.03 mg/kg or less. The distribution of PCBs among zones in catch basins differed from the roof and pavement areas—the highest catch basin concentration was observed in Zone B (0.7 mg/kg; this was also the highest PCB concentration observed for the entire program). Although this distribution is difficult to explain, it is not necessarily unexpected given that catch basins tend to integrate solids from larger areas.

Stormwater solids collected during Phase 1 were fractionated into three size classes (<62 micrometers [µm], 62 to 250 µm, and >250 µm) that were analyzed for PCBs separately in addition to analyzing the bulk sample. Figure 2-9 shows the distribution of PCBs among the three size classes (and the bulk sample) in each sample. As expected, the highest PCB

[4] The outfall flows and PCB loads shown on Figures 2-5 and 2-6 were presented in the Work Plan, and were calculated consistent with the methods historically used by the BFC to estimate outfall flows and PCB loads. This methodology is described in Sections 2.2.1.2 and 2.2.1.3 of the Work Plan, and is not repeated here for brevity.

concentrations are typically observed on the finer size classes (<62 µm and 62 to 250 µm); however, on average, these fractions account for less than 25% of the sediment sample mass. That is, 75% of the sample mass is contained in the >250 µm fraction, which generally contains the lowest PCB concentrations. On a PCB mass basis, approximately one third of the PCB mass is contained within the >250 µm fraction, and the remaining two-thirds is contained in the finer fractions.

Phase 2 of the stormwater sampling program included sample collection at twelve locations within the BFC storm sewer system (three in Basin 001, four in Basin 002, two in Basin 003, two in Basin 004, and one at Outfall D). Two types of samples were collected at each location:

- Composite water PCB samples were collected at the four outfall compliance points during two storm events; flows were measured in conjunction with the sampling to facilitate the development of contemporary outfall PCB loads for input to the PCB fate and transport model (described in Section 3.2.4.1). This program also included collection of samples at locations upgradient of the compliance points in an attempt to identify ongoing low-level sources of PCBs to the stormwater system. Sampling was conducted during two rainfall events: August 6-7, 2014 (total rainfall of 2.8 inches) and October 1-2, 2014 (total rainfall of 3.4 inches).
- Sediment traps were deployed at each location for approximately 3 months (June 24 to September 30, 2014) to capture sediments as they are transported through the storm sewer system. The use of sediment traps facilitated the collection of time-integrated sediment samples from the storm sewer system. Section 2.2 of the DSR (Appendix A) provides a description of the type of sediment trap used for this sampling.

Figures 2-10a through 2-10e show Phase 2 stormwater sample locations and PCB results (one figure per basin) overlaid with a simplified schematic of the BFC stormwater drainage system. The following is a discussion of the results from this sampling.

- Basin 001 (Figure 2-10a): Sampling was conducted at three locations within this basin: one location adjacent to a roof drain (Location RF), one location near the center of the drainage basin (Location 01), and the Outfall 001 compliance point (Location 02). Composite water PCB concentrations in this basin are relatively low compared to

Basin 002 (described below), but generally increase with distance downstream. For example, composite water PCB concentrations during the first event on August 6-7, 2014, increased from 4 nanograms per liter (ng/L) at the roof drain to 7 ng/L at Location 01 and then to 36 ng/L at the Outfall 001 compliance point. PCB concentrations in the sediment trap samples from this basin are also relatively low compared to the other basins (ranging from 0.3 to 1.2 mg/kg), and are generally consistent with PCB concentrations on solids entering the storm sewer system from PCB-impacted areas (i.e., Zone A pavement and roof samples collected from Basin 001 during Phase 1 are on the order of 0.5 mg/kg). However, sediment trap samples do not show the same upstream to downstream increase as the composite water samples.

- Basin 002 (Figure 2-10b): Sampling was conducted at four locations within this basin: one location adjacent to a roof drain (Location RF), one location downstream of the Department 26 PCB-impacted area (Location 01), the Outfall 002 compliance point (Location 02), and one location in the Outfall 002 raceway (Location 03). Composite water samples collected during the first event show a large increase in concentration between the roof location (0.2 ng/L) and Location 01 (427 ng/L), indicative of a source in this area. Many of the smaller lateral sewer lines in the vicinity of Department 26 leading from the building to the main trunk line in Basin 002 are un-lined (in an area where subsurface soils are known to be impacted by PCBs) and provide a possible transport pathway for PCBs. Concentrations then decrease with distance downstream of Location 01, likely as a result of dilution from lower concentration stormwater entering the system downstream of this location. PCBs on sediment trap solids are also relatively high in this basin (ranging between 13 and 35 mg/kg at Locations 01, 02, and 03) and show a similar spatial pattern to the first round of composite water samples. Composite water samples from the second round of sampling show a different spatial pattern relative to the first round. However, these data still show a relatively significant increase in PCB concentrations between the roof drain location and Location 01.
- Basin 003 (Figure 2-10c): Sampling was conducted at two locations within this basin: one location near the center of the drainage basin (Location 01) and at the Outfall 003 compliance point (Location 02). Composite water PCB results are generally consistent between the two rounds of sampling, and show more than a factor of 3 increase in concentration from approximately 20 ng/L at Location 01 to 70 ng/L at

Location 02. PCBs in sediment trap solids do not show that same spatial pattern, but are relatively low and generally consistent with levels observed in the Outfall 001 basin.

- Basin 004 (Figure 2-10d): Sampling was conducted at two locations within this basin: one location in the vicinity of the monitoring pit north of the Outfall 004 compliance point (Location 01) and at the Outfall 004 compliance point (Location 02). Location 01 was selected relatively close to Location 02 as it was not possible to gain access to locations further up in the drainage basin. At Location 01, it was not possible to place a sediment trap due to a large accumulation of sediment in the pipe at this location. Instead, a grab sample of the accumulated sediment was collected and submitted for analysis. PCBs in the accumulated sediment at this location were relatively high (16 mg/kg) and may serve as an ongoing low-level source in this basin. That said, composite water PCB concentrations downstream of this location at the compliance point (Location 02) were relatively low during both sampling events (8 and 15 ng/L).
- Basin D (Figure 2-10e): Sampling at this location was conducted at one location near the upstream end of the pipe segment leading to the outfall. A composite water PCB sample was only collected during the second sampling event due to equipment problems during the first event; the PCB concentration of this sample was relatively low (8 ng/L). PCBs in sediment trap solids were also low and comparable to levels observed at un-impacted areas of the site during Phase 1 (0.3 mg/kg).

In summary, PCB concentrations in composite water and sediments moving through the BFC storm sewers are generally low in Basins 001, 003, and 004. Higher concentrations are observed in Basin 002. A large increase in PCB concentration is observed between the roof location and Location 01 in Basin 002, which is indicative of the previously identified subsurface PCB source in this area (DOE 2003).

2.2.2 Receiving Waters (Indian Creek, Blue River, Boone Creek)

2.2.2.1 Water Column

Water column samples are collected routinely by the BFC (approximately once to twice annually) from eight surface water stations in the vicinity of the BFC (locations shown in orange on Figure 2-11) and analyzed for congener-specific PCBs (USEPA Method 1668a). The following is a summary of the evaluation of these data as presented in Section 2.2.2.1 of the Work Plan:

- There was no obvious decline in PCB concentrations from 2003 to 2012 at any of the eight sampling locations, except for some limited evidence of a decline in Boone Creek.
- Most of the water column data were collected during low to moderate flows, when the BFC outfalls were generally not discharging (with the exception of a small amount of base flow from Outfalls 003/004 and 001). As such, the majority of the available water column data are representative of ambient conditions in the receiving streams at times when they are not directly impacted by PCB loadings from the BFC outfalls.
- PCB concentrations in Indian Creek ranged from non-detect to 1 ng/L.
- PCB concentrations in Blue River ranged from non-detect to 15 ng/L, and PCB concentrations and load in Blue River generally increased with distance downstream.
- PCB concentrations in Boone Creek were the highest of all locations and ranged from non-detect to approximately 120 ng/L based on water column sampling conducted immediately upstream and downstream of the Outfall 001 discharge. As noted in Section 2.2.2.1.4 of the Work Plan, SPMD samples collected throughout Boone Creek during 2007 and 2008 also showed elevated PCB concentrations relative to Indian Creek and Blue River, including the upstream-most Boone Creek SPMD (located well upstream of Outfall 001), which may be indicative of a possible non-BFC upstream PCB source on Boone Creek.
- The PCB load observed in Indian Creek could not fully account for the load increase observed in Blue River immediately downstream of the Indian Creek/Blue River confluence. Assuming there were no external PCB loads to Blue River over this reach, this load difference implied that there may be an internal (i.e., in-stream) load to the water column, likely originating from the sediments and/or bank soil.
- Average water column concentrations in Blue River increased from approximately 1 ng/L (upstream of Boone Creek) to 5 ng/L (downstream of Boone Creek). This increase in concentration in Blue River at the downstream location may be the result of loading from Boone Creek, and/or internal loads (flux from sediments and/or banks) across this reach of the river.

Additional water column data were collected as part of the Fate and Transport Study to better define the sources, fate, and transport of PCBs within the system. Specifically, samples were collected at the same eight locations monitored by the BFC, plus an additional six locations (two in Indian Creek and four in Blue River; locations shown in yellow on Figure 2-11) during six events between September 2013 and October 2014. Samples were collected during two moderate to high flow events when the BFC outfalls were discharging, and during four low-flow events. Spatial profiles of water column PCB concentrations measured during the four low-flow events (Figure 2-12 and Table 5-4 of the DSR [Appendix A]) show patterns that are consistent with the previous BFC sampling data described in the preceding discussion. PCB concentrations throughout Indian Creek were generally low and ranged from non-detect to less than 2 ng/L (maximum concentration was 5 ng/L at the location downstream of Outfall 002 [ICDB]). PCB concentrations at the upstream background location in Indian Creek at Holmes Road (IC-UBC, located more than 1 km upstream of the BFC) ranged from non-detect to 0.5 ng/L. Concentrations in Blue River at the two background locations upstream of Indian Creek (BR-UBC and ICBR) were also low and ranged from non-detect to 1 ng/L.[5] In addition to general urban runoff, one potential source of low-level background PCBs could be treated wastewater effluent from three POTWs discharging to Indian Creek and Blue River upstream of the BFC (as noted in Section 2.1.2.3). Under low-flow conditions, water column concentrations in Blue River downstream of Indian Creek show a relatively consistent increase with distance downstream (Figure 2-12), although the magnitude of the increase varied by event, some of which is related to flow differences. Specifically, concentrations increase from approximately 1 to 2 ng/L near the Indian Creek/Blue River Confluence to a maximum of 20 to 30 ng/L at the downstream-most sampling location near Highway 71. As described in Section 2.2.2.2.1, the spatial increase observed over this portion of Blue River under low-flow conditions can be explained by internal flux of sediment porewater to the overlying water column and, therefore, is not the result of any external load of PCBs to the system. Lastly, similar to the BFC dataset, PCB concentrations at the two locations (upstream and downstream of

[5] This excludes one uncharacteristically high sample (19.8 ng/L) collected at BR-UBC on September 22, 2014. This sample was excluded because there are no known PCB sources at this location (located nearly 2 km upstream of Indian Creek), and it is considerably higher than the remainder of the dataset at this location, and the upstream background location on Indian Creek (IC-UBC). A Grubbs' test for outliers conducted on the population of samples collected at these two background locations indicated that this high sample is indeed a statistical outlier.

Outfall 001) in Boone Creek were the highest of all locations and ranged from 30 to 95 ng/L. Both the upstream and downstream Boone Creek sample locations showed relatively similar PCB levels.

Under higher flow conditions, water column PCB concentrations were much more variable, and clear spatial patterns in the data were not evident (Figure 2-13).[6] PCB concentrations in Indian Creek were still generally low, but were somewhat higher than those observed under low-flow conditions, ranging from non-detect to 11 ng/L. In Blue River, the spatial increase observed under low-flow conditions was less apparent during higher flows. Also, concentrations observed at higher flows are generally lower, ranging from non-detect to 12 ng/L, which is expected as a result of greater dilution in the stream at high-flow conditions.

Figure 2-14 shows a spatial profile of PCB loads in Indian Creek and Blue River during the two high-flow sampling events. This figure also includes estimates of the PCB load from the BFC outfalls during the same events. This figure demonstrates that the load entering the receiving streams from upstream plus the outfall loading cannot account for the observed downstream load. For example, during the August 7-8 event, the upstream PCB load (Indian Creek and Blue River combined) was approximately 1 gram per day (g/d). The outfall loading during this same event was approximately 3 g/d; therefore, the combined upstream and outfall loading was approximately 4 g/d. By comparison, the PCB load observed in Blue River downstream of Indian Creek ranged from 10 to 22 g/d, indicating that other non-outfall sources (likely internal sediments) were contributing to the majority of the downstream load. Table 2-1 provides a summary of the estimated PCB loads for both high-flow events. Note that there is considerable variability in the PCB load estimates derived from the five water column sampling locations in the Blue River downstream of Indian Creek during high flow (ranging from 5 to 300 g/d; Figure 2-14).

[6] It is possible that some of this variability is because the grab sampling conducted from shore during the high-flow events was not representative of average stream conditions. Also, in-stream sampling needed to be conducted over 2 days; because flows in the stream were much lower and the outfalls were not flowing on the second day of sampling, Figure 2-13 only shows data from the first day of the event.

Table 2-1
High Flow PCB Load Summary

Sampling Event	PCB Loading (grams/day)				
	Upstream (Indian Creek and Blue River)	Outfalls	Total (Upstream and Outfalls)	Blue River Downstream	
				Minimum	Maximum
August 7, 2014	1	3	**4**	10	22
October 2, 2014	<1	3	**4**	5	300

2.2.2.2 Sediment

As described in the Work Plan, historical sediment PCB data within Indian Creek and Blue River near the BFC are limited and are insufficient to reasonably characterize sediment PCB levels throughout the system. One exception is surface sediment data collected routinely (approximately quarterly from 2001 to present) at three locations in the immediate vicinity of the Outfall 002 discharge point (10 feet upstream, 10 feet across, and 30 feet downstream). A relatively high-level evaluation of these data in the Work Plan concluded there was no apparent change in surface sediment PCBs at these locations over time. This conclusion was largely influenced by the data collected from the locations upstream and across from the outfall—decreases in PCB concentration are not expected at these locations because sediments from the outfall are not expected to be deposited in these locations. However, closer inspection of the data collected at the location 30 feet downstream of the outfall show that a considerable decline in surface sediment concentrations has occurred at this location since 2001 (Figure 2-15). Moreover, the data collected at this location since 2005 show a relatively fast rate of decline (PCB half-life of approximately 3 years). In 2005, the Outfall 002 re-route system was completed, which resulted in a significant reduction in PCB loading from the outfall; therefore, the continuing decline in sediment PCB concentrations in Indian Creek after 2005 is likely a result of in-stream natural recovery processes.

Because sediment data in the system were relatively limited, and little was known regarding contemporary PCB levels in Indian Creek, Blue River, and Boone Creek sediments, additional in-stream sediment sampling was conducted as part of the Fate and Transport Study to better understand the sediment exposure pathway to fish, and sediment-derived PCB loading to the overlying water column. Consistent with the SAP, the site was divided into subreaches (8 in Indian Creek, 15 in Blue River, and 6 in Boone Creek; Figure 2-16). Several discrete sediment samples were collected from each subreach and then composited for analysis of PCBs. Figures 2-17a through 2-17c show spatial profiles of PCB concentrations in the composite samples collected from Indian Creek, Blue River, and Boone Creek, respectively. Sediment PCB concentrations in most of the Indian Creek subreaches are generally low and less than 0.05 mg/kg (Figure 2-17a). Concentrations in the segments immediately upstream and downstream of the Outfall 003/004 discharge are somewhat higher (0.1 to 0.2 mg/kg). The highest concentration in Indian Creek (and anywhere at the site) is the segment immediately downstream of Outfall 002 (IC-7), which has a concentration of approximately 1 mg/kg—the concentration in this segment is considerably higher than the segment immediately upstream of the outfall, which is consistent with the trend analysis of the BFC sediment data described above (shown on Figure 2-15). The concentration in the next segment downstream of IC-7 (i.e., IC-8) is considerably lower than IC-7 (approximately 0.05 mg/kg), which demonstrates a relatively localized impact from Outfall 002. In the portion of Blue River upstream of Indian Creek, sediment PCBs are low, ranging from 0.0001 to 0.01 mg/kg (Figure 2-17b). In the first three Blue River segments downstream of Indian Creek (BR-6 through BR-8), sediment PCBs increase to an average of approximately 0.05 mg/kg. Downstream of BR-8, sediment PCB concentrations increase by an order of magnitude to between 0.3 and 0.6 mg/kg, and then decrease back to approximately 0.05 mg/kg in segments BR-14 and BR-15. The increase in sediment PCB concentrations in Blue River downstream of Indian Creek is likely due to the physical characteristics of this reach, which has been channelized (i.e., deeper water depth and lower velocity as described in Section 3.2.2.2), that result in more deposition of fine, PCB-containing sediment (relative to other regions of the system). Sediment PCB concentrations in Boone Creek are somewhat variable, and range from 0.04 to 0.7 mg/kg, similar to the sediment PCB levels observed in the portion of Blue River downstream of Indian Creek (Figure 2-17c).

2.2.2.2.1 Sediment Porewater Exchange

A data-based analysis was conducted to assess whether the flux of PCBs from sediment porewater in the portion of Blue River downstream of Indian Creek can account for the observed spatial increase in water column PCB concentration under low-flow conditions (as described in Section 2.2.2.1). Under low-flow conditions (when there is no outfall discharge and presumably no sediment resuspension due to higher flows), sediment porewater exchange should be the dominant PCB loading mechanism to the water column. Sediment loading to the water column from porewater flux can be estimated according to Fick's Law using the following equation (Chapra 1997):

$$W_s = \frac{k_f A_s C_s}{f_{oc} K_{oc}}$$

where:

W_S = Sediment porewater loading [M/T]

k_f = Porewater exchange mass transfer coefficient [L/T]

A_s = Sediment surface area [L^2]

C_S = Surface sediment dry weight PCB concentration [M/M]

f_{oc} = Surface sediment organic carbon fraction

K_{oc} = Organic carbon partition coefficient of PCBs [L^3/M]

Sediment PCB concentrations and organic carbon fractions collected for the Fate and Transport Study were used for this calculation, and sediment surface area was computed using spatial analysis tools in GIS. The remaining parameters in this calculation were set consistent with the values used to develop and calibrate the PCB fate and transport model described in Section 3.2.4. The cumulative loading calculated using the equation above was then converted to an equivalent water column concentration by dividing by the stream flow on the days of sampling. Figures 2-18a through 2-18d show water column concentrations calculated using this equation compared to observed water column concentrations during the four low-flow sampling events. The reasonably good agreement between the calculated and observed values demonstrates that the water column PCB increase observed over this portion of Blue River can be attributed to dissolved-phase flux of PCBs from stream sediment porewater.

2.2.2.3 Bank Soil

As described in the SAP, few samples were collected historically to characterize PCB concentrations in the streambank soils of Indian Creek and Blue River. Visual observations indicate that portions of the streambanks are subject to periodic erosion; as such, bank erosion has the potential to contribute to the water column and sediment PCB load. Therefore, composite sampling and analysis of surface soils (similar to the sediment sampling described above) was conducted as part of the Fate and Transport Study in streambank areas visually observed to be subject to erosion. As described in the DSR (Appendix A), eroding banks were identified in 13 of the 29 compositing reaches (five in Indian Creek, seven in Blue River, and one in Boone Creek). PCB concentrations in bank soil samples collected from these areas were generally low (Figure 2-19). The majority of samples had PCB concentrations less than 0.001 mg/kg. The average bank PCB concentration in Indian Creek and Blue River was 0.0006 mg/kg. PCB concentration in the one eroding bank identified within Boone Creek was somewhat higher at 0.7 mg/kg.

2.2.2.4 Fish Tissue

PCB concentrations in fish from Indian Creek and Blue River were first measured by the MDNR in the late 1980s. Detectable concentrations of PCBs found in the fish at that time prompted regular fish monitoring. Since 1991, ORNL has been conducting periodic fish monitoring studies on behalf of the BFC to investigate PCB concentrations and assess the contribution of PCBs from the BFC. Specifically, fish tissue (fillet) samples were collected in 1991, 1992, 1993, 2002, 2005, 2007, and 2012 from seven locations in the vicinity of the BFC and analyzed for PCBs—three in Indian Creek (ICK3.0, ICK1.0, and ICK0.2), three in Blue River (BLK31, BLK27, and BLK25), and one in Boone Creek (BCK0.2; Figure 2-20)[7]. The upstream-most location on Indian Creek (ICK3.0) is upstream of the BFC and represents background PCB concentrations in fish. Indian Creek locations ICK1.0 and ICK0.2 are located downstream of the Outfall 003/004 and 002 discharge points, respectively. The upstream-most Blue River monitoring station is located several kilometers upstream of the Indian Creek confluence in the vicinity of the I-435 Bridge (BLK31); this location provides

[7] Locations shown represent those where fish samples are collected routinely; there are a few other locations not listed here where fish have been collected periodically. Samples were also collected in 1998 from Indian Creek only.

an estimate of Blue River fish PCB concentrations well upstream of Indian Creek and the influence of the BFC. The next downstream Blue River station (BLK27) is located just upstream of Boone Creek, and the downstream-most station (BLK25) is located approximately 2 km downstream of Boone Creek. The Boone Creek station (BCK0.2) is located just downstream of the point where the flow from Outfall 001 enters Boone Creek.

Green Sunfish and Channel Catfish are the species targeted and analyzed for PCBs. Green Sunfish are relatively abundant in both Indian Creek and Blue River and typically have a smaller home range, making them a good indicator species of local contaminant exposure. Channel Catfish accumulate higher concentrations of PCBs in the same environment due to their larger size, longer lifespan, higher trophic level, and higher lipid content.

The fish sampling program conducted by the BFC is relatively robust; therefore, no additional fish data were collected as part of the Fate and Transport Study. The following is a summary of the evaluation of the fish PCB data presented in the Work Plan:

- Contemporary average fillet PCB concentrations (wet weight) at the upstream background locations in Indian Creek and Blue River are approximately 0.02 mg/kg in Green Sunfish and 0.1 mg/kg in Channel Catfish.
- Figure 2-21a presents a spatial profile of contemporary (2005 and 2007) average lipid-normalized[8] total PCB concentrations in Green Sunfish and Channel Catfish fillets from Indian Creek, Blue River, and Boone Creek (no Channel Catfish were collected in Boone Creek).
  - Fish fillet concentrations in Indian Creek (both Green Sunfish and Channel Catfish) increased with distance downstream (by more than a factor of 5 compared to upstream background concentrations), indicating the presence of a PCB source over this reach.

[8] Lipid-normalized concentrations were calculated by dividing the wet-weight fish tissue concentrations by the lipid content; the results are expressed as mass of PCB per mass of lipid (e.g., µg/kg-lipid). This lipid normalization is useful when evaluating spatial and temporal changes in fish concentrations because it removes the possible differences in concentration that may result from varying sizes and body condition of fish from year to year.

  - Fish collected at both locations in Blue River downstream of Indian Creek showed somewhat lower PCB concentrations than fish collected downstream of Outfall 002 in Indian Creek (ICK0.2), but were elevated relative to the upstream-most station in Blue River (by a factor of 3 to 5).
  - Figure 2-21b shows the same spatial profile as Figure 2-21a, except the averages presented on Figure 2-21b now include fish fillet data collected in 2005, 2007, and 2012 (the 2012 data were not available when the Work Plan was prepared). The spatial pattern in the 2005, 2007, and 2012 averages is generally similar to that observed in the 2005 and 2007 averages. In addition, whole fish tissue PCB concentrations were calculated from fillet and offal samples collected in 2012 in support of the ecological risk assessment (shown as open symbols on Figure 2-21b). The spatial pattern in the 2012 whole body fish PCBs is also generally consistent with the contemporary fillet-based averages.
- Time series of annual average total PCB concentrations in Green Sunfish and Channel Catfish generally show a decrease in average lipid-normalized PCB concentrations between the early collection years and the contemporary data (Figures 2-22a and 2-22b[9]). Indian Creek fish PCB concentrations were somewhat variable in the earlier collection years, although a general decrease in PCB concentrations was still observed over time. Blue River fish had PCB concentrations (on a lipid-normalized basis) in 1992 that were up to five times higher than those observed in 1993 through 2012. Similarly, Boone Creek lipid-normalized fish PCB concentrations have decreased by more than an order of magnitude since the early 1990s.

2.3 Conceptual Site Model Summary

The data analyses presented in the preceding subsections (which are a combination of analysis originally presented in the Work Plan and analyses of the additional data collected as part of the Fate and Transport Study) informed the development of a refined CSM, which provides a conceptual understanding of the origin, fate, transport, and bioaccumulation of

[9] Aroclor- and congener-based averages are shown separately on these figures (i.e., congener-based total PCB concentrations are shown with a dot in the center of the symbol. This time series figure has been updated from the original version in the Work Plan to include data from 2012 that were not available at the time).

PCBs within Indian Creek and Blue River in the vicinity of the BFC. The following is a summary of the refined CSM:

- PCB sources to the water column and fish exist within Indian Creek and Blue River upstream of the BFC. PCBs are ubiquitous in the urban environment and low-level background sources are evident in the water column and fish sampling and analysis results. Possible sources include general urban runoff, plus the three POTWs that discharge to Indian Creek and Blue River upstream of the BFC.
- The BFC contributes PCB loading to Indian Creek and Boone Creek through the stormwater outfalls. Stormwater PCB loads have been reduced substantially over the last several decades through an aggressive BMP program conducted at the facility. Nonetheless, under contemporary conditions, PCBs are found at low levels in stormwater from the facility. A portion of this loading is background loading of solids containing low-level PCBs from relatively un-impacted areas of the site.
- Approximately two-thirds of the PCB mass entering the storm sewer system from roof and pavement runoff is present on soil particles finer than 250 µm. These finer size fractions are those that are generally transported a greater distance downstream of the outfalls.
- Outfall 002 is the primary conveyor of PCBs to Indian Creek from the BFC.
  - PCB concentrations in composite water and sediments moving through the BFC storm sewers are generally low in Basins 001, 003, and 004. Higher concentrations are observed in Basin 002. A large increase in PCB concentration between the roof location and Location 01 in Basin 002 (i.e., the first location in the trunk line in the Department 26 area) is indicative of a subsurface PCB source. This source is likely associated with the un-lined lateral sewer lines leading from the building to the main trunk line in this area.
  - PCBs found in sediments that have accumulated within the storm sewer immediately upstream of the Outfall 002 discharge point have not changed significantly in the last 10 years, suggesting that source control measures conducted to date have not impacted PCB concentrations in the sediments that tend to accumulate at this location, despite the significant reductions in flow volume and PCB mass loading to Indian Creek that have been achieved.
- Spatial trends in contemporary water column monitoring data indicate an increase in

PCB concentration and loading with distance downstream in Indian Creek and Blue River. Under low-flow conditions, these increases can be attributed to dissolved-phase flux from in-stream sediment porewater to the overlying water column.

- Under high-flow conditions, PCB loading from areas upstream of the BFC combined with BFC outfall loadings are considerably lower than the load observed in the downstream portion of Blue River. This indicates that sources other than outfall loading (i.e., in-stream sediments) are contributing PCBs to the water column.
- Surface sediment data collected in Indian Creek immediately downstream of the Outfall 002 discharge indicate that PCB levels in sediments in this area have declined by nearly a factor of 5 between 2006 and 2012 (approximate 3-year half-life). This decline occurred after completion of the Outfall 002 re-route system in 2005 and, therefore, is indicative of ongoing natural recovery processes in the stream.
- Riverbank soils are a relatively insignificant source of PCBs to Indian Creek and Blue River.
- PCB concentrations in fish in Indian Creek, Blue River, and Boone Creek appear to have decreased by one to two orders of magnitude at most locations relative to concentrations measured in the early 1990s.

3 MODELING STUDY

As described in Section 1.2, the following are key questions to be answered as part of the Fate and Transport Study:

- How important are the ongoing loads from the permitted BFC outfalls relative to other sources of PCBs to fish?
- Are PCB concentrations in fish anticipated to decline in the future if external PCB loads to the system continue at contemporary levels?
- If additional BMPs can be implemented at the BFC, will further reductions in outfall loading have any meaningful impact on sediments and fish?

The CSM (described in Section 2) that was developed based on the empirical site data was the first step toward answering these questions. However, a mechanistic mathematical model was developed to simulate stormwater PCB loading dynamics and the effect of stormwater PCB loading on fish and sediments of the receiving streams.

3.1 Model Background and Technical Approach

3.1.1 General Description of Modeling Framework

The mathematical modeling framework applied to the BFC site consists of linked hydrologic/hydraulic, in-stream hydrodynamic, sediment transport, chemical fate and transport, and bioaccumulation models (Figure 3-1). The hydrologic and hydraulic models provide continuous simulations of BFC site runoff, storm sewer system conveyance and storage routing, and flows discharging from BFC site outfalls, which when combined with PCB concentration data are used to compute PCB loadings to receiving waters. The in-stream hydrodynamic model is used to simulate temporal and spatial changes in water depth, current velocity, and bed shear stress. This information is transferred from the hydrodynamic model to the sediment transport model, which is used to simulate the erosion, deposition, and transport of sediment in Indian Creek and Blue River. The sediment transport model is used to simulate temporal and spatial changes in suspended sediment concentrations in the water column and bed elevation changes (i.e., bed scour depth and net sedimentation rate). The results from the hydrodynamic and sediment transport models are transferred to the chemical fate and transport model, which calculates spatial and temporal variations of chemical (i.e., PCB) concentrations in the water column and sediment bed of the receiving streams. Water column and sediment exposure concentrations from the chemical fate and transport model are then transferred to the bioaccumulation model, which calculates PCB concentrations in the aquatic food web (i.e., invertebrates and fish). The hydrodynamic, sediment transport, and chemical fate and transport models are constrained by governing equations that are based on the conservation of mass and momentum. Likewise, the bioaccumulation model is constrained by governing equations that are based on conservation of mass and energy within an organism. Mechanistic formulations and algorithms based on the state of the science are used in these models to simulate the processes governing the transfer and movement of water, sediments, and contaminants.

Data collected from the BFC site were used to specify the various inputs and parameters used in the mathematical models as a means of constraining the simulated processes, thereby reducing the uncertainty in the model formulations, and increasing overall model reliability.

3.1.2 Model Development and Application History

3.1.2.1 Hydrology/Hydraulics

There are several public domain modeling tools available that provide accounting of the accumulation, washoff, and transport of contaminants from impervious and pervious land surfaces through a stormwater drainage system. The hydrologic and hydraulic models used for this project are WWHM4 and PCSWMM, respectively. WWHM4 is a simplified derivative of the EPA-supported Hydrologic Simulation Program-Fortran (HSPF; USEPA 1997) model, which is being used to continuously simulate the rainfall runoff processes at the BFC and Boone Creek watersheds. PCSWMM is a proprietary version of the USEPA Storm Water Management Model (SWMM; USEPA 2011), which provides a GIS interface to SWMM that allows importing of the stormwater pipe network data and visual assessment of the input and output data. These two models are dynamically linked. Specifically, WWHM4 simulates site runoff (for both the BFC and Boone Creek watershed); time series of site runoff from WWHM4 are fed forward into PCSWMM, which simulates flow routing via the BFC stormwater pipe network and outfall discharge.

3.1.2.2 Hydrodynamics

The hydrodynamic model that was applied in this study is the Environmental Fluid Dynamics Code (EFDC), which is supported by USEPA. Hamrick (1992) provides a complete description of the model's underlying theory. EFDC is a hydrodynamic model capable of simulating time-variable flow in rivers, lakes, reservoirs, estuaries, and coastal areas, and has been applied to a wide range of environmental studies. For this study, EFDC was applied in a one-dimensional, cross section-averaged mode.

3.1.2.3 Sediment Transport

The sediment transport model used in this study, referred to as SEDZLJ, is capable of simulating erosion and deposition of sediment within cohesive and non-cohesive sediment bed areas (Ziegler et al. 2000; Jones and Lick 2001; QEA 2008). The sediment transport model has the following characteristics and capabilities: 1) two- or three-dimensional transport of suspended sediment in the water column; 2) specification of spatially variable bed properties; and 3) inclusion of a sediment bed model that tracks temporal changes in bed composition (i.e., sediment size class, sediment source). The sediment transport model predicts the transport and fate of inorganic sediment; the transport and fate of organic solids is not simulated by the model. Organic solids are not incorporated into the sediment transport model because organic matter settling onto the sediment bed has a minimal effect on long-term burial rates due to organic decomposition processes within the bed. This approximation has been successfully used in modeling studies at numerous contaminated sediment sites, including the five sites listed below.

The sediment transport model's calculations are performed using the hydrodynamic model's predictions of flows, current velocities, water depths, and bottom shear stress. This model has been developed by Anchor QEA personnel during the course of approximately 30 years of modeling practice and has been recently applied to the following sites:

- Lower Duwamish Waterway, Washington (QEA 2008)
- Patrick Bayou, Texas (Anchor QEA 2011)
- Upper Hudson River, New York (Anchor QEA 2010)
- Tittabawassee River, Michigan (Dow Chemical Co. 2011)
- Portland Harbor/Lower Willamette River, Oregon (Anchor QEA 2012a)

3.1.2.4 Contaminant Fate and Transport

The model used to simulate PCB fate and transport within the Indian Creek/Blue River system is AQFATE. The AQFATE model simulates temporal and spatial changes in dissolved- and particulate-phase chemical concentrations in the water column and sediment bed. In the water column, this model calculates partitioning between the particulate and dissolved phases, chemical fluxes across the air-water interface due to volatilization and atmospheric deposition, and exchange fluxes at the sediment-water interface due to erosion, deposition, and dissolved-phase exchange processes. This model also simulates chemical dynamics in the sediment bed, which is discretized into multiple layers to allow for simulation of vertical gradients in contaminant concentrations. The bed communicates with the water column through the exchange processes listed above. Within the bed itself, the fate processes simulated include mixing (i.e., bioturbation) within the surficial sediments, vertical transport/exchange via diffusion within the porewater phase, and partitioning. The processes described above are combined together in mass balance computations for both the water column and the sediment bed.

AQFATE is built into the hydrodynamic model (EFDC) framework that includes sediment transport based on the SEDZLJ algorithm (described above). As such, AQFATE is seamlessly linked with both the hydrodynamic and sediment transport models. The AQFATE model framework has a long development and application history, and has been successfully applied at a wide range of sites across the country. Recent examples include the following:

- Neal's Landfill (Conard's Branch and Richland Creek), Indiana (QEA 2007; USEPA 2007)
- Hudson River, New York (e.g., Connolly et al. 2000; QEA 2005; Anchor QEA 2010)
- Housatonic River, Connecticut (ARCADIS, Anchor QEA, and AECOM 2010)
- Grasse River, New York (e.g., Alcoa 2012)
- Portland Harbor/Lower Willamette River, Oregon (Anchor QEA 2012a)
- San Jacinto River, Texas (Anchor QEA 2012b)

3.1.2.5 Bioaccumulation

The bioaccumulation model was developed within the AQFDCHN model framework—a bioenergetic, mechanistic, dynamic modeling framework originally developed 30 years ago by Thomann and Connolly (1984) and subsequently updated and applied to numerous projects. In addition to fish movement and food web structure, this model accounts for growth rates of organisms throughout their lives as well as diet and lipid content. AQFDCHN simulates the net accumulation of PCBs by an organism through all exposure routes (water, sediment, food). Based on the principles of mass and energy conservation, AQFDCHN computes the uptake and loss of PCBs in fish. Uptake occurs from the water column dissolved phase through respiration and from water column and sediment particulates through predation, while losses occur through diffusion across respiratory surfaces. Uptake and loss rates are calculated from respiration, feeding, and empirically defined PCB transfer efficiencies.

The AQFDCHN model framework has been successfully applied at a wide range of sites across the country. Recent examples include the following:

- Ports of Los Angeles and Long Beach, California (Anchor QEA 2013c)
- Neal's Landfill (Conard's Branch and Richland Creek), Indiana (QEA 2007; USEPA 2007)
- Grasse River, New York (Alcoa 2012)
- Housatonic River, Massachusetts and Connecticut (USEPA 2006)
- Fox River, Wisconsin (QEA 2001)
- Upper Hudson River, New York (QEA 1999)

3.1.3 Overview of Technical Approach

This modeling study was conducted in general accordance with the Work Plan. For each of the submodels described above, site-specific data were used to develop the various inputs and parameters to the extent possible. The application of site-specific data constrains the model calculations to conditions observed within the system and reduces the uncertainty associated with model predictions, thus promoting model reliability. In some cases, site-specific data did not exist to develop a particular model input or parameter. In those cases, literature values, or values selected based on professional judgment and/or experience at other sites were applied. Also, a limited number of model parameters were selected through calibration, whereby they were adjusted within acceptable ranges so that the model was able to reproduce the trends in PCB concentrations within the site over relevant spatial and temporal scales.

During model calibration, numerous sensitivity analyses were conducted to elucidate model behavior, evaluate the relative importance of various mechanisms, and identify the model parameters/inputs to which the model predictions are most sensitive (i.e., relatively small to modest changes in the input value [within a range of values that is supported by the available site data or literature] illicit a modest to large response in the model). Sensitivity analyses are typically conducted to help identify key parameters that contribute to uncertainty in model predictions, and help define where efforts to improve predictions are best placed (i.e., decrease the uncertainty of the parameters to which the model is most sensitive; USEPA 2009). A general understanding of model sensitivity has been developed based on past experience with the various submodels described previously. Each section below describing model calibration provides a brief summary of the most sensitive model inputs/parameters for each submodel. In most cases, the most sensitive model parameters are relatively well constrained by the site data and/or literature. However, one of the larger model uncertainties is associated with the outfall PCB load calculation methodology—specifically, the uncertainty of model predictions related to the assumption used for PCB concentration on days when stormwater discharge is not sampled. The sensitivity of this input is described in Section 3.2.4.3.

3.2 Model Development and Calibration

3.2.1 Hydrologic and Hydraulic Model

3.2.1.1 Spatial Domain

The stormwater model domain includes the BFC site proper and the Boone Creek Watershed (Figure 3-2).[10] The Boone Creek watershed was included in the stormwater analysis domain to facilitate the quantification of Boone Creek PCB sources and loadings to Blue River. Stormwater discharges from the BFC Outfall 001 and other off-site sources of runoff to Boone Creek commingle behind the Dodson Industrial Flood Control Levee before being discharged through a gated outfall pipe to Blue River. Note that the receiving streams

[10] The model domain for the receiving streams (described in Sections 3.2.2, 3.2.3, and 3.2.4) is also shown on Figure 3-2.

(Indian Creek and Blue River) were not included in the domain for the hydrologic model because both of these waterbodies have long-term flow gauges maintained by the USGS (i.e., a hydrologic model is not needed to estimate flows in these waterbodies based on rainfall-runoff).

3.2.1.2 Hydrologic Model

A hydrologic model was developed to provide continuous simulations of BFC site runoff and Boone Creek discharge to the Blue River. The hydrologic model of Boone Creek and the BFC (WWHM4) was developed and calibrated using site-specific data available on the stormwater system as well as data collected as part of the Fate and Transport Study stormwater monitoring program (described in Section 2.2.1).

3.2.1.2.1 Model Development

Subbasin Delineation

Boone Creek Subbasins

The Boone Creek drainage area, located to the north of the BFC, is approximately 1,700 acres in size (Figure 3-2). The Boone Creek watershed was divided into six smaller subbasins using 1-m resolution Light Detection and Ranging (LiDAR) elevation data[11] and stream information from the National Hydrography Dataset (NHD; Figure 3-3). Delineated subbasins range in size from approximately 190 to 500 acres (Table 3-1). The smallest subbasin is the downstream-most subbasin located between Outfall 001 and the mouth of the creek, where it discharges into Blue River (BC 6), whereas the largest subbasin is at the headwaters of Boone Creek (BC 1).

[11] LiDAR data were downloaded from the Missouri Spatial Data Information Service (http://www.msdis.missouri.edu/data/lidar/index.html).

Table 3-1
Summary of Boone Creek Subbasins

Subbasin ID	Area (acres)
BC 1	505
BC 2	213
BC 3	257
BC 4	233
BC 5	329
BC 6	189
Total	**1,726**

BFC Site Subbasins

The BFC drainage area is approximately 320 acres (Figure 3-2). Delineation of subbasin/ subcatchment areas within the BFC site was based on available stormwater drainage system information; specifically, drainage system and available topographic data were used to provide the basis for the delineation of subbasins and subcatchments within the site. Previous delineation efforts, including those described in GBA (1989), were also used to inform the delineation, including the breakdown of roof drainage areas.

The major BFC site subbasins draining to the Indian Creek/Blue River system (i.e., drainage subbasins associated with numeric Outfalls 001, 002, 003, and 004, and alpha Outfalls B, C, D, and F) were divided into 126 subcatchments ranging in size from 0.05 acres to 28 acres (Figure 3-4). Table 3-2 provides a breakdown of the number and size of the subcatchments delineated within each drainage subbasin.

Table 3-2
Summary of BFC Subbasins

BFC Subbasin	Number of Subcatchments	Area (acres)
Outfall 001	41	123 (0.3 to 20)
Outfall 002	29	45 (0.3 to 5.2)
Outfall 003	21	40 (0.1 to 6.8)
Outfall 004	14	20 (0.05 to 3.2)
Outfall B	3	4 (0.9 to 1.9)
Outfall C	3	3 (0.6 to 1.5)
Outfall D	12	45 (1.4 to 9.2)
Outfall F	3	39 (3 to 28)
Total	**126**	**320**

Model Inputs

The WWHM4 model required several datasets to characterize each subbasin, including land cover, soil type, and slope. A summary of the data used to characterize each subbasin is as follows:

- Land cover: 30-m resolution data coverage from the Missouri Spatial Data Information Service (2005)
- Soil type: soil hydrologic groups from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (defined in Table 3-3)

Table 3-3
USDA NRCS Soil Hydrologic Groups

Soil Group	Runoff Potential	Soil Description
Group A	Low	Soils consisting mainly of deep, well-drained to excessively drained sands or gravelly sands
Group B	Moderately low	Soils consisting mainly of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture
Group C	Moderately high	Soils consisting mainly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture
Group D	High	Soils consisting mainly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material

- Slope: calculated in GIS using USGS 7.5 Minute Digital Elevation Model (DEM) coverage for Jackson County, Missouri
  - Three slope types were specified in the model including flat (0 to 5%), moderate (5 to 15 %), and steep (>15 %)

Details on how each of these datasets were used to develop model inputs are provided in the remainder of this subsection.

Land cover data were broken out into pervious and impervious land cover types for use in the model (Figure 3-5 and Table 3-4). Pervious land use types specified in WWHM4 include cropland/pasture, grassland, forest, and urban lawn areas. The impervious areas in the model were defined based on three different land use categories in the land cover dataset, including areas characterized as impervious and low- and high-density urban areas. The percent imperviousness of the low-density and high-density urban land use areas was estimated as 20% and 65%, respectively (Center for Watershed Protection 1998). The remaining 80% and 35% of the low- and high-density urban area was specified as pervious urban lawn areas in the model (as described above; Table 3-4). Also, open-water areas within the Boone Creek subbasins were considered impervious in the model.

Table 3-4

Summary of Land Cover Information for Each Subbasin

Subbasin ID	Pervious (acres)				Impervious (acres)	
	Pasture/ Cropland	Forest	Grassland	Urban Lawn	Impervious	Open Water
Boone Creek Subbasins						
BC 1	5	16	27	326	132	0
BC 2	0	26	1	145	40	1
BC 3	3	3	6	177	68	0
BC 4	4	5	13	146	65	2
BC 5	4	73	30	157	65	0
BC 6	3	22	41	79	44	0
Total	**19**	**145**	**118**	**1029**	**413**	**3**
BFC Subbasins						
Outfall 001	—	5	43	—	75	—
Outfall 002	—	0	3	—	42	—
Outfall 003	—	0	0.4	—	39	—
Outfall 004	—	0	0.1	—	20	—
Outfall B	—	0	0	—	4	—
Outfall C	—	0	1	—	3	—
Outfall D	—	0	16	—	30	—
Outfall F	—	28	9	—	2	—
Total	—	**33**	**72**	—	**215**	—

The Boone Creek watershed and BFC site is predominately composed of soils with moderately high to high runoff potential. Only the more downstream portion of the Boone Creek watershed and Outfall 001 drainage basin contains pervious areas with low runoff potential (Figure 3-6). Table 3-5 summarizes the hydrologic soil group within each subbasin.[12]

[12] The soil areas presented in Table 3-5 represent the total area of each subbasin; however, soil types are only relevant to the pervious portion of each subbasin (i.e., soil information is not used by the model in impervious areas).

Table 3-5
Summary of Hydrologic Soil Group for Each Subbasin

Subbasin ID	Area (acres)				
	Total	Group A	Group B	Group C	Group D
Boone Creek Subbasins					
BC 1	505	0	—	495	11
BC 2	213	0	—	132	81
BC 3	257	0	—	231	25
BC 4	233	0	—	127	107
BC 5	329	34	—	67	229
BC 6	189	66	—	41	82
Total	**1,726**	**100**	**—**	**1,093**	**534**
BFC Subbasins					
Outfall 001	123	29	—	91	3
Outfall 002	45	0	—	45	0
Outfall 003	40	0	—	40	0
Outfall 004	20	0	—	20	0
Outfall B	4	0	—	4	0
Outfall C	3	0	—	3	0
Outfall D	45	8	—	37	0
Outfall F	40	0	—	17	23
Total	**320**	**36**	**—**	**257**	**26**

Based on the 7.5 minute DEM, 97% of the Boone Creek watershed area is topographically characterized by flat (45%) to moderately sloped terrain (52%), and the entire BFC site is characterized as flat terrain.

In addition to the watershed-specific information described above, WWHM4 also requires meteorological data (precipitation and evaporation). Localized precipitation time series (Figure 3-7) were specified in the model using hourly data obtained from Precipitation Gauge 1720 (Stormwatch.com). This gauge was selected based on its location, which is relatively close to the site (approximately 2 miles southwest of the BFC), and its relatively long period of record (2000 to present). Regional evaporation time series were specified in the model using daily data obtained from the National Climatic Data Center (NCDC) website for the Kansas City Downtown Airport.[13]

3.2.1.2.2 Model Calibration

The Boone Creek hydrologic model was calibrated over the 13-month period between September 2013 and October 2014. This represents the available period of record for the flow gauge installed at the outlet of Boone Creek as part of the Fate and Transport Study (see Section 2.3.4 of the DSR [Appendix A] for a description of the continuous flow monitoring conducted at this location). The calibration process focused on reproducing observed patterns and relative magnitudes in Boone Creek flow over time. Hydrologic models are typically most sensitive to precipitation inputs—as described in Section 3.2.1.2.1, the precipitation dataset is relatively robust, and is from a location in close proximity to the BFC. The model is also sensitive to parameters affecting the amount of infiltration, and those that affect the proportion of direct overland flow versus interflow (i.e., the lateral movement of water in the unsaturated zone). Adjustment of the latter affects the magnitude of peak flows, and the shape of the predicted hydrograph. Specifically, two parameters related to this (INTFW and IRC) were the primary parameters adjusted during calibration.

Figure 3-8 shows a time series of recorded flows in Boone Creek (blue lines) compared to WWHM4-simulated flows in Boone Creek (red lines). There were several occasions where the recorded flows were considered inaccurate due to the presence of debris or ice near the monitoring equipment, beaver activity, or equipment failure as indicated by field personnel. These suspect periods are shaded in gray on Figure 3-8 and were excluded from the evaluation of model performance. During periods where the measured flow data were deemed reliable, the simulated model flows are in reasonable agreement with the recorded data (Figure 3-8). For example, on average, model predictions during the higher peak flows (i.e., peak flows greater than 10 cfs that occurred outside the suspect periods noted above) are within 5% of the measured data. The model also reasonably captures the relative magnitude of the lower base flows during most of the sustained low-flow periods, although it does not capture the high variability observed in the data during lower flows. The relatively good agreement between model predictions and data is further demonstrated by Figure 3-9, which

[13] http://www.ncdc.noaa.gov/cdo-web/

shows a cross plot of observed and model-predicted flows in Boone Creek (averaged daily). Although this figure shows some variability around the 1-to-1 line, there is no apparent bias in the model predictions. On a total volume basis over the entire simulation period (excluding periods that were deemed unreliable), the observed volume is 38% percent higher than the simulated volume. This difference is largely driven by numerous storm events that occurred during June 2014 where the model somewhat under-predicts the peak flow; if June 2014 is excluded from the comparison of observed and simulated volume, this difference drops to approximately 6%.

In addition to simulation of Boone Creek, the WWHM4 model was used to generate runoff hydrographs for each of the BFC subcatchment areas described above. These hydrographs were input directly to the PCSWMM hydraulic model described in Section 3.2.1.3.

3.2.1.3 Hydraulic Model

A hydraulic model of the BFC was developed to provide continuous simulations of storm sewer system conveyance and storage routing, and flows discharging from BFC site outfalls using BFC site runoff volumes predicted by the hydrologic model described previously. These flows, when combined with PCB concentration data, are used to compute PCB loadings to the receiving waters. The BFC hydraulic model (PCSWMM) was developed and calibrated using site-specific data available on the stormwater drainage system as well as data collected as part of the Fate and Transport Study stormwater monitoring program (described in Section 2.2.1).

3.2.1.3.1 Model Development

Several sources of information were used to develop the stormwater drainage system inputs for the PCSWMM model, including the following:

- CAD drawings of the stormwater drainage system provided by BFC
- Previous delineations presented in GBA (1989)
- Discussions with BFC personnel familiar with the BFC drainage system
- Observations made by Anchor QEA staff during oversight of installation of Phase 2 stormwater sampling equipment

The primary objective of the stormwater hydraulic (and hydrologic) model was to provide a time series of flows (and associated volumes) to apply in generating PCB load estimates delivered to Indian Creek and Blue River. Therefore, it was not necessary to fully simulate every component of the BFC stormwater system.

To develop the hydraulic model, the stormwater pipe network was represented by a series of major laterals and trunk storm drainage lines. Figure 3-10 shows the simplified stormwater drainage system simulated within the PCSWMM model, which is consistent with the actual BFC stormwater drainage system. For the most part, information regarding system junctions, pipe slopes and materials, manhole invert elevations, etc., was available in the CAD files provided by BFC; however, some information on the system configuration was provided by site personnel (Dibal 2014). Also, in order to properly simulate flow routing through the drainage system, several natural channels were simulated in the model using available topography data from the BFC (Figure 3-10).

Reduction in drainage system complexity was required for certain site areas, and the following assumptions were made regarding flow routing:

- Discharge occurs from the drainage system into the receiving waters under typical operating conditions (i.e., flood gates and flap gates are open).
- At junctions where two drainage networks intersect (where some flow split between systems is expected), flow is routed to the drainage system most likely to carry flow under typical operating conditions (i.e., lower pipe invert, larger pipe, and higher slope).
- Discharge from the drainage ditch at the northern portion of the site was split evenly between Outfall 001 and Outfall F.
- Runoff from the roof areas was routed directly into the main trunk lines and laterals specified in the model (versus through connecting sublateral connector pipes not represented in the model).

The hydrograph input locations for the 126 BFC subcatchment areas within the PCSWMM model are also shown on Figure 3-10. The hydrograph input location (or node) is simply the location where runoff from a particular drainage subcatchment area calculated using the WWHM4 hydrologic model enters the stormwater pipe network. At some locations, the simplifications made in the model stormwater pipe network required the combination of drainage subcatchment area hydrographs. In such cases, the combined discharge was added at the nearest downstream hydrograph input location in the PCSWMM model.

Finally, the PCSWMM model was executed using the kinematic wave flow routing method (USEPA 2011). Although the kinematic wave function allows for simulation of time-variable flows within the system, it does not account for flow reversals or interconnections between outfalls.[14] This modeling effort was focused on long-term water quality simulations; therefore, a fully dynamic simulation that could account for flow complexities such as flow reversals was deemed unnecessary, particularly considering the other constraints on the modeling effort (e.g., reduction in model complexity associated with pipe network simplifications).

3.2.1.3.2 Model Calibration

The hydraulic model predictions are most sensitive to: 1) the inflow hydrographs (provided by the calibrated hydrologic model described above); and 2) the representation of the stormwater pipe network within the model. As described above, the BFC stormwater pipe network was simplified to represent major laterals and trunk lines only and, therefore, does not include the relatively minor features of the BFC stormwater system (e.g., feeder lines). Consequently, during model calibration, some minor adjustments in flow routing were required to achieve good agreement between monitored and simulated flows (see Section 3.2.1.3.1). The lack of a long-term record of continuous flow monitoring at each of the BFC outfalls precluded a rigorous hydraulic model calibration effort. Rather, runoff volumes generated by the PCSWMM model were compared to those estimated based on the GBA (1989) methodology (described in Section 2.2.1.2 of the Work Plan; these are the flows used historically to estimate outfall PCB loads). Figure 3-11 shows a comparison of average annual flow rates from each outfall between the GBA (1989) methodology and the PCSWMM model simulation, for the period from 2003 to 2011. Volume estimates using the GBA methodology are not available for the alpha outfalls (B, C, D, and F); therefore, Figure

[14] Flow reversals at the BFC are expected to be localized and of short duration (i.e., backflow to detention storage areas near Outfalls 001 and 002 under receiving water levels), and would not measurably affect the simulated outfall runoff volumes used for the longer term PCB loading evaluation.

3-11 only shows the PCSWMM model estimate for these outfalls. As shown on Figure 3-11, the runoff volumes (expressed as average annual flow) predicted by PCSWMM are in relatively good agreement with the estimates made using the GBA methodology in terms of magnitude and relative distribution of volumes between the outfalls. The PCSWMM results do not exactly match the estimates developed using the GBA method because of general differences in the methodologies. The GBA method utilizes a simplified empirical runoff method with generic runoff coefficients, which does not directly account for factors included in the more robust PCSWMM continuous runoff simulation including flow-routing effects through the stormwater drainage system.

Time series of monitored and simulated flows during the two stormwater sampling events conducted for the Fate and Transport Study (at the four numeric outfall compliance points) are shown on Figures 3-12a through 3-12d. In summary, there is good agreement between measured and simulated runoff peak flow and volume in Outfall 003 (Figure 3-12c); the model performs best at this location (as compared to the other three outfalls), likely because there is no offline storage in Basin 003, and this outfall is not affected by high stage in Indian Creek. At Outfall 004, there is reasonably good agreement between simulated and observed runoff peak flow and volume for the August event; however, measured flows were unexpectedly low during the October event (Figure 3-12d). One possible explanation is the presence of an inlet obstruction that attenuated flow from this predominately paved parking area as has been observed by BFC staff in the past. At Outfall 002, monitoring data are only available for the August event.[15] During this event, observed flows are somewhat lower than those predicted by the model (Figure 3-12b). It is likely that the calibration at this location is affected by off-line storage and high stage in Indian Creek. Also, the period of flow measurement is truncated; therefore, the hydrograph does not reflect extended discharge from storage that may be occurring. Similarly, in Outfall 001, the calibration is likely affected by off-line storage and high stage in Boone Creek (Figure 3-12a). There is reasonable agreement between measured and simulated total runoff volume, but not peak flow—the third peak in the data during the August event may reflect storage outflow at lower creek stage that is not captured by the model. Overall the model provides a good representation of the hydraulics of the stormwater system and outfall flows (although at

[15] There was an issue with the flow monitor during the October event.

short timescales, it is less accurate), and is sufficiently accurate to provide a means of specifying PCB loads for the fate model.

3.2.2 Hydrodynamic Model

An in-stream hydrodynamic model was developed to simulate temporal and spatial changes in water depth, current velocity, and bed shear stress in Indian Creek and Blue River. This model was developed and calibrated using publicly available, site-specific data, as well as data collected as part of the Fate and Transport Study.

3.2.2.1 Model Development

3.2.2.1.1 Numerical Grid and Geometry

The spatial domain of the model includes 4.8 km of Blue River extending from I-435 to Highway 71, and 2.4 km of Indian Creek extending from Holmes Road to the confluence with Blue River. The numerical grid used for the model is composed of approximately 300 one-dimensional, cross section-averaged grid cells (200 grid cells in Blue River and 100 grid cells in Indian Creek). The average grid cell length was 80 feet and the average width was 60 feet. For upper Blue River and Indian Creek, the bed elevation for each grid cell was specified using bathymetry information obtained from the Federal Emergency Management Agency (FEMA) flood insurance study (FIS; FEMA 1990). For lower Blue River, initial model simulations indicated that the FEMA FIS bathymetry information produced water depths and current velocities that were not realistic (i.e., water depths and velocities in this reach were unrealistically deep and low, respectively). Thus, bed elevations in the lower Blue River were adjusted such that realistic model results were achieved (i.e., model predictions were consistent with water depth and current velocity data collected during the Fate and Transport Study). The numerical grid and specified bathymetry in the model domain (mapped to the model grid) are shown on Figures 3-13 and 3-14, respectively.

3.2.2.1.2 Boundary Conditions

The hydrodynamic model required specification of the following boundary conditions: 1) inflow at the upstream boundaries of Blue River and Indian Creek; and 2) water surface elevation at the downstream boundary of Blue River. Inflows at the two upstream boundaries were estimated using flow rate data collected at the Blue River USGS Gauge 06893500 (located 0.4 miles downstream of the confluence with Indian Creek, with a period of record from 1939 to present). Flow rate data collected at the Blue River gauging station, which represents the combined flow of Indian Creek and Blue River, were used to estimate inflows at the two upstream boundaries in Blue River and Indian Creek using drainage area proration. The watershed areas for Blue River and Indian Creek are 58 and 75 square miles, respectively (Figure 3-15). These two watersheds represent 56% and 44% of the total area for Indian Creek and Blue River, respectively. Thus, the inflow rate for Indian Creek was specified as 56% of the flow rate at USGS Gauge 06893500; similarly, the inflow rate for Blue River was specified as 44% of the flow rate at USGS Gauge 06893500.

The inflow rate for Indian Creek was compared to flow rate data at the USGS Gauge 06893390 (Indian Creek at State Line Road, Leawood, Kansas) located 3.5 km upstream of the BFC. This gauge was used instead of USGS Gauge 06893400 (Indian Creek at 103rd Street in Kansas City, Missouri), which was closer to the site, because of a 2-year gap in the data coverage of the latter. The peak flow rate during the historical record was 5,320 cfs. Figure 3-16 compares cumulative frequency distributions for the model inflow rate and measured flow rate at the Indian Creek gauge. These results indicate that the method used to estimate inflows at the upstream model boundaries in Indian Creek and Blue River is sufficiently reliable for the objectives of this study.

Water surface elevation at the downstream boundary was specified using stage height data collected at the USGS Blue River gauge, as well as information from the FEMA FIS report. Variation in the water surface elevation at the downstream boundary as a function of flow rate is shown on Figure 3-17. Data from the FEMA FIS are added for comparison and follow the regression trend. The rating curve (where Q is the flow rate in cubic feet per second, and η is the stage height in feet) can be described as follows:

$$Q < 100 \text{ cfs}, \eta = 758 \text{ feet} \quad (3\text{-}1)$$

$$Q > 100 \text{ cfs and } Q < 500 \text{ cfs}, \eta = 755 * Q^{8.19e-004} \text{ feet} \quad (3\text{-}2)$$

$$Q > 500 \text{ cfs and } Q < 2{,}100 \text{ cfs}, \eta = 734 * Q^{5.49e-003} \text{ feet} \quad (3\text{-}3)$$

$$Q > 2100 \text{ cfs and } Q < 40{,}000 \text{ cfs}, \eta = 683 * Q^{1.48e-002} \text{ feet} \quad (3\text{-}4)$$

3.2.2.2 Model Calibration

The hydrodynamic model was calibrated using water depth and current velocity data collected during water column sampling conducted as part of the Fate and Transport Study (as described in Section 2.2.2.1). Table 3-6 shows the dates of sampling and corresponding flow rates during the six water column sampling events.

Table 3-6
Sampling Dates and Flow Rates during Six Water Column Sampling Events

Flow Condition	Sampling Round	Sampling Period	Average Flow Rate (cfs)[1]
Low	1	September 9-10, 2013	25
	2	July 14-15, 2014	89
	3	August 28-29, 2014	40
	4	September 22-23, 2014	34
High	1	August 7-8, 2014	780
	2	October 2-3, 2014	1,068

Notes:
1 Daily average flow from USGS gauge at Blue River (06893500)

At each sampling location, current velocity and water depth were measured at three locations along a transect perpendicular to stream flow (along each bank and at mid-channel). Correlations between the measured water depth and flow rate for three sections of the site are shown on Figure 3-18.[16] During low-flow conditions, water depths ranged between 1 and 2 feet in the upstream section of Blue River and Indian Creek, with a somewhat wider range of 0.5 to 2 feet in the downstream section of Blue River. This larger range in water depth is consistent with the shallower bed slope in the downstream portion of Blue River. During higher flow conditions, water depths (nearshore) ranged between 1.5 and 3 feet in the upstream section of Blue River and Indian Creek, and between 2 and 3 feet in the downstream section of Blue River. Correlations between the measured current velocity and flow rate are shown on Figure 3-19. During low-flow conditions, current velocities were generally low and ranged between approximately 0.1 and 1 foot per second in the upstream section of Blue River and in Indian Creek. However, in the downstream

[16] Each water column sampling location in the three sections of the site is shown in a different color on this figure (as referenced on Figure 2-11), and is listed in downstream to upstream order.

section of Blue River, current velocities were generally lower because of the greater water depths in this area. During higher flow conditions, current velocities ranged between 0.5 and 4 feet per second in all three sections.
The hydrodynamic model was calibrated over two time periods: 1) September 2013, which included the first low-flow water column sampling event; and 2) July through October 2014, which included the remaining five water column sampling events. Time series of inflow and water surface elevation at the upstream and downstream boundaries for these two time periods are shown on Figure 3-20.

The hydrodynamic model is most sensitive to the effective bed roughness parameter, which determines the resistance to water flow within the stream channel. This parameter was adjusted to achieve the optimum agreement (i.e., calibration) between predicted and measured water depth and current velocity was the effective bed roughness. Typically, effective bed roughness ranges between 0.1 and 10 centimeters (cm; Blumberg and Mellor 1987). Effective bed roughness values of 1 cm for Blue River and 10 cm for Indian Creek resulted in acceptable agreement between measured and predicted water depth (Figure 3-21) and current velocity (Figure 3-22) during model calibration.[17] The higher effective bed roughness specified in Indian Creek is supported by a generally higher observed median particle diameter (D_{50}) in Indian Creek (Figure 3-23), and the presence of generally rockier substrate in this stream. Good agreement between predicted and measured current velocities was achieved in the upstream segment of Blue River and Indian Creek during low- and higher flow conditions. As discussed previously, bed elevation inputs in the downstream portion of Blue River needed to be modified (relative to the original FEMA data) to be consistent with observed water depths in this area. As such, the uncertainty in this adjustment has resulted in some uncertainty in the prediction of water depths in this area. That said, sediment transport model predictions are primarily controlled by current velocities predicted by the hydrodynamic model. Predicted current velocities are within a factor of 2 of the data in the downstream segment of Blue River. Thus, hydrodynamic model performance in the downstream segment of Blue River was considered acceptable to meet the objectives of the sediment transport modeling.

[17] Figures 3-21 and 3-22 are similar to Figures 3-18 and 3-19 (discussed previously), except Figures 3-21 and 3-22 have the addition of model results shown as black cross symbols.

3.2.3 Sediment Transport Model

An in-stream sediment transport model was developed to simulate the erosion, deposition, and transport of sediment in Indian Creek and Blue River. Specifically, the sediment transport model is used to simulate temporal and spatial changes in suspended sediment concentrations in the water column and bed elevation changes (i.e., bed scour depth and net sedimentation rate). This model was developed and calibrated using publicly available, site-specific data, as well as data collected as part of the Fate and Transport Study.

3.2.3.1 Model Development

The sediment transport model requires the following inputs: 1) sediment properties; 2) bed properties; and 3) boundary conditions. Sediment properties correspond to the physical properties of sediment particles (i.e., effective particle diameter and settling speed). Bed properties include bulk bed characteristics (e.g., dry density, grain size distribution). Boundary conditions for the sediment transport model are the sediment loads that are specified at various inflow locations. Data collected during field studies were used to develop these inputs including surface sediment texture observations, sediment probing results, sediment bed sample grain size distributions, and dry density data.

3.2.3.1.1 Sediment Properties

Streams such as Blue River and Indian Creek typically have suspended sediment particles with diameters that range from less than 1 µm clays to coarse sands with particle diameters on the order of 1,000 µm (van Rijn 1993). Sediment particles represented in the model were separated into five discrete size classes: 1) clay and silt with particle diameters less than 62 µm; 2) fine sand (62 to 250 µm); 3) medium/coarse sand (250 to 1,000 µm); 4) coarse sand and gravel (1,000 to 5,000 µm); and 5) gravel (greater than 5,000 µm). Use of these five size classes provides an adequate approximation of the grain size distribution of bed sediment needed to achieve the objectives of the Fate and Transport Study.

The effective diameters of the five sediment size classes are used to determine the settling speeds of Class 1, 2, 3, 4, and 5 particles; effective diameter values also affect the simulation of bed erosion. The settling velocity of clay/silt (Class 1) particles typically range between 1 and 40 m per day. The settling velocity of Class 1 (clay/silt) particles was specified as 10 m per day, which corresponds to an effective diameter of 15 µm. Effective particle diameters for sediment size Classes 2, 3, 4, and 5 were assumed to be 150, 1,000, 5,000 µm, and 15,000 µm, respectively. These values were specified based on a combination of professional judgment and modeling experience on similar riverine systems, and initial model testing.

3.2.3.1.2 Bed Properties

The sediment transport model requires specification of the following bed property inputs: 1) dry density; 2) sediment bed composition (i.e., relative amounts of sediment size Classes 1, 2, 3, 4, and 5); 3) the median particle diameter (D_{50}); and 4) effective bed roughness (which is proportional to the 90th percentile particle diameter [D_{90}]). Composite grain size distribution and dry density data were collected from 23 compositing reaches within the model domain as part of the sediment sampling conducted for the Fate and Transport Study (15 reaches in Blue River and 8 reaches in Indian Creek; see Section 2.2.2.2). Spatial distributions of D_{50}, D_{90}, and the dry density are shown on Figure 3-23.[18] Although there is some spatial variation in the D_{50}, particularly around the mouth of Boone Creek, the D_{90} and dry density data show less spatial variability. These three datasets demonstrate that the sediment bed in both Indian Creek and Blue River is composed predominantly of coarse sands and gravels.[19] The average D_{50} and D_{90} values were 5,000 and 12,300 µm, respectively. The average dry density was approximately 2 grams per cubic centimeter (g/cm^3).

Dry density data shown on Figure 3-23 generally ranged from 1.8 to 2.1 g/cm^3, with relatively low spatial variation. Thus, dry density of the bed was specified in the model as

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[18] Data from Indian Creek and Blue River are shown together on Figure 3-23. River kilometer 0 represents the location of the Indian Creek/Blue River confluence (i.e., negative river kilometers are upstream of the confluence and positive river kilometers are downstream).

[19] This is consistent with results of a sediment probing survey conducted for the Fate and Transport Study during a 7-day period between September 11 and 19, 2013 (see Section 2.3.1 of the DSR [Appendix A] for a description of the probing survey). Soft sediment probing depths and corresponding water depths were collected from 357 locations along Blue River and 194 locations along Indian Creek (see Figure 2-6 of the DSR [Appendix A]). Observations also included descriptions of sediment bed characteristics. The data indicated the presence of predominantly sand and gravel beds throughout the majority of the Study Area. While the sediment bed of Indian Creek and Blue River is composed of predominantly coarse sands and gravels, it also contains fine-grained sediment that is mixed with the coarser material. Sediment grain size data collected during the Fate and Transport Study indicate that, on average, sediments in Indian Creek and Blue River contain approximately 20% fines (mix of clay, silt, and fine sand), 10% medium sand, 25% coarse sand, and 45% gravel.

spatially constant at the average value of 2 g/cm^3. Similar to dry density, spatially constant average values of D_{50} (5,000 μm) and D_{90} (12,300 μm) were specified in the model. Specification of initial bed composition was determined from analysis of grain size distribution data. Spatially constant values of size Class 1, 2, 3, 4, and 5 bed content were 15%, 5%, 30%, 30%, and 20%, respectively.

3.2.3.1.3 Boundary Conditions

Temporally variable incoming sediment loads (i.e., magnitude and composition) were specified at the upstream boundaries in Blue River and Indian Creek using a sediment rating curve (i.e., correlation between total suspended solids [TSS] concentration and flow rate). The sediment rating curve was developed using TSS concentration and flow rate data collected at the USGS Blue River gauging station; a total of 76 TSS concentration samples were collected between 1999 and 2010 (Figure 3-24). Use of data collected at the USGS Blue River gauging station to specify inflow TSS concentrations at the upstream boundaries in Indian Creek and Blue River is a valid approximation because no significant tributaries exist between the upstream boundaries and the gauging station, so no significant increase in sediment load would be expected. Historical TSS concentration data collected between 1996 and 1999 by the BFC, as well as TSS data collected during water column sampling conducted as part of the Fate and Transport Study, are shown on Figure 3-24 for reference. These data were used to develop the sediment rating curve that can be described as follows:

$$Q < 100 \text{ cfs, TSS} = 35 \text{ milligrams per liter (mg/L)} \quad (3\text{-}5)$$

$$Q > 100 \text{ cfs and } Q < 300 \text{ cfs, TSS} = 1.895\text{e-}005 * Q\,\hat{}\,3.14 \text{ mg/L} \quad (3\text{-}6)$$

$$Q > 300 \text{ cfs, TSS} = 1{,}110 \text{ mg/L} \quad (3\text{-}7)$$

The sediment rating curve was used to specify a time series of incoming sediment loads for long-term sediment transport model simulations that was linked to the PCB fate and transport model. However, the sediment rating curve was not used to specify model inputs during the sediment transport model calibration process. The TSS concentrations at both upstream boundaries were set at 20 mg/L for the low-flow simulations, and the boundary condition values for the higher flow simulations were set at 100 and 200 mg/L for Indian Creek and Blue River, respectively.[20]

3.2.3.2 Model Calibration

Sediment transport model predictions are generally most sensitive to the following input parameters: 1) the spatial distribution of bed properties (i.e., D_{50} and bed composition); and 2) the thickness of the active layer (which impacts the erosion rate of a non-cohesive bed). As described previously, site-specific data were used to determine the spatial distribution of bed properties in Indian Creek and Blue River. Minor adjustments were made during initial model testing due to data limitations and uncertainty in bed properties in some areas of the system. Parameters that control the thickness of the active layer in the non-cohesive sediment bed were adjusted within an acceptable range (based on previous experience on similar systems). The primary calibration target for the sediment transport model was TSS concentration data collected throughout the site during the 2013 to 2014 water column sampling events. Comparisons of predicted and measured TSS concentrations (as a function of flow) are presented on Figure 3-25. Generally, these results demonstrate that there is acceptable agreement between predicted and observed TSS concentrations; however, the sediment transport model tends to under-predict TSS concentrations at higher flow rates in Indian Creek and in the portion of Blue River downstream of Indian Creek. One possible reason for the under-prediction of TSS concentrations during the calibration simulations

[20] A limited number of TSS concentration samples were collected during the Fate and Transport Study near the upstream boundaries under low-flow (seven samples) and high-flow (five samples) conditions. The low-flow average TSS concentration collected during the Fate and Transport Study was approximately 12 mg/L, whereas the high-flow average TSS concentration was approximately 60 and 190 mg/L at the Indian Creek and Blue River upstream boundaries, respectively. A much larger set of TSS concentration data, collected over a wide range of flow conditions, were available at the USGS gauging station (06893500), and these data were used to create the sediment rating curve presented on Figure 3-24. Comparison of TSS concentrations of samples collected near the upstream boundaries during the Fate and Transport Study to the TSS concentrations at the USGS gauging station indicated that the relatively small Fate and Transport Study dataset did not fully characterize incoming TSS concentrations at the upstream boundaries (in general, the TSS results from the Fate and Transport Study were somewhat lower than the data at the USGS gauging station). Thus, the TSS concentration data collected at the USGS gauging station were used to guide specification of incoming TSS during model calibration. Based on these data, in conjunction with knowledge of site conditions and professional judgment, it was determined that specifying incoming TSS concentrations at 20 mg/L for low-flow conditions and 100 to 200 mg/L for high-flow conditions was a valid approximation to be used during the model calibration process.

could be the exclusion of sediment loads from bank erosion (which is a process that has been observed in the model domain). Because bank soils contained low levels of PCBs, this was assumed to be an insignificant source of PCBs to Indian Creek and Blue River and, therefore, was excluded from the model. Nonetheless, they may be a source of clean solids under elevated flow conditions.

A longer term simulation (i.e., a 25-year period between 1990 and 2014) was conducted with the sediment transport model (and the hydrodynamic model) to evaluate the ability of the model to predict deposition patterns and net sedimentation rate over multi-year periods. This simulation was also used to support the PCB hindcast and future projection simulations described in Sections 3.2.4.4 and 3.3.2, respectively. Figure 3-26 shows a comparison of predicted net sedimentation rate (top panel) and the sediment thickness measured during the probing survey (bottom panel). The model reasonably captures the areas of net deposition, particularly at the confluence between Indian Creek and Blue River, and in Blue River near the mouth of Boone Creek.

3.2.4 PCB Fate and Transport Model

A PCB fate and transport model was developed to simulate spatial and temporal variations of PCB concentrations in the water column and sediment bed of Indian Creek and Blue River, using information from the calibrated hydrodynamic and sediment transport models. The PCB fate and transport model was developed and calibrated using available site-specific data, including data collected as part of the Fate and Transport Study.

3.2.4.1 Model Development

3.2.4.1.1 Numerical Grid

The spatial domain and numerical grid of the PCB fate and transport model is the same as that used for the hydrodynamic and sediment transport models (Figure 3-13). In addition, the sediment bed is simulated in the PCB fate and transport model using multiple layers; such discretization of the bed is necessary to properly simulate changes in surface sediment concentrations over time. The model was used to predict concentrations in the surficial sediment zone defined as the upper 4 inches of sediment in this application. A depth of 4 inches was selected to represent surficial sediments based on sediment probing information, which indicated that average sediment thickness throughout most of the site is on the order of 4 inches (see Table 2-1 of the DSR [Appendix A]); this depth was also selected based on experience and data at other sites indicating that the surficial sediment mixing zone is typically on the order of 4 to 6 inches (Anchor QEA 2013b). The 1-foot-deep bed model for the site was segmented into twelve 1-inch layers. Although the total simulated bed thickness does not necessarily correspond to the total thickness of sediments across the site, it provides ample resolution to allow for simulation of the surface sediment layer (i.e., top 4 inches), as well as potential interactions of the surface layer with sediments deeper than 4 inches, through scouring that may be associated with elevated flow events.

3.2.4.1.2 Model Calibration Period

The 22-month calibration period for the PCB fate and transport model extended from January 2013 through October 2014. This simulation period corresponds to the Fate and Transport Study in-stream water column data collection period. This period was considered representative of contemporary BFC stormwater loadings because it captures a number of stormwater flow events and covers a range of flow conditions in the receiving streams.

3.2.4.1.3 Model Inputs

The PCB fate and transport model was developed using a number of site-specific datasets to specify inputs to the model, including boundary conditions, time series of external (BFC outfall) PCB loads, initial sediment PCB concentrations, and water column and sediment organic carbon content. Also, several parameters representing physical and chemical-specific characteristics and fate and transport properties within the water column and sediment bed are required in the model. These values were developed from a combination of site data (when available), literature, and professional experience gained from model applications to other similar systems.

Boundary Conditions

The PCB fate and transport model requires specification of time-variable PCB concentrations at each of the model boundaries throughout the model simulation period. These boundaries are the same as those used for the hydrodynamic model and include: 1) an upstream boundary on Indian Creek at Holmes Road; 2) an upstream boundary on Blue River at I-435;

and 3) a downstream boundary on Blue River at Highway 71. Water column PCB samples were collected at all three of these boundary locations during the six water column sampling events conducted between September 2013 and October 2014 as part of the Fate and Transport Study. Figure 3-27 shows the locations of these boundaries and the associated water column sampling locations along with the other nine water column locations in Indian Creek and Blue River that were sampled as a part of the study. Surface water data at these boundary locations exhibited limited variability in PCB concentrations; as such, boundary condition concentrations were set to constant, average values calculated from the data. Table 3-7 contains a summary of the average water column concentrations at these three sampling locations.

Table 3-7
Mean Water Column PCB Concentrations at Boundary Locations

Location	Station	Total PCB (ng/L)	Number of Samples
Indian Creek Upstream	IC-UBC	0.39	6
Blue River Upstream[1]	BR-UBC	0.52	5
Blue River Downstream	BR-DBC	11.2	6

Notes:
1 One uncharacteristically high sample (19.8 ng/L) collected on September 22, 2014, was excluded from average.

External (BFC Outfall) Sources

Stormwater at the BFC is conveyed through an extensive network of storm sewer systems to four outfalls that discharge to Indian Creek (Outfalls 002, 003, and 004) and Boone Creek (Outfall 001). The hydrologic and hydraulic models applied to the site (see Section 3.2.1) are continuous simulation models that provide a time series of stormwater runoff flows at each of these four permitted outfalls and Boone Creek. This time series of stormwater flows predicted by the hydrologic and hydraulic models was combined with the composite stormwater PCB concentration data collected at the outfall compliance points (i.e., the sampling location closest to the end of the pipe) during the model calibration period to compute a time series of stormwater PCB loads. These loads were then used as input into the PCB fate and transport model.[21] The methodology used for this load calculation is consistent

[21] This includes stormwater data collected as part of the Fate and Transport Study, as well as stormwater monitoring data collected routinely by the BFC.

with that used for load calculations conducted by the BFC historically. Specifically, daily PCB loads were estimated by multiplying the daily runoff volumes predicted by the hydraulic model by PCB concentrations on the days of sampling. For days where sampling did not occur, or days where Aroclor PCB results (routinely collected by the BFC) were non-detect, loading was calculated using an assumed PCB concentration equal to the average concentration calculated from a combination of stormwater samples collected during the Fate and Transport Study, and stormwater congener PCB samples collected by the BFC during the PCB fate and transport model calibration period.[22] Approximately 3% of the calculated outfall loading is based on measured data; the remainder was derived from the assumed value used on days where sampling did not occur. Because of this, an evaluation of the model sensitivity to the assumed value used on un-sampled days was performed (see Section 3.2.4.3). Time series of calculated PCB loads that were input to the model for each outfall over the model calibration period are shown on Figure 3-28.

Initial Conditions

The PCB fate and transport model requires specification of an initial sediment PCB concentration within each grid cell and for each vertical layer within the simulated bed. Composite surface sediment data collected in 2014 as part of the Fate and Transport Study (see Section 2.2.2.2) were used to define the initial sediment PCB concentrations in the model domain. The samples collected were spatially composited surface grab samples and, therefore, represent a general characterization of PCBs within the top few inches of sediment. To properly simulate changes in surface sediment concentrations over time, the sediment bed in the model is discretized into twelve 1-inch layers (for a total simulated bed thickness of 1 foot). All twelve sediment bed layers in the model were assigned PCB concentrations from the surface grab samples—this is a conservative assumption based on probing conducted during sediment sampling, which indicated that the total sediment inventory in most areas of Indian Creek and Blue River is less than 6 inches on average. PCB

[22] Historically, the BFC has used a value of half of the minimum detection limit (50 ng/L; based on a low-resolution Aroclor PCB method) for days where sampling did not occur, or days where sampling results were non-detect. For model calibration, a value equal to the average concentration from the days of sampling during the calibration period was used (because the data collected from this period as part of the Fate and Transport Study were high resolution congener data, and represent contemporary stormwater PCB levels during the events that were sampled in 2014).

concentrations from each compositing reach were assigned to the corresponding PCB fate and transport model grid cells (Figure 3-29).

The PCB fate and transport model also requires specification of a water column initial condition. Because initial water column concentrations "wash through" the system relatively quickly (in a matter of hours), the model is insensitive to the water column initial condition; therefore, the initial water column concentration was set to zero throughout the model domain.

Sediment Organic Carbon

The PCB fate and transport model requires specification of the organic carbon content of sediments to facilitate calculation of contaminant partitioning in the bed. Total organic carbon was measured as part of the composite surface sediment sampling conducted for the Fate and Transport Study. Average total organic carbon concentrations (converted to a fraction organic carbon [f_{oc}] for input to the model) measured within each reach were assigned to the corresponding model grid cells (Figure 3-30). Sediment f_{oc} across the entire site is relatively low at approximately 1% to 2% by weight. It should be noted that the model requires specification of f_{oc} on all five sediment size classes simulated by the sediment transport model (see Section 3.2.3.1). All five sediment classes were assigned the same f_{oc} in the PCB fate and transport model because differences in f_{oc} with sediment grain size were not evident in the sediment data. Doing this effectively aggregates the various sediment classes for the purposes of simulating PCB fate and transport.

Water Column Organic Carbon

The PCB fate and transport model requires specification of organic carbon concentrations for water column particulate matter (f_{oc}). Water column particulate f_{oc} was calculated from direct measurements of particulate organic carbon (POC) and TSS collected during the Fate and Transport Study water column sampling events (f_{oc} = POC / TSS). Water column f_{oc} values varied over the five events for which POC was measured, with generally lower values observed during the two high-flow events (August 2014 and October 2014). Spatially, f_{oc} measured in the sampling events exhibited no clear pattern with most events having relatively constant f_{oc} across the site (Figure 3-31). There is some evidence of a correlation between f_{oc} and flow (i.e., f_{oc} is higher at lower flows); however, this difference between low and high flow f_{oc} is generally within a factor of 2. Due to the relatively limited degree of variation within the data, a spatially and temporally constant average value of 4.7% (based on data from all five events) for water column f_{oc} was specified in the PCB fate and transport model.

Partition Coefficients

Due to the hydrophobic nature of PCBs, partitioning between particulate and dissolved phases is a key process affecting PCB fate and transport in a surface water/sediment system. Partitioning of organic contaminants between the aqueous and sorbed (i.e., sediment) phases is described in the PCB fate and transport model using chemical-specific organic carbon equilibrium partition coefficients (K_{oc}). Selection of values for K_{oc} for use in the model was based on congener-specific K_{oc} values developed using a combination of K_{ow} values in Hawker and Connell (1988) (converted to K_{oc} using the relationship of K_{ow} to K_{oc} in DiToro [1985]) and the congener distribution of the site-specific sediment data. Analysis of site-specific data demonstrated spatial variability in PCB congener composition across the site. A relatively simple metric used to quantify PCB composition in a sample is the average number of chlorines per biphenyl (Cl/BP); Figure 3-32 shows a spatial profile of average Cl/BP in the sediment composite samples collected as part of the Fate and Transport Study. This figure shows that segments downstream of Outfall 002 (Segments IC-7 and IC-8 in Indian Creek and downstream of Segment BR-5 in Blue River; see Figure 2-16 for a map showing locations of the various reaches) have a less chlorinated PCB signature (2 to 4 Cl/BP) as compared to upstream segments (4 to 6 Cl/BP). This is consistent with the nature of historical PCB discharges at the BFC (i.e., lower chlorinated Aroclor 1242 was the predominant Aroclor used in Basin 002, whereas higher chlorinated Aroclor 1260 was present in Basins 003 and 004). Because of these spatial differences in composition, spatially variable K_{oc} values were specified for the water column and sediment in the PCB fate and transport model (Table 3-8).

Table 3-8

Spatially Variable Partition Coefficients Used in the Model

Location	Log K_{OC} (liters per kilogram)
Indian Creek Upstream of Outfall 002	5.9
Indian Creek Downstream of Outfall 002	5.1
Blue River Upstream of Confluence with Indian Creek	5.4
Blue River Downstream of Confluence with Indian Creek	5.1

Parameterization for Water Column and Sediment Bed Processes

Several parameters representing physical and chemical-specific characteristics and fate and transport properties within the water column and sediment bed are required in the model. Examples of these parameters include water temperature, volatilization rate coefficients, sediment bed properties such as bulk density and porosity, surface porewater exchange coefficient (k_f), surface sediment mixing (bioturbation) rate, and porewater diffusion coefficient. These values, which are listed in Table 3-9, were developed from a combination of site data (when available), literature, and professional experience gained from model application to other similar systems.

Table 3-9

Summary of Parameterization for Water Column and Sediment Bed Processes

Parameter	Description and Application in Model	Data Source(s)	Value
Water Column Parameters			
Water Temperature	The rates of most kinetic reactions in natural waters increase with temperature (e.g., Chapra 1997). Water temperature is used within the PCB fate and transport model to account for such temperature effects. A monthly average temperature function was developed for the model based on available site data.	• USGS Gauge 6893390 on Indian Creek (2007 to 2015) • Temperature measurements from 2013 to 2014 Fate and Transport Study water column sampling	Annual temperature function shown on Figure 3-33
Volatilization Parameters	The model computes volatilization flux for each model grid cell dynamically over the course of a simulation. The following parameters are needed as inputs to support these calculations.		
Henry's Law Constant (HLC)	The model uses the input value of HLC divided by the product of the absolute water temperature and universal gas constant to dynamically calculate a unitless HLC.	Literature (Brunner et al. 1990)	12 J/mol
PCB Concentration in Ambient Air	Set to zero because atmospheric PCB concentrations are typically several orders of magnitude lower than those in water	Professional judgment	0
Wind Speed	Constant average value specified based on wind data from Dodge City	1930 to1996 (NOAA 1998)	4.9 m/s
Molecular Weight of PCB	Used to calculate Schmidt Number of the contaminant in air and water as a function of temperature. Value represents weighted molecular weight based on average congener composition observed in surface water samples		313 g/mol
Molar Volume of PCB	Used to calculate Schmidt Number of the contaminant in air and water as a function of temperature. Value represents weighted molecular volume based on average congener composition observed in surface water samples	Congener-specific molar volumes from Mackay et al. 1992	281 cm^3/mol

Table 3-9

Summary of Parameterization for Water Column and Sediment Bed Processes

Parameter	Description and Application in Model	Data Source(s)	Value
Sediment Bed Parameters			
Bulk Density	Physical property of the sediment bed	Consistent with value used in the sediment transport model	1.96 g/cm^3
Porosity	Physical property of the sediment bed	Calculated from bulk density and assumed particle density of 2.6 g/cm^3	0.25
Mass Transport Parameters			
Porewater Diffusion Coefficient	Diffusive transport of contaminants within sediment porewater is computed in the model using a molecular diffusion coefficient, which is adjusted by a tortuosity factor to account for porous media effects	4.89 E-06 cm^2/s (Hayduk and Laudie 1974) and accounting for tortuosity using relationship developed by Millington and Quirk for unconsolidated sediment, which relates tortuosity to the porosity of the sediment	7.71E-07 cm^2/s
Surface Porewater Exchange Coefficient	Represents the combined effects of a number of processes occurring at the sediment surface that result in a dissolved-phase mass transfer at the sediment-water interface (e.g., diffusion, bioturbation-driven porewater release, gas ebullition, and groundwater advection)	Calibration parameter	8 cm/day
Mixing (Bioturbation) Rate	Fate and transport model represents mixing by bioturbation as a vertical dispersion process	Thoms et al. 1995; Clarke et al. 2001	1.0E-06 cm^2/s
Mixing (Bioturbation) Depth	Depth over which the mixing rate is applied		10 cm

Notes:
cm/day – centimeters per day
cm^2/s – square centimeters per second
cm^3/mol – cubic centimeters per mole
g/cm^3 – grams per cubic centimeter
g/mol – grams per mole
J/mol – joules per mole
m/s – meters per second

3.2.4.2 Model Calibration

The model calibration period selected for the PCB fate and transport model was the 22-month period from January 2013 through October 2014. This simulation period was selected because it corresponds to the Fate and Transport Study in-stream water column data collection period. The calibration process focused on reproducing spatial patterns and relative magnitudes of water column PCB concentrations observed during the four low-flow and two high-flow events conducted during the Fate and Transport Study. Sensitivity analyses conducted during model calibration indicated that the parameters to which the PCB fate and transport model is most sensitive are the surface porewater exchange coefficient (k_f) and partition coefficient (K_{oc}). The PCB fate and transport model employs k_f to represent the combined effects of a number of processes occurring at the sediment surface that result in a dissolved-phase mass transfer at the sediment-water interface (e.g., diffusion, bioturbation-driven porewater release, gas ebullition, groundwater advection). The final calibrated k_f value for Indian Creek and Blue River was 8 cm per day, which is well within the range of values used for modeling PCBs at other sites (e.g., USEPA 2000; Anchor QEA 2012a). Also, as noted in Section 3.2.4.1.3, spatially varying partition coefficients were specified in the PCB fate and transport model; the decision to do this was partly informed by sensitivity analyses and model calibration (in addition to the site-specific PCB composition data), which indicated the use of a single, average K_{oc} could not generate a water column PCB spatial profile that matched the observed data.

The comparison of model-predicted and observed water column total PCB concentrations in Indian Creek and Blue River under low-flow conditions (less than 100 cfs) is presented on Figure 3-34.[23] In general, the model captures the observed longitudinal gradients in PCB concentrations across the site. Specifically, the model generally reproduces the observed increase in PCBs across the portion of Blue River downstream of the Indian Creek confluence; however, the model under-predicts the average concentration at the

[23] On this figure, the low-flow data are presented as points (average +/- two standard errors) at the sampling station in which they were collected. Green symbols represent water column data collected in Indian Creek, and blue symbols represent water column data collected in Blue River. For comparison to these data, model results on low-flow days (less than 100 cfs) were averaged temporally over the 22-month calibration period for each grid cell, as shown by the solid line; the ranges associated with the model averages are also indicated on these figures as dashed lines.

downstream-most sampling location (recognizing that the error bars associated with the average at that location are relatively large). The model also generally captures the increase in PCB concentration observed at the sampling location downstream of Outfall 002, although the magnitude of the increase is over-predicted, on average.

Figure 3-35 depicts the spatial profiles of observed and model-predicted water column PCB concentrations for the individual sampling events, including the four low-flow events that were averaged on Figure 3-34 and the two high-flow events sampled during the Fate and Transport Study. The model generally captures the observed longitudinal gradients in PCB concentrations across the site under both low- and high-flow conditions. One exception is that the model does not capture the relatively high concentrations observed throughout most of Indian Creek during the October 2014 high-flow event. This may be due to some localized resuspension of bottom sediments during this high-flow event that the model did not capture, or possibly the grab sampling conducted during the event was not representative of average stream conditions (because the samples were collected from shore, as the center of the channel could not be accessed safely). Nonetheless, this elevated loading was not consistently observed in the sampling results from other events.

Figure 3-36 shows a time series of model-predicted surface sediment concentrations averaged over four different spatial reaches including: 1) Indian Creek upstream of Outfall 002; 2) Indian Creek downstream of Outfall 002; 3) Blue River upstream of the Indian Creek/Blue River confluence; and 4) Blue River downstream of the Indian Creek/Blue River confluence. There is almost no change in sediment PCB concentration over time in the stream segments upstream of any influence of the BFC (upstream of Outfall 002 in Indian Creek and Blue River upstream of Indian Creek). In the areas where sediment PCB levels are elevated relative to these areas due to historical loadings from BFC (i.e., downstream of Outfall 002 in Indian Creek, and Blue River downstream of Indian Creek), the model is predicting a decline in sediment PCB concentrations of approximately 20% over the 22-month calibration period. Such a decline may be indicative of the system's continued response to stormwater PCB loading abatement measures conducted on the plant site in conjunction with in-stream natural attenuation processes, such as sediment deposition.

3.2.4.3 Model Sensitivity to Stormwater PCB Load Calculation Assumptions

There are a considerable number of days during a given year where stormwater discharge occurs and it is not sampled. As noted in Section 3.2.4.1.3, approximately 3% of the calculated outfall loading during the model calibration period is based on PCB concentrations actually measured in the discharge; the remainder were derived from an assumed value used on days when sampling did not occur. Therefore, there is considerable amount of uncertainty in the estimated BFC outfall loads. The sensitivity of the model to this uncertainty was evaluated by using different assumptions for PCB concentrations on days where sampling did not occur.

The base calibration of the model used PCB concentrations equal to the average concentration calculated from a combination of stormwater samples collected during the Fate and Transport Study, and stormwater congener PCB samples collected by the BFC during the PCB fate and transport model calibration period. For the sensitivity analysis, three other assumptions were evaluated including: 1) the 50 ng/L Aroclor PCB detection limit used by the BFC historically to evaluate trends in outfall PCB loading; 2) the maximum concentration observed during the PCB fate and transport model calibration period; and 3) the 90th percentile concentration observed during the model calibration period. A summary of these values for each outfall is provided in Table 3-10. The use of these different assumptions produced a range of outfall PCB loads that varied by nearly a factor of 10.

Table 3-10
Summary of PCB Concentrations used for Sensitivity Analysis

PCB Statistic	Outfall PCB Concentration on Days Not Sampled (ng/L)			
	001	**002**	**003**	**004**
Average	22	115	26	3
BFC Historical Value	50	50	50	50
90th Percentile	31	196	61	10
Maximum	93	534	83	21

Figures 3-37 and 3-38 show time series overlays of model-predicted water column and sediment PCB concentrations for the base calibration and each of the sensitivity cases. These figures demonstrate that the model predictions are relatively insensitive to the load calculation methodology. This insensitivity is due to the fact that the outfall loads are a relatively small component of the overall PCB load to the system, even when these loads are varied by as much as a factor of 10 (see mass balance results presented in Section 3.3.1, which show the relative contributions of the various PCB sources to the water column of Indian Creek and Blue River).

3.2.4.4 Hindcast Simulation

In addition to the calibration of the model to contemporary conditions over a 22-month period, a "hindcast" simulation was conducted with the calibrated model to test model performance over a longer timeframe and under different (historical) loading conditions. As described in Section 2.2.2.4, fish tissue sampling has been conducted since the early 1990s; therefore, this dataset provides a means of evaluating the model's predictive ability over time, and under loading conditions that differ from contemporary conditions. Because measured fish tissue PCB concentration data are available dating back to 1991, the hindcast simulation was conducted over the 25-year period from 1990 through 2014.

For this hindcast simulation, a long-term hydrodynamic and sediment transport model simulation (utilizing hydrodynamic conditions in Indian Creek and Blue River over this 25-year period) was first conducted (as described in Section 3.2.3.2). Results from these simulations were input to the calibrated PCB fate and transport model. As discussed in Section 3.2.4.1.3, the PCB fate and transport model requires the specification of an initial PCB concentration in sediments at the beginning of a simulation. Because there was no site-wide characterization of sediment PCB concentrations in Indian Creek and Blue River in 1990, an initial sediment PCB concentration was estimated by backward-extrapolating based on the initial conditions used for the 22-month calibration and the rate of decline in sediments predicted by the model over that timeframe. In other words, the rate of decline predicted during the 22-month model calibration period (shown on Figure 3-36) was extrapolated backward to estimate a starting concentration in 1990 for the hindcast simulation (an example of this extrapolation is shown on Figure 3-39 for Segment BR-6).

The PCB fate and transport model hindcast simulation also required specification of a time series of outfall PCB loads starting in 1990. These loads were calculated using the same method described in Section 3.2.4.1.3 for model calibration (i.e., daily PCB loads were estimated by multiplying the daily runoff volumes predicted by the hydraulic model by PCB concentration[24]). It should be noted that outfall PCB concentration data were available dating back to 1996, but were unavailable for the period from 1990 to 1995—for this period, average outfall PCB concentrations from 1996 were used to estimate outfall PCB loads. The time series of outfall PCB loads used for the hindcast simulation are shown on Figure 3-40 (summed annually for this graphic).

Water column and sediment PCB concentrations predicted by the PCB fate and transport model over the 25-year hindcast period are shown on Figures 3-41 (averaged monthly) and 3-42, respectively. These exposure concentrations were input into the calibrated bioaccumulation model to predict a time series of fish concentrations over this period. An evaluation of model performance during the hindcast simulation (based on a comparison between observed and model-predicted fish PCB concentrations) is provided in Section 3.2.5.3.

3.2.5 Bioaccumulation Model

A bioaccumulation model was developed to calculate PCB concentrations in the aquatic food web (i.e., invertebrates and fish) of Indian Creek and Blue River, using water column and sediment exposure concentrations predicted by the calibrated PCB fate and transport model. The bioaccumulation model was developed and calibrated using available site-specific data, and relevant information from the literature.

3.2.5.1 Model Development

3.2.5.1.1 Spatial Domain

The spatial domain of the bioaccumulation model is the same as that described above for the PCB fate and transport model (shown on Figure 3-13). The bioaccumulation model domain was divided into six exposure areas spanning a number of the PCB fate and transport model grid cells. This was necessary because the simulated fish species forage over longer distances

[24] For days where sampling did not occur, or days where sampling results were non-detect, loading was calculated using an assumed PCB concentration equal to half of the minimum detection limit (50 ng/L) consistent with the outfall PCB loading calculation method employed by the BFC historically.

than the relatively small grid cells used for the other models). These exposure areas were delineated based on a combination of physical constraints that could limit the movement of fish (e.g., the presence of low head dams at the upstream end of Indian Creek), the locations where fish data were collected, and other site data such as water depth/bathymetry. The six exposure areas are shown on Figure 3-43; this figure also shows the locations where fish have been collected historically.

3.2.5.1.2 Model Calibration Period

As described in Section 3.2.4.1.2, the PCB fate and transport model calibration period extended from January 2013 through October 2014, corresponding to the Fate and Transport Study data collection period. The sediment and water column total PCB concentrations estimated by the PCB fate and transport model during this period were used as exposure concentrations input to the bioaccumulation model. Bioaccumulation model results were averaged over this calibration period and compared to the 2012 fish data.

3.2.5.1.3 Model Inputs

The bioaccumulation model relies on several parameters to describe the food web structure, species-specific bioenergetics and body composition, water temperature, and uptake and loss of PCBs. The various model parameters are described in the following subsections.

Food Web

The food web for the PCB bioaccumulation model consists of four trophic levels (TL1 to TL4; Figure 3-44). TL1 is the lowest trophic level and represents both water column and surficial sediment algae and detrital particulate organic matter. TL2 consists of two functional groups: deposit-feeding invertebrates and algae/detritus-feeding invertebrates. Invertebrates are consumed by forage fish (TL3), which in turn can be consumed by larger predatory fish (TL4). Channel Catfish and Green Sunfish are the primary fish species targeted for sampling and analysis in Indian Creek and Blue River; therefore, these species form the basis of the representative food web. Channel Catfish is a TL4 predatory fish and Green Sunfish is TL3 prey fish.

For the purpose of quantifying PCB transfer, invertebrates (TL2) are distinguished by their degree of bioaccumulation and exposure source—either water column via ingestion of algae or freshly deposited detritus, or sediments through the ingestion of sediment particles by deposit feeders. The relative importance of these two categories of invertebrates, herbivores/detritivores and deposit feeders, is based on prey availability in the system and feeding preferences of Green Sunfish and Channel Catfish. A biota-sediment accumulation factor (BSAF; i.e., ratio of lipid-normalized tissue concentration to organic carbon-normalized sediment concentration) was used to describe accumulation of PCBs in invertebrates feeding on particulate matter (i.e., algae, detritus, or sediment). The BSAF for sediment was calculated based on paired Asiatic clam and sediment data collected from the site at locations BLK 25, BLK 27, and ICK 0.2 in 2005[25]; the resulting BSAF values were 1.4, 2.3, and 1.6 at each of these locations, respectively. For model inputs, the BSAF values for the Blue River locations were based on the average of BLK 25 and BLK 27 (1.8) and the value calculated at ICK 0.2 was used for the Indian Creek stations. These values fall within the expected range based on similar invertebrate BSAFs reported in the literature (Wong et al. 2001; Connolly et al. 1992; Morrison et al. 1996; and Lamoureux et al. 2011).

Green Sunfish consume primarily zooplankton as juveniles and graduate to feeding primarily on other invertebrates and small fish as adults (Stuber et al. 1982). Consumed invertebrates typically consist of mayflies, chironomids, various unidentified insects, snails, and crayfish (Vadas 1990; Etnier 1971; Buck and Cross 1951). These prey items were divided into herbivores/detritivores and deposit feeders, and the relative proportions consumed by Green Sunfish for the model was based on the literature cited above (Table 3-11).

[25] This calculation utilized organic carbon data from the 2014 Fate and Transport Study sediment sampling program because organic carbon was not measured in the 2005 study.

Table 3-11
Green Sunfish Diet

Green Sunfish	Herbivores/ Detritivores	Deposit Feeders	Green Sunfish	
			Age 2	Age 3
Age 1	0.80	0.20		
Age 2	0.80	0.20		
Age 3	0.70	0.30		
Age 4	0.60	0.30	0.20	
Age 5	0.50	0.30	0.10	0.10
Age 6	0.40	0.40	0.10	0.10
Age 7	0.40	0.40	0.10	0.10
Age 8	0.40	0.40	0.10	0.10

Channel Catfish are omnivorous and their diet changes based on region, habitat type, and prey availability (Jearld and Brown 1971; Carlander 1969). In general, Channel Catfish feed primarily on invertebrates as juveniles and on filter-feeding and benthic fish as adults. Brown bullhead was introduced into the model to represent benthic fish prey. The Channel Catfish diet for the model (based on the literature cited above) is summarized in Table 3-12.

Table 3-12
Channel Catfish Diet

Channel Catfish	Herbivores/ Detritivores	Deposit Feeders	Green Sunfish					Brown Bullhead			
			Age 1	Age 2	Age 3	Age 4	Age 5	Age 1	Age 2	Age 3	Age 4
Age 1	0.50	0.50									
Age 2	0.50	0.25	0.25								
Age 3	0.50	0.25	0.25								
Age 4	0.50	0.25	0.25								
Age 5	0.50	0.25	0.25								
Age 6	0.45	0.15		0.30				0.10			
Age 7	0.30	0.10		0.30				0.25			
Age 8	0.20			0.35				0.45			
Age 9	0.20				0.35				0.45		
Age 10	0.20				0.35				0.45		
Age 11	0.20				0.35				0.45		
Age 12	0.20					0.35				0.45	
Age 13	0.20					0.35				0.45	
Age 14	0.20					0.35				0.45	
Age 15	0.20						0.35				0.45

The efficiency with which PCBs are assimilated from food was set to 0.8 based on the literature (Connolly et al 1992).

Growth

Growth is specified in the model as age- and time-dependent changes in body weight. To parameterize weights for each age class, length-weight curves with the best fit to the Indian Creek and Blue River data were selected from the literature for Green Sunfish (Swingle 1965) and Channel Catfish (Anderson 1980; Figure 3-45); the weight breaks for each age class were determined from literature-based, length-age relationships.

Lipid Content

Modeled lipid values were parameterized using the site data from 2012. Because the model computes uptake and elimination of PCB concentrations on a lipid basis, the weighted-harmonic mean (H_{f_l}) was deemed to be more representative of average lipid values than the arithmetic mean[26]:

$$H_{f_l} = \frac{1}{\sum_{i=1}^{n} \frac{v_i}{\sum_{i=1}^{n} v_i} * \frac{1}{f_{l_i}}}$$

where:

v_i = fish total PCB concentration (mg/kg wet-weight)

f_{l_i} = fish lipid fraction (gram lipid/gram wet-weight)

The AQFDCHN model simulates whole fish; thus, the model requires lipid contents as a fraction of the whole body wet weight. Because the available site data are fillet samples, whole body to fillet conversion factors were taken from the literature. For Channel Catfish, adult fish (10+ years) whole body lipid contents were set equal to fillet lipid contents, and for intermediate sized fish (7 to 10 years), a factor of 1.6 was used (based on Kohler and Heidinger 1994).[27] For Green Sunfish, a whole body to fillet ratio of 7.5 was used (ENVIRON 2010). The resulting lipid values used for the model calibration are presented in Table 3-13.

Table 3-13
Fish Lipid Content

	Percent Lipids		
	Channel Catfish		Green Sunfish
Site	Ages 1 to 10	Ages 11 to 15	All Ages
ICK 3.0	6.4	4.0	4.5
ICK 1.0	4.8	3.0	5.5
ICK 0.2	2.7	1.7	4.3
BLK 31	4.2	2.6	6.3
BLK 27	5.0	3.1	6.0
BLK 25	5.0	3.1	6.5

[26] The bioaccumulation model computes uptake and elimination of PCB concentrations on a lipid basis. Model results are compared to averages of the measured data on a lipid and wet-weight basis. By weighting the lipid contents of each fish included in the average by its PCB concentration, better agreement in the relative wet-weight and lipid-based concentrations predicted by the model and those measured in the fish is obtained.

[27] The ratio for younger fish (greater than 7 years) from the same reference is closer to 1.9 but there are few fish collected from the site in this age category.

Respiration

Respiration rate is calculated in the bioenergetics portion of the model from an organism's weight, the temperature of the water, an activity multiplier, and empirical coefficients from allometric relationships. The weight of the organism is based on its growth rate, as described above. The temperature profile is based on measurements taken from Indian Creek. The activity multipliers and empirical coefficients were based on literature values; values for Channel Catfish were developed from Andrews and Matsuda (1975) and Blanc and Margraf (2002), and values for Green Sunfish were based on values for Longear Sunfish available from Hansen et al. (1997).

Contaminant Mass Transfer at the Gill

Estimation of the lipid/blood partition coefficient is required for the computation of the contaminant loss rate across the gills. The octanol-water partition coefficient (K_{ow}) is used as an estimate of this model parameter and was estimated based on the observed PCB congener composition in the 2012 fish dataset. The rate of contaminant exchange between water and the organism is also controlled by the efficiency with which the contaminant is absorbed from the water. This chemical uptake efficiency was approximated to be 0.54 based on its relationship to K_{ow} (Connolly et al. 1992; Arnot and Gobas 2004).

3.2.5.2 Model Calibration

The bioaccumulation model was calibrated to the Channel Catfish and Green Sunfish PCB data (both Aroclor and congener total PCB data) collected during 2012 using water column and sediment PCB exposure concentrations predicted by the calibrated PCB fate and transport model. The bioaccumulation model is generally most sensitive to these water column and sediment PCB exposure concentrations, but is also sensitive to the lipid/blood partition coefficient, lipid content, and diet. As described in the preceding section, K_{ow} was used as an estimate of the lipid/blood partition coefficient and was estimated based on the observed PCB congener composition in 2012 fish dataset. Similarly, lipid contents were calculated from the 2012 fish dataset. Thus, these parameters are well-constrained. However, although there is some uncertainty in the literature-based diets specified for Green Sunfish and Channel Catfish, these diets resulted in reasonable agreement between model predictions and data, suggesting that the food web is reasonably represented in the model.

Because the AQFDCHN model simulates PCB concentrations in whole fish, the whole body to fillet ratios described above were applied to the model outputs for comparison with the fillet data collected by the BFC. Model results for each age class were also weighted by the proportion of that age class observed in the 2012 data collected at the site.
PCB concentrations predicted by the bioaccumulation model for Green Sunfish generally show good agreement with the data collected in 2012 at most locations (Figure 3-46a). Specifically, the model predictions are generally within 2 standard errors of the mean at ICK 0.2 and BLK 27, but tend to somewhat overestimate and underestimate the mean concentrations at ICK 1.0 and BLK 25, respectively (Figure 3-46a). At the background locations in Indian Creek and Blue River (ICK 3.0 and BLK 31), the model underestimates the data. Model-predicted PCBs for Channel Catfish also generally compare well with measured data at all locations, with the exception of the lipid-based results at BLK 27, which are over-predicted by the model (Figure 3-46b).

3.2.5.3 Hindcast Simulation

Water column and sediment exposure concentrations predicted by the PCB fate and transport model over the 25-year hindcast period (described in Section 3.2.4.4) were input into the calibrated bioaccumulation model. For this simulation, measured lipid values for historical fish collected prior to the 2012 calibration were utilized; however, no other changes were made to the bioaccumulation model inputs/parameters. Figures 3-47 and 3-48 show a time series of model-predicted PCB concentrations in Green Sunfish and Channel Catfish, respectively, by location. With the exception of fish collected at the upstream boundary locations on Indian Creek and Blue River (ICK 3.0 and BLK 31), the model reasonably captures the general decline in fish tissue PCB concentrations observed at nearly all locations. Moreover, the model also captures the differences in concentration observed among the various sampling locations. At the upstream boundary locations, contemporary sediment concentrations are very low, and exhibit no apparent change in concentration over time during the 22-month model calibration period. Because of this lack of change, there is no way to reasonably estimate starting sediment concentration for the hindcast simulation.

In summary, the good agreement between observed and predicted fish tissue PCB concentrations over this 25-year historical period is a validation of both the PCB fate and transport model (which was used to provide historical exposures for the bioaccumulation model) and the bioaccumulation model. Despite the relatively limited data available over this historical period, the models are able to generally capture the historical temporal trends in fish.

3.3 Model Application

3.3.1 Mass Balance

The calibrated PCB fate and transport model was used to develop a water column mass balance to assess the relative magnitude of the various PCB sources and sinks in the system. Table 3-14 summarizes the water column PCB mass balance calculated by the PCB fate and transport model over the 22-month calibration period. For this summary, the model domain was divided into four segments: 1) Indian Creek; 2) Blue River upstream of Indian Creek; 3) Blue River between Indian Creek and Boone Creek; and 4) Blue River downstream of Boone Creek.

Table 3-14
Water Column Mass Balance

			Mass Balance by Reach			
	Mechanism	**Site-wide Mass Balance**	**Indian Creek**	**Blue River (Upstream of Indian Creek)**	**Blue River (Indian Creek Confluence to Boone Creek)**	**Blue River (Downstream of Boone Creek)**
Sources	Upstream Advection	20%	34%	99%	63%	64%
	BFC Outfalls	3%	6%	---	---	1%
	Boone Creek (excluding Outfall 001)	17%	---	---	---	18%
	Sediment Erosion	3%	2%	0%	2%	1%
	Sediment Porewater Exchange	57%	58%	1%	35%	16%
	Total	**100%**	**100%**	**100%**	**100%**	**100%**
Sinks	Downstream Advection	92%	99%	98%	95%	92%
	Deposition to Sediments	2%	<1%	0%	3%	6%
	Volatilization	6%	1%	2%	2%	2%
	Total	**100%**	**100%**	**100%**	**100%**	**100%**

The PCB mass balance indicates that the majority of the PCB load to the water column in Indian Creek and Blue River originates from a combination of background sources upstream of the BFC and in-stream sediments (via porewater exchange) within the model domain. For example, on a site-wide basis, 20% of the PCB load to the water column in the model domain originates from sources in Indian Creek and Blue River upstream of the BFC, and nearly 60% of the load to the water column originates from internal bedded sediments via sediment porewater exchange. The next largest loading is that from Boone Creek (17% on a site-wide basis, excluding contributions from Outfall 001 during storm events). The nature of sources in Boone Creek are not fully understood, but a large component of this loading is likely derived from bedded sediments in the creek and/or other sources within the Boone Creek watershed besides Outfall 001. By contrast, the BFC outfalls contribute a relatively small proportion of the total load to the water column during the calibration period (3% on a site-wide basis).

3.3.2 Future Stormwater Scenarios

3.3.2.1 Scenario Description

Two stormwater loading scenarios were evaluated using the calibrated models:

- **Scenario #1: Continuation of Contemporary Outfall Loadings.** For this simulation, contemporary (i.e., 2013/2014) BFC stormwater PCB loadings were assumed to continue unabated into the future. As such, this scenario can be considered a “no further action” scenario that provides estimates of future PCB concentrations in sediment and fish if stormwater PCBs were to remain at current levels. This simulation also provides a means to evaluate the effects of in-stream natural recovery processes (e.g., ongoing sediment deposition) on future surface sediment and fish PCB concentrations.
- **Scenario #2: Complete Cessation of Outfall Loadings.** For this simulation, BFC stormwater PCB loadings were assumed to be zero for all four outfalls (001[28], 002, 003, and 004). This scenario is intended to represent redevelopment of 100% of the

[28] In this scenario, the Outfall 001 PCB loading is assumed to be zero; however, there is still continued loading from Boone Creek to Blue River defined based on observed water column concentrations and flows in Boone Creek.

BFC site, including abandonment of all existing BFC subsurface stormwater infrastructure.

These two scenarios represent upper and lower bound future BFC PCB loading scenarios. Because redevelopment plans for the BFC site have not yet been finalized, it is possible that a scenario between these two bounding conditions may be selected (i.e., a scenario could be selected that includes partial abatement of the BFC stormwater PCB load).

3.3.2.2 Approach and Setup

Long-term projection simulations were conducted over a 25-year period starting in 2013.[29] These future projections used hydrologic conditions from the hindcast simulation described in Section 3.2.4.4; this approach of using historical hydrodynamic information to project future conditions assumes that flows in the future will be statistically similar to those observed in the past. Specifically, the 25-year time series of hydrologic conditions for the model projections was constructed by applying two full series of outfall flows (predicted by the calibrated hydraulic model) and in-stream flows (predicted by the in-stream hydrodynamic model) measured/calculated from 2001 to 2012.[30] That is, outfall and in-stream flows in model projection Years 1 through 12 were assumed to be equal to those calculated/measured in 2001 through 2012, as were outfall and in-stream flows in model projection Years 13 through 24. Flows applied to the 25th projection year were set equal to flows measured/calculated in 2001.

For Scenario #1 (Continuation of Contemporary Outfall Loadings), a time series of stormwater PCB loads for each of the four outfalls was constructed by multiplying daily runoff volumes from the hydraulic model (over the 25-year forecast period described above) by the corresponding PCB concentration. Consistent with the methodology used to calculate contemporary outfall PCB loading for the 22-month calibration period, the load calculations

[29] The model forecast simulations were started at the same point in time as the model calibration (January 2013); however, the model calibration was conducted over a 22-month period (from January 2013 through October 2014), whereas the forecast simulated 25 years into the future.
[30] The 25-year time series of flows was constructed using two cycles of this full 12-year period (2001 to 2012). The historical period of record used for the forecast simulation is limited by the available rainfall data used to develop the hydrologic/hydraulic model (Precipitation Gauge 1720 [Stormwatch.com] with a period of record from 2000 to present [Anchor QEA 2014]).

for this 25-year simulation used a PCB concentration equal to the average concentration from the days of sampling during the Fate and Transport Study. A time series of calculated PCB loads that were input to the model for each outfall for Scenario #1 are shown on Figure 3-49 (summed annually for this graphic).

For Scenario #2 (Complete Cessation of Outfall Loadings), stormwater PCB loads for each of the four outfalls were set to zero for the full length of the 25-year forecast period.

3.3.2.3 Results

The time series of model-predicted surface sediment PCB concentrations for Scenarios #1 and #2 averaged over four different spatial reaches are depicted on Figure 3-50. The spatial reaches shown on this figure include: Indian Creek upstream of Outfall 002, Indian Creek downstream of Outfall 002, Blue River upstream of the Indian Creek/Blue River confluence, and Blue River downstream of the Indian Creek/Blue River confluence. In the segments that have relatively low PCB concentrations (i.e., upstream of Outfall 002 in Indian Creek and Blue River upstream of Indian Creek), sediment PCB concentrations are predicted to decrease by less than a factor of 2 over the 25-year projection period, likely because the sediments in these upstream reaches are close to steady state with upstream (background) sources. However, in the reaches that have the highest sediment PCB concentrations (i.e., downstream of Outfall 002 in Indian Creek and Blue River downstream of Indian Creek), the model predicts a faster rate of decline for both scenarios (sediment PCB half-lives of approximately 5 years[31]). This rate of decline is generally consistent with trends observed in recent sediment PCB data collected routinely by the BFC downstream of Outfall 002 (described in Section 2.2.2.2 and shown on Figure 2-15). These data show that a considerable decline in surface sediment concentrations has occurred at this location since 2001. Moreover, sediment data collected at this location since 2005 show a rate of decline consistent with that predicted by the model (PCB half-life of approximately 3 years). In 2005, the Outfall 002 re-route system was completed, which resulted in a significant reduction in PCB loading; therefore, the continuing decline in sediment PCB concentrations

[31] In this context, half-life is a metric used to quantify the rate of decline in sediment PCB concentrations. There are several factors contributing to decreasing sediment PCB concentrations observed in the site data and predicted by the model, including BFC outfall load reductions and ongoing natural recovery processes in the stream.

in Indian Creek after 2005 is a result of in-stream natural recovery processes (which can include processes such as sediment deposition/burial and sediment mixing/bioturbation, resuspension, and porewater advection followed by downstream transport).

The model predicts essentially no difference in future sediment PCB concentrations between Scenarios #1 and #2 (Figure 3-50). This indicates that contemporary stormwater PCB loadings have little impact on bedded sediment PCB concentrations, even if these loads were to continue at current levels for 25 years into the future. This result is not unexpected based on the water column PCB mass balance that indicates stormwater contributes a relatively small proportion of the total PCB load to the system. Specifically, the BFC outfalls only contribute approximately 3% of the total PCB mass to the water column of Indian Creek and Blue River during the calibration period, and less than 1% of that mass is deposited to the sediment bed (see Table 3-14).

The model projections also show that sediment PCB concentrations begin to "level off" toward the end of the simulation period. This indicates that the sediment bed is reaching steady state with respect to the various sources of particulate-bound PCBs to the system. Steady-state concentrations predicted by the model are generally less than 50 μg/kg and are consistent with background PCB levels on solids entering the storm sewer system from relatively un-impacted areas of the BFC (i.e., Zone B and C PCB data from the Phase 1 stormwater solids sampling program).

A time series of model-predicted Green Sunfish and Channel Catfish PCB concentrations are presented on Figures 3-51 and 3-52, respectively. Similar to the model predictions of sediment PCB concentrations, the bioaccumulation model predicts little difference in future Green Sunfish (Figure 3-51) and Channel Catfish (Figure 3-52) PCB concentrations between Scenarios #1 and #2. Also, the model-predicted rates of decline in fish are generally consistent with the rates of decline predicted in sediments at the same locations. This is because: 1) fish PCB concentrations are largely controlled by sediment exposure due to a high proportion of benthic organisms in their diet; and 2) natural recovery processes are acting to reduce sediment PCB concentrations in the system over time.

4 CONCLUSIONS

The following conclusions were drawn based on a conceptual understanding of BFC stormwater, Indian Creek, and Blue River developed from the empirical data and mechanistic modeling performed for the Fate and Transport Study:

- Stormwater BMP implementation and other remedial actions completed by the BFC to date have achieved significant reductions in PCB loads to Indian Creek and Blue River. Specifically, outfall PCB loads have been reduced by more than a factor of 5 to 10 since the mid-1990s (Figure 2-6). Ongoing PCB loads from each of the BFC outfalls are small (on the order of 5 to 10 grams per year), and represent a relatively small proportion of the total PCB load to the water column of Indian Creek and Blue River (approximately 3%; Table 3-14).
- Low-level background sources of PCB entering Indian Creek and Blue River upstream of the BFC contribute a relatively large portion of the total PCB load to the system. For example, the average water column PCB concentration at the upstream boundary in Indian Creek (at Holmes Road) and Blue River (at I-435) is approximately 0.4 to 0.5 ng/L (Table 3-7). On a loading basis, this accounts for approximately 20% of the total PCB load to the water column of Indian Creek and Blue River in the model domain (Table 3-14).
- The largest component of the PCB load to the water column in Indian Creek and Blue River is derived from in-stream sediments (via porewater exchange). This in-stream sediment source is from remnants of historical spills/loading from the BFC outfalls, and is continuing to decline as a result of natural attenuation processes (including downstream transport, and burial to a lesser extent).
- Model results and empirical site data indicate that PCB loading from Boone Creek is the third-largest PCB loading to the water column of Blue River (which accounts for 17% of the PCB load on a site-wide basis). The nature of sources in Boone Creek is not fully understood, but a large component of this loading is likely derived from bedded sediments in the creek.

- Empirical PCB data demonstrate that sediment and fish in Indian Creek and Blue River have declined considerably since the early 1990s as a result of BFC outfall load reductions and ongoing natural recovery processes. The model is able to reproduce the observed decline from the early 1990s to the present. Also, model forecast results indicate that sediment and fish PCBs will continue to decline into the future (at a half-life of approximately 5 years) as a result of natural recovery processes in the receiving streams.
- Model forecast results indicate that additional reductions in BFC stormwater loads are not required to achieve continued reductions in Indian Creek and Blue River sediments and fish. Specifically, model predictions from forecast Scenarios #1 and #2 showed essentially no difference in future sediment and fish between these two scenarios. This indicates that contemporary stormwater PCB loadings have little impact on bedded sediment and fish PCB concentrations, even if these loads were to continue at current levels for 25 years into the future. This result is not unexpected based on the water column PCB mass balance that indicates stormwater contributes a relatively small proportion of the total PCB load to the system.

5 RECOMMENDATIONS

Although the model illustrates that further reductions in stormwater PCB loading from the BFC will have a negligible impact on sediments and fish, one recommendation of the Fate and Transport Study is to continue periodic bioaccumulation studies at a 5-year interval (such that a minimum of three additional studies are performed) to evaluate that the observed downward trend in the historical fish data continues into the future. Future bioaccumulation studies will collect both fillet and whole fish data. If a continued downward trend is observed, a request to suspend additional studies will be submitted to the regulatory agencies. Future studies should continue to use historical fish tissue collection locations, and should include water column and sediment sampling at these stations. Sampling will be performed during 2017 to baseline conditions prior to site demolition, implementation of the revised remedy, and regrading. Another round of collection will be completed 1 year post site demolition, implementation of the revised remedy, and regrading, and the final collection will be completed 5 years after the second round.

While further reductions in stormwater PCB loading from the BFC will likely have a negligible impact on sediments and fish, it may be prudent to implement additional BMPs at the site until redevelopment is complete. Also, as of the date of completion of this report, redevelopment plans for the BFC site have not yet been finalized; therefore, it is possible that redevelopment may not include 100% of the site, including abandonment of all existing BFC subsurface stormwater infrastructure. Assuming this is the case, Anchor QEA recommends consideration of the following additional stormwater source control BMPs to limit residual PCB source contact with redeveloped site runoff:

- **Trunk and primary lateral storm drains.** Confirm the extent and integrity of drainage system lining that was installed as part of prior BMP actions. Lined portions of the main trunk line are currently inspected on an annual basis. For any unlined system components, evaluate the need for lining those segments based on potential for contact with residual PCB source areas. If the integrity of the existing storm drain lining is compromised, identify those sections of storm drain or junction structure lining that will need repair.
- **Outfall 002 raceway.** Sample accumulated sediment within the raceway on a quarterly basis for PCBs (composite of four grab samples). If the annual average is

greater than 2.45 mg/kg,[32] sediment will be removed from the raceway during the following year. In order to initiate baseline conditions, sediments will be removed from the raceway during 2016. In addition, water samples are collected at the Outfall 002 flap gate/raceway two times per month. Samples collected at this location can entrain PCB-contaminated sediments present in the raceway causing an anomalous result. If water samples collected at this location detect PCBs greater than 0.5 µg/L four times within a 6-month period, removal of sediments from the raceway will be scheduled to occur within 6 months.

- **Secondary lateral storm drains.** Evaluate effectiveness of additional efforts to disconnect, fill, and abandon secondary lateral storm drains in residual PCB source areas (particularly in Basin 002) to further reduce potential PCB discharges.
- **Existing on-site detention/flood storage areas.** Confirm the need to retain and/or modify existing on-site detention/flood storage areas consistent with the site redevelopment plan. If preserved, test any accumulated sediment/soil for PCBs and remove if deemed necessary.

Additional source controls that could be retained for evaluation and potential implementation include: 1) implementation of a routine pavement sweeping program (combined with extensive cleaning of the remaining sewer system) to reduce a source of solids containing low-level PCBs; and 2) installation of catch basin filters to capture source sediments from pavement runoff areas. However, as described in Section 2.2.1, fractionated stormwater solids samples collected during Phase 1 indicated that the majority of the PCB mass is contained on relatively fine soil particles (<250 µm)—catch basin filters are not highly effective at removing finer suspended sediments. Therefore, Low-impact Development (LID) options to reduce runoff volume (which would translate to reduced PCB loading) would likely be more effective. The simplest BMP to reduce runoff volume would be to reduce the amount of impervious area at the site, perhaps by eliminating unused pavement areas in portions of the site with soils that are not impacted by PCBs. Reducing impervious site area will increase infiltration losses, and result in smaller peak runoff flows and volumes (translating to lower PCB loadings). Any portion of the site where pavement is

[32] 2.45 mg/kg is one half of the Indian Creek Sediment Remedy stipulated in the *95th Terrace Corrective Measures Implementation Work Plan* (DOE 2006).

removed would require vegetative cover or other stabilization measures to avoid erosion of soil.

In addition, there are numerous stormwater capture and treatment BMP options that could be installed at the site (e.g., settling devices, ponds, or vaults; filtration treatment BMPs such as filter drains or swales; or advanced treatment BMPs such as granular activated carbon and/or sand/mixed media filtration systems). However, the cost of implementing these types of BMPs would likely far outweigh any benefit of reduced loading to the receiving streams based on the model results, which show little impact on in-stream fish, even with the current BFC stormwater flow regime deleted.

Current efforts to transfer DOE and GSA property located west of the Union Pacific railroad tracks on the BFC to a private developer will, when transferred, ultimately have a significant impact on the storm sewer envelope for this portion of the facility. As a part of the property transfer, the MHWMF Permit will transfer to the developer. Transfer of the MWHMF Permit includes the development of updated corrective action objectives. Updated corrective action objectives will be developed to address the stormwater PCB migration pathway/receiving stream issues investigated and identified in this report.

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FIGURES

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Figure 1-1
Timeline of Activities at the BFC Related to BMP Implementation in the Outfall 002 System
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

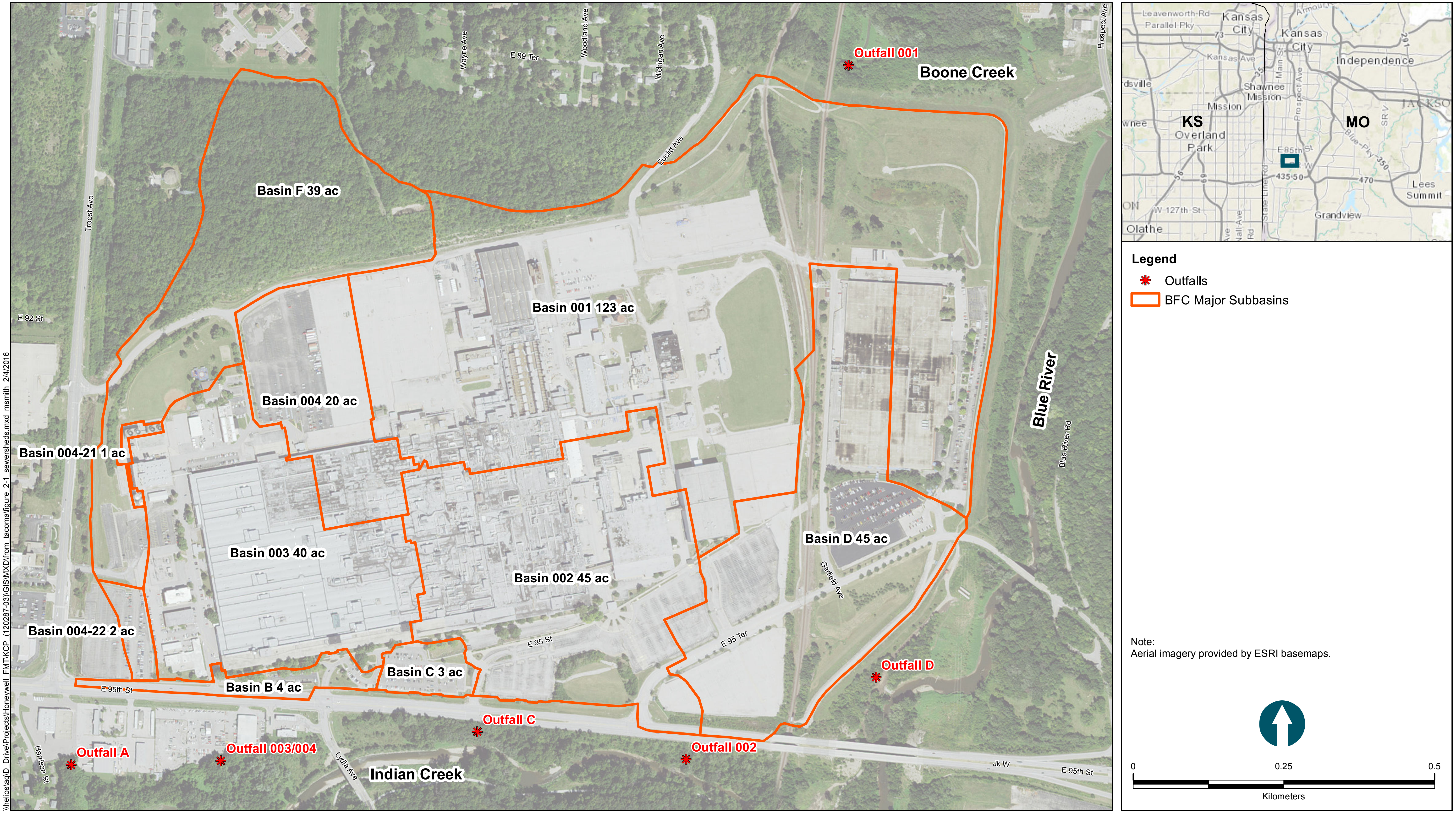

Figure 2-1
BFC Drainage Basins and Outfalls Discharging to Indian Creek and Blue River
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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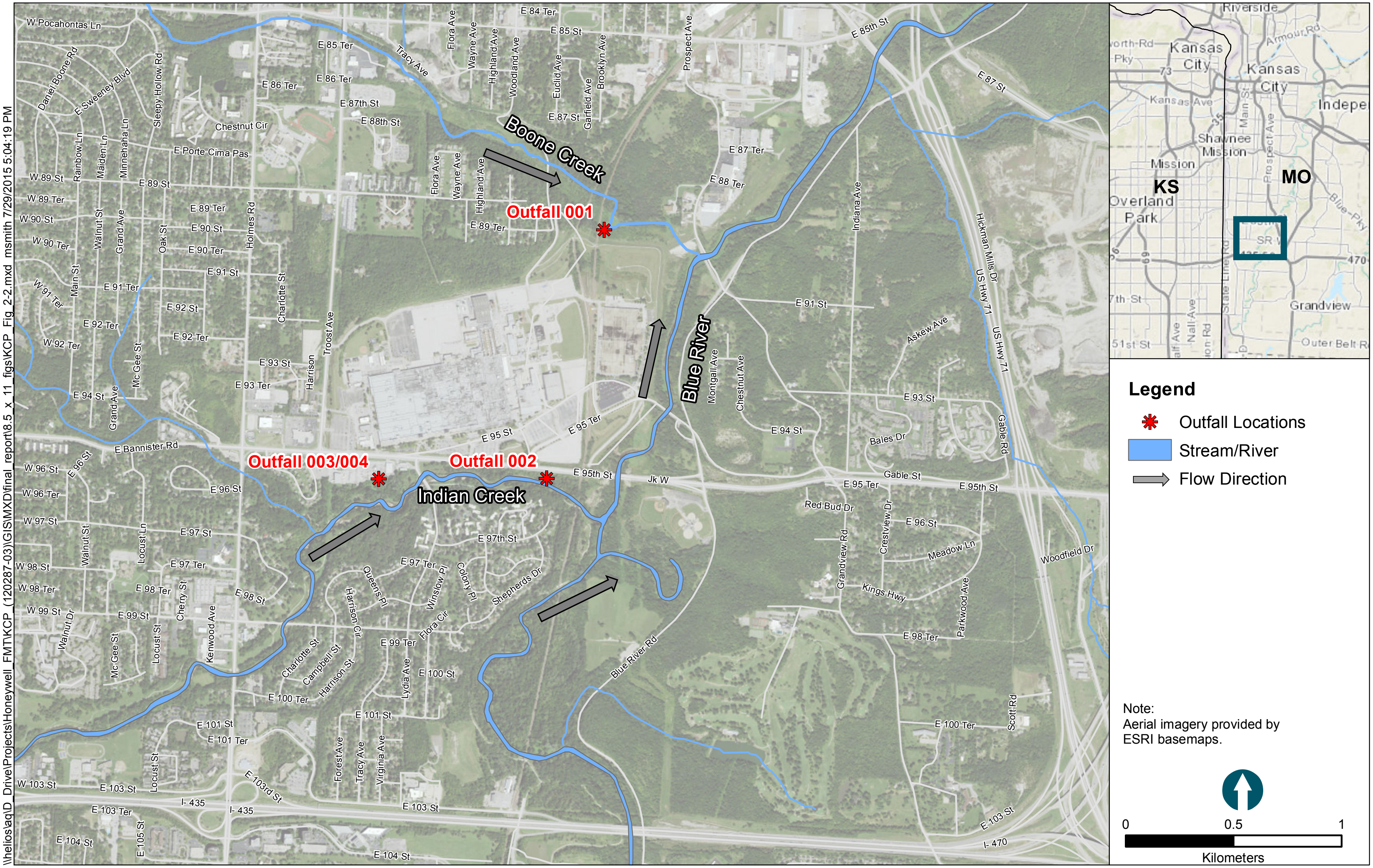

Figure 2-2
BFC, Indian Creek, and Blue River Study Area
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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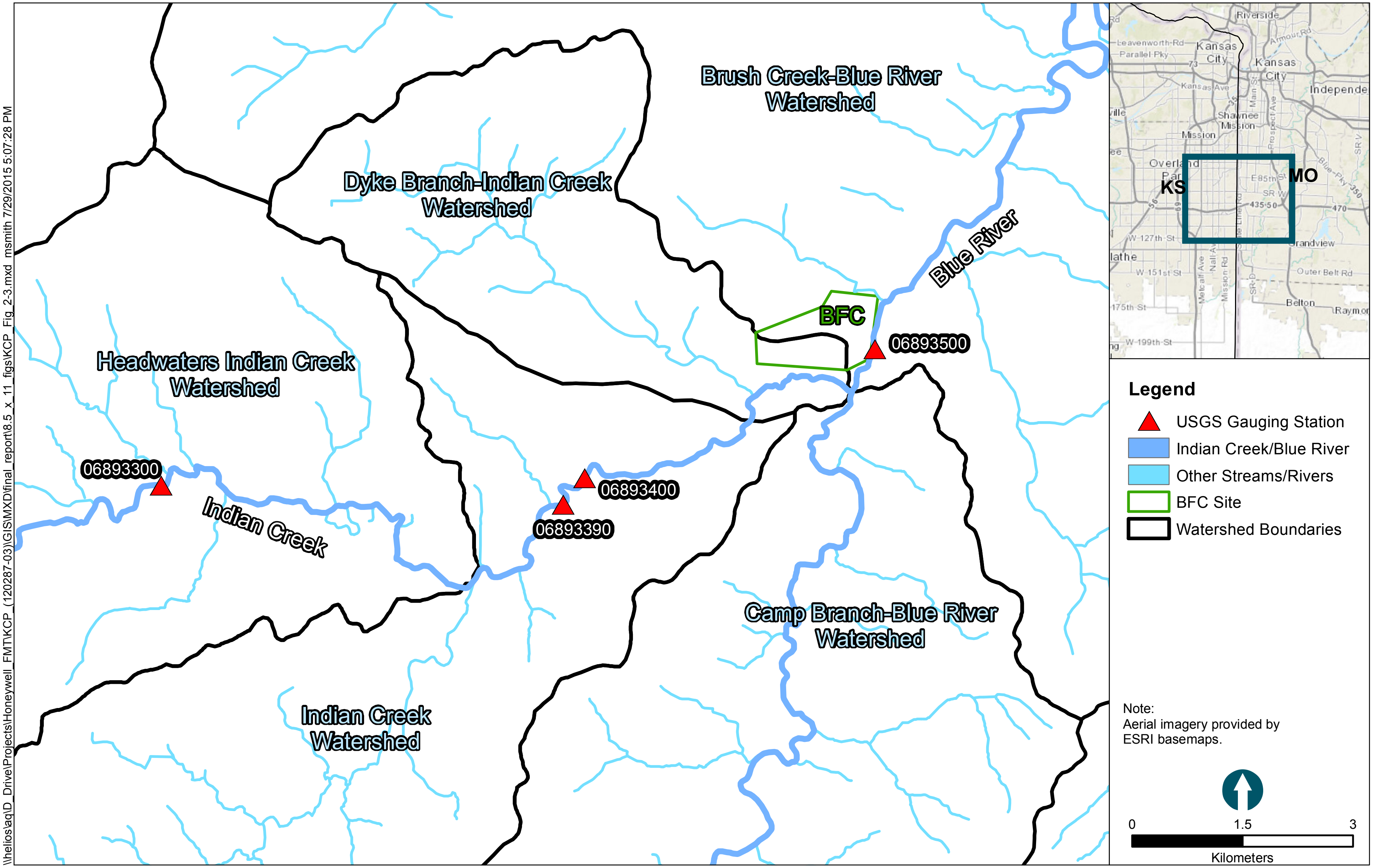

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Figure 2-3
USGS Gauging Stations in the Vicinity of the BFC
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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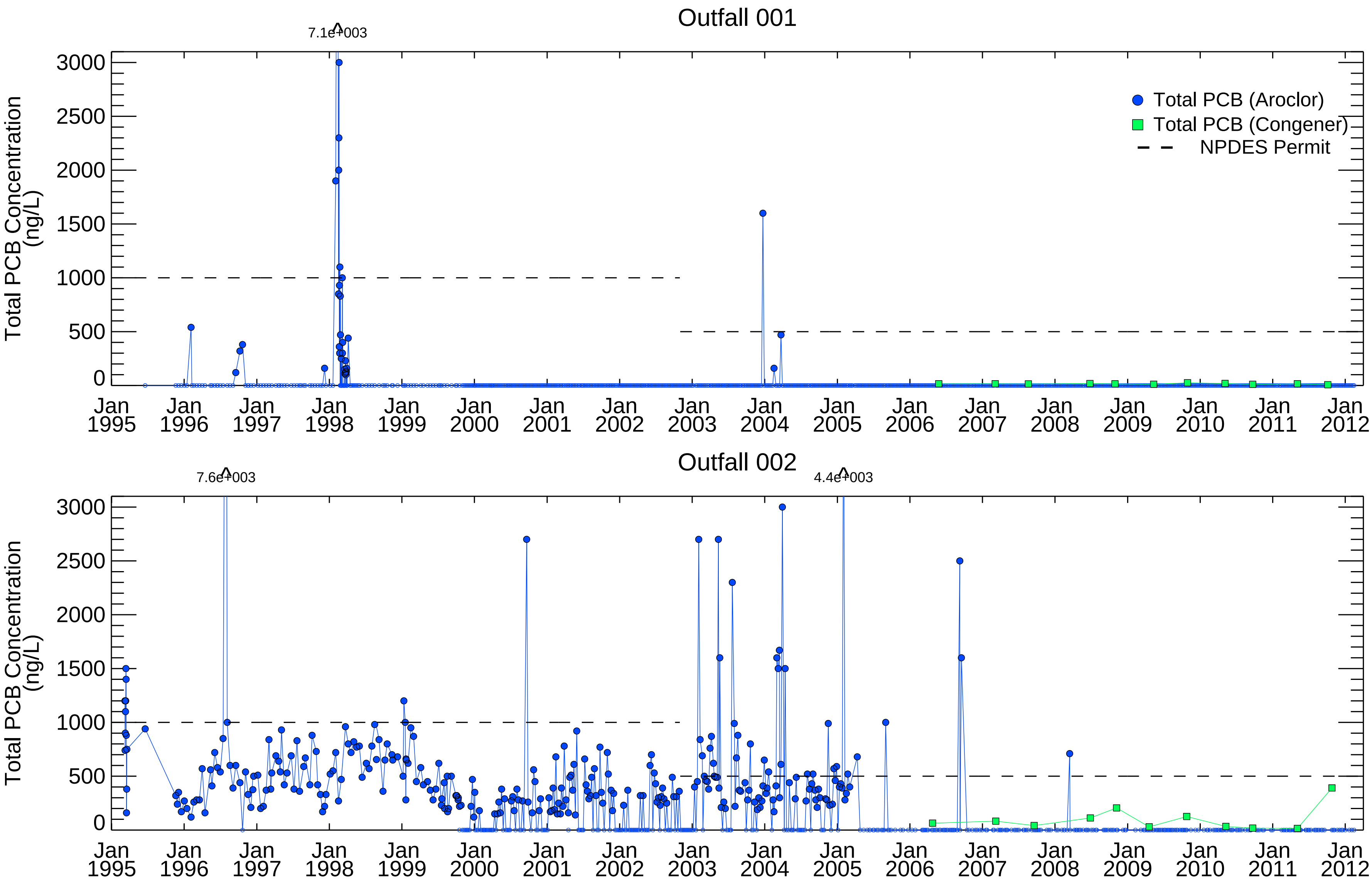

Figure 2-4a

Time Series of KCP Outfall PCB Concentrations

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

Notes: Non-detects for Total PCB set to zero. Non-detects shown as open symbols.

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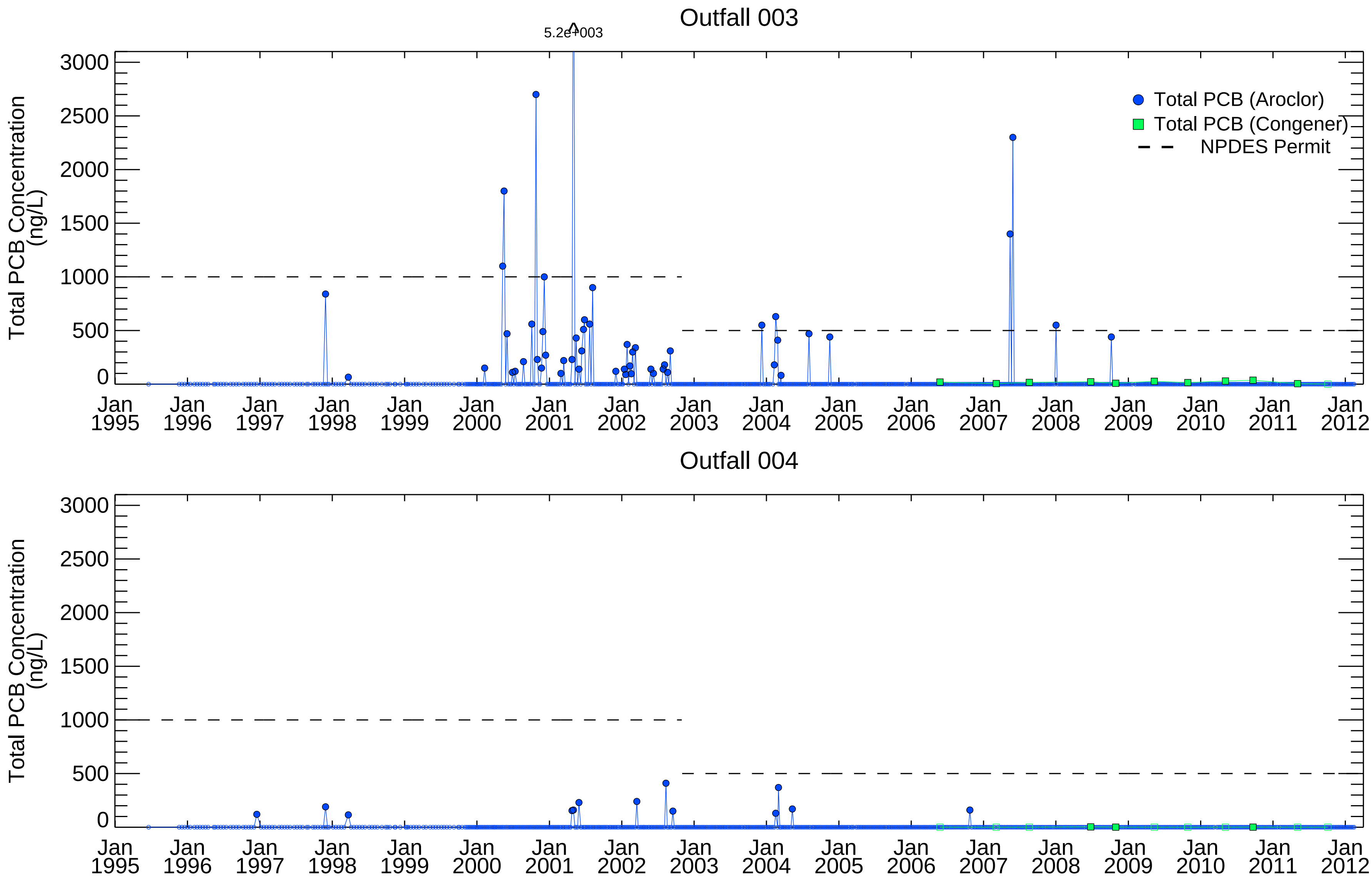

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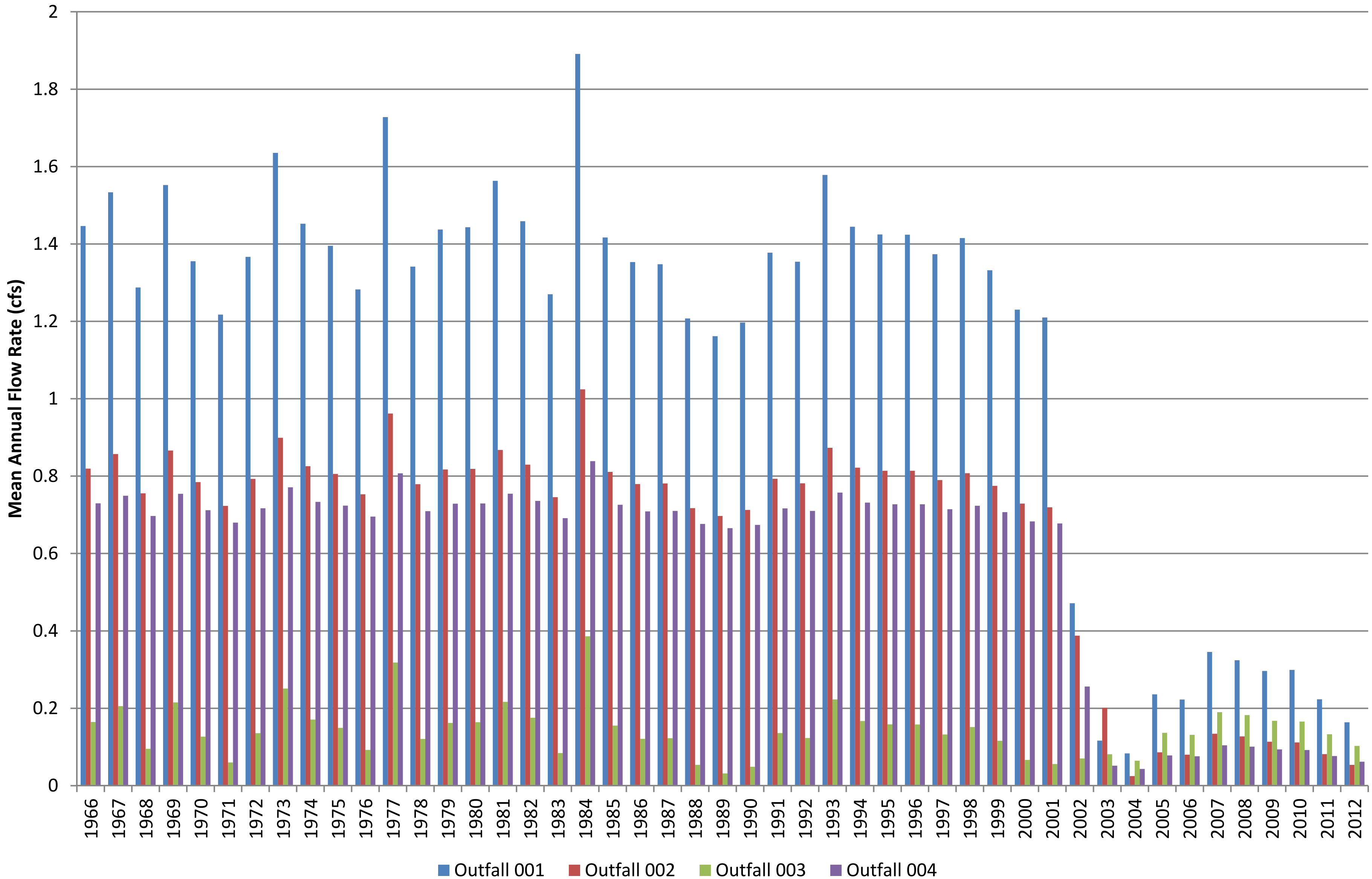
Figure 2-4b

Time Series of KCP Outfall PCB Concentrations

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

Notes: Non-detects for Total PCB set to zero. Non-detects shown as open symbols.



Note: Reduction in flow after 2002 associated with reroute of non-contact single pass cooling water.

Figure 2-5
Calculated Annual Mean Flow Rate From BFC Outfalls
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

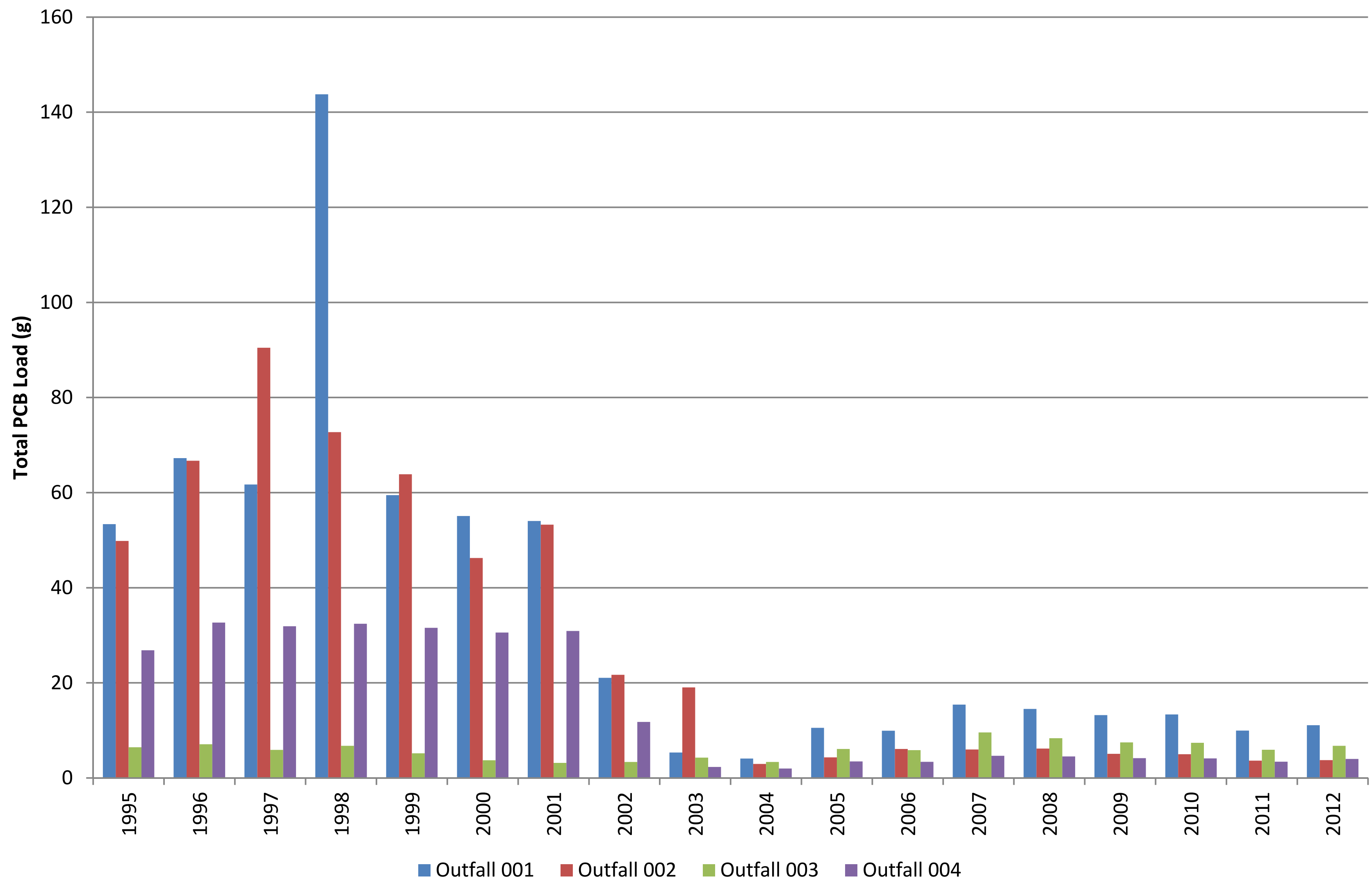


Figure 2-6
Annual Total PCB Load (1995 to 2012)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

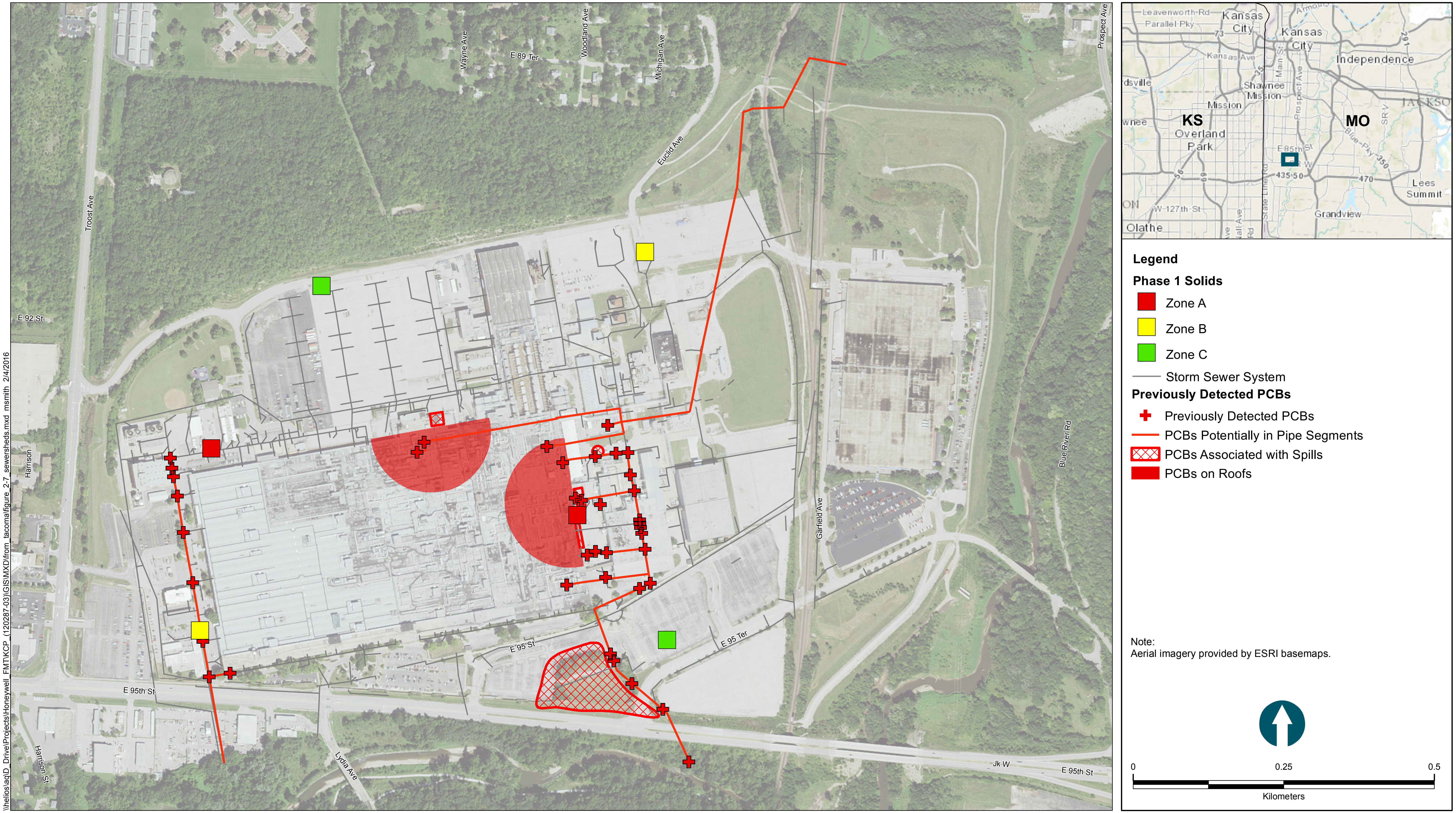


Figure 2-7a

Phase 1 Stormwater Sampling Locations (Pavement)

Final Report – Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

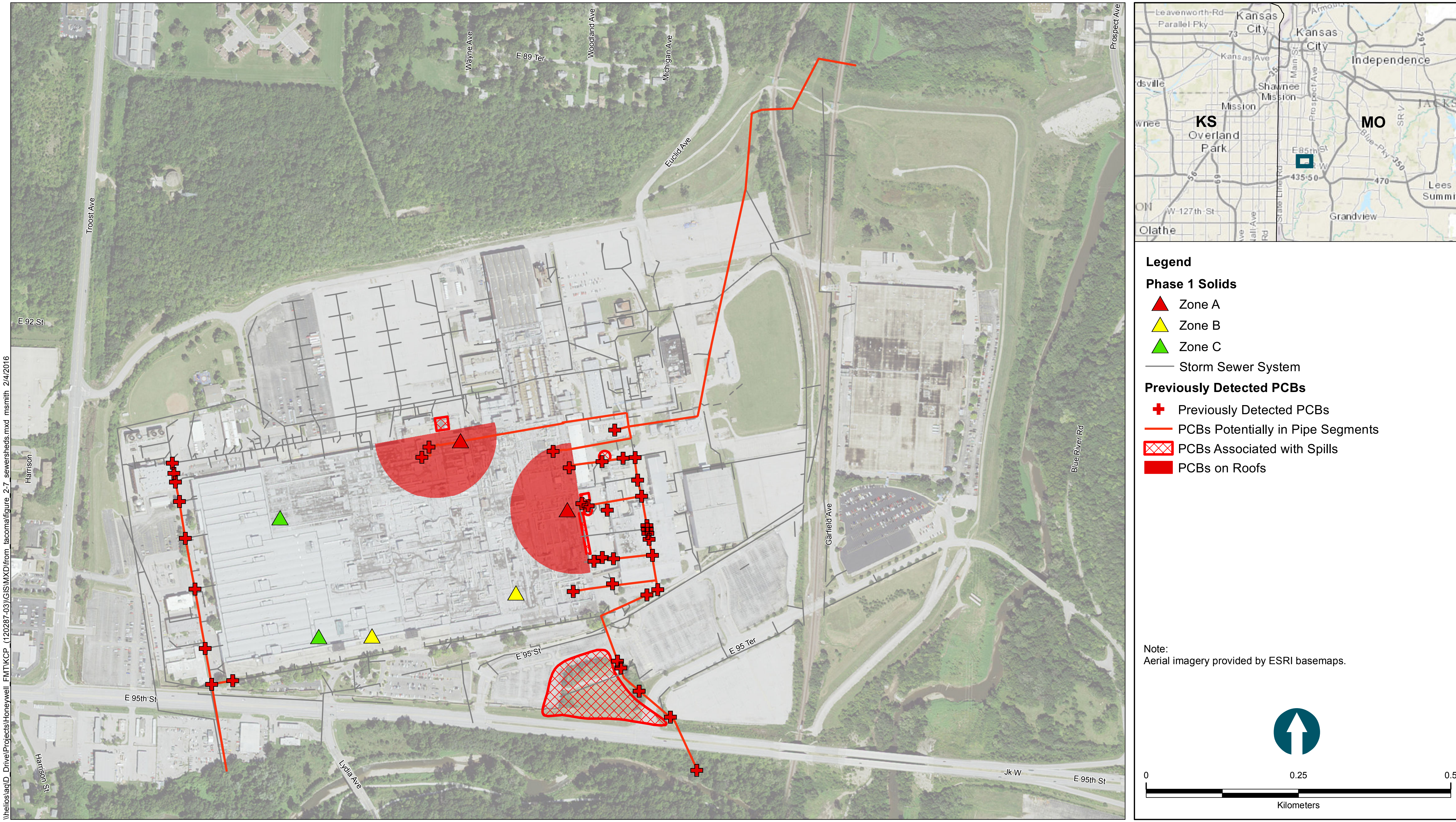


Figure 2-7b
Phase 1 Stormwater Sampling Locations (Roofs)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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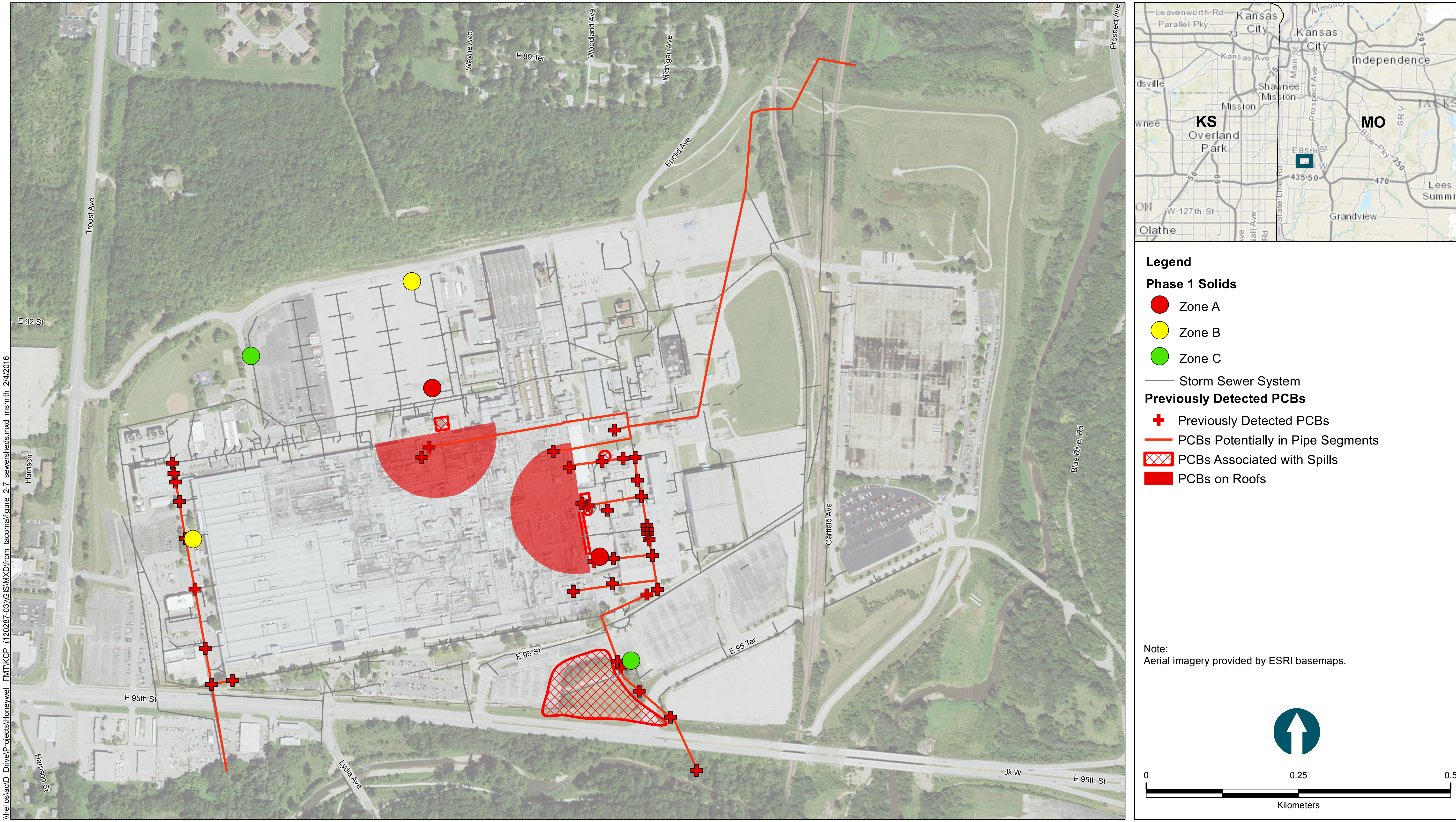


Figure 2-7c
Phase 1 Stormwater Sampling Locations (Catch Basins)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

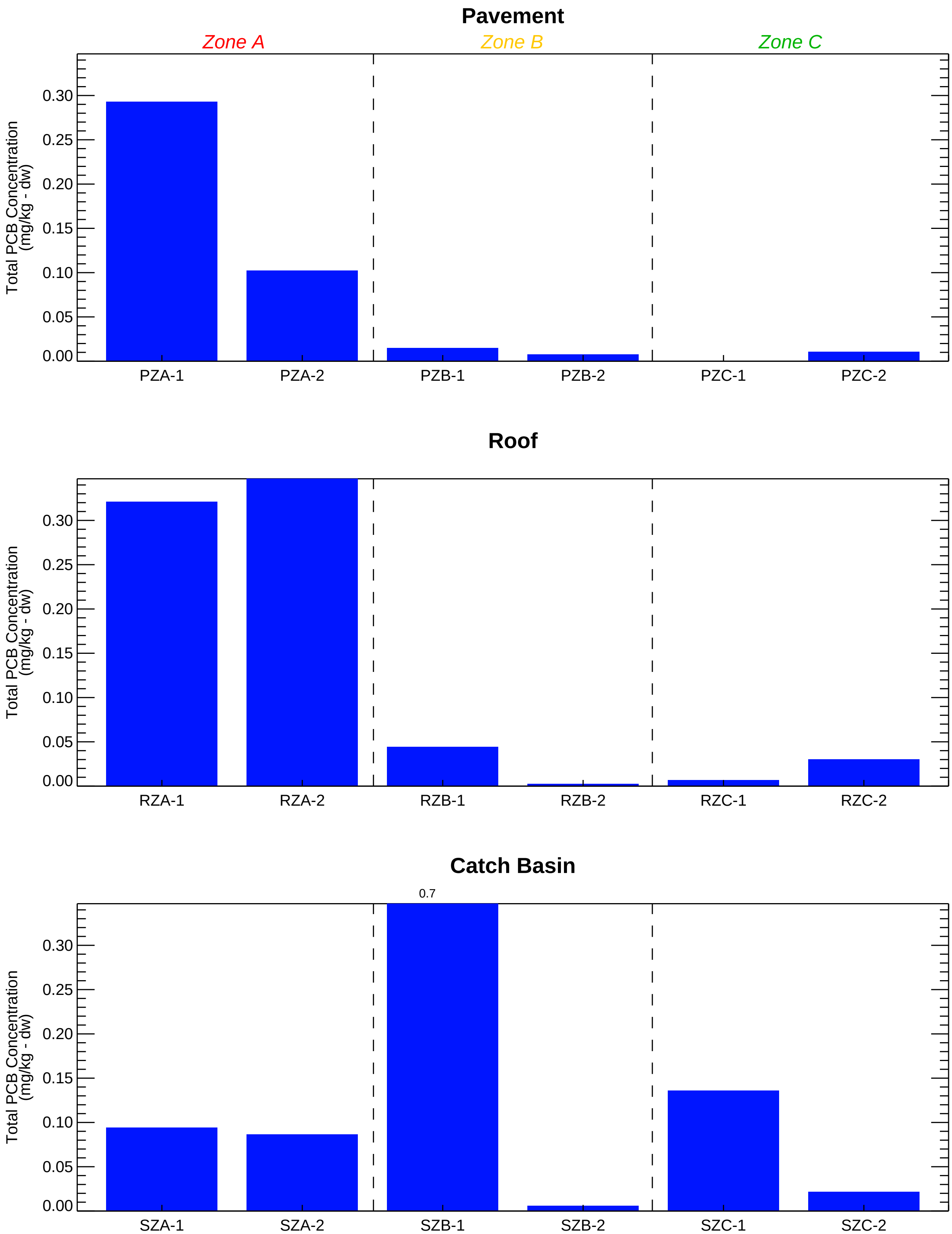


Figure 2-8

Bulk Sample Total PCB Concentrations from Phase 1
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

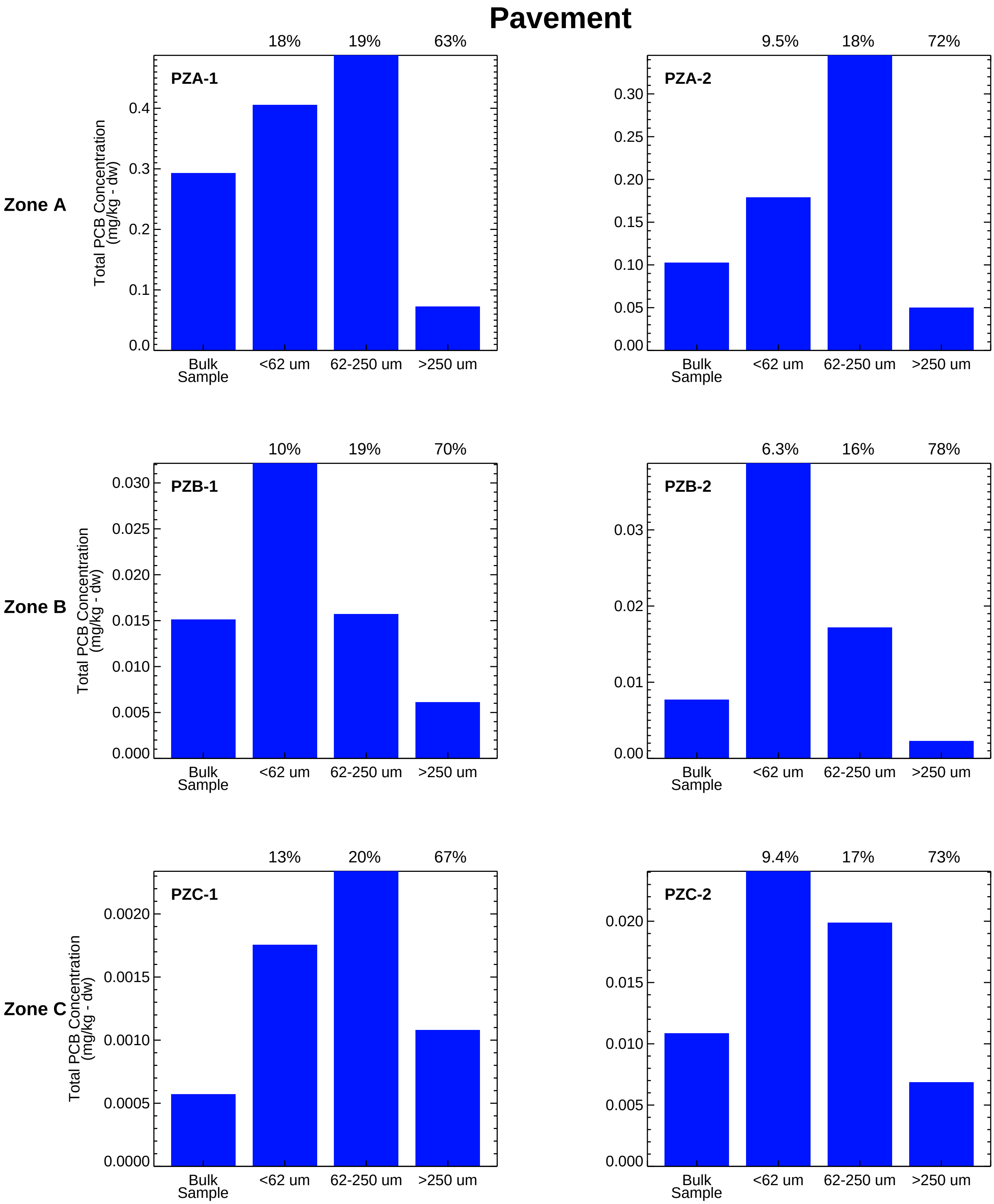


Figure 2-9a

Total PCB Concentrations (Dry Weight) in Phase 1 Stormwater Solids Samples from Pavement

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Note: Values posted above individual size fractions represent percent of solids mass in bulk sample.

Roofs

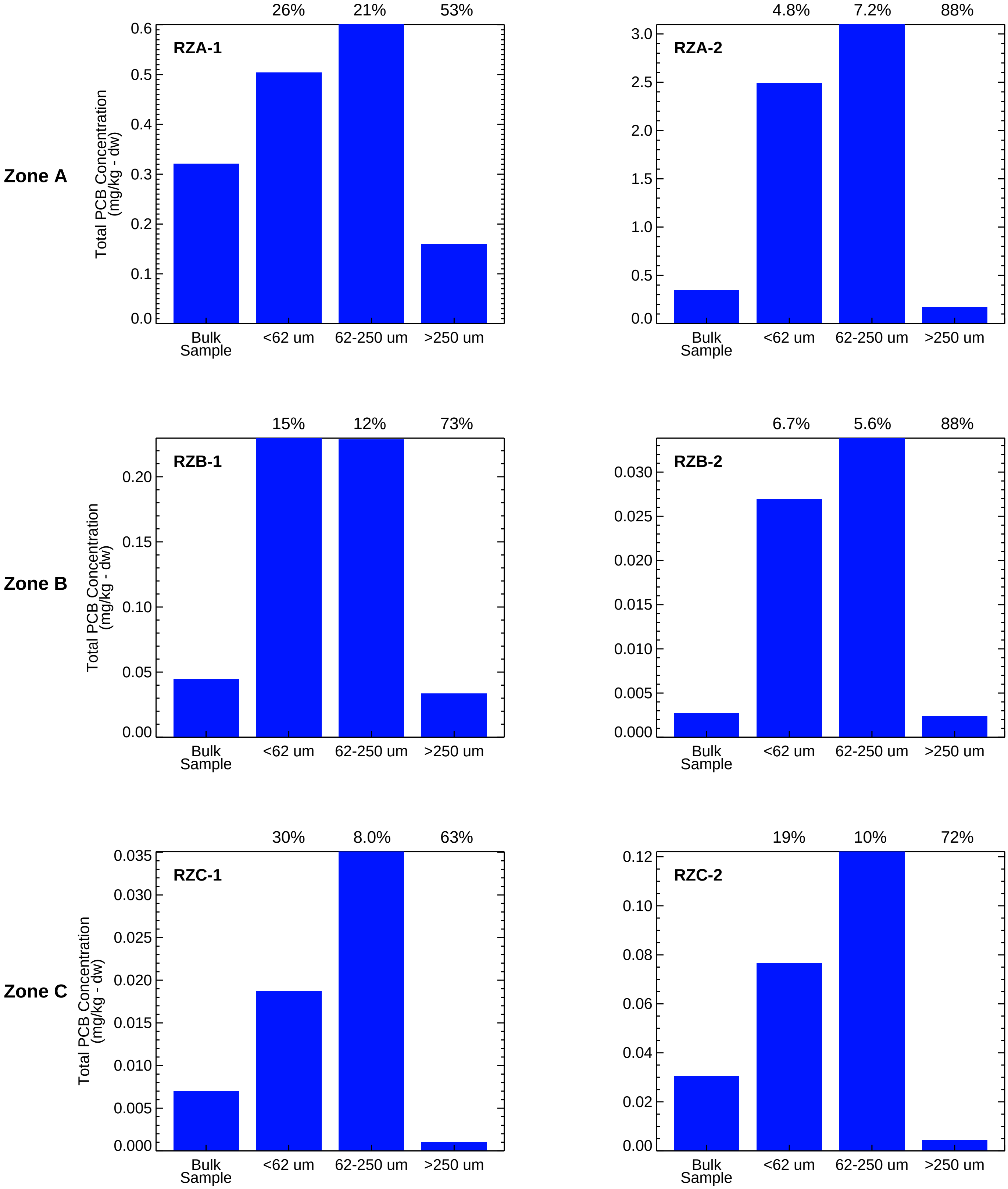


Figure 2-9b

Total PCB Concentrations (Dry Weight) in Phase 1 Stormwater Solids Samples from Roofs
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Note: Values posted above individual size fractions represent percent of solids mass in bulk sample.

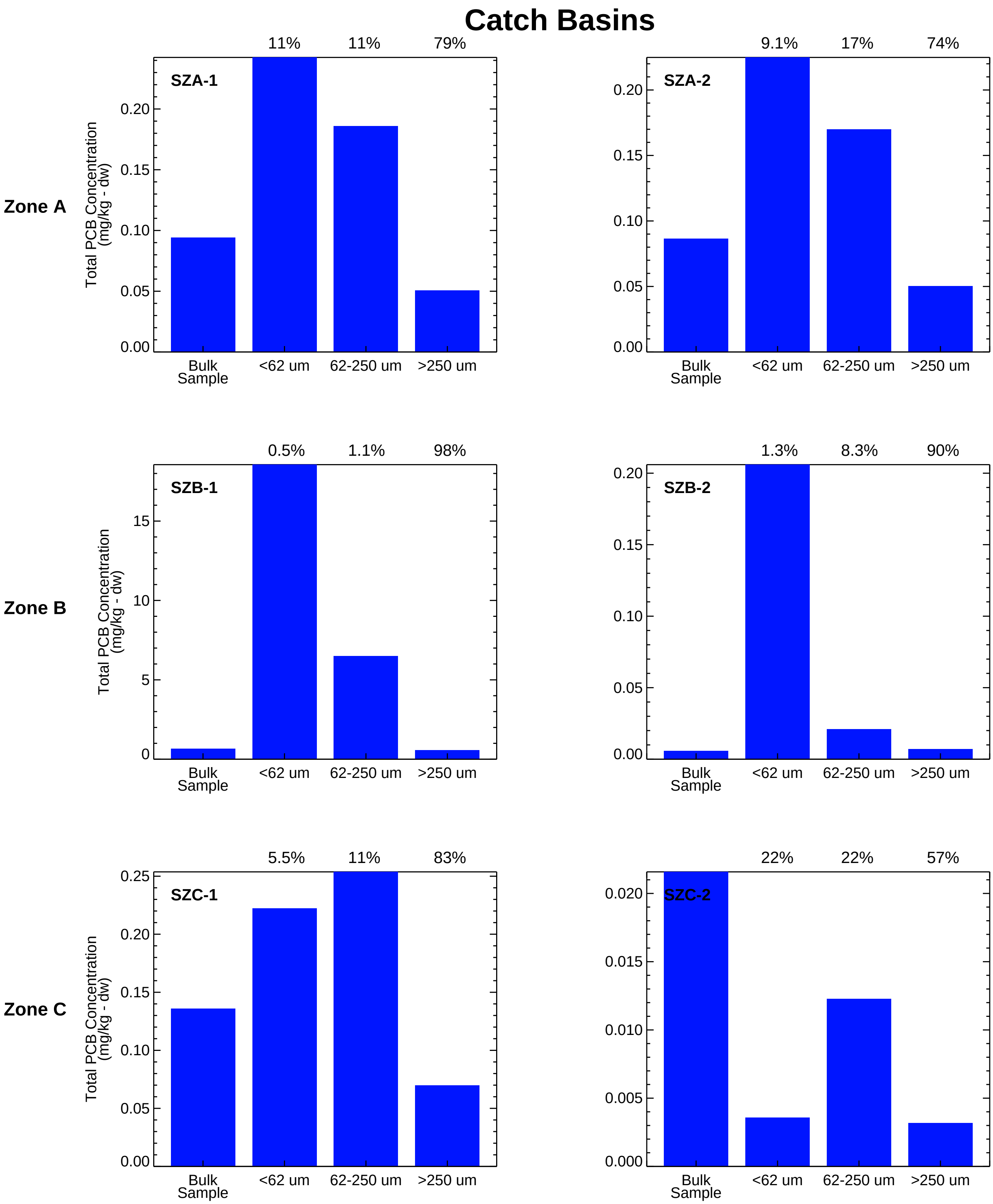
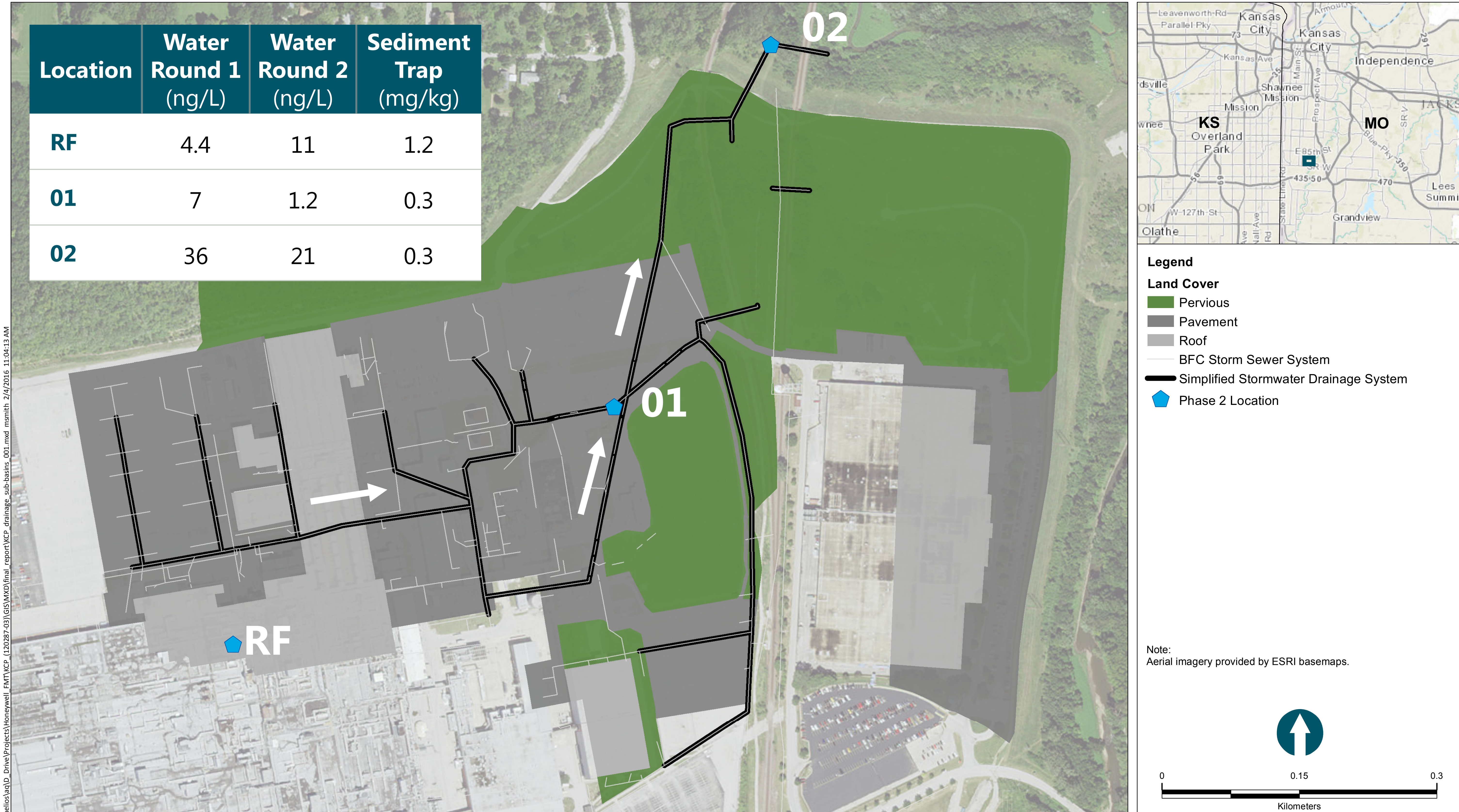


Figure 2-9c

Total PCB Concentrations (Dry Weight) in Phase 1 Stormwater Solids Samples from Catch Basins
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

Note: Values posted above individual size fractions represent percent of solids mass in bulk sample.



Location	Water Round 1 (ng/L)	Water Round 2 (ng/L)	Sediment Trap (mg/kg)
RF	4.4	11	1.2
01	7	1.2	0.3
02	36	21	0.3

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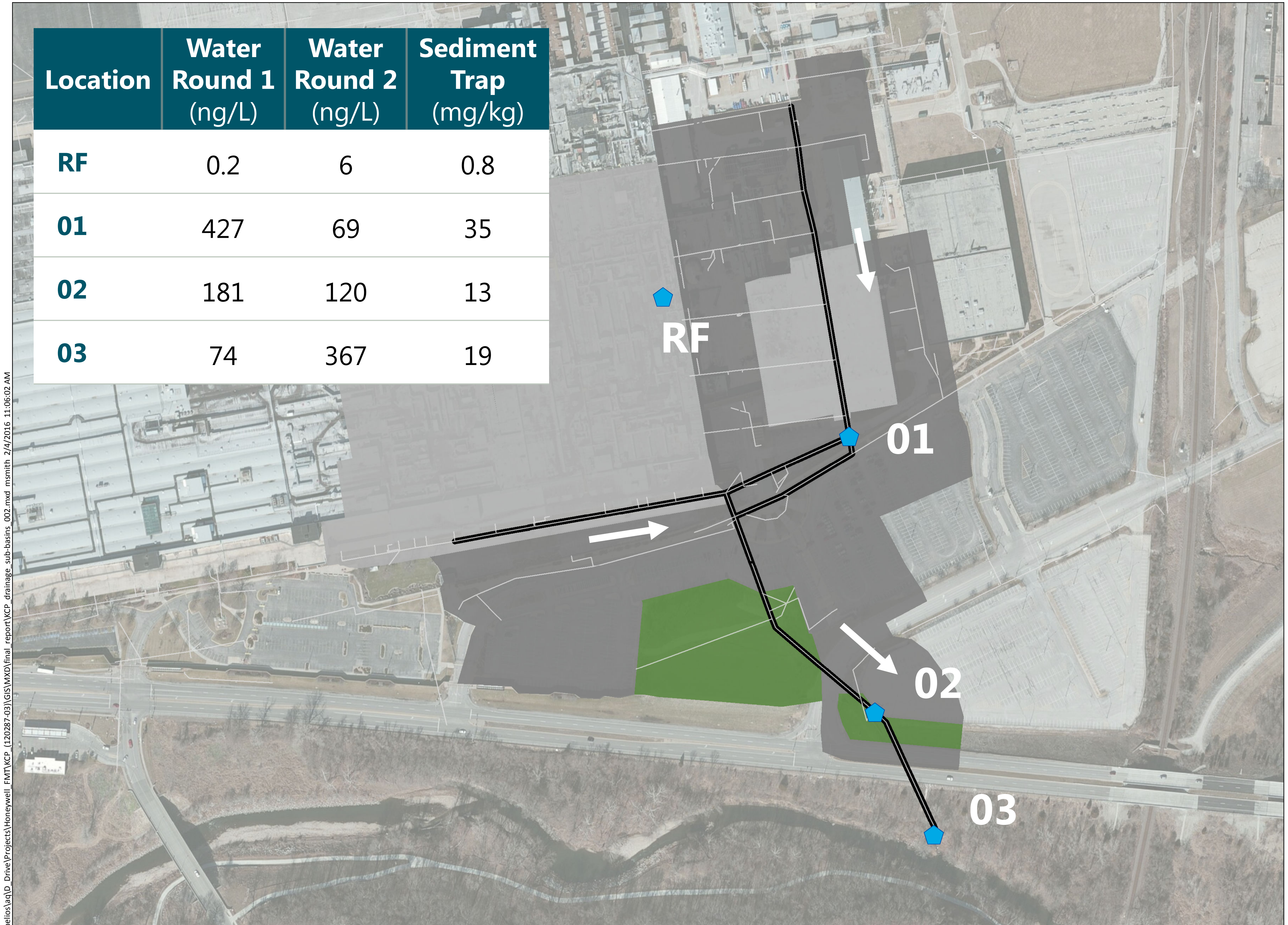
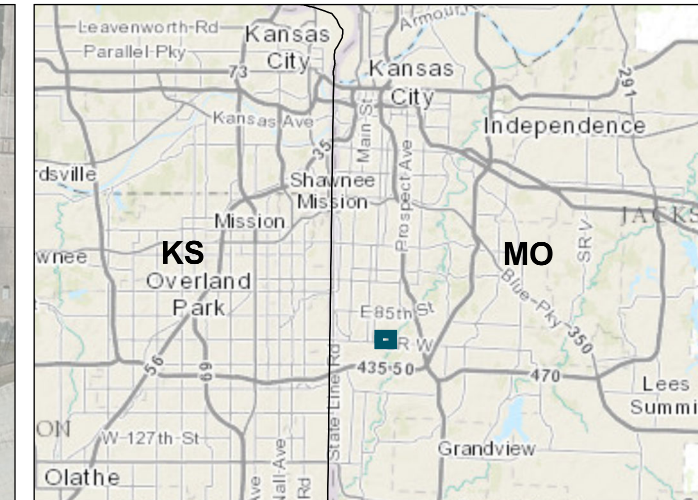
ANCHOR QEA

Figure 2-10a
Phase 2 Stormwater Results - Drainage Basin 001
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T



Location	Water Round 1 (ng/L)	Water Round 2 (ng/L)	Sediment Trap (mg/kg)
RF	0.2	6	0.8
01	427	69	35
02	181	120	13
03	74	367	19

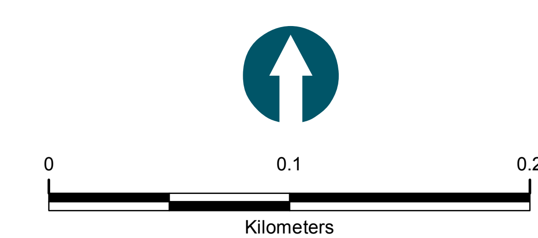


Legend

Land Cover

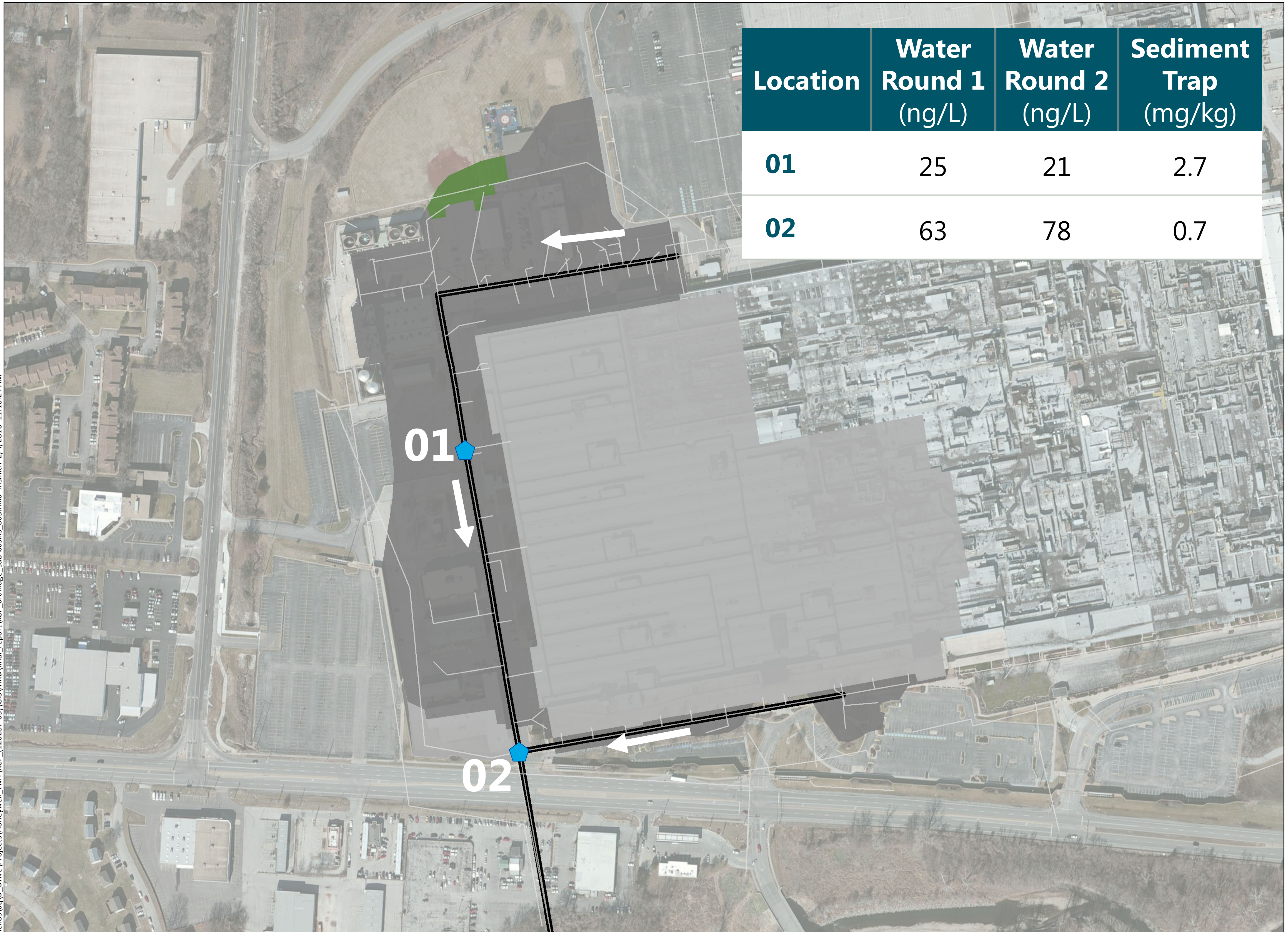
- Pervious
- Pavement
- Roof
- BFC Storm Sewer System
- Simplified Stormwater Drainage System
- Phase 2 Location

Note:
Aerial imagery provided by ESRI basemaps.

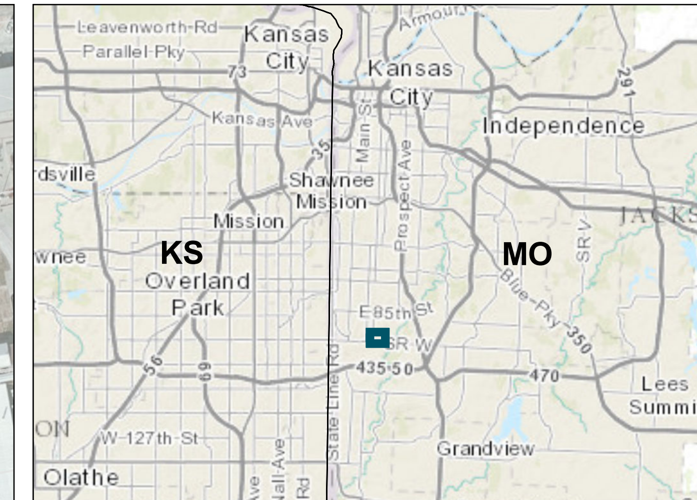


ANCHOR QEA

Figure 2-10b
Phase 2 Stormwater Results - Drainage Basin 002
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T



Location	Water Round 1 (ng/L)	Water Round 2 (ng/L)	Sediment Trap (mg/kg)
01	25	21	2.7
02	63	78	0.7



Legend

Land Cover

- Pervious
- Pavement
- Roof
- BFC Storm Sewer System
- Simplified Stormwater Drainage System
- Phase 2 Location

Note:
Aerial imagery provided by ESRI basemaps.

0 0.1 0.2
Kilometers

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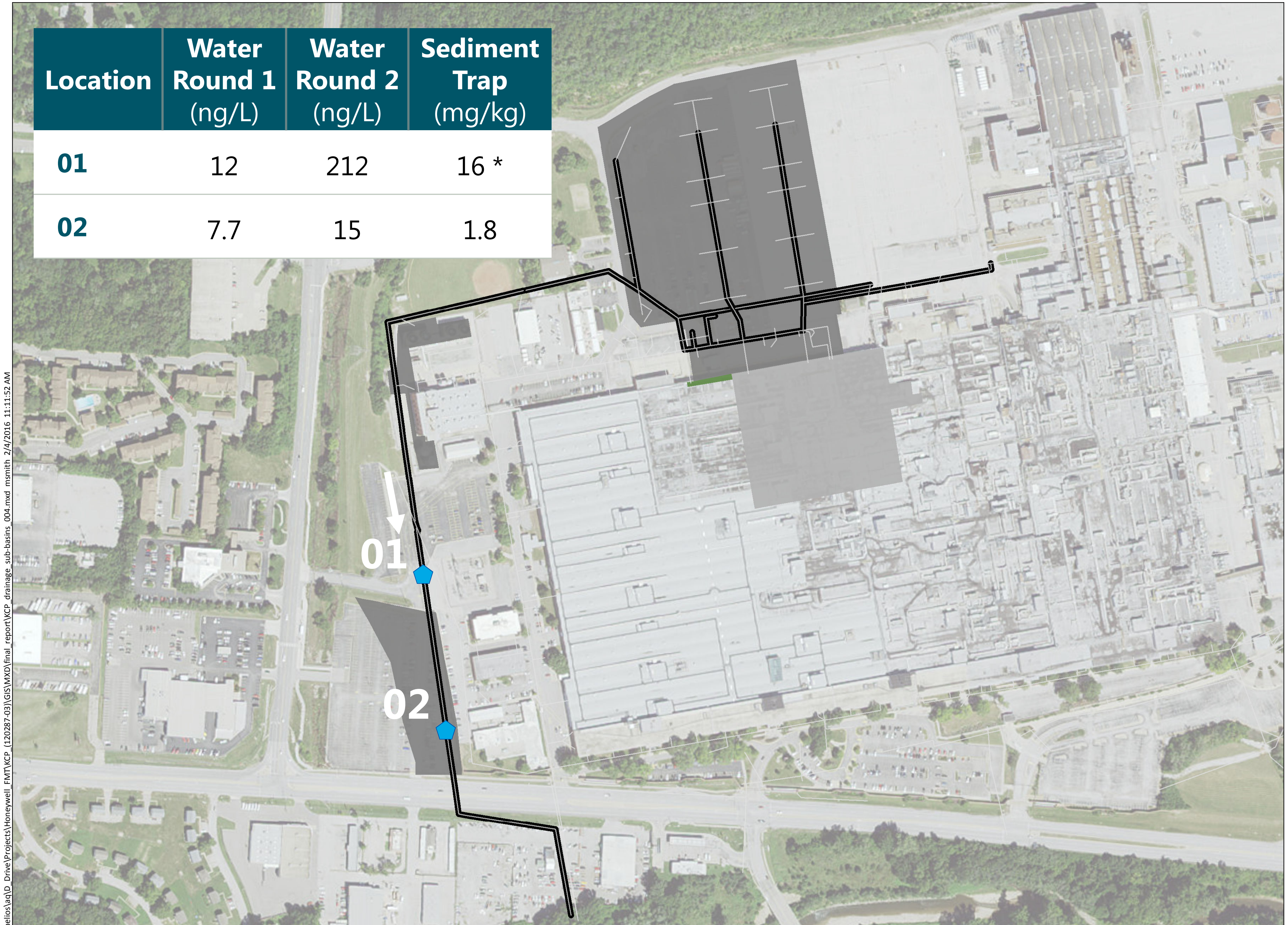
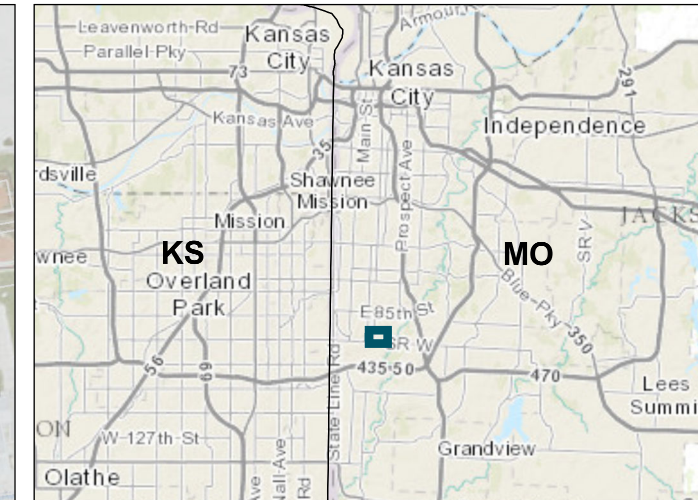
ANCHOR QEA

Figure 2-10c
Phase 2 Stormwater Results - Drainage Basin 003
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Location	Water Round 1 (ng/L)	Water Round 2 (ng/L)	Sediment Trap (mg/kg)
01	12	212	16 *
02	7.7	15	1.8





Legend

Land Cover

- Pervious
- Pavement
- Roof
- BFC Storm Sewer System
- Simplified Stormwater Drainage System
- Phase 2 Location

Notes:
Aerial imagery provided by ESRI basemaps.
* Represents result from sediment grab sample collected from accumulated sediment in pipe (not sediment trap sample).

0 0.15 0.3
Kilometers

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ANCHOR QEA

Figure 2-10d
Phase 2 Stormwater Results - Drainage Basin 004
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Location	Water Round 1 (ng/L)	Water Round 2 (ng/L)	Sediment Trap (mg/kg)
01	NS*	7.7	0.3

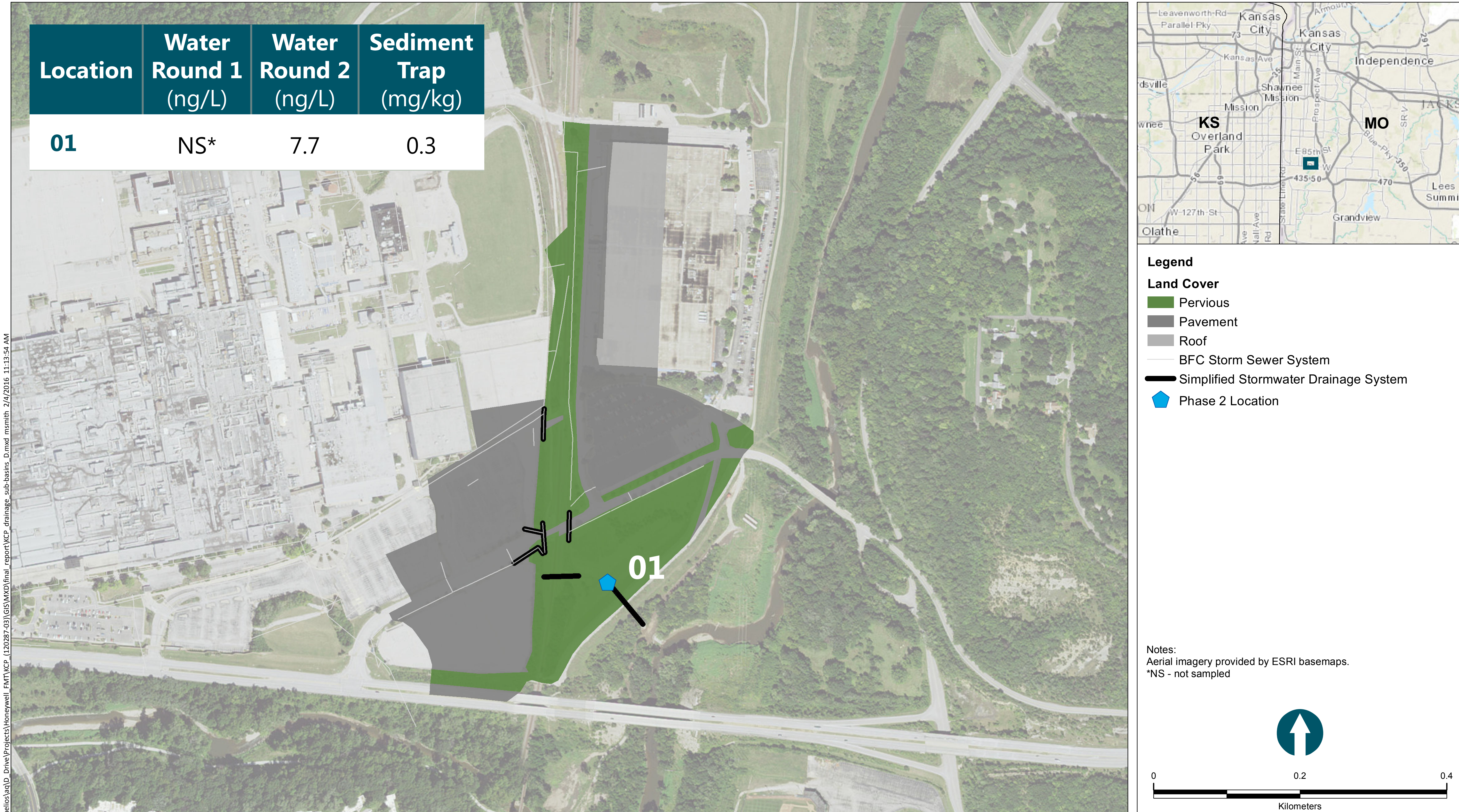

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Figure 2-10e
Phase 2 Stormwater Results - Drainage Basin D
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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Figure 2-11
Surface Water Sampling Locations
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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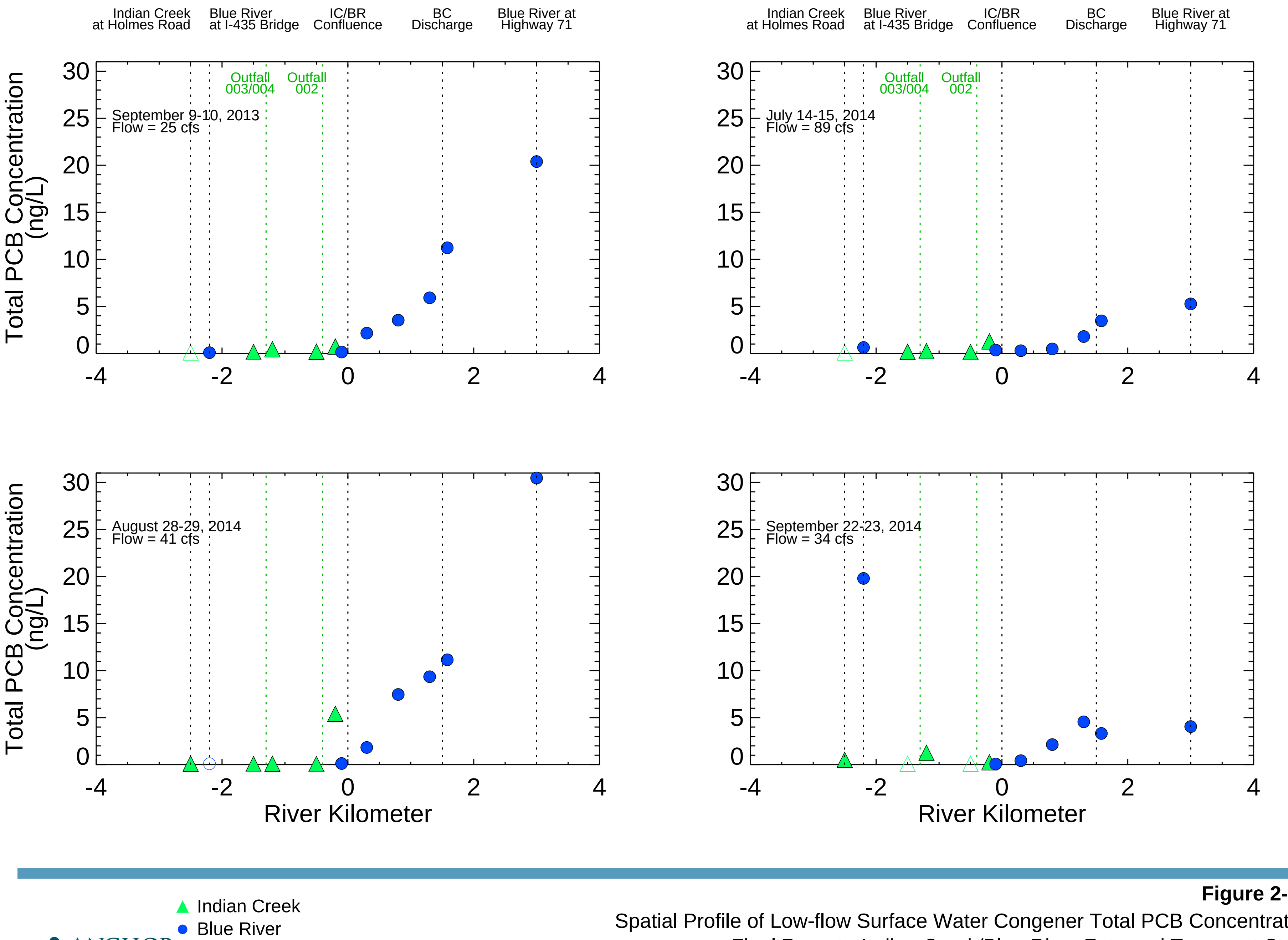

Figure 2-12

Spatial Profile of Low-flow Surface Water Congener Total PCB Concentration

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

Notes: Non-detects for Total PCB set at 0.1 ng/L. Non-detects shown as open symbols.

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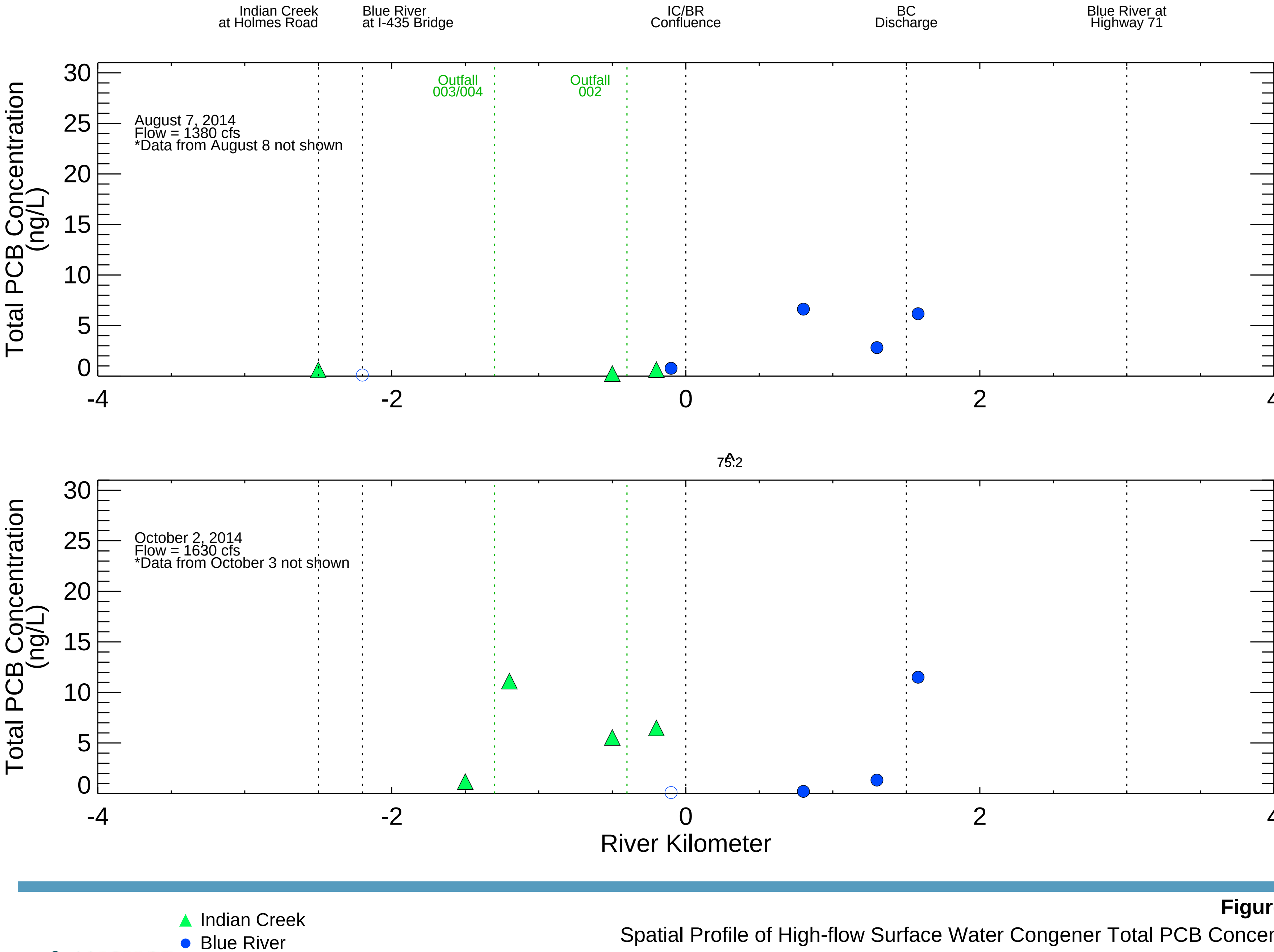


Figure 2-13

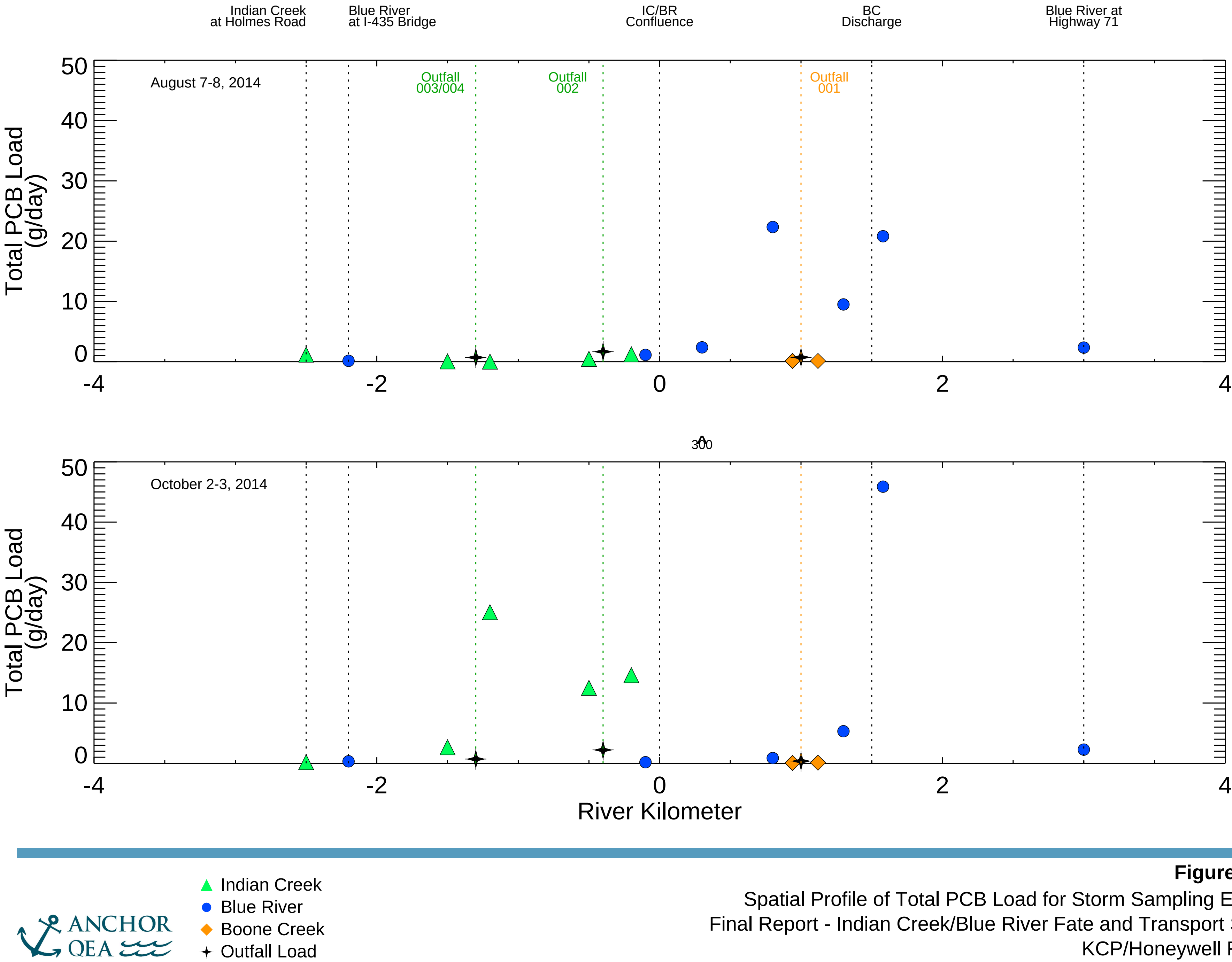
Spatial Profile of High-flow Surface Water Congener Total PCB Concentration

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

Notes: Non-detects for Total PCB set at 0.1 ng/L. Non-detects shown as open symbols.

PS - \\helios\aq\D_Drive\Projects\Honeywell_FMT\KCP_(120287-03)\ANALYSIS\Surface_Water\Spatials\final_report\spatial_byevent_tpcb_2015_hiflow.pro Wed Jul 29 17:22:24 2015



ANCHOR QEA

Figure 2-14

Spatial Profile of Total PCB Load for Storm Sampling Events
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Note: Load values plotted at outfall locations calculated using measured Total PCB and flow in outfall at compliance point.

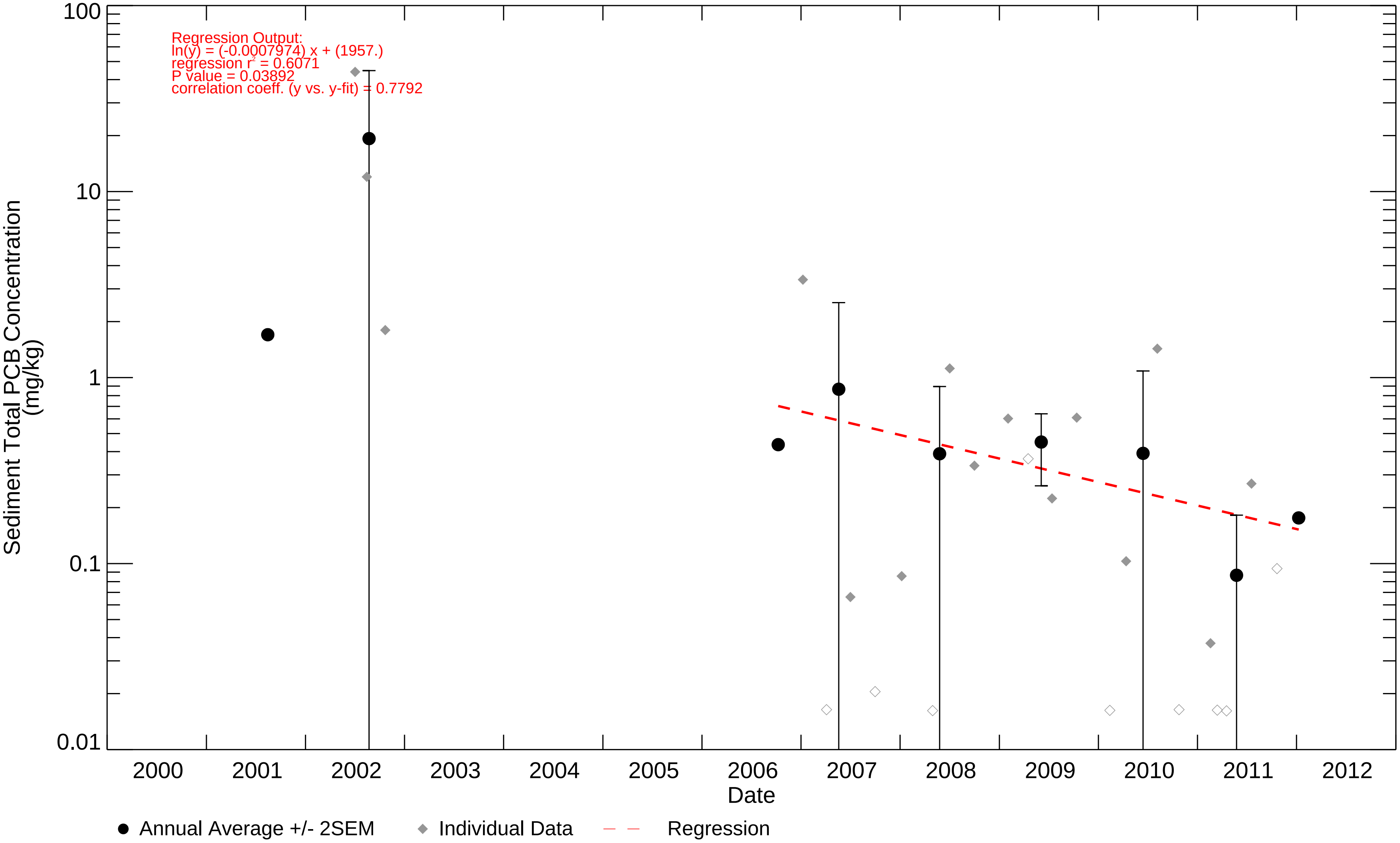


Figure 2-15

Total PCB Concentration in Sediment Samples Near BFC Outfall 002
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Note: Non-detect Total PCBs set to half the maximum detection limit and shown as open symbols.

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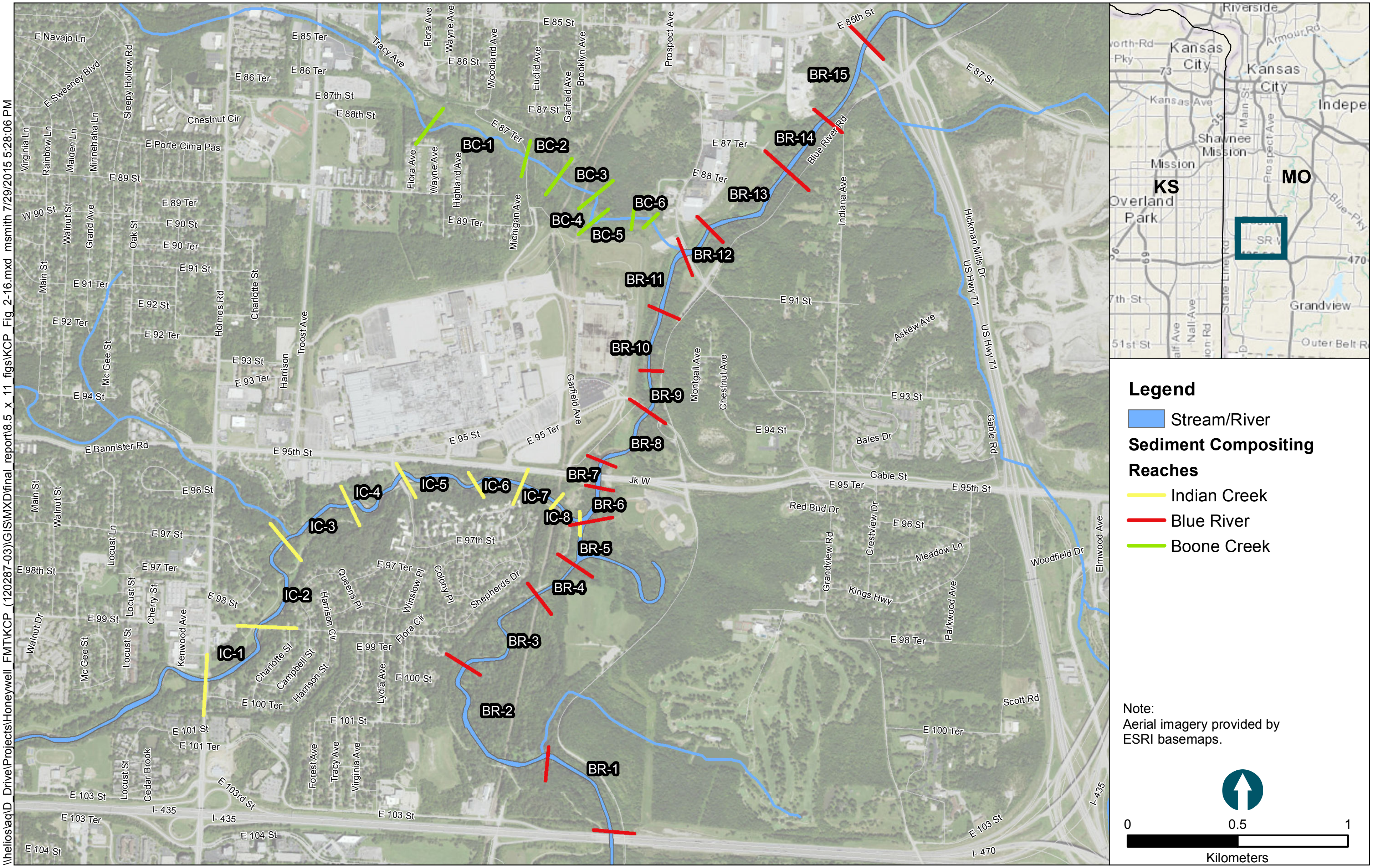

Figure 2-16
Sediment Sampling Compositing Reaches
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

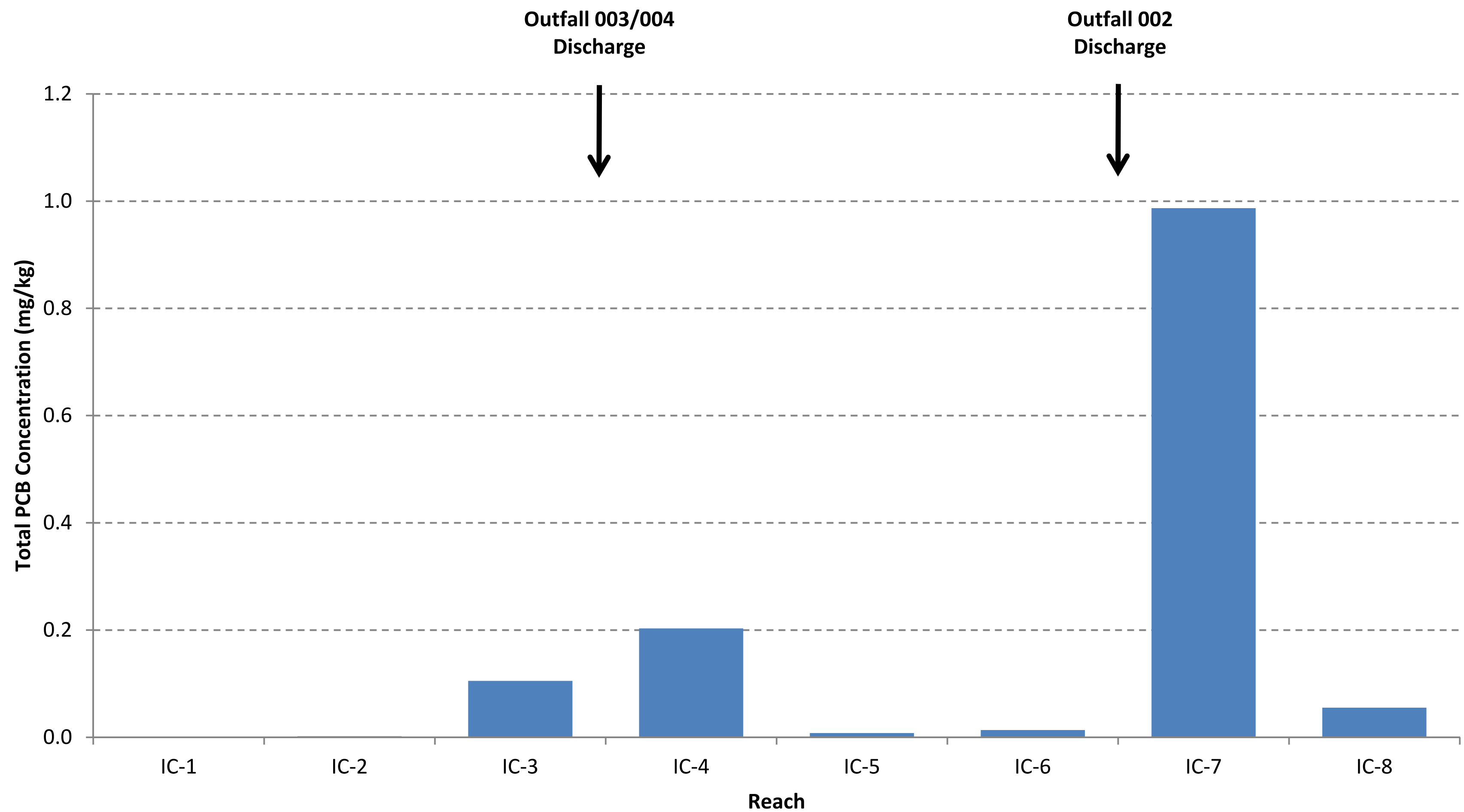

Figure 2-17a
Sediment Total PCB Concentration in Indian Creek
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

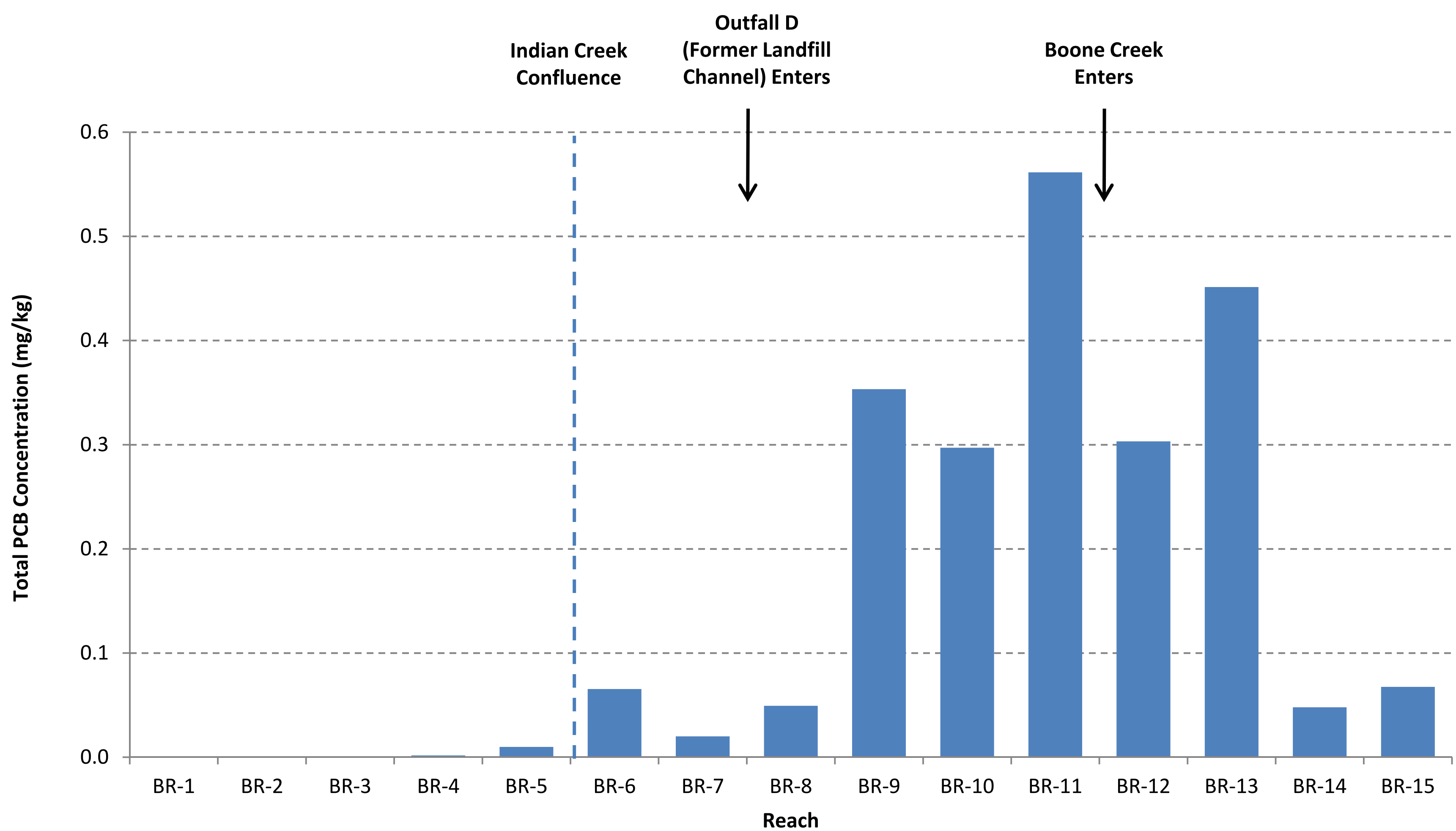

Figure 2-17b
Sediment Total PCB Concentration in Blue River
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

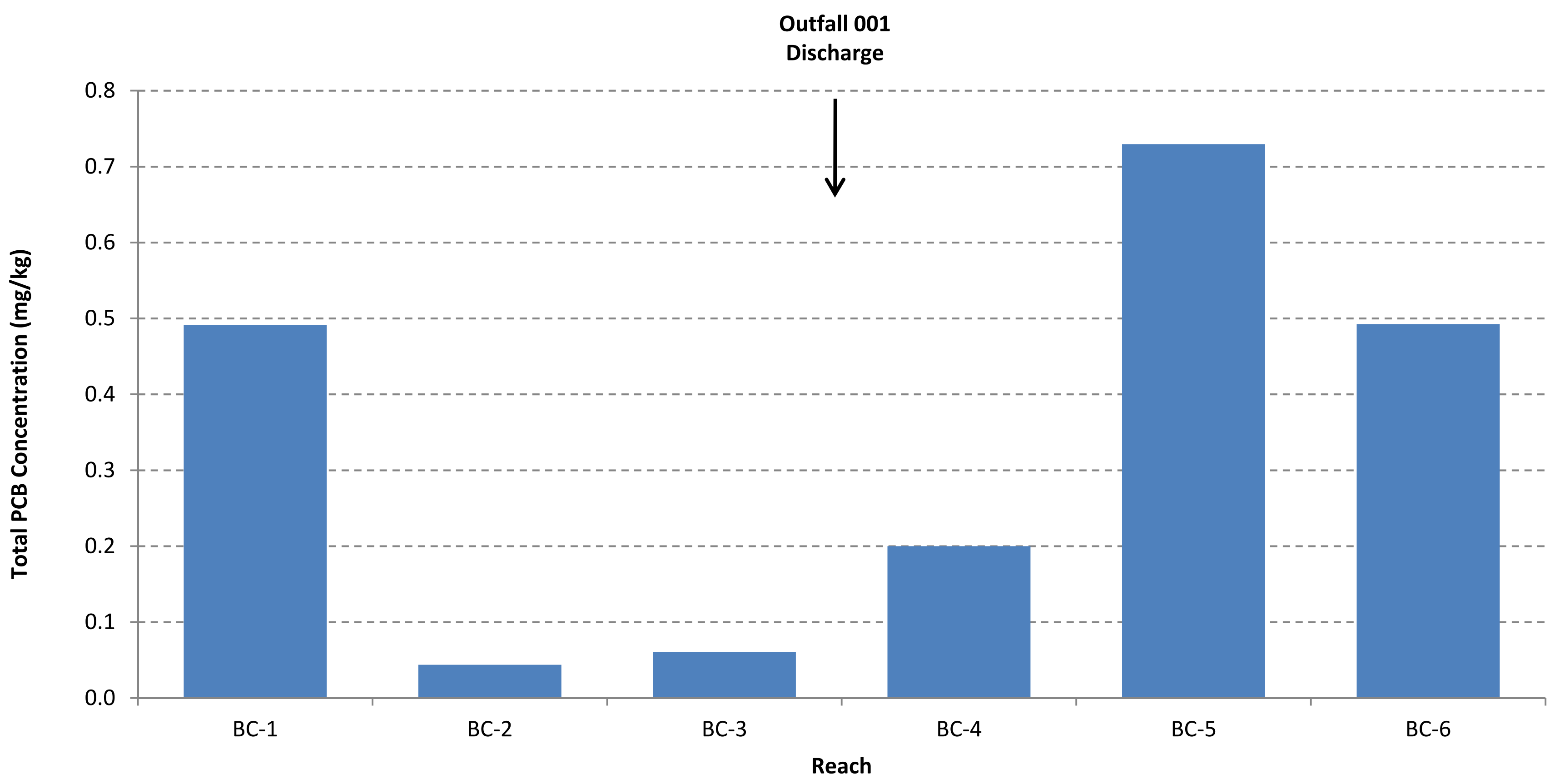

Figure 2-17c
Sediment Total PCB Concentration in Boone Creek
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

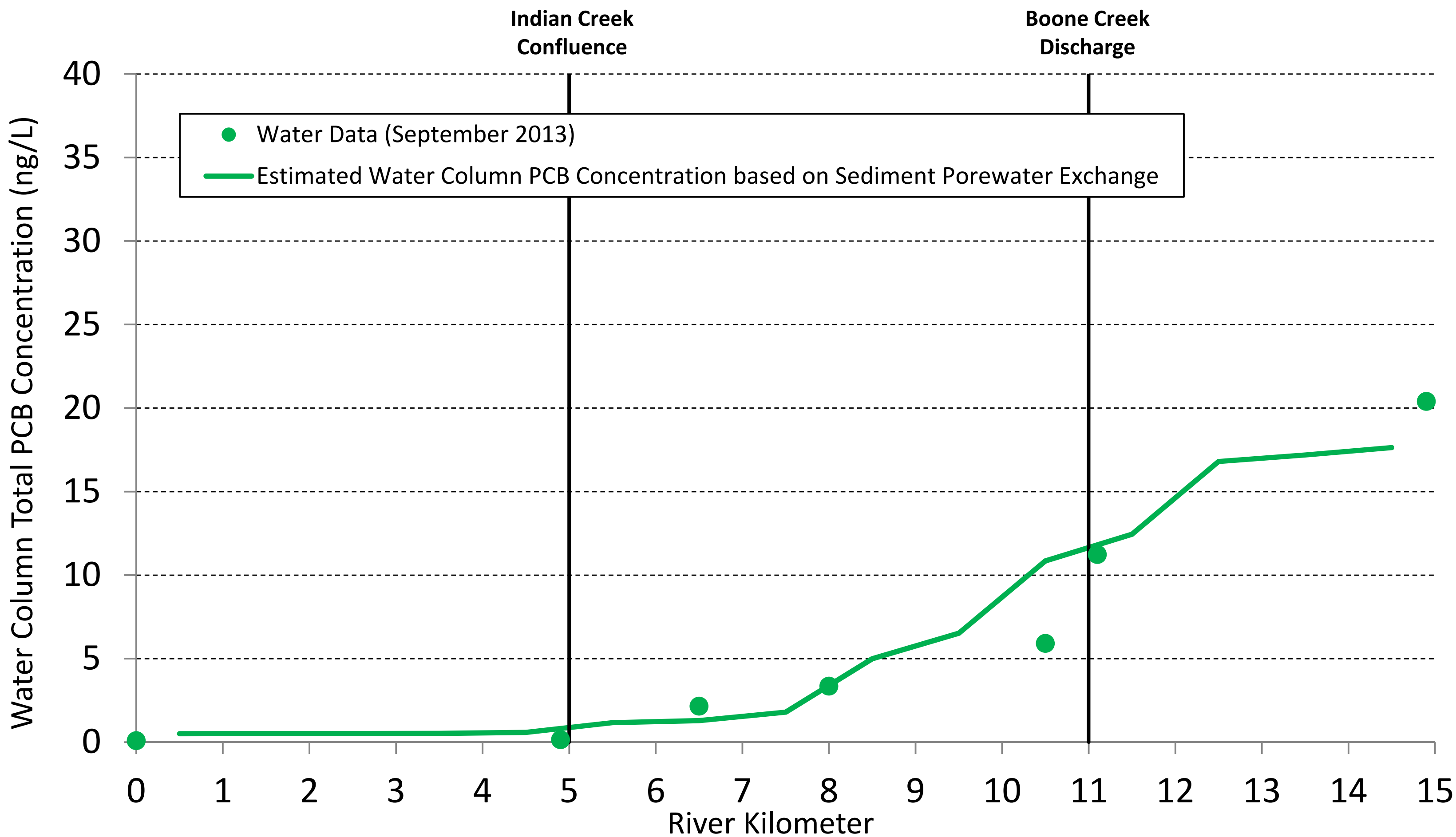

Figure 2-18a
Sediment Porewater Exchange Calculation (September 9-10, 2013 Event)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

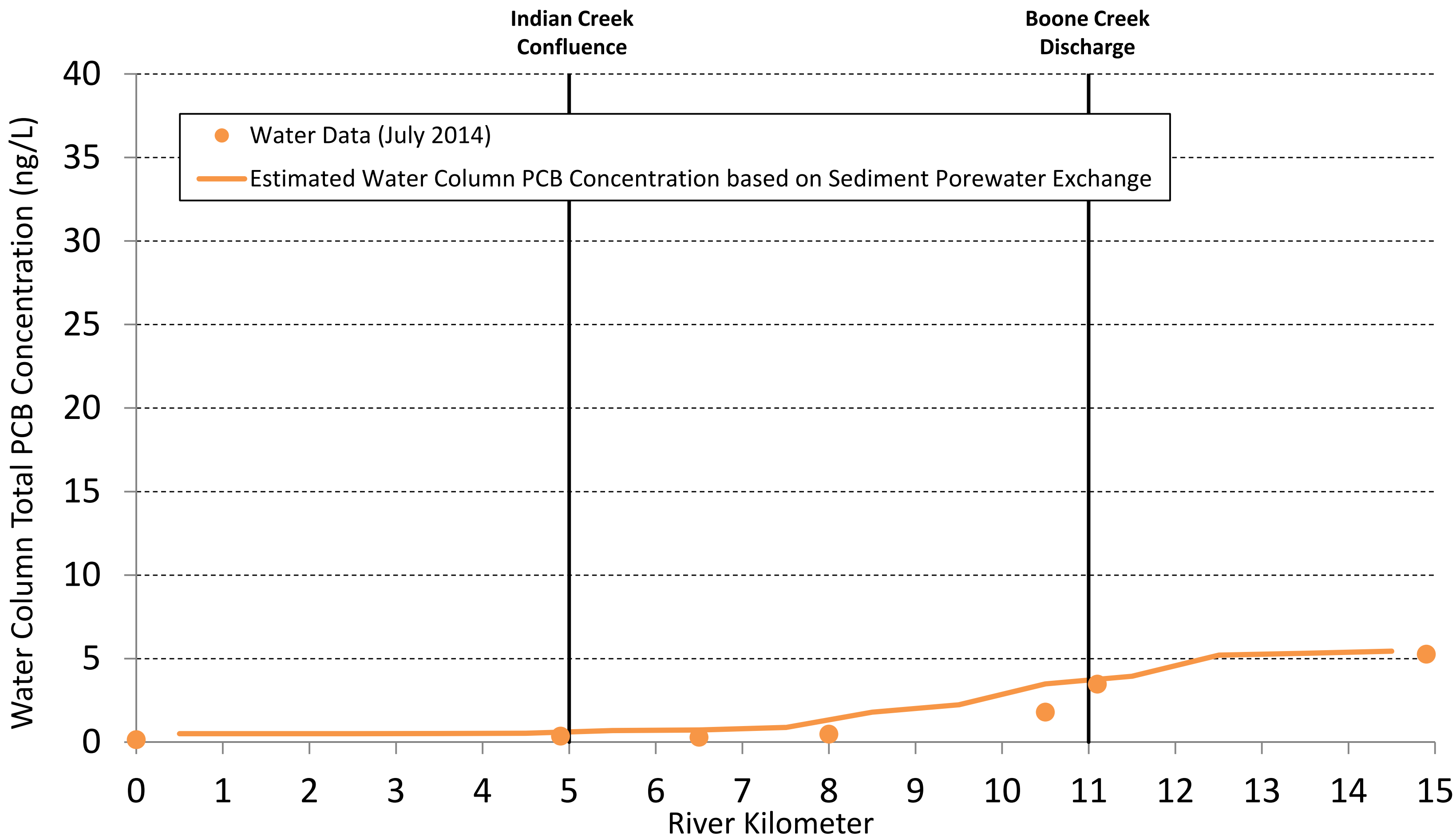

Figure 2-18b
Sediment Porewater Exchange Calculation (July 14-15, 2014 Event)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

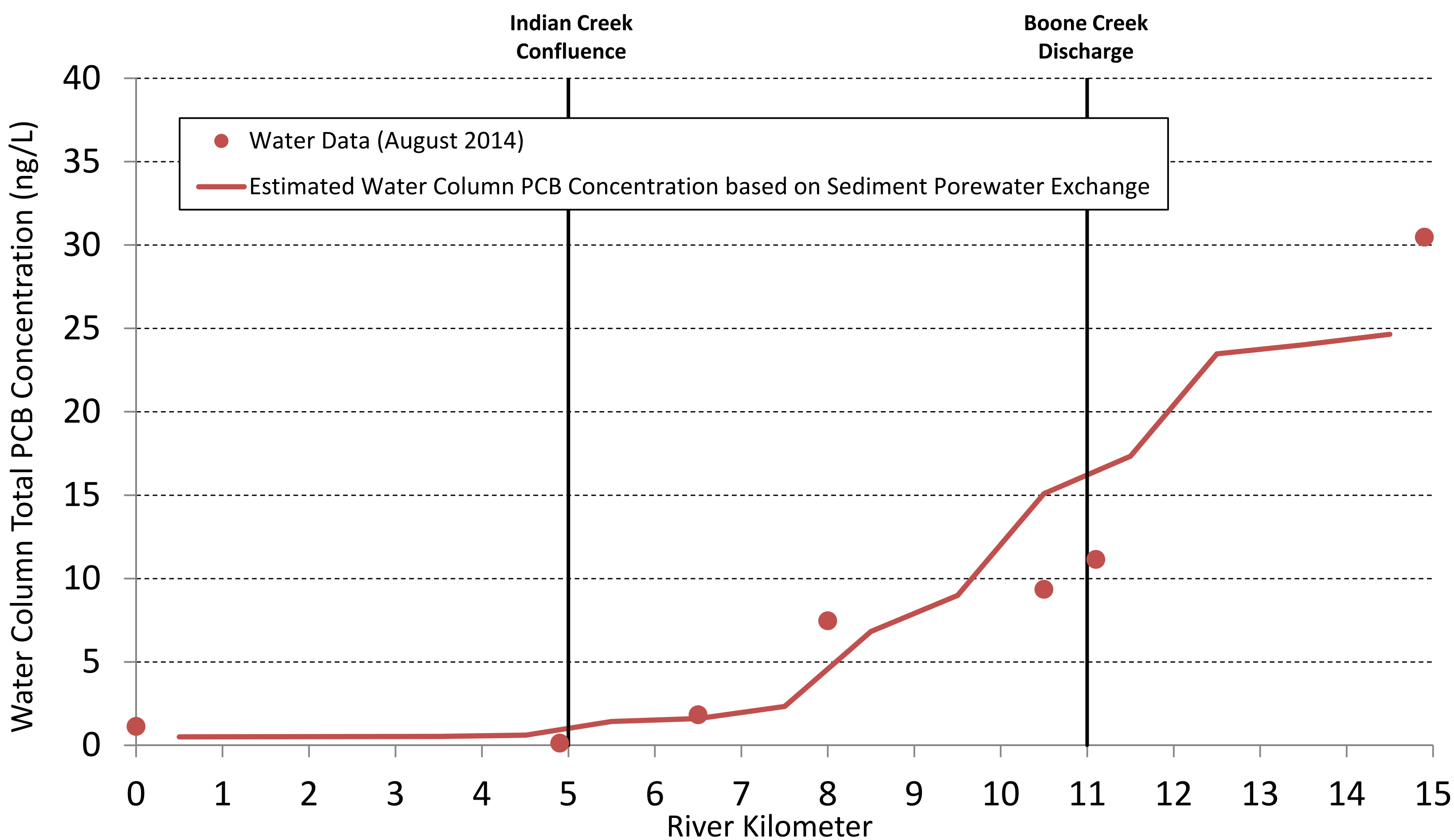

Figure 2-18c
Sediment Porewater Exchange Calculation (August 28-29, 2014 Event)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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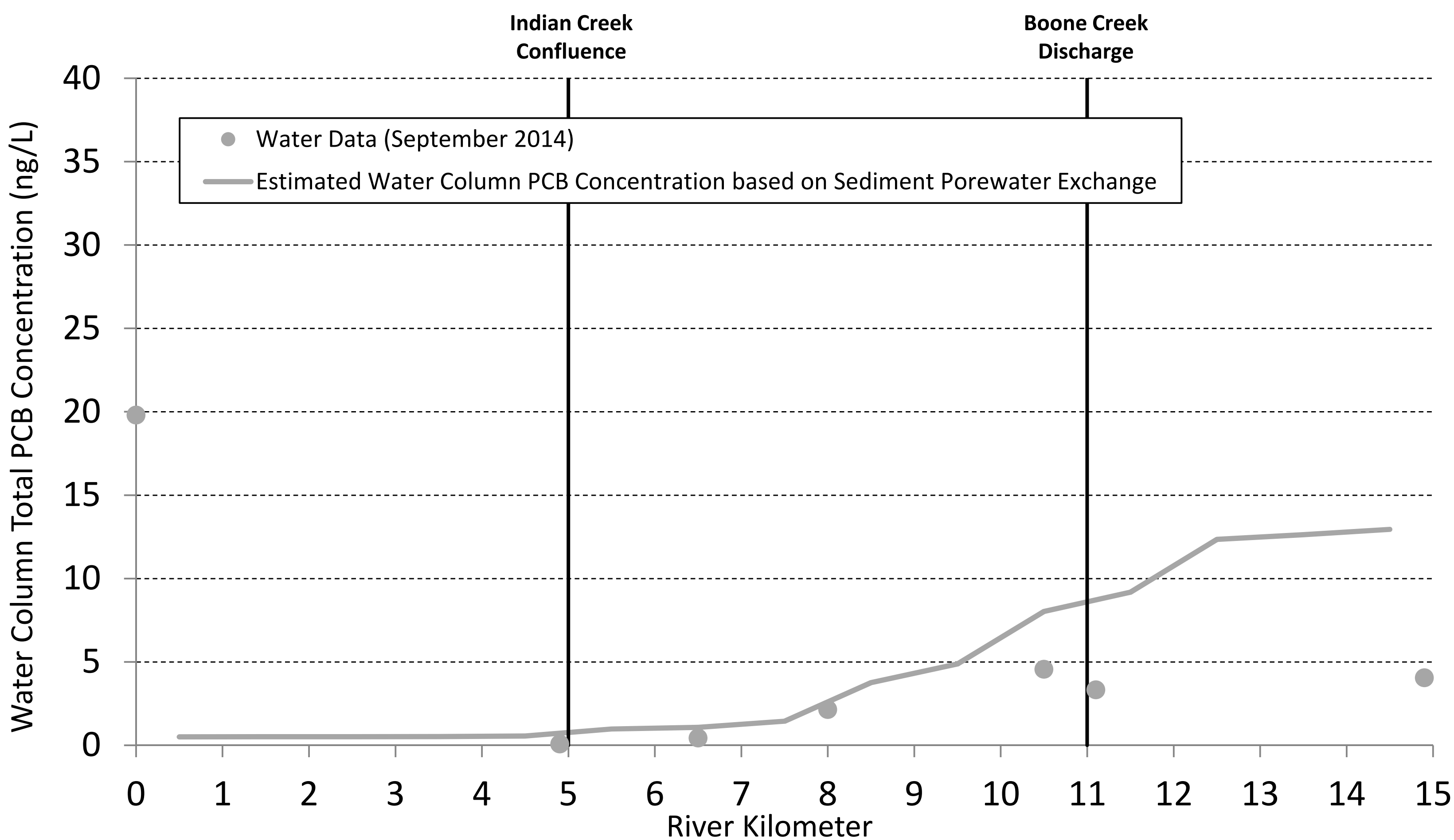

Figure 2-18d
Sediment Porewater Exchange Calculation (September 22-23, 2014 Event)
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

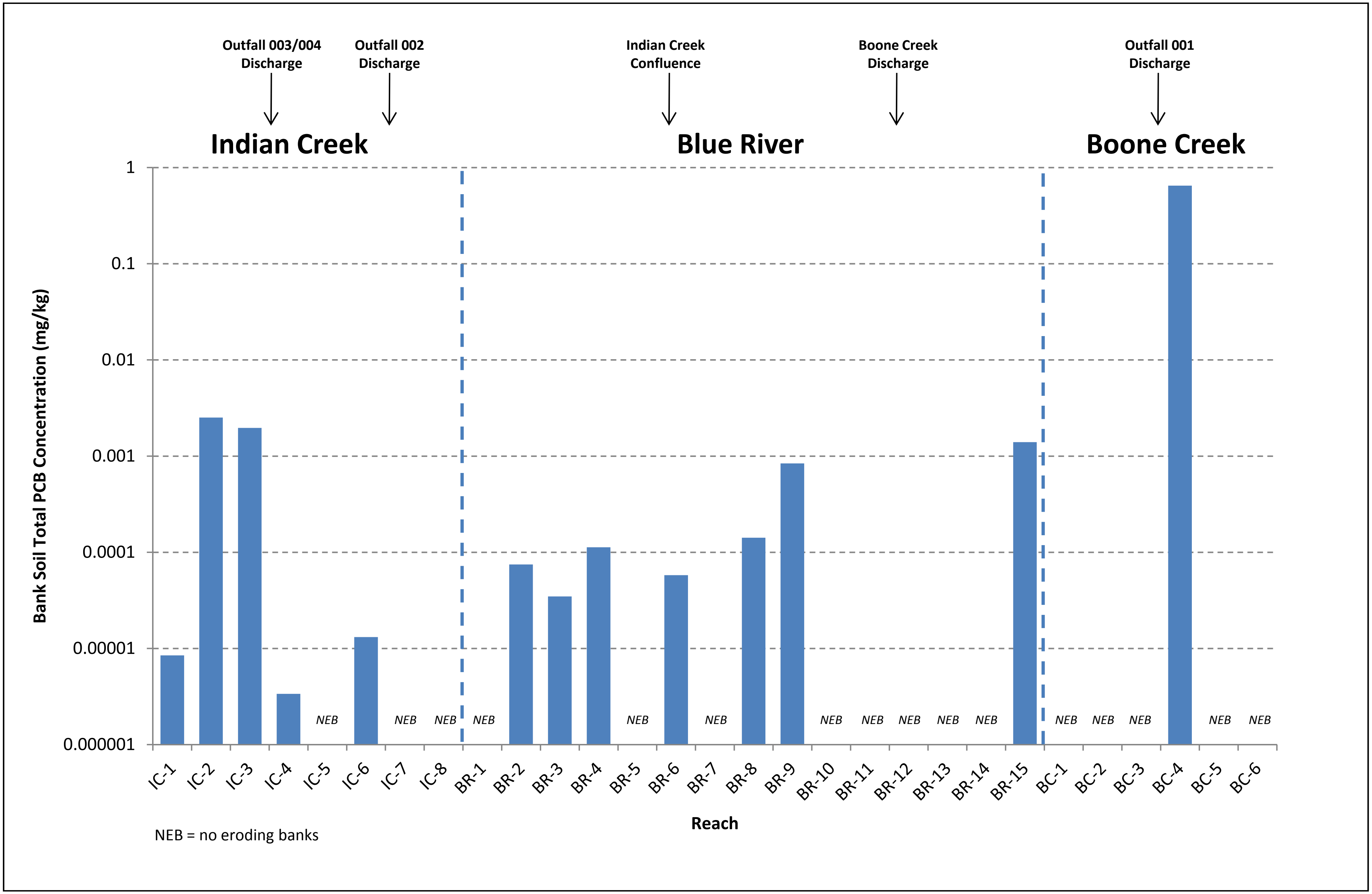

Figure 2-19
Spatial Profile of Soil PCB Concentrations in Areas with Eroding Streambanks
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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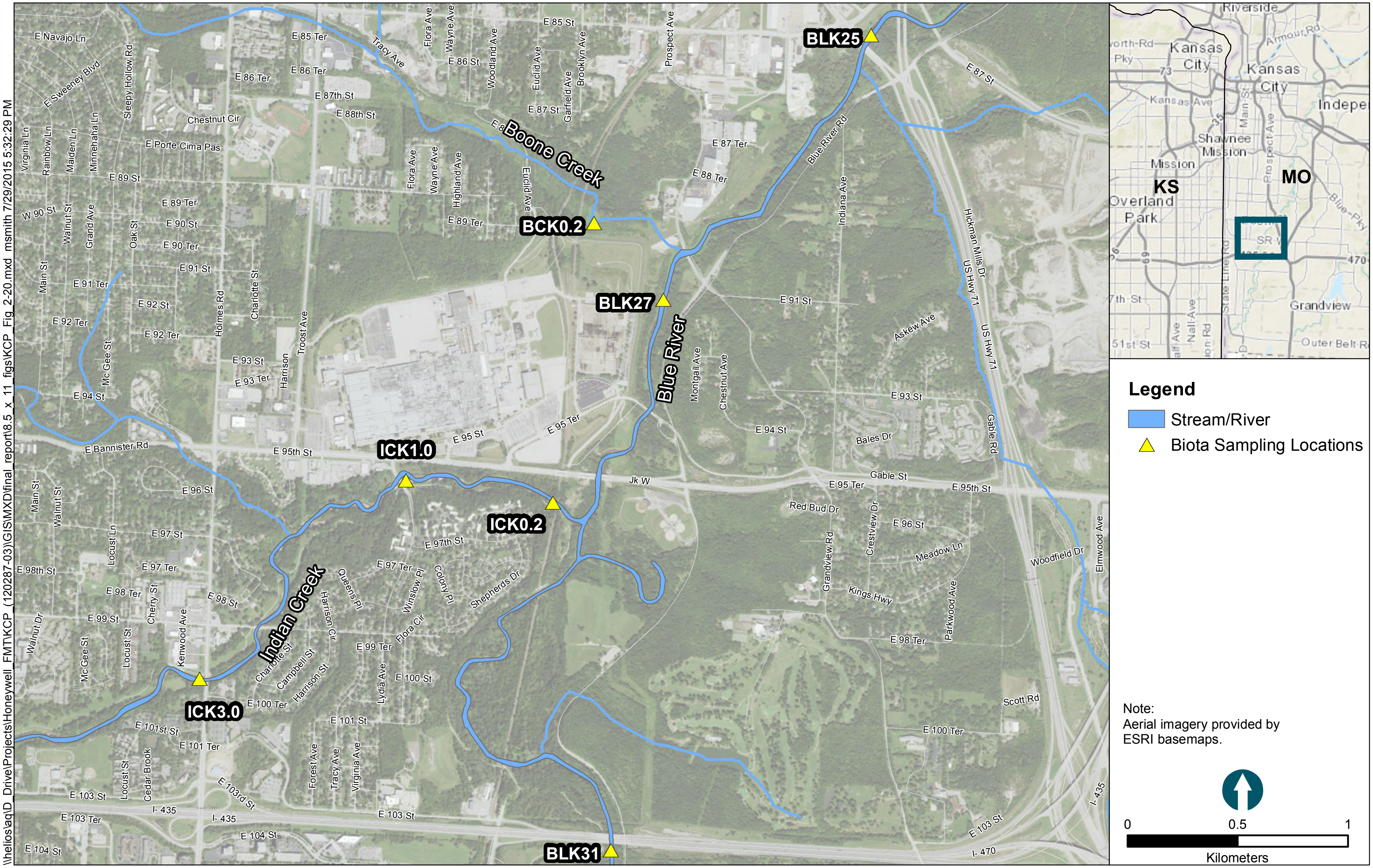

Figure 2-20
Biota Sampling Locations
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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River Kilometer 0 represents the location of the Indian Creek/Blue River confluence
(i.e., negative River Kilometers are upstream of the confluence and positive River Kilometers are downstream).
Boone Creek samples are shown at a location equivalent to the approximate distance
upstream of the confluence of Boone Creek and Blue River.

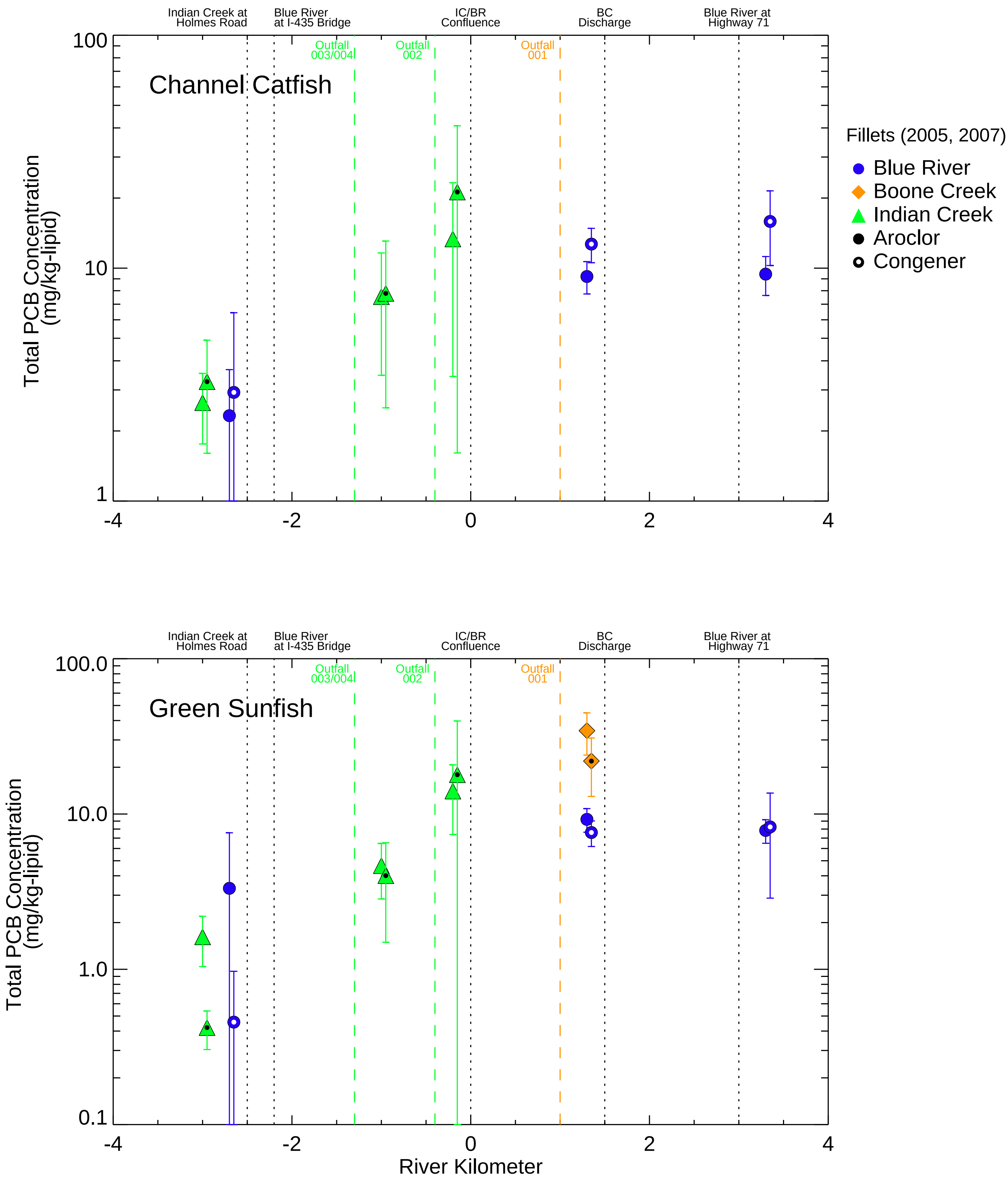


Figure 2-21a

Spatial Profiles of Lipid-normalized Total PCB Concentrations in Channel Catfish and Green Sunfish (2005 and 2007 data)

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non-detect samples set to half the detection limit. Error bars are 2 standard errors of the mean.

MJR - B:\Projects\Honeywell_FMT\Kansas_City_Plant(120287-03)\Analysis\Biota\KCP_spatial_fish_PCB.pro Thu Jan 21 09:27:20 2016

River Kilometer 0 represents the location of the Indian Creek/Blue River confluence
(i.e., negative River Kilometers are upstream of the confluence and positive River Kilometers are downstream).
Boone Creek samples are shown at a location equivalent to the approximate distance
upstream of the confluence of Boone Creek and Blue River.

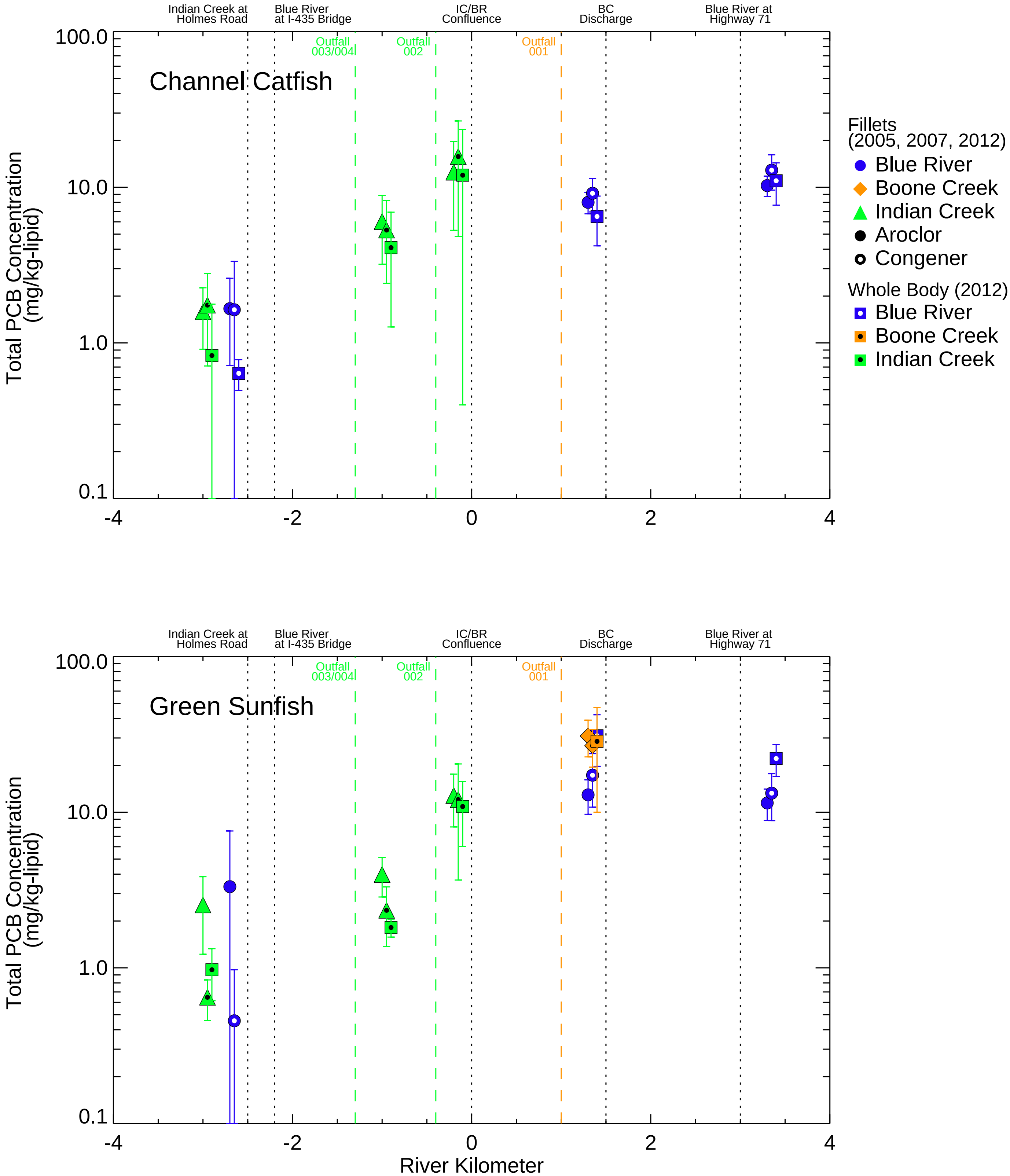


Figure 2-21b

Spatial Profiles of Lipid-normalized Total PCB Concentrations in Channel Catfish and Green Sunfish (2005, 2007 and 2012 data)
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Notes: Non-detect samples set to half the detection limit. Error bars are 2 standard errors of the mean.

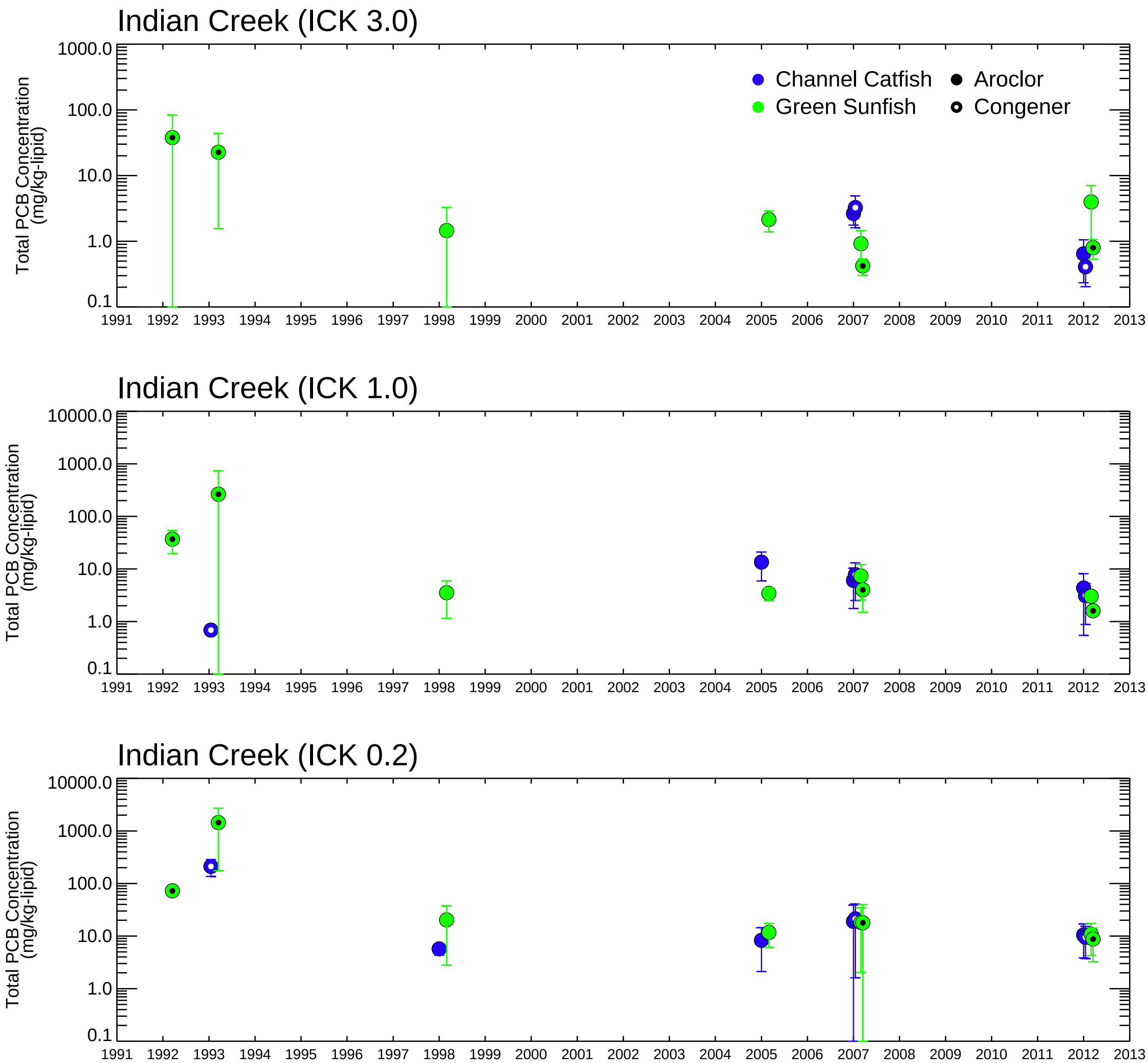


Figure 2-22a

Time Series of Lipid-normalized Total PCB Concentrations in Channel Catfish and Green Sunfish

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

Note: Non-detect samples set to half the detection limit. Error bars are 2 standard errors of the mean.

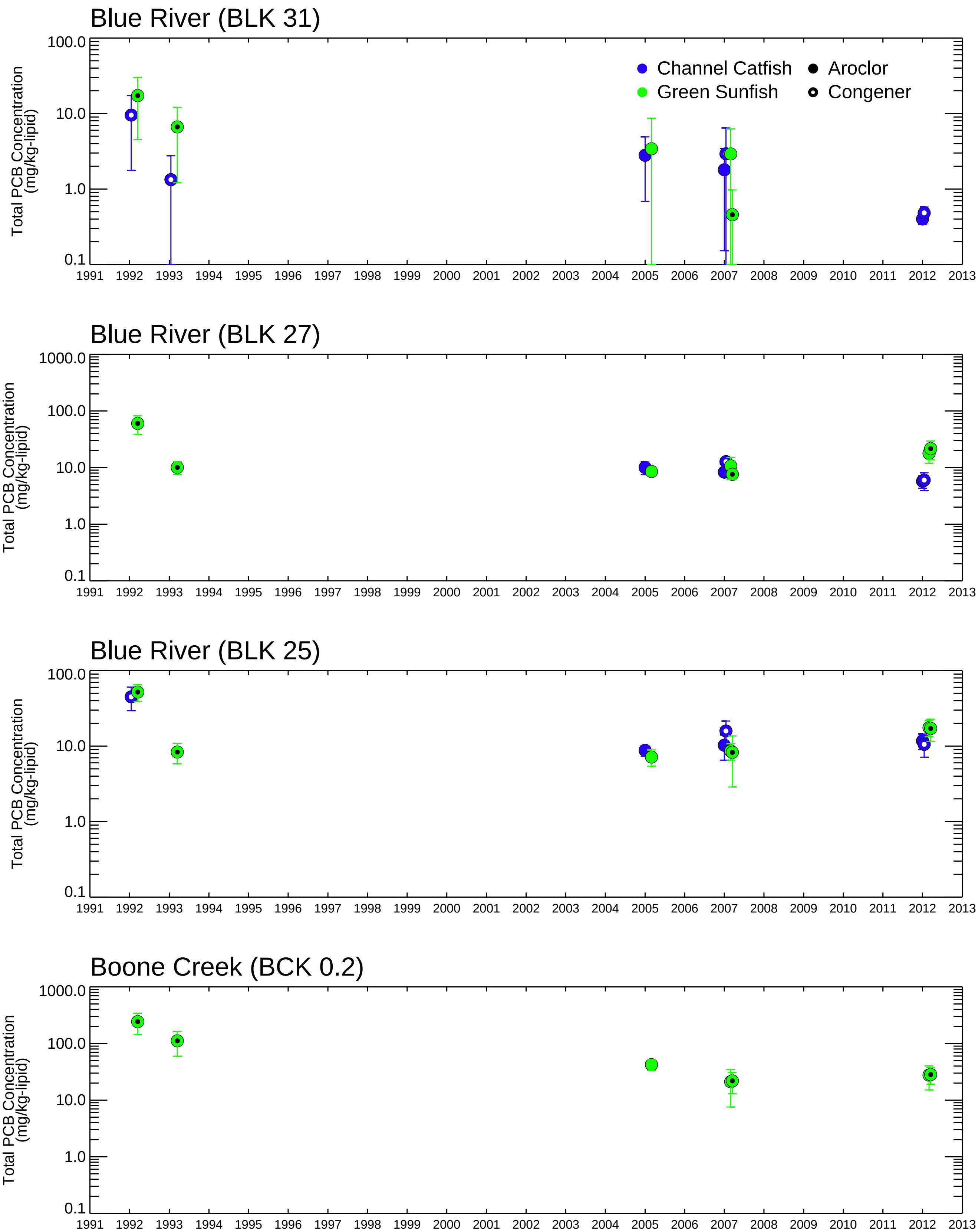


Figure 2-22b

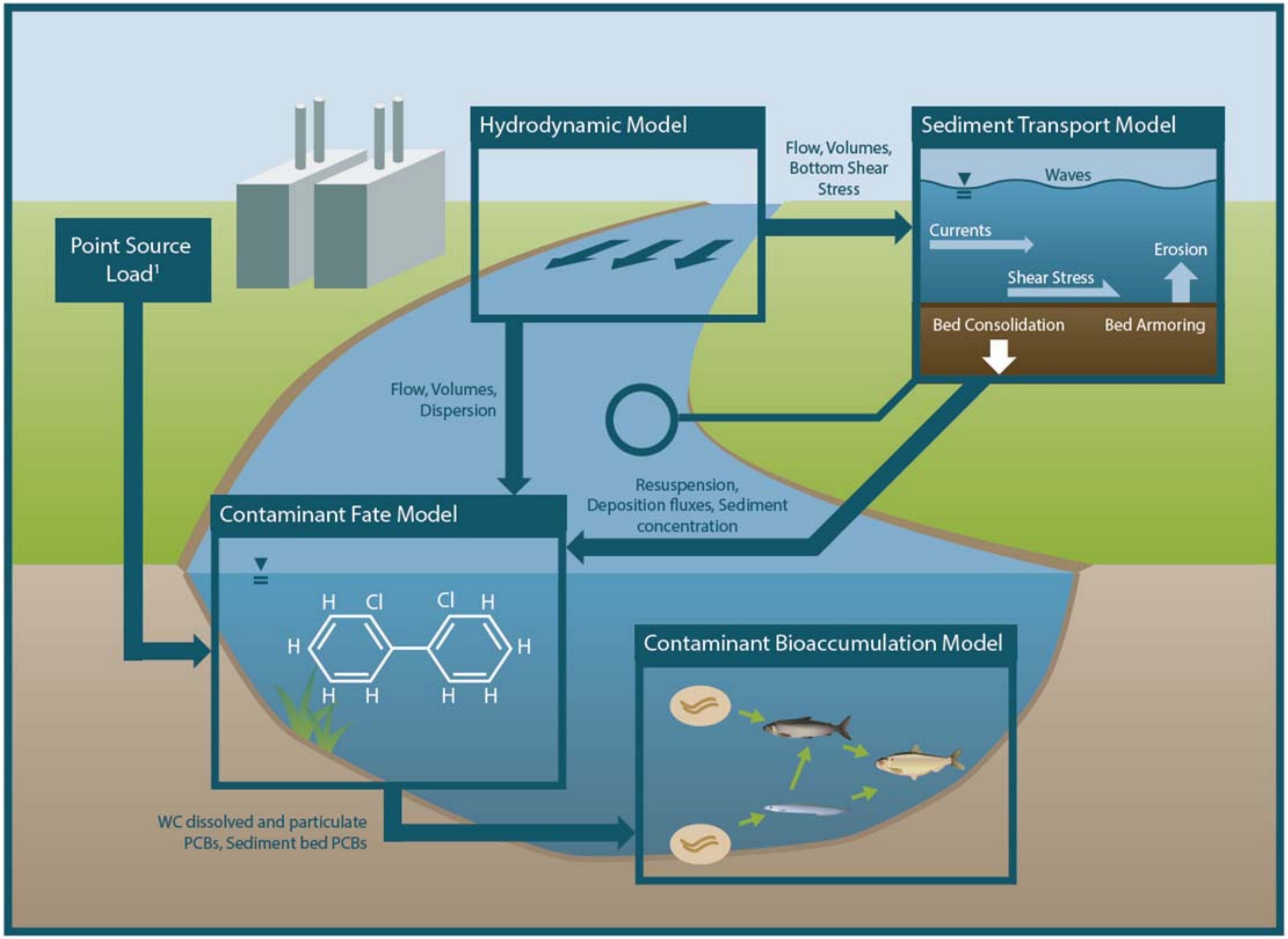
Time Series of Lipid-normalized Total PCB Concentrations in Channel Catfish and Green Sunfish

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Note: Non-detect samples set to half the detection limit. Error bars are 2 standard errors of the mean.



[1]Based on flows from hydrologic/hydraulic models and stormwater sampling PCB data

Figure 3-1
Model Framework
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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ANCHOR QEA

Figure 3-2
Model Domain
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

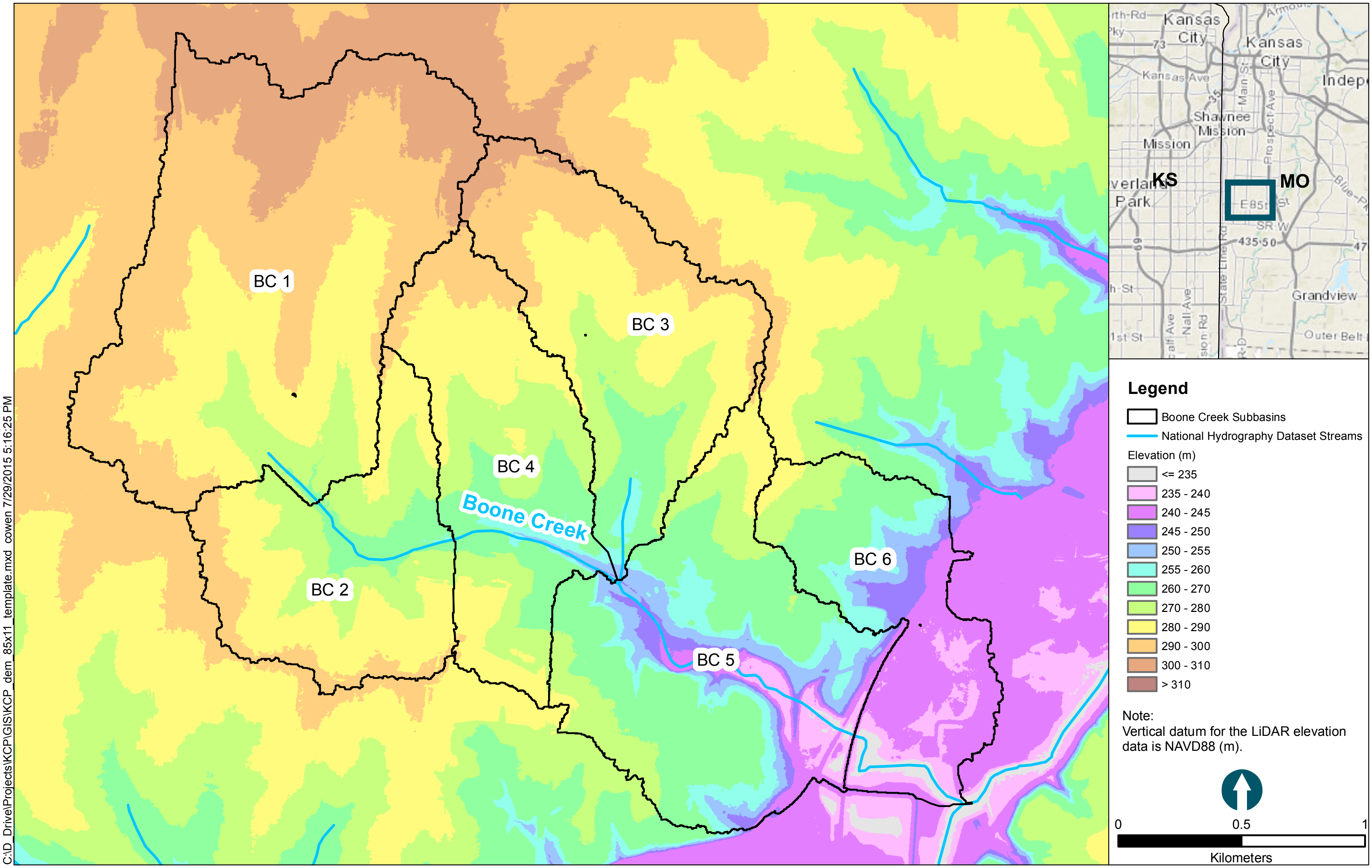

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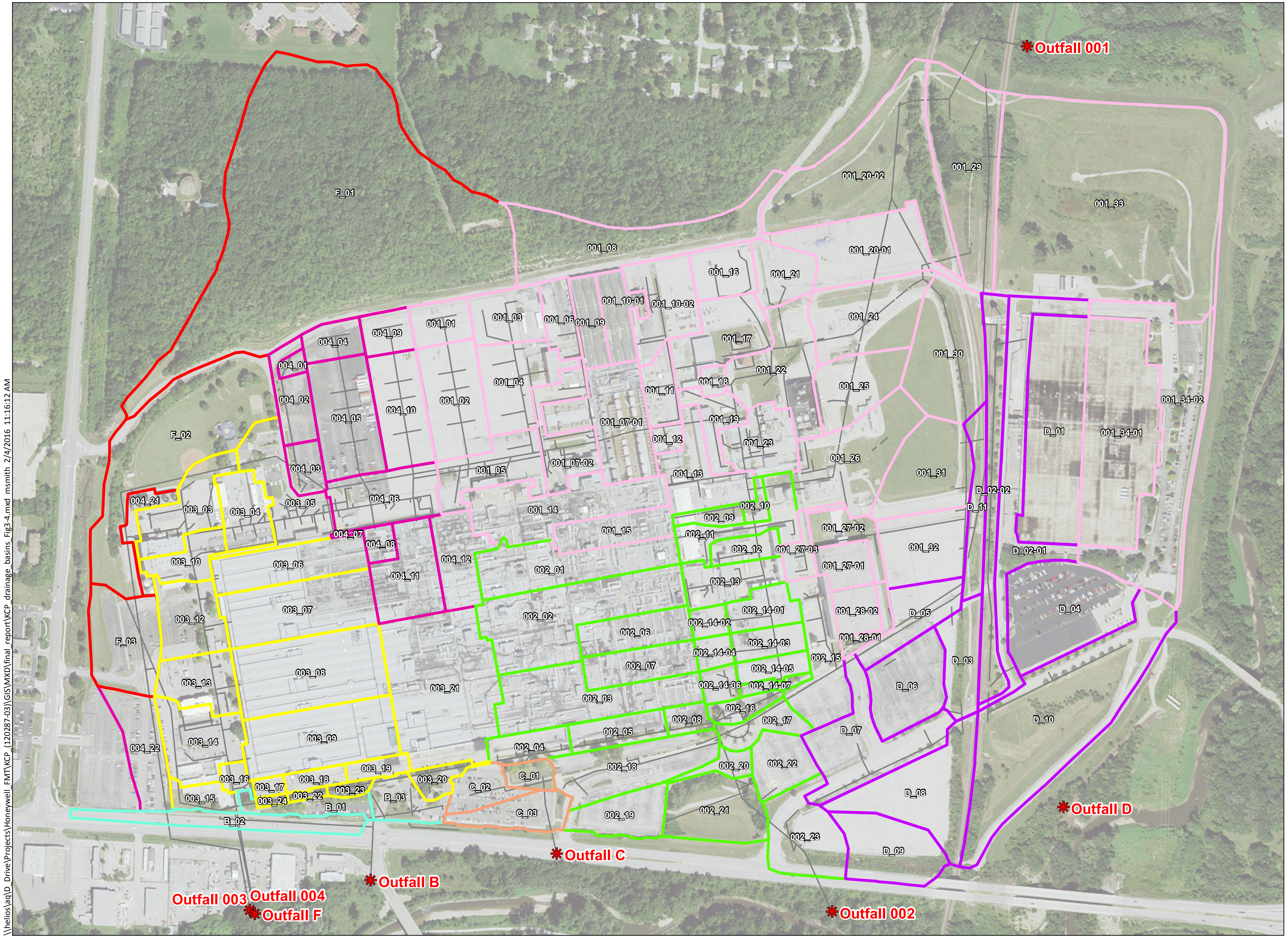
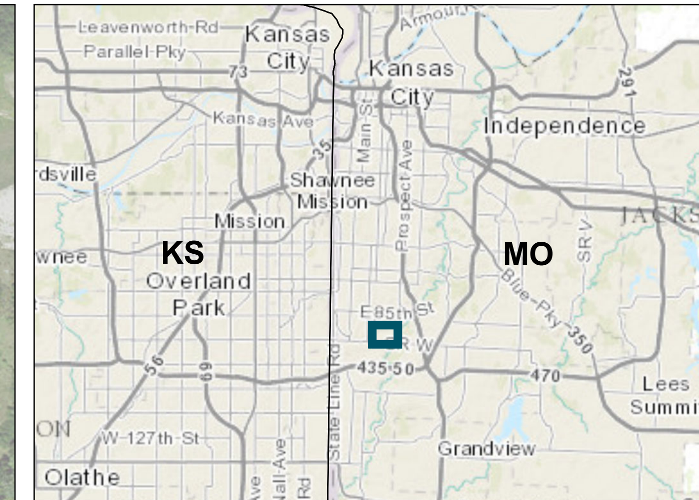
Figure 3-3
Boone Creek Subbasin Delineation
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA





Legend

- BFC Storm Sewer System Outfalls
- BFC Storm Sewer System

BFC Subcatchments Simulated in PCSWMM Model (unique colors by outfall subbasin)

- 001
- 002
- 003
- 004
- B
- C
- D
- F

Note:
Aerial imagery provided by ESRI basemaps.

0 0.2 0.4
Kilometers

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ANCHOR QEA

Figure 3-4
BFC Subcatchment Delineation
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

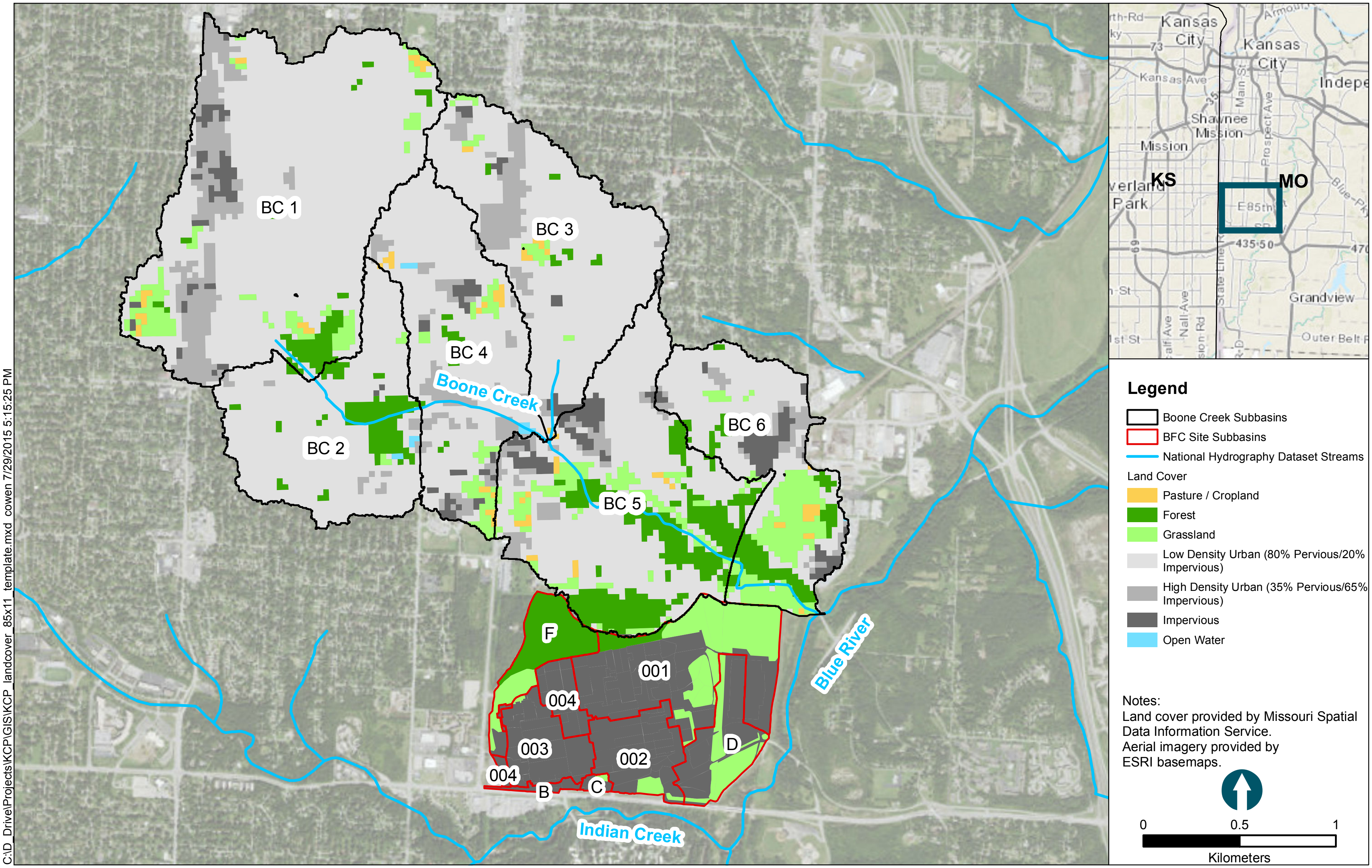

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Figure 3-5
Boone Creek and BFC Site Land Cover Data
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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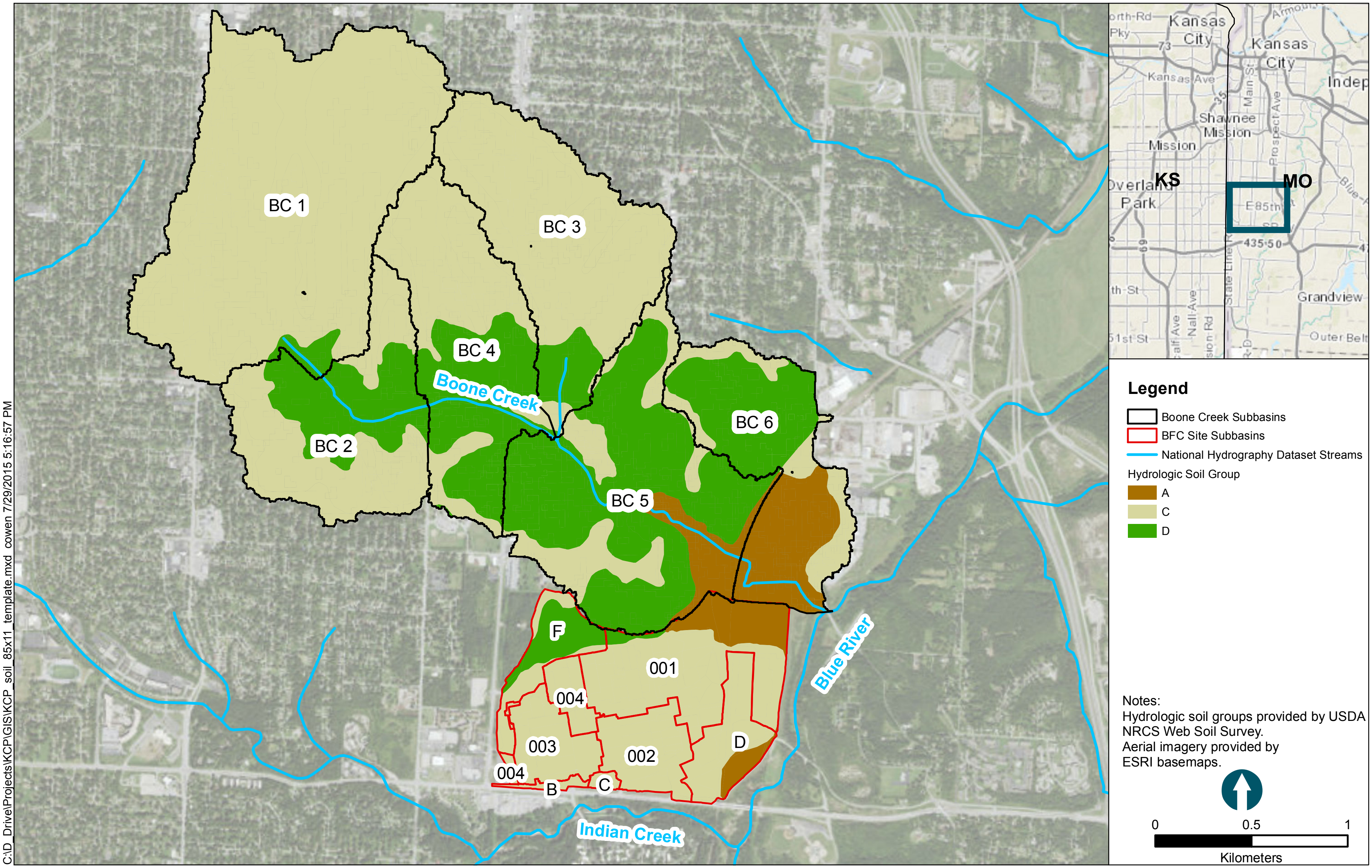

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Figure 3-6

Boone Creek and BFC Site Hydrologic Soil Groups

Final Report - Indian Creek/Blue River Fate and Transport Study

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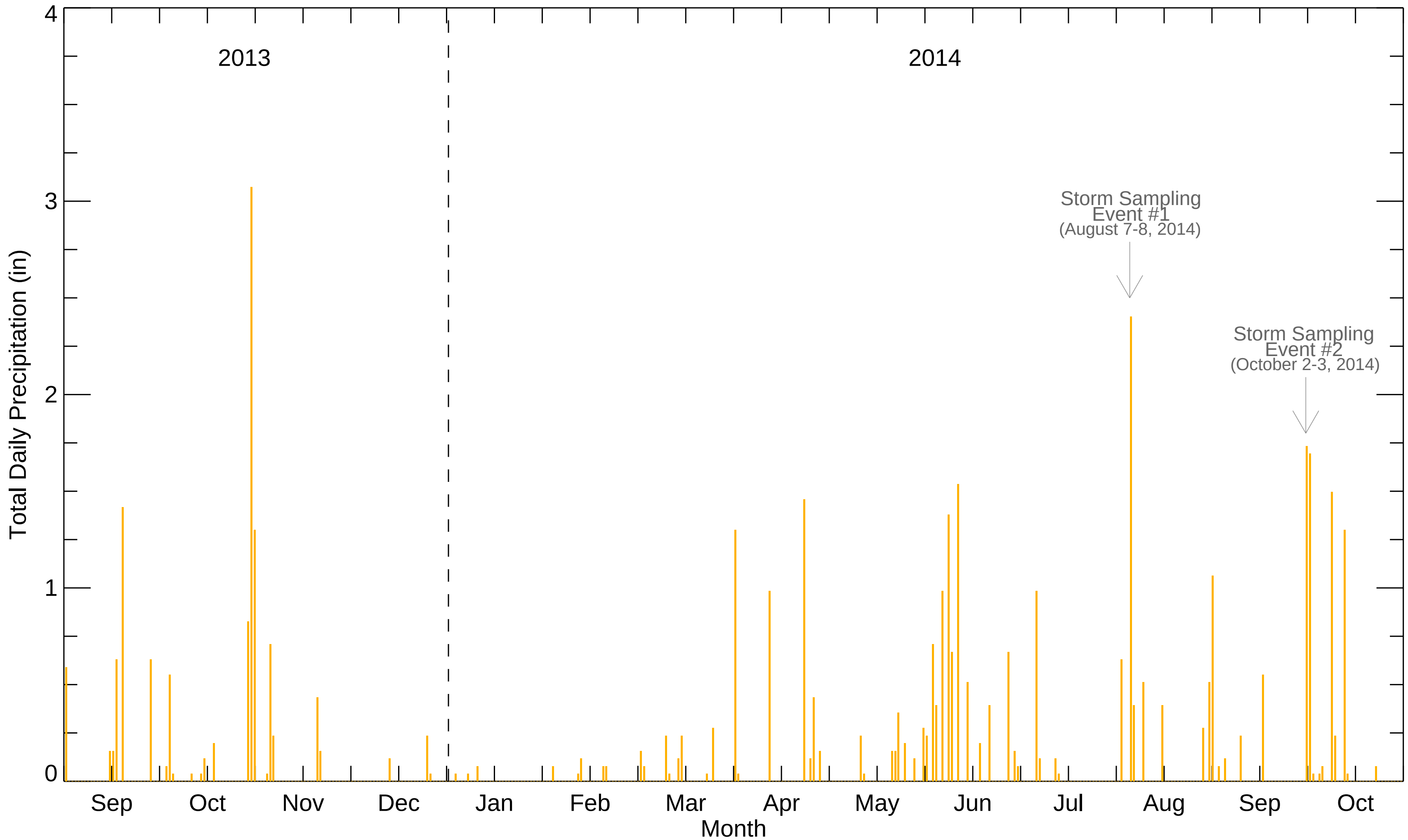

ANCHOR QEA

Figure 3-7

Time Series of Observed Precipitation in Boone Creek from September 2013 to October 2014
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T
Note: Precipitation time series obtained from StormWatch Gauge #1720 (103rd St. @ Indian Creek).

CFO - C:\D_Drive\Projects\KCP\Analysis\Precip\plot_temporal_precip_16panel.pro Wed Jul 29 17:09:59 2015

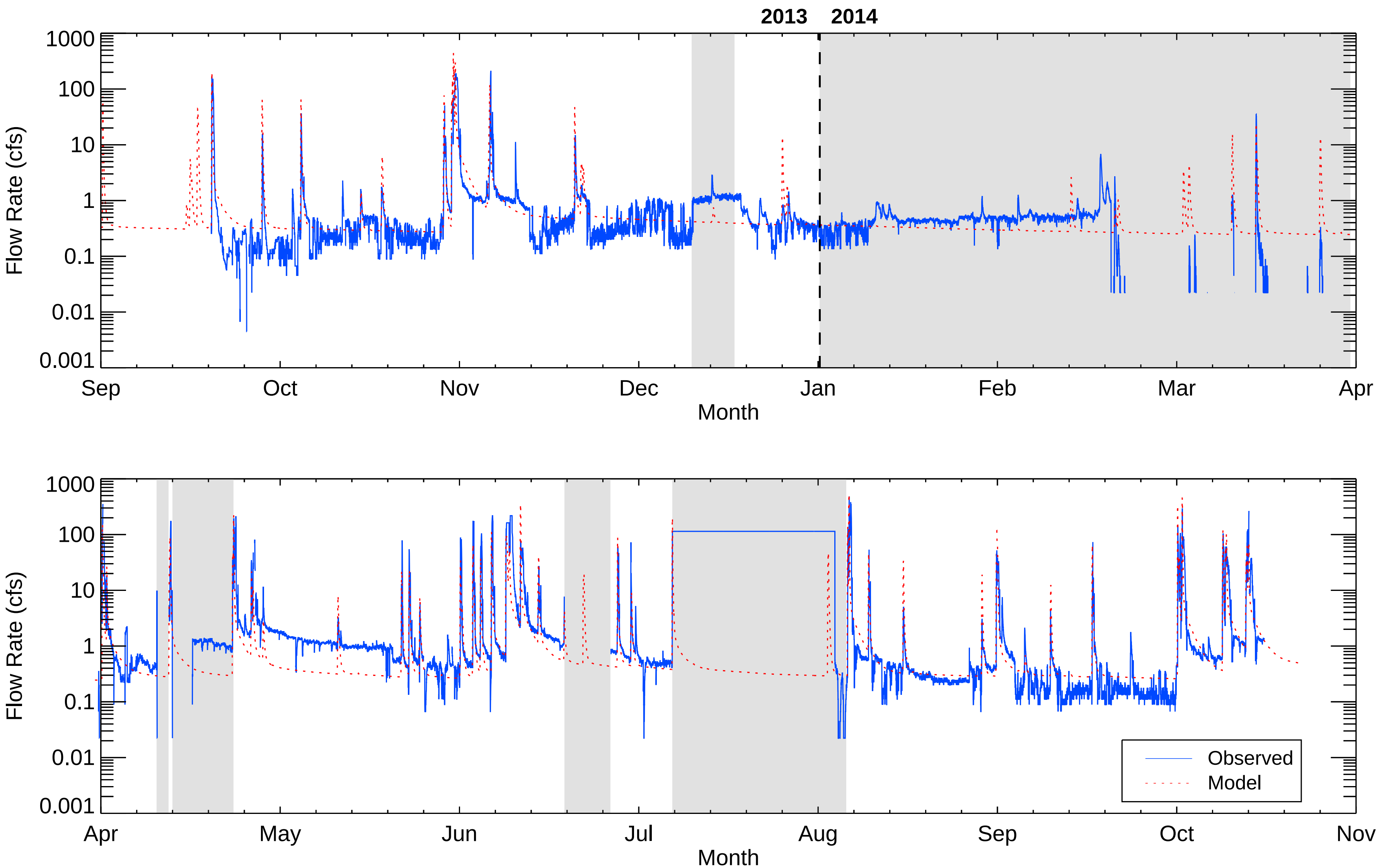

Figure 3-8a

Time Series of Observed and Model-predicted Flows in Boone Creek from September 2013 to October 2014 (Log Scale)
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Note: Gray shading indicates periods where recorded flows were inaccurate due to the presence of debris or ice (during winter months), observed beaver activity, or equipment failure.

CFO - C:\D_Drive\Projects\KCP\Analysis\Flow\plot_temporal_flow_2panel.pro Thu Jan 21 14:02:43 2016

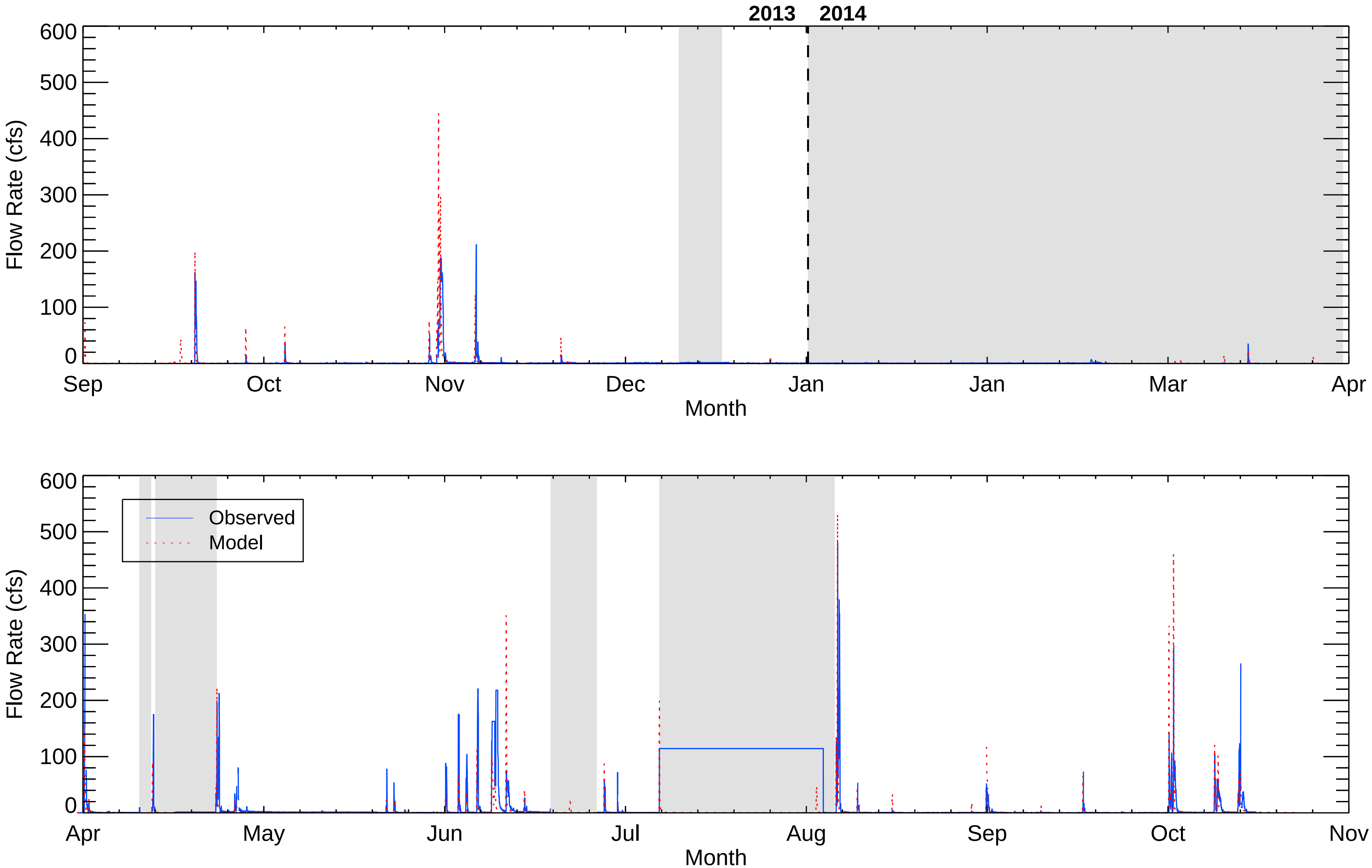

Figure 3-8b

Time Series of Observed and Model-predicted Flows in Boone Creek from September 2013 to October 2014 (Linear Scale)
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Note: Gray shading indicates periods where recorded flows were inaccurate due to the presence of debris or ice (during winter months), observed beaver activity, or equipment failure.

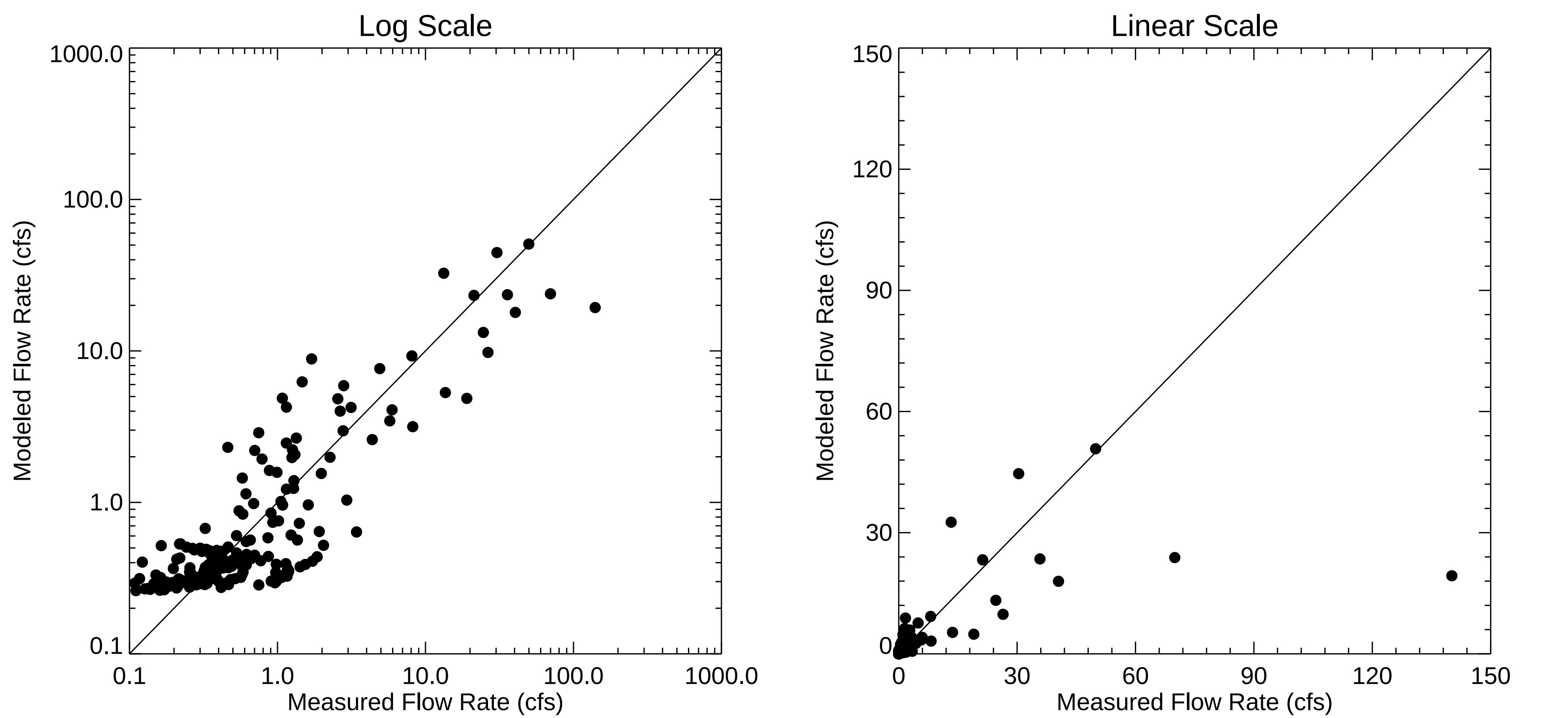

Figure 3-9

Comparison of Observed and Model-predicted Flows in Boone Creek from September 2013 to October 2014
Final Report - Indian Creek/Blue River Fate and Transport Study
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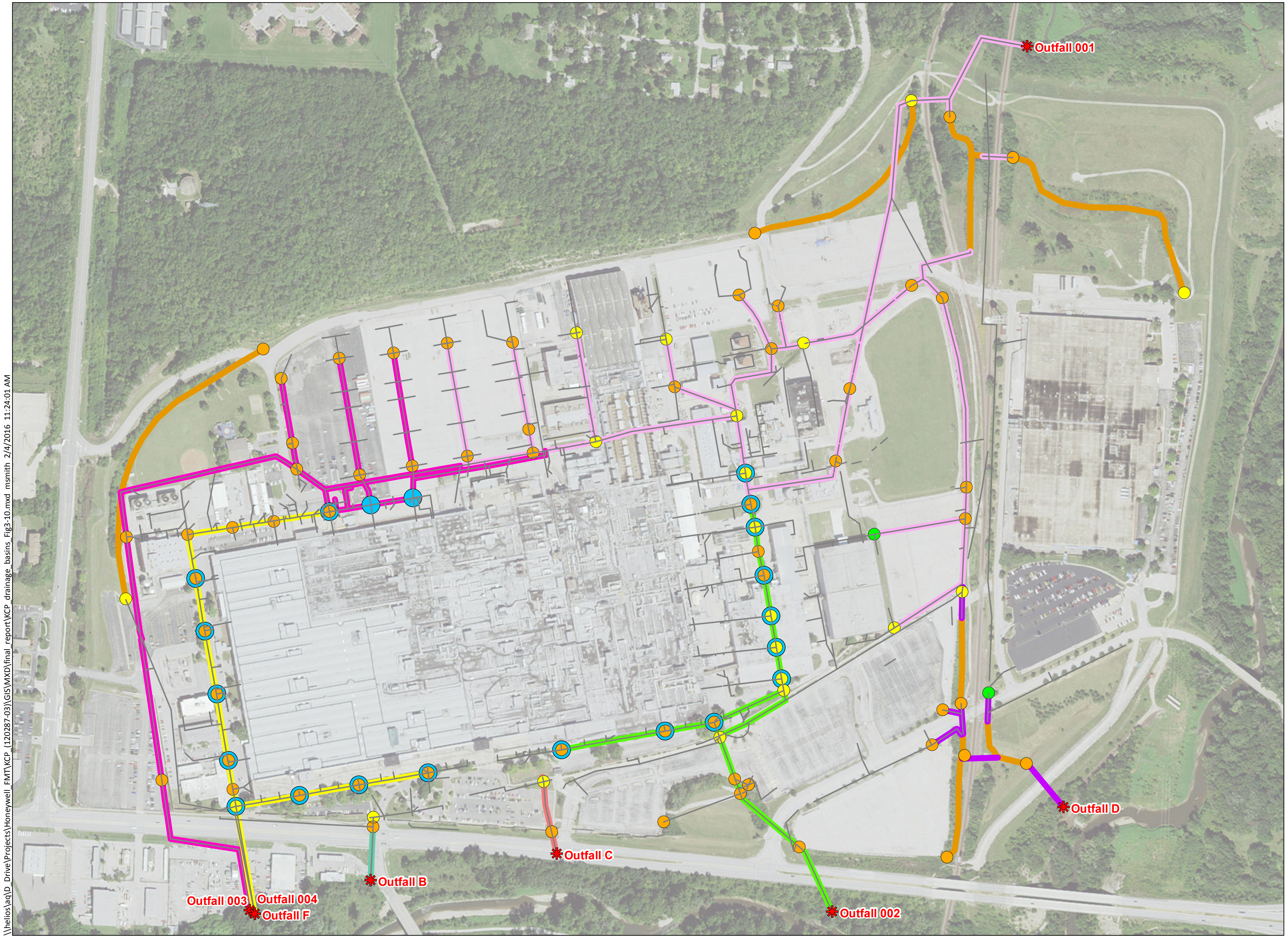
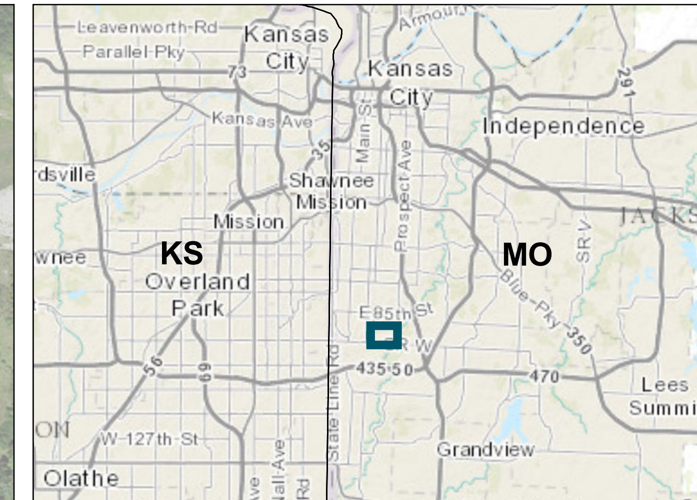
Note: Periods where recorded flows were inaccurate due to the presence of debris or ice (during winter months), observed beaver activity, or equipment failure were excluded.

CFO - C:\D_Drive\Projects\KCP\Analysis\Flow\compare_flows_2panel.pro Thu Jan 21 14:06:48 2016





Legend

- BFC Storm Sewer System Outfalls
- BFC Storm Sewer System

Simplified Stormwater Drainage System Simulated in PCSWMM Model

- 001
- 002
- 003
- 004
- B
- C
- D
- Simulated Channels

Hydrograph Input Locations

- Single
- Double
- Multiple
- Roof

Notes:
Aerial imagery provided by ESRI basemaps.
Simplified drainage system displayed as unique colors by outfall subbasin.

0 0.2 0.4
Kilometers

\\helios\aq\D_Drive\Projects\Honeywell FMT\KCP_(120287-03)\GIS\MXD\final_report\KCP_drainage_basins_Fig3-10.mxd msmith 2/4/2016 11:24:01 AM

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Figure 3-10
Simulated Stormwater Drainage System
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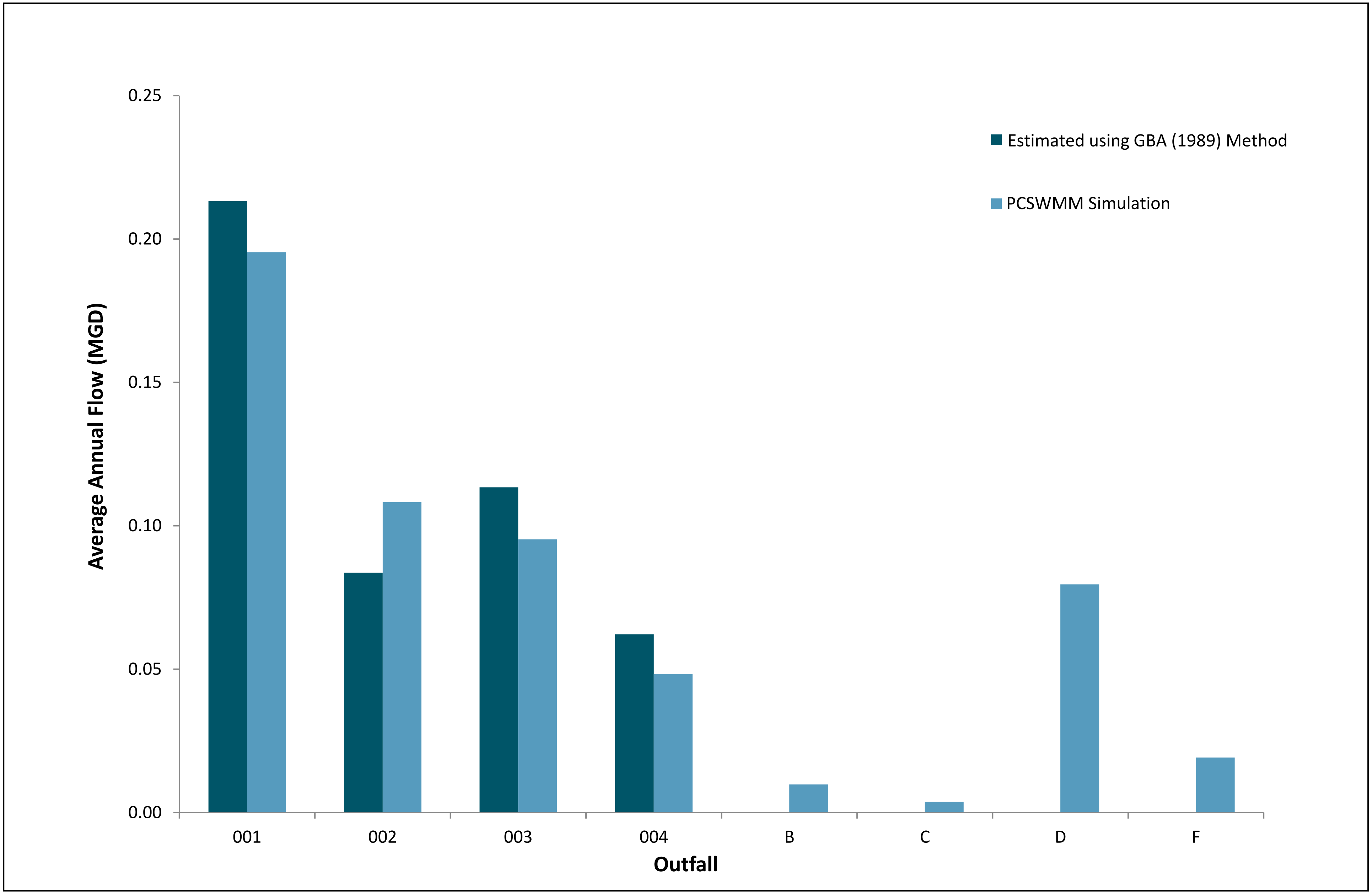

Figure 3-11
Comparison Between Annual Average Flow Simulated by PCSWMM Model and Flows Estimated using GBA (1989)
Final Report – Indian Creek/Blue River Fate and Transport Study
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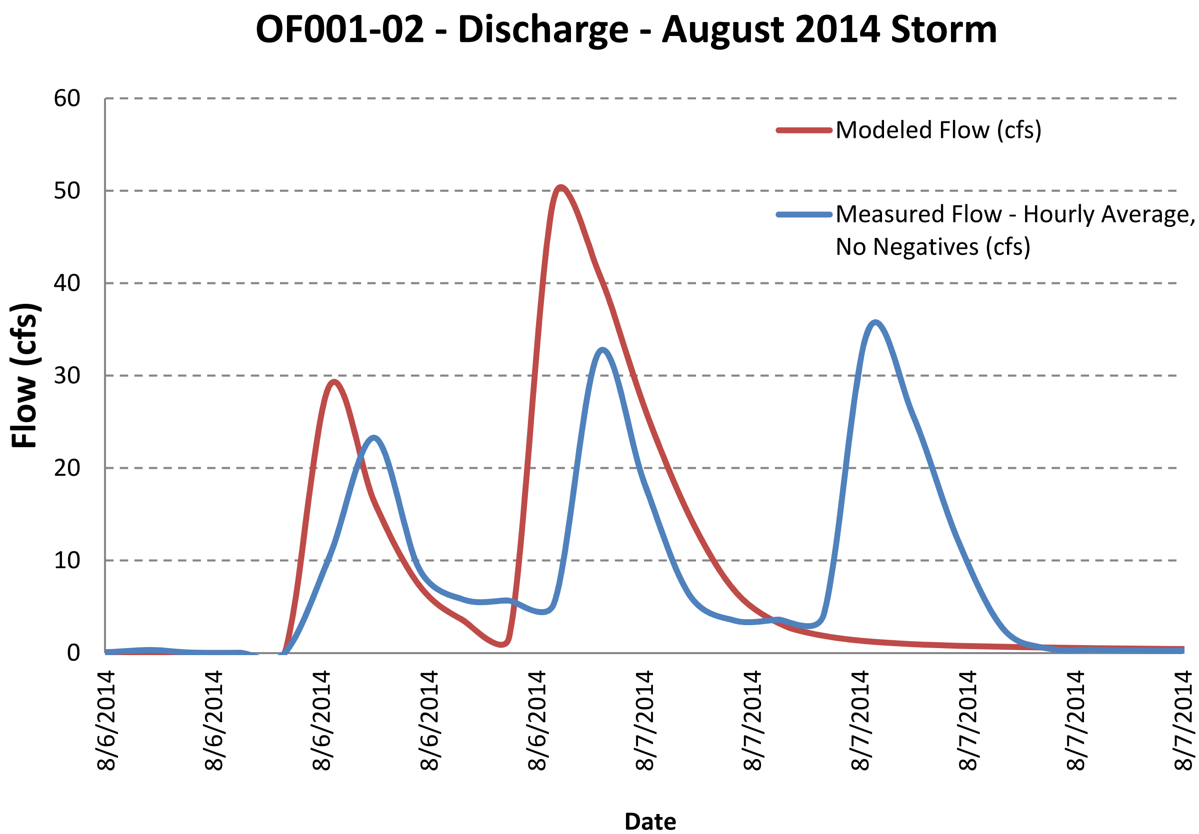

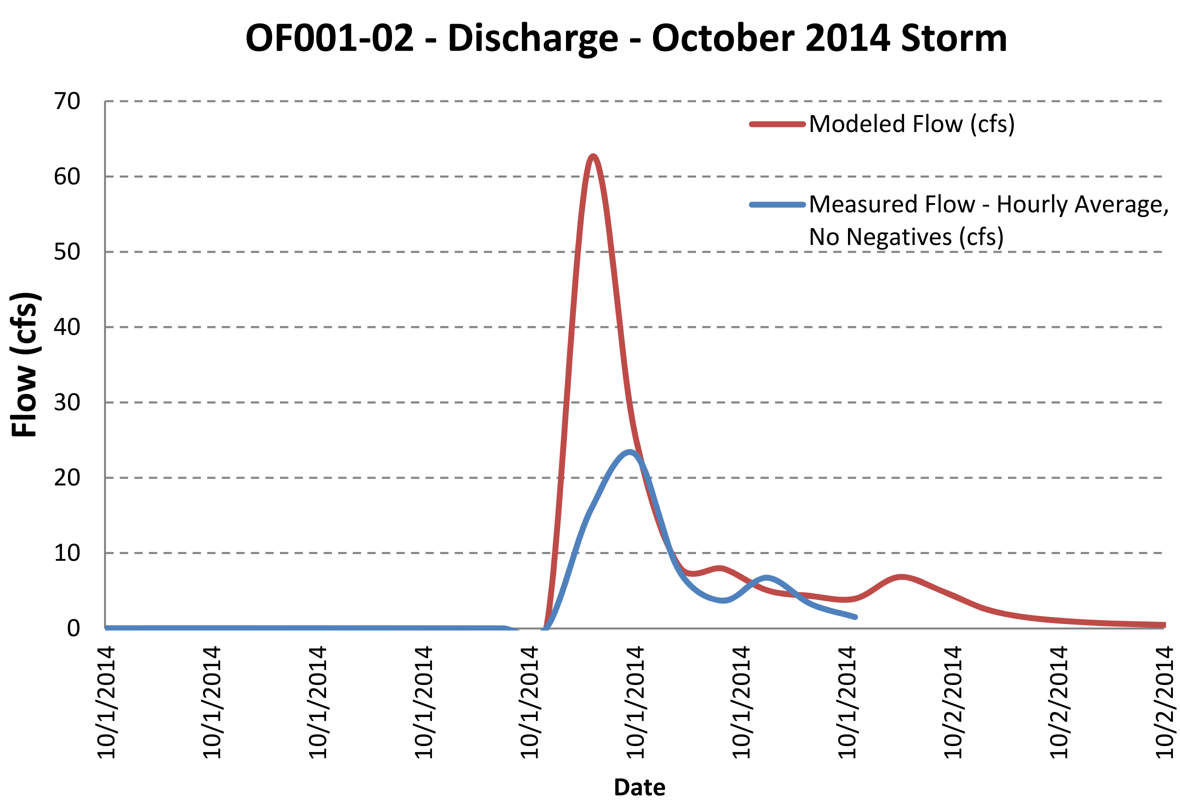

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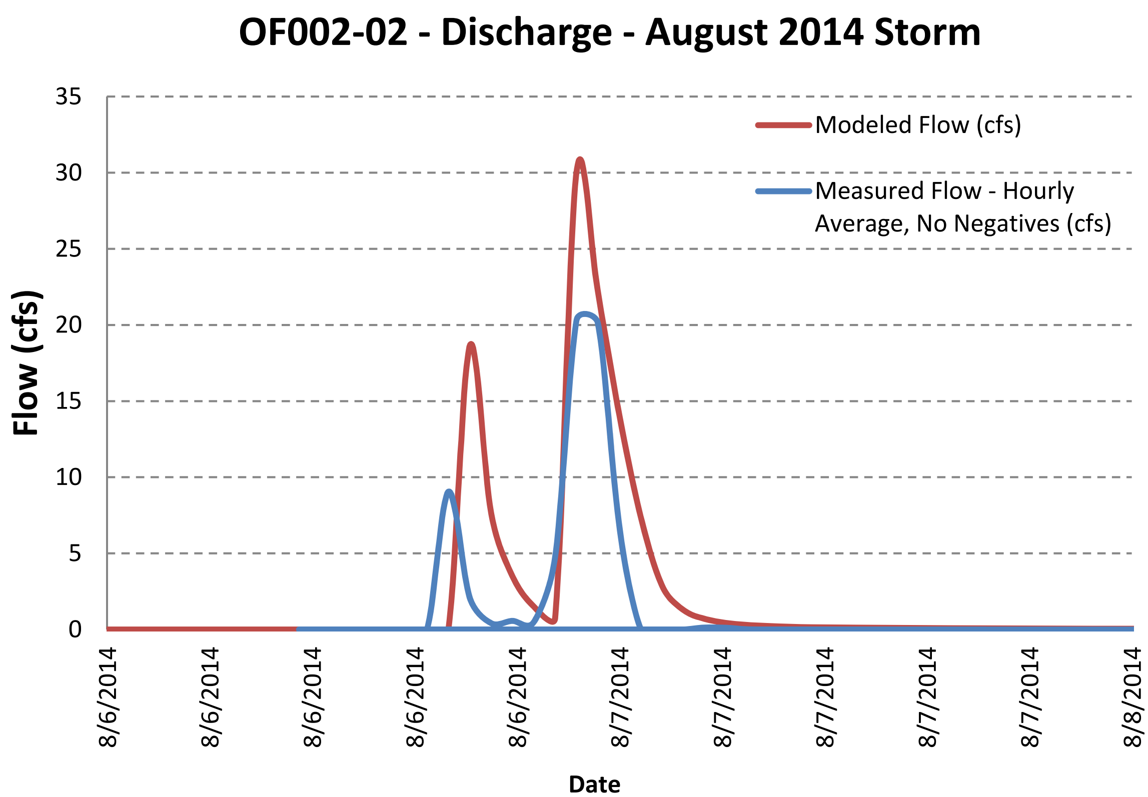
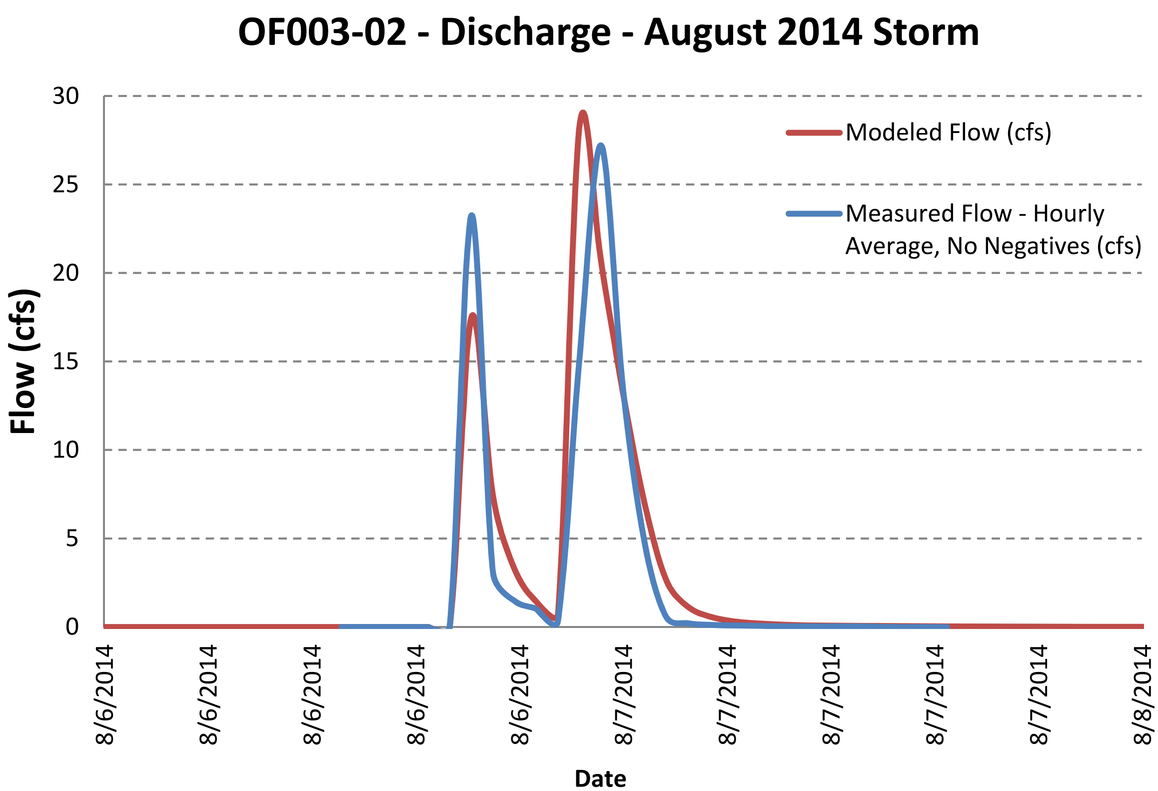
Figure 3-12a
Outfall 001 Sampling Event Calibration
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

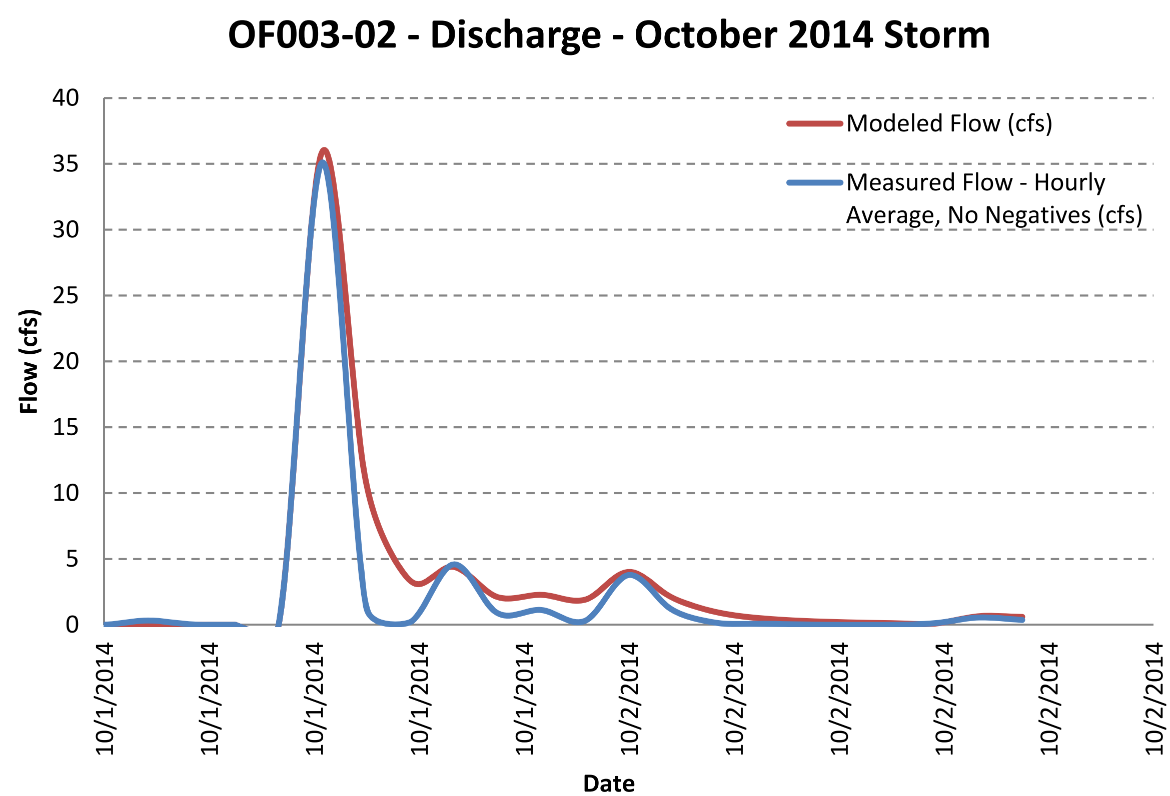


No data at OF002-02 for October event

(issue with flow monitor)

Figure 3-12b
Outfall 002 Sampling Event Calibration
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T





ANCHOR QEA

Figure 3-12c
Outfall 003 Sampling Event Calibration
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

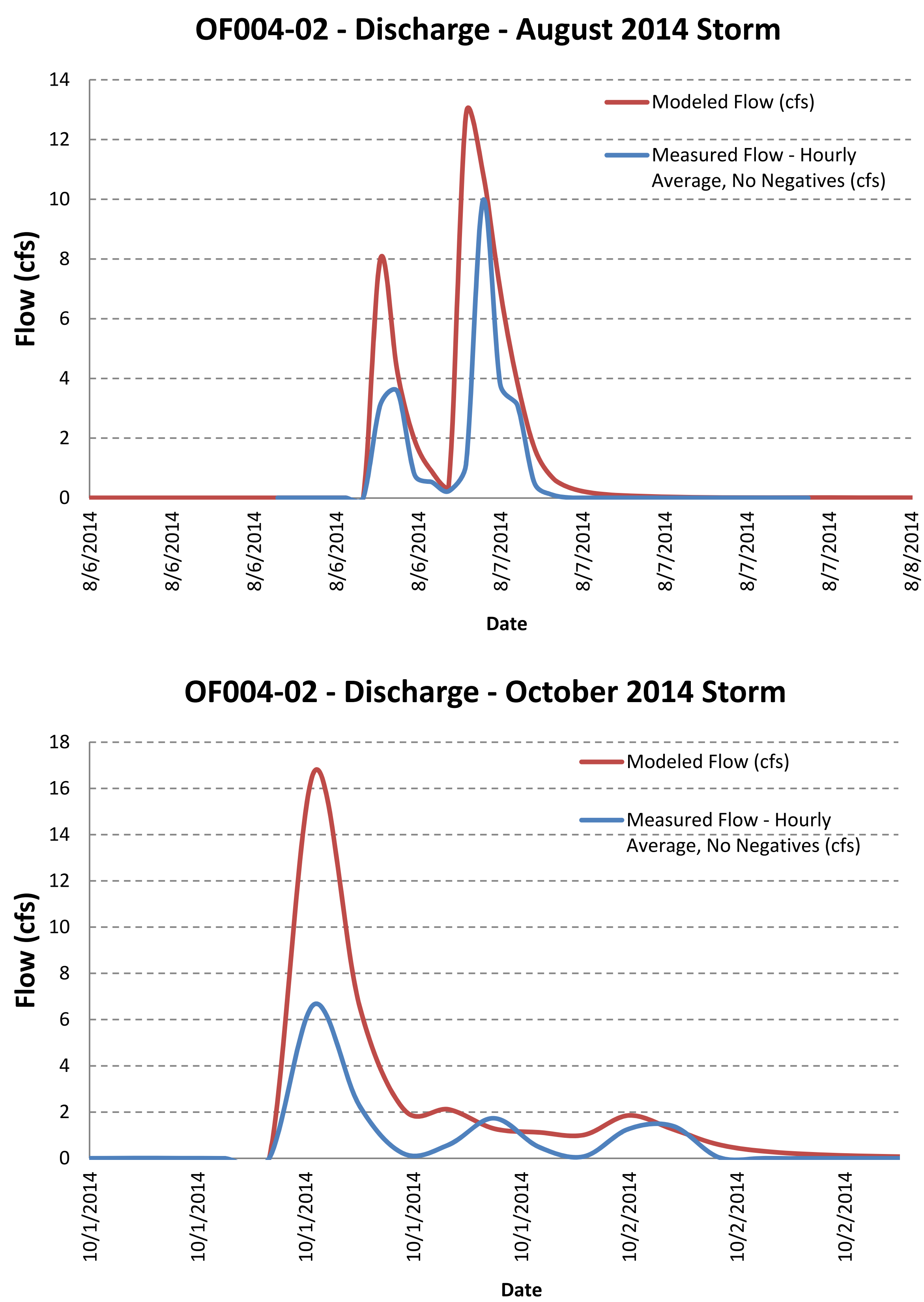


Figure 3-12d
Outfall 004 Sampling Event Calibration
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

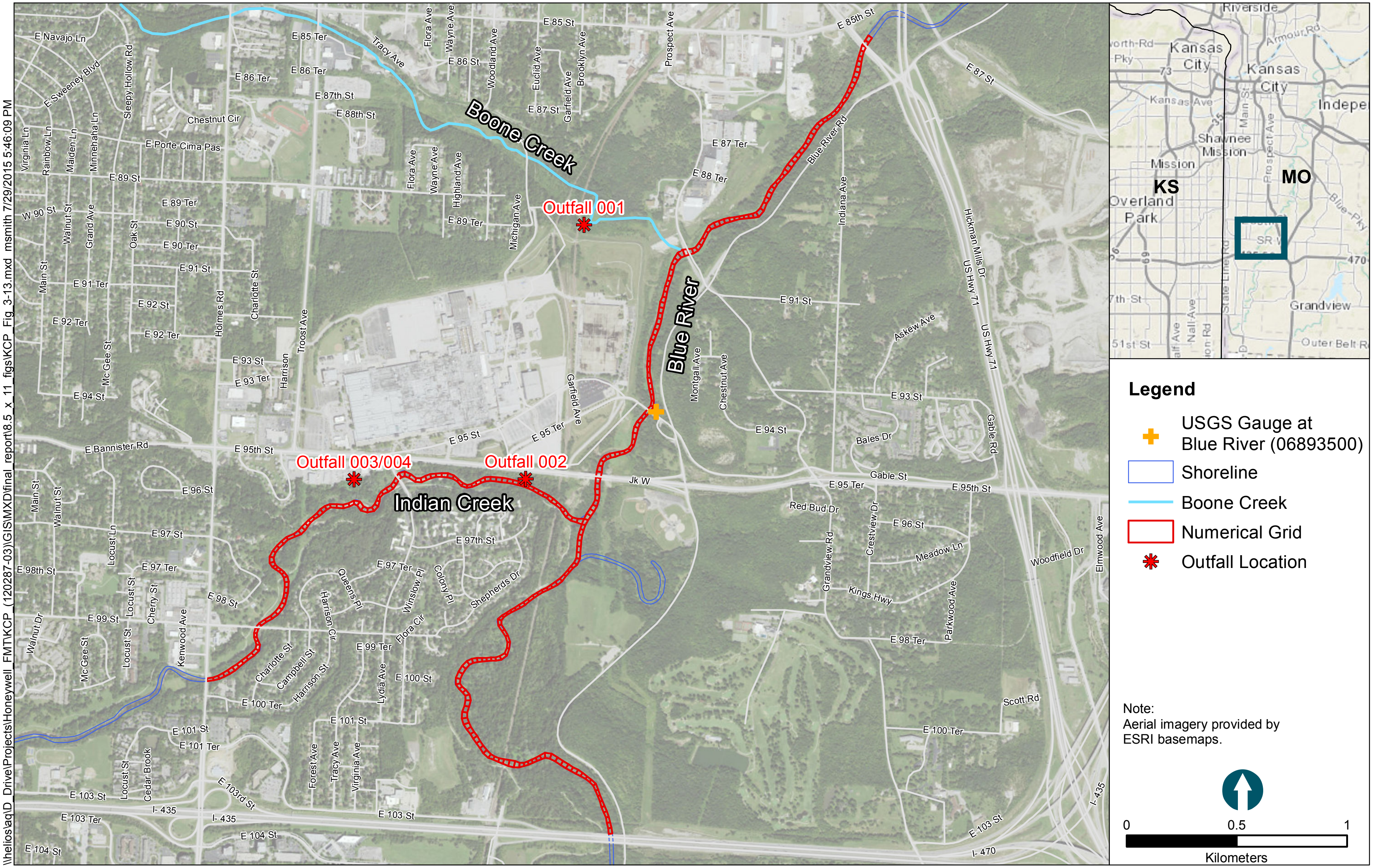


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Figure 3-13
Hydrodynamic, Sediment Transport, and PCB Fate and Transport Model Numerical Grid
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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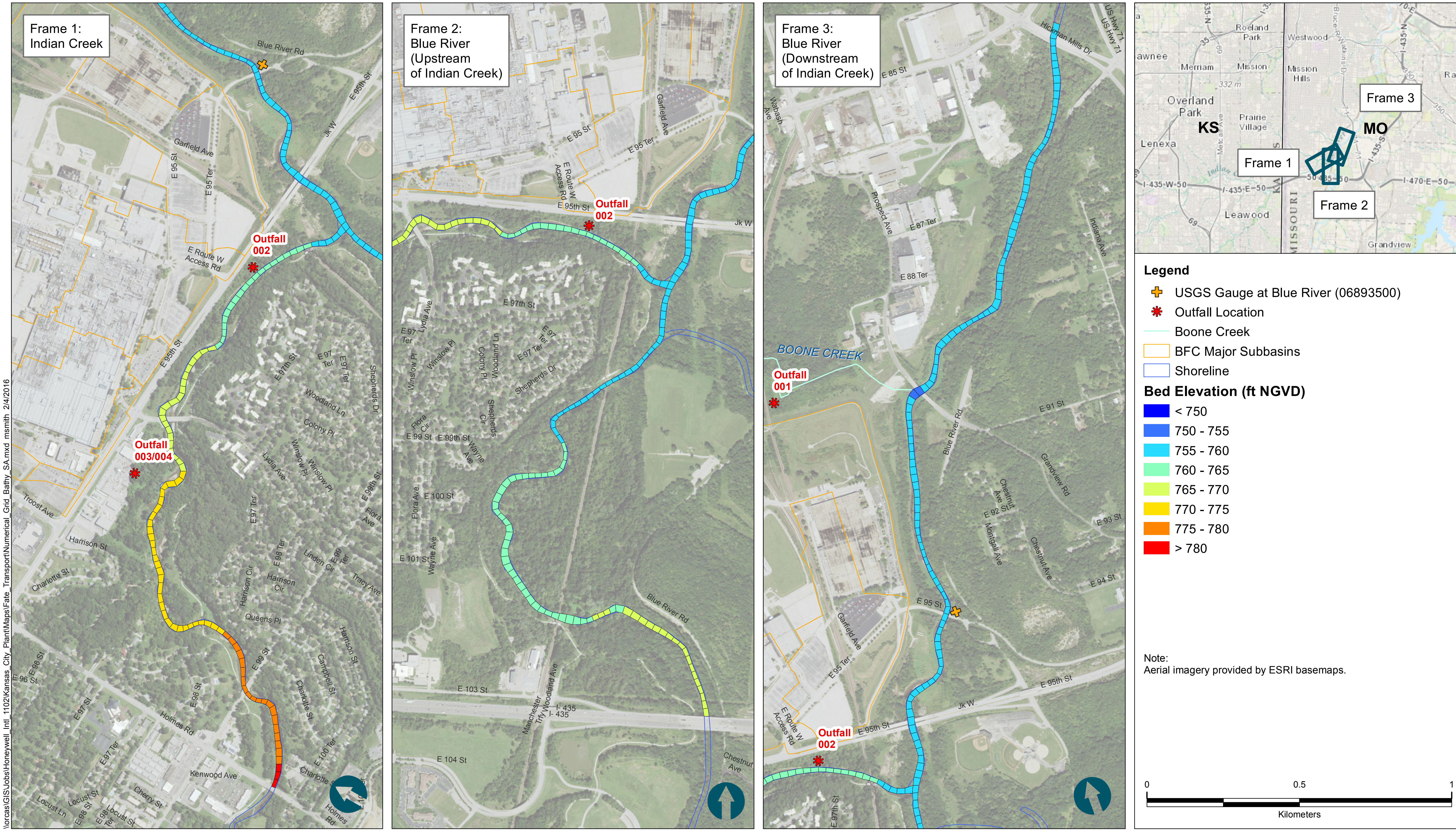

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Figure 3-14
Numerical Grid and Bathymetry in Study Area
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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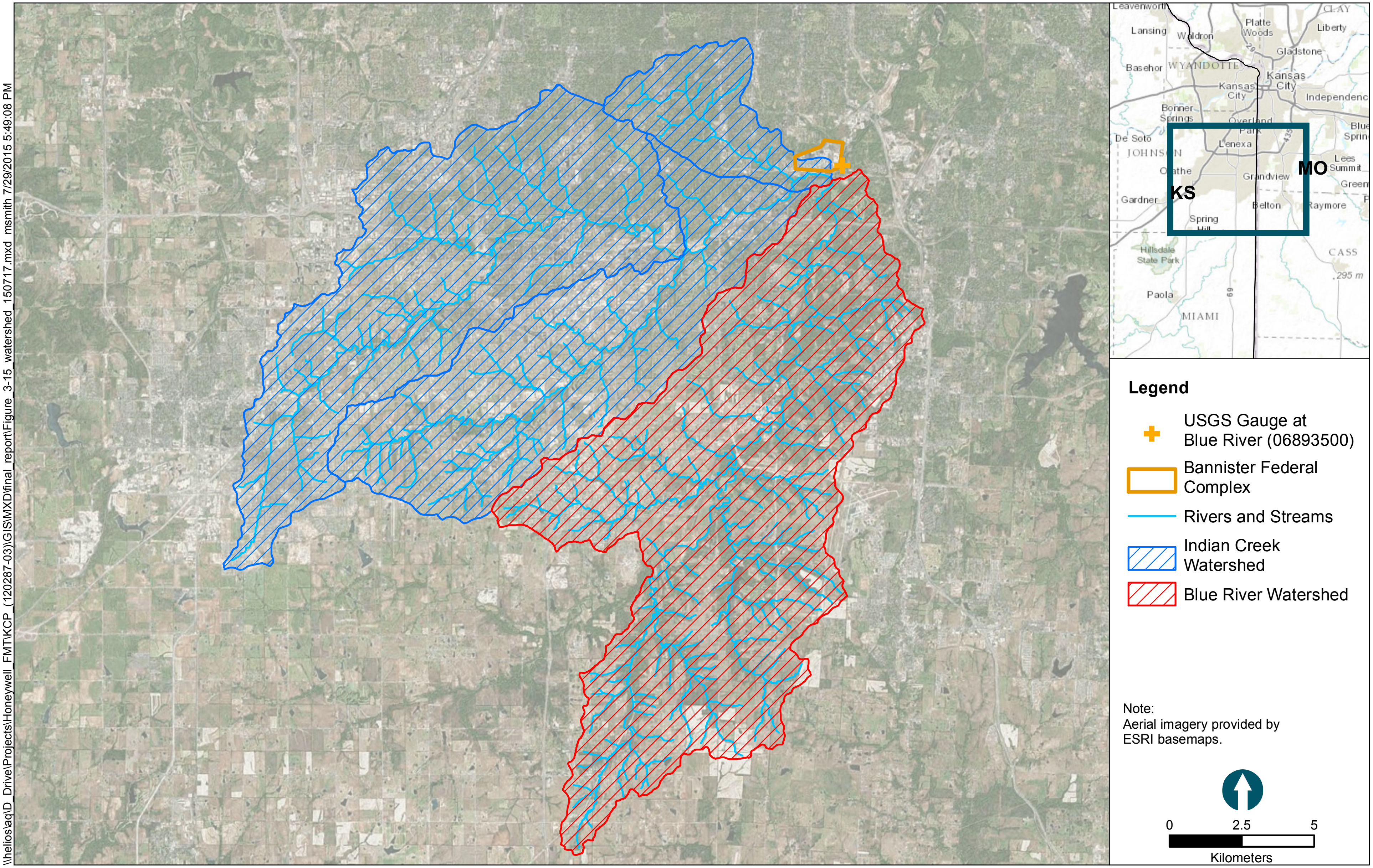

Figure 3-15

Delineation of Watershed Area for Indian Creek and Blue River Upstream of the Confluence

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KCP/Honeywell FM&T

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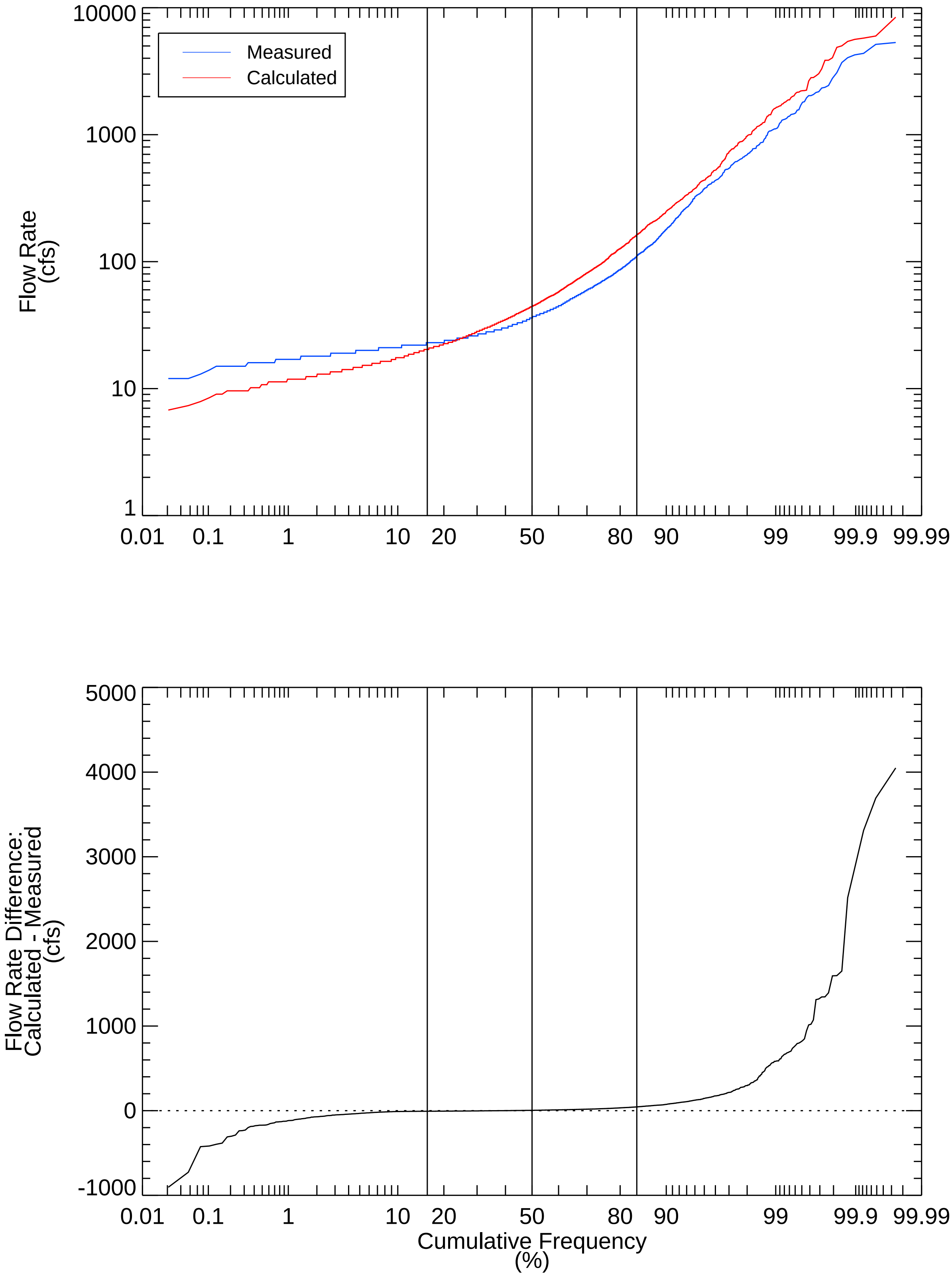

Figure 3-16

Comparison of Flow Rate in Indian Creek for Period 2003 to 2013:
Calculated Value versus Data from USGS 06893390
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

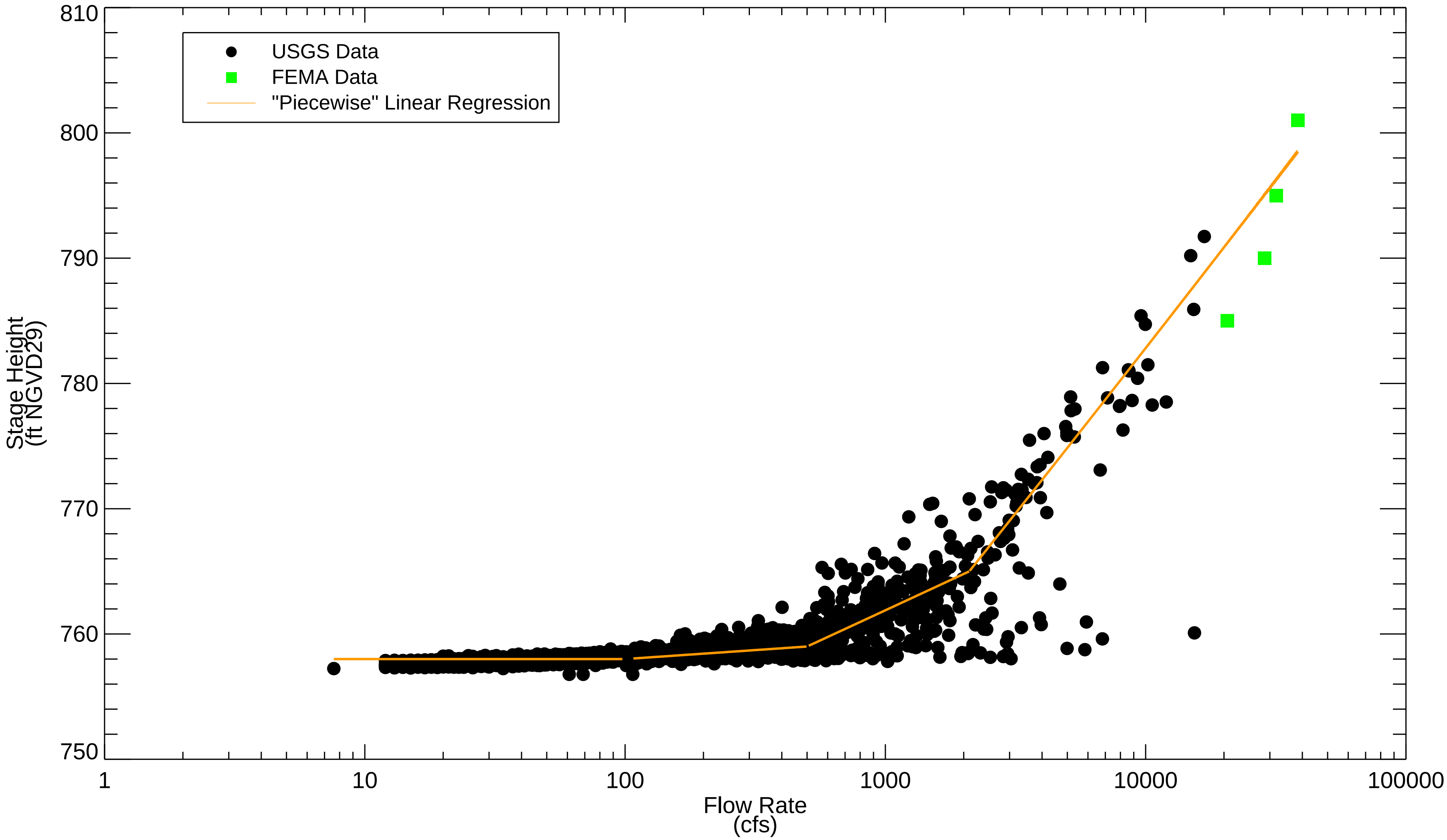

Figure 3-17

Stage Height Rating Curve at Downstream Boundary
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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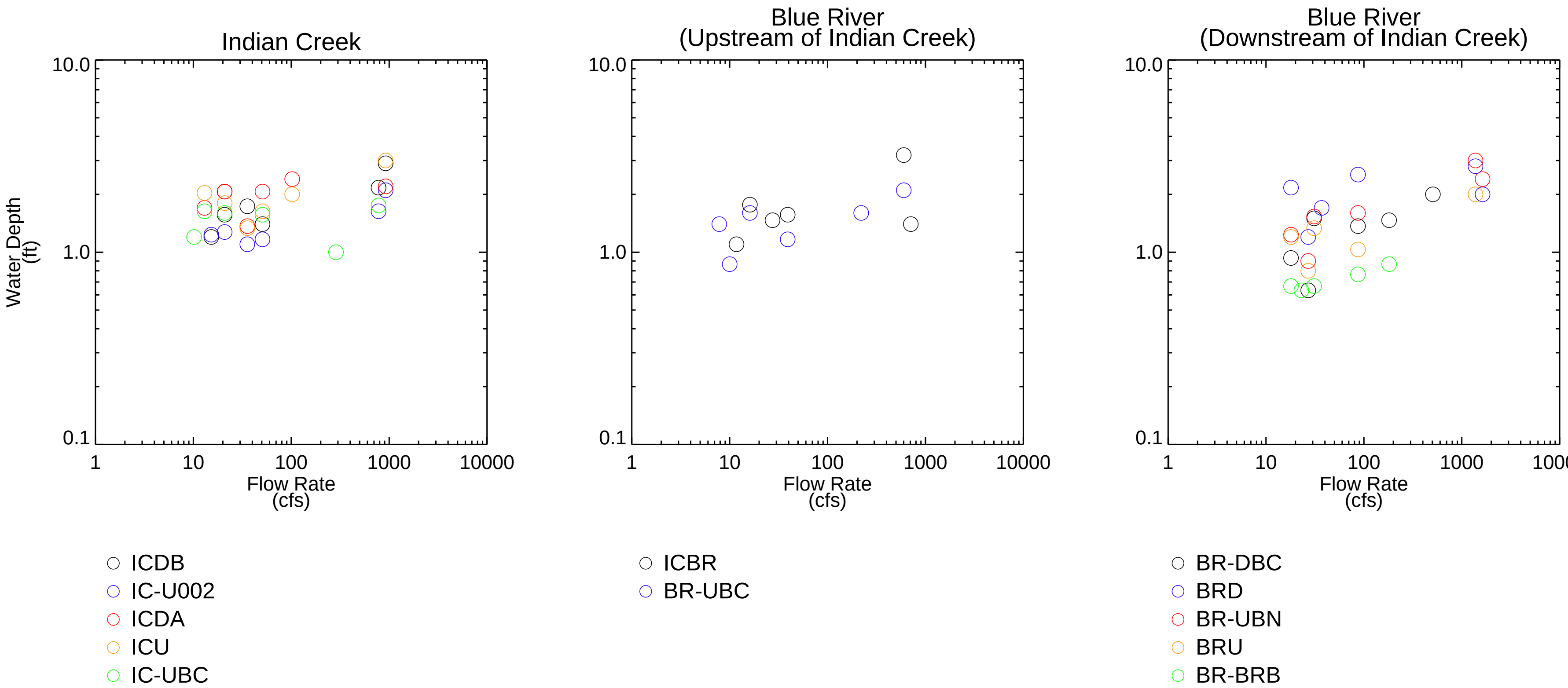

Figure 3-18

Correlation Between Measured Water Depth and Flow Rate During Water Column Sampling Events
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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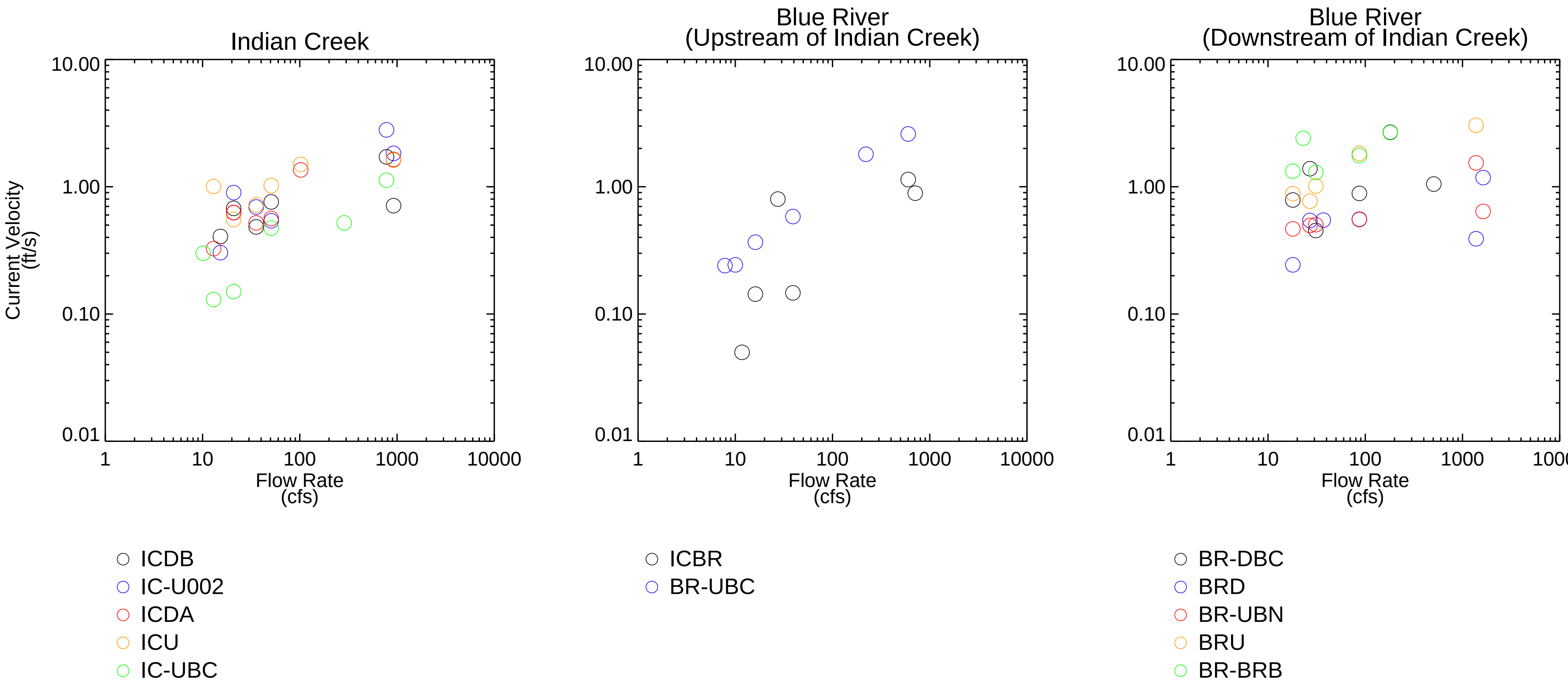

Figure 3-19

Correlation Between Measured Current Velocity and Flow Rate During Water Column Sampling Events
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

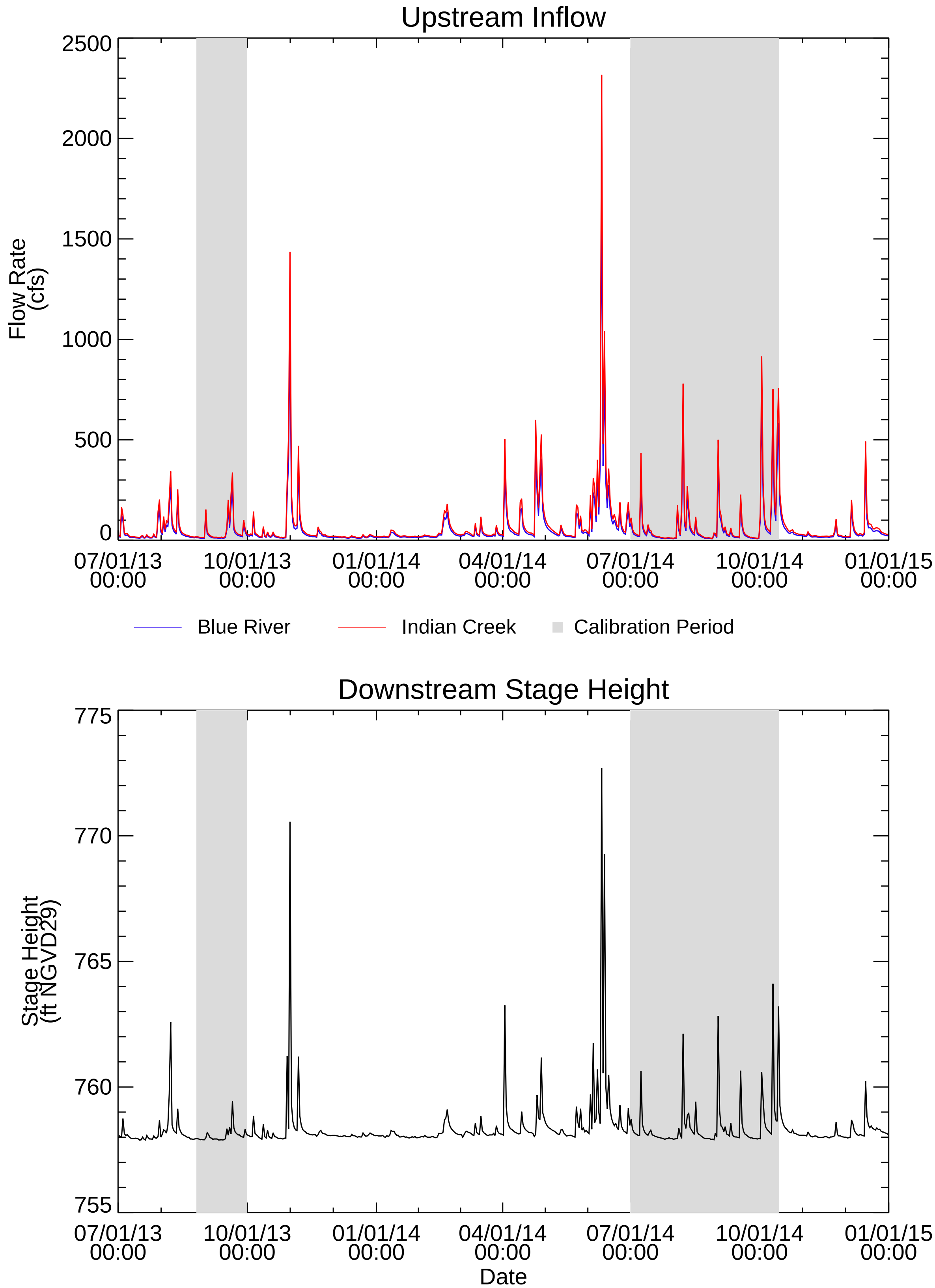

Figure 3-20

Time History of Flow Rate at Upstream Boundaries and Water Surface Elevation at Downstream Boundary During Calibration Period (September 2013 to October 2014)
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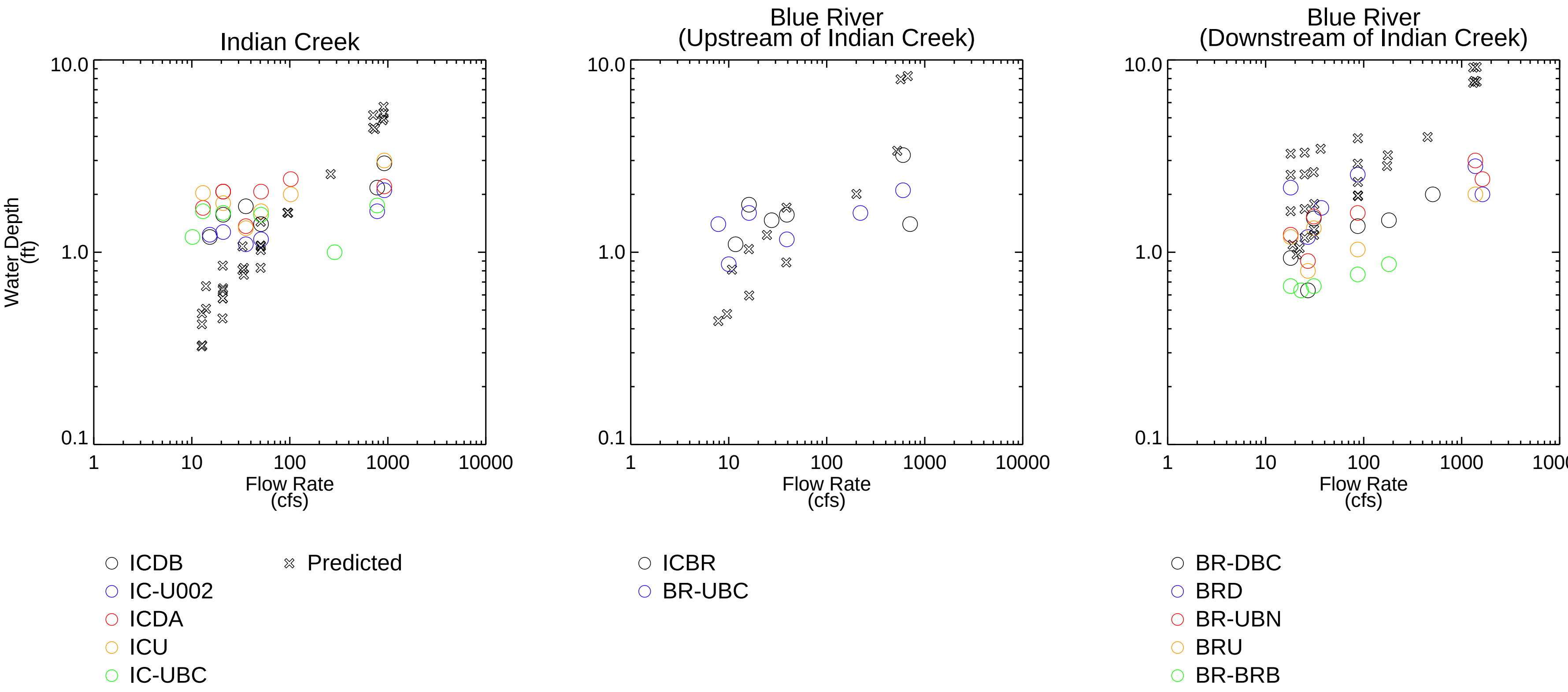

Figure 3-21

Comparison of Model-predicted and Measured Water Depth During Calibration Period (September 2013 to October 2014)
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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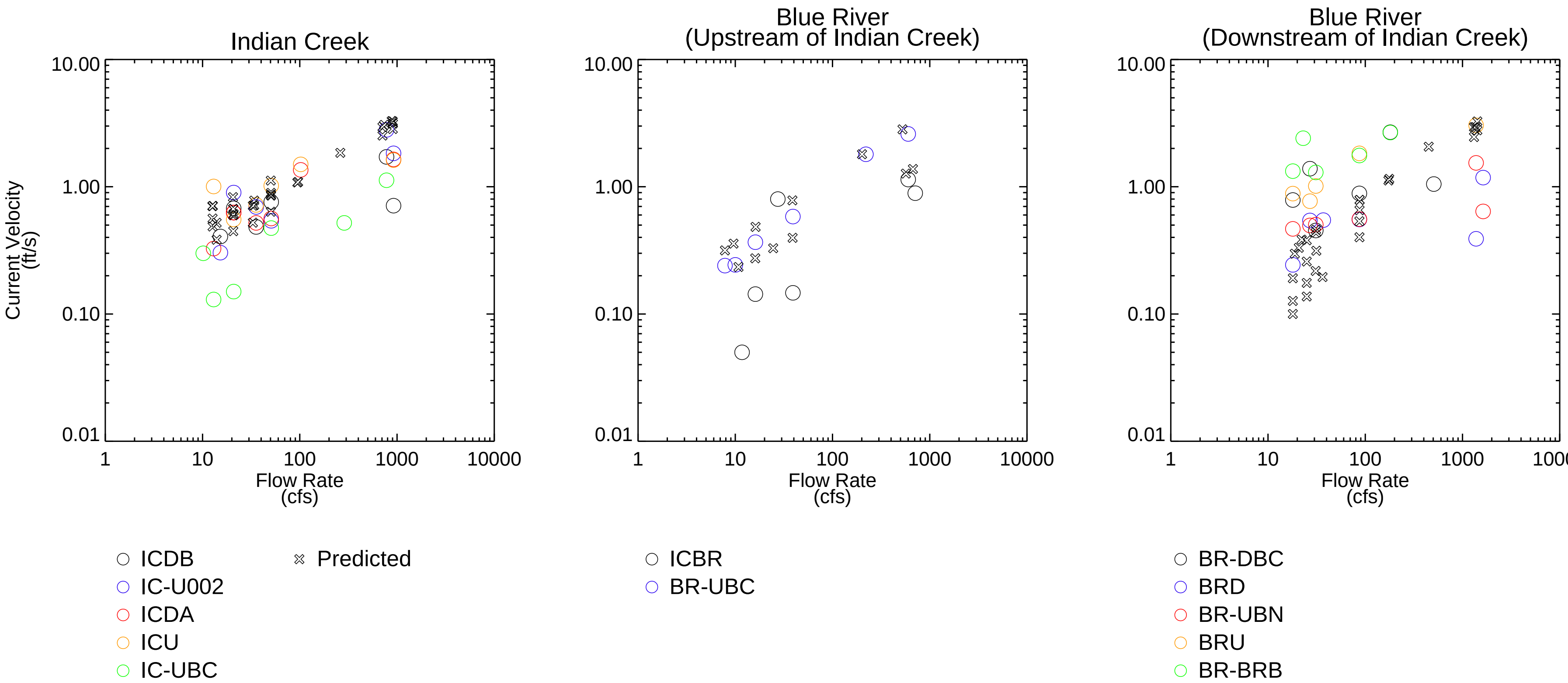

Figure 3-22

Comparison of Model-predicted and Measured Current Velocity During Calibration Period (September 2013 to October 2014)
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

DN/HS - \\daleel\G_DRIVE\Kansas_City_Plant\Documents\Reports\2015_STM\IDL\Figure_3_21_22_150717.pro Thu Jul 30 09:26:44 2015

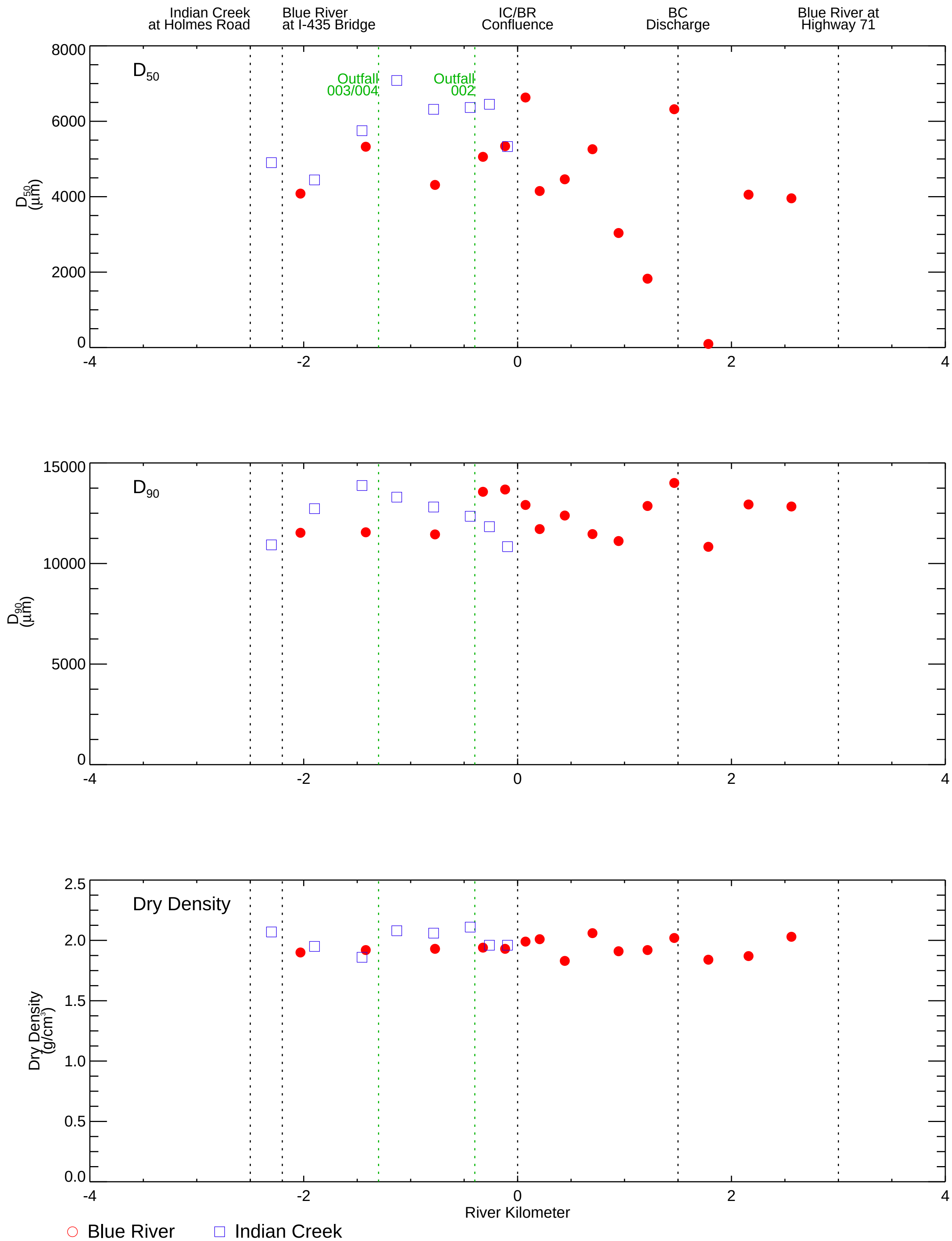

Figure 3-23

Spatial Distribution of D_{50}, D_{90}, and Dry Density Data
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

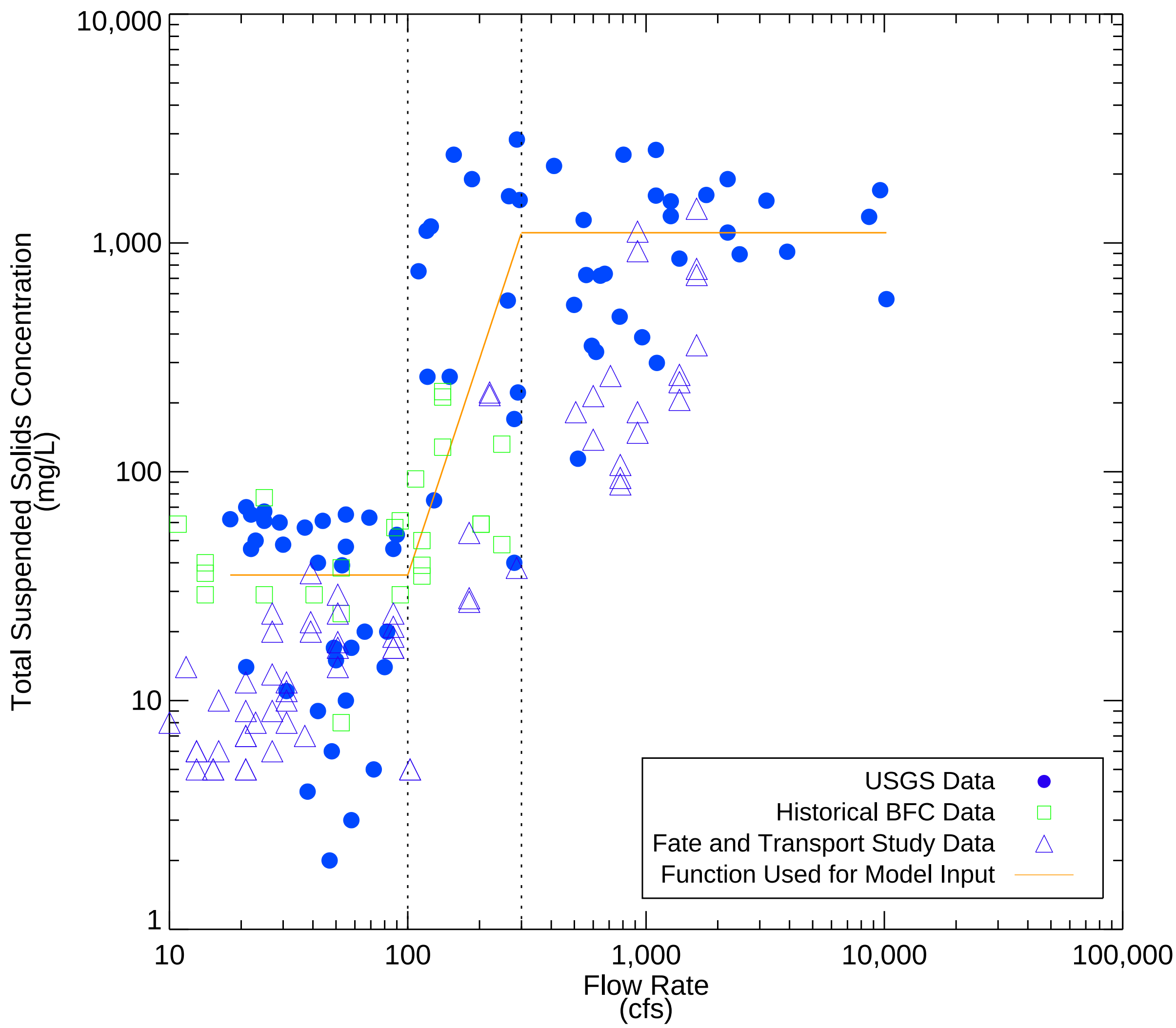

Figure 3-24

Correlation Between Total Suspended Solids Concentration and Flow Rate at USGS Gauge 06893500

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

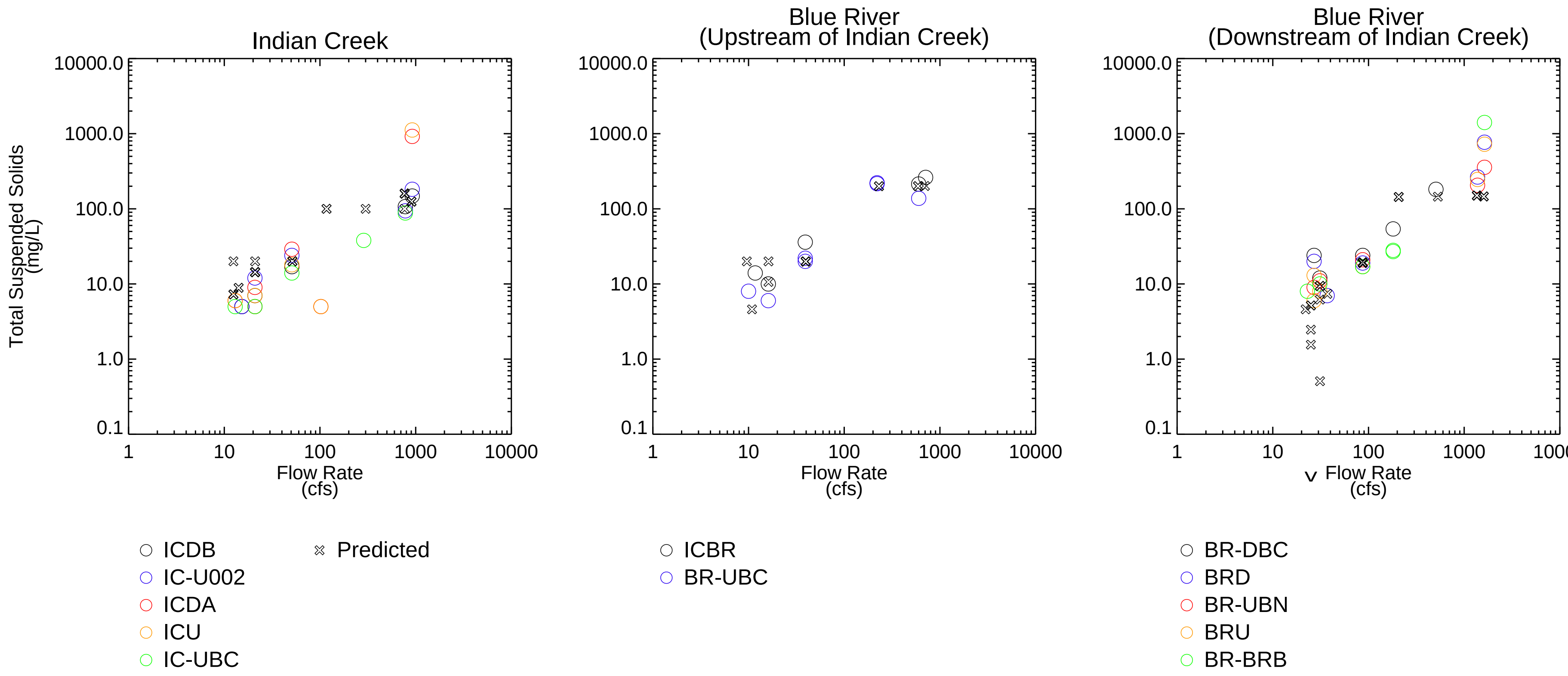

Figure 3-25

Comparison of Model-predicted and Measured Total Suspended Solids Concentration During Calibration Period
(September 2013 to October 2014)
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

DN/HS - \\daleel\G_DRIVE\Kansas_City_Plant\Documents\Reports\2015_STM\IDL\Figure_3_21_22_150717.pro Thu Jul 30 08:42:30 2015

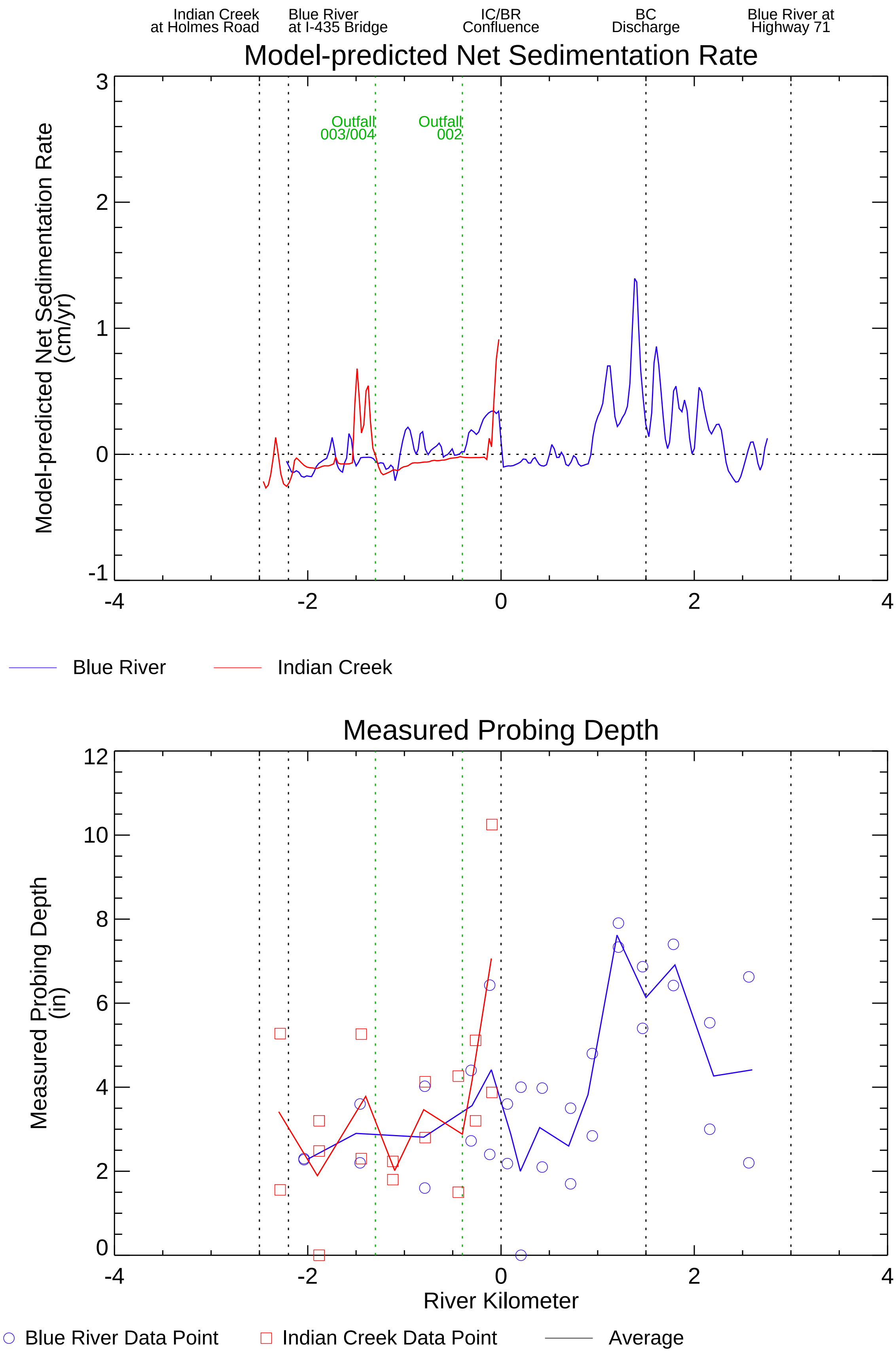

Figure 3-26

Spatial Distribution of Net Sedimentation Rate Based on Long-term Simulation (1990 to October 2014) and Comparison to Measured Probing Depths
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

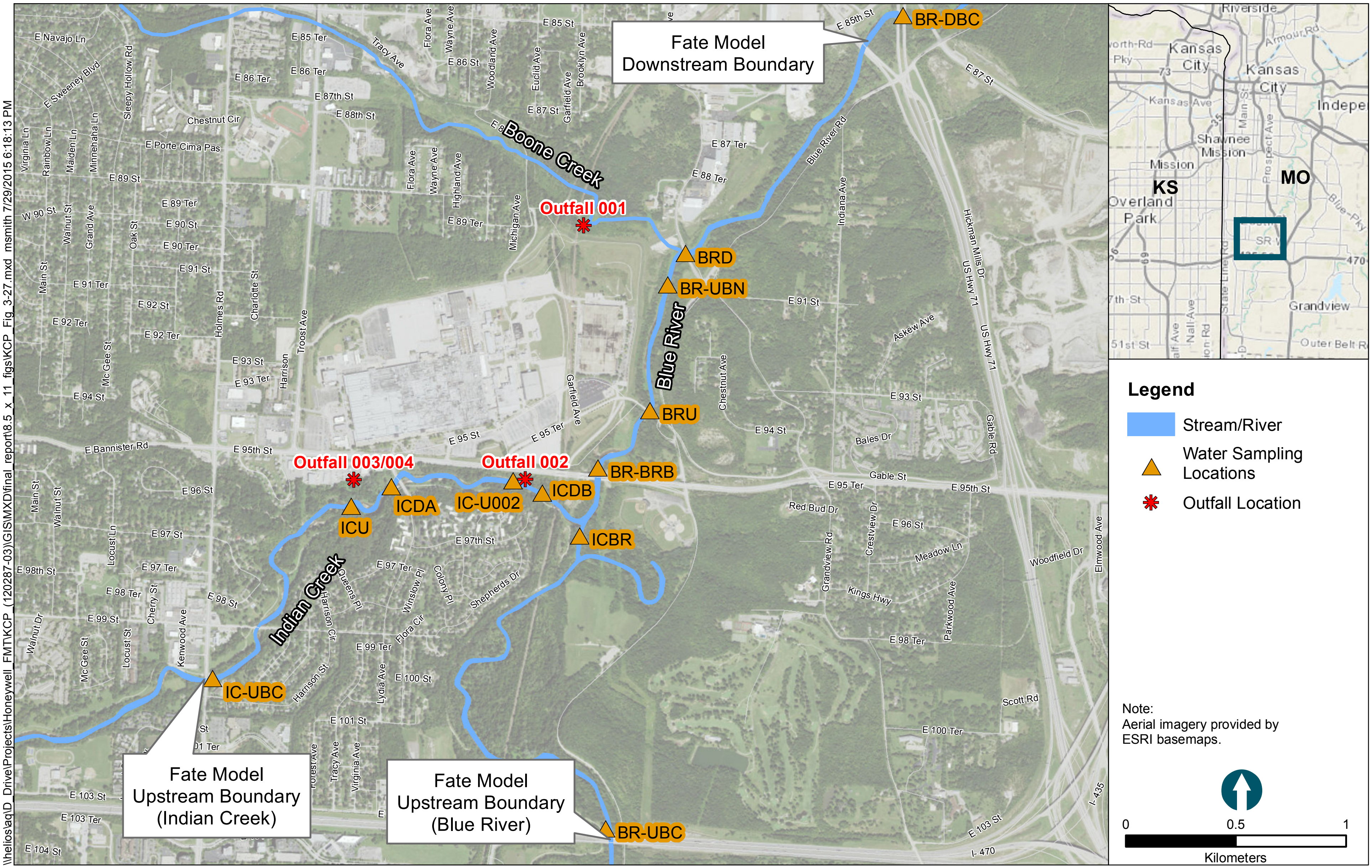

Figure 3-27

PCB Fate and Transport Model Boundary Locations and Water Column Sampling Locations
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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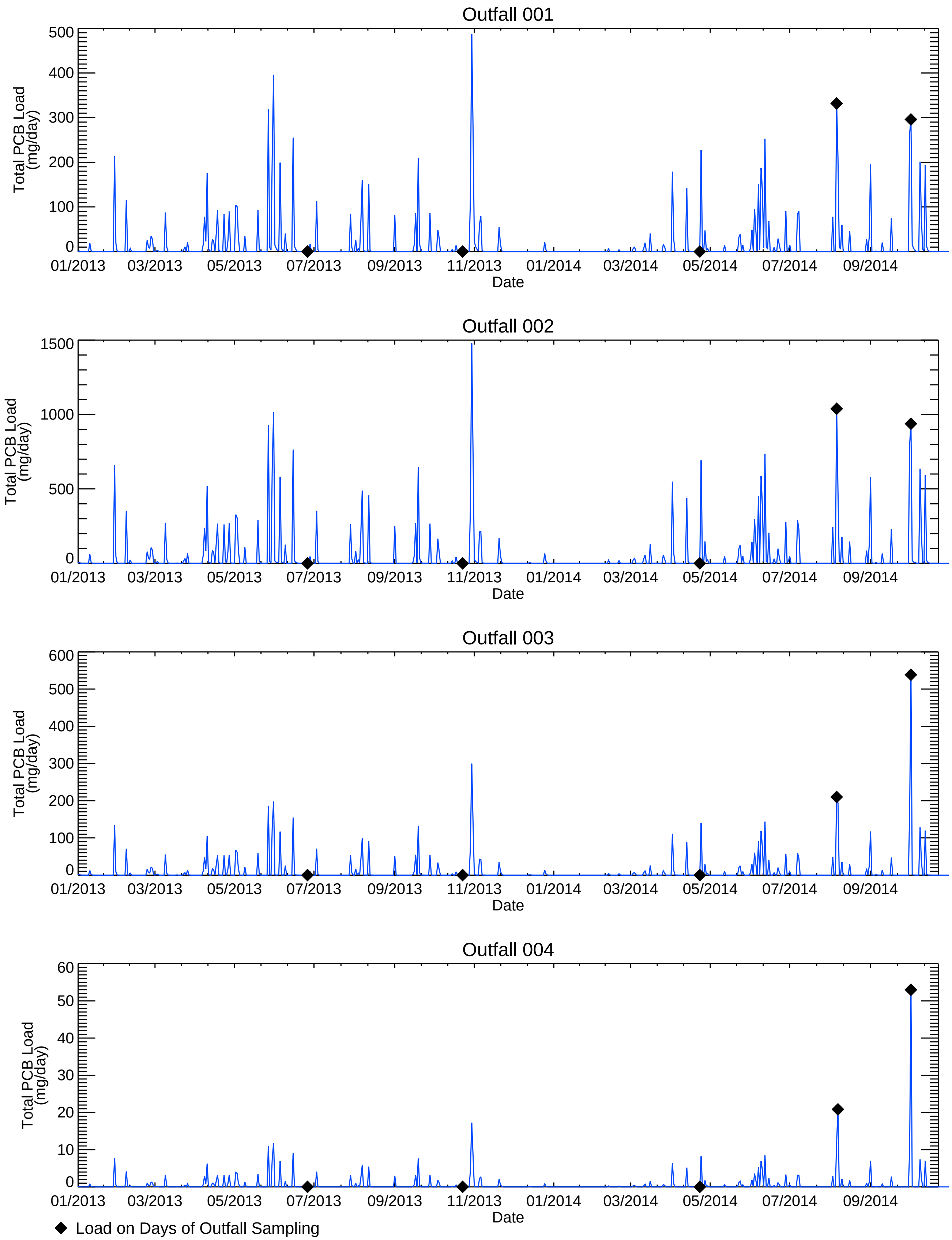

Figure 3-28

Time Series of Outfall Total PCB Loads
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KCP/Honeywell FM&T

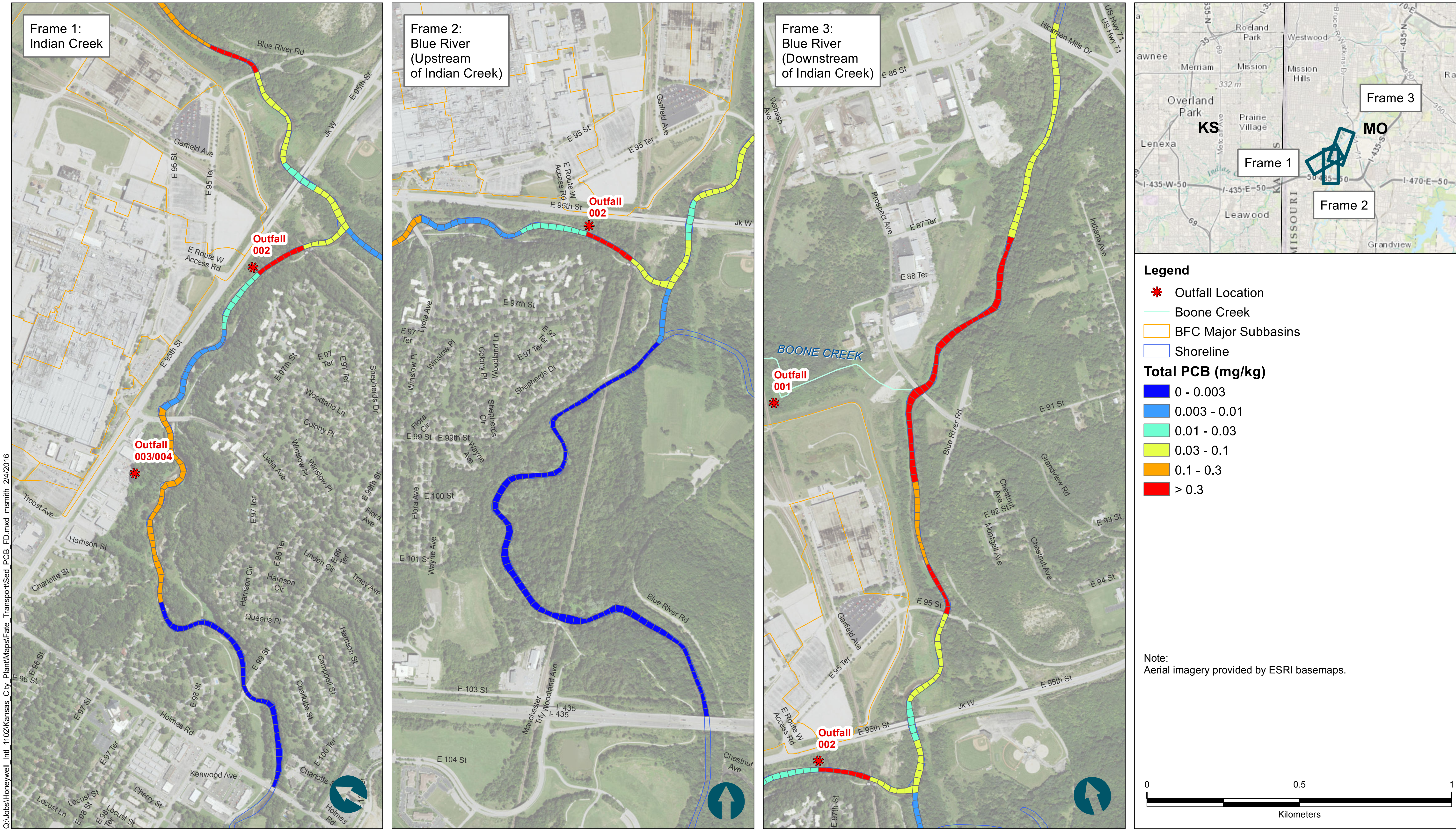

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Figure 3-29
Sediment PCB Initial Conditions
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KCP/Honeywell FM&T

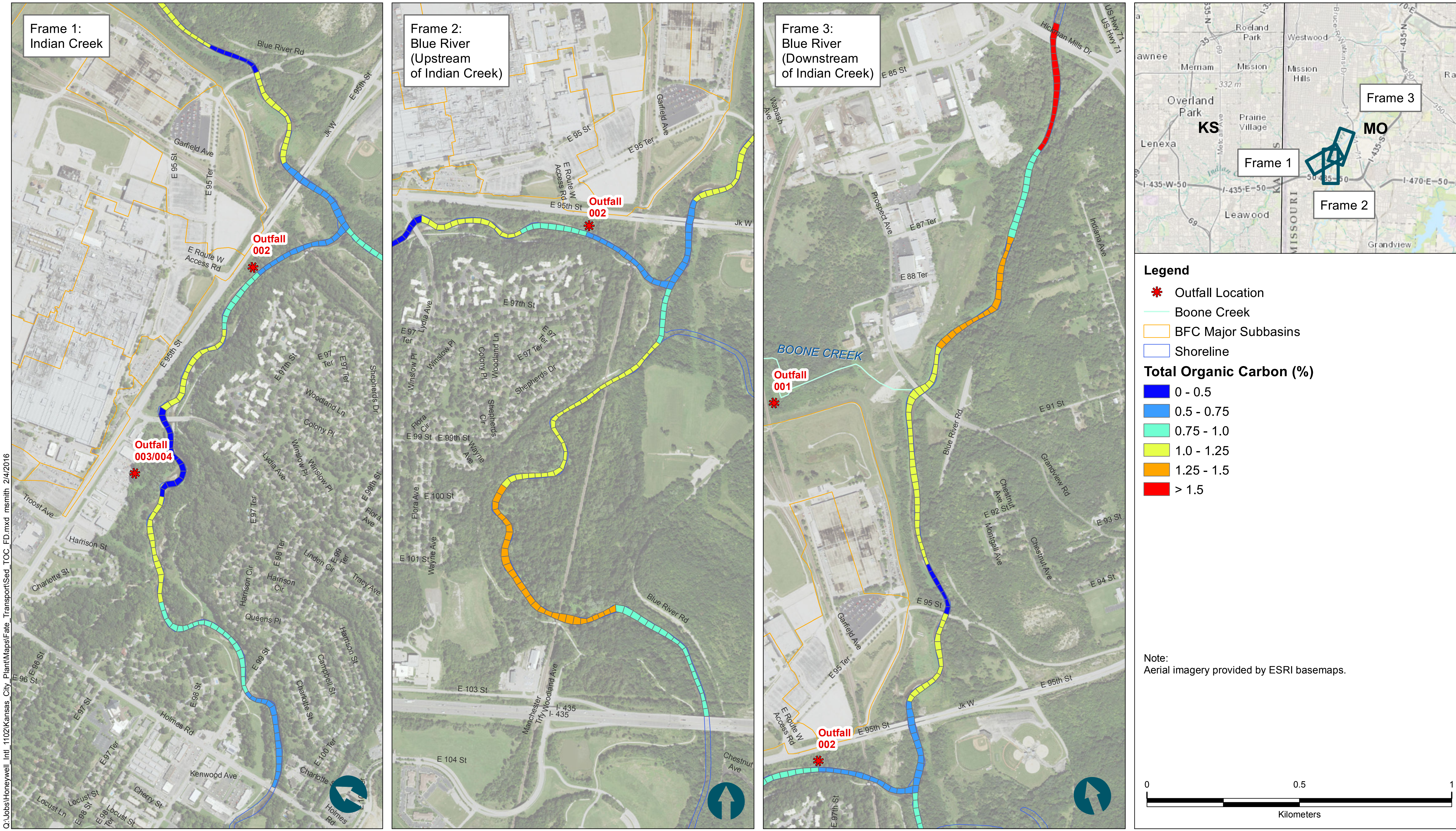

Figure 3-30
Sediment Organic Carbon Fraction
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KCP/Honeywell FM&T

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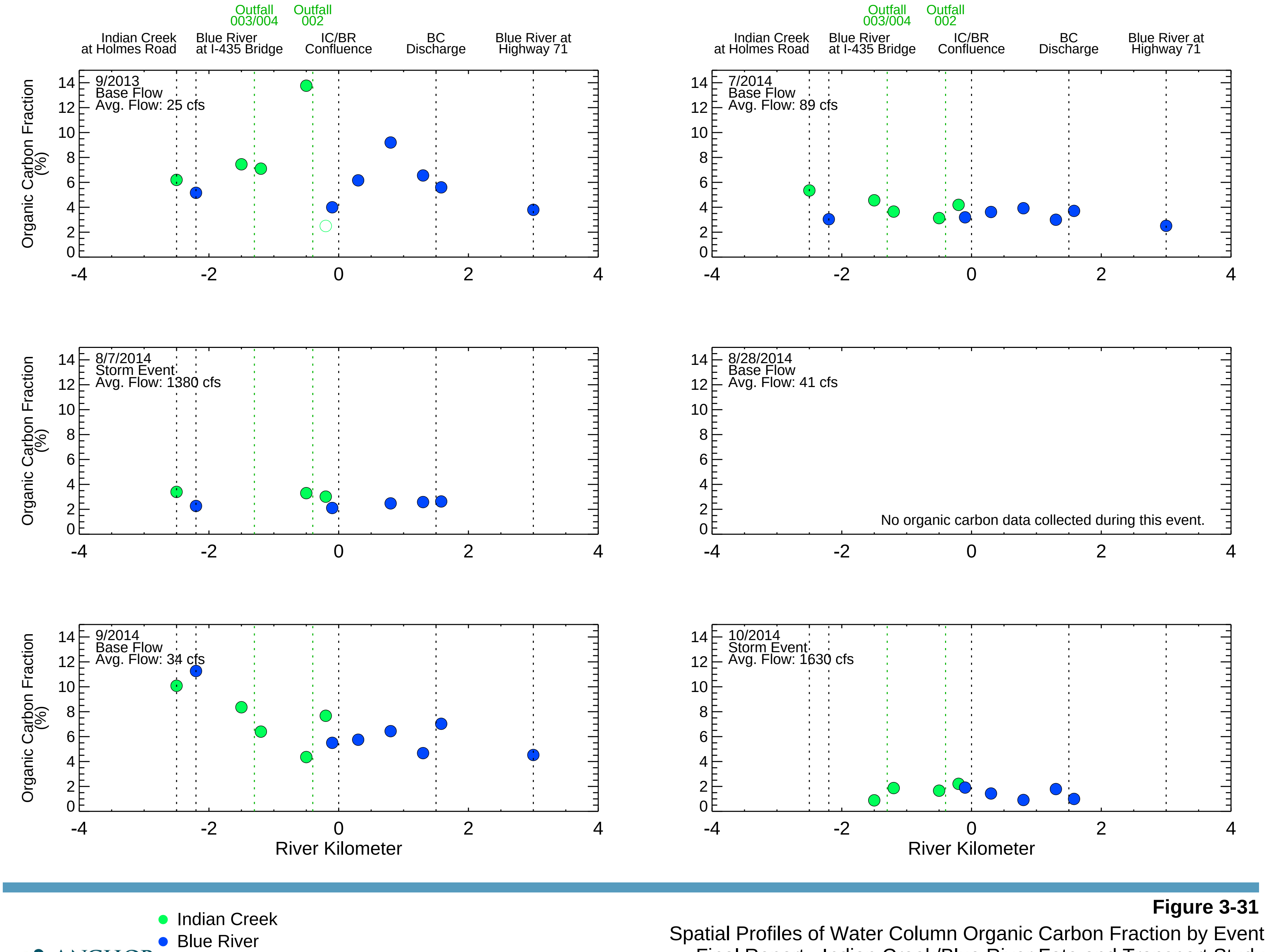

Figure 3-31

Spatial Profiles of Water Column Organic Carbon Fraction by Event
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KCP/Honeywell FM&T

ANCHOR QEA

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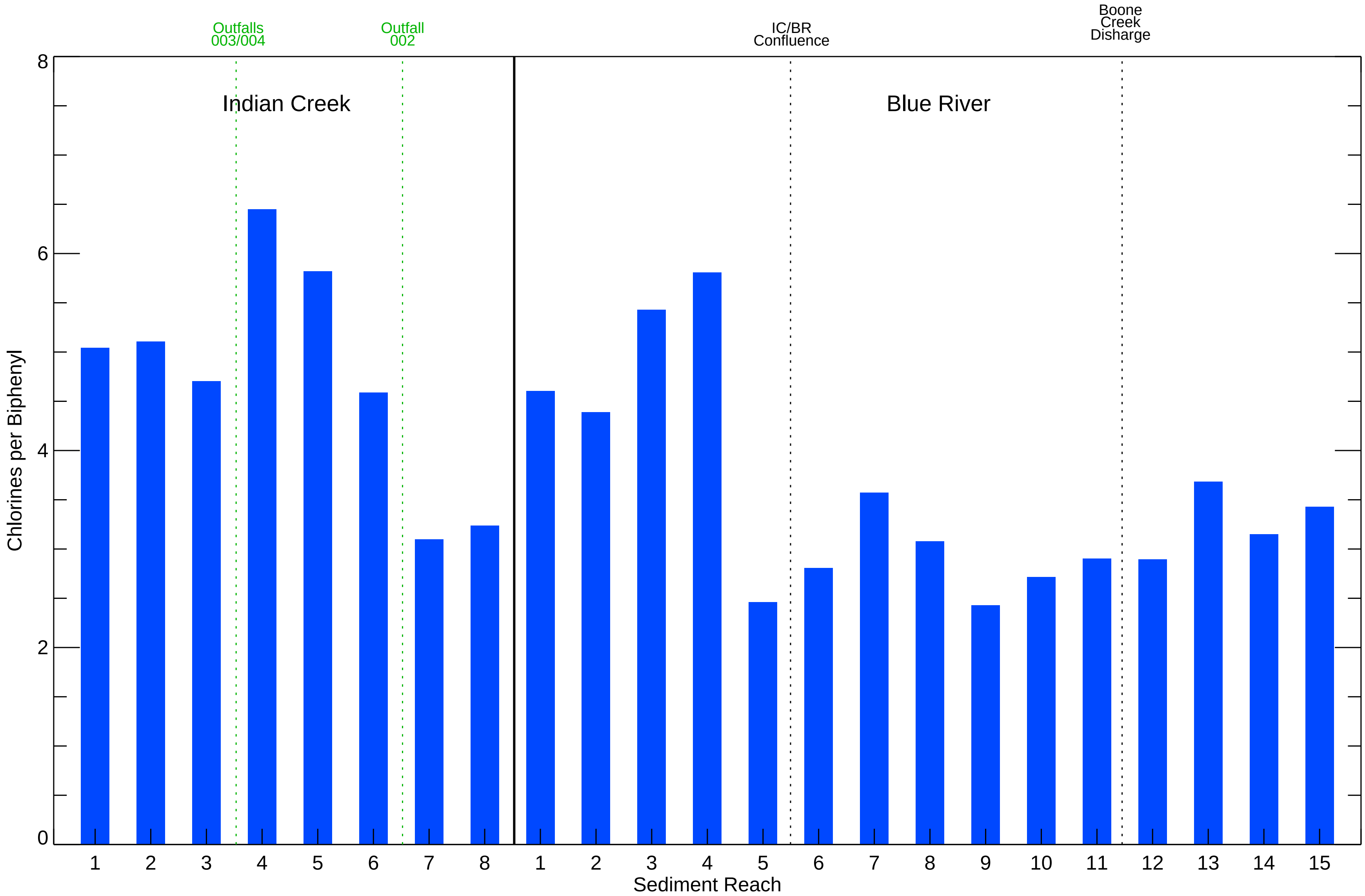

Figure 3-32

Spatial Profile of Sediment Chlorines per Biphenyl in Indian Creek and Blue River
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KCP/Honeywell FM&T

ANCHOR QEA

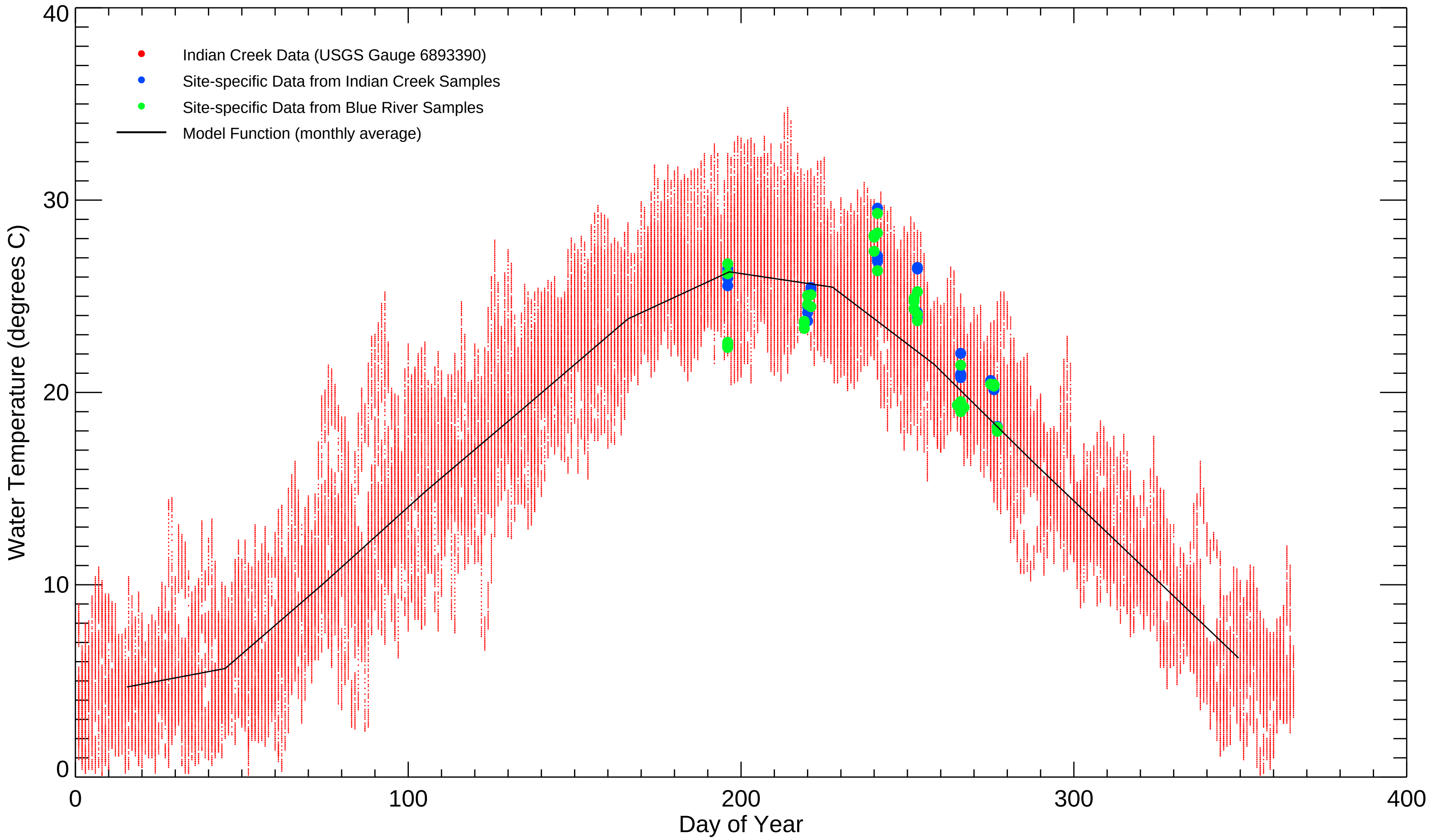

Figure 3-33

Annual Water Temperature Function

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Note: Water temperature data from USGS Gauge 6893390 from October 2007 through January 2015.

MCS - \\helios\aq\D_Drive\Projects\Honeywell_FMT\KCP_(120287-03)\MODEL\EFDC\input_files\TEMPERATURE_FILES\prep\temp_input_gen_KCP.pro Thu Jul 30 08:44:29 2015

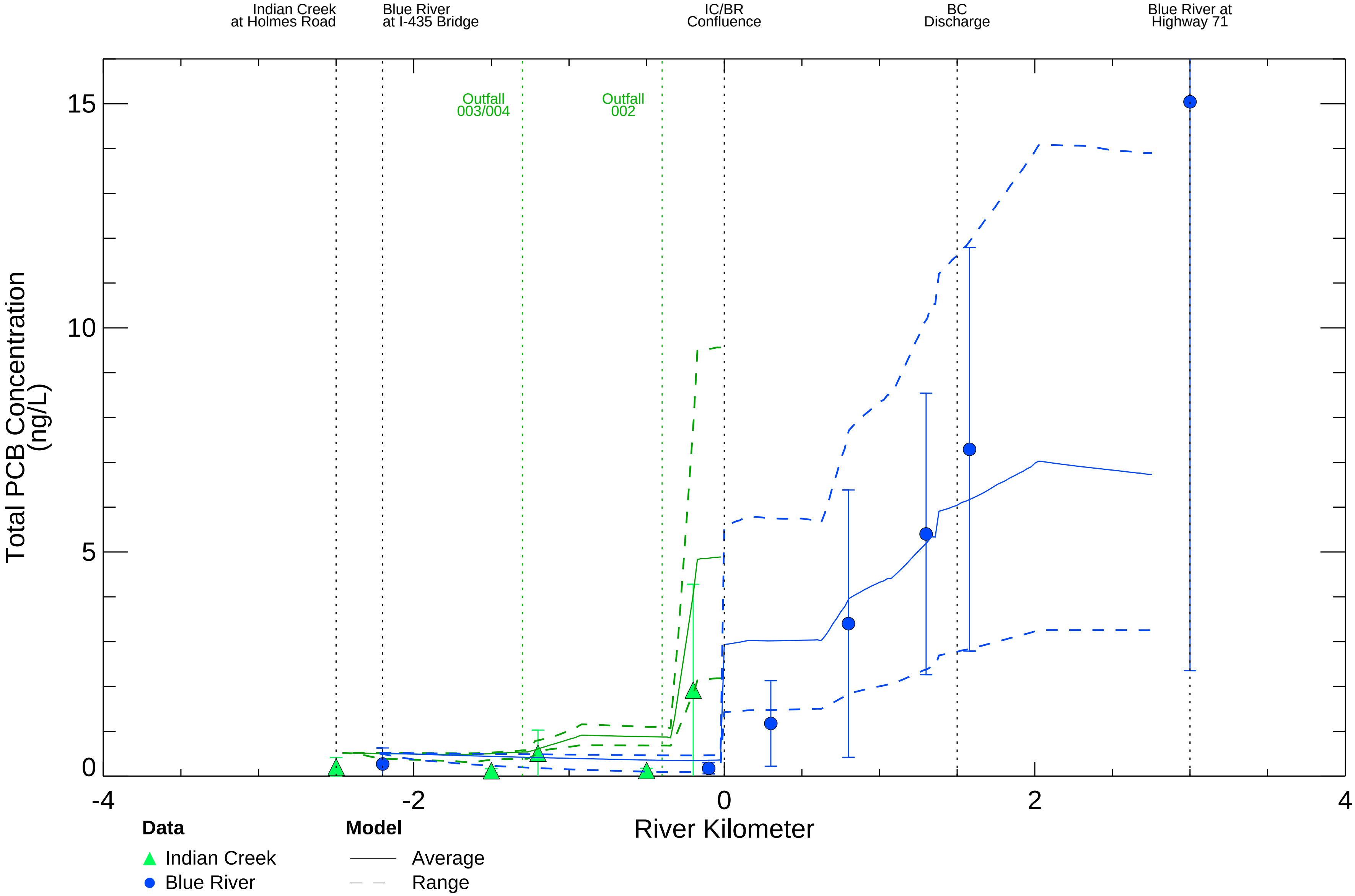

Figure 3-34

Spatial Profile of Model-predicted Low-flow (<100 cfs) Water Column PCB Concentrations and Data

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Notes: Data are plotted as average +/- 2 standard errors by location. Sample result of 19.8 ng/L collected at BR-UBC not included.

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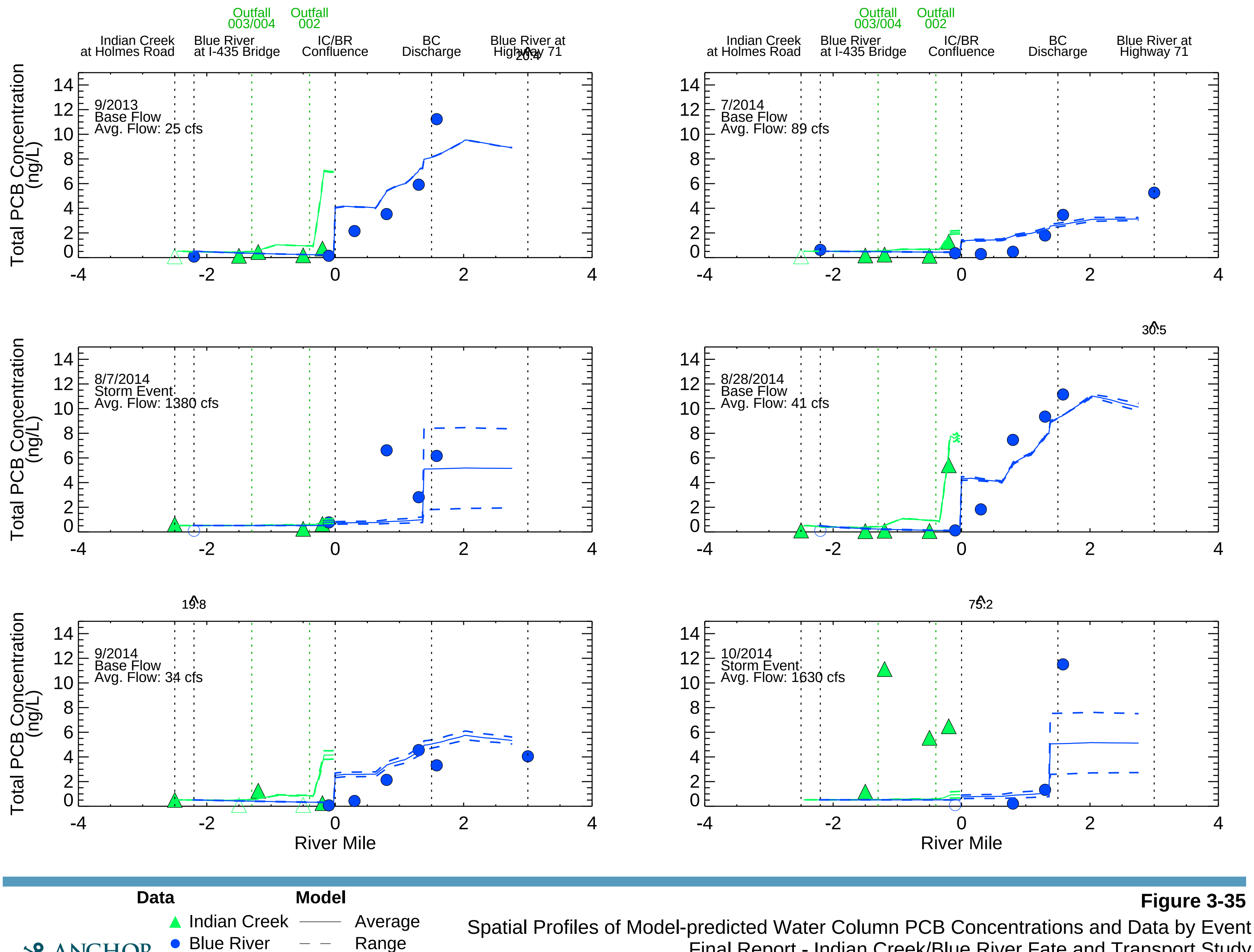

Figure 3-35

Spatial Profiles of Model-predicted Water Column PCB Concentrations and Data by Event
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KCP/Honeywell FM&T

ANCHOR QEA

MCS - \\helios\aq\D_Drive\Projects\Honeywell_FMT\KCP_(120287-03)\MODEL\EFDC\Post_process\Water_Column\plot\model_memo\KCP_WC_model_spatial_byevent_wdata_LT_memo.pro Thu Jul 30 08:46:37 2015

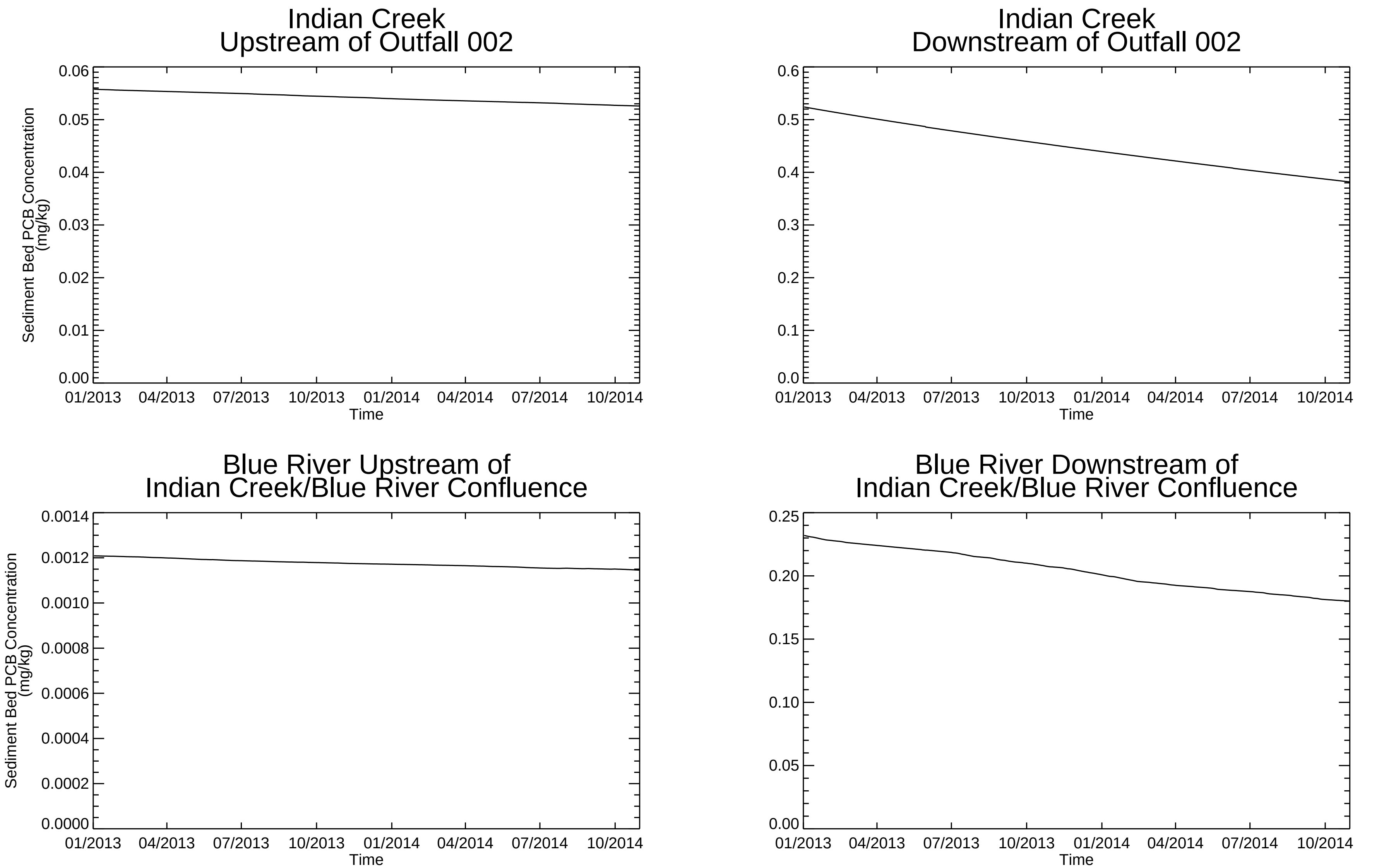

Figure 3-36

Time Series of Model-predicted Surface Sediment (0-4") PCB Concentrations by Reach During the Calibration Period
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KCP/Honeywell FM&T

ANCHOR QEA

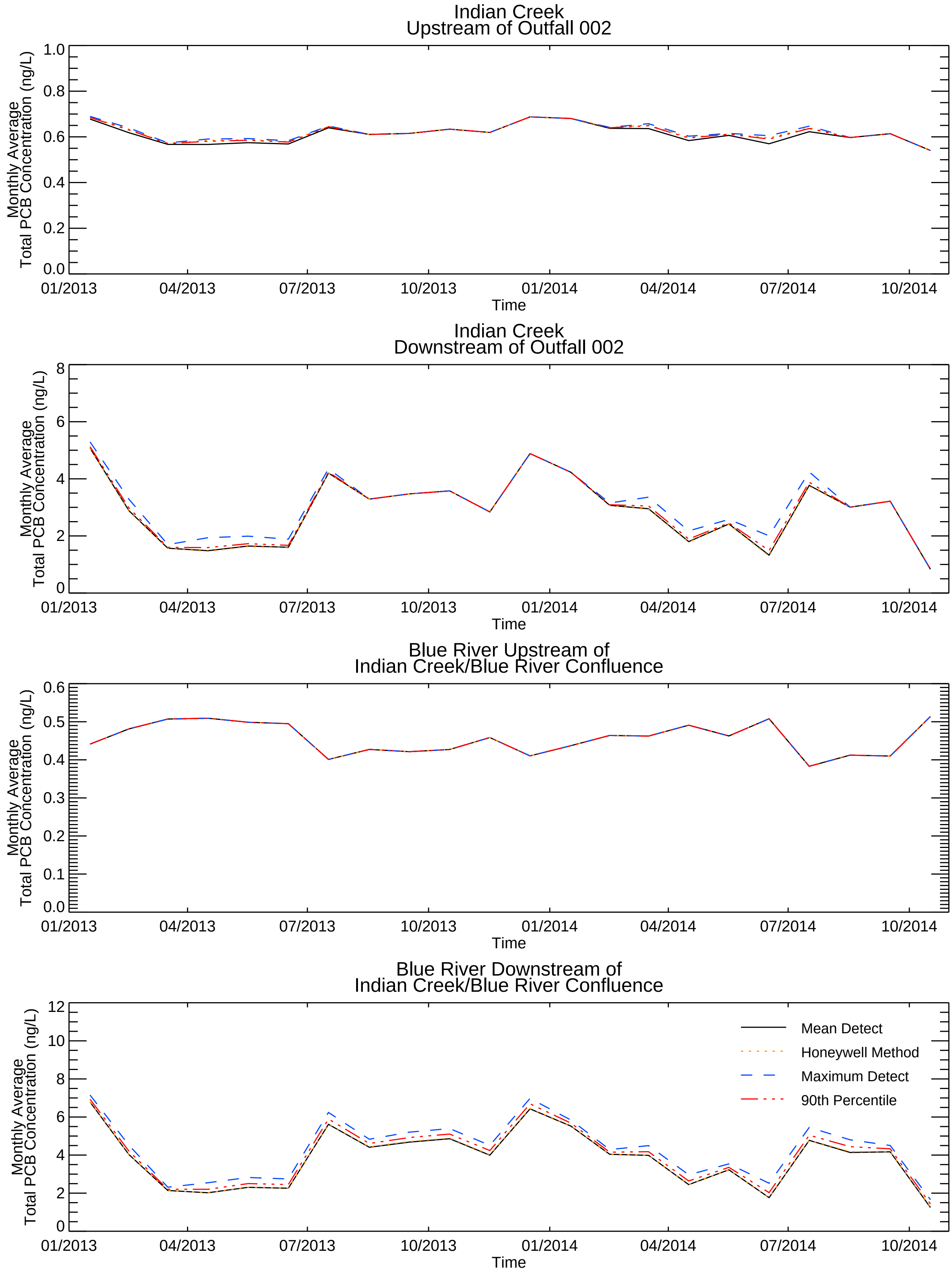

Figure 3-37

Time Series of Monthly Average Model-predicted Water Column PCB Concentrations by Reach
for Stormwater Sensitivity Scenarios During the Calibration Period
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

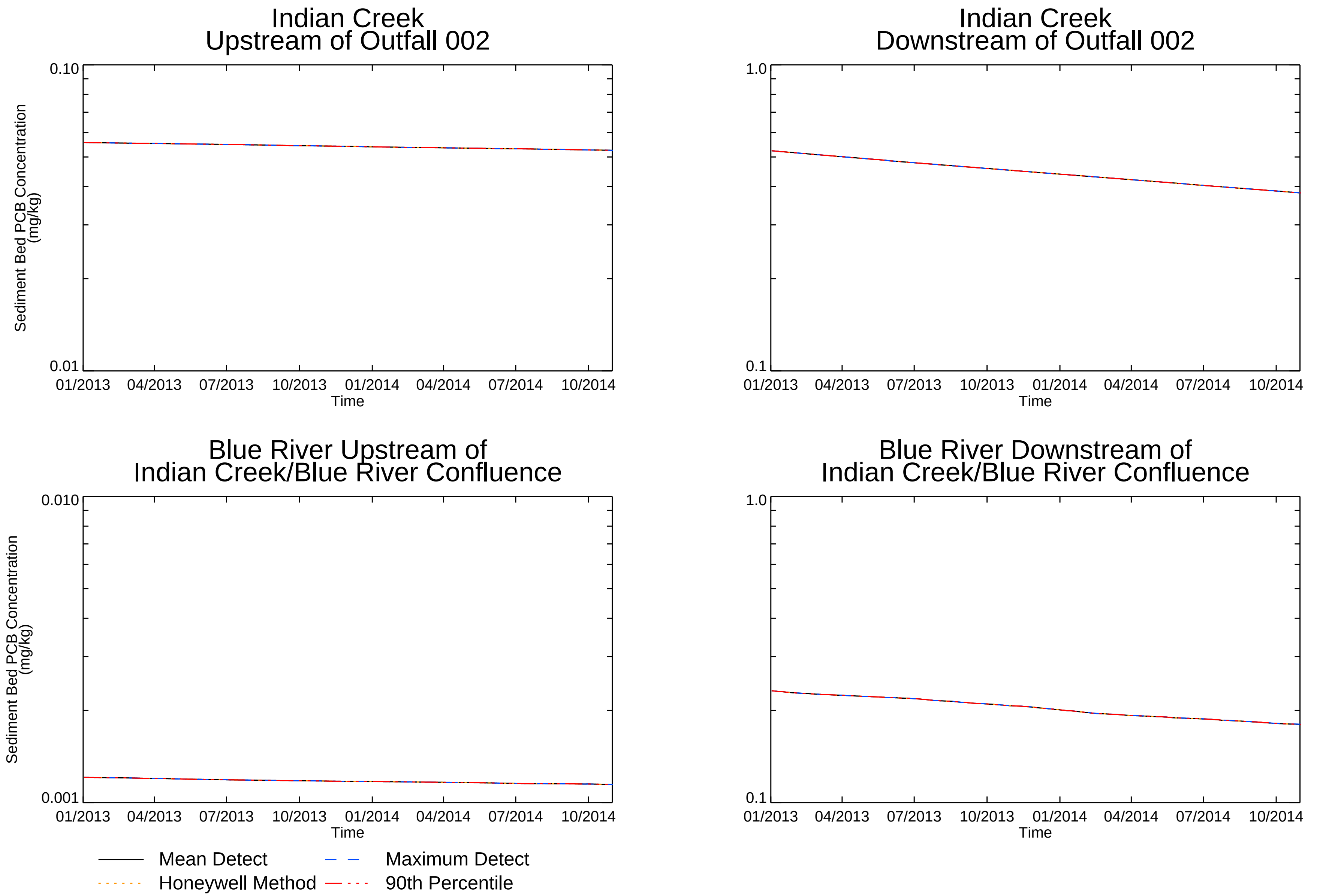

Figure 3-38

Time Series of Model-predicted Surface Sediment (0-4") PCB Concentrations by Reach
for Stormwater Sensitivity Scenarios During the Calibration Period
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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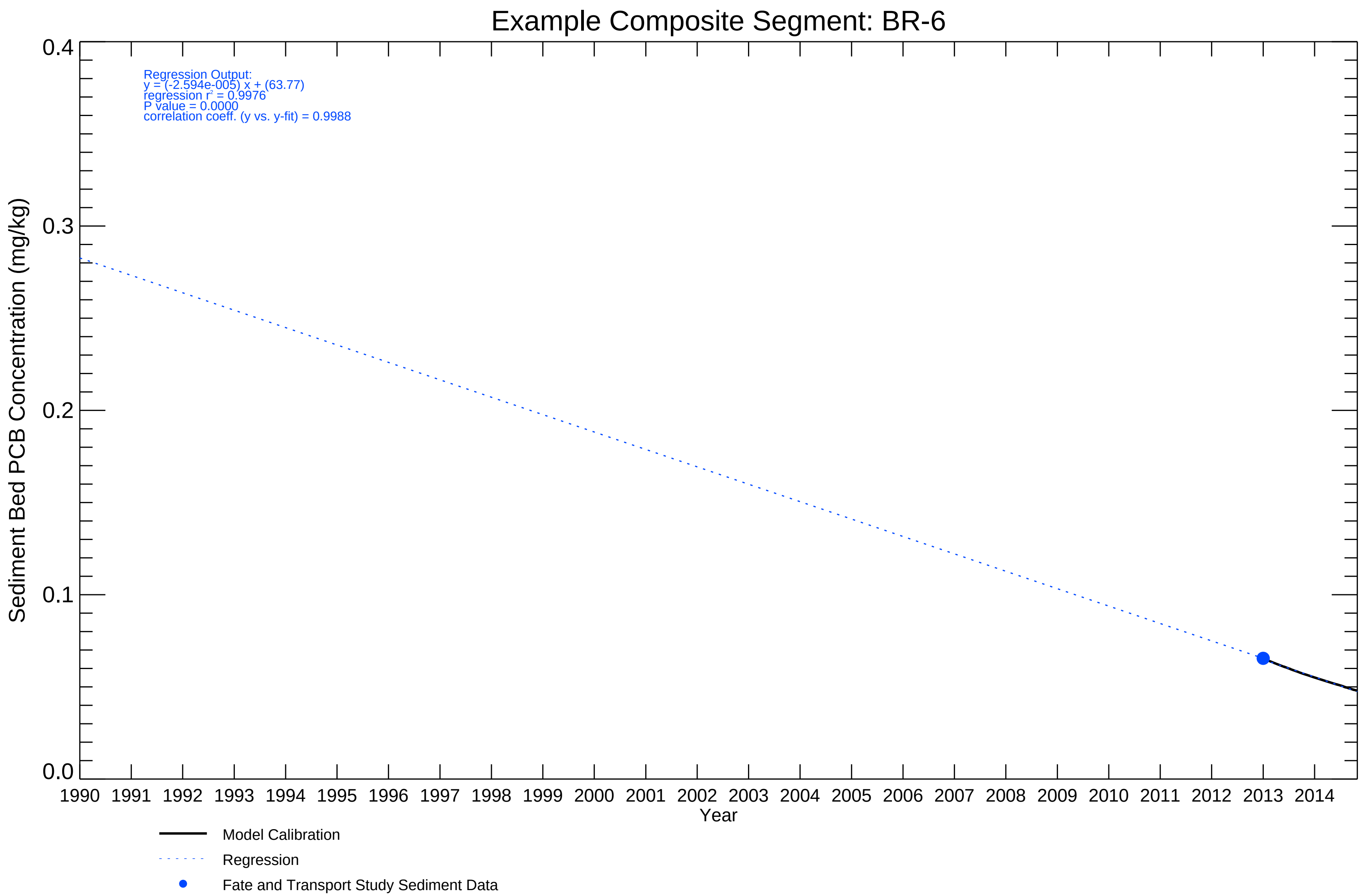

Figure 3-39

Example Backward Extrapolation for Hindcast Initial Sediment PCB Concentration
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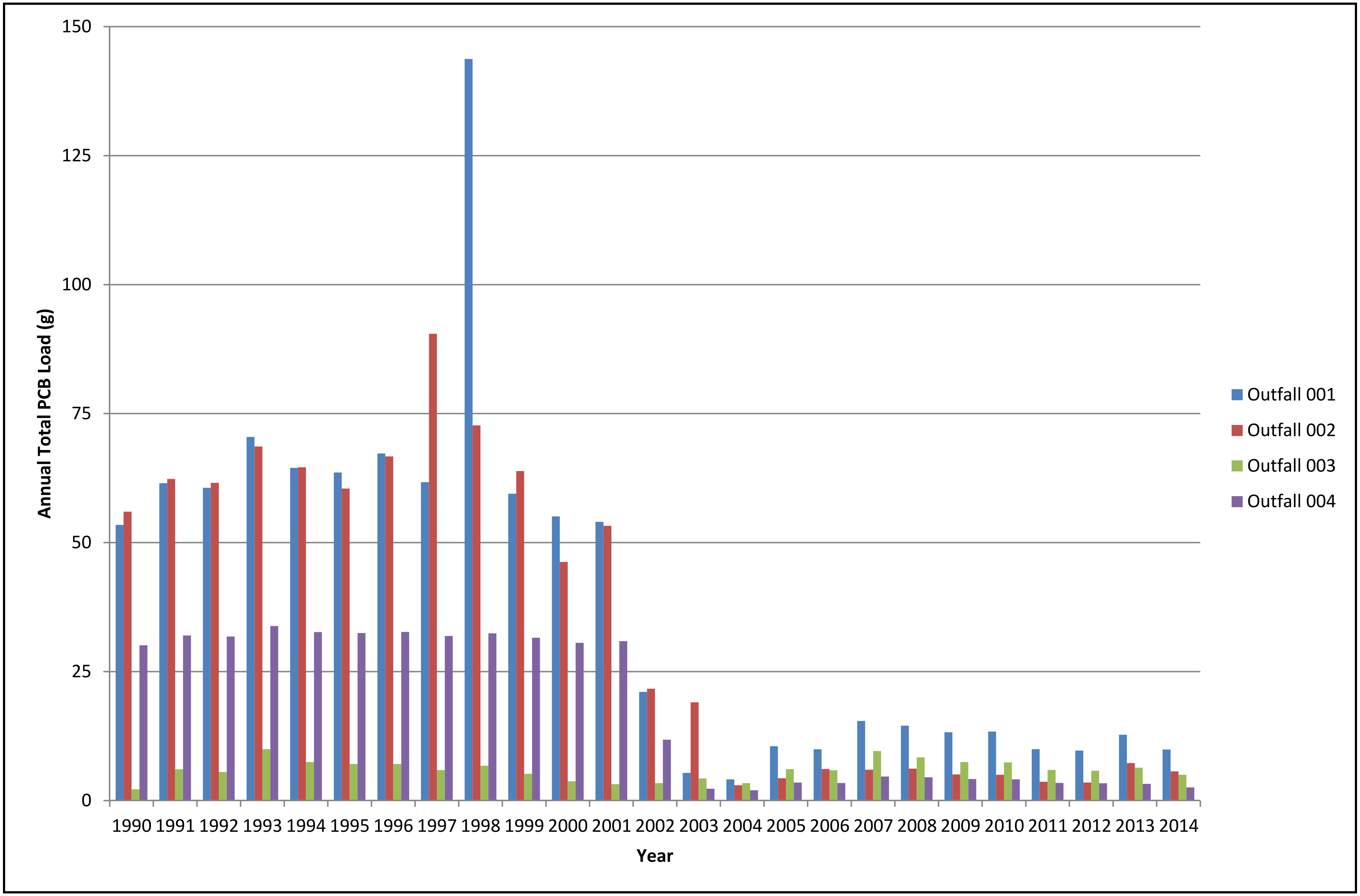
KCP/Honeywell FM&T

ANCHOR QEA

MCS - \\helios\aq\D_Drive\Projects\Honeywell_FMT\KCP_(120287-03)\MODEL\EFDC\Post_process\Bed_Sed\plot\model_memo\KCP_plot_bed_conc_temp_memo.pro Thu Jul 30 08:47:46 2015



ANCHOR QEA

Figure 3-40
Time Series of Outfall Total PCB Loads used for Hindcast Simulation
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

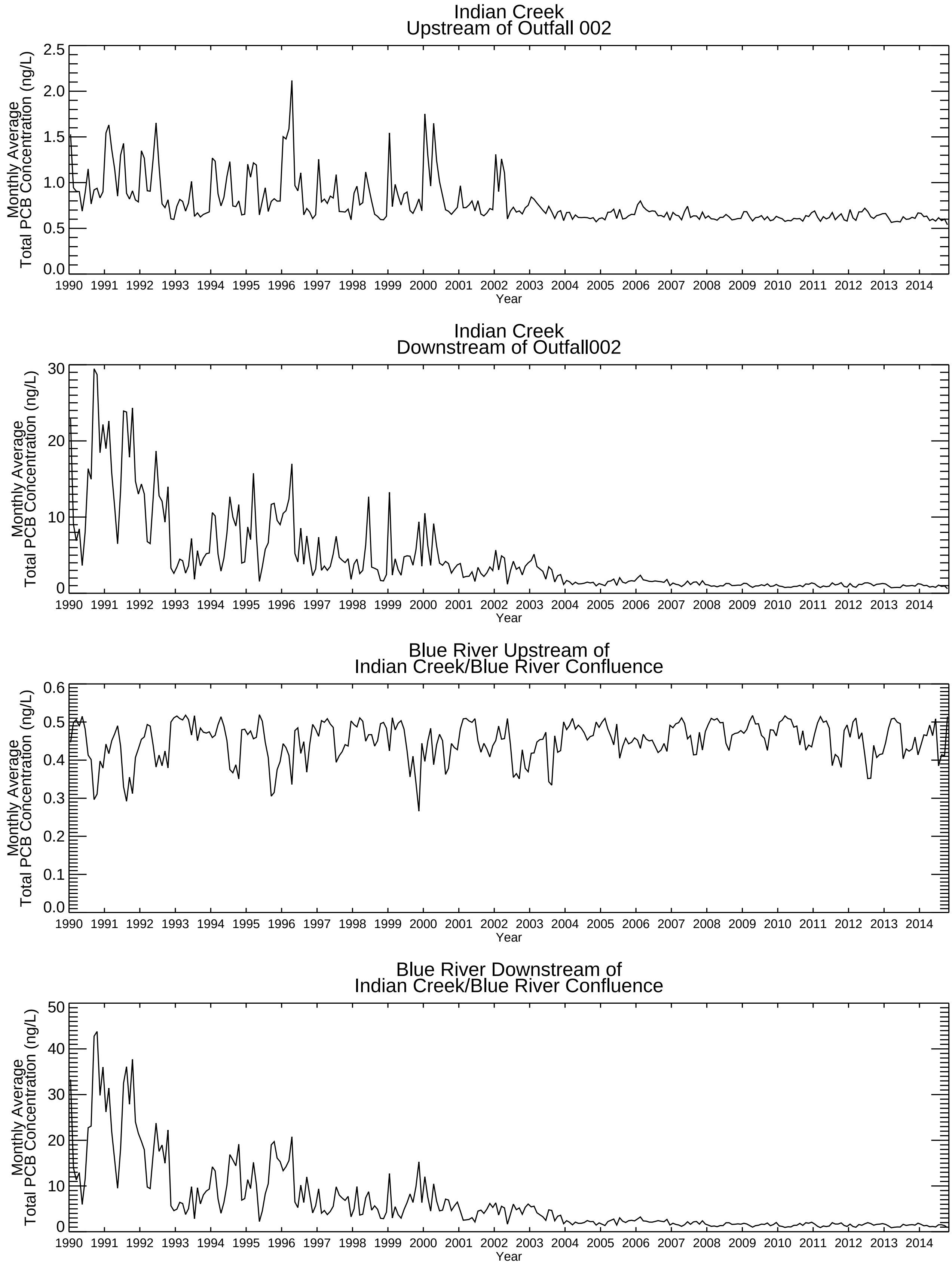


Figure 3-41

Time Series of Monthly Average Model-predicted Water Column PCB Concentrations by Reach from the 25-Year Hindcast

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

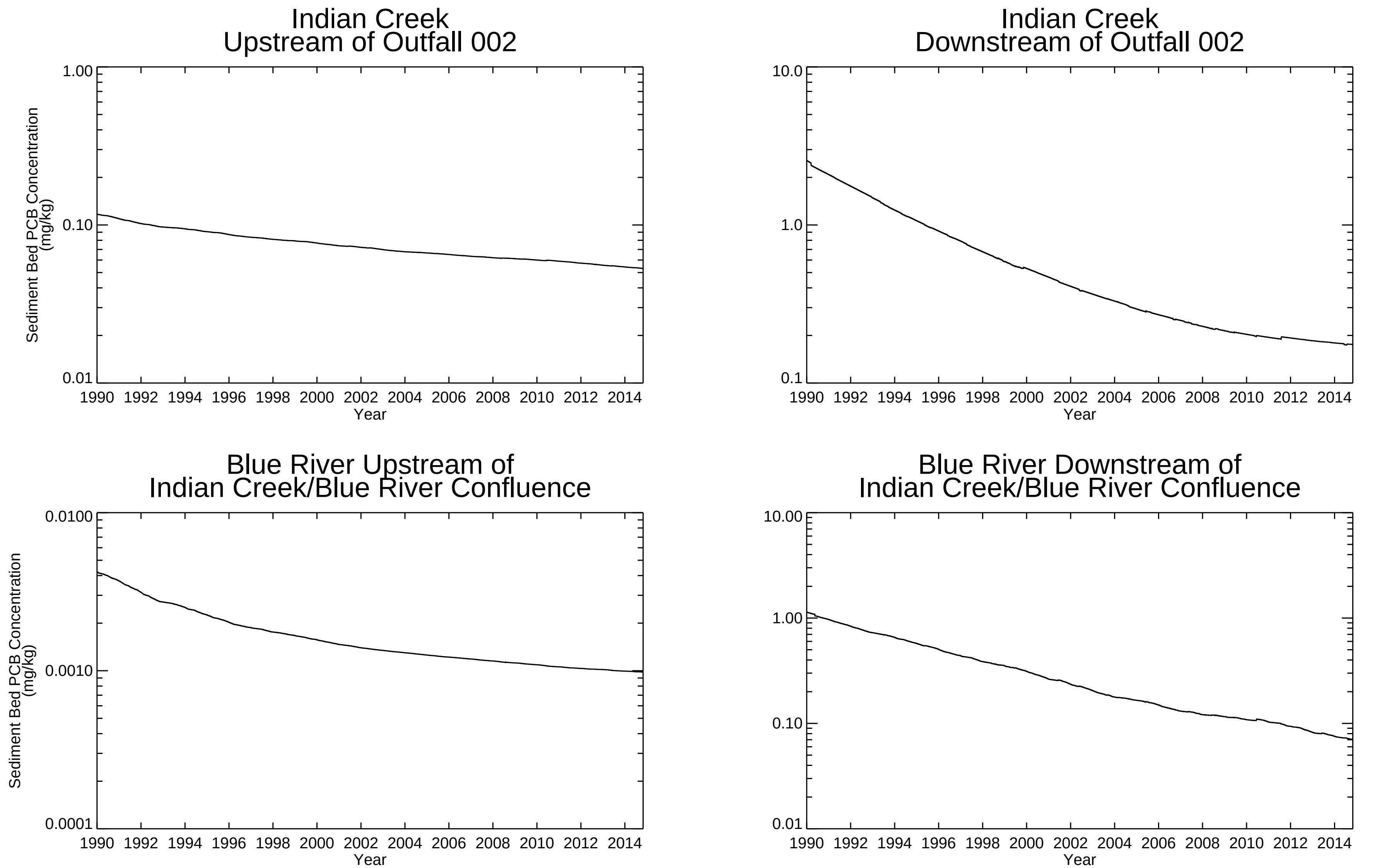


Figure 3-42

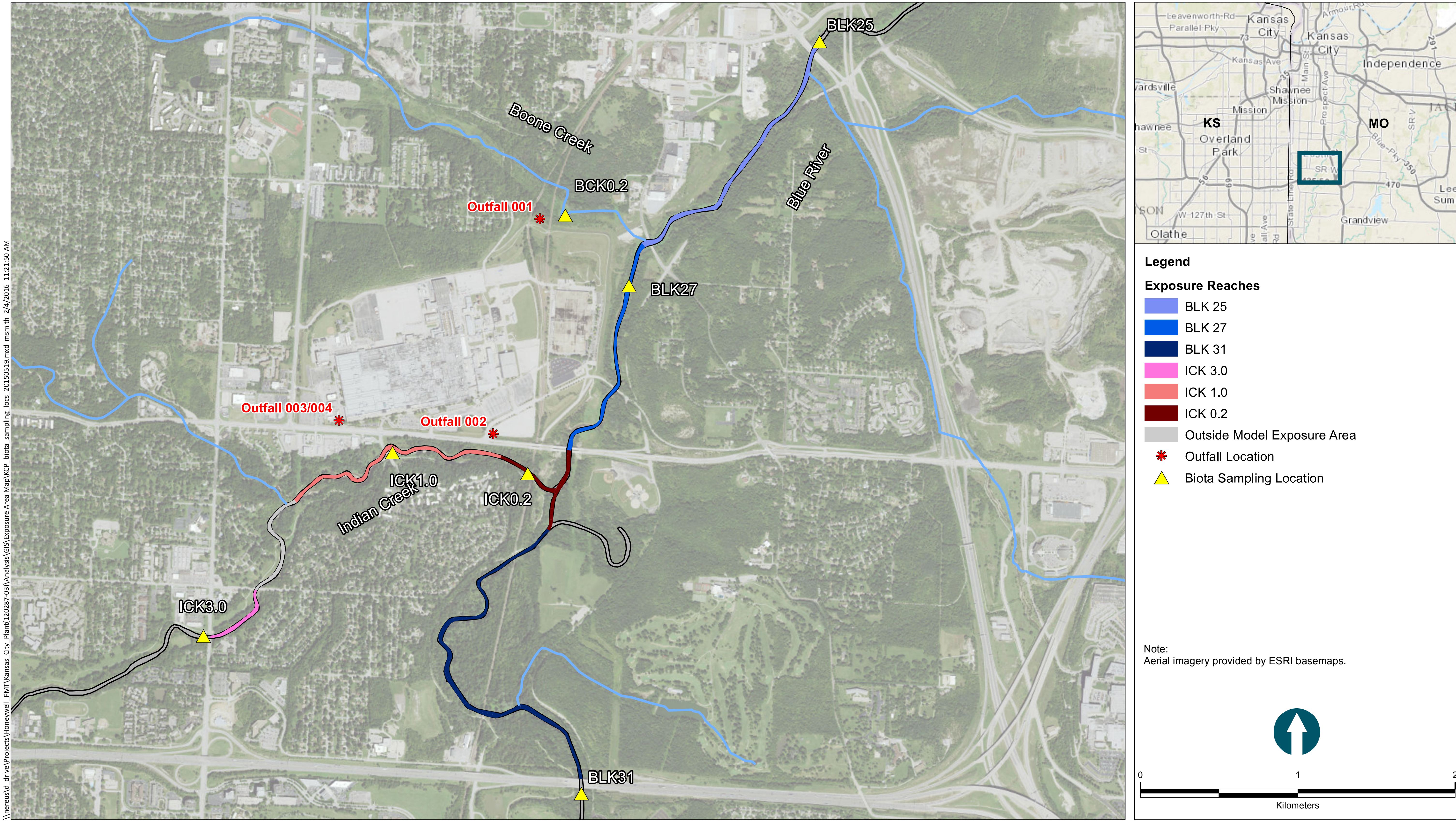
Time Series of Model-predicted Surface Sediment (0-4") PCB Concentrations by Reach from the 25-Year Hindcast

Final Report - Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

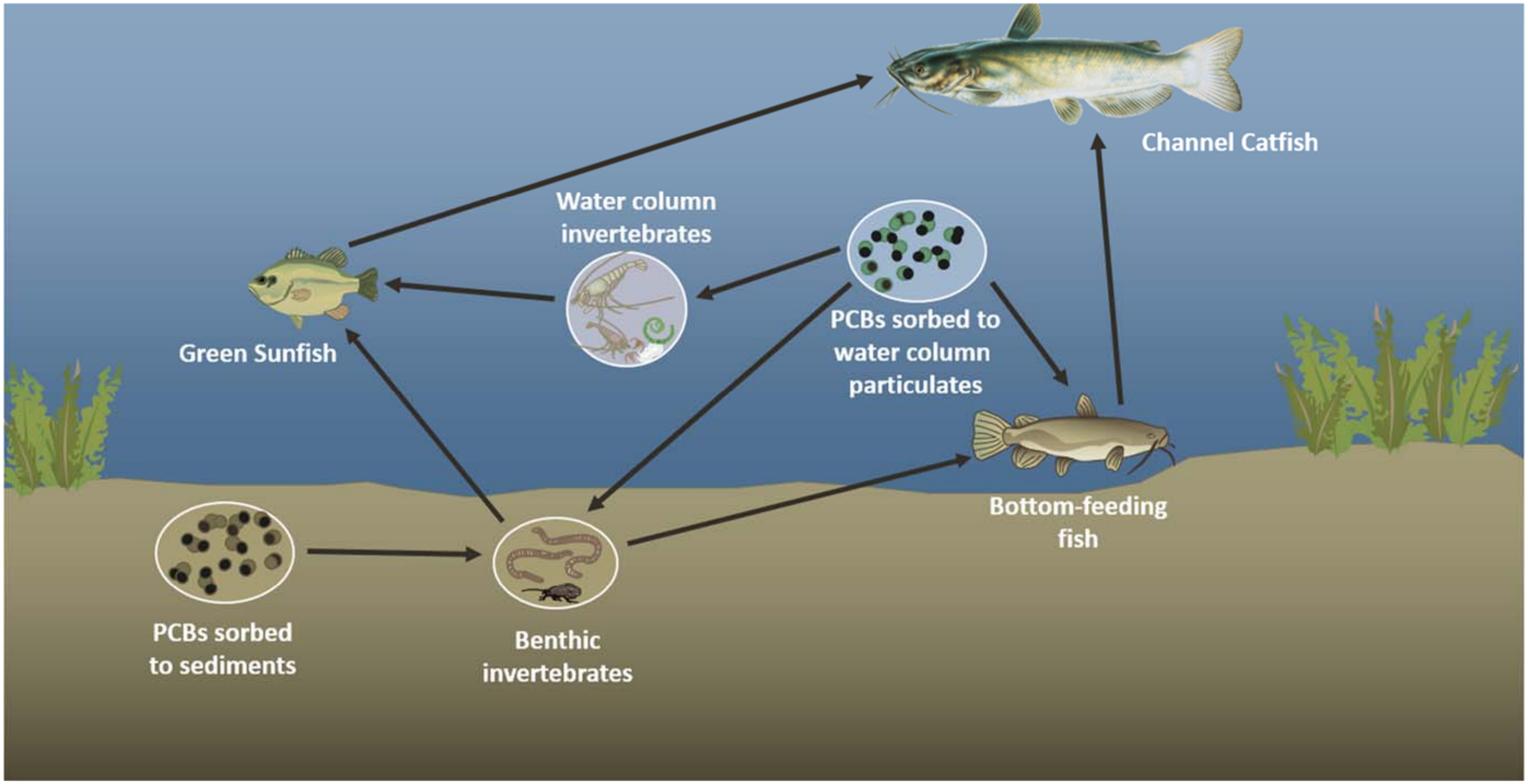
ANCHOR QEA

MCS - \\helios\aq\D_Drive\Projects\Honeywell_FMT\KCP_(120287-03)\MODEL\EFDC\Post_process\Bed_Sed\plot\model_memo\KCP_plot_bed_conc_temp_report_hindcast.pro Thu Jul 30 08:52:02 2015



ANCHOR QEA

Figure 3-43
Bioaccumulation Model Exposure Areas
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T



ANCHOR QEA

Figure 3-44
Food Web Model Framework/Schematic
Final Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

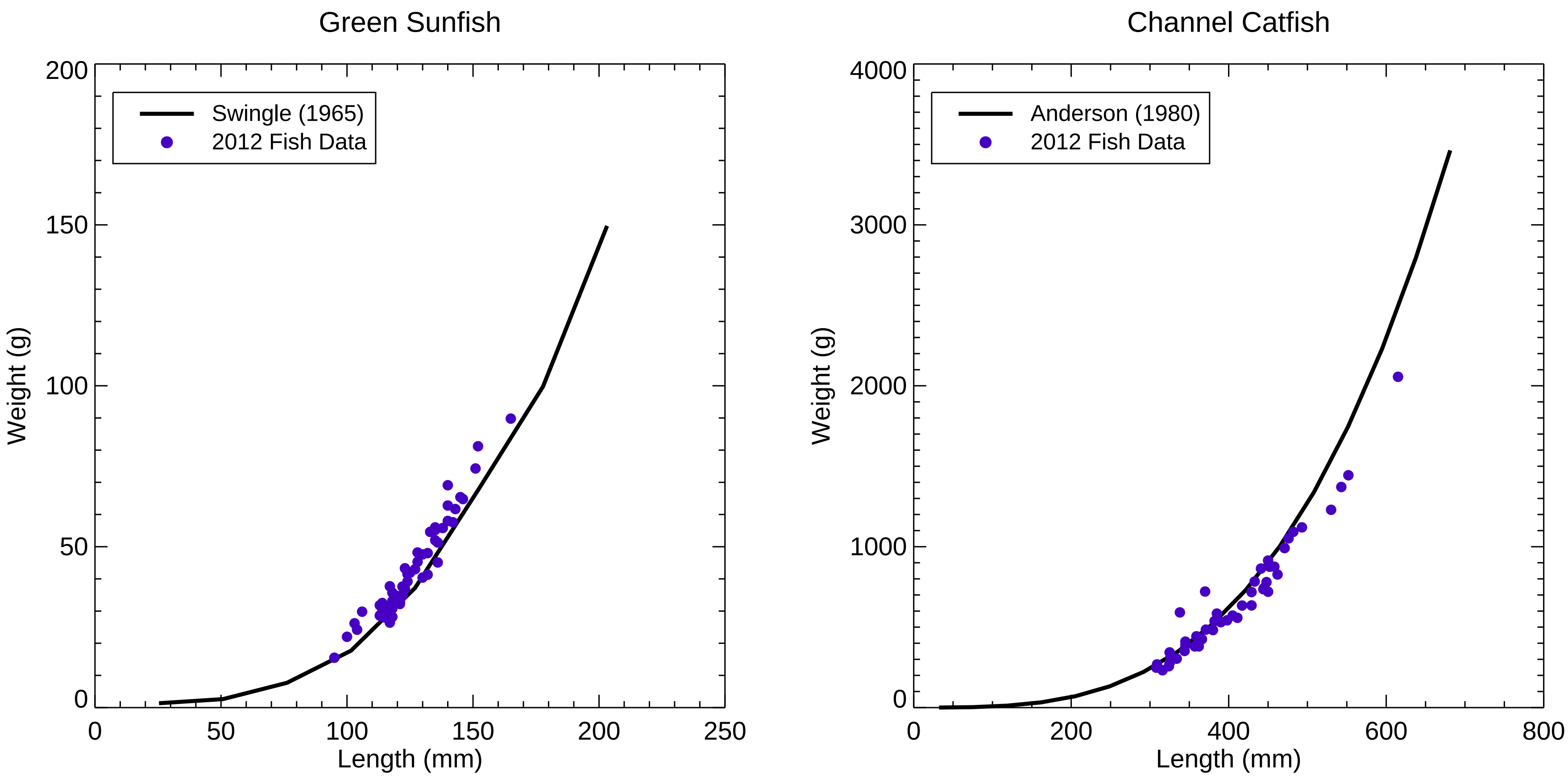


Figure 3-45

Length-weight Relationship for Green Sunfish and Channel Catfish
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

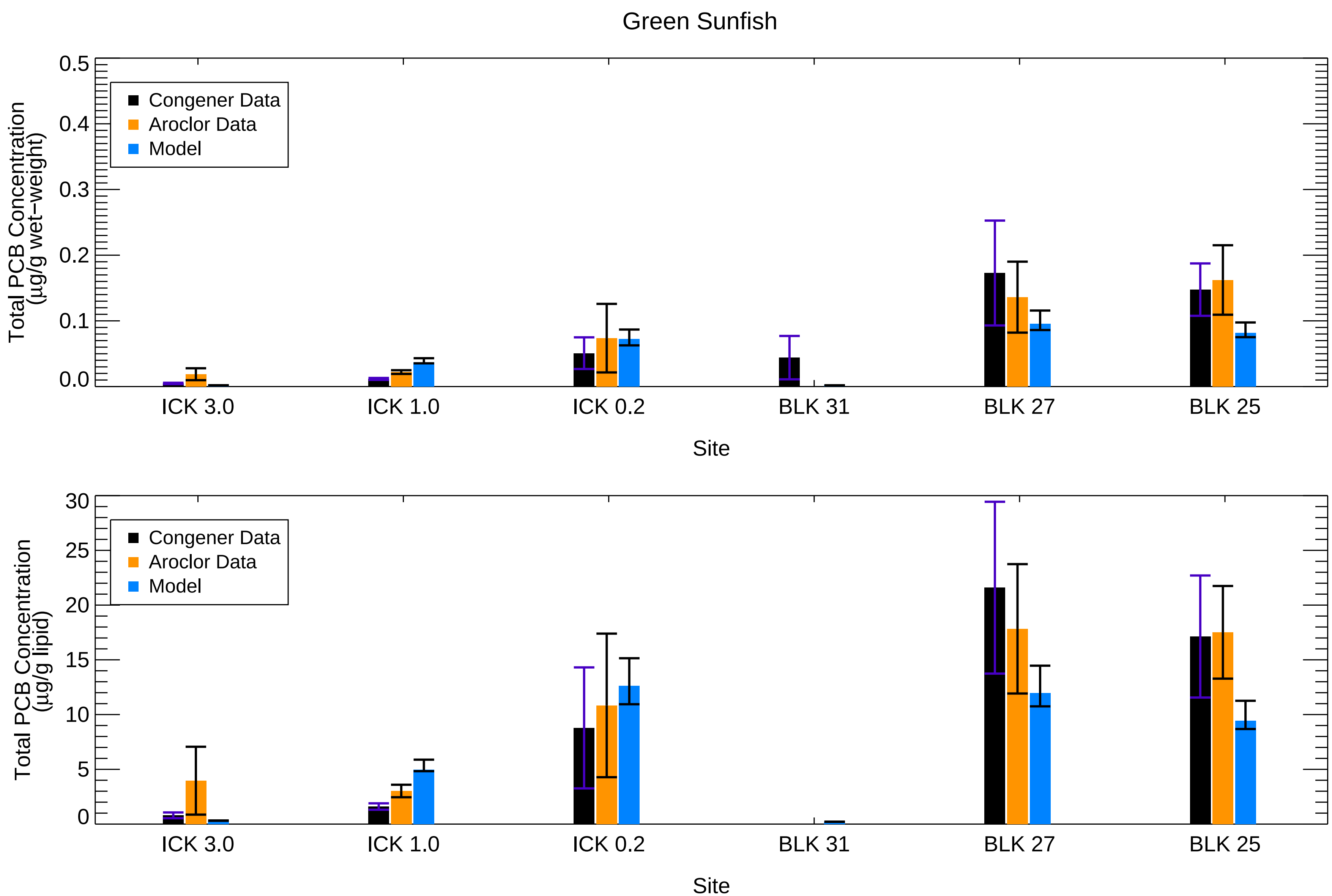


Figure 3−46a

Comparison of Model−predicted Fish Tissue PCB Concentrations and 2012 Data (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

Notes: Data represent spatial average concentrations for 2012 samples and error bars are +/− 2 standard errors. Non−detects are set to half detection limit.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\spatial_fish_model_data_comparison.pro Thu Jul 30 09:01:50 2015

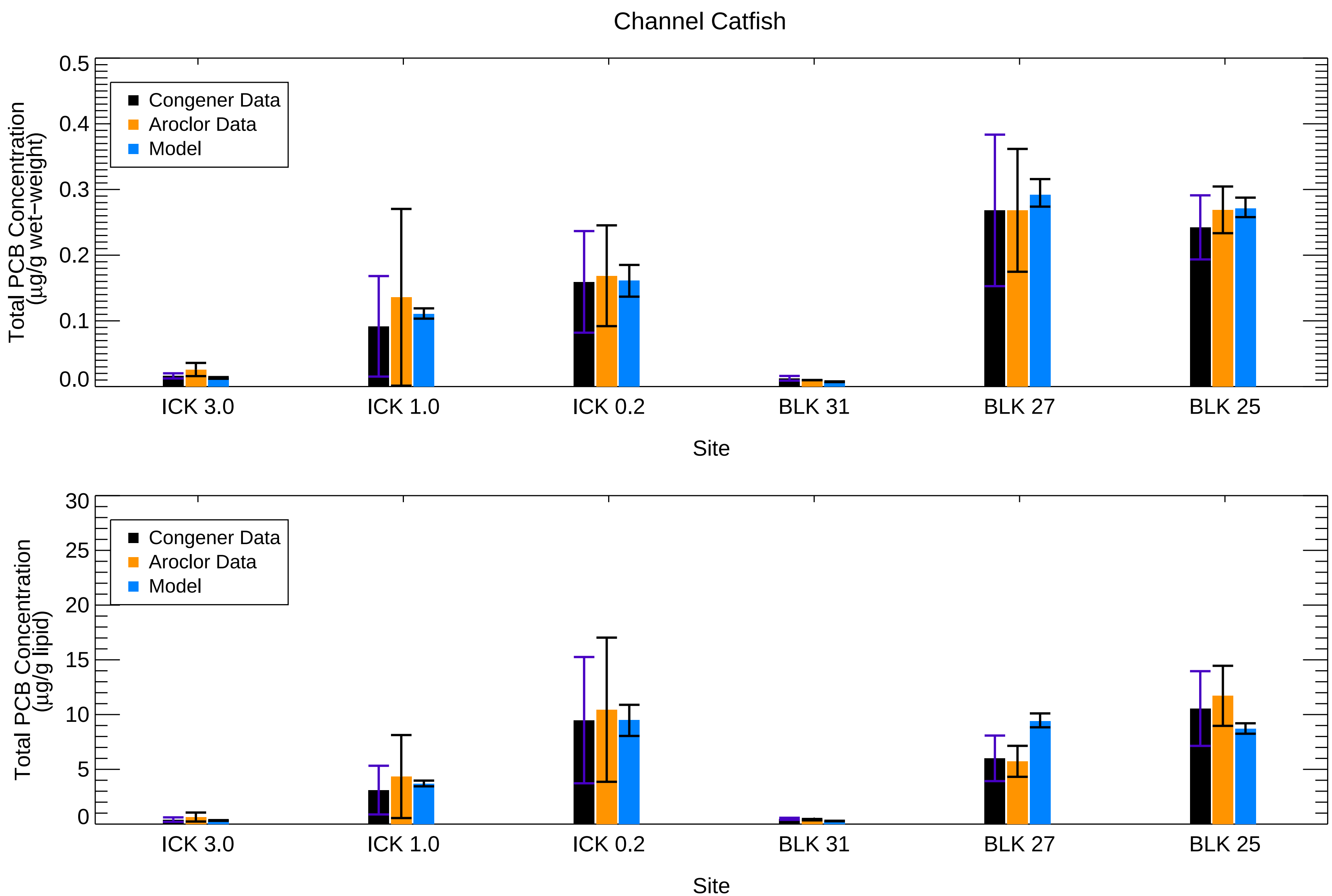


Figure 3−46b

Comparison of Model−predicted Fish Tissue PCB Concentrations and 2012 Data (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

Notes: Data represent spatial average concentrations for 2012 samples and error bars are +/− 2 standard errors. Non−detects are set to half detection limit.

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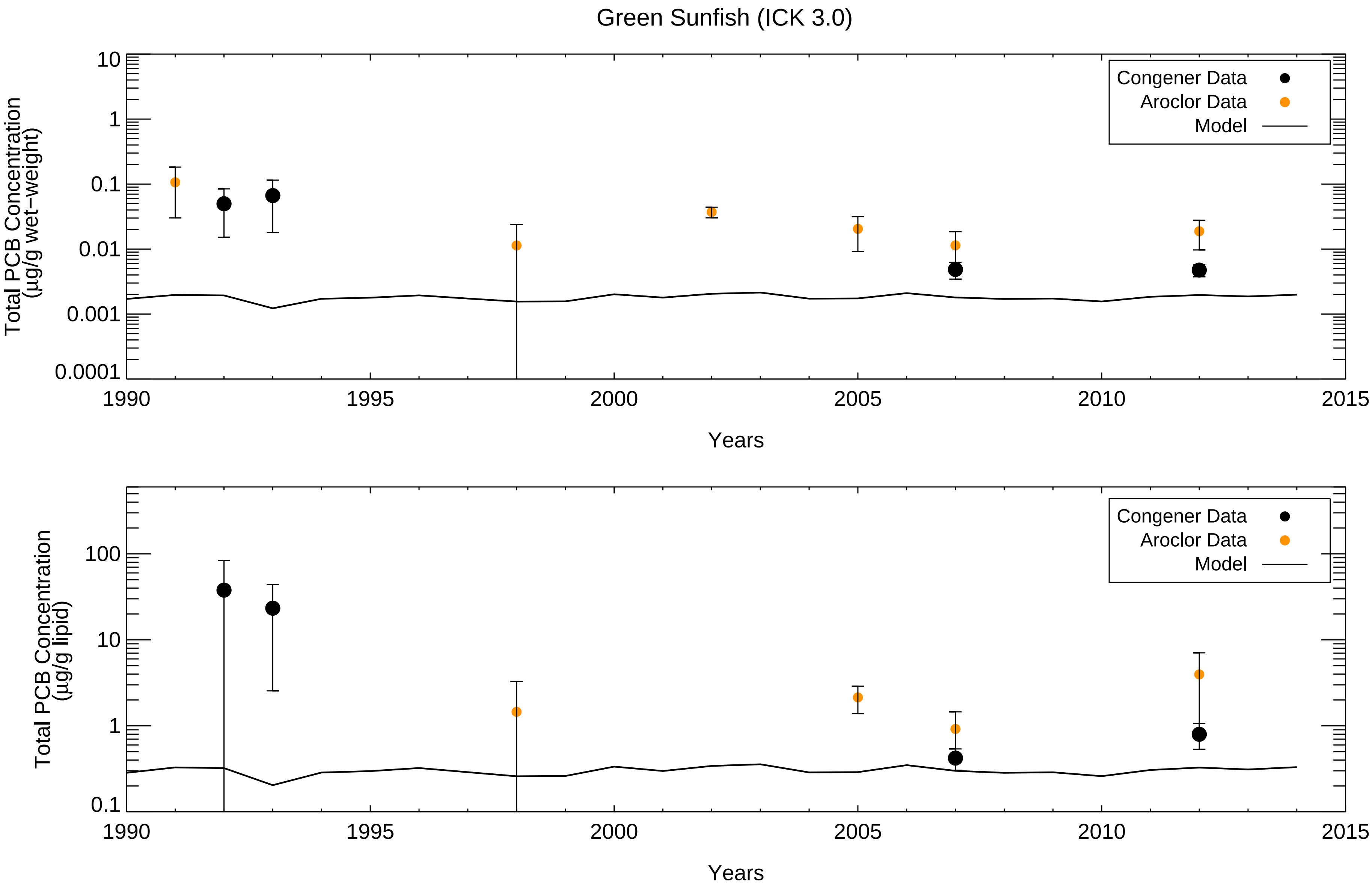

Figure 3−47a

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 3.0 for the Hindcast Simulation (Green Sunfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

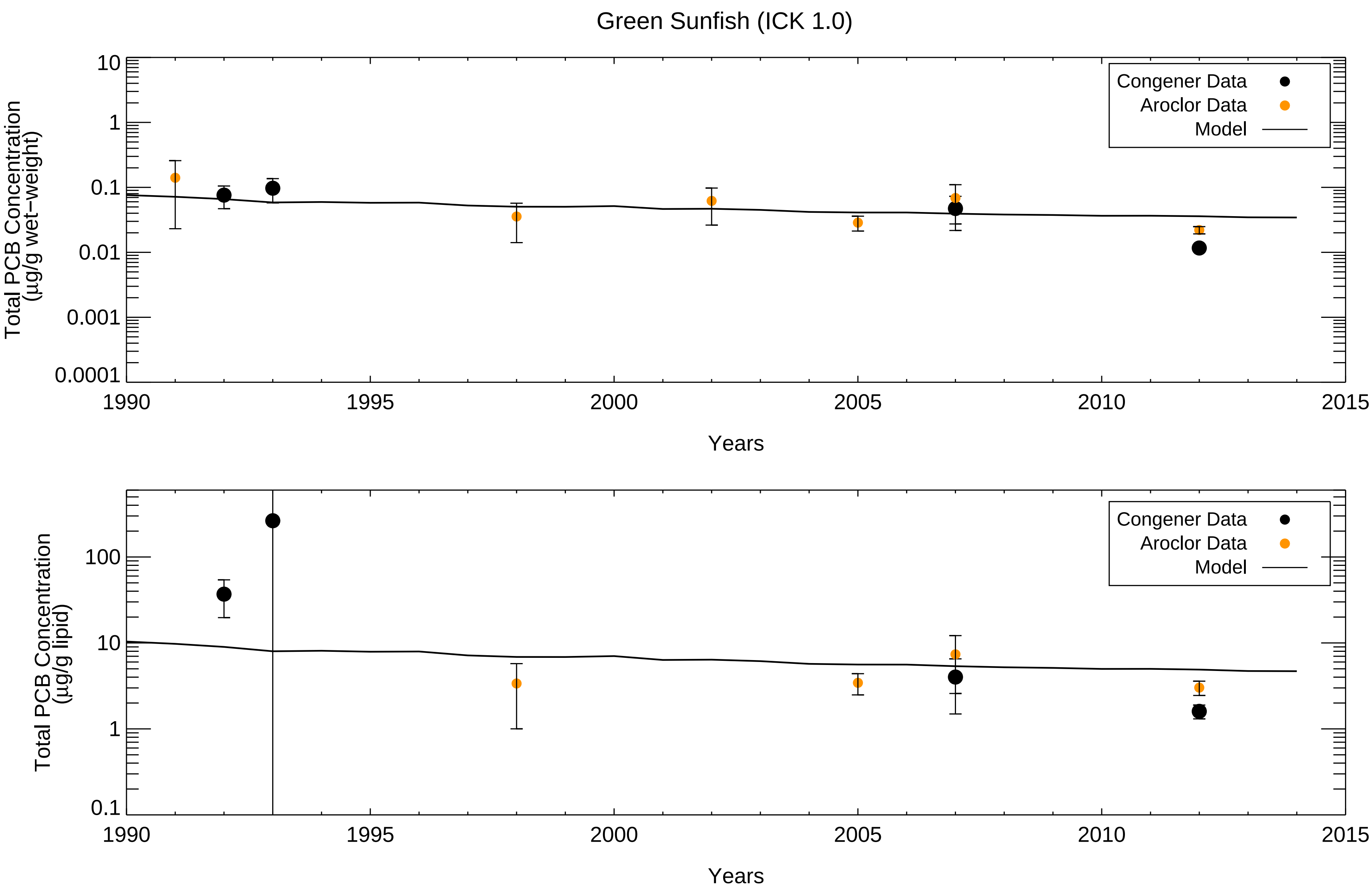

Figure 3−47b

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 1.0 for the Hindcast Simulation (Green Sunfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

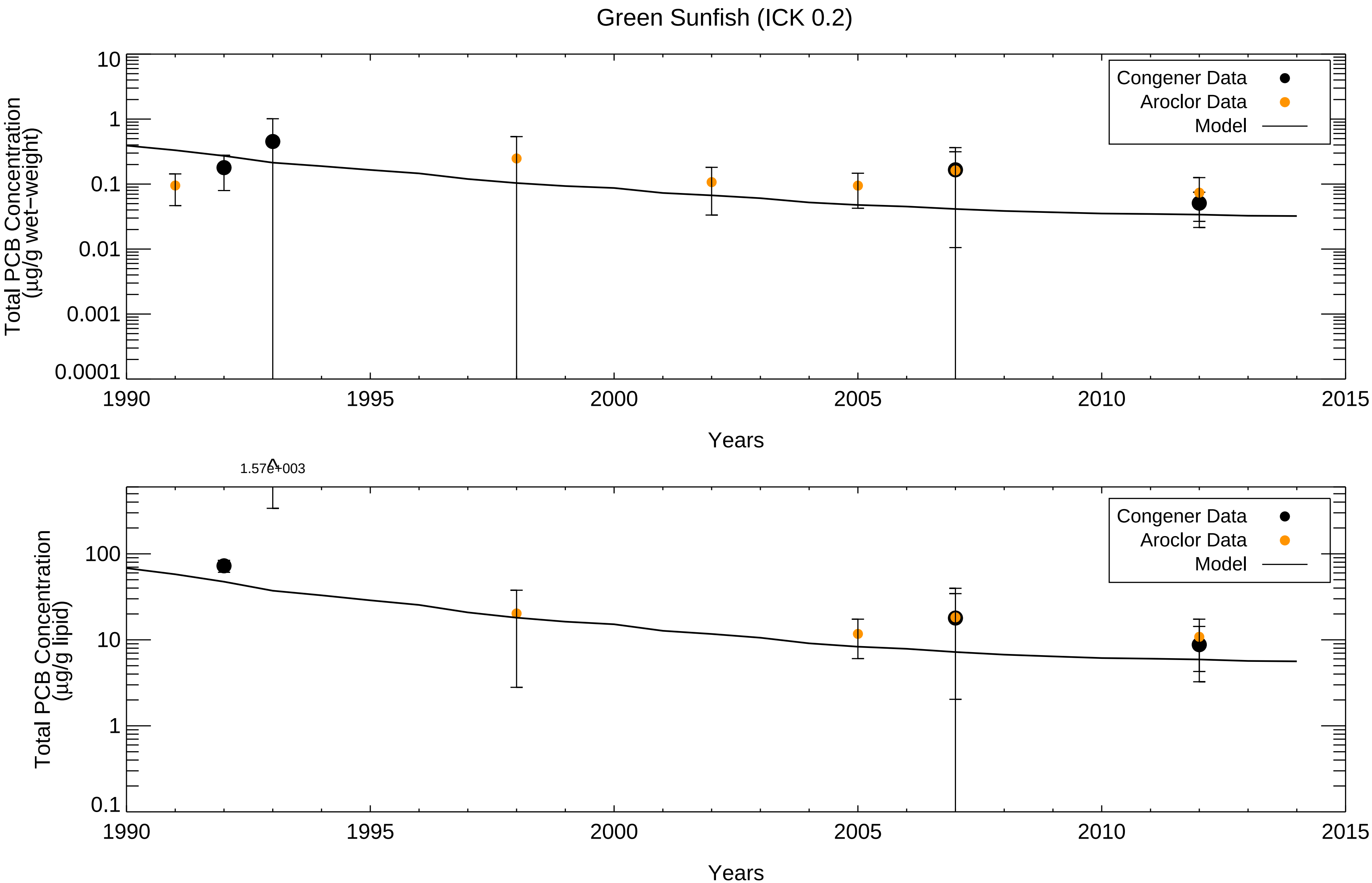

Figure 3−47c

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 0.2 for the Hindcast Simulation (Green Sunfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

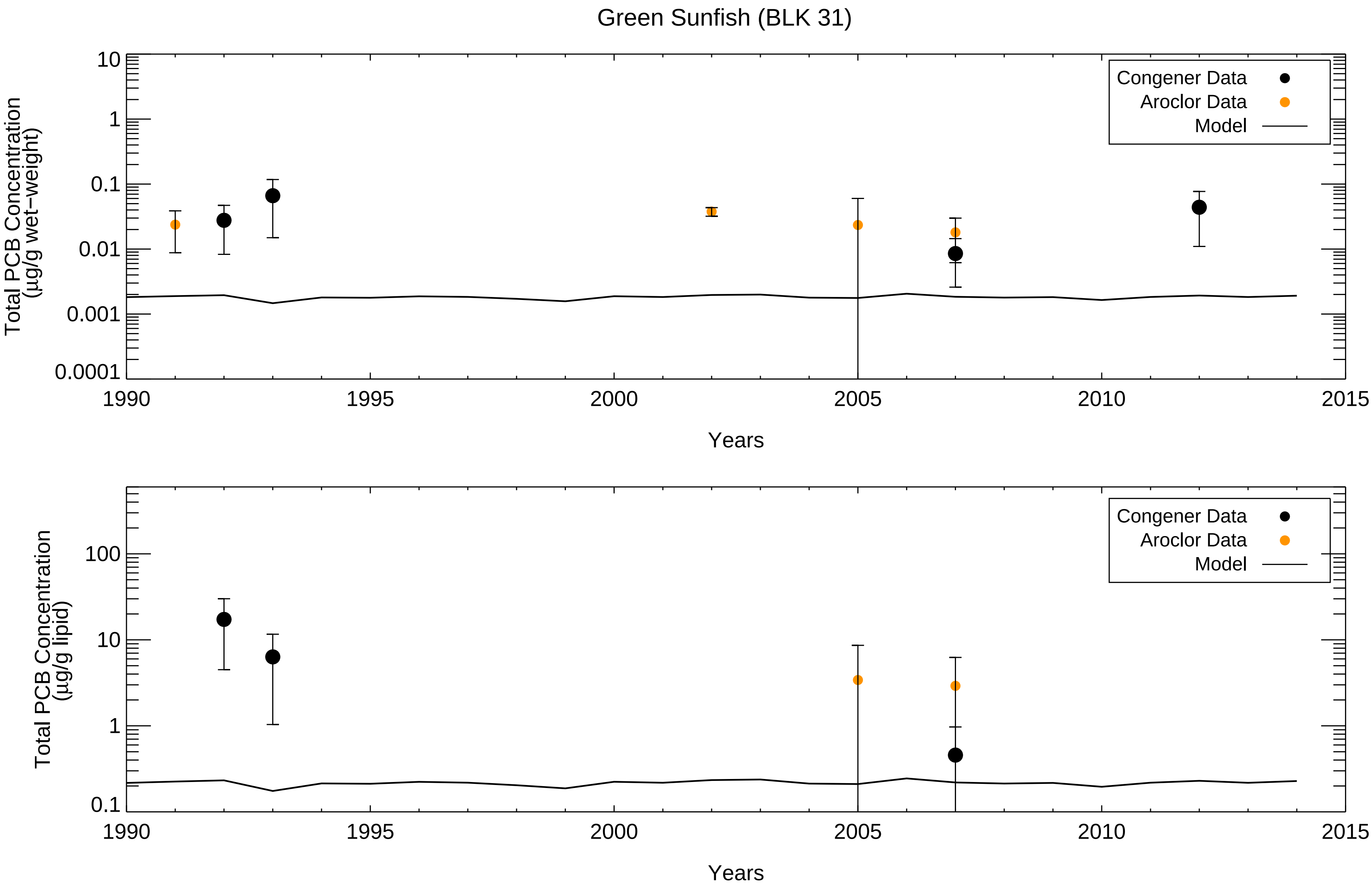

Figure 3−47d

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 31 for the Hindcast Simulation (Green Sunfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

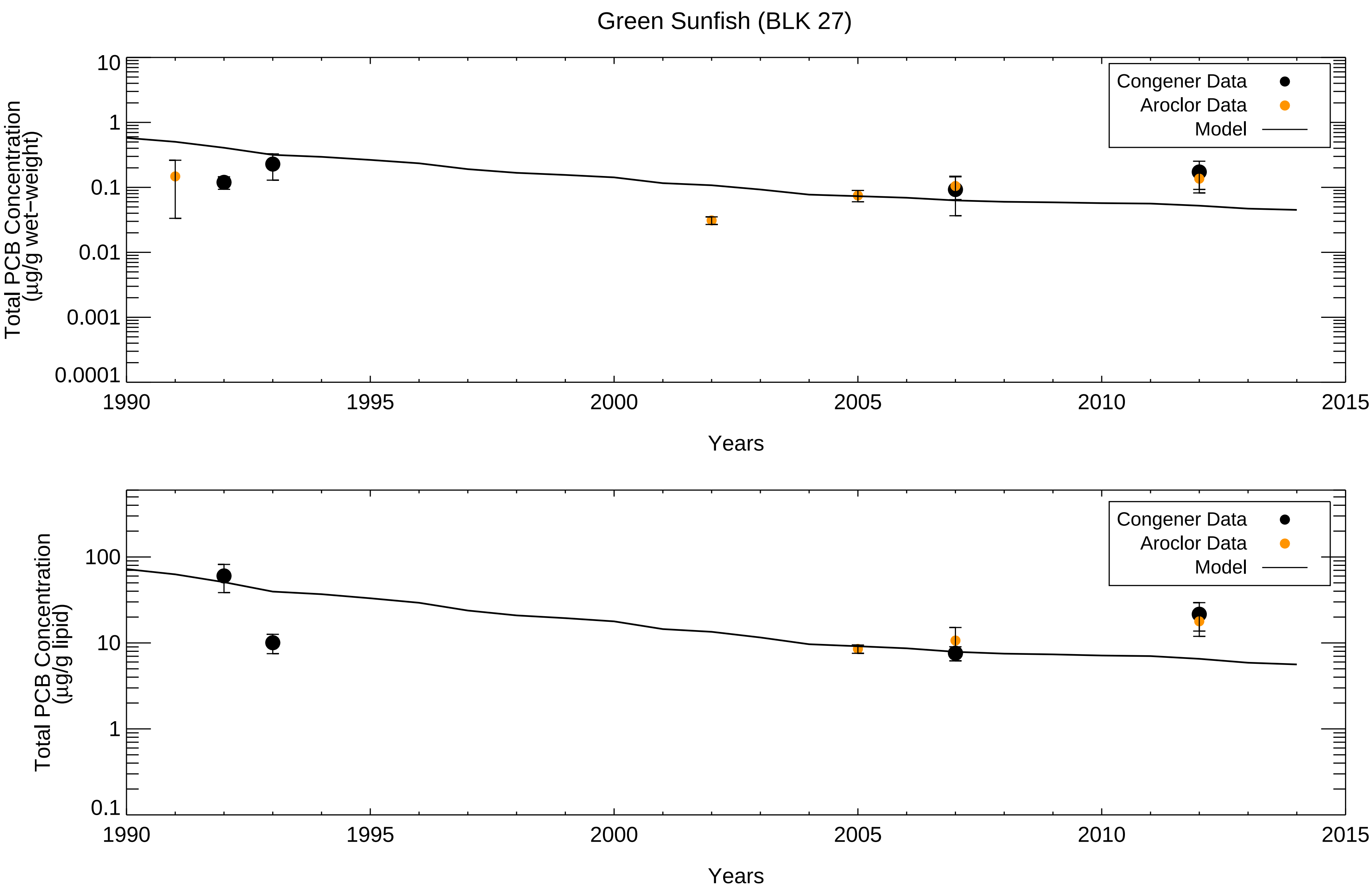

Figure 3−47e

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 27 for the Hindcast Simulation (Green Sunfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

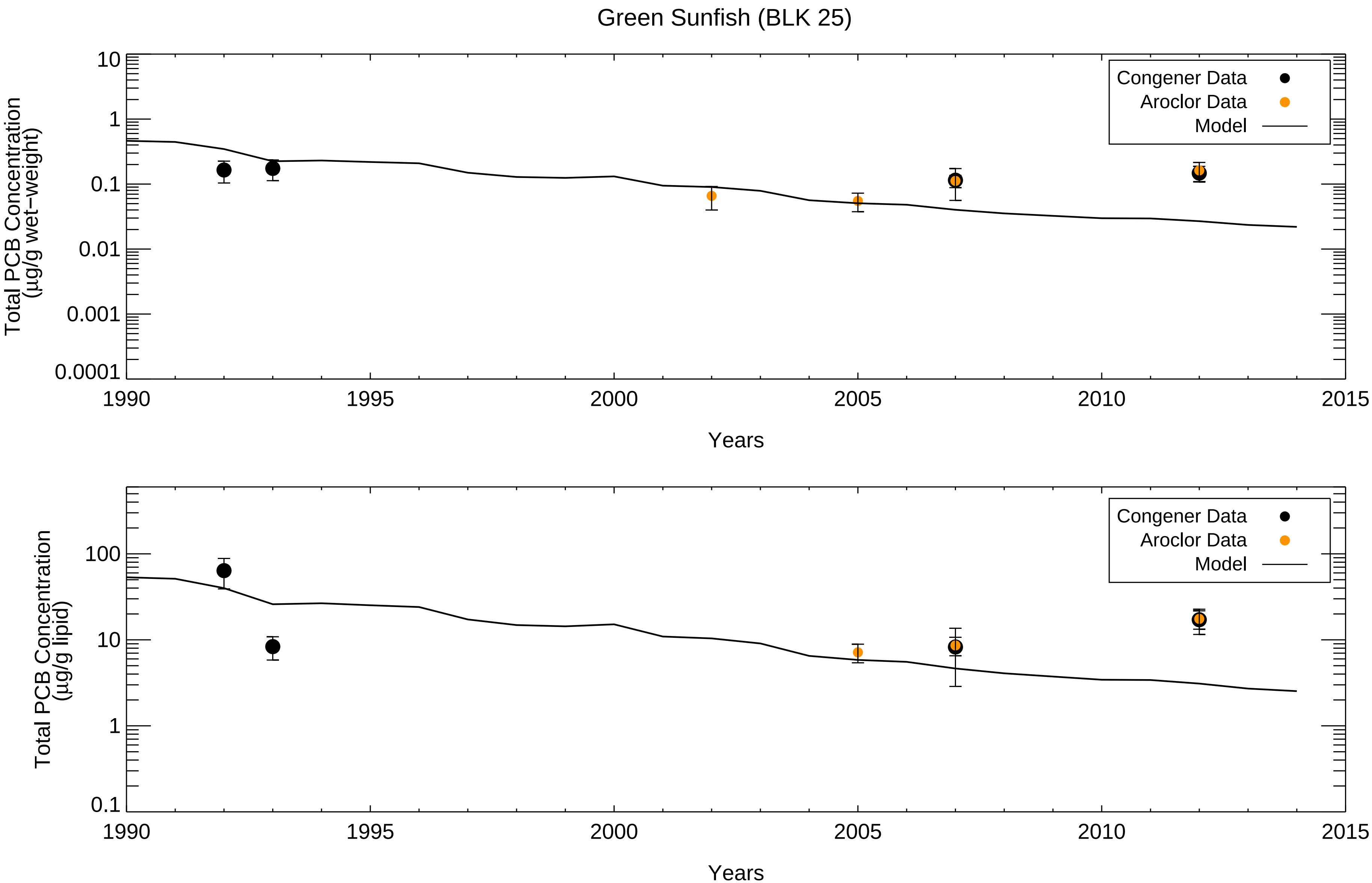

Figure 3−47f

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 25 for the Hindcast Simulation (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

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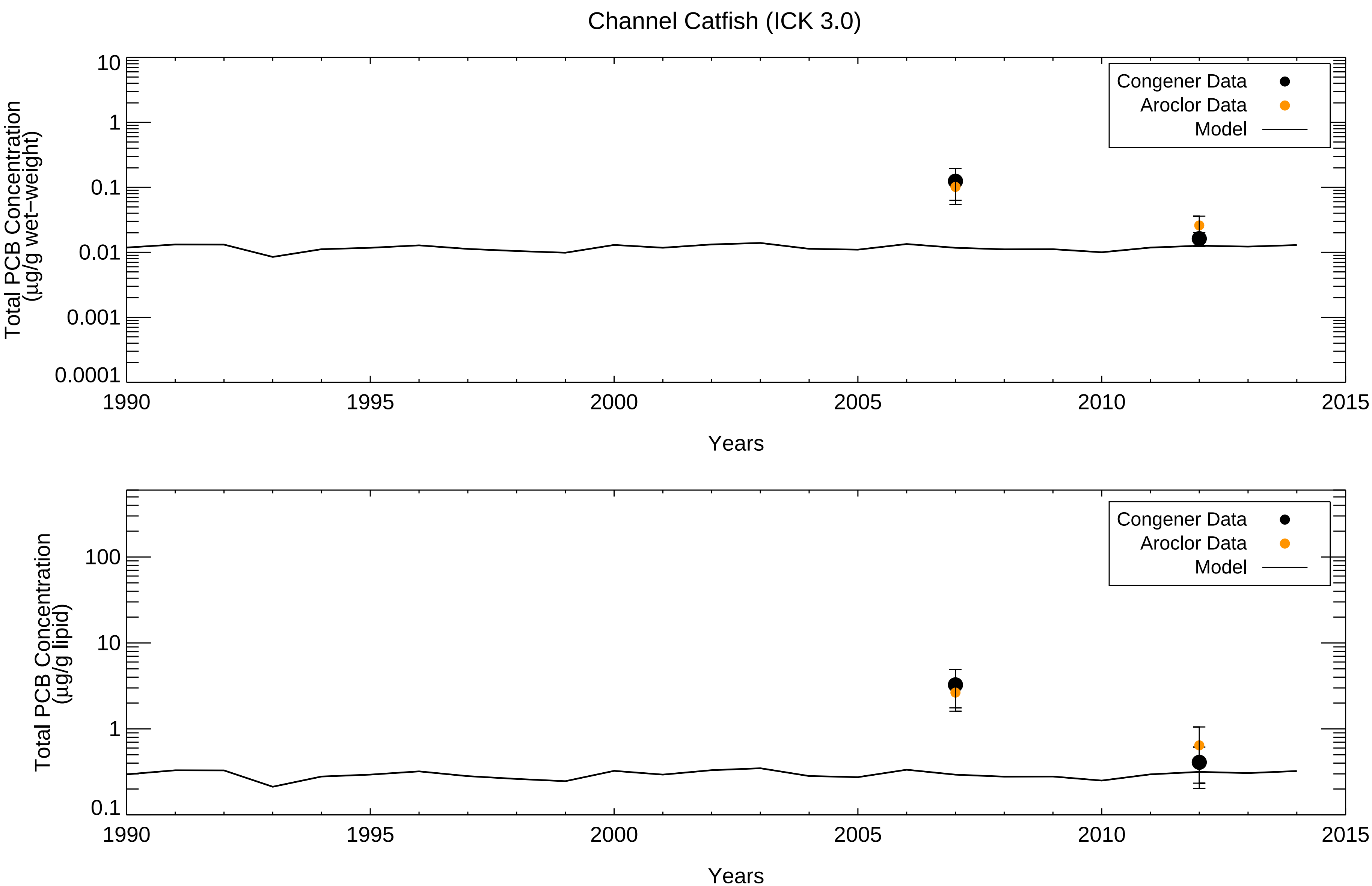

Figure 3−48a

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 3.0 for the Hindcast Simulation (Channel Catfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:14 2015

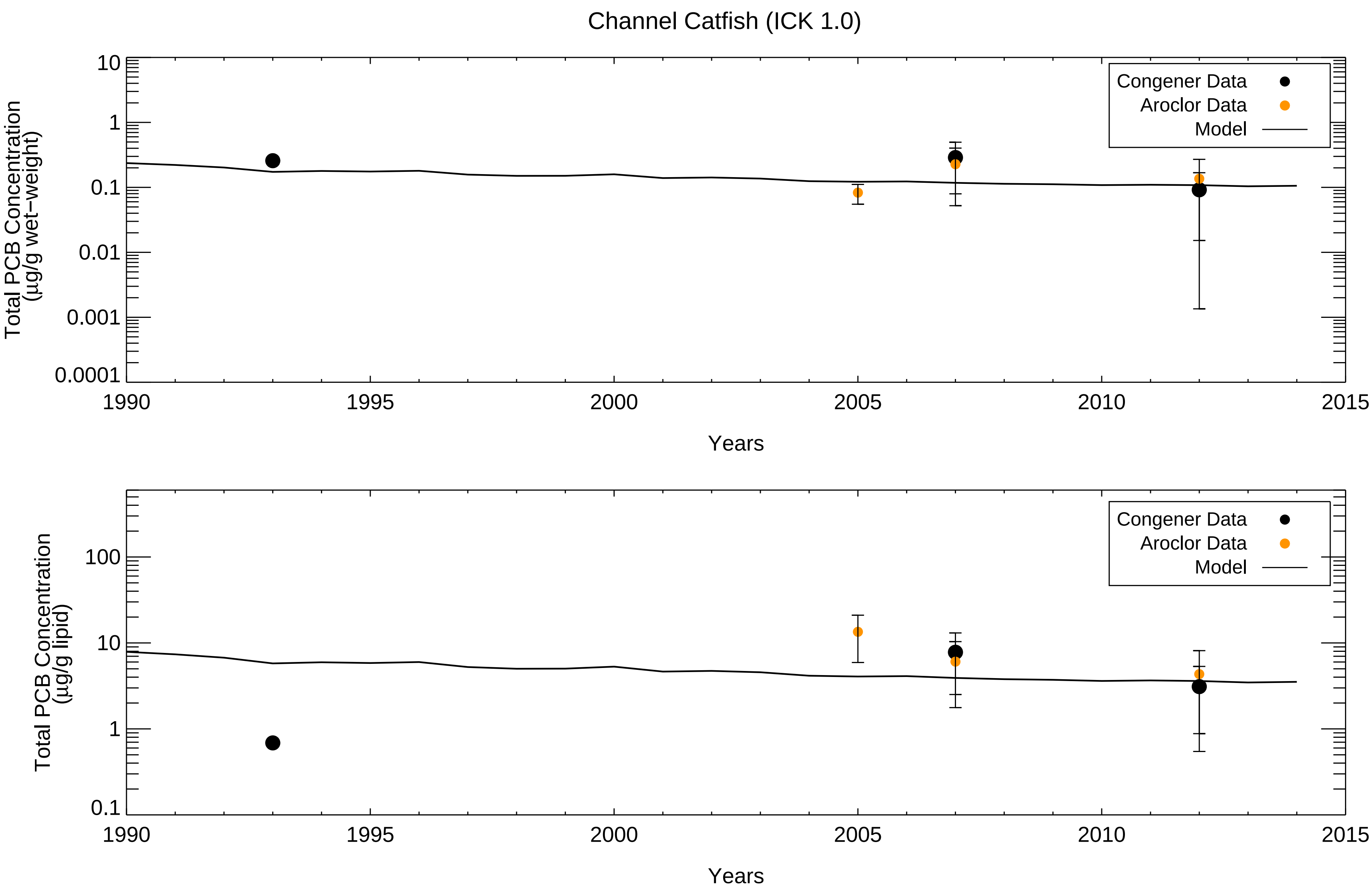

Figure 3−48b

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 1.0 for the Hindcast Simulation (Channel Catfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

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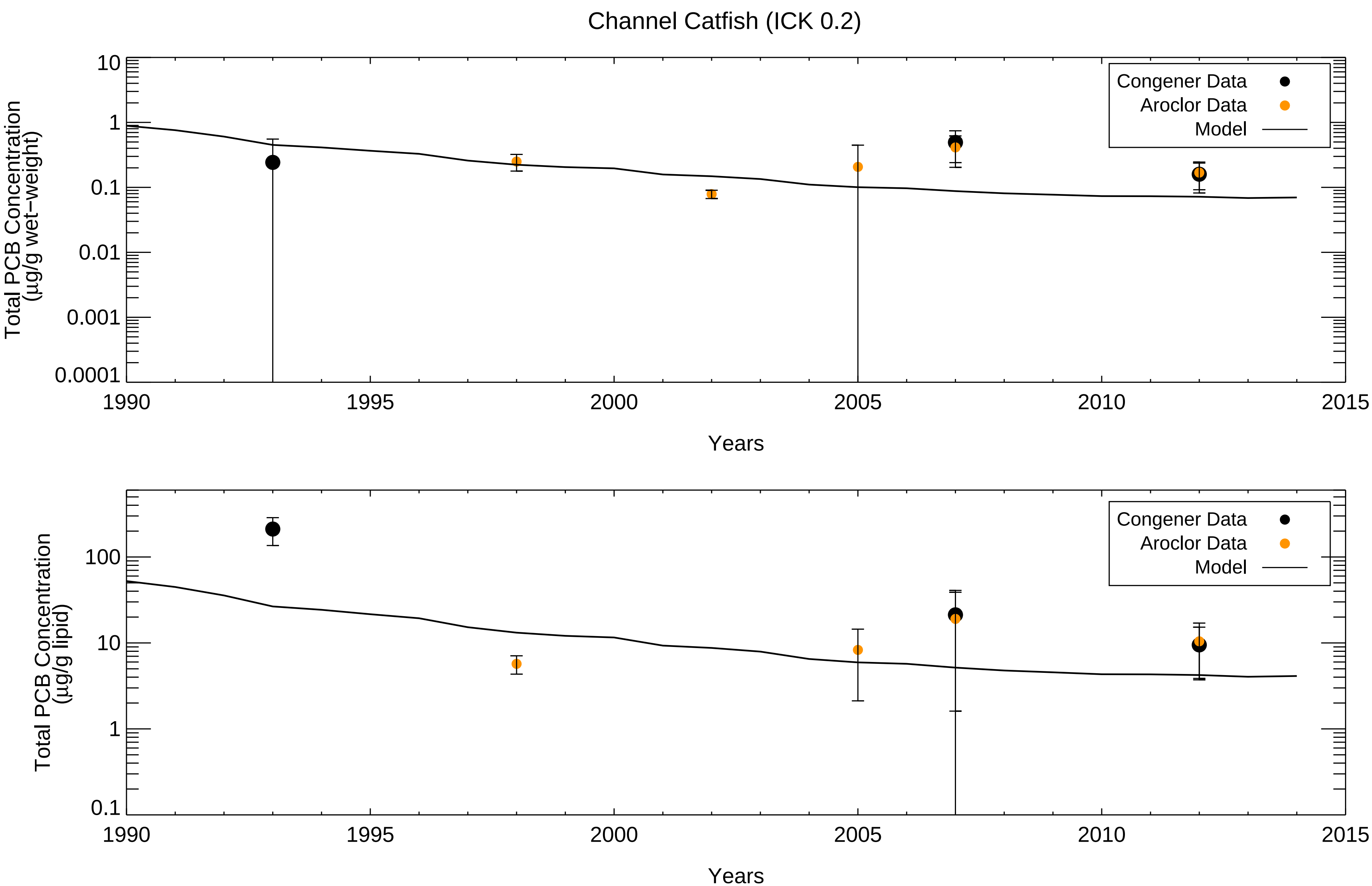

Figure 3−48c

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at ICK 0.2 for the Hindcast Simulation (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

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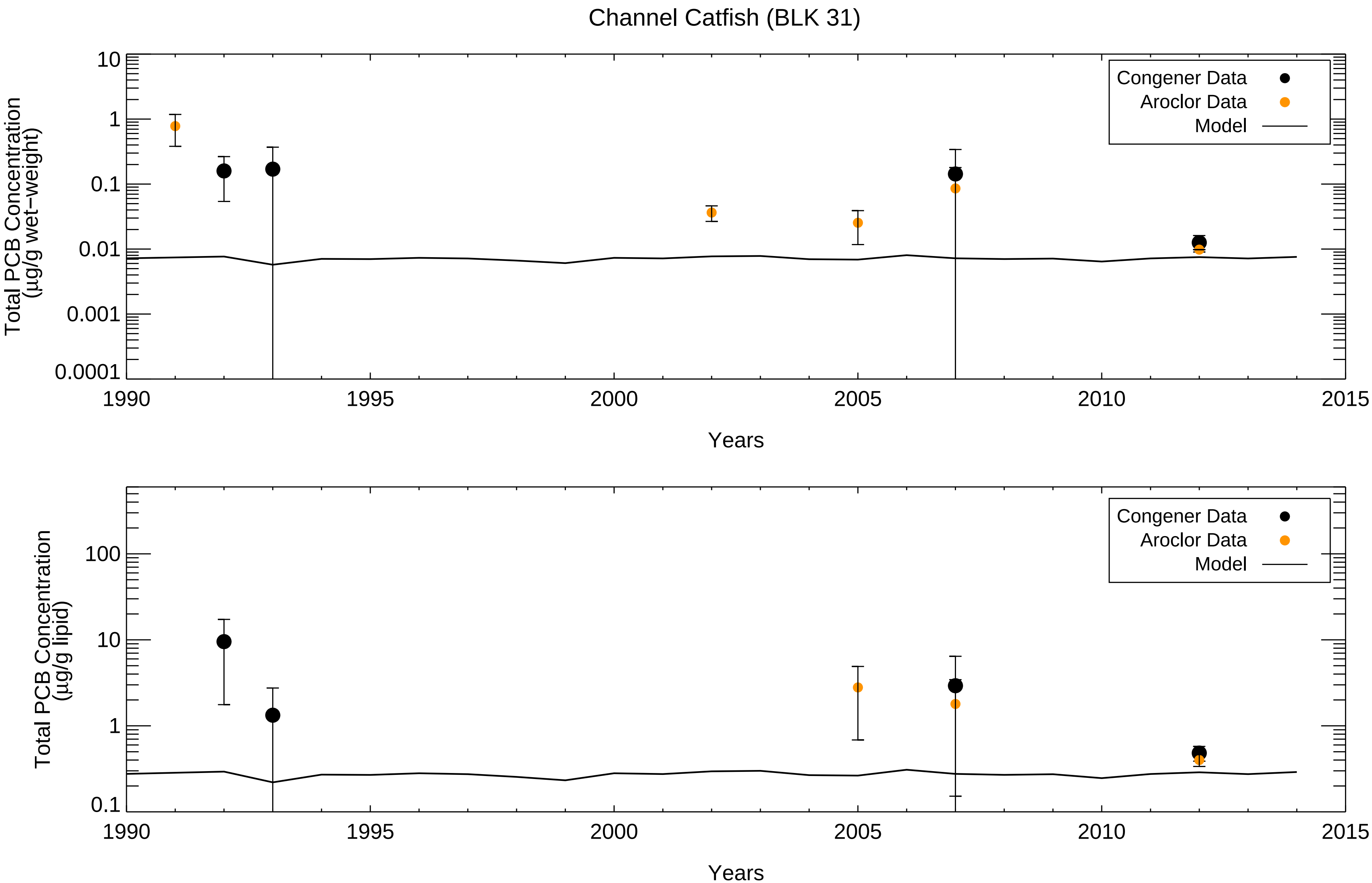

Figure 3−48d

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 31 for the Hindcast Simulation (Channel Catfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

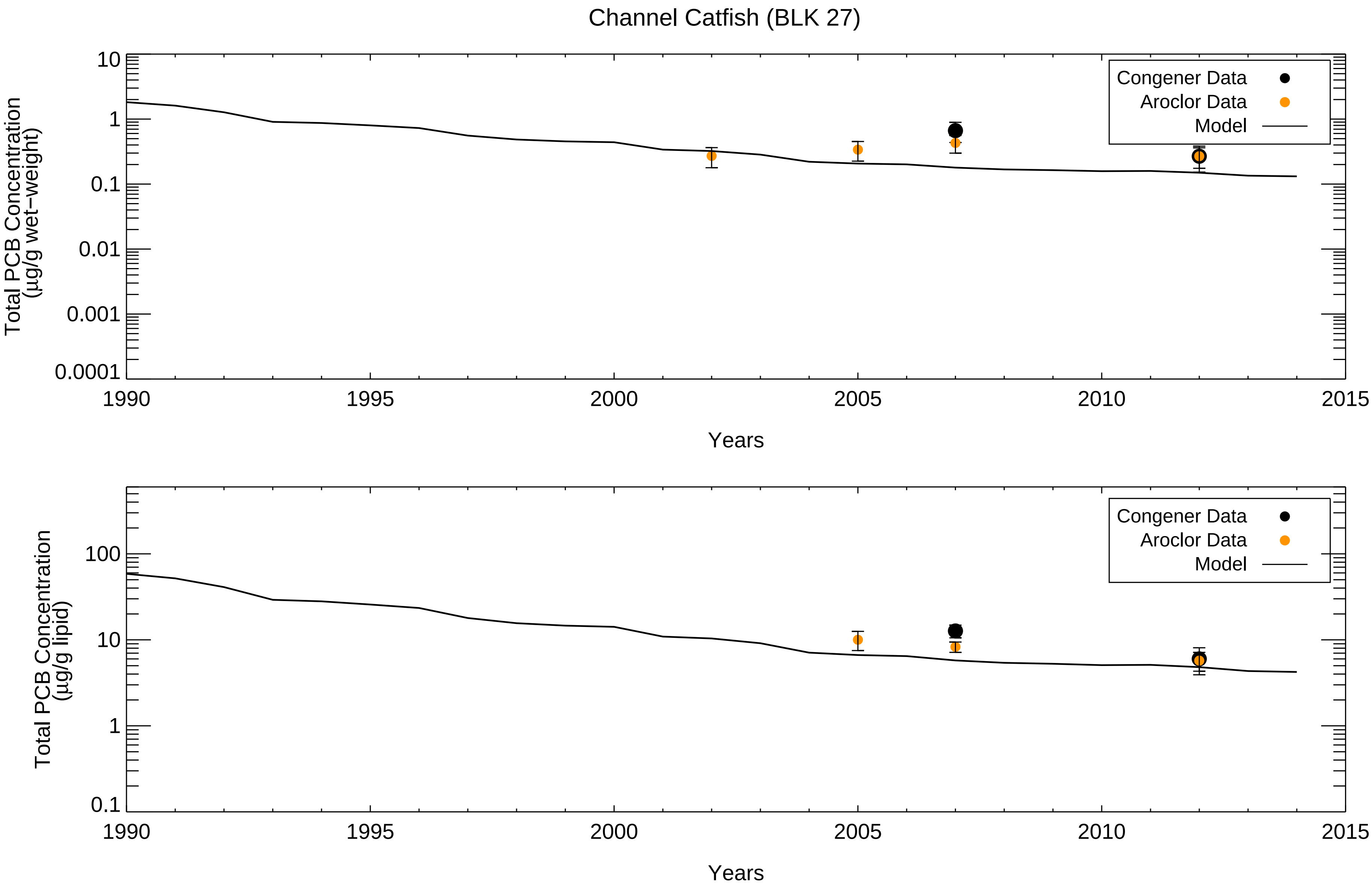

Figure 3−48e

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 27 for the Hindcast Simulation (Channel Catfish)

Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

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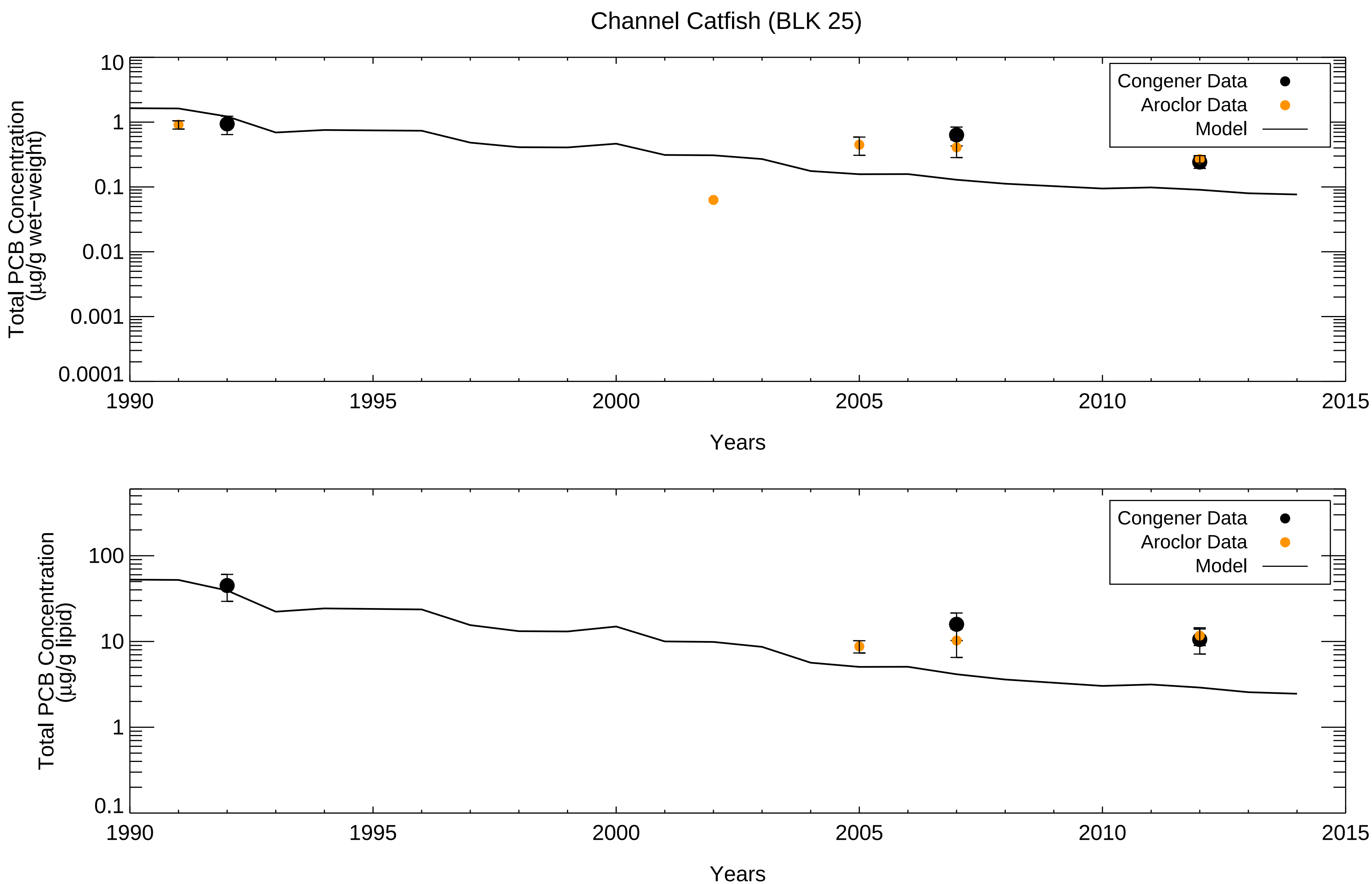


Figure 3−48f

Time Series of Model−predicted Fish Tissue PCB Concentrations and Data at BLK 25 for the Hindcast Simulation (Channel Catfish)

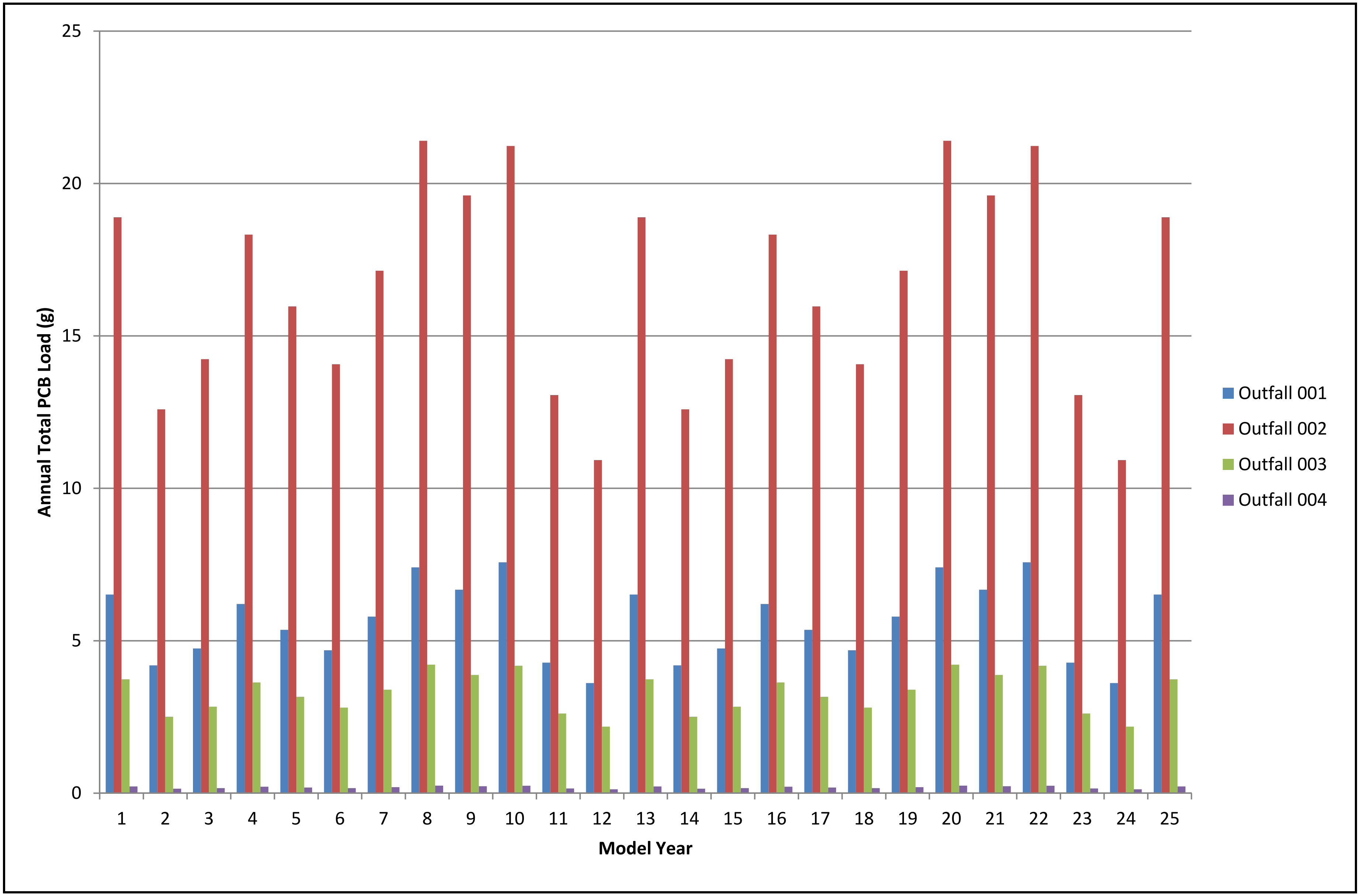
Final Report − Indian Creek/Blue River Fate and Transport Study

KCP/Honeywell FM&T

ANCHOR QEA

Notes: Non−detects are set to half detection limit. Points are arithmetic means +/− 2 standard errors.

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_temporal_model_data_comparison.pro Thu Jul 30 09:11:26 2015



ANCHOR QEA

Figure 3-49
Time Series of Outfall Total PCB Loads used for Simulation of Scenario #1
Final Report – Indian Creek/Blue River Fate and Transport Study KCP/Honeywell FM&T

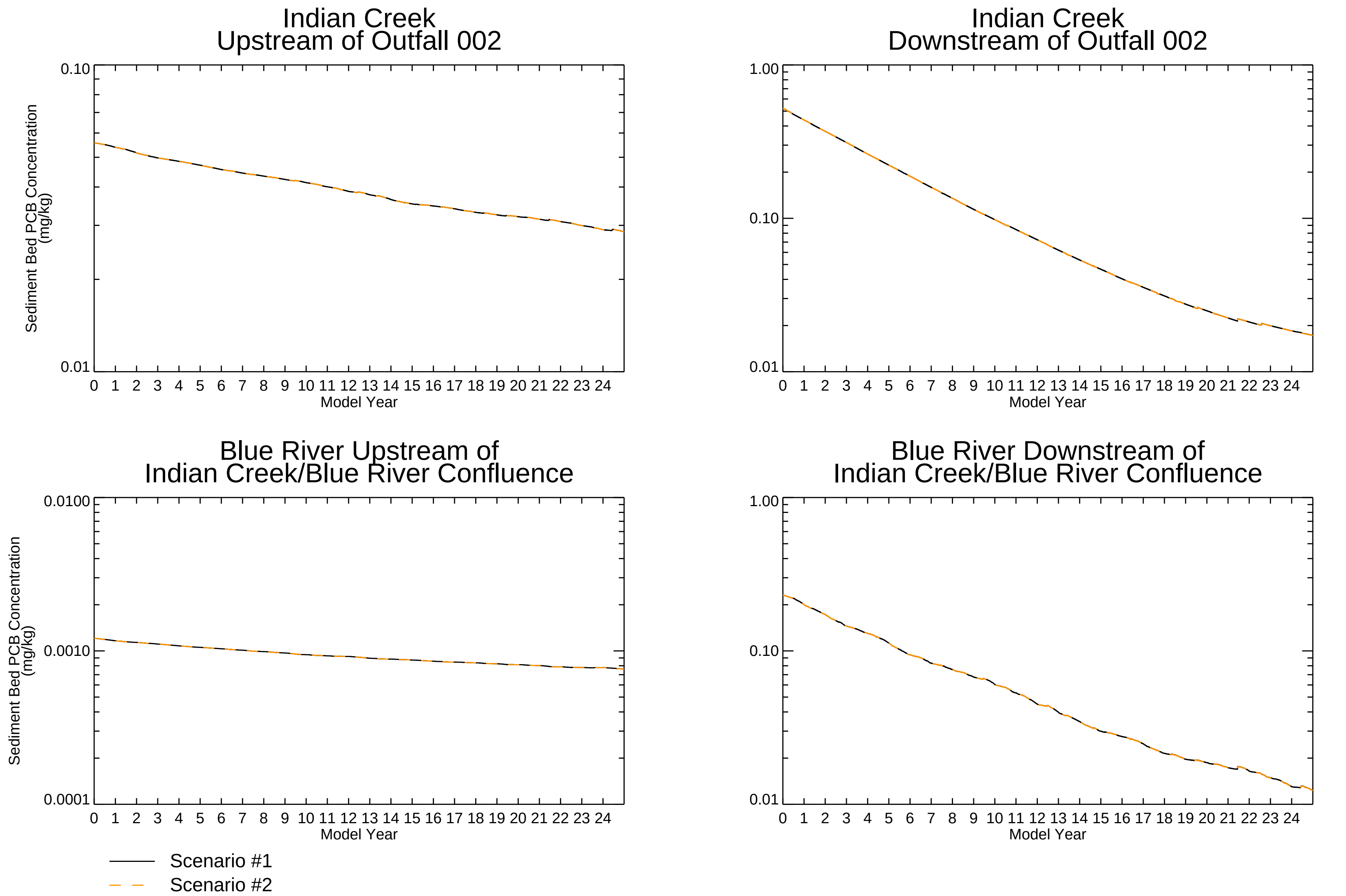


Figure 3-50

Time Series of Model-predicted Future Surface Sediment (0-4") PCB Concentrations by Reach
Final Report - Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

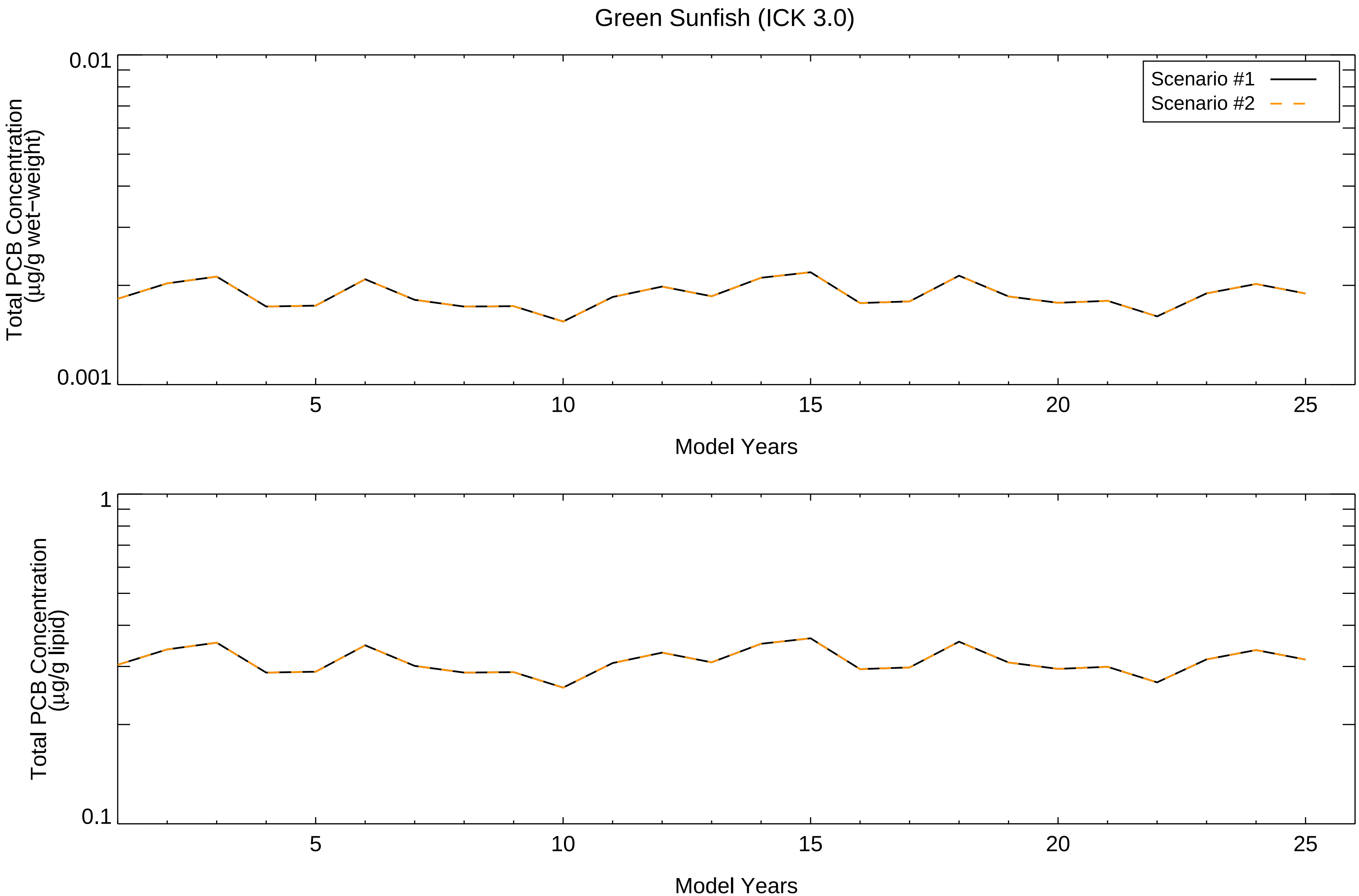


Figure 3−51a

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 3.0 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:30 2015

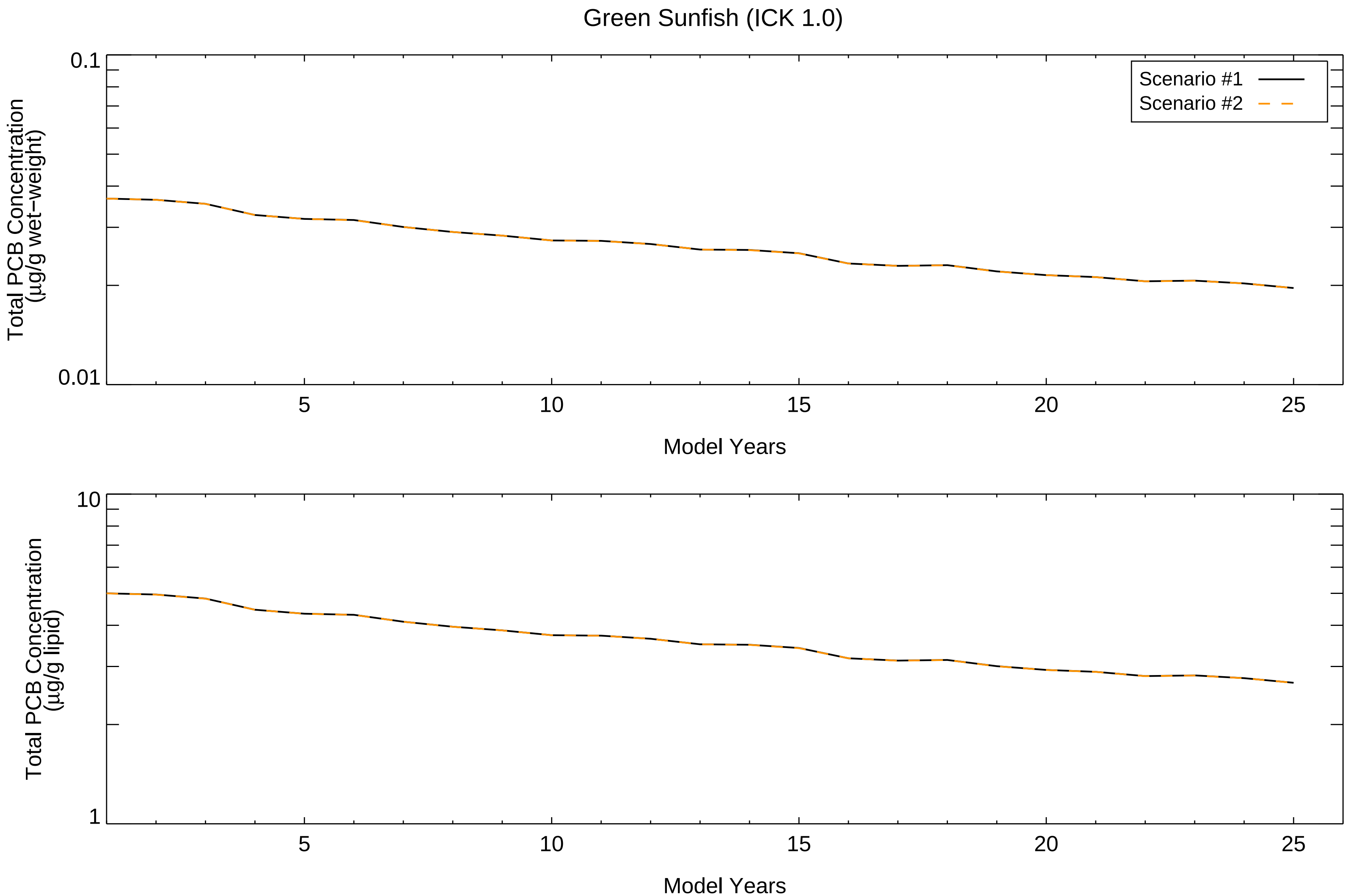


Figure 3−51b

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 1.0 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

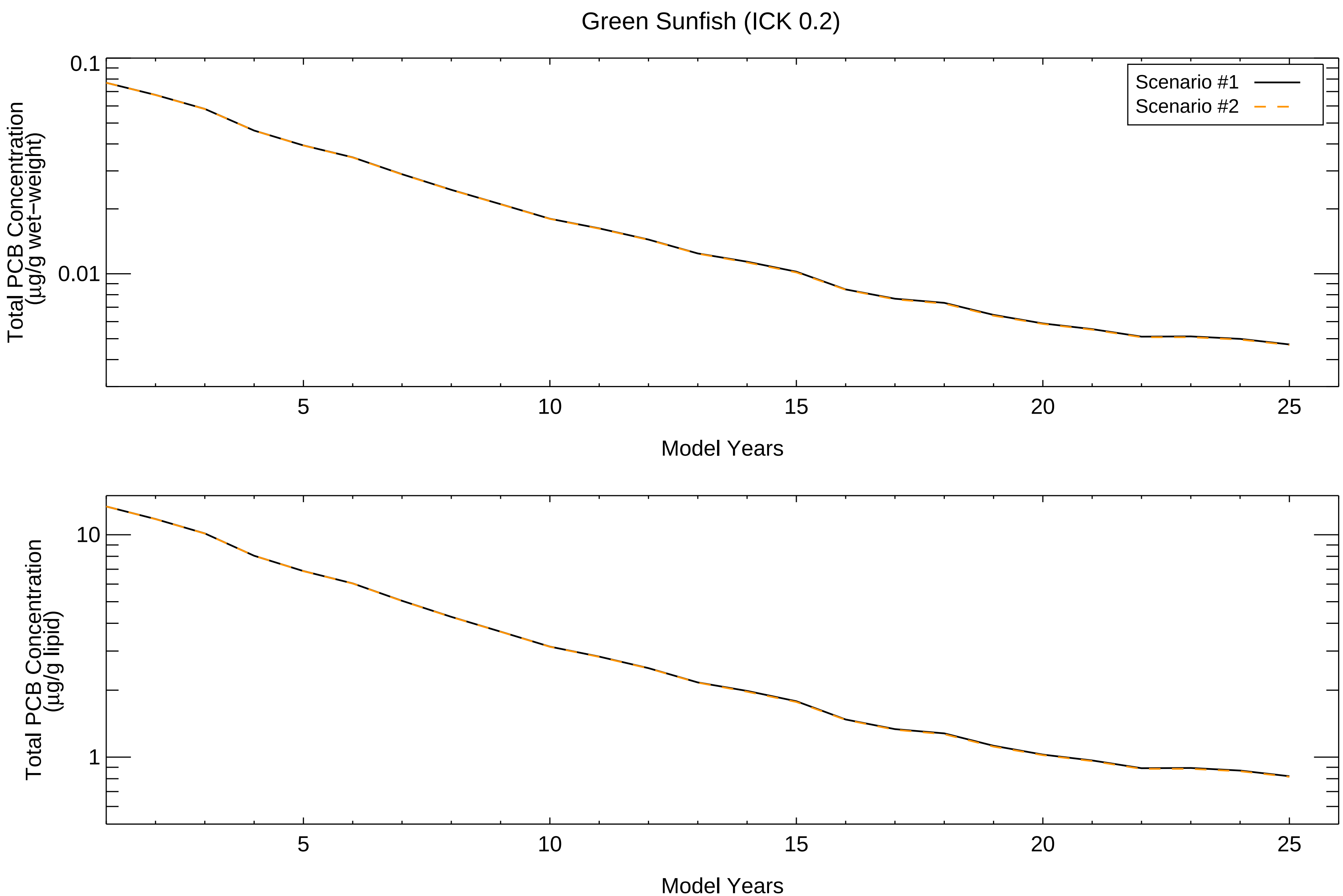


Figure 3−51c

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 0.2 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

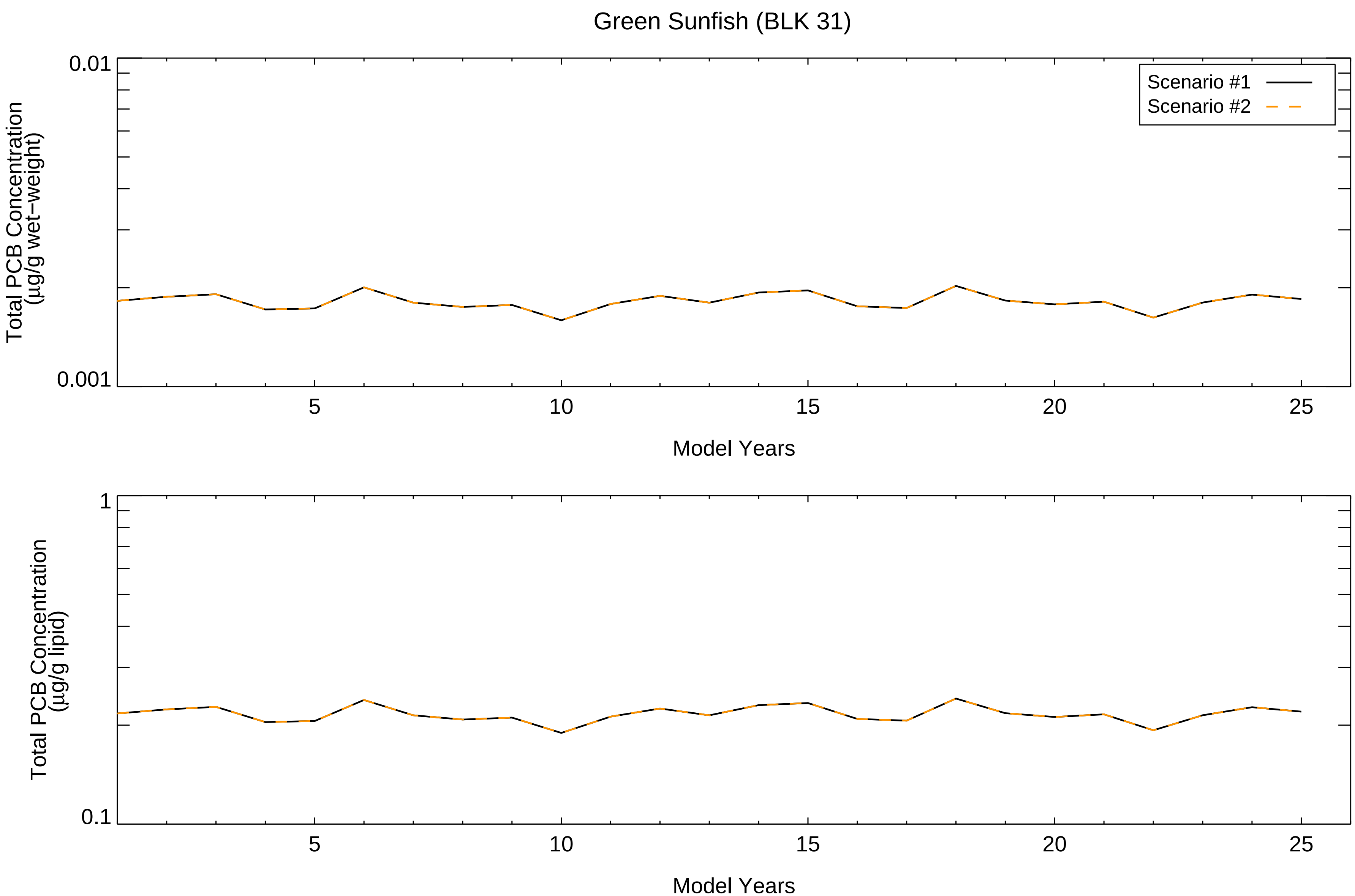


Figure 3−51d

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 31 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

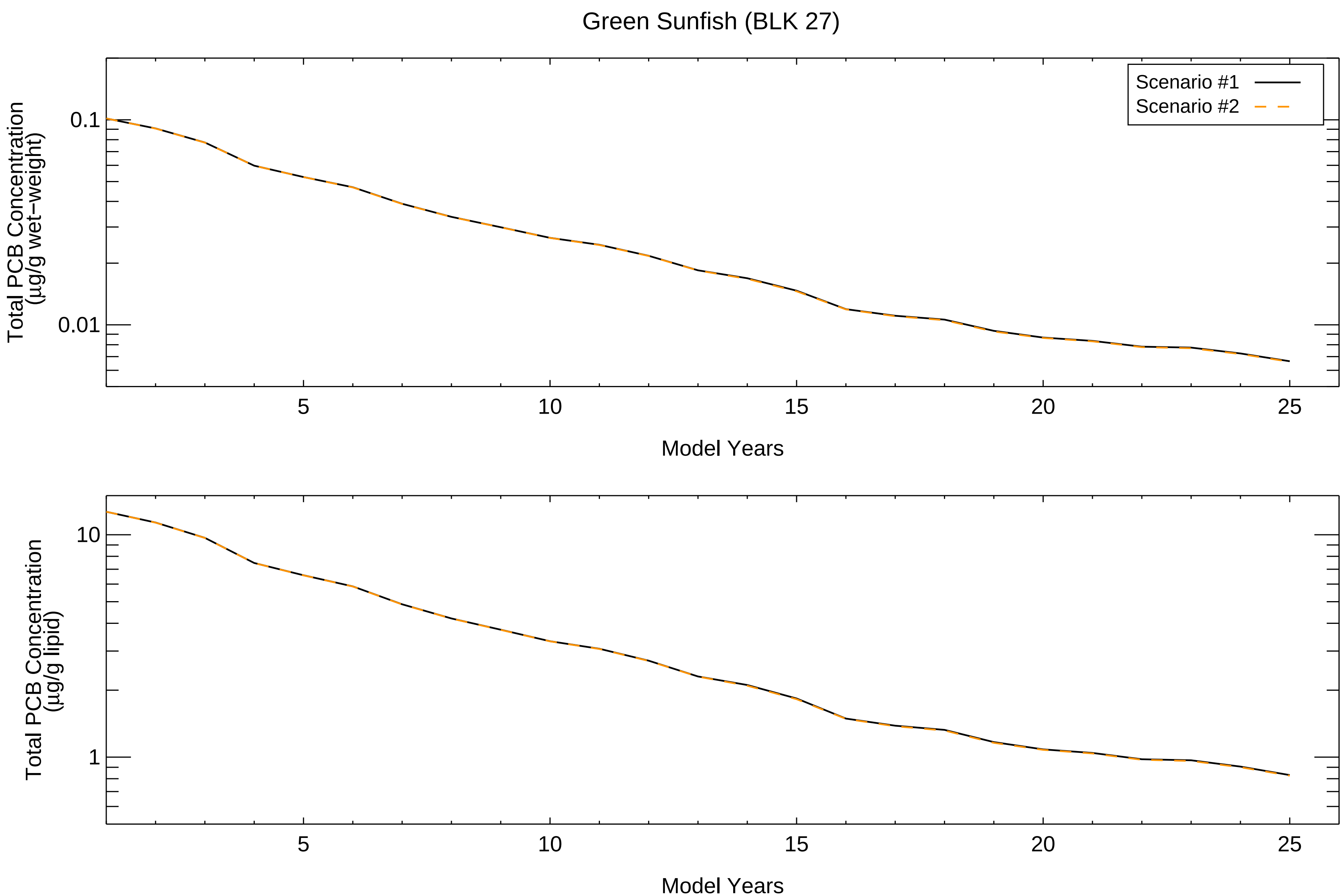


Figure 3−51e

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 27 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

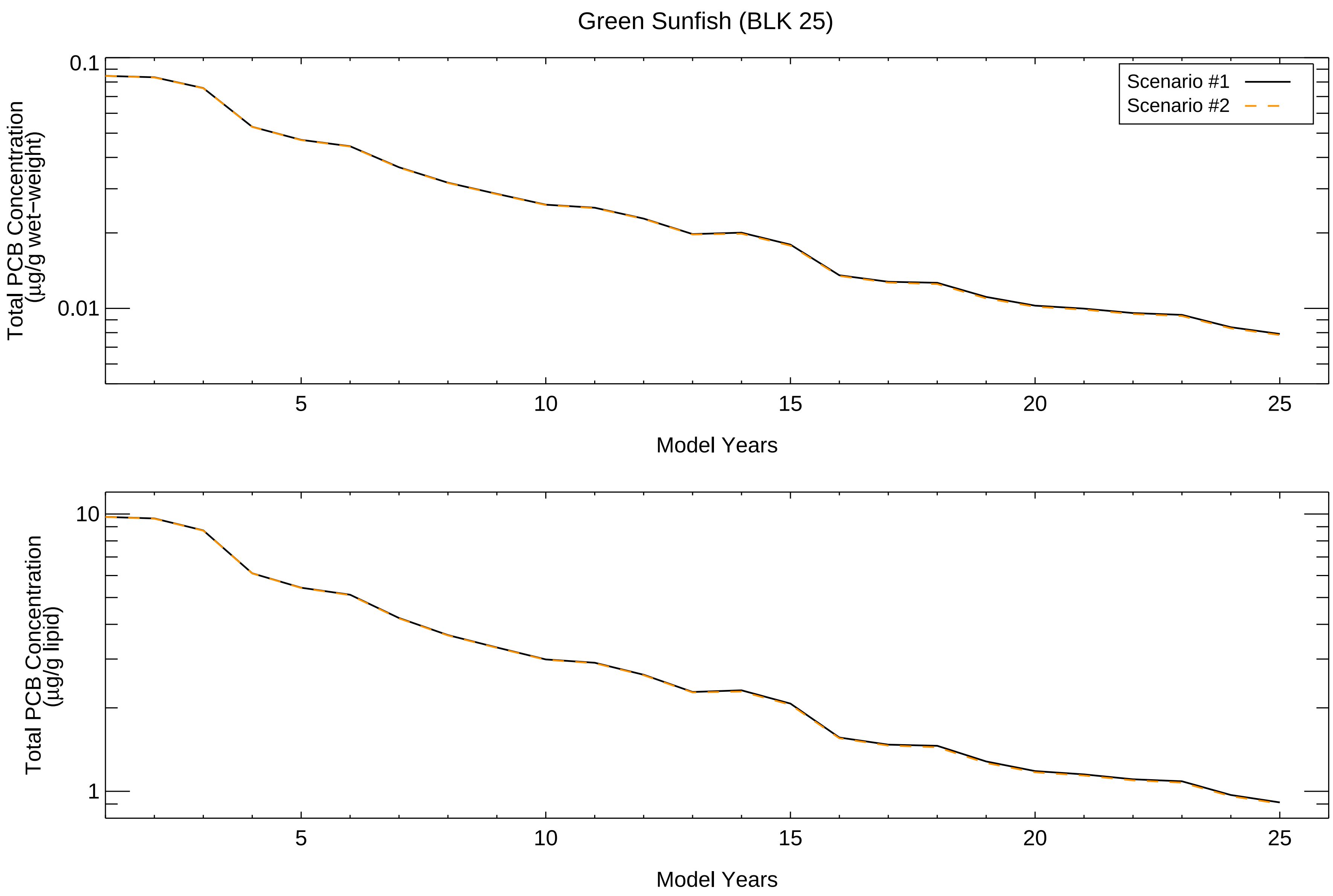


Figure 3−51f

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 25 (Green Sunfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

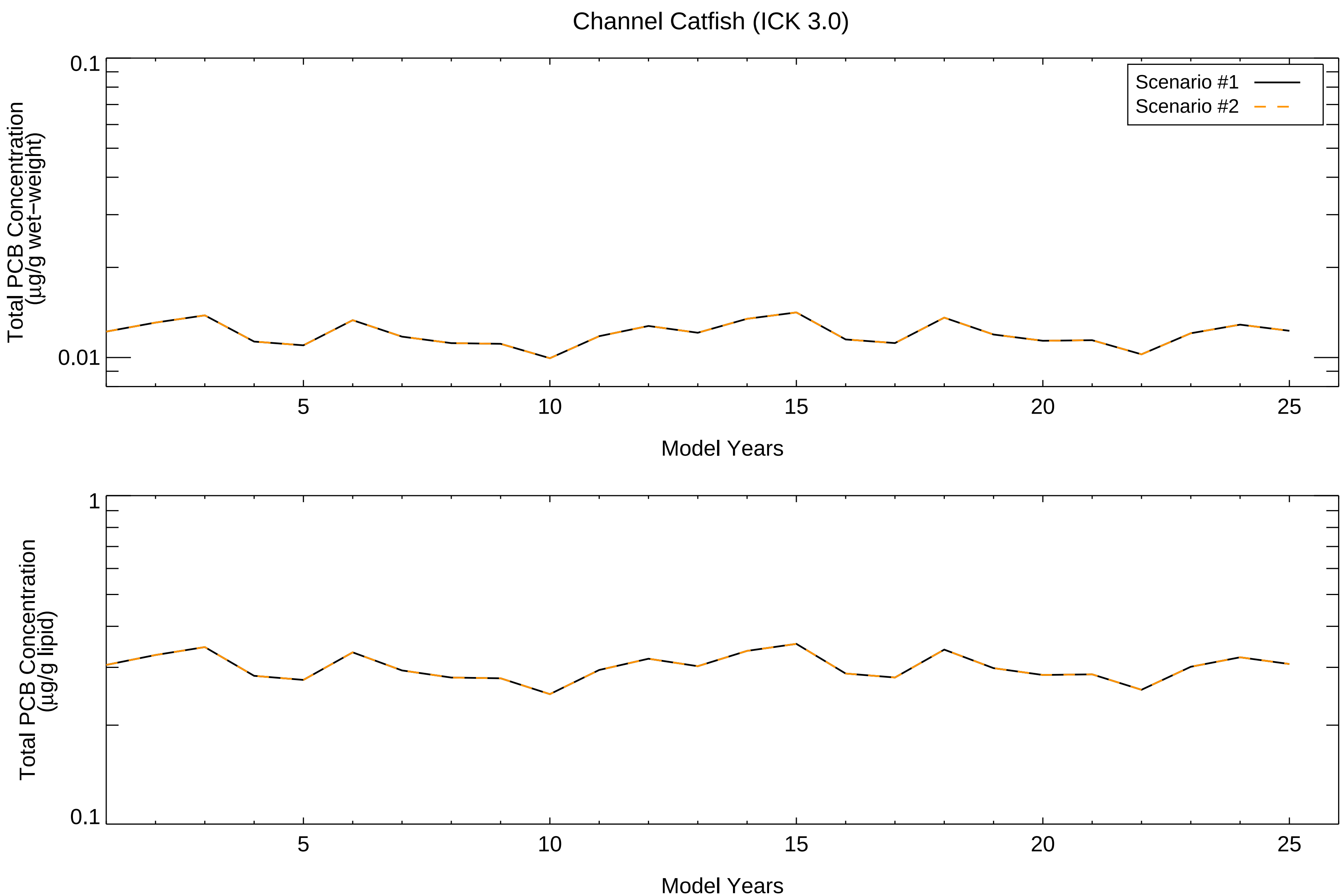


Figure 3−52a

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 3.0 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

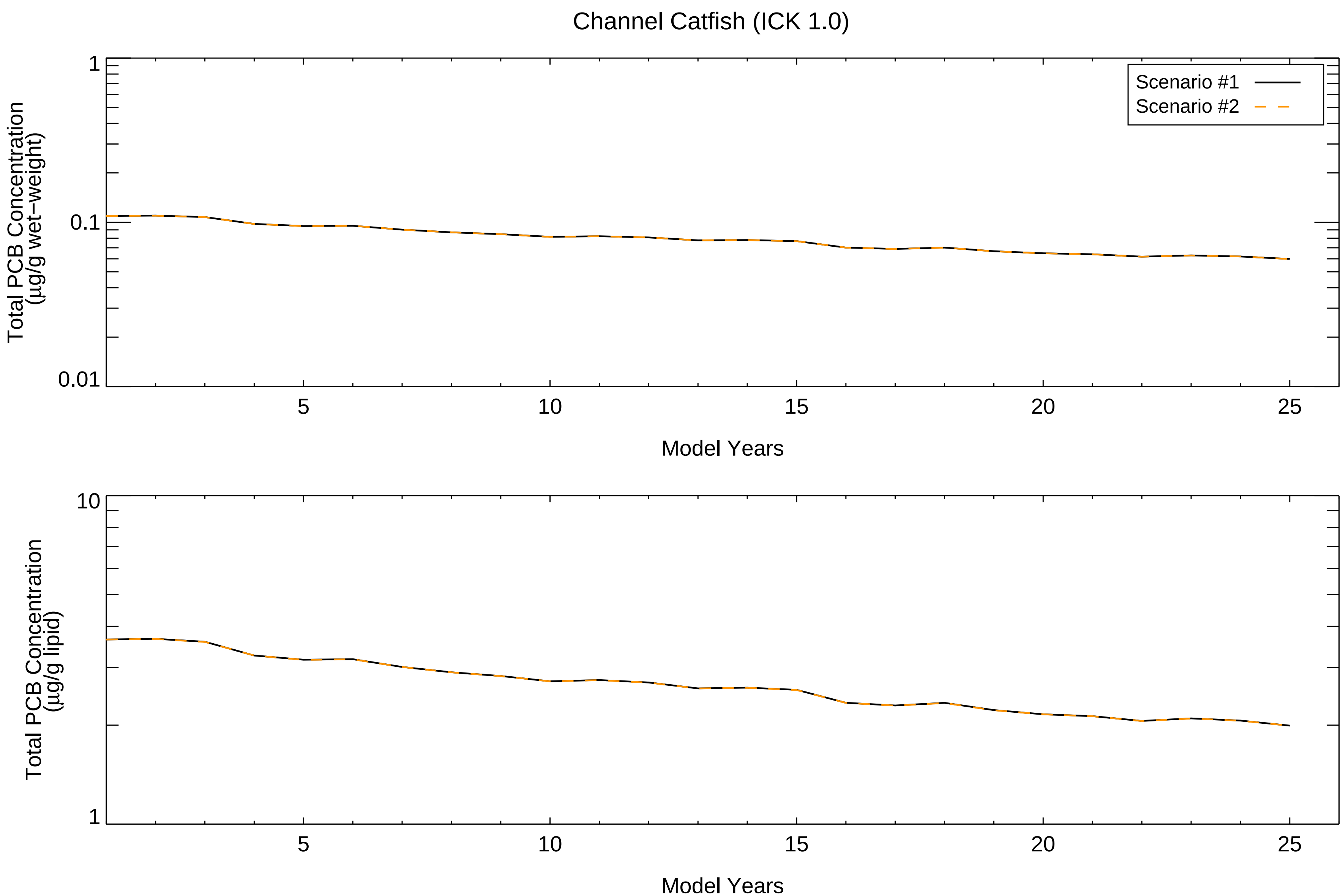


Figure 3−52b

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 1.0 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

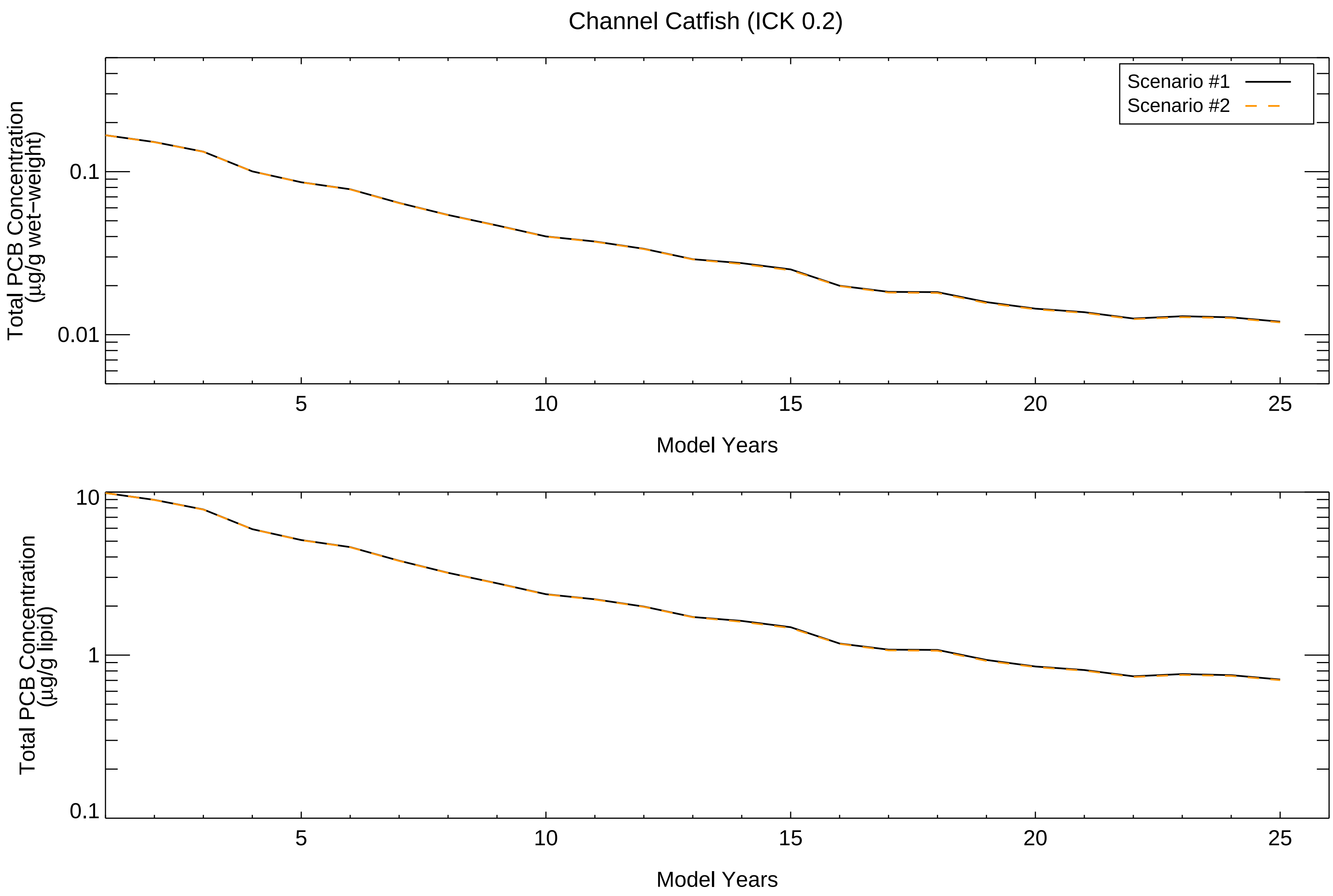


Figure 3−52c

Time Series of Model−predicted Future Fish Total PCB Concentrations at ICK 0.2 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

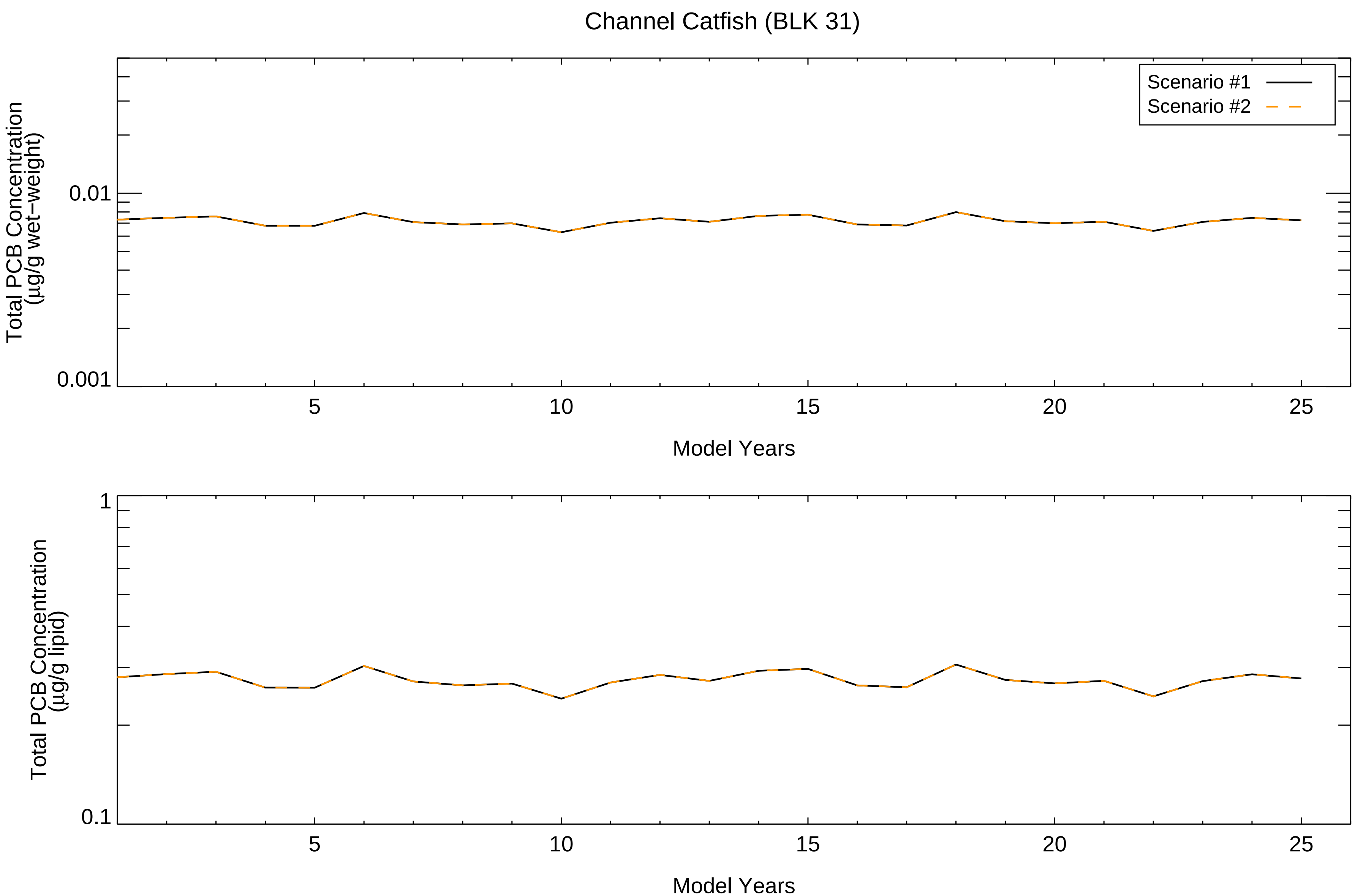


Figure 3−52d

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 31 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

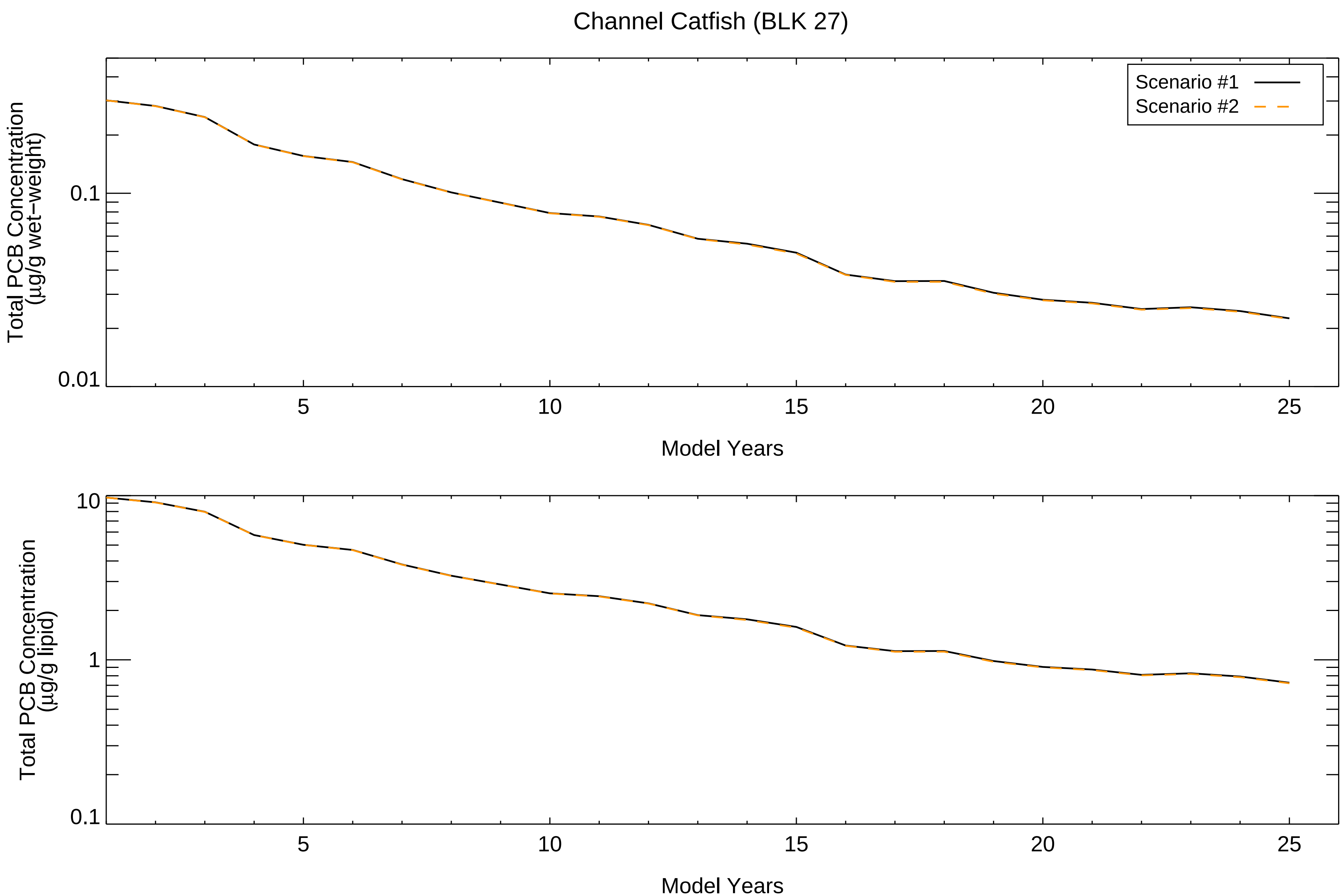


Figure 3−52e

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 27 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

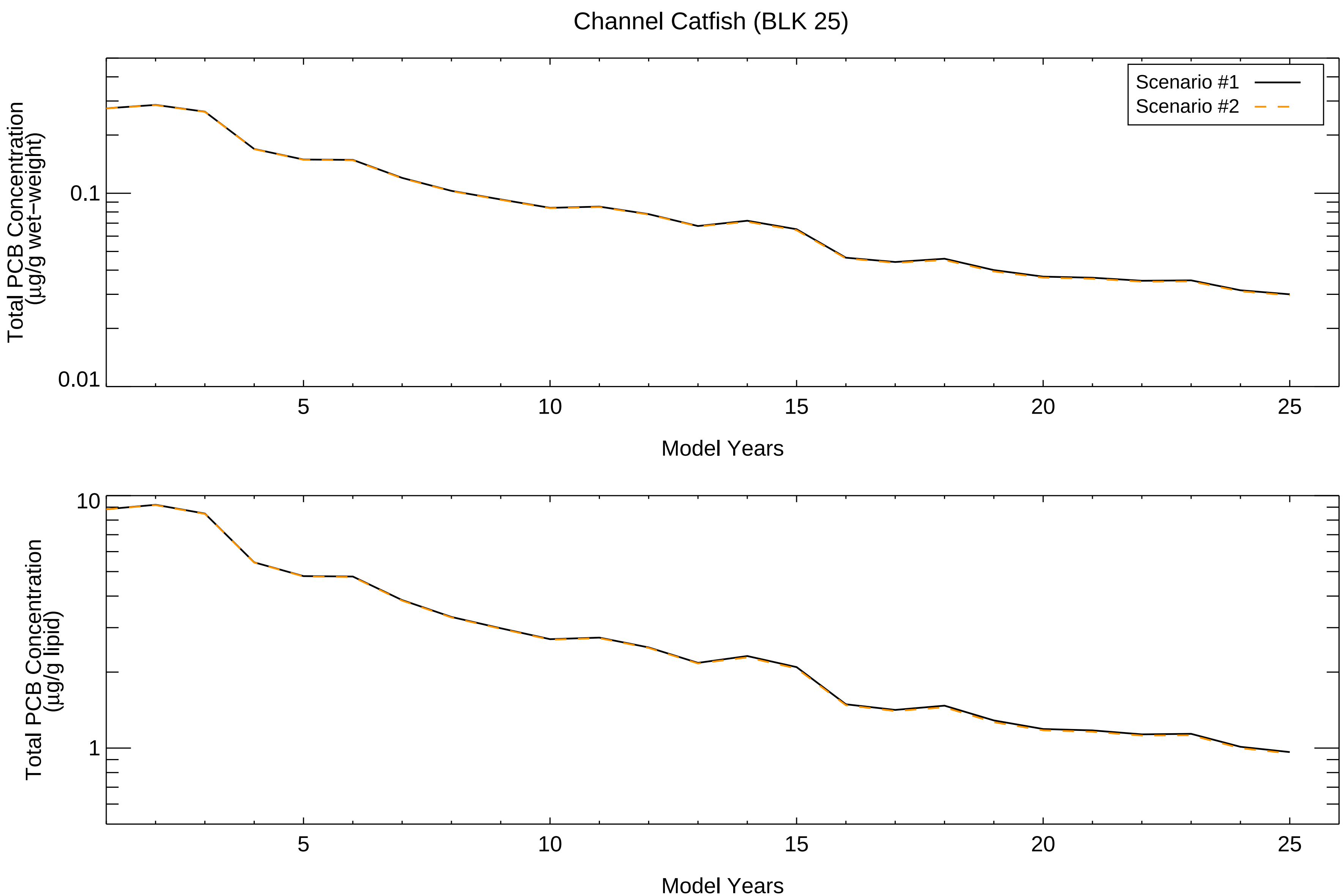


Figure 3−52f

Time Series of Model−predicted Future Fish Total PCB Concentrations at BLK 25 (Channel Catfish)
Final Report − Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

ANCHOR QEA

MM − \\nereus\D_Drive\Projects\Honeywell_FMT\Kansas_City_Plant(120287−03)\Model\Bioaccumulation\Plots\kcp_proj_temporal_model_data_comparison.pro Thu Jul 30 09:30:31 2015

APPENDIX A
DATA SUMMARY REPORT

Attachment 1 Laboratory Data Reports

Attachment 2 Data Validation Reports

Attachment 3 Electronic Copies of Final Project Analytical Database and Field Data Files

INDIAN CREEK/BLUE RIVER FATE AND TRANSPORT STUDY

DATA SUMMARY REPORT

Prepared for

U.S. Department of Energy

Kansas City Plant

Operated by Honeywell Federal Manufacturing & Technology

Prepared by

Anchor QEA, LLC

290 Elwood Davis Road, Suite 340

Liverpool, New York 13088

February 2016

TABLE OF CONTENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

µm	micrometer
ASTM	American Society for Testing and Materials
BFC	Bannister Federal Complex
DSR	Data Summary Report
EMPC	Estimated Maximum Potential Concentration
MS	matrix spike
MSD	matrix spike duplicate
NELAP	National Environmental Laboratory Accreditation Program
NFG	National Functional Guidelines
PCB	polychlorinated biphenyl
POC	particulate organic carbon
QC	quality control
RPD	relative percent difference
SAP	*Indian Creek/Blue River Fate and Transport Study Sampling and Analysis Plan*
TOC	total organic carbon
TSS	total suspended solids

1 INTRODUCTION

The *Indian Creek/Blue River Fate and Transport Study Final Work Plan* (Anchor QEA 2013a) identified a number of gaps in the understanding of PCB sources and sinks within the system. These data gaps were addressed through focused sampling and analysis of stormwater and stormwater solids from the Bannister Federal Complex (BFC), as well as water column, sediment, and bank soils from Indian Creek, Blue River, and Boone Creek. Specifically, this sampling was conducted to meet several data quality objectives:

- Stormwater sampling was conducted to characterize contemporary sources of PCBs in BFC stormwater, and provide additional data to develop PCB loading estimates to the receiving waters.
- In-stream sediment sampling and analysis was conducted to better understand the sediment exposure pathway to fish, and sediment-derived PCB loading to the overlying water column.
- Bank soil samples were collected and analyzed to better understand the potential for bank soils to contribute to the water column and sediment PCB load; visual observations indicated that portions of the streambanks are subject to periodic erosion.
- Water column sampling and analysis was conducted to further characterize water column PCB loads, and to quantify the impact of stormwater PCB loadings to the system.

These data collection programs were implemented during 2013 and 2014 consistent with the field and analytical procedures described in the *Indian Creek/Blue River Fate and Transport Study Sampling and Analysis Plan* (SAP; Anchor QEA 2013b). This Data Summary Report (DSR) provides a summary of the data collected, and a description of any deviation from the methods described in the SAP.

The remainder of this DSR is organized into the following four sections:

- Section 2 presents a summary of the various field investigations conducted for the Fate and Transport Study, including a brief summary of the field sample collection methods used, and the number of samples collected. This section also describes any deviation in sampling methods from those described in the SAP.

- Section 3 provides a summary of the laboratory analytical methods used to analyze the environmental samples, and laboratory quality control samples.
- Section 4 provides a summary of the data validation performed by Anchor QEA, LLC, on each of the chemical and physical datasets.
- Section 5 provides a summary of validated analytical results for the samples collected during the various sampling efforts, including relevant data qualifiers for each sample.

There are three attachments to this DSR, including the following:

- Attachment 1 contains laboratory analytical data reports.
- Attachment 2 contains four Data Validation Reports prepared by Anchor QEA that summarize the validation of the data described in Section 4.
- Attachment 3 contains electronic versions of the final project analytical database (in Microsoft Access format) and field data files (in Microsoft Excel format).

2 FIELD INVESTIGATION SUMMARY

This section provides a summary of stormwater and in-stream water column, sediment, and streambank soil sampling conducted between September 2013 and October 2014. Samples were collected in accordance with the methods described in the SAP, except as otherwise noted in the following subsections.

2.1 Phase 1 Stormwater Solids Sampling

Pavement, roof, and catch basin solids samples were collected using a high-powered, backpack-type commercial vacuum cleaner (ProTeam MegaVac). Prior to sample collection, the limits of the sample collection area were marked (with nails and high-visibility cord in pavement areas, and spray paint in roof areas) to delineate the sampling area. Figure 2-1 shows sample collection at typical roof (top panel), pavement (middle panel), and catch basin (bottom panel) locations, including demarcation of the sampling area. The roof and pavement sampling areas were vacuumed in a systematic manner using the aluminum wand and floor tool. Within catch basins, a depth-integrated sample of the accumulated sediments was collected using the aluminum straight wand section of the sampling device to push through and vacuum up the accumulated sediments. The vacuum filter bag was then removed from the vacuum and placed in a sample jar for shipment to the analytical laboratory.

Some of the target sampling locations shown on Figure 2-1 of the SAP were refined based on field conditions (as anticipated in Section 2.1.2 of the SAP). Many of the target locations had insufficient solids or difficult access that necessitated the selection of alternative sampling locations. Also, at three of the catch basin locations (SZA-1, SZA-2, and SZC-2), insufficient solids and/or access issues made it necessary to collect a sample from the pavement in the vicinity of the catch basin rather than from the bottom of the catch basin itself. Actual sample collection locations are shown on Figure 2-2. The number of samples collected was consistent with that described in the SAP (18 locations [two from each of the three zones in the pavement, roof, and catch basins], plus one field duplicate).

Each sample was assigned a unique alphanumeric identifier using a "Location Type and Zone-Location Number-Sample Type-Date" format. The first character of the location ID indicated if the sample is a pavement (P), roof (R), or storm sewer catch basin (S). The next two characters represented the sampling zone (ZA, ZB, or ZC) as defined in Section 2.1.2 of the SAP. The next character identifies the unique location number (1 or 2 because two samples were collected from each zone). The sample type for this program was always (STS) for "stormwater solids," and the sample collection date was appended to the end of the sample ID in YYMMDD format.

At the analytical laboratory, the filter bags containing each sample were dried and then the contents were sieved into three size fractions (<62.5 micrometers [μm], 62.5-250 μm, and >250 μm). These three fractions and the bulk sample were submitted for analysis of PCBs (Method 1668A) and total organic carbon (TOC; Lloyd Kahn).

2.2 Phase 2 Stormwater Sampling

The Phase 2 stormwater sampling program included sample collection at 12 locations within the BFC storm sewer system (three in Basin 001, four in Basin 002, two in Basin 003, two in Basin 004, and one at Outfall D; see Figure 2-3 for sample collection locations). Two types of samples were collected at each location—composite stormwater and sediment trap samples.

Composite Water Samples

Composite stormwater PCB samples (and flows) were collected at 12 locations during two storm events. Sampling was conducted on August 6 to 7, 2014 (total rainfall of 2.8 inches) and October 1 to 2, 2014 (total rainfall of 3.4 inches). Composite stormwater samples were collected using Teledyne/Isco (Isco) 6700 series automatic samplers. A pre-determined volume of stormwater was collected at regular intervals depending on the anticipated duration of the storm being sampled. For example, for an anticipated 3-hour event, the samplers were pre-programmed to collect 750 milliliters every 15 minutes. At the conclusion of each sampling event, sample bottles from the Isco sampler were retrieved and sealed with Teflon-lined caps, and then labeled and packaged appropriately for transportation to a field laboratory. At the field laboratory, samples were combined into a single volume-weighted composite and prepared for transport to the analytical laboratory for analysis of PCBs (Method 1668A), total suspended solids (TSS; SM 2540D), and TOC (SM

5310B). Following each event, the sampling team also downloaded the sampling report and flow data from the data logger using an Isco 581 Rapid Transfer Device.

Each sample was assigned a unique alphanumeric identifier using a "Location ID-Date" format. The location ID corresponds to the Phase 2 sample location ID shown on Figure 2-3. The sample collection date was appended to the end of the sample ID in YYMMDD format.

Sediment Trap Samples

Sediment traps were deployed at 11 of the 12 locations shown on Figure 2-3 for approximately 3 months (June 24 to September 30, 2014).[1] Based on the type of sediment observed within the BFC storm sewer system (i.e., predominantly coarse roof sands), a sediment trap design known as a Hamlin sampler (developed by Ted Hamlin with Washington State Department of Ecology; Figure 2-4) was selected for this sampling program. This type of sampler is an in-line sampler that is installed in the bottom of a storm sewer pipe; any solids entrained in stormwater that pass over the top of the sampler are trapped and retained. Additional details on the Hamlin sampler (and other type of in-line sediment traps) are provided in Lubliner (2012).

At the conclusion of the approximate 3-month deployment period, the sediment traps were retrieved, and the entire contents of the samplers (including any overlying water) were transferred to sample jars for shipment to the analytical laboratory (Figure 2-5 shows a disassembled trap after deployment, and sample jars after transfer). Note that the transfer from the sampler to the sample jars was completed at the deployment location to avoid loss of the overlying water. Prior to analysis, samples were allowed to settle for a minimum of 24 hours to allow fine sediment particles in suspension to settle out. After settling, the overlying water in the sample jars was syphoned from the sampling container and discarded. The resulting sediment samples were then dried, sieved into three size fractions (<62.5 µm, 62.5-250 µm, and >250 µm) and submitted for analysis of PCBs (Method 1668A) and TOC (Lloyd Kahn).

[1] A sediment trap could not be installed at location OF004-01 due to a large accumulation of sediment in the pipe at this location. Instead, a sample of the accumulated sediment was collected and submitted for analysis.

Each sample was assigned a unique alphanumeric identifier using a "Location ID-Sample Type-Date" format. The location ID corresponds to the Phase 2 sample locations shown on Figure 2-3. The sample type for this program was always (TRAP), and the sample collection date was appended to the end of the sample ID in YYMMDD format.

2.3 Receiving Water Sampling

2.3.1 Surface Sediment Sampling

Sediments collected in Indian Creek, Blue River, and Boone Creek were composited over 29 pre-defined reaches (see Figure 2-16 of the *Indian Creek/Blue River Fate and Transport Study Draft Final Report* [Anchor QEA 2015]). Prior to selection of discrete sediment sampling locations within each compositing reach, extensive sediment probing was conducted to qualitatively characterize sediment properties including sediment thickness and texture, as well as water depth, throughout the streams. A sharpened 0.5-inch-diameter steel rod marked in 6-inch intervals (or equivalent) was used to probe the sediment to determine the sediment thickness and type. The probe was advanced into the riverbed, and the depth of penetration and type of resistance met by the probe, if any, was noted. The approximate maximum sediment thickness and estimated sediment type (e.g., rock, fine-grained, or coarse-grained) and GPS coordinates of the probing location were recorded in the field log. Figure 2-6 shows probing locations in Indian Creek, Blue River, and Boone Creek. In summary, a total of 620 stream locations were probed (357 in Blue River, 194 in Indian Creek, and 69 in Boone Creek). Sediment probing indicated that most sediments in Indian Creek and Blue River are relatively coarse, but contain a mixture of gravels, sands, and silt. Average probing depth was relatively shallow in both streams (less than 6 inches), although some limited areas contained sediment deposits that were 12 to 24 inches thick. In Boone Creek, probing depth upstream of reach BC-5 was generally consistent with Indian Creek and Blue River; however, probing depth in reaches BC-5 and BC-6 was considerably greater (averaging more than 20 inches) and sediments consisted predominantly of fine silts and organic material. A summary of average, median, and maximum probing depths is provided in Table 2-1. A Microsoft Excel spreadsheet containing the probing data is included in Attachment 3.

Table 2-1
Summary of Probing Depth

Reach	Number of Probes	Probing Depth (inches)		
		Maximum	Median	Average
Indian Creek	194	24	3	4
Blue River (upstream of Indian Creek)	130	24	3	4
Blue River (downstream of Indian Creek)	227	27	4	5
Boone Creek	69	31	6	9

Based on the results of the sediment probing, five discrete locations (on average) within each of the 29 sampling compositing reaches were identified for sediment sample collection.[2] Collection of sediment in most reaches was not possible using a ponar-type grab sampler (as prescribed in the SAP) due to the relatively coarse nature of the sediments. Instead, a decontaminated stainless-steel trowel was used to obtain surface sediments (approximately the top 2 inches) at each location. Sediments collected at each discrete location were placed in individual aluminum pans—a composite sediment sample was then created for each reach by combining equal weights of the individual sediment samples, homogenizing, and then transferring the necessary sample mass to clean, laboratory-approved containers. Samples were submitted to the laboratory for analysis of PCB (Method 1668A), TOC (Lloyd Kahn), grain size distribution (American Society for Testing and Materials [ASTM] D422), bulk density (ASTM 5057), and percent moisture (ASTM D2974). A total of 29 composite samples were collected and submitted for analysis (consistent with the SAP), plus one field duplicate.

In addition to the stream sediment samples, discrete surface (0 to 2 inches) soil samples were collected from the open channel that flows through the former landfill area (between BFC Outfall D and Blue River).

Each sample was assigned a unique alphanumeric identifier using a "Composite Reach ID-Sample Type-Date" format. The composite reach IDs correspond to those identified in the SAP (also shown on Figure 2-16 of Anchor QEA 2015). Composite Reach IDs for the four former landfill channel samples were FLF-1 through FLF-4. The sample type for composite

[2] Only two to four discrete samples were collected in some reaches due to a lack of sediment deposits.

sediment sampling program was always (CSED), and the sample collection date was appended to the end of the sample ID in YYMMDD format.

2.3.2 Bank Soil Sampling

A visual survey of the streambanks within each compositing reach was conducted (at the same time as sediment probing described in Section 2.3.1) to identify areas subject to erosion. Out of the 29 compositing reaches in Indian Creek, Blue River, and Boone Creek identified in the SAP, 13 had observable bank erosion (seven in Blue River [BR-2, -3, -4, -6, -8, -9, and -15], five in Indian Creek [IC-1, -2, -3, -4, and -6], and one in Boone Creek [BC-4]). Eroding banks were sampled concurrently with the stream sediment sampling in each reach. Consistent with the methods used for sediment sample collection, discrete bank soil samples were collected using a decontaminated stainless-steel trowel to a depth of approximately 2 inches, and placed into individual aluminum pans. Composite samples were then created for each reach by combining equal weights of the individual bank soil samples, homogenizing, and then transferring the necessary sample mass to clean, laboratory-approved containers. Samples were submitted to the laboratory for analysis of PCB (Method 1668A), TOC (Lloyd Kahn), grain size distribution (ASTM D422), bulk density (ASTM 5057), and percent moisture (ASTM D2974). A total of 13 composite bank soil samples were collected and submitted for analysis.

Sample IDs for composite bank soil samples were similar to the composite sediment samples described above, except the sample type for these samples was (CBNK).

2.3.3 Water Column Sampling

Consistent with the SAP, water column samples were collected at all 14 locations shown on Figure 2-11 of Anchor QEA 2015 (five in Indian Creek, seven in Blue River, and two in Boone Creek). Water samples were collected during six events (four during low-flow conditions, and two during higher flow conditions when the outfalls were flowing; Table 2-2).

Table 2-2
Sampling Dates and Flow Rates during Six Water Column Sampling Events

Flow Condition	Sampling Round	Sampling Period	Average Flow Rate (cfs)[1]
Low	1	September 9 and 10, 2013	25
	2	July 14 and 15, 2014	89
	3	August 28 and 29, 2014	40
	4	September 22 and 23, 2014	34
High	1	August 7 and 8, 2014	780
	2	October 2 and 3, 2014	1,068

Notes:
1 Daily average flow from U.S. Geological Survey gauge at Blue River (#06893500)
cfs = cubic feet per second

Water samples were collected by lowering a closed collection container (1-liter amber bottle or similar) into the water column with the nozzle pointed upstream. Once at approximate mid-depth, the cap was removed and the collection container was allowed to fill. Samples were then transferred from the collection container to sample bottles supplied by the laboratory. Because the total volume of water required for analysis exceeded the size of the sample collection container, the water collected was evenly distributed to each of the sample bottles. A total of 84 water column samples (14 locations times six events), plus six field duplicates (one per event) were submitted to the laboratory for analysis of PCBs (Method 1668A), TSS (SM 2540D), TOC (SM 5310B), and particulate organic carbon (POC; SM 5310B).

Each sample was assigned a unique alphanumeric identifier using a “Location ID-Sample Type-Date” format. The location IDs correspond to those identified in the SAP (also shown on Figure 2-11 of Anchor QEA 2015). The sample type for the surface water sampling program was (SW), and the sample collection date was appended to the end of the sample ID in YYMMDD format.

In addition to collection of water samples, water quality parameters including water temperature, conductivity, pH, and turbidity were measured at each sampling location using a YSI 6820 multiparameter probe. Also, at each location, flow velocity (collected using a

Marsh-McBirney Flowmate 2000) and water depth were measured at three points across the channel (one location near each shore, and center channel). One exception was during the two high-flow events—water quality measurements and velocity/water depth was only measured near shore due to safety concerns during higher flows. A Microsoft Excel spreadsheet containing the water quality, flow velocity, and water depth measurements is included in Attachment 3.

2.3.4 Continuous Flow Monitoring at Boone Creek Flap Gate

Continuous flow monitoring was conducted upstream of the Boone Creek flap gate[3] using an Isco 4250 AV flow meter. Specifically, this meter provided continuous measurement of flow rate, velocity, and water level (in 15-minute intervals) at this location from September 19, 2013, through October 16, 2014. Figure 2-7 shows a time-series of flow rate measured in Boone Creek over this period. It should be noted that there were several occasions where the recorded flows were considered inaccurate due to the presence of debris or ice (during winter months), observed beaver activity, or equipment failure as indicated by field personnel—these suspect periods are shaded in gray on Figure 2-7. A Microsoft Excel spreadsheet containing this continuous monitoring data is included in Attachment 3.

2.4 Field Quality Control

Field quality control (QC) samples were collected in the field (along with environmental samples) to ensure the appropriateness of the sample collection protocol, maintain sample integrity, and provide data of suitable quality. Three types of QC samples were collected in the field, including field duplicates, matrix spike (MS)/matrix spike duplicates (MSDs), and rinse/field blanks. Field QC samples were collected at a frequency of at least one in 20 samples processed as required by the SAP.

[3] This is the gated outfall pipe that allows water from Boone Creek to pass through the Dodson Industrial Flood Control Levee to Blue River.

3 LABORATORY METHODS

This section briefly describes the analytical methods used to generate the physical and chemical data for the samples discussed in this report. The analytical methods used are listed and discussed in Section 5 of the SAP. This section also summarizes any deviations by the laboratory from the SAP.

3.1 Analytical Methods

This report includes data from analyses conducted by Pace Analytical Laboratories in Lenexa, Kansas; Minneapolis, Minnesota; Virginia, Minnesota; and Schenectady, New York. The analytical data are summarized in Section 5, and the original laboratory data reports are provided in Attachment 2. The laboratories listed above performed the following analyses:

- Lenexa: percent moisture, density, specific gravity, and TSS
- Minneapolis: PCB congener
- Virginia: grain size distribution
- Schenectady: TOC and POC

Pace laboratories are National Environmental Laboratory Accreditation Program (NELAP) accredited. Eighty-four reports were received from the laboratories, and were validated as described in Section 4.

3.2 Sample Analyses

Samples were analyzed for the requested analyses consistent with Table 5-2 of the SAP, with the exception of the following:

- Some of the sieved stormwater solids could not be analyzed for TOC because of insufficient sample mass in certain fractions.
  - For Phase 1, there were three samples where there was insufficient quantity of the fine fraction (<62.5 µm; PZC-1, SZB-2, and SZC-1), and insufficient quantity of both the fine and intermediate fractions (<62.5 µm and 62.5-250 µm; SZB-1) for analysis of TOC.
  - For the Phase 2 sediment traps, all but four of the sieved samples had insufficient quantity of both the fine and intermediate fractions (<62.5 µm and 62.5-250 µm)

for analysis of TOC. Also, one sample (OF004-01) had insufficient quantity of the coarse fraction (>250 µm) for analysis of TOC.

- PCB results for one Phase 2 sieved sediment trap sample (>250 µm fraction in OF004-01) were reported on a wet-weight basis because the total solids analysis was not conducted on the sample and results could not be dry-weight corrected.
- One surface water sample was not analyzed for POC because the sample container was broken during transport (sample collected at location BR-BRB [Bannister Road Bridge] on August 8, 2014).
- The water column samples collected during the August 28 to 29, 2014 sampling event were inadvertently not analyzed for TSS, TOC, and POC.

3.3 Laboratory Quality Control

Laboratory QC samples were analyzed at the required frequencies (i.e., one for every 20 [or fewer] environmental samples). The data validation reports (Attachment 1) indicate the majority of the results did not require qualification due to laboratory QC, with the following exceptions:

- Some data were qualified as estimated based on data quality objective or method exceedances.
- Some PCB congener results were qualified as non-detects due to detections in the associated method blanks, and detection limits in some of these cases were elevated above the project target limit.
- Some TOC and POC results for water, soil, and sediment were qualified as estimated because the samples were analyzed past recommended hold times.
- Some results were qualified as estimated due to MS and/or MSD and/or laboratory control sample recoveries that were outside of the project-specified control limits. Some results were also qualified as estimated due to relative percent difference (RPD) values that were outside of the project-specified control limits in the MS/MSD and/or laboratory duplicate analyses.
- Some PCB congener results were qualified as estimated due to labeled compound recoveries outside of method control limits or because they exceeded the calibration range.

- Some PCB congener results were qualified because the ion ratios were outside of the acceptable range and they were qualified as Estimated Maximum Potential Concentration (EMPC) results by the laboratory.

No data were rejected and all data are usable as reported or as qualified.

4 ANALYTICAL DATA VALIDATION AND DATA MANAGEMENT

Stage 2A data validation (USEPA 2009) was performed by Anchor QEA on each of the chemical and physical datasets. Data validation verified the accuracy and precision of chemical and physical determinations performed during this investigation. This section summarizes the overall data quality, but does not summarize each individual sample result affected by data qualification. Detailed information regarding sample result qualifications is available in the data validation reports (Attachment 2).

The data validation results summarized in the validation reports indicate that the overall quality of the chemistry data generated for this project was acceptable. Details regarding data quality objectives and quality assurance procedures are provided in the SAP. As noted above, a Stage 2A validation was conducted on all laboratory data, and data were validated under U.S. Environmental Protection Agency National Functional Guidelines (NFG; USEPA 1999, 2004, 2008), by method requirements, and by using the data quality objectives described in the SAP. Any data qualifiers applied to the data during the final validation procedures have been incorporated into the final database for this project (Attachment 3). Data qualifiers assigned as a result of the data validation and their definitions are shown on the analytical results presented in the summary tables in Section 5. Data are considered usable as reported or as qualified, and no data were rejected. The data may have been qualified as estimated for a particular analysis based on method or technical criterion as stated in the NFG. Data qualified with a "J" indicate that the associated numerical value is the estimated concentration of the analyte. Data qualified with a "UJ" indicate the estimated reporting limit above which the analyte was not detected. In some cases, reporting limits were raised to account for method blank contamination or matrix interference.

5 SUMMARY OF ANALYTICAL DATA

Summaries of the analytical results for the samples collected during the various sampling efforts described in Section 2 are provided in Tables 5-1 through 5-4. The results shown in these tables have undergone Stage 2A data validation (as described in Section 4) and include the relevant data qualifiers. Definitions of the data qualifiers are provided in the notes below each table. Specifically, these tables show the following:

- Table 5-1 provides a summary of analytical results for Phase 1 and Phase 2 stormwater solids. This table summarizes the mass of solids obtained for each sample, including the total mass of each size fraction (<62.5 µm, 62.5-250 µm, and >250 µm) after sieving. This table also includes analytical results for total PCB, percent moisture, and TOC for the bulk (un-sieved) sample, and for each size fraction. PCB analytical results are presented on a dry-weight basis.
- Table 5-2 provides a summary of analytical results for the Phase 2 composite stormwater samples collected during the August 2014 and October 2014 storm events, including total PCB, TSS, and TOC.
- Table 5-3 is a summary of analytical results for composite sediment and bank soil samples collected from the 29 in-stream compositing reaches, and the four discrete soil samples collected within the open channel that flows through the former landfill area between BFC Outfall D and Blue River. This table includes total PCB, bulk density, percent moisture, and TOC for each sample. PCB analytical results are presented on a dry-weight basis. These samples were also submitted for grain size distribution analysis; however, given the quantity of data generated by this type of analysis, it was not summarized in a table. Rather, grain size distributions for each sample are included in the original laboratory data reports provided in Attachment 2.
- Tables 5-4a through 5-4f provide summaries of analytical results for samples collected during the six in-stream water column sampling events (one table for each event). This table includes total PCB, TSS, POC, and TOC for each sample.

6 REFERENCES

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TABLES

Table 5-1
Summary of Phase 1 Stormwater Solids Samples and Phase 2 Sediment Trap Samples

Task Code	Sampling Area	Sampling Zone	Location ID	Sample ID	Collection Date	Collection Time	Total Mass (g)	Sample Mass after Sieve (g)			Total PCB Congener (µg/kg)				Moisture (%)				Total Organic Carbon (%)			
								<62.5 µm	62.5-250 µm	>250 µm	Bulk	<62.5 µm	62.5-250 µm	>250 µm	Bulk	<62.5 µm	62.5-250 µm	>250 µm	Bulk	<62.5 µm	62.5-250 µm	>250 µm
Phase 1	Pavement	A	PZA-1	PZA-1-STS-130724	7/24/2013	9:15	558	95	107	357	305 J	461 J	556 J	89 J	0.23	0.77	0.62	0.14	4.4 J	5.1 J	7.0 J	1.3 J
			PZA-1	PZA-1-STS-130724-DUP	7/24/2013	9:20	536	99	106	330	281 J	350 J	419 J	56 J	0.18	0.59	0.39	0.10 U	3.0 J	3.9 J	5.2 J	1.3 J
			PZA-2	PZA-2-STS-130723	7/23/2013	11:15	783	74	143	566	103 J	179 J	345 J	50 J	0.10 U	1.1	0.53	0.10 U	2.9 J	3.7 J	3.8 J	2.3 J
		B	PZB-1	PZB-1-STS-130723	7/23/2013	15:25	793	80	154	559	15 J	32 J	16 J	6.1 J	0.10 U	0.93	0.10 U	0.10 U	2.7 J	3.8 J	3.2 J	0.73 J
			PZB-2	PZB-2-STS-130723	7/23/2013	10:30	987	62	157	769	7.7 J	39 J	17 J	2.3 J	0.10 U	0.10 U	0.10 U	0.10 U	1.6 J	4.5 J	2.9 J	0.82 J
		C	PZC-1	PZC-1-STS-130724	7/24/2013	11:30	549	74	109	366	0.57 J	1.8 J	2.3 J	1.1 J	0.20	0.28	0.28	0.14	3.1 J	--	4.6 J	1.9 J
			PZC-2	PZC-2-STS-130723	7/23/2013	12:30	720	68	125	527	11 J	24 J	20 J	6.9 J	0.10 U	0.10 U	0.40	0.10 U	2.1 J	2.3 J	3.1 J	1.5 J
	Roof	A	RZA-1	RZA-1-STS-130723	7/23/2013	14:30	793	205	168	420	321 J	504 J	600 J	160 J	0.10 U	0.55	0.55	0.38	8.0 J	8.9 J	10 J	6.6 J
			RZA-2	RZA-2-STS-130724	7/24/2013	8:25	958	46	69	843	347 J	2492 J	3097 J	170 J	0.32	2.3	2.3	0.34	6.2 J	11 J	14 J	4.0 J
		B	RZB-1	RZB-1-STS-130723	7/23/2013	9:25	564	83	69	412	44 J	230 J	229 J	34 J	0.10 U	1.6	0.88	0.10 U	2.3 J	7.9 J	7.7 J	1.0 J
			RZB-2	RZB-2-STS-130724	7/24/2013	7:50	1122	75	63	984	2.7 J	27 J	34 J	2.4 J	0.10 U	1.4	0.51	0.10 U	2.4 J	6.4 J	5.7 J	0.29 J
		C	RZC-1	RZC-1-STS-130723	7/23/2013	7:45	976	288	78	610	7.0 J	19 J	35 J	1.0	0.41	1.6	1.1	0.10 U	2.2 J	4.0 J	8.0 J	0.24 J
			RZC-2	RZC-2-STS-130723	7/23/2013	8:50	586	109	58	419	30 J	77 J	122 J	4.5 J	0.10 U	1.1	0.96	0.10 U	5.8 J	6.8 J	9.3 J	1.4 J
	Catch Basin	A	SZA-1	SZA-1-STS-130724	7/24/2013	10:15	542	58	57	427	94 J	242 J	186 J	51 J	0.13	0.44	0.24	0.10 U	3.4 J	5.9 J	5.3 J	1.8 J
			SZA-2	SZA-2-STS-130723	7/23/2013	14:50	756	69	128	558	87 J	225 J	170 J	50 J	0.10 U	0.99	0.10 U	0.39	5.3 J	7.4 J	6.8 J	2.8 J
		B	SZB-1	SZB-1-STS-130723	7/23/2013	10:50	1763	8	20	1735	667 J	18554 J	6490 J	566 J	0.10 U	--	0.10 U	0.10 U	1.8 J	--	--	1.7 J
			SZB-2	SZB-2-STS-130723	7/23/2013	13:50	689	9	57	623	5.9 J	206 J	21 J	7.2 J	0.10 U	1.4	0.10 U	0.10 U	1.3 J	--	1.8 J	0.79 J
		C	SZC-1	SZC-1-STS-130723	7/23/2013	12:00	568	31	64	473	136 J	222 J	254 J	70 J	0.42	1.8	1.7	0.47	8.1 J	--	14 J	6.8 J
			SZC-2	SZC-2-STS-130724	7/24/2013	13:30	559	122	121	316	22 J	3.6 J	12 J	3.2 J	0.26	0.38	0.45	0.23	4.9 J	3.7 J	9.7 J	4.4 J
Phase 2 (Sediment Traps)	Basin 004		OF004-01	OF004-01-140625	6/25/2014	16:05	1994	11	44	1940	16186 J	4802 J	4431 J	16236 J	0.27	0.14	0.30	--	1.1 J	1.3 J	2.1	--
			OF004-02	OF004-02-TRAP-140929	9/29/2014	12:15	3166	24	111	3032	1752 J	7705	2877	1858 J	0.31	1.6	0.49	0.22	2.3	--	--	1.7
	Basin 003		OF003-01	OF003-01-TRAP-140929	9/29/2014	12:50	1249	12	36	1201	2711 J	20116 J	22647	1560 J	0.82	2.9	2.9	0.91	1.2	--	--	1.1
			OF003-02	OF003-02-TRAP-140929	9/29/2014	13:30	1733	7	20	1706	697	23049 J	18586 J	2251	0.16	2.2	1.2	0.15	0.77	--	--	0.61
	Basin 002		OF002-01	OF002-01-TRAP-140929	9/29/2014	14:20	953	6	17	929	35463 J	--	217697 J	39801 J	1.5	4.1	5.0	1.2	1.8	--	--	1.1
			OF002-02	OF002-02-TRAP-140930	9/30/2014	11:45	2875	33	75	2768	13460 J	88038 J	54116 J	10878	0.24	1.9	1.0	0.21	1.7	--	--	1.4
			OF002-03	OF002-03-TRAP-140929	9/29/2014	11:05	--	--	--	--	18826 J	--	--	--	0.41	--	--	--	2.0	--	--	--
	Basin 001		OF001-01	OF001-01-TRAP-140929	9/29/2014	15:15	2330	88	210	2033	260	205	305	58 J	2.6	2.6	4.4	1.7	0.85	--	--	0.53
			OF001-02	OF001-02-TRAP-140929	9/29/2014	16:05	1751	39	50	1663	344 J	1176	2083 J	9425	1.4	3.7	6.1	1.5	0.59	--	--	0.79
	Roof (001)		RF-01	RF-01-TRAP-140926	9/26/2014	12:55	2972	160	224	2589	1198 J	3341	4251 J	553	0.82	2.4	2.4	0.40	4.0	9.0	11	1.4
	Roof (002)		RF-02	RF-02-TRAP-140926	9/26/2014	12:40	952	142	202	609	832 J	531	1013 J	491 J	3.4	5.9	6.5	1.2	14	14	22	10
	Outfall D		OFD-01	OFD-01-TRAP-140926	9/26/2014	14:55	2752	167	156	2429	269 J	637	641	184	0.57	1.5	1.7	0.35	2.3	1.8	3.4	1.7

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
-- = results not reported or not applicable
µg/kg = micrograms per kilogram
µm = micrometer
g = grams
PCB = polychlorinated biphenyl

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-2
Summary of Phase 2 Composite Stormwater Samples

					Storm Event 1 (August 2014)							Storm Event 2 (October 2014)						
Basin	Location ID	Access Junction	Equipment Location Relative to Access Junction	Compliance Point?	Collection Date	Total PCB (ng/L)		TSS (mg/L)		TOC (mg/L)		Collection Date	Total PCB (ng/L)		TSS (mg/L)		TOC (mg/L)	
004	OF004-01	C38R-10 (Monitoring Pit)	Pipe north of junction		8/7/2014	12		5.0	U	3.4		10/2/2014	212		12		16	
	OF004-02	C56R-14 (Manhole)	Pipe north of junction	Yes	8/7/2014	7.7		5.0	U	3.4		10/2/2014	15		17		18	
003	OF003-01	C47R-11 (Manhole)	Pipe north of junction		8/7/2014	25	J	5.0	U	4.2		10/2/2014	78		--		21	
	OF003-02	C56R-06 (Manhole)	Pipe south of junction	Yes	8/7/2014	63		12		3.3		10/3/2014	21	J	20		8.3	
002	OF002-01	C60R-05 (Catch Basin)	Pipe north of junction		8/7/2014	427	J	5.0	U	3.2		10/2/2014	69		8.0		24	
	OF002-02	C68R-01 (Gatewall)	Square channel at the sluice in the southernmost parking lot	Yes	8/7/2014	181		31		5.4		10/2/2014	120		24		50	
	OF002-03	OF002-Raceway	Raceway south of headwall		8/7/2014	74		94		4.8		10/2/2014	367	J	56		33	
001	OF001-01	C33R-14 (Junction Box)			8/7/2014	7.0	J	5.0	U	3.5		10/2/2014	1.2		16		13	
	OF001-02	C09R-04 (Area Inlet)	Downstream side of the inlet structure in the channel	Yes	8/7/2014	36		31		6.3		10/2/2014	21		30		16	
	OF001-02	C09R-04 (Area Inlet) Field Duplicate			8/7/2014	34		38		6.9		--	--		--		--	
Roof (001)	RF-01				8/7/2014	4.4	J	--		--		10/2/2014	11		--		--	
Roof (002)	RF-02				8/7/2014	0.17		5.0	U	3.6		10/2/2014	6.4	J	119		9.6	
Outfall D	OFD-01	OFD-01	Upstream of levee headwall		--	--		--		--		10/2/2014	3.0	J	99		8.1	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-3
Summary of In-stream Sediment and Bank Soil Samples

Sampling Area	Compositing Reach	Collection Date	In-stream Sediment						Bank Soil				
			Total PCB (µg/kg)		Bulk Density (g/mL)	Percent Moisture (%)	TOC (%)		Total PCB (µg/kg)		Bulk Density (g/mL)	Percent Moisture (%)	TOC (%)
Indian Creek	IC-1	9/18/2013	0.87	J	2.1	18	0.63		0.0085	J	1.9	22	0.79
	IC-2	9/18/2013	2.0	J	2.0	23	0.88	J	2.5	J	2.0	14	0.90
	IC-3	9/18/2013	105	J	1.9	26	1.1		2.0	J	1.7	20	1.1
	IC-4	9/19/2013	203	J	2.1	17	0.49		0.0034		1.8	29	0.48
	IC-5	9/19/2013	7.8	J	2.1	17	1.2	J	--		--	--	--
	IC-6	9/19/2013	13	J	2.1	20	0.84		0.013	J	2.0	18	0.44
	IC-7	9/19/2013	987	J	2.0	18	0.63	J	--		--	--	--
	IC-8	9/19/2013	55	J	2.0	23	0.64		--		--	--	--
Blue River	BR-1	9/13/2013	0.090	J	1.9	23	0.76		--		--	--	--
	BR-2	9/13/2013	0.53	J	1.9	18	1.3	J	0.075		1.9	11	1.0
	BR-3	9/13/2013	0.16	J	1.9	24	1.1		0.035		2.1	8	0.71
	BR-4	9/13/2013	1.7	J	1.9	28	1.0		0.11		2.1	15	0.45
	BR-5	9/13/2013	9.9	J	1.9	21	0.88	J	--		--	--	--
	BR-6	9/18/2013	65	J	2.0	21	0.56		0.058		1.7	15	0.56
	BR-7	9/18/2013	20	J	2.0	19	0.55	J	--		--	--	--
	BR-8	9/18/2013	49	J	1.8	32	1.1		0.14		1.8	18	0.49
	BR-9	9/16/2013	353	--	2.1	18	0.50		0.84	J	1.9	19	0.53
	BR-10	9/16/2013	297	J	1.9	25	1.2		--		--	--	--
	BR-11	9/16/2013	561	J	1.9	26	1.1		--		--	--	--
	BR-12	9/16/2013	303	--	2.0	18	1.1		--		--	--	--
	BR-13	9/16/2013	451	J	1.8	31	1.4		--		--	--	--
	BR-14	9/16/2013	48	J	1.9	30	0.99		--		--	--	--
	BR-15	9/16/2013	68	J	2.0	20	1.6		1.4	J	1.6	13	0.78
Boone Creek	BC-1	9/25/2013	491	J	2.0	13	0.53		--		--	--	--
	BC-2	9/25/2013	44	J	2.2	13	0.48		--		--	--	--
	BC-3	9/25/2013	61	--	2.1	19	0.70	J	--		--	--	--
	BC-3 (Duplicate)	9/25/2013	63	--	2.0	17	0.73		--		--	--	--
	BC-4	9/20/2013	200	J	2.0	19	0.99		649	J	1.8	23	1.3
	BC-5	9/20/2013	730	J	1.5	40	3.8		--		--	--	--
	BC-6	9/20/2013	493	J	1.5	46	3.8		--		--	--	--
Former Landfill Channel (Outfall D)	FLF-1	9/17/2013	316	J	1.9	20	1.9		--		--	--	--
	FLF-2	9/17/2013	150	J	2.0	21	1.0	J	--		--	--	--
	FLF-3	9/17/2013	22	J	1.9	28	0.64		--		--	--	--
	FLF-4	9/17/2013	118	J	2.1	22	3.0	J	--		--	--	--

Notes:
µg/kg = micrograms per kilogram
g/mL = grams per milliliter
PCB = polychlorinated biphenyl
TOC = total organic carbon

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-4a
Summary of In-stream Water Column Samples (Low-flow Event 1: September 9 and 10, 2013)

Sampling Area	Location ID	Location Description	Base Flow Event 1 (September 2013)										
			Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	09/10/2013	09:20	0.28	U	5.0	U	0.31		8.1	
	ICU	Indian Creek Upstream of Outfall 003/004	09/10/2013	08:35	0.14	J	6.0		0.45		7.8	
	ICDA	Indian Creek Downstream of Outfall 003/004	09/10/2013	08:05	0.45	J	6.0		0.43		7.5	
	IC-U002	Indian Creek Upstream of Outfall 002	09/09/2013	14:30	0.18	J	5.0	U	0.69		7.2	
	ICDB	Indian Creek Downstream of Outfall 002	09/09/2013	14:15	0.73	J	5.0	U	0.13	U	6.9	
Blue River	BR-UBC	Blue River at I-435 Bridge	09/10/2013	11:30	0.083	J	8.0		0.41		5.6	
	ICBR	Blue River Upstream of Indian Creek Confluence	09/09/2013	13:45	0.15	J	14		0.56		5.3	
	BR-BRB	Blue River at Bannister Road Bridge	09/10/2013	10:35	2.2	J	8.0		0.49		7.1	
	BRU	Blue River at 95th Terrace	09/09/2013	11:45	3.3	J	6.0		0.55		6.6	
	BRU	Blue River at 95th Terrace (Field Duplicate)	09/09/2013	12:00	3.7	J	13		0.42		6.7	
	BR-UBN	Blue River Upstream of Boone Creek	09/09/2013	10:05	5.9	J	9.0		0.59		6.5	
	BRD	Blue River Downstream of Boone Creek	09/09/2013	09:30	11	J	20		1.1		6.8	
	BR-DBC	Blue River at Hickman Mills Drive	09/09/2013	08:00	20	J	24		0.91		5.9	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	09/09/2013	11:00	57	J	5.0	U	0.18		5.8	
	BCD	Boone Creek Downstream of Outfall 001	09/09/2013	10:45	88	J	5.0	U	1.5		5.5	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
POC = particulate organic carbon
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-4b
Summary of In-stream Water Column Samples (Low-flow Event 2: July 14 and 15, 2014

Sampling Area	Location ID	Location Description	Base Flow Event 2 (July 2014)									
			Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	07/14/2014	19:55	1.1	U	14		0.75		7.1	
	ICU	Indian Creek Upstream of Outfall 003/004	07/14/2014	15:55	0.17		18		0.82		6.6	
	ICDA	Indian Creek Downstream of Outfall 003/004	07/14/2014	16:35	0.24	J	29		1.1		6.5	
	IC-U002	Indian Creek Upstream of Outfall 002	07/14/2014	17:05	0.15	J	24		0.75		6.5	
	ICDB	Indian Creek Downstream of Outfall 002	07/14/2014	17:35	1.3	J	17		0.71		6.4	
Blue River	BR-UBC	Blue River at I-435 Bridge	07/14/2014	19:55	0.14	J	22		0.67		4.1	
	BR-UBC	Blue River at I-435 Bridge (Field Duplicate)	07/14/2014	20:03	1.1	J	20		0.94		4.2	
	ICBR	Blue River Upstream of Indian Creek Confluence	07/14/2014	18:00	0.35		36		1.2		4.3	
	BR-BRB	Blue River at Bannister Road Bridge	07/15/2014	07:30	0.29		17		0.62		5.4	
	BRU	Blue River at 95th Terrace	07/15/2014	08:05	0.48		17		0.67		5.4	
	BR-UBN	Blue River Upstream of Boone Creek	07/15/2014	09:55	1.8	J	21		0.63		5.5	
	BRD	Blue River Downstream of Boone Creek	07/15/2014	10:20	3.5		19		0.71		5.4	
	BR-DBC	Blue River at Hickman Mills Drive	07/15/2014	11:05	5.3	J	24		0.60		5.4	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	07/15/2014	12:30	44		5.0	U	0.27		4.6	
	BCD	Boone Creek Downstream of Outfall 001	07/15/2014	12:05	54		12		0.91		5.2	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
POC = particulate organic carbon
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-4c
Summary of In-stream Water Column Samples (High-flow Event 1: August 7 and 8, 2014)

Sampling Area	Location ID	Location Description	Storm Event 1 (August 7 and 8, 2014)									
			Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	08/07/2014	13:15	0.62		88	J	3.0	J	6.3	
	ICU	Indian Creek Upstream of Outfall 003/004	08/08/2014	16:00	0.23		5.0	U	0.69	J	5.3	
	ICDA	Indian Creek Downstream of Outfall 003/004	08/08/2014	16:00	1.0	U	5.0		0.70	J	5.3	
	IC-U002	Indian Creek Upstream of Outfall 002	08/07/2014	14:55	0.25		94	J	3.1	J	4.6	
	ICDB	Indian Creek Downstream of Outfall 002	08/07/2014	14:25	0.64	J	107	J	3.2	J	4.7	
Blue River	BR-UBC	Blue River at I-435 Bridge	08/07/2014	15:40	1.0	U	138	J	3.1	J	5.8	
	ICBR	Blue River Upstream of Indian Creek Confluence	08/07/2014	13:50	0.77		214	J	4.5	J	5.3	
	BR-BRB	Blue River at Bannister Road Bridge	08/08/2014	14:45	0.73	J	28		--		4.8	
	BR-BRB	Blue River at Bannister Road Bridge (Field Duplicate)	08/08/2014	14:45	10		27		1.4	J	5.1	
	BRU	Blue River at 95th Terrace	08/07/2014	10:50	6.6	J	246		6.1	J	4.9	
	BR-UBN	Blue River Upstream of Boone Creek	08/07/2014	11:40	2.8	J	206		5.3	J	4.9	
	BRD	Blue River Downstream of Boone Creek	08/07/2014	10:05	6.2		265		7.0	J	4.8	
	BR-DBC	Blue River at Hickman Mills Drive	08/08/2014	14:00	5.3	J	54		1.5	J	5.1	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	08/08/2014	12:35	56		5.0	U	0.18	J	4.5	
	BCD	Boone Creek Downstream of Outfall 001	08/08/2014	12:15	59		5.0	U	0.57	J	6.2	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
POC = particulate organic carbon
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-4d

Summary of In-stream Water Column Samples (Low-flow Event 3: August 28 and 29, 2014)

Sampling Area	Location ID	Location Description	Base Flow Event 3 (August 28 and 29, 2014)									
			Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	08/28/2014	14:15	0.11	J	--		--		--	
Indian Creek	ICU	Indian Creek Upstream of Outfall 003/004	08/29/2014	10:25	0.062	J	--		--		--	
Indian Creek	ICDA	Indian Creek Downstream of Outfall 003/004	08/29/2014	10:00	0.11		--		--		--	
Indian Creek	ICDA	Indian Creek Downstream of Outfall 003/004 (Field Duplicate)	08/29/2014	10:00	0.082		--		--		--	
Indian Creek	IC-U002	Indian Creek Upstream of Outfall 002	08/29/2014	09:30	0.069	J	--		--		--	
Indian Creek	ICDB	Indian Creek Downstream of Outfall 002	08/29/2014	09:10	5.4		--		--		--	
Blue River	BR-UBC	Blue River at I-435 Bridge	08/28/2014	14:15	1.1	U	--		--		--	
Blue River	ICBR	Blue River Upstream of Indian Creek Confluence	08/29/2014	08:40	0.12		--		--		--	
Blue River	BR-BRB	Blue River at Bannister Road Bridge	08/28/2014	13:30	1.8	J	--		--		--	
Blue River	BRU	Blue River at 95th Terrace	08/28/2014	12:15	7.5	J	--		--		--	
Blue River	BR-UBN	Blue River Upstream of Boone Creek	08/28/2014	11:30	9.4	J	--		--		--	
Blue River	BRD	Blue River Downstream of Boone Creek	08/28/2014	11:00	11	J	--		--		--	
Blue River	BR-DBC	Blue River at Hickman Mills Drive	08/28/2014	09:00	30		--		--		--	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	08/28/2014	10:20	54	J	--		--		--	
Boone Creek	BCD	Boone Creek Downstream of Outfall 001	08/28/2014	10:00	95	J	--		--		--	

Notes:

Non-detect PCB congeners set to zero in calculation of Total PCBs.

mg/L = milligrams per liter

ng/L = nanograms per liter

PCB = polychlorinated biphenyl

POC = particulate organic carbon

TOC = total organic carbon

TSS = total suspended solids

Qualifiers:

J = estimated value

U = compound analyzed, but not detected above detection limit

Table 5-4e
Summary of In-stream Water Column Samples (Low-flow Event 4: September 22 and 23, 2014)

Sampling Area	Location ID	Location Description	Base Flow Event 4 (September 2014)									
			Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	09/22/2014	15:00	0.51		5.0	U	0.50	J	6.5	
	ICU	Indian Creek Upstream of Outfall 003/004	09/22/2014	13:55	1.2	U	7.0		0.59	J	6.0	
	ICDA	Indian Creek Downstream of Outfall 003/004	09/22/2014	13:40	2		9.0		0.58	J	5.8	
	ICDA	Indian Creek Downstream of Outfall 003/004	09/22/2014	13:40	1.1	U	5.0	U	0.63	J	6.2	
	IC-U002	Indian Creek Upstream of Outfall 002	09/22/2014	13:15	1.1	U	12		0.52	J	5.8	
	ICDB	Indian Creek Downstream of Outfall 002	09/22/2014	12:50	0.25		7.0		0.54	J	5.8	
Blue River	BR-UBC	Blue River at I-435 Bridge	09/22/2014	11:50	20		6.0		0.68	J	4.6	
	ICBR	Blue River Upstream of Indian Creek Confluence	09/22/2014	12:20	0.072		10		0.55	J	4.4	
	BR-BRB	Blue River at Bannister Road Bridge	09/23/2014	11:30	0.43		10		0.58	J	5.5	
	BRU	Blue River at 95th Terrace	09/23/2014	11:05	2.1		8.0		0.52	J	5.5	
	BR-UBN	Blue River Upstream of Boone Creek	09/23/2014	10:30	4.6		11		0.51	J	5.3	
	BRD	Blue River Downstream of Boone Creek	09/22/2014	14:30	3.3		7.0		0.49	J	5.5	
	BR-DBC	Blue River at Hickman Mills Drive	09/23/2014	12:25	4.0		12		0.54	J	5.1	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	09/23/2014	10:10	30		5.0		0.75	J	4.4	
	BCD	Boone Creek Downstream of Outfall 001	09/23/2014	09:45	35		351		0.78	J	6.8	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
POC = particulate organic carbon
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

Table 5-4f
Summary of In-stream Water Column Samples (High-flow Event 2: October 2 and 3, 2014)

Sampling Area	Location ID	Location Description	Storm Event 2 (October 2014) Collection Date	Collection Time	Total PCB (ng/L)		TSS (mg/L)		POC (mg/L)		TOC (mg/L)	
Indian Creek	IC-UBC	Indian Creek at Holmes Road	10/03/2014	15:50	0.26	J	38		1.7		6.3	
	ICU	Indian Creek Upstream of Outfall 003/004	10/02/2014	13:15	1.2		1120		9.9	J	13	
	ICDA	Indian Creek Downstream of Outfall 003/004	10/02/2014	12:45	11		920		17	J	12	
	IC-U002	Indian Creek Upstream of Outfall 002	10/02/2014	11:40	5.5		182		3.0	J	8.6	
	ICDB	Indian Creek Downstream of Outfall 002	10/02/2014	11:20	6.5	J	148		3.3	J	8.7	
Blue River	BR-UBC	Blue River at I-435 Bridge	10/03/2014	15:25	0.78	J	222		5.2		12	
	BR-UBC	Blue River at I-435 Bridge (Field Duplicate)	10/03/2014	15:25	0.42		216		5.7		12	
	ICBR	Blue River Upstream of Indian Creek Confluence	10/02/2014	10:15	1.1	U	262		5.0	J	8.5	
	BR-BRB	Blue River at Bannister Road Bridge	10/02/2014	14:05	75		1410		20	J	14	
	BRU	Blue River at 95th Terrace	10/02/2014	14:05	0.22		724		6.6	J	12	
	BR-UBN	Blue River Upstream of Boone Creek	10/02/2014	16:55	1.3		357		6.4	J	11	
	BRD	Blue River Downstream of Boone Creek	10/02/2014	16:15	12	J	770		7.7	J	12	
	BR-DBC	Blue River at Hickman Mills Drive	10/03/2014	16:20	1.8	J	182		4.8		9.9	
Boone Creek	BCU	Boone Creek Upstream of Outfall 001	10/03/2014	17:00	17	J	6.0		0.39		4.8	
	BCD	Boone Creek Downstream of Outfall 001	10/03/2014	16:40	25		12		0.55		4.6	

Notes:
Non-detect PCB congeners set to zero in calculation of Total PCBs.
mg/L = milligrams per liter
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
POC = particulate organic carbon
TOC = total organic carbon
TSS = total suspended solids

Qualifiers:
J = estimated value
U = compound analyzed, but not detected above detection limit

FIGURES

Figure 2-1
Collection of Roof, Pavement, and Catch Basin Solids
During Phase 1 Stormwater Sampling
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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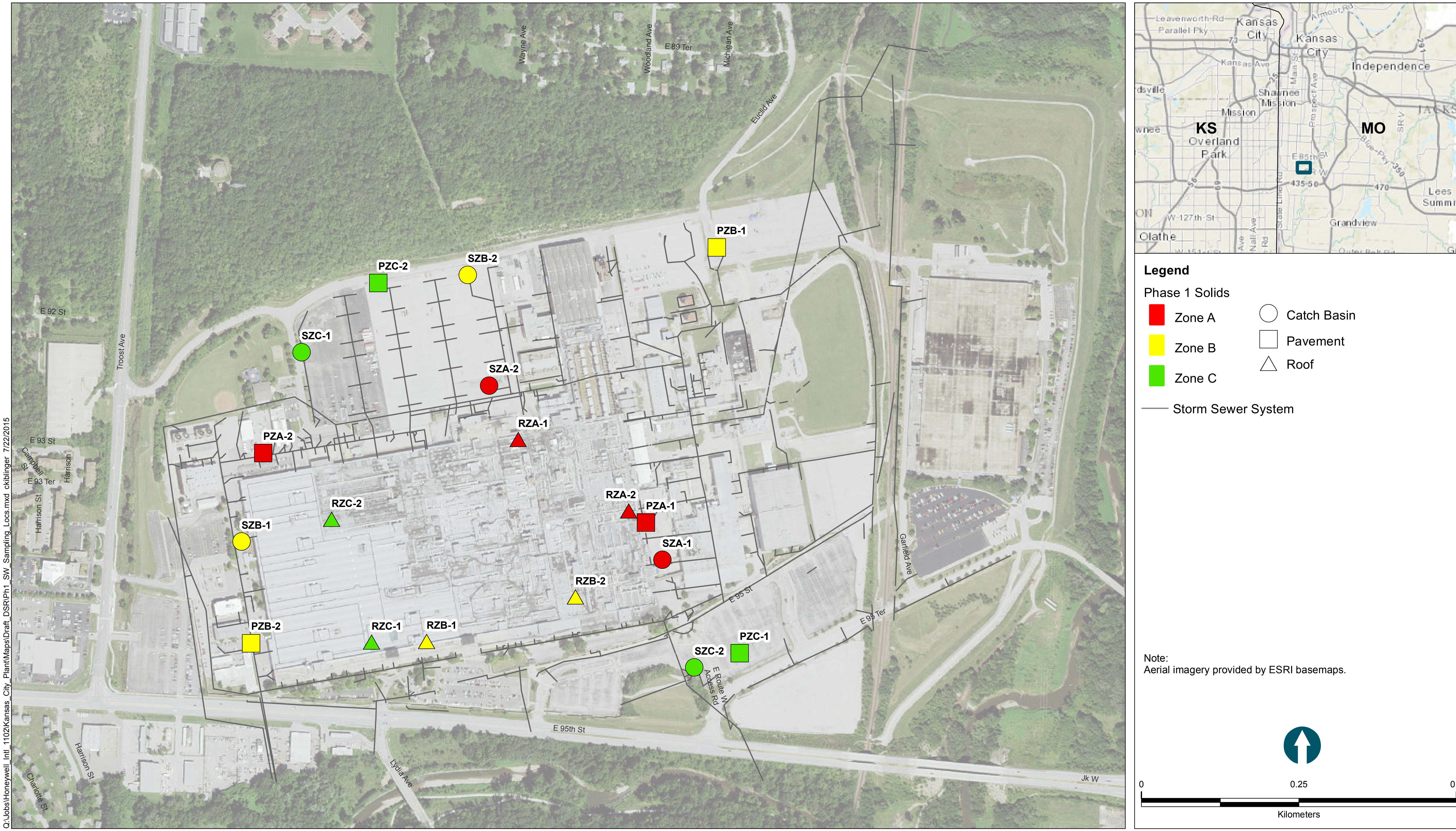

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Figure 2-2
Phase 1 Stormwater Solids Sampling Locations
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

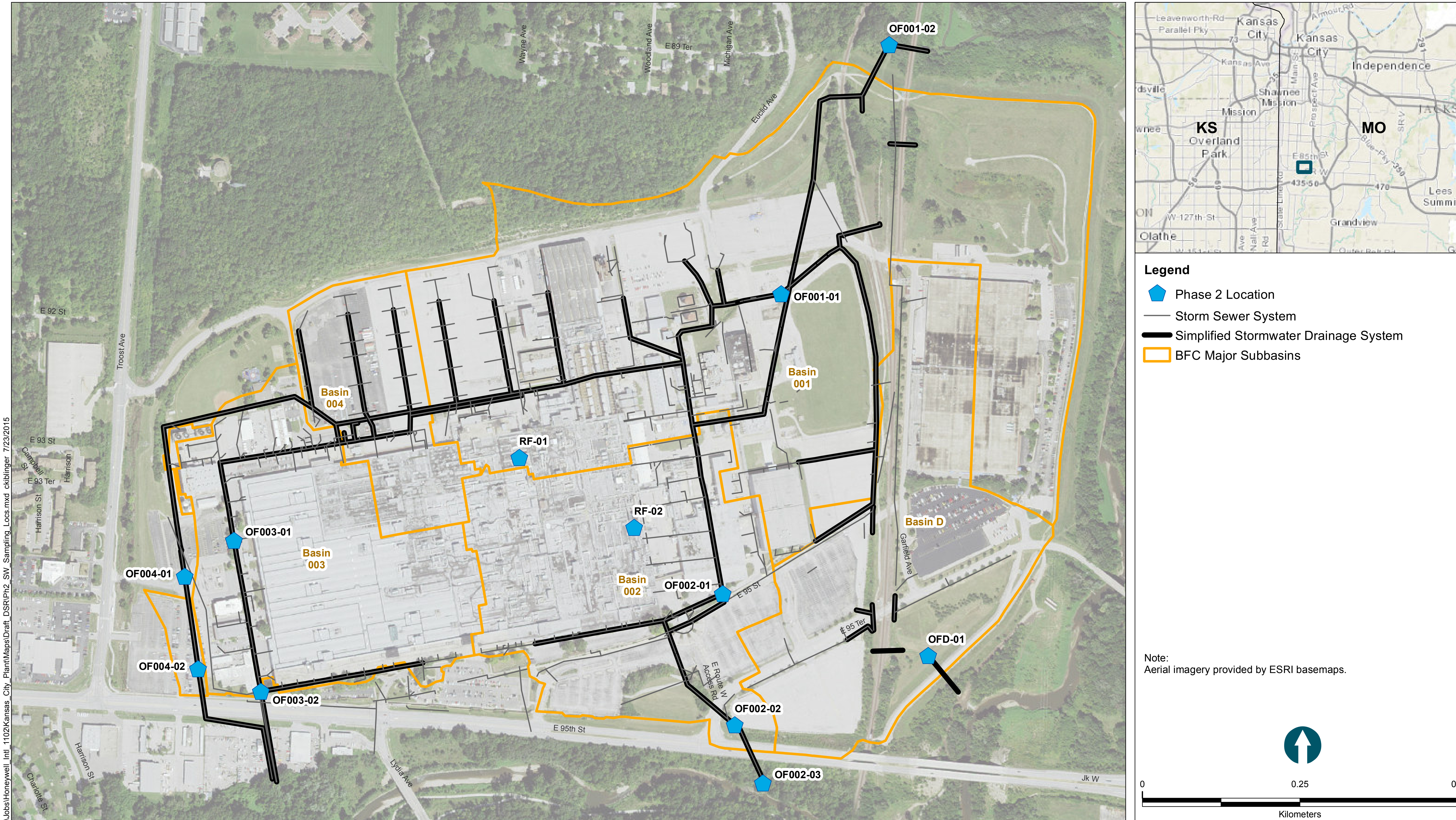

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Figure 2-3
Phase 2 Stormwater Sampling Locations
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

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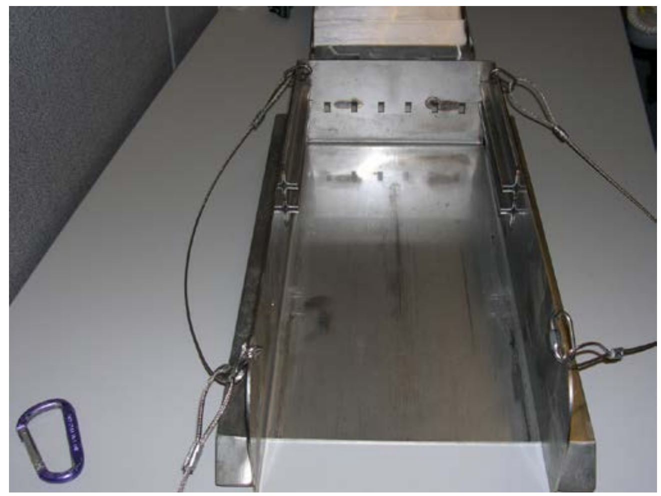
Device ready for deployment

Device with upper deck removed, exposing middle deck

Device with upper and middle decks removed, exposing baffle plate



Device with decks and baffles removed, showing slots in downstream end

Photographs courtesy of WA Department of Ecology

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Figure 2-4
Hamlin Sampler
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Figure 2-5
Sediment Trap Sample Retrieval
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

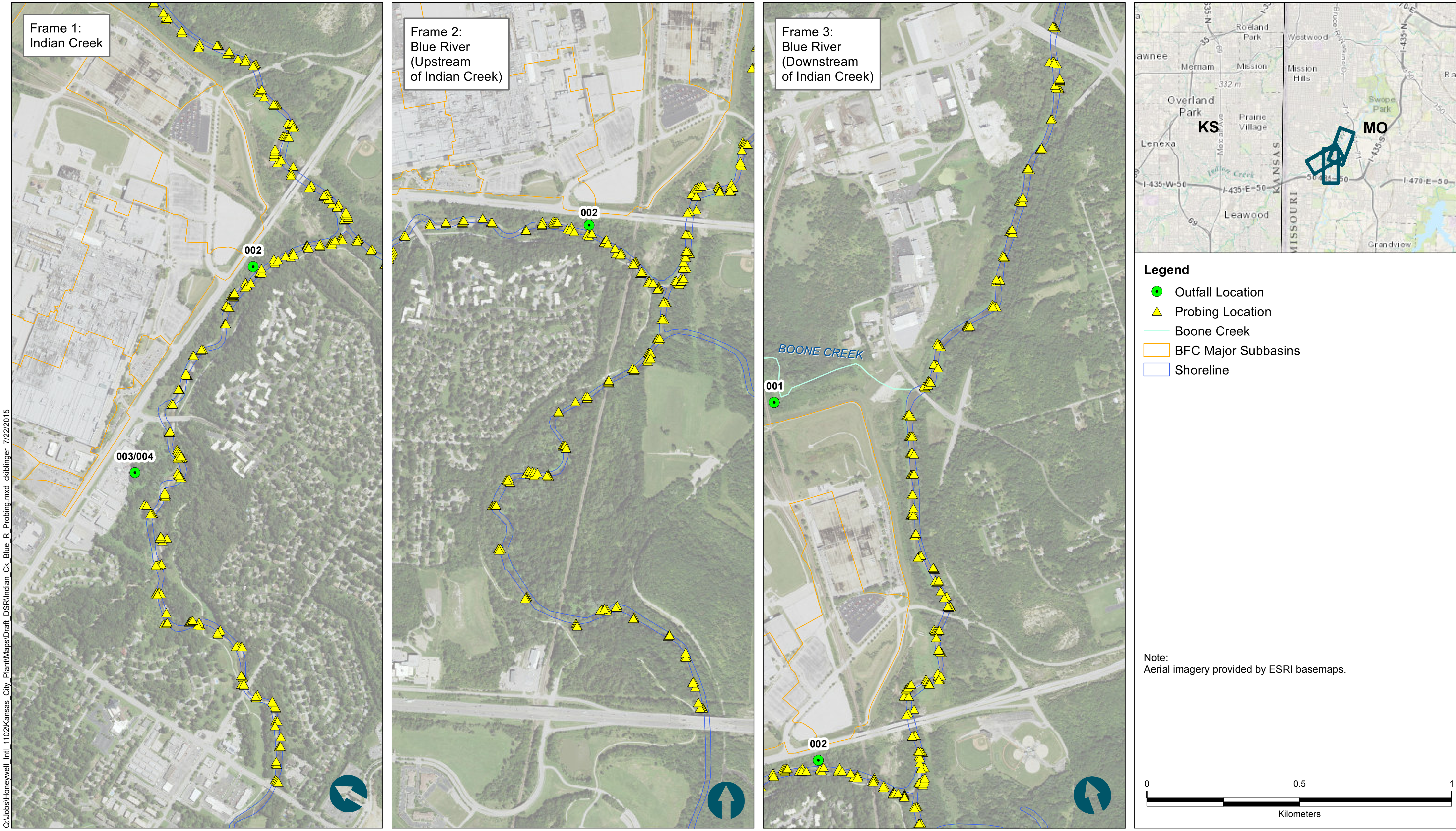

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Figure 2-6
Indian Creek and Blue River Probing Locations
Data Summary Report – Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

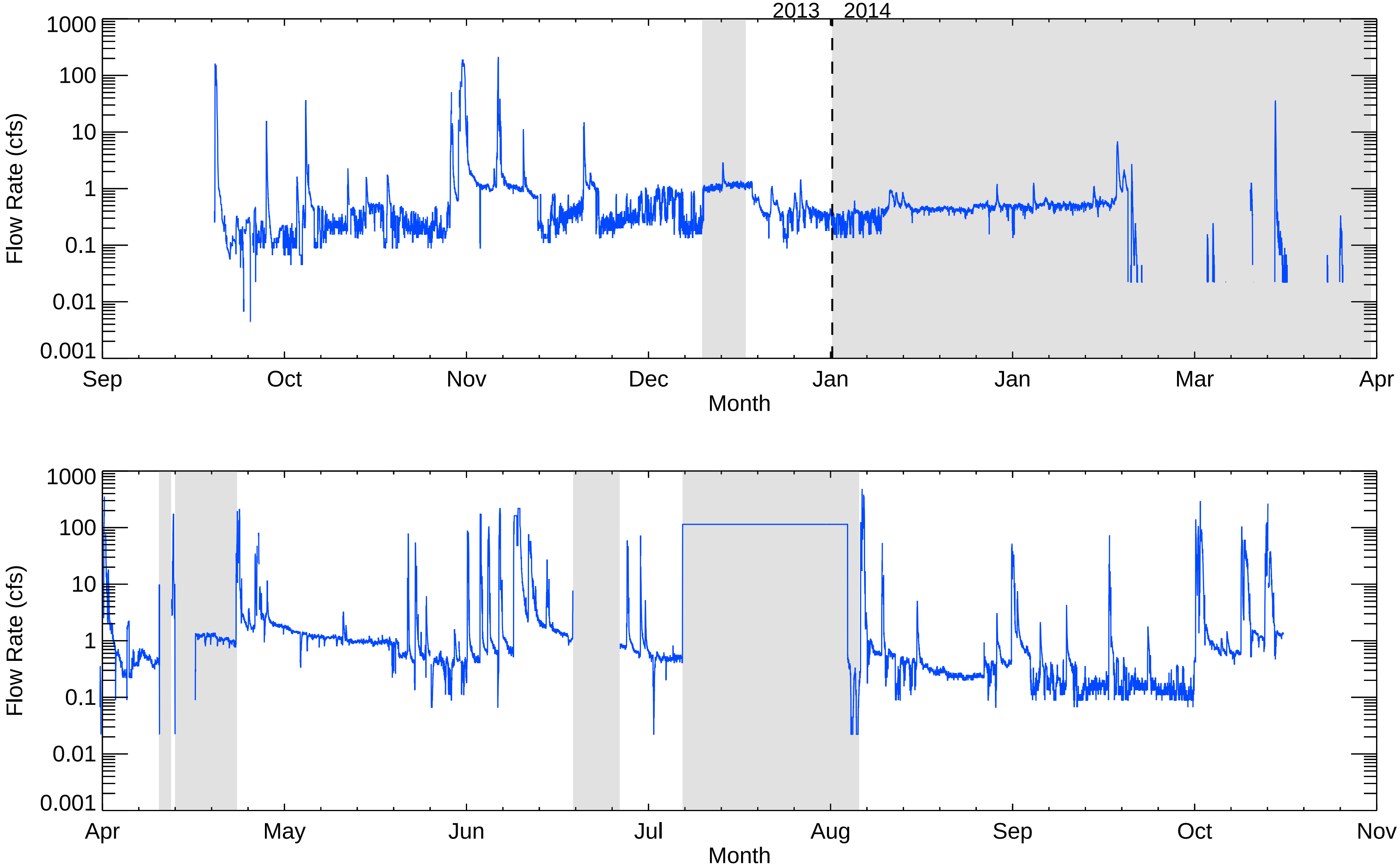

Figure 2-7

Time Series of Observed Flows in Boone Creek from September 2013 to October 2014
Data Summary Report--Indian Creek/Blue River Fate and Transport Study
KCP/Honeywell FM&T

Note: Gray shading indicates periods where recorded flows were inaccurate due to the presence of debris or ice (during winter months), observed beaver activity, or equipment failure.

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ATTACHMENT 1
LABORATORY DATA REPORTS

ATTACHMENT 2

DATA VALIDATION REPORTS

ATTACHMENT 3

ELECTRONIC COPIES OF FINAL PROJECT ANALYTICAL DATABASE AND FIELD DATA FILES