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1.0 SANTA CRUZ RIVER NEAR NOGALES, ARIZONA

1.1 STUDY AREA OVERVIEW

1.1.1 Study Area Description

The Santa Cruz River originates as a small southerly flow in the San Rafael Valley in southern Arizona, looping down into Mexico and then back up into the United States (Arizona Department of Environmental Quality [ADEQ] 1995). The main sources of flow in the Santa Cruz watershed are precipitation, groundwater discharge, irrigation return flow, and treated sewage effluent. The majority of the river and tributary streams are intermittent or ephemeral (Cordy et al. 1998). Flow from the headwaters into and out of Mexico is perennial. The stream just north of the border is essentially dry except during the winter and then is perennial up to the confluence with Nogales Wash where it receives effluent from the Nogales International Wastewater Treatment Plant (NIWTP). Flow downstream of this point is mainly effluent. Groundwater inflow in this area is suspected (ADEQ 1995).

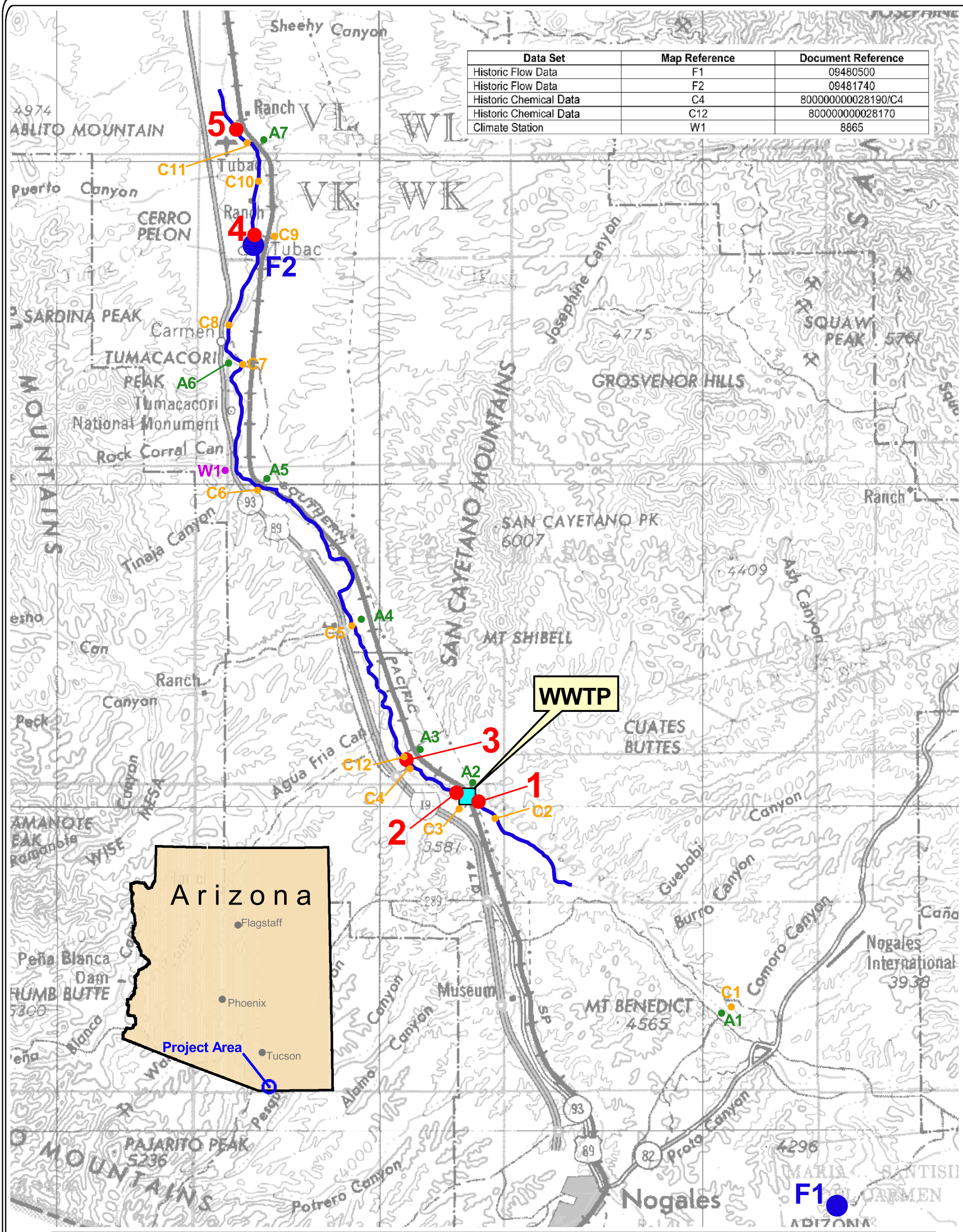
Figure C-2-1 shows the locations of the site reconnaissance sites (red numbers 1 through 5) and the locations of historical data. Table C-2-1 describes each data point.

Table C-2-1
Historical Data Locations for the Santa Cruz River Near Nogales, Arizona

Site Label	Data Summary	Reference
09480500	Historical flow data	USGS
A1	Invertebrate, algae and fish data	Lawson 1995; Wennmacher 1996
C1	Chemical data	Wennmacher 1996; Lawson 1995a, 1995b
C2	Chemical data	Wennmacher 1996
C3	Chemical data	Wennmacher 1996
A2	Algae data	Wennmacher 1996
A3	Invertebrate and fish data	ADEQ 1990; Lawson 1995a, 1995b; King et al. 1999
800000000028190	Historical chemical data	*STORET*
800000000028179	Historical chemical data	*STORET*
C4	Chemical and tissue data	Lawson 1995a, 1995b; King et al. 1999; Wennmacher 1996
A4	Algae data	Wennmacher 1996
C5	Chemical and tissue data	King et al. 1999; Wennmacher 1996
A5	Invertebrate and fish data	ADEQ 1994; Lawson 1995a, 1995b
C6	Chemical data	Wennmacher 1996; Lawson 1995a, 1995b
8865	Historical precipitation and climate data	NCDC
A6	Invertebrate and fish data	Lawson 1995a, 1995b; King et al. 1999
C7	Chemical and tissue data	Lawson 1995a, 1995b; King et al. 1999
C8	Chemical data	Wennmacher 1996
09481740	Historical flow data	USGS
C9	Chemical data	Wennmacher 1996
C10	Chemical and tissue data	King et al. 1999
C11	Chemical and tissue data	Wennmacher 1996; Lawson 1995a, 1995b; King et al. 1999
A7	Invertebrate, algae and fish data	Lawson 1995a, 1995b; Wennmacher 1996; USGS 1998

NCDC – National Climatic Data Center
STORET – EPA's Storage and Retrieval Database
USGS – U.S. Geological Survey

Data Set	Map Reference	Document Reference
Historic Flow Data	F1	09480500
Historic Flow Data	F2	09481740
Historic Chemical Data	C4	800000000028190/C4
Historic Chemical Data	C12	800000000028170
Climate Station	W1	8865



Arid West Water Quality Research Project Habitat Characterization Study
Santa Cruz River Near Nogales, Arizona

Legend

- Stream Study Area
- Reconnaissance Data (1 - 5)
- Historic Flow Data (F1 - F2)
- Historic Chemical Data (C1 - C12)
- Historic Aquatic Data (A1 - A7)
- Climate Station (W1)
- Wastewater Treatment Plant (WWTP)

1 0 1 2
Scale in Miles

N

Source: US Geological Survey 1x2 Degree Quadrangle Maps
Nogales, Arizona (1969)

URS

Figure C-2-1

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1.1.2 Ecoregion Description

Nogales and the upper end of the Santa Cruz River are in Ecoregion 79, Madrean Archipelago (Omernick and Bailey 1997). Ecoregion 79 is limited to a relatively small area in southeastern Arizona between the Chihuahuan Desert and the Sonoran Desert. Ecoregion 79 is at the southeast end of the Basin and Range physiographic province, with a land surface that includes broad valleys separated by high mountain ranges. Because of the wide range in elevations, this ecoregion has varied climatic conditions, with warm to hot summers and mild to cold winters, with distinct summer and winter rainy seasons. Natural vegetation in this ecoregion is very diverse because of the elevational and climatic variability. The valleys are dominated by semi-desert grasslands, and the mountains include a mixture of evergreen woodlands and forests. Some characteristic plant species of this region include Arizona white oak, alligator bark juniper, Schott agave, wait-a-minute bush, and plains lovegrass. Grazing of domestic livestock is a common land use in this ecoregion. Some of the vertebrate wildlife species that are characteristic of Ecoregion 79 include Arizona gray squirrel, yellow-nosed cotton rat, southern pocket gopher, broad-billed hummingbird, Strickland's woodpecker, Mexican jay, western barking frog, bunch grass lizard, Yarrow's spiny lizard, and ridge-nosed rattlesnake (URS 2000).

1.2 WATER QUALITY STANDARDS

The Salt River from the NIWTP to Tubac, Arizona has the following designated uses:

- aquatic and wildlife – effluent-dependent water (A&Wedw)
- partial body contact (PBC)
- agricultural livestock watering (AgL)

Water quality standards that apply to these uses are shown in Table C-2-2.

Table C-2-2
Water Quality Standards for Constituents of Concern for the Santa Cruz River Near Tucson, Arizona

Constituent of Concern	Criteria to protect A&Wedw	Criteria to protect PBC	Criteria to protect AgL
Ammonia	–	–	–
Arsenic	360 µg/L dissolved (acute) 190 µg/L dissolved (chronic)	2,800 µg/L total recoverable	200 µg/L total recoverable
Beryllium	65 µg/L dissolved (acute) 5.3 µg/L dissolved (chronic)	700 µg/L total recoverable	–
Cadmium	24 µg/L dissolved (acute)[1] 1.1 µg/L dissolved (chronic)[1]	70 µg/L total recoverable	50 µg/L total recoverable
Chlorine	11 µg/L (total residual)	–	–

Table C-2-2 Water Quality Standards for Constituents of Concern for the Santa Cruz River Near Tucson, Arizona			
Constituent of Concern	**Criteria to protect A&Wedw**	**Criteria to protect PBC**	**Criteria to protect AgL**
Copper	17.7 µg/L dissolved (acute) [1] 11.8 µg/L dissolved (chronic) [1]	5,200 µg/L dissolved	500 µg/L total recoverable
DDT	1.1 µg/L (acute) 0.001 µg/L (chronic)	700 µg/L	0.001 µg/L
Mercury	2.6 µg/L dissolved (acute) 0.2 µg/L dissolved (acute)	42 µg/L total recoverable	10 µg/L total recoverable
PCBs	2 µg/L (acute) 0.02 µg/L (chronic)	–	0.001 µg/L
Selenium	50 µg/L total recoverable (acute) 2 µg/L total recoverable (chronic)	420 µg/L total recoverable	50 µg/L total recoverable
Fecal Coliform Bacteria	200 cfu/100 mL (30-day geometric mean) 400 cfu/100 mL (10% of samples for 30-day period) 800 cfu/100 mL (single sampling maximum)	1,000 cfu/100 mL (30-day geometric mean) 2,000 cfu/100 mL (10% of samples for 30-day period) 4,000 cfu/100 mL (single sampling maximum)	1,000 cfu/100 mL (30-day geometric mean) 2,000 cfu/100 mL (10% of samples for 30-day period) 4,000 cfu/100 mL (single sampling maximum)
pH	9.0 (maximum) 6.5 (minimum) 0.5 (max change to due discharge)	9.0 (maximum) 6.5 (minimum) 0.5 (max change to due discharge)	6.5 - 9.0 0.5 (max change to due discharge)
Temperature	3.0°C (max increase due to a discharge)	–	–
Turbidity	50 NTU	50 NTU	–
Dissolved Oxygen	1.0 (single sample minimum)	–	–
Total Dissolved Solids	–	–	–
Nutrients	–	–	–
Salinity	–	–	–

[1] Criteria calculated via formula based on hardness of 100 mg/L as $CaCO_3$
µg/L – micrograms per liter
cfu – colony forming unit
NTU – Nepholometric Turbidity Unit
mL – milliliter(s)
°C – degrees Celsius

1.3 WASTEWATER TREATMENT PLANTS DISCHARGING TO THE STUDY AREA

The City of Nogales, Arizona, and the International Boundary and Water Commission (IBWC) are co-permittees for the NIWTP. The NIWTP treats wastewater from Nogales, Arizona and surrounding communities as well as wastewater originating in Nogales, Sonora, Mexico. Treated

effluent is discharged to the Santa Cruz River adjacent to the plant site. The location of the NIWTP is depicted on **Figure C-2-1**.

1.3.1 National Pollutant Discharge Elimination System Discharge Permits

A summary of selected National Pollutant Discharge Elimination System (NPDES) parameters from the current permit for the NIWTP is provided in Table C-2-3. A draft permit was issued in August 2000 and is under review. Because the draft permit has not been finalized, it is not cited here. However, requirements for nitrogen removal are expected to be a significant new component of the permit. A copy of the existing permit is included in **Appendix L**.

Table C-2-3
Summary of Selected NPDES Permit Parameters for NIWTP

Parameter	Units	Limit Type	Value
BOD_5	mg/L	30-day average 7-day average	30 45
Total Suspended Solids	mg/L	30-day average	90
Settleable Solids	mL/L	30-day average Daily maximum	1 2
Fecal Coliform Bacteria	#/100 mL	30-day average Daily maximum	200 800
Total Residual Chlorine	mg/L	30-day average Daily maximum	0.005 0.011
pH	s.u.	Maximum Minimum	9 6.5
WET Testing		Required/Not Required	Required

The permit also specifies that the receiving water temperature is not to be raised by more than 3°C. The discharge is not to lower dissolved oxygen in the receiving water to any lower than 90 percent saturation or 1 to 3 mg/L (depending on the time of day), whichever is less. Specific metal limits and other trace constituents are defined in the permit. The permit does not include a limit for effluent flow rate, but flows must be monitored.

1.3.2 Effluent Quality

EPA's Permit Compliance System (PCS) was queried to obtain historical data on effluent quality as reported by the NIWTP. This system is a holding of discharge monitoring reports that are submitted to EPA by state NPDES programs. Table C-2-4 summarizes the discharge monitoring data for the NIWTP.

Table C-2-4
Summary of Selected PCS Parameters for NIWTP

Parameter	Units	Average Reporting Concentrations		Number of Measurements	POR
4,4'-DDT (P,P'-DDT)	µg/L	Minimum Average Maximum	 10	 4	1992-1999
BOD_5	mg/L	Minimum	2	136	1989-2000

Table C-2-4
Summary of Selected PCS Parameters for NIWTP

Parameter	Units	Average Reporting Concentrations		Number of Measurements	POR
		Average	27.6	136	
		Maximum	159	136	
Fecal Coliform Bacteria	#/100 mL	Minimum	2	36	1989-2000
		Average	11.6	99	
		Maximum	16,000	136	
pH	s.u.	Minimum	6.5	136	1989-2000
		Average			
		Maximum	13	136	
Settleable Solids	ml/L	Minimum	0.1	36	1989-2000
		Average	<0.3	67	
		Maximum	5	103	
Total Ammonia (as N)	µg/L	Minimum			1992-2000
		Average			
		Maximum	24,500	100	
Total Dissolved Solids	µg/L	Minimum			1992-1999
		Average			
		Maximum	508,000	8	
Total Nitrate (as N)	µg/L	Minimum			1992-2000
		Average			
		Maximum	22,000	74	
Total Organic Carbon (TOC)	µg/L	Minimum			1992-1999
		Average			
		Maximum	182,000	8	
Total Organic Nitrogen (as N)	µg/L	Minimum			1992-2000
		Average			
		Maximum	38,200	97	
Total Phosphate (as PO_4)	µg/L	Minimum			1989-2000
		Average			
		Maximum	89,500	136	
Total Recoverable Arsenic	µg/L	Minimum			1992-2000
		Average			
		Maximum	100	70	
Total Arsenic (as As)	mg/L	Minimum			1989-1991
		Average			
		Maximum	0.035	4	
Total Recoverable Cadmium	µg/L	Minimum			1992-2000
		Average			
		Maximum	25	60	
Total Cadmium (as Cd)	mg/L	Minimum			1989-1991
		Average			
		Maximum	0.01	12	
Total Recoverable Copper	µg/L	Minimum			1992-2000
		Average			
		Maximum	603	68	
Total Copper (as Cu)	mg/L	Minimum			1989-1997
		Average			
		Maximum	0.22	36	
Total Recoverable	µg/L	Minimum			1992-2000

Table C-2-4
Summary of Selected PCS Parameters for NIWTP

Parameter	Units	Average Reporting Concentrations		Number of Measurements	POR
Mercury		Average Maximum	 31	 31	
Total Mercury (as Hg)	mg/L	Minimum Average Maximum	 0.003	 35	1989-1991
Total Recoverable Selenium	µg/L	Minimum Average Maximum	 50	 60	1989-2000
Total Residual Chlorine	mg/L	Minimum Average Maximum	0.2 <0.73 2	36 48 56	1989-2000
Total Suspended Solids	mg/L	Minimum Average Maximum	7.8 20.4 200	36 100 136	1989-2000
S.U. – Standard Unit(s)					

1.3.3 NIWTP Processes

All effluent from the NIWTP historically has been discharged to the plant's outfall on the Santa Cruz River. Originally constructed in 1972 with a rated capacity of 8.2 million gallons per day (mgd), the NIWTP initially consisted of aerated lagoons, a stabilization lagoon, and disinfection with chlorine. Capacity and discharge water quality issues led to construction of major upgrades at the NIWTP, completed in 1992. The liquid-train treatment processes now in use at the NIWTP, with a rated capacity of 17.2 mgd, include the following:

- trash rack
- supplemental grit removal
- bar screens
- grit removal
- complete-mix aerated lagoons
- partial-mix lagoons (aeration in upstream portion only)
- filtration
- chlorination and dechlorination

Ultraviolet (UV) disinfection equipment, located downstream of the filters, was added as part of the 1992 upgrades but presently is not used. Citing maintenance requirements and disinfection effectiveness issues (related to high algae loading to the filters and resulting high effluent turbidity), the private contractor operating the plant in 1996 reinstated the use of gaseous chlorine and sulfur dioxide for chlorination/dechlorination and abandoned the UV equipment in place.

Essentially no nitrification occurs at the lagoon-based NIWTP. Requirements for nitrification were included in a pre-draft permit being prepared for the facility transmitted February 8, 2000,

from EPA Region IX to the co-permittees. Recognizing the downstream use of effluent discharged to the Santa Cruz River as a source of potable supply, denitrification also may be required. Upgrades to the plant's filters currently are under design. Design of additional improvements to the plant, including nitrogen removal and possible replacement/reinstatement of UV disinfection equipment, is expected to begin later in 2000.

1.3.4 NIWTP Flows to Receiving Water and Reuse

The NIWTP discharges all of its effluent to the Santa Cruz River at one outfall, serial number 001. Effluent is not reused, and no plans for reuse currently exist. Daily discharge data are available in electronic format for 1992 through 1997 and January 2000 through the present. Hard copy daily data are available for 1998 and 1999. In 1997, the most recent full year for which electronic data are available, the plant's discharge averaged 10.9 mgd.

1.4 PHYSICAL DATA OVERVIEW

This section summarizes available historic hydrologic and geomorphology data. A summary of the geomorphology site reconnaissance effort is also included.

1.4.1 Hydrologic Data and Geomorphology Summary

The NIWTP discharges approximately 15 mgd of effluent into the Santa Cruz River. Streamflow statistics for nearby USGS flow gages indicate that the mean monthly streamflow just above Nogales Wash ranges from 1 cubic foot per second (cfs) (June) to 87 cfs (August) and that mean monthly streamflow just below Nogales Wash ranges from 2 cfs (June) to 27 cfs (August). Mean monthly flows for these two points, as well as the gauged points of record (PORs), are presented on **Figure C-2-2**. A summary of the hydrologic and hydraulic data availability is shown in Table C-2-5.

Table C-2-5
Available Hydrologic and Hydraulic Data for the Santa Cruz River Near Nogales, Arizona

Gage ID	Gage Name	Average Daily Flow POR	Annual Peak Daily Flow POR	Partial Duration Peak Daily Flow POR	Stage-Discharge Relationship Availability
09480500 (upstream)	Santa Cruz River near Nogales, AZ	1913 - 1991	1930 - 1996	1930 - 1994	1982 - 2000
09481740 (downstream)	Santa Cruz River at Tubac, AZ	1995 - 1998	NA	NA	1995 - 2000

Hydrologic controls upstream of Nogales appear to be primarily irrigation withdrawals and return flows. A dam on the Santa Cruz ("Kino Springs") was identified near Nogales in the National Inventory of Dams (U.S. Army Corps of Engineers [USACE] Internet site).

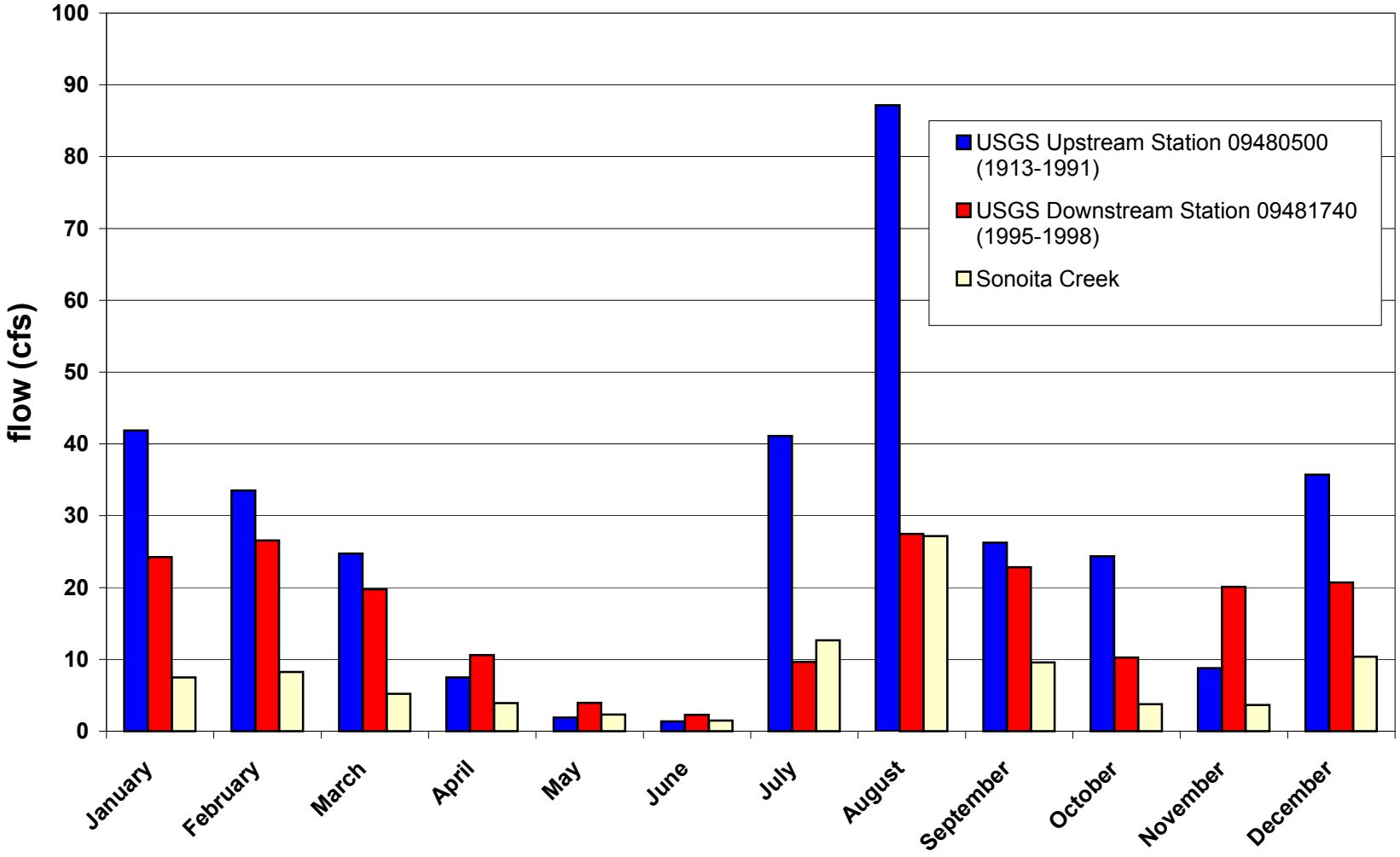


Figure C-2-2
WQRP Habitat Characterization Study
Mean Monthly Streamflow Santa Cruz River
NIWTP

A 1995 ADEQ study found channel widths in the Santa Cruz River to generally increase with downstream distance in this portion of the watershed (near Nogales). Bank widths were measured from approximately 150 feet near Guevavi Ranch (5.5 miles upstream of the confluence with Nogales Wash) to approximately 250 feet north of Tubac (16 miles north of the confluence with Nogales Wash). Channel widths were measured from approximately 15 feet to 70 feet over the same reach. Flow depth rarely exceeds 0.5 foot in this reach and the channel shape is generally rectangular with a vertical bank slope. Bed material is reported as loose sand (ADEQ 1995).

Air temperature and precipitation data were recorded in Nogales at NCDC station number 8865 (refer to **Figure C-2-1**) from 1948 through 1998. The estimated average annual precipitation in this area is 16.3 inches. The estimated average temperature in this area is 64 degrees Fahrenheit (°F), the minimum daily temperature is 5°F, and the maximum daily temperature is 113°F Table C-2-6 presents the average monthly precipitation and temperature. Table C-2-7 presents minimum, mean, and maximum daily temperatures.

Table C-2-6
Mean Monthly Precipitation and
Maximum Daily Precipitation near Nogales, Arizona

NCDC Station 8865 (1948-1998)		
Month	**Mean Monthly Precipitation (Inches)**	**Maximum Daily Precipitation (Inches)**
January	1.1	2.25
February	0.9	1.90
March	0.9	1.95
April	0.3	0.80
May	0.2	1.03
June	0.4	1.31
July	3.9	2.91
August	3.8	3.47
September	1.6	2.80
October	1.0	3.63
November	0.7	3.25
December	1.4	3.20
Annual Precipitation Total (inches)	16.2	

Table C-2-7
Mean, Maximum, and Minimum Monthly Temperature
Near Nogales, Arizona

NCDC Station 8865 (1948 - 1998)			
Month	**Minimum Temperature (°F)**	**Mean Temperature (°F)**	**Maximum Temperature (°F)**
January	8	49	89
February	11	51	92
March	15	55	95
April	25	61	100
May	28	68	109

Table C-2-7
Mean, Maximum, and Minimum Monthly Temperature
Near Nogales, Arizona

NCDC Station 8865 (1948 - 1998)			
Month	**Minimum Temperature (°F)**	**Mean Temperature (°F)**	**Maximum Temperature (°F)**
June	38	78	113
July	42	81	113
August	47	79	108
September	36	75	108
October	21	66	104
November	16	56	93
December	5	50	88
Min/Mean/Max	5	64	113

1.4.2 Geomorphological Site Reconnaissance Summary

The Santa Cruz River at the NIWTP drains an area of approximately 540 square miles, approximately 348 square miles of which are in Mexico. The climate is semi-arid, with hot summers, cool winters, and mean annual precipitation of approximately 16.2 inches. The Santa Cruz River drainage basin above Nogales and contributions downstream to Chavez Siding Road are in the Basin and Range Physiographic Province, characterized by fault-block mountains separated by valley fill alluvium. Along the reach north of Nogales, the river and its tributaries incise moderately cemented fan deposits of Tertiary age; alluvium within 325 feet of the river is generally of Holocene age and reflects recent conditions of fluvial-sediment transport and deposition.

A site visit was conducted on May 3, 2000 to collect data at the following five sites within the study area (all shown on **Figure C-2-1**):

- Site 1 – Immediately upstream of the NIWTP discharge; site was dry on the day of sampling.
- Site 2 – Immediately downstream of the NIWTP discharge.
- Site 3 – At Rio Rico, 1.5 miles downstream of the NIWTP discharge.
- Site 4 – At Bridge Road crossing.
- Site 5 – At Chavez Siding Road crossing, 16 miles downstream of the NIWTP discharge.

Morphometric data from the visited reach are presented below and in Table C-2-8.

Table C-2-8
Morphometric Data from Santa Cruz River Near NIWTP

	Site 1	Site 2	Site 3	Site 4	Site 5
Site description	NIWTP Upstream	NIWTP Downstream	Rio Rico Rd.	Bridge Rd.	Chavez Siding
Discharge (cfs)	17.7	17.7	17.7	31.8	45.9
Bed load texture	Fine to medium sand	Fine to medium sand	Coarse sand	Coarse sand to fine gravel	Medium to coarse sand
Channel texture	Gravel to cobble	Gravel to cobble	Coarse sand	Coarse sand	Coarse sand
Bank texture	Fine sand to gravel	Fine sand to gravel		V. fine sand	Fine to medium sand
Sinuosity	1.04	1.04	1.04	1.03	1.02
Channel gradient	0.0035	0.0035	0.0036	0.0033	0.0029
Channel width (ft)	138	197	39	39	14.8
Channel depth (ft)	1.0	1.0		2.0	
Channel incision (ft)			6.2	5.3	3.9
Floodplain width (ft)			482	433	182
Floodplain bank height (ft)			6.6		
Channel vegetation	Absent	Absent	Absent	Minor	Absent
Floodplain vegetation	Cottonwood/ willow	Cottonwood/ willow	Cottonwood/ willow	Cottonwood/ willow	Cottonwood/ willow w/saltcedar, grass
Terrace vegetation	Cottonwood/ willow		Mesquite	Cottonwoods and mesquite	

1.4.2.1 Reach Streamflow

Streamflow of the Santa Cruz River in recent years at Site 1, immediately upstream from effluent inputs, has been ephemeral, occurring no more than 10 percent of the time and averaging less than 20 cfs. Estimated effluent input to Site 2 at the time of field inspection (May 3, 2000) was 50 cfs. At Sites 3 (Rio Rico Road), 4 (Bridge Road), and 5 (Chavez Siding Road), respectively, estimated discharges in the Santa Cruz River were 20, 30, and 45 cfs. It is inferred that the latter two estimates are the results of effluent inputs below Rio Rico and additions by irrigation returns or possibly flow remaining of larger release rates from the NIWTP the preceding day. At a gage Site at Tubac (Site 4, Bridge Road), streamflow in May typically is approximately 7 cfs, whereas at Continental, approximately 19 miles farther downstream, the Santa Cruz River channel ordinarily is dry throughout May. Thus, present streamflows along this reach of the Santa Cruz River suggest highly ephemeral conditions above the NIWTP, transmission loss of discharge wherever streamflow occurs, and local increases in streamflow due to other sources of wastewater and irrigation-return flow.

1.4.2.2 Site 1 and 2 Field Observations

North of Nogales at Sites 1 and 2, sewage effluent enters a single, flood-dominated channel of the Santa Cruz River that has a bed mostly of medium-grained sand; less than 5 percent of the bed material appears to be finer than sand and a larger fraction, approximately 30 percent, is in the gravel and cobble range. Bank material is as coarse as gravel but is largely fine sand.

Sinuosity is 1.04 and channel gradient is 0.0035. Channel widths at Sites 1 and 2 are 138 and 197 feet, respectively, and do not signify adjusted conditions owing to modifications including the effluent channel, a railroad bridge and embankment, and other bottomland disturbances. Channel depths average 1.0 foot. At both sites several surfaces are suggestive of modern floodplain, old (pretreatment plant) floodplain, and one or more terraces; the lower surfaces support several small cottonwood trees, a few willows, and Bermuda grass. Evidence of erosion along the channel, deposition of sand on floodplain and terrace surfaces, and flood debris, mostly logs and limbs, indicates that this reach of the Santa Cruz River has been altered significantly by one or more recent floods.

At Site 2 both banks are erosional, the left bank being the more resistant owing to natural cementation of the overbank deposits. Sediment transport is minor, most being suspended with a small amount of bed load movement as fine to medium sand. Consequently, bedforms are largely absent and channel activity is minimal. Sediment-free wastewater inputs have caused a small amount of channel cutting, and a tendency for this incision has extended upstream as well toward Site 1 and the railroad bridge.

1.4.2.3 Site 3 Field Observations

The Santa Cruz River at Rio Rico Road (Site 3) has a channel gradient of 0.0036, a sinuosity of 1.04, and is 39 feet wide and inset into an apparent floodplain approximately 482 feet across. Alluvial terrace borders the floodplain and is 6.6 feet higher. The floodplain is 6.2 feet higher than the thalweg, suggesting that channel incision has occurred, thereby elevating the floodplain relative to the channel. The median size of bed material is coarse sand; the silt-clay fraction is less than 10 percent, and the gravel cobble component is approximately 40 percent. The channel in this reach is unstable, exhibiting ripples, dunes, mid-channel and longitudinal bars, and a poorly defined thalweg. Even at low-flow conditions there is substantial bed instability and moderate bed load of medium to coarse sand. Although there are few channel islands, lee-side deposition of bed load is active at many minor protuberances from the channel bed. Bars are active and highly ephemeral but the banks are relatively stable, showing only occasional failures and erosion. Channel vegetation is absent but grasses, willows, and cottonwoods are common on the floodplain; terrace surfaces have mesquites.

1.4.2.4 Site 4 Field Observations

The channel width at Bridge Road (Site 4) is 39 feet and the distance between floodplain edges is 433 feet. The gradient is 0.0033 and the sinuosity is 1.03. Channel depth is 2.0 feet and thalweg depth below floodplain level is 5.2 feet, suggesting less incision than at Site 3. Both sides of the channel have been much disturbed, but the bottomland is generally stable. Bed material is mostly coarse sand, with a smaller amount of gravel and little fine sediment, and bank material is dominated by fine sand. Bed load is substantial and is composed largely of coarse sand and fine gravel, resulting in dunes, bars, channel islands, and minor pool-riffle sequences. Channel vegetation is minor. An active channel shelf supports thick willows and young cottonwoods, the floodplain has older cottonwoods, and terraced areas have mature cottonwoods and mesquites.

1.4.2.5 Site 5 Field Observations

Presumably because of transmission loss and thus flow reductions, the channel width at Chavez Siding Road (Site 5) is only 14.8 feet. The combined channel and floodplain width is 197 feet, and the channel depth below the floodplain is 3.9 feet. Channel gradient is 0.0029 and the sinuosity is 1.02. Bed material is mostly coarse sand and includes lesser amounts of gravel and finer sand and silt. Bank material is largely fine to medium-grained sand. The Santa Cruz River channel is very active at Site 5, showing much bed load of medium to coarse sand and therefore ripples, dunes, and a poorly defined thalweg. Vegetation is absent in the channel but floodplain areas support many willows, salt cedars, grasses, and some cottonwoods. Banks are generally stable and lack slumps or other failures; channel islands are absent. High-water channels that cut the right floodplain are indicative that channel incision is occurring despite a concrete bed control at the road crossing. If so, the floodplain at this site, as at upstream sites, is becoming a terrace. Support for this inference is that vegetation is much more suggestive of a terrace environment than of a floodplain.

1.5 PHYSICAL ANALYSIS

1.5.1 Flow Assessment

Figure C-2-3 presents the average daily flow versus time for the NIWTP and USGS gages upstream and downstream of the NIWTP. **Figure C-2-4** shows the mean annual flow for the USGS gages upstream and downstream of the NIWTP and from the NIWTP itself.

The mean monthly streamflow upstream and downstream of NIWTP and the mean monthly NIWTP discharge are plotted on **Figure C-2-5**. The average monthly flow from the NIWTP is fairly constant during the year, unlike the streamflows, which vary significantly upstream of the plant. The peak flows upstream and downstream of the NIWTP occur in August, and the low flows occur in June. The peak flow pattern is consistent with the peak rainfall observed at the climate station near Nogales (NCDC 8865). **Figure C-2-5** shows that, for portions of the year, the flows at the downstream gage (09481740) are less than the combined flow of the Ina and Roger Road wastewater treatment plants (WWTPs). This is an indication that this portion of the stream is losing flow to the groundwater systems or other withdrawals. Several months have an upstream flow that is higher than the downstream flow. This is not a trend that is expected in arid West streams. The reason for the higher upstream flow is most likely due to the difference in PORs between the upstream and downstream gages. The upstream gage has almost 100 years of data, whereas the downstream gage has only 3 years of data.

Log Pearson Type III flood frequency analysis was performed for the Santa Cruz USGS stream gage (09480500), which is located upstream of the NIWTP (**Figure C-2-6**). The analysis estimates that the 2-year flood event is approximately 5,000 cfs, the 10-year flood event is approximately 10,000 cfs, the 50-year event is close to 20,000 cfs, and the 100-year event is 25,000 cfs. The drainage area for this stream gage is 533 square miles. A flood frequency analysis was not performed on the USGS stream gage located downstream of the WWTP due to the short POR.

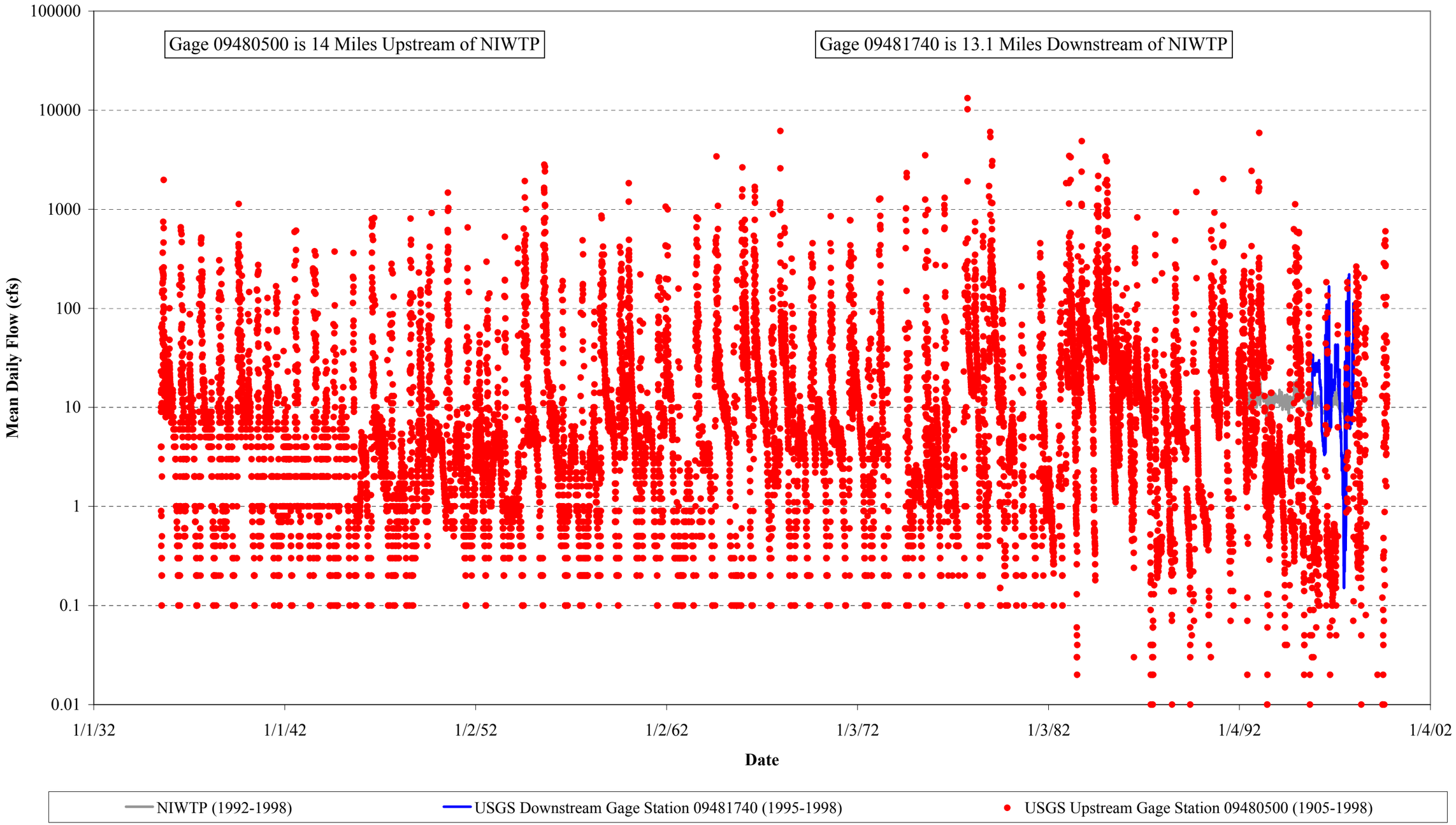


Figure C-2-3
Mean Daily Flow Values
Santa Cruz River Near Nogales, Arizona

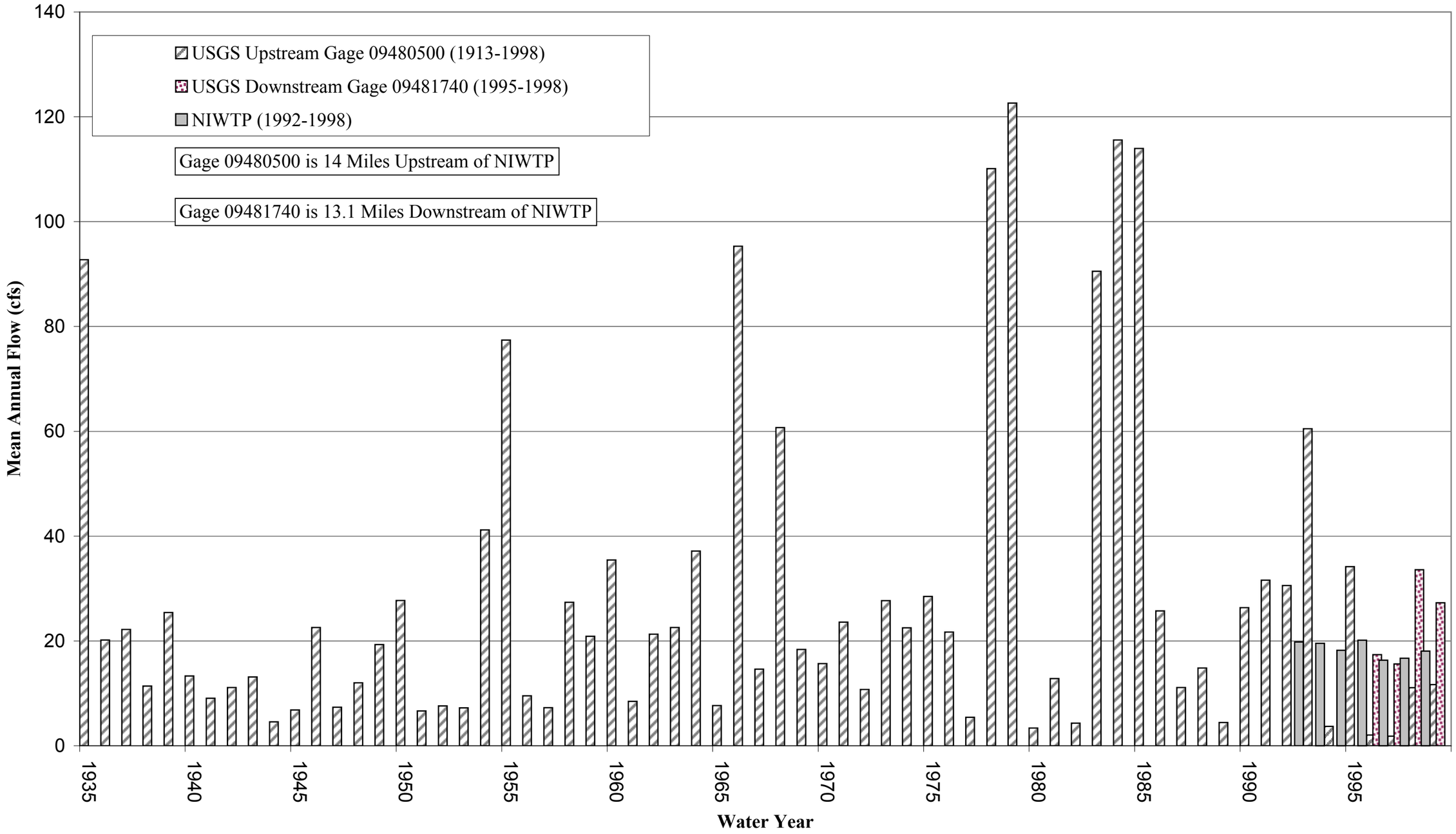


Figure C-2-4
Mean Annual Flow Values
Santa Cruz River Near Nogales, Arizona

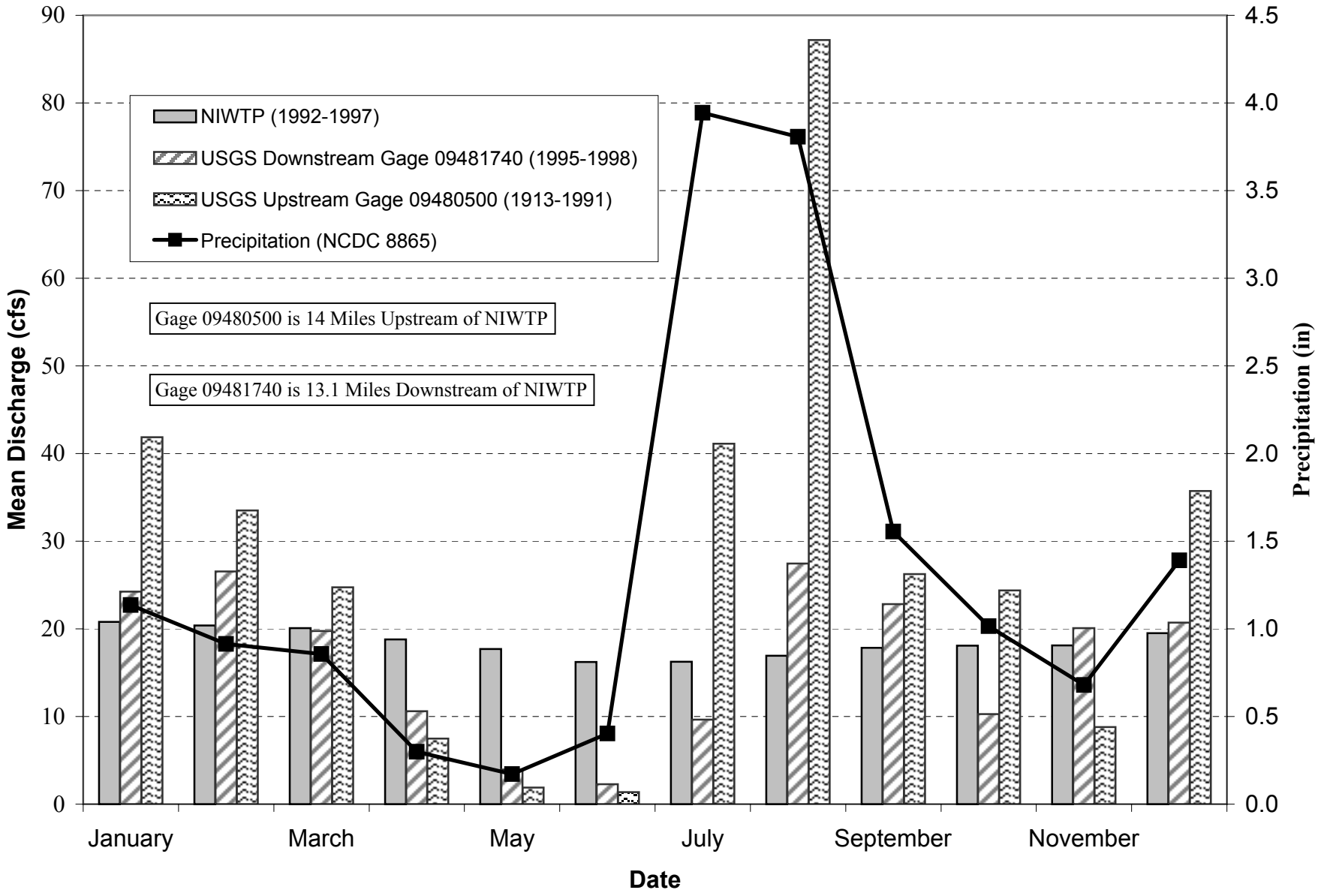


Figure C-2-5
Mean Monthly Flow Values
Santa Cruz River Near Nogales, Arizona

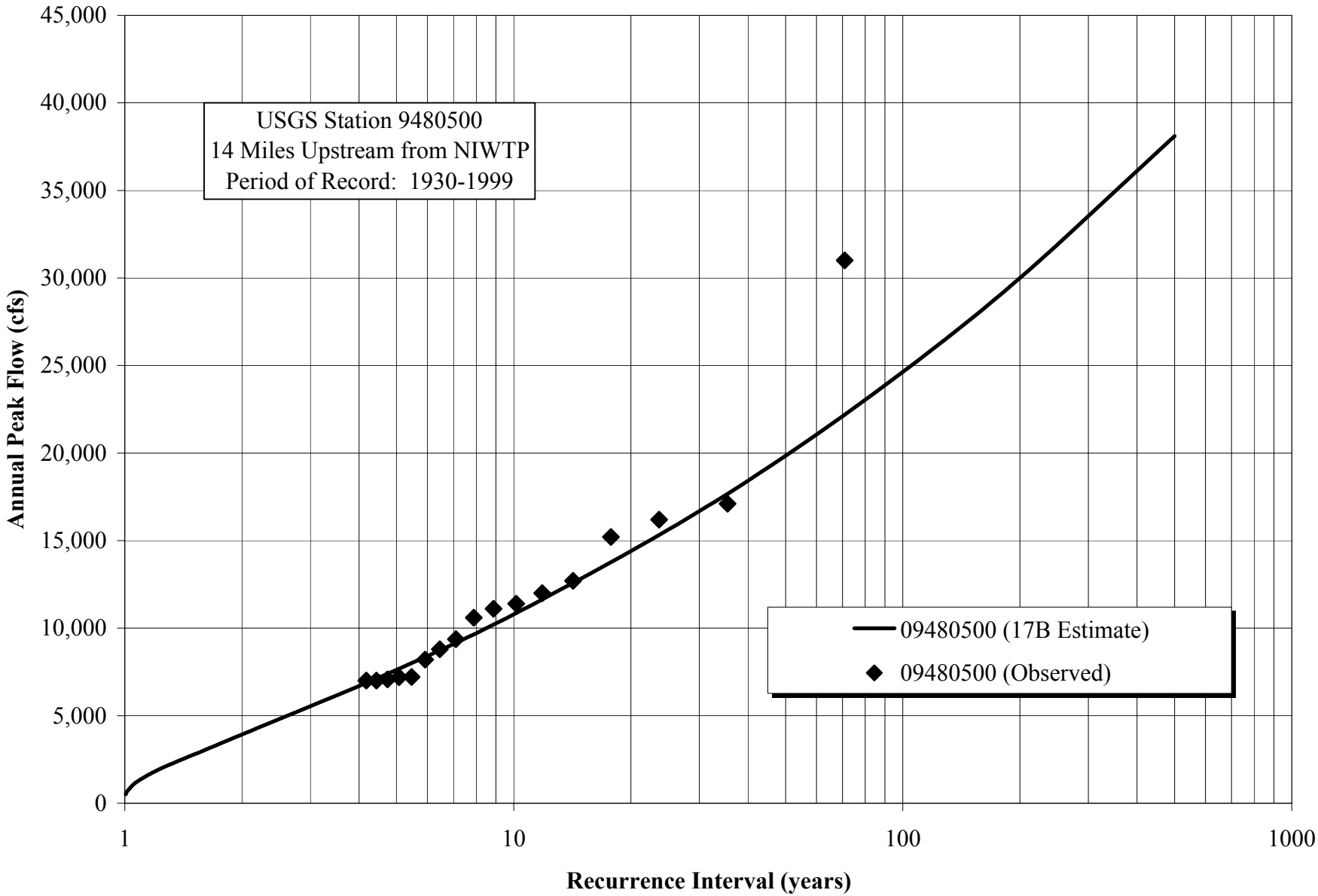


Figure C-2-6
Annual Peak Flow Frequency Analysis
Santa Cruz River Near Nogales, Arizona

Log Pearson Type III low-flow frequency analysis was performed for the Santa Cruz USGS stream gage located downstream of the NIWTP (**Figure C-2-7**). The analysis was only performed on the downstream gage because the recurrence interval of 0 flow is less than 1 year for the 30-day, 7-day, and 1-day durations at this location. The low flow analysis predicts a 3-year low flow of approximately 0.7 cfs for a 1-day duration period, 0.9 cfs for a 7-day duration period, and 3 cfs for a 30-day duration period. The 10-year low flow is estimated at 0.15 cfs for a 1-day duration period, 0.2 cfs for a 7-day duration, and 0.5 cfs for a 30-day duration. It should be noted that POR for this gage is only four years and that additional years of data may be needed to establish long-term frequency information.

In addition to flood frequency and low-flow frequency analysis, flow duration curves were used to establish the percent of time that mean daily flows occur. The flow was analyzed on a daily, 7-day, and 30-day duration of occurrence. **Figures C-2-8, C-2-9, and C-2-10** show the duration frequency curves for USGS upstream of the NIWTPs (09480500). These curves show the percent of time that a given flow occurs. For example, **Figure C-2-8** shows that the daily flow in the Santa Cruz River upstream of the Roger Road WWTP is less than or equal to 10 cfs 75 percent of the time. **Figures C-2-8, C-2-9, and C-2-10** also show cumulative frequency curves during different periods of time. **Figures C-2-8, C-2-9, and C-2-10** also show that in recent decades (1981 to 1999) upstream of the NIWTP, flow occurred more frequently than in early decades. For example, as shown on **Figure C-2-8** a flow of 20 cfs or more in the Santa Cruz River upstream of the NIWTP occurred 86 percent of the time during 1935 through 1980, and 25 percent of the time during 1981 to 1999.

Figures C-2-11, C-2-12, and C-2-13 show the frequency duration curves for the USGS gages downstream of the NIWTP. **Figures C-2-14, C-2-15, and C-2-16** show the frequency duration curves for upstream and downstream of the NITWP for recent history and also include frequency duration of the NITWP flows.

1.5.2 Depth and Velocity

The project team used USGS stage discharge relationship data to establish power equations relating discharge, velocity, and depth for USGS gage 09480500 (upstream of the NIWTP) and 09481740 (downstream of the NIWTP). From these relationships and the maximum mean daily flow for each gage, the maximum velocity to occur upstream and downstream of the NIWTP is shown in Table C-2-9. Velocities and depths that occur 50 percent and 80 percent of the time are also presented in Table C-2-9.

Table C-2-9
Velocities and Depths of the Santa Cruz River Near Nogales

USGS Gage	Max Velocity	Velocity and depth that occur 50% of time	Velocity and depth that occur 80% of time
09480500 (upstream of NIWTP)	11 ft/s	1.1 ft/s and 0.3 ft	0 ft/s and 0.3 ft
09481740 (downstream of NIWTP)	3 ft/s	1.5 ft/s and 1 ft	1.7 ft/s and 0.5 ft
ft/s = feet per second			

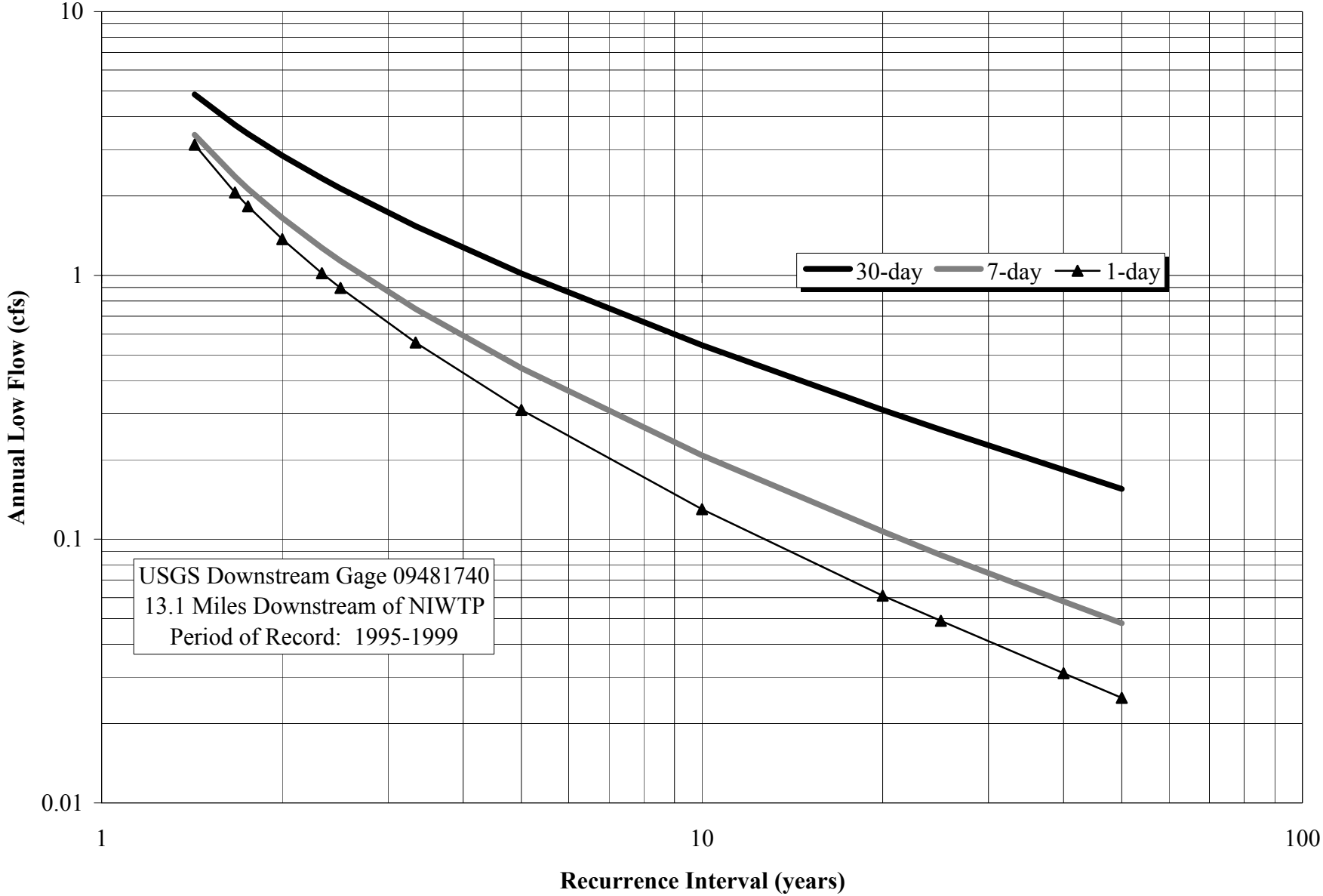


Figure C-2-7
Low Flow Duration Frequency Analysis
Santa Cruz River Near Nogales, Arizona

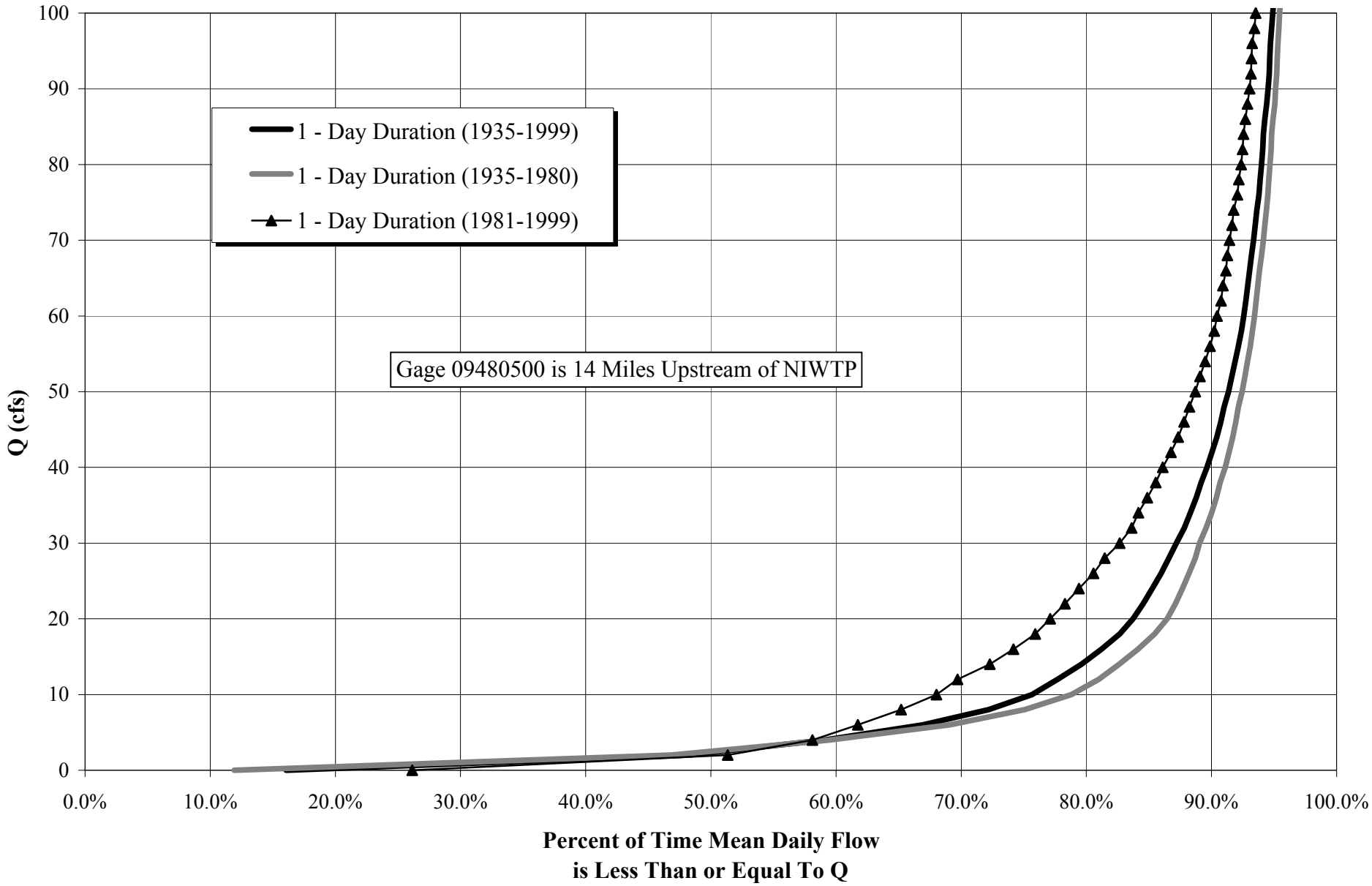


Figure C-2-8
Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09480500
Santa Cruz River Near Nogales, Arizona

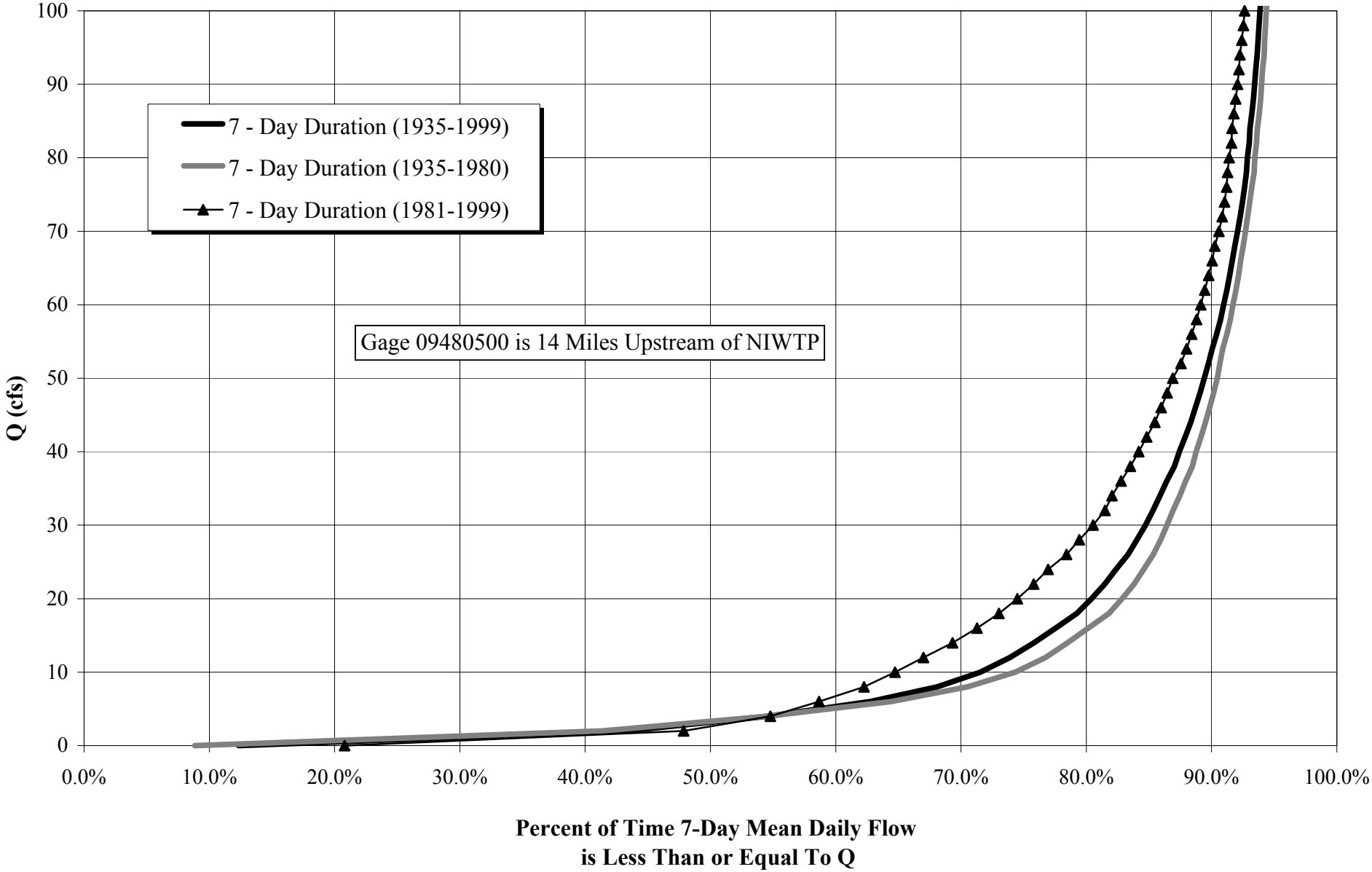


Figure C-2-9
7-day Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09480500
Santa Cruz River Near Nogales, Arizona

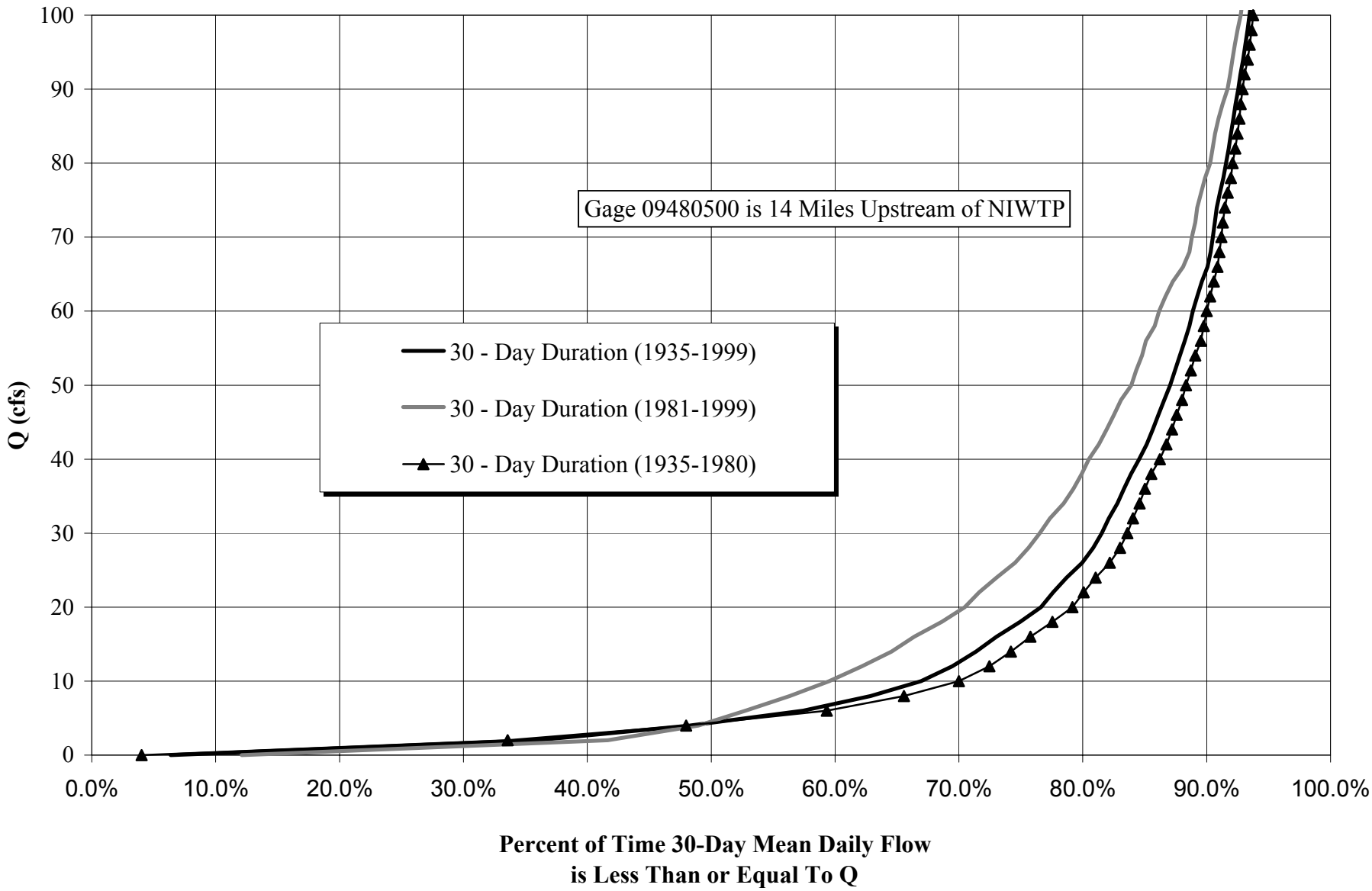


Figure C-2-10
30-day Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09480500
Santa Cruz River Near Nogales, Arizona

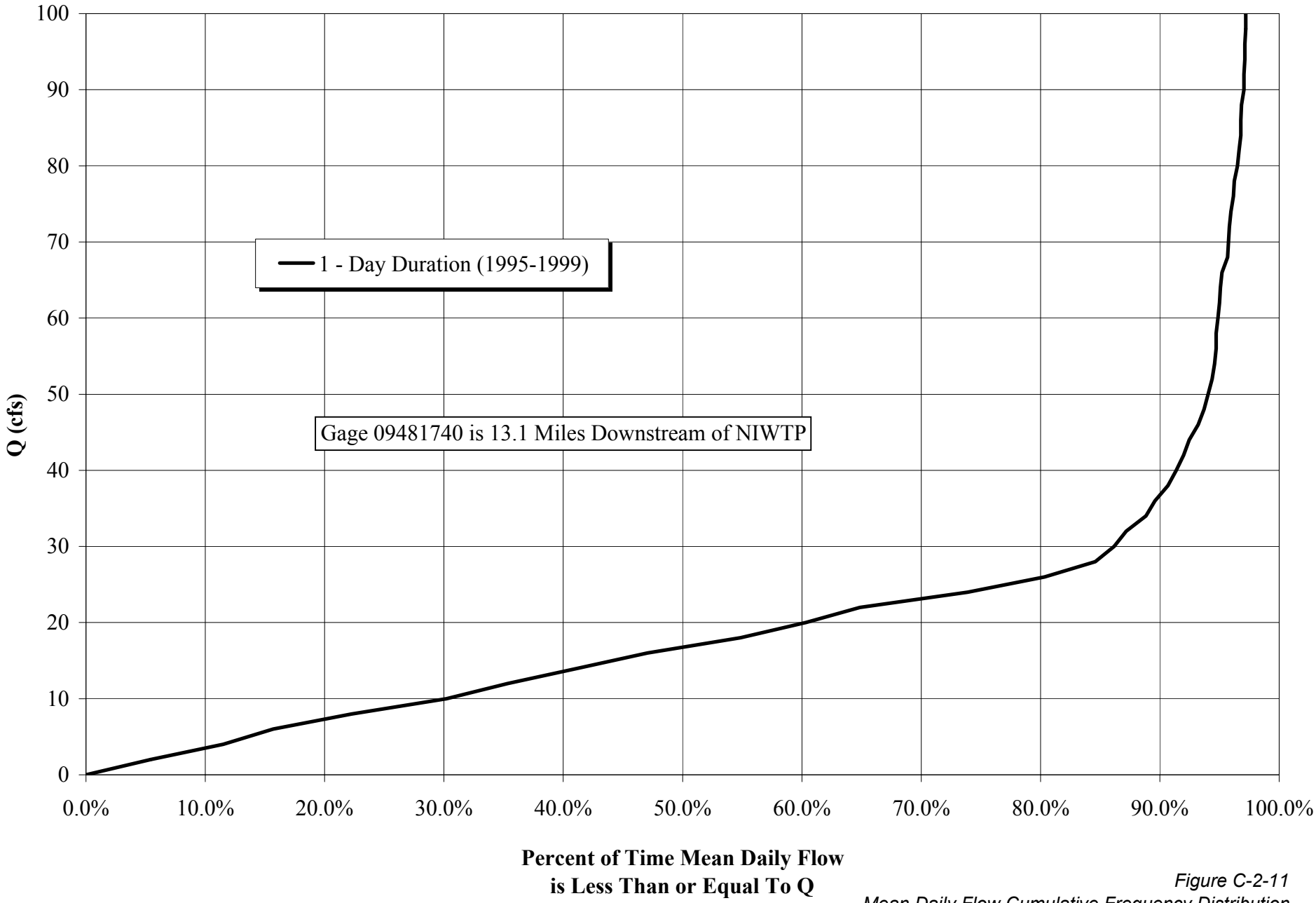


Figure C-2-11
Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09481740
Santa Cruz River Near Nogales, Arizona

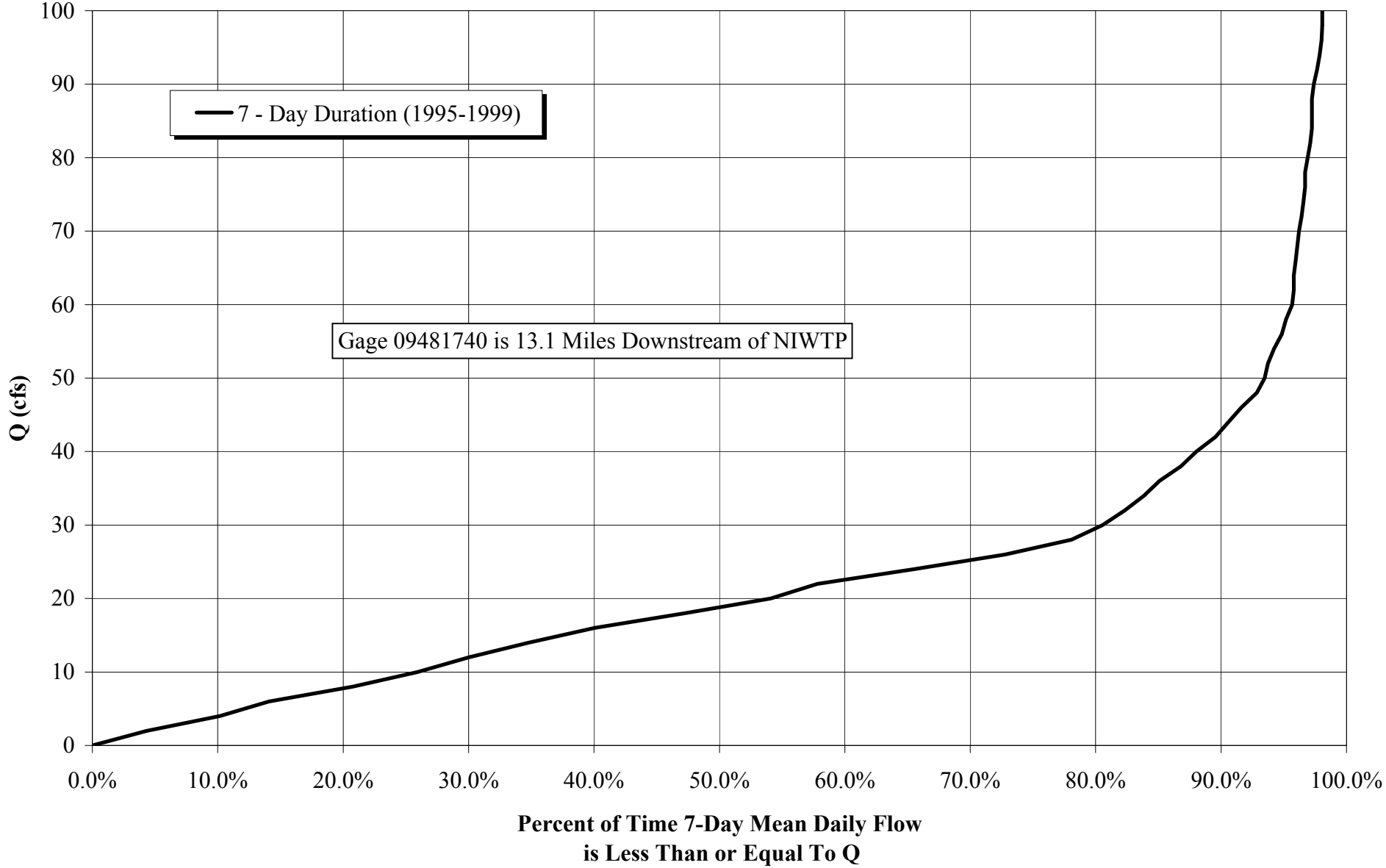


Figure C-2-12
7-Day Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09481740
Santa Cruz River Near Nogales, Arizona

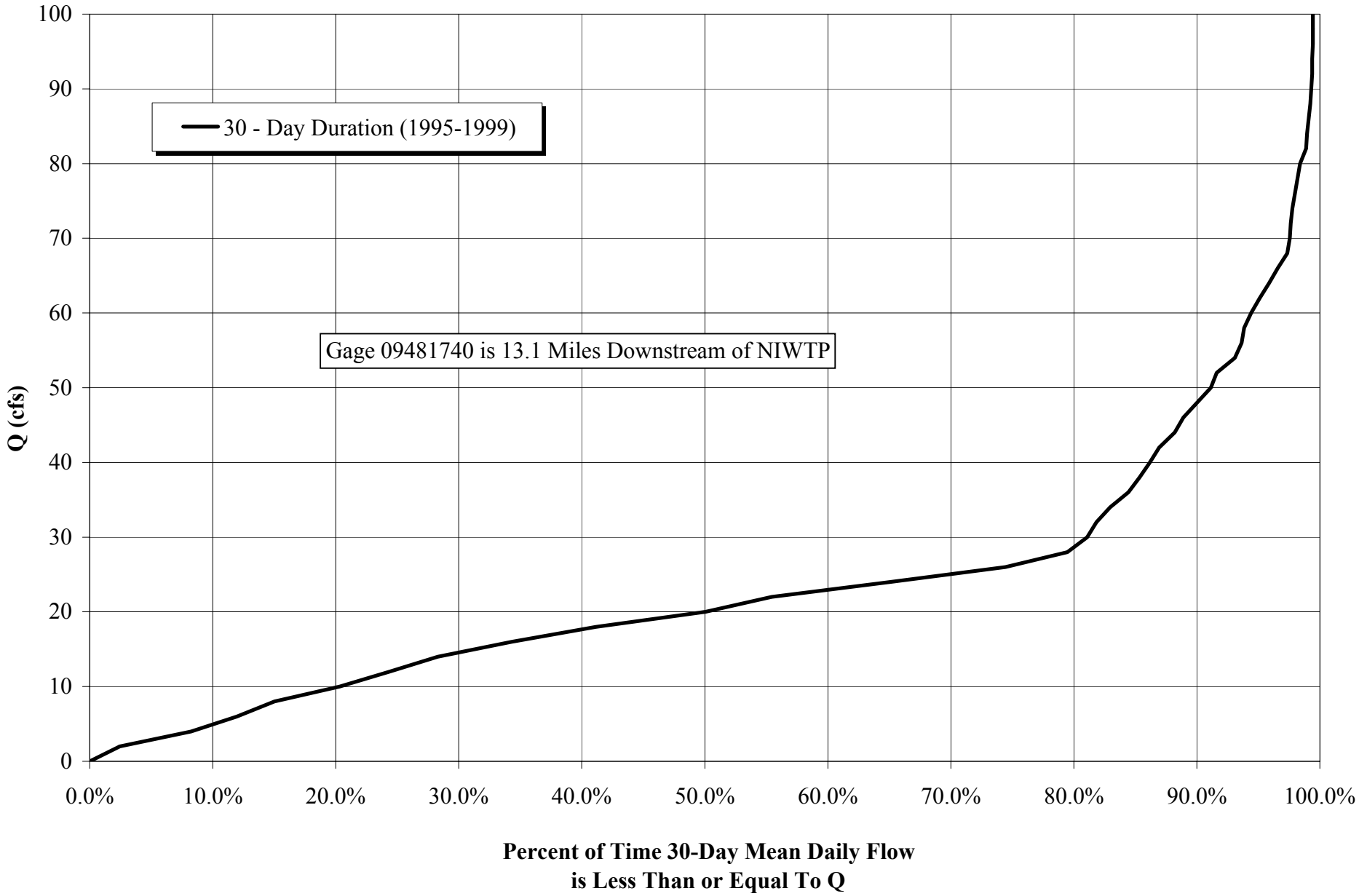


Figure C-2-13
30-day Mean Daily Flow Cumulative Frequency Distribution
USGS Station 09481740
Santa Cruz River Near Nogales, Arizona

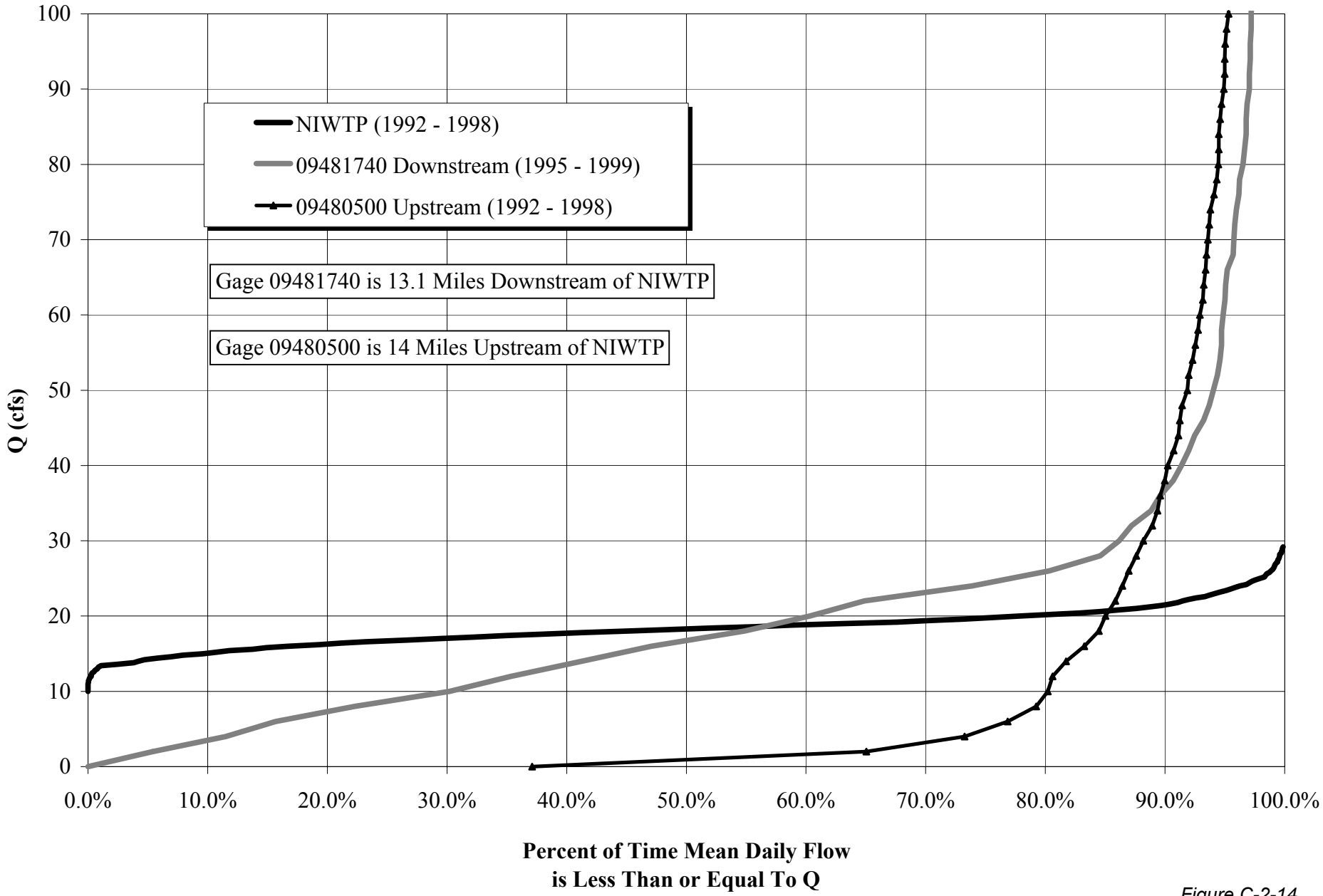


Figure C-2-14
Mean Daily Flow Cumulative Frequency Distribution
NIWTP and Upstream and Downstream Gages
Santa Cruz River Near Nogales, Arizona

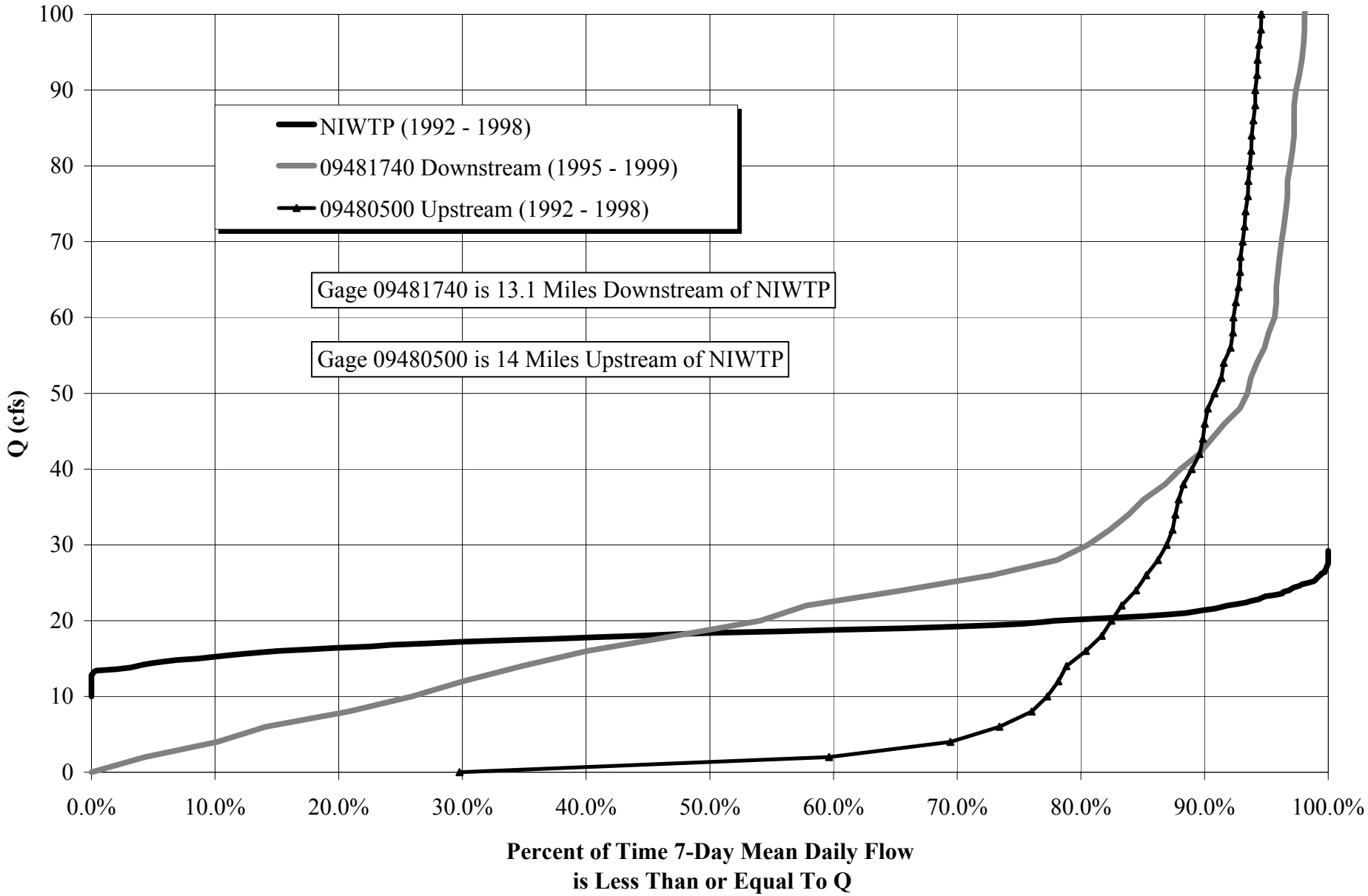


Figure C-2-15
7-day Mean Daily Flow Cumulative Frequency Distribution
NIWTP and Upstream and Downstream Gages
Santa Cruz River Near Nogales, Arizona

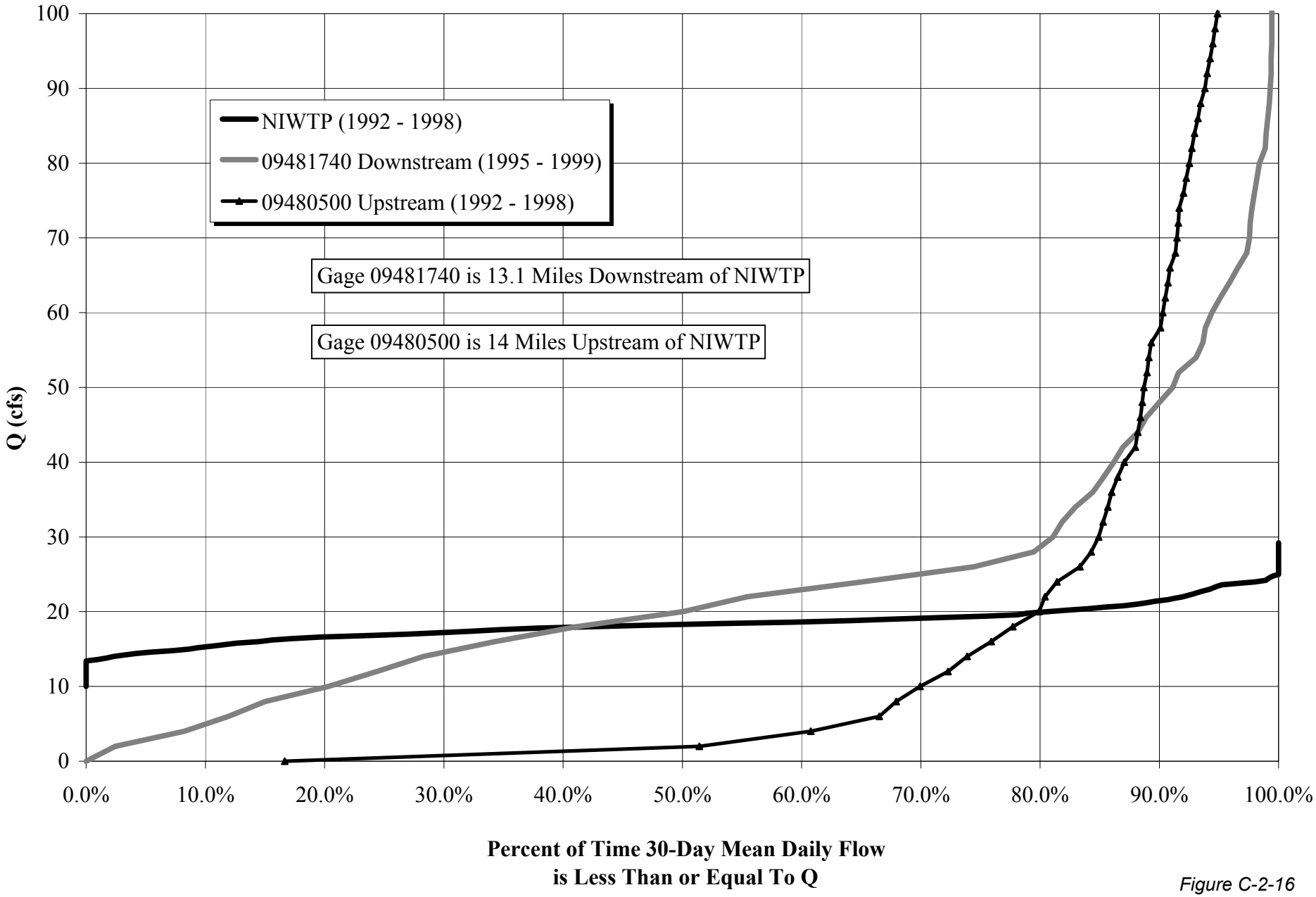


Figure C-2-16
30-day Mean Daily Flow Cumulative Frequency Distribution
NIWTP and Upstream and Downstream Gages
Santa Cruz River Near Nogales, Arizona

Using the classification provided by Novotny and Olem (1997) the Santa Cruz River near Nogales could be categorized as a fast and shallow stream.

1.6 CHEMICAL DATA OVERVIEW

The following two historical chemical data summaries were identified as relevant for the Santa Cruz River near Nogales, Arizona:

This study area was included in the Central Arizona Basins National Water Quality Assessment (NAWQA) report (USGS 1999). There were no sampling stations upstream from the NIWTP included in the NAWQA study. The downstream NAWQA sampling station was located at Tubac, Arizona, approximately 16 miles from Nogales. This sampling station was designated as a basic fixed site and was sampled on a monthly basis for major ions, nutrients, organic carbon, and suspended sediment from October 1995 to September 1997.

- An intensive survey of the upper Santa Cruz River was completed between 1992 and 1993 (Lawson 1995a, 1995b). It included sampling the Santa Cruz River at five fixed stations. One station was located upstream from the NIWTP (5.5 miles) and four were located downstream from the NIWTP (1.5, 7.5, 9.5, and 16 miles, respectively). The five stations were sampled monthly, by either ADEQ or ADEQ-trained volunteers, for field parameters, major ions, nutrients, total metals, and biological indicators; and quarterly for filtered metals. This study did not include analysis for organics, pesticides, or human pathogens. Their findings were that the upper Santa Cruz River was impacted by the NIWTP; however, the water quality was found to increase with distance.

Station number 800000000028170 was sampled for physical parameters, nutrients, trace elements, major ions, and biological parameters. Extensive amounts of data were available for all constituent categories except biological parameters. The POR for this station is August 1986 through September 1992.

Station number 800000000028190 was sampled for physical parameters, nutrients, major ions, and biological parameters; however, only minimal data were available for these constituent categories. The POR for this station for the physical parameters, nutrients, and major ions is April 1973 though July 1984. The POR for the biological parameters lasted one month only, September 1992.

For the data analysis phase of this project, historical data from two sampling stations—800000000028170 and 800000000028190—are used. The data were retrieved from EPA's *STORET* database. Table C-2-10 summarizes the records for these stations.

Table C-2-10
Summary of Records Available for the Santa Cruz River Near Nogales, Arizona

Parameter Category	800000000028170		800000000028190	
	POR	Description	POR	Description
Physical Parameters	8/86 - 9/92	Substantial records for all parameters except OH ions and turbidity	4/73-7/84	Minimal data available
Nutrients	8/86 - 9/92	Substantial records for all parameters except nitrogen (NO_3)	4/73-7/84	Minimal data available
Trace Elements	8/86 - 9/92	Substantial records for boron, manganese, zinc		None Available
Major Ions	8/86 - 9/92	Substantial records for all parameters	4/73	Minimal data available
Organics		None Available		None Available
Sediments		None Available		None Available
Biological	8/86 - 9/92	Minimal data available	9/92	Minimal data available
Radiological		None Available		None Available
Isotopical		None Available		None Available

All of the sample results for the four sampling stations described above were collected and analyzed by ADEQ; thus, it is believed that EPA-acceptable methods and quality control procedures were adhered to during sampling and analysis.

1.7 CHEMICAL ANALYSIS

Four stations were used in the chemical analysis of this study area. One station was upstream from the NIWTP (09480500), and three were downstream from the NIWTP (800000000028190, 800000000028170, and 09481740). Table C-2-11 contains a qualitative description of the chemical data available at these stations. A more thorough summary of the data available is located in **Appendix L**.

Table C-2-12 summarizes the data quality assessment for the Nogales study area. Overall, the data quality for this study area is rated as marginal.

For station 09480500, only one of the four assessment methods (specific conductivity versus total dissolved solids [TDS]) could be completed because of the lack of adequate data. This assessment method indicated that the data quality was good for this station based on eight sets of data.

For station 800000000028190, only one of the four assessment methods (specific conductivity versus TDS) could be completed due to the lack of data. This assessment method indicated that the quality of the data was good for this station based on one set of data.

For station 800000000028170, all four assessment methods could be completed. Three of the four assessment methods (major ion charge balance, measured TDS versus calculated TDS, and anions/cations to specific conductivity) indicated that the quality of the data was marginal based

on 37, 37, and 38 sets of data, respectively. The remaining assessment method (specific conductivity versus TDS) indicated that the data quality was good based on 39 sets of data.

For station 09481740, only one of the four assessment methods (specific conductivity versus TDS) could be completed. This method indicated that the quality of the data collected at this station was marginal based on two data sets.

Table C-2-11
Brief Summary of the Data Available for the Nogales Study Area

Station	POR	Average Number of Measurements								
		Physical	Nutrients	Major Ions	Trace Elements	Organics	Biological	Sediments	Radiological	Isotopical
09480500 (upstream)	12/67 - 9/81	17	5	8	11	–	1	–	–	3
800000000028190 (downstream)	4/73 - 7/84	2	2	2	1	–	2	–	–	–
800000000028170 (downstream)	8/86 - 9/92	28	25	37	22	–	6	–	–	–
09481740 (downstream)	10/95 - 6/98	13	15	2	2	2	–	–	–	–

Table C-2-12
Data Quality Assessment for the Nogales Study Area

Station ID	Major Ion Charge Balance	Specific Conductance vs TDS	Measured TDS vs Calculated TDS	Anions or Cations to Specific Conductivity
09480500 (upstream)	–	OVERALL: Good (n=8) Good:8 Marginal:0 Poor:0	–	–
800000000028190 (downstream)	–	OVERALL: Good (n=1) Good:1 Marginal:0 Poor:0	–	–
800000000028170 (downstream)	OVERALL: Marginal (n=37) Good:12 Marginal:17 Poor:8	OVERALL: Good (n=39) Good:29 Marginal:8 Poor:2	OVERALL: Marginal (n=37) Good:10 Marginal:8 Poor:19	OVERALL: Marginal (n=38) Good:18 Marginal:13 Poor:7

Table C-2-12
Data Quality Assessment for the Nogales Study Area

Station ID	Major Ion Charge Balance	Specific Conductance vs TDS	Measured TDS vs Calculated TDS	Anions or Cations to Specific Conductivity
09481740 (downstream)	–	OVERALL: Marginal (n=2) Good:0 Marginal:2 Poor:0	–	–

Figure C-2-17 is a Piper diagram for this study area. The data used in the Piper diagram included 29 downstream samples from one location (800000000028170) in which both anion and cation data were available. An additional two samples from one downstream location (800000000028190) in which only anion data were available were also included.

The anion data indicate the waters are predominantly bicarbonate (HCO_3+CO_3). The cation data indicate the waters are enriched in sodium plus potassium (Na+K) and calcium (Ca) relative to magnesium (Mg).

1.8 AQUATIC HABITAT AND SPECIES OVERVIEW

This section provides an overview of the historic records regarding aquatic life and habitat in the Santa Cruz River near Nogales and provides a summary of the site reconnaissance effort.

1.8.1 Historical Data Summary

Other than two documents published prior to 1975 that document historic fish populations in the Santa Cruz River, the historical record is limited to studies conducted since 1990 (**Appendix M**). The recent emphasis on biological studies on the Santa Cruz River downstream of the NIWTP has been driven by concerns on the quality of effluent produced by the then existing NIWTP, the need to upgrade that facility, and concerns about the quality of effluent entering the United States from Mexico. The following is a summary of the identified historical records containing aquatic biology information:

- Miller (1961) summarized the native fish community that originally inhabited the Santa Cruz River as follows:

  > "For many years the Santa Cruz River, intermittent from near Nogales almost to Tucson, rose to the surface shortly above San Xavier Mission, approximately 8 miles south of Tucson. Here on March 29, 1904, Chamberlain obtained five species [of fish]: *Agosia chrysogaster, Gila robusta intermedia, Catostomus insignis, Pantosteus clarki*, and *Poeciliopsis occidentalis*. By April 25, 1937, when Allan R. Phillips sampled this perennial flow, only the resistant *Agosia* remained, and this is the only species that I found there on July 12, 1939. By April 13, 1950, the flow had disappeared, and I was informed by Raymond Hock (then of the University of Arizona) that it went dry for the first time during the

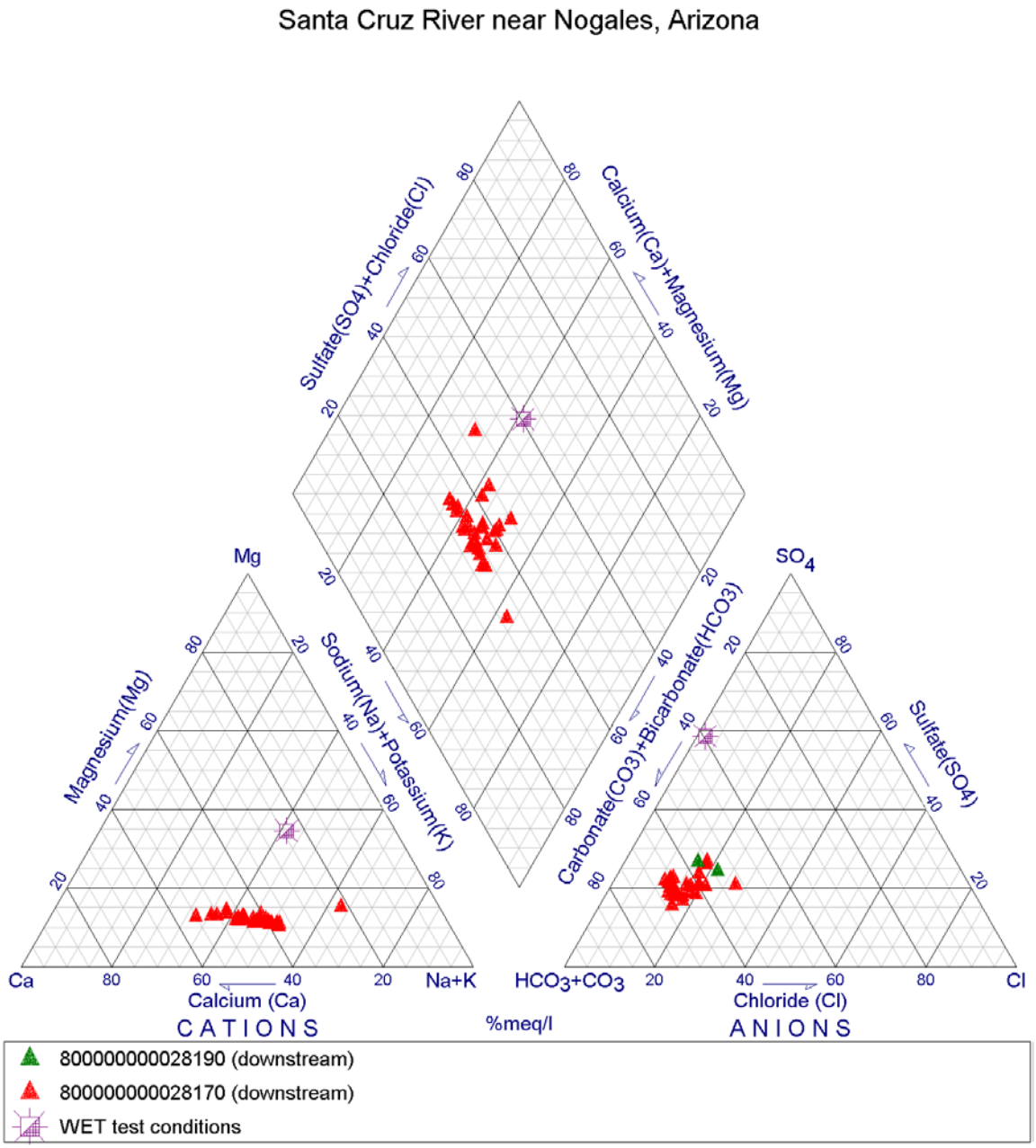


Figure C-2-17
Piper Diagram for the Nogales Study Area

previous winter. Even in early historic times, the Santa Cruz ordinarily had no surface flow from some distance below Tucson to its confluence with the Gila River. It formerly maintained a permanent flow in the headwaters, near Lochiel (Schwalen, 1942, pl. II [Schwalen, H.C., Rainfall and runoff in the Upper Santa Cruz River Drainage Basin, *Univ. of AZ Agr. Expt. Sta., Tech. Bull*. 95:421-472]), but pumping in the San Rafael Valley eliminated this surface water and its fishes (*Gila, Agosia, Poeciliopsis*) between 1950 and 1956 (C.H. Lowe, Jr., personal communication) (Miller, 1961)."

- ADEQ (1990) conducted a brief survey of aquatic invertebrates in the Santa Cruz River at Rio Rico Road to support the development of water quality criteria to protect aquatic organisms resident in effluent-dominated waters. Sampling was limited to the Santa Cruz River at Rio Rico Road (equivalent to Reconnaissance Site 3). No information is provided on the number of samples or methods used to collect macroinvertebrate data. Only a list of taxa was documented; no individual taxonomic abundances are included. This list is documented in **Appendix B**.

- ADEQ (1994) sampled the Santa Cruz River below Nogales in 1994 to document the kinds of aquatic invertebrates present in the effluent-dominated reach. These results are briefly discussed below.

- Lawson (1995a, 1995b) summarized the results of a year-long effort to characterize the chemical and biological characteristics (invertebrates and fish) of the Santa Cruz River downstream of the NIWTP discharge. This work was conducted as a cooperative effort between ADEQ and the Friends of the Santa Cruz, a local volunteer river monitoring organization. The primary purpose of the study was to evaluate water quality in the Tubac, Arizona area 16 miles downstream of the NIWTP discharge to the river. Both chemical and biological data were collected monthly for a period of a year beginning in November 1992. The primary outcome of the study was the following statement:

  "Water quality throughout the study reach was generally good except during a high flow event. Ambient metals concentrations and metals exported to the river through the treatment plant do not appear to be a threat to aquatic life. Nutrients exported to the river from the treatment facility rapidly diminished downstream, but un-ionized ammonia concentrations near the treatment plant had severe impacts on fish populations. The macroinvertebrate community was severely impaired near the treatment plant but recovered somewhat downstream, but not to control site conditions" (Lawson 1995b).

A more complete discussion of the sample sites, methods, and findings of this study relevant to the site reconnaissance effort is included in the following documents:

- Camp Dresser & McKee, Inc. (CDM) (1997) prepared an environmental inventory of the Santa Cruz River watershed in the Nogales, Arizona area in preparation for designing a new wastewater treatment facility in Nogales. Section 6 of the CDM report summarizes the

characteristics of the aquatic biology of the Santa Cruz River downstream of Nogales. No aquatic invertebrate data are included. Fish data were obtained from the U.S. Fish and Wildlife Service (USFWS) (Note: The same data are also published in King et al. 1999 – see below for discussion).

- Wennmacher (1996) prepared a Master of Science thesis that evaluated the chemical, physical, and biological characteristics of the Santa Cruz River to assess use attainability. Emphasis of the study was on the algae community. Chemical and biological samples were collected from September 1992 to June 1994. The study found a total of 82 species of algae representing 43 genera and four divisions. Overall, algal diversity and biomass was found to be low throughout the river, and based on the types of algae present the study concluded that the river is likely moderately to heavily polluted.

- USGS (1998) reported some of the results of the Central Arizona Basins NAWQA study conducted in central and southern Arizona. The 1998 report compared chlorophyll *a* levels and aquatic invertebrate community characteristics of effluent-dependent and non-effluent-dependent streams. Chemical and biological samples were collected in January 1996 near Tubac, Arizona. The conclusion of the study was that "Aquatic-invertebrate communities from effluent-dependent streams were characterized by an abundant, yet taxonomically depauperate fauna of tolerant organisms…water quality of effluent-dependent streams is poor compared with water quality of non-effluent-dependent streams." A more complete discussion of the sample sites, methods, and findings relevant to the site reconnaissance conducted at this site are included below.

- King et al. (1999) summarized the findings of a 1997 study to evaluate levels of contaminants in water, sediment, fish, and birds in the Santa Cruz River downstream of the NIWTP. The study was prompted by declining populations of the endangered Gila topminnow in the Santa Cruz River. Samples were collected from sites upstream and downstream of the NIWTP. In addition to gathering estimates on fish diversity and abundance (see discussion below), results from the study included the following:

  - Independent laboratory toxicity tests run concurrently with the study showed that discharges from the NIWTP were highly toxic to fathead minnows. Un-ionized ammonia was identified as the toxicant responsible for fish mortality.

  - A high proportion of longfin dace had skin and skeletal anomalies at sites downstream of the NIWTP.

  - Toxicants in the effluent appear to have nearly extirpated populations of invertebrates, amphibians, semi-aquatic reptiles, and fish at sites closest to the NIWTP outfall.

  - The entire ecosystem was contaminated with chromium; the NIWTP did not appear to be the source.

– Other metals identified as concerns were nickel and copper. The pesticide dichlorodiphenyltrichloroethane (DDT) and metabolites were elevated in areas downstream of the NIWTP; however, the discharge is not the likely source.

1.8.2 Site Reconnaissance Summary

Appendix N reports the habitat scoring results using the Rapid Bioassessment Protocols (RBP) Habitat Assessment Method and the habitat scoring results using the Project Habitat Assessment Method. Following is a summary the results of the macroinvertebrate sampling as well as descriptive information gathered from each sample site.

1.8.2.1 Evaluation of Aquatic Habitat Quality

Nogales Site 1.

Site 1 – Reference Reach Upstream of the NIWTP Outfall. The Santa Cruz River upstream of the NITWP was dry on the day of the site visit (May 3, 2000). The lack of water naturally results in a low habitat quality score since the within-channel habitat factors are not applicable under dry conditions. Even when flow occurs after a runoff event, instream habitat quality will remain poor due to the temporary nature of the water and the harsh physical conditions that occur.

Nogales Site 2 - Upstream.

Nogales Site 2 - Downstream.

Site 2 – Below the NIWTP Outfall. Effluent flow from the NIWTP enters the Santa Cruz River from a created channel. Habitat quality improves from Site 1 because of the addition of water. However, habitat scores are still fairly low because of low instream habitat diversity and limited riparian vegetation. Instream habitat is limited to runs dominated by sand and silt. Riffle and pool habitats are not present, and, with the exception of some filamentous algae, aquatic plants are uncommon.

Nogales Site 3 - Cross-section.

Site 3 – Santa Cruz River at Rio Rico Road. Habitat quality improves markedly between Sites 2 and 3, primarily as a result of improved riparian habitat. Instream habitat diversity remains limited. Run habitat is dominant but some riffle habitat is present as well. Pools remain absent.

Nogales Site 3 - Upstream.

Nogales Site 3 – Downstream.

Instream substrate continues to be dominated by sand and silt, which appear to be anoxic immediately below the surface. Aquatic plant density increases from Site 2, but remains a relatively minor component of the habitat. Cattle gazing impacts, indicated by trampled stream banks and gravel bars, are readily apparent.

Site 4 – Santa Cruz River at Bridge Road. Habitat scores decline slightly between Sites 3 and 4. This change results primarily from lower scores on factors related to channel structure and riparian habitat. This site is adjacent to a highway bridge and several residences. To protect these structures, the stream has undergone some channelization, which impacts riparian habitat. Instream habitat diversity is limited to sandy run habitat; riffles and pools are not present. Upstream of Site 4, the instream habitat for aquatic invertebrates is generally limited to substrates dominated by sand and silt. These substrate types provide limited habitat because they are typically unstable. At Site 4, habitat diversity is enhanced by the presence of a dense growth of emergent macrophytes along the stream edge. Emergent macrophytes provide a relatively stable habitat as compared to the sandy/silty substrates present mid-channel.

Nogales Site 4 – Upstream.

Nogales Site 4 - Downstream.

Site 5 – Santa Cruz River at Chavez Siding Road. Habitat scores increase at Site 5 and are essentially the same as the habitat scores at Site 3. Instream habitat remains limited to sandy runs, but, as with Site 4, emergent macrophytes are abundant along both edges of the flowing channel. The channel appears to be fairly natural with no evidence of channelization activities. Riparian vegetation is present but somewhat impacted by grazing activities.

Nogales Site 5 - Upstream.

1.8.2.2 Comparison of Results of Habitat Scoring Methods

The two scoring methods produced similar results: habitat scores are lowest at Site 1 and highest at Sites 3 and 5. Both methods also result in similar habitat scores for Sites 2 and 4 with Site 4 having a slightly better score than Site 2.

1.8.2.3 Evaluation of Macroinvertebrate Community

The results of the May 3, 2000 macroinvertebrate sampling are documented in **Appendix N**. The macroinvertebrate sampling was conducted as a screening-level assessment only. The identification of aquatic organisms was limited to field recognition; no organisms were taken to a laboratory for complete identification. Consequently, many of the organisms observed could only be identified to the class or order level and comparisons with the results of historical data collection efforts are limited. Following is a brief description of the results of the screening-level macroinvertebrate sampling at each site.

Site 1 – Reference Reach Upstream of the NIWTP Outfall. This sample site was dry; no aquatic macroinvertebrates were present.

Site 2 – Below the NIWTP Outfall. The invertebrate community at this site was dominated by cladoceran zooplankton. One of the three samples collected was particularly dense with zooplankton too numerous to count. Overall, nine taxa were collected from this site, none of them Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa. In addition to zooplankton, other common taxa included chironomid midges, blackflies, and oligochaete worms. Mosquito larvae were collected from an edge habitat indicating relatively stagnant conditions in that portion of the reach.

Site 3 – Santa Cruz River at Rio Rico Road. The number of taxa declined between Sites 2 and 3 from nine taxa at Site 2 to six taxa at Site 3. No EPT taxa were collected in any samples. Oligochaete worms were the most abundant taxa at this site, closely followed by cladoceran zooplankton. Other common taxa included chironomid midges, blackflies, and ostracods.

Site 4 – Santa Cruz River at Bridge Road. The addition of dense growths of emergent macrophytes along the edges of the stream channel provided important habitat for macroinvertebrates. The result was a significant increase in the number of taxa between Site 3 (6 taxa) and Site 4 (15 taxa). None of these taxa were EPT taxa. The dominant taxa were similar to upstream sites. At Site 4, cladoceran zooplankton and oligochaete worms were the most abundant taxa. Other common taxa included ostracods, copepods, and chironomid midges. In addition to the macroinvertebrate results, kick samples also produced one Gila topminnow, a fish species listed as threatened and endangered.

Site 5 – Santa Cruz River at Chavez Siding Road. The number of taxa declined to 11 at Site 5, which was strongly dominated by oligochaete worms. Cladoceran zooplankton, although still common, were not nearly as abundant at Site 5 as they had been at all other sites. Other common taxa included blackflies and copepods.

1.8.2.4 Summary of Changes Downstream of Outfall

The most significant change downstream of the NIWTP effluent discharge was the increase in the number of taxa with increased distance from the discharge. Some of this change is likely attributable to improved instream habitat quality at Sites 4 and 5 (i.e., the presence of emergent macrophytes along the stream edge). Taxonomic dominance varied little downstream of the

facility with either cladoceran zooplankton or oligochaete worms being the dominant taxon at each site. No EPT taxa were collected at any site in the sample reach.

1.9 AQUATIC BIOLOGY ANALYSIS

1.9.1 Analysis of Available Data

1.9.1.1 Macroinvertebrates

1.9.1.1.1 Comparability of Methods

Table C-2-13 summarizes the sample methods used by the studies discussed in the following sections. The comparison shows that different samples were used as well as different methods for processing and identifying organisms. The D-frame kick net was used most commonly as a sampling device, but the mesh on the net varied from as small as 250 microns to 500 microns. The Lawson (1995a, 1995b) results, while the most comprehensive because of monthly sampling, only sampled areas with aquatic emergent and submergent vegetation; all other studies appear to have sampled both vegetated and nonvegetated habitats. Finally, the sample processing methods varied to the degree that it is difficult to compare relative abundance among studies. For example, Lawson (1995a, 1995b) purposely counted organisms until a number between 100 and 200 animals/samples was reached. No effort was made to correct this subsample number to a total sample abundance. Other data sources, while relying on subsampling to minimize the numbers of organisms identified, converted results to yield a total abundance.

Table C-2-13
Comparison of Invertebrate Collection and Identification Methods

Invertebrate Study	Sample Period	Sample Method	Sample Processing	Reported Taxonomic Identification
ADEQ (1994)	April 1994	D-frame kick net with 500 micron mesh; 1-minute kick sample in riffle	Approximately 300 organisms processed; All large organisms counted	Insects - lowest level practical except Chironomidae; noninsects – typically order or class
Lawson (1995a, 1995b)	Monthly samples – November 1992 - November 1993	D-frame kick net with 250 micron mesh. Samples only collected from streamside vegetation; number of samples or level of sample effort unknown, but based on results assumed to be one sample collected.	100 - 200 organisms processed.	Insects – lowest practical level except Chironomidae; noninsects – typically order or class
USGS (1998)	January 1996	NAWQA method: Five semi-quantitative riffle samples using modified Surber sampler with 425 micron mesh net. Samples composited (1.25 m^2). Qualitative sample from all habitat types using 210 micron mesh D-frame kick net.		Insects – family level; noninsects – lowest level practical – usually order or class

Table C-2-13
Comparison of Invertebrate Collection and Identification Methods

Invertebrate Study	Sample Period	Sample Method	Sample Processing	Reported Taxonomic Identification
Site Reconnaissance	May 2000	D-frame kick net with 500 micron mesh; Three 1-minute kick nets from variety of habitat types.	Field counted; subsampled as necessary (see text for details)	Field identification to lowest practical level – typically, family for insects; order or class for noninsects

1.9.1.1.2 Comparability of Data Sets

The following four aquatic invertebrate data sets were used for the analysis of the Nogales study area:

- Lawson (1995a, 1995b) – Data collected at four sites monthly from November 1992 through November 1993:
  - SC19 – Site A1 on **Figure C-2-1**. Near Guevavi Ranch on a perennial reach of the Santa Cruz River, 5.5 miles upstream of the NIWTP discharge.
  - SC2 – Site A3 on **Figure C-2-1**. At Rio Rico, 1.5 miles downstream of the NIWTP discharge. Same location as Reconnaissance Site 3.
  - SC18 – Site A5 on **Figure C-2-1**. At Rancho Santa Cruz, 7.5 miles downstream of the NIWTP discharge. Abandoned after January 1993 flood; relocated at site SC20. Same location as ADEQ 1994 sampling site.
  - SC20 – Site A6 on **Figure C-2-1**. At Santa Gertrudis Lane Crossing, 9.5 miles downstream of NIWTP discharge. Replaced site SC18 following January 1993 flood.
  - SC17 – Site A7 on **Figure C-2-1**. 2000 feet downstream of Chavez Siding Road, 16 miles downstream of the NIWTP discharge. Same general location as Reconnaissance Site 5.
- ADEQ (1994) – Site A5 on **Figure C-2-1**. Sample collected at Rancho Santa Cruz, 7.5 miles downstream of NIWTP discharge. Near Lawson (1995) sites SC18 and SC20.
- USGS (1998) – Site A7 **on Figure C-2-1**. Sample collected near Chavez Siding Road crossing, 16 miles downstream of NIWTP discharge. Nearby Lawson (1995) site SC17 and Reconnaissance Site 5.
- Site Reconnaissance – data collected from five sites in May 2000 (all shown on **Figure C-2-1**):
  - Site 1 – Immediately upstream of the NIWTP discharge. No biological data collected since site was dry.

- Site 2 – Immediately downstream of the NIWTP discharge.
- Site 3 – At Rio Rico; same location as Lawson (1995a, 1995b) Site SC2.
- Site 4 – At Bridge Road crossing.
- Site 5 – At Chavez Siding Road crossing; nearby USGS 1998 site and Lawson (1995a, 1995b) site SC17.

Because data were collected on a monthly basis, the Lawson (1995a, 1995b) data set represents one of the better data sets collected from an effluent-dominated water in the Southwest. It allows an analysis of (1) spatial trends from upstream of the NIWTP discharge downstream to near Tubac, Arizona, 16 miles downstream of the discharge; and (2) temporal changes that occur within a given site over a period of a year. Unfortunately or fortunately, depending on one's perspective, a fairly significant flood occurred in January 1993, early in the study. This event allows a review of the impact of flooding on the aquatic invertebrate community, but also possibly modifies somewhat the interpretation that might have been gained about impacts of effluent on aquatic communities under stable conditions.

The ADEQ (1994) and USGS (1998) studies represent snapshots in time at individual but relatively nearby locations. No conclusions can be drawn from these samples; they can only be viewed in the context of other data to see if any notable changes might have occurred at these specific locations.

The site reconnaissance effort conducted in May 2000 provides data that can be used to evaluate spatial patterns in community structure downstream of the NIWTP discharge as well as provide data that allows some general comparisons with other data sets, especially Lawson (1995a, 1995b).

Differences in levels of effort in taxonomic identification are apparent between Lawson (1995a, 1995b) and other studies. With the exception of the chironomid midges, Lawson (1995a, 1995b) identified aquatic insects to a much lower level than was accomplished by other studies. To evaluate the significance of this issue, analysis was first conducted on all available data at the lowest practical taxonomic level, and then these results were compared with the same data using a more coarse level of taxonomic identification (i.e., family/order level, which is equivalent to the other data sets).

1.9.2 Data Analysis Results

1.9.2.1 Macroinvertebrates

1.9.2.1.1 Effect of Varying Levels of Taxonomic Identification

Four aquatic biological measures were used to compare data results: total number of taxa; Hilsenhoff Biotic Index (HBI) values; percent EPT taxa; and relative abundance of the following major taxonomic groups: Oligochaetes (segmented worms); *Diptera* (flies); and Other [primarily

Crustacea, Gastropoda (snails), Odonata (dragonflies and damselflies), Hemiptera (true bugs) and Coleoptera (beetles)].

Figures C-2-18 and C-2-19 show the total number of taxa collected on a monthly and average monthly basis. **Figure C-2-18** illustrates the results when the lowest level of taxonomic identification is used; **Figure C-2-19** provides the results using a higher level of taxonomic identification. Although according to **Figure C-2-19** the number of taxa on a given month at a given site is less than what is shown on **Figure C-2-18**, the overall spatial and temporal patterns of taxa richness are the same. Specifically, taxa richness is highest upstream of the effluent discharge, declines by approximately 50 percent at the Rio Rico site (SC 2), but rebounds somewhat downstream with sites SC18 and SC20 having slightly higher richness than site SC17.

Figures C-2-20 and C-2-21 provide a similar comparison of analysis results using different taxonomic levels of identification when calculating the HBI. As with taxa richness, the results are generally the same. There may be some individual site or date-specific changes, but overall the pattern is the same; the lowest HBI was found at site SC19, upstream of the wastewater discharge. Higher HBI values occurred at sites SC2, SC18, and SC20, and the HBI value at site SC17, the most downstream site, declined to a value only a little higher than found at site SC19.

The use of the two pairs of figures (**Figures C-2-18, C-2-19, C-2-20, and C-2-21**) suggest that regardless of the level of taxonomic identification, the outcome of data interpretation will be the same.

1.9.2.1.2 Seasonal Patterns in Macroinvertebrate Community Structure

Number of Families/Orders. The Lawson (1995a, 1995b) data set shows seasonal changes in macroinvertebrate community structure over the period of a year. The number of taxa varied substantially from month to month at the site upstream of the discharge as well as downstream sites. For example, at site SC19, upstream of the discharge, 20 or more taxa were collected in two different months, but samples collected on two other occasions yielded only 12 taxa (refer to **Figure C-2-19**). At downstream sites, the number of taxa was lower than upstream of the discharge, but the same monthly variation occurred. For example, at sites SC18 and SC20 as few as 6 taxa were collected during an April sampling event, while in other months the number of taxa was greater than 15; in fact in May, a month later, the number of taxa collected was 16 (refer to **Figure C-2-19**).

Lawson (1995a, 1995b) reports that a flood event occurred during their study. A two-week period of heavy rains resulted in rainfall in the study area 430 percent above the normal January rainfall. Typical January flows in the area of site SC19 are 35 cfs, but that year flows peaked at 5,880 cfs. Sixteen miles downstream of site SC17 the channel is usually dry, but in January 1993 flows peaked at 14,800 cfs. Flows were still high at all sites until March/April 1993.

Sampling occurred from November 1992 to October 1993. The flood event occurring in January 1993 elevated river flows sufficiently to prevent collection of any macroinvertebrate samples that month. An expectation from a flood event is a reduction in taxa immediately following the event. The data suggest that there may have been some impact, especially downstream of the effluent,

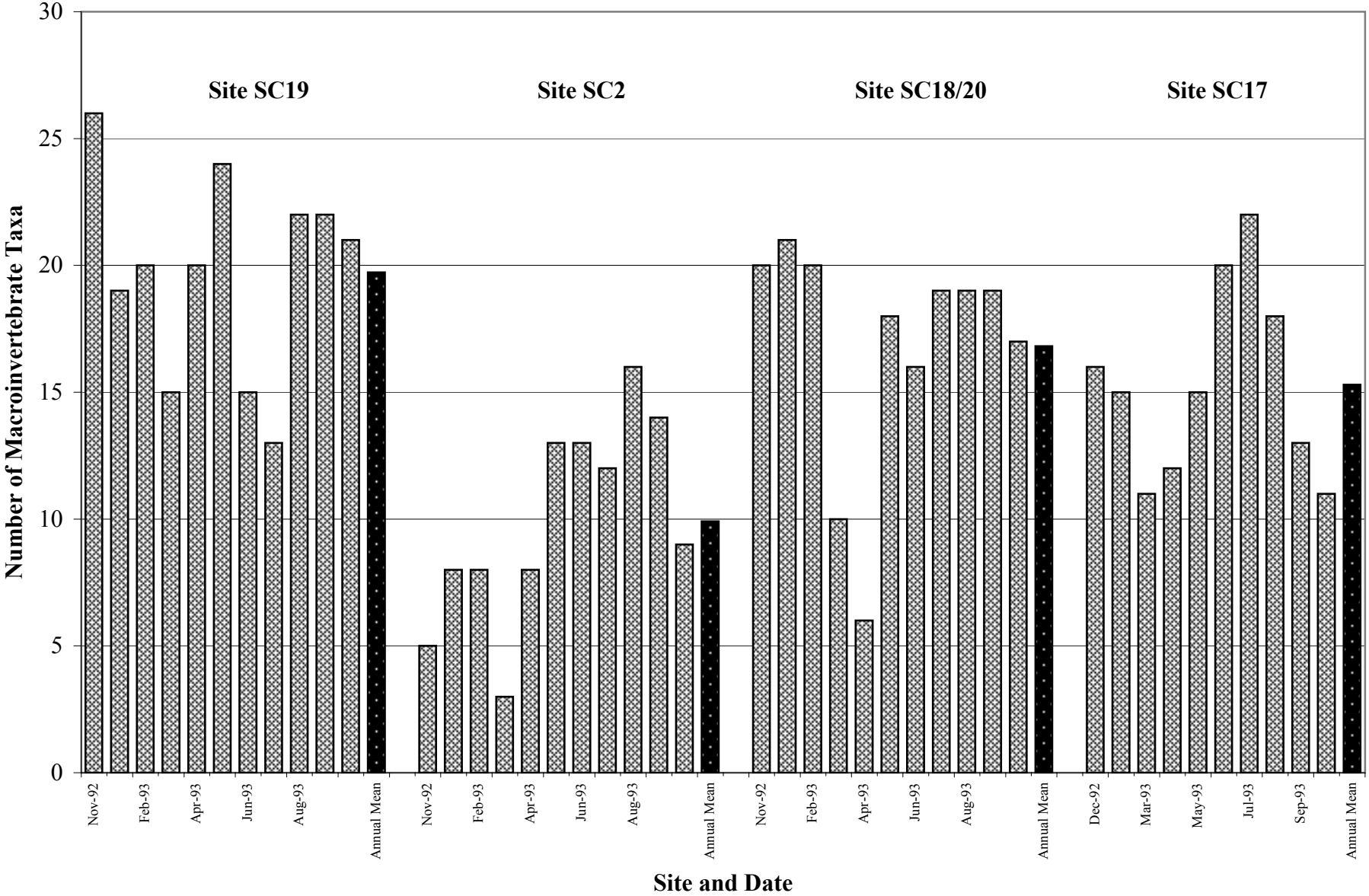


FIgure C-2-18
Total Number of Macroinvertebrate Taxa
Lawson 1995 - Taxa Identified to Lowest Practical Level
Santa Cruz River Near Nogales, Arizona

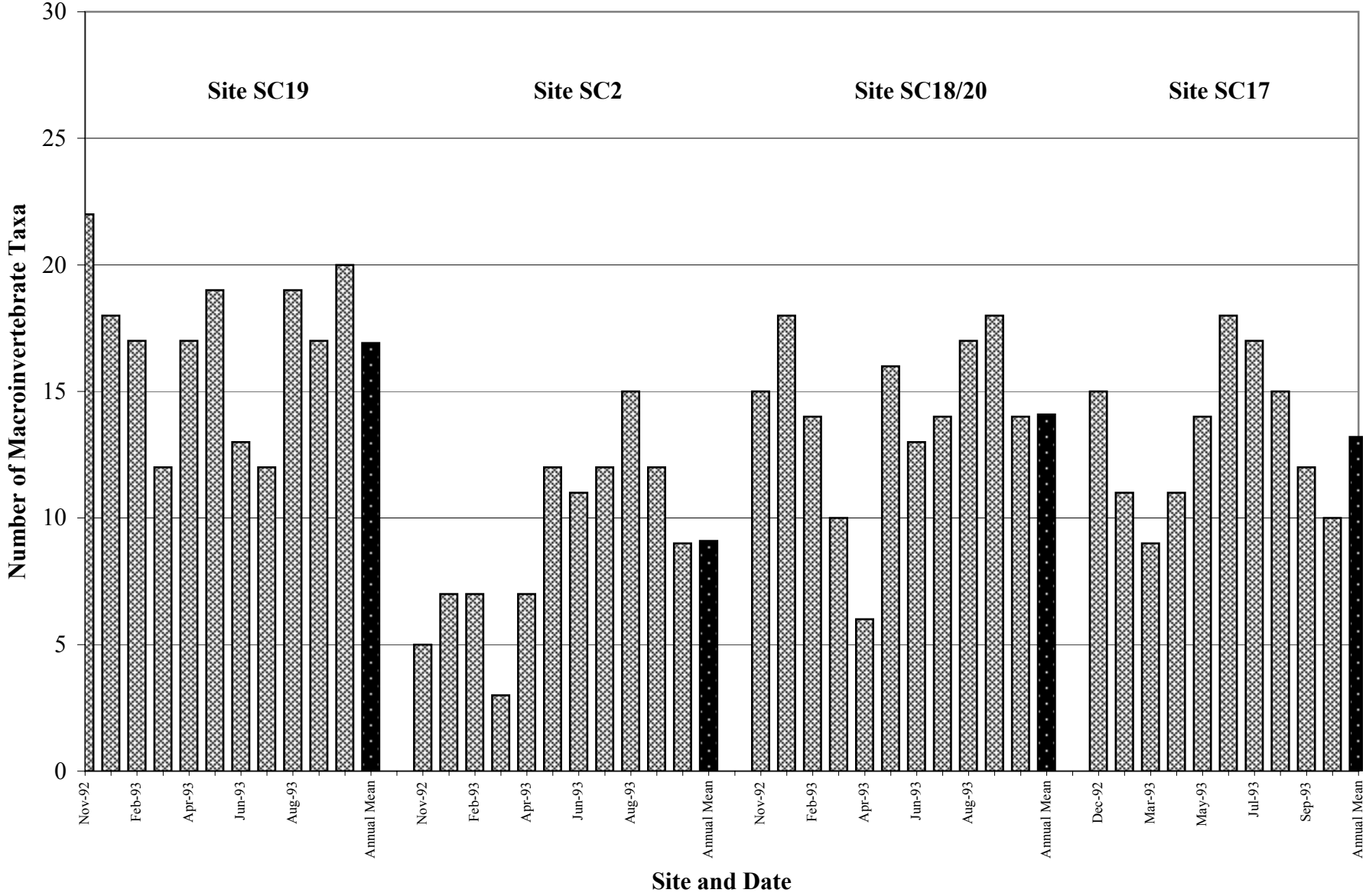


Figure C-2-19
Total Number of Macroinvertebrate Taxa
Lawson 1995 - Family/Order Identification Level
Santa Cruz River Near Nogales, Arizona

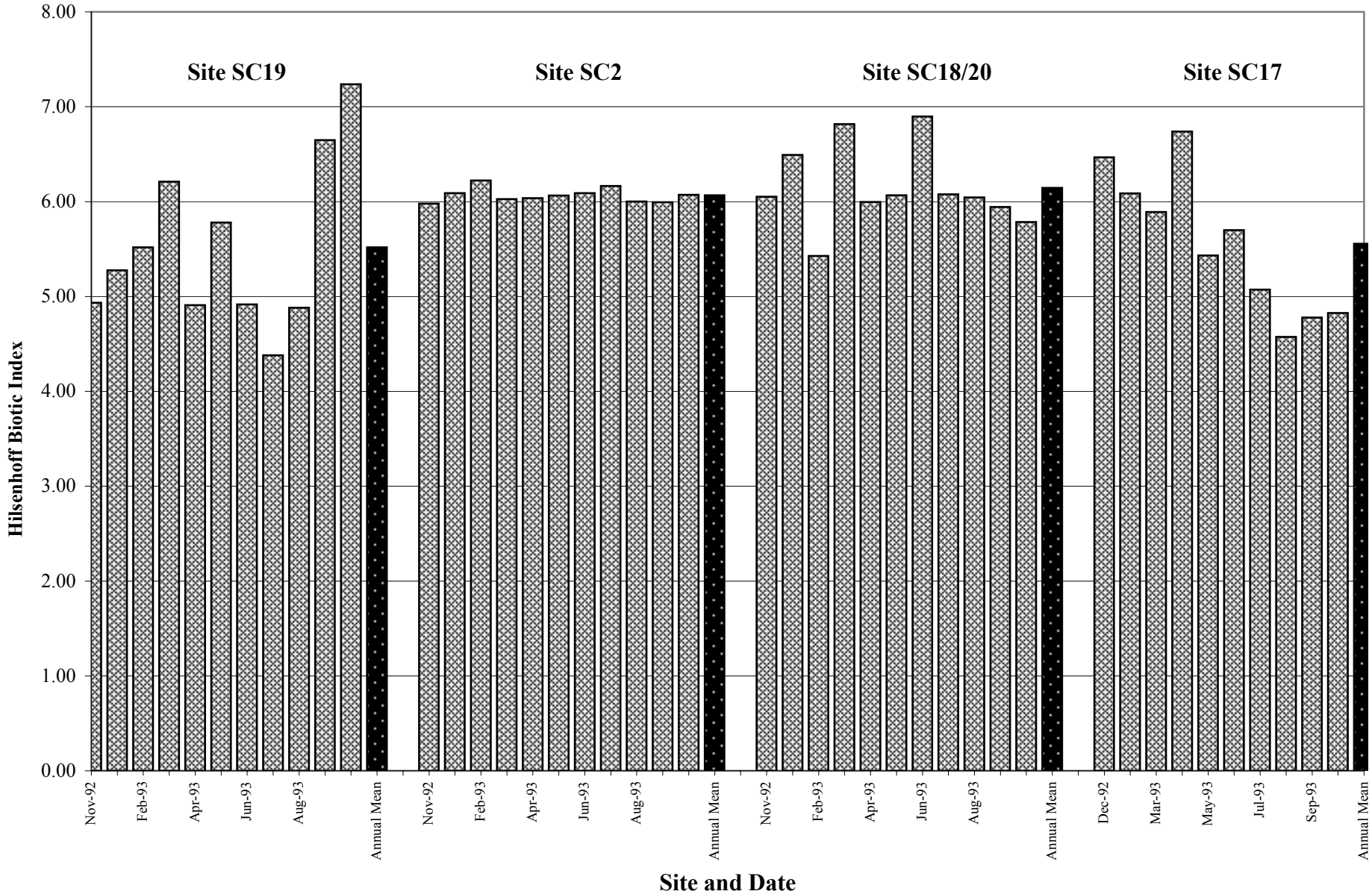


FIgure C-2-20
Hilsenhoff Biotic Index
Taxa Identified to Lowest Practical Level
Santa Cruz River Near Nogales, Arizona

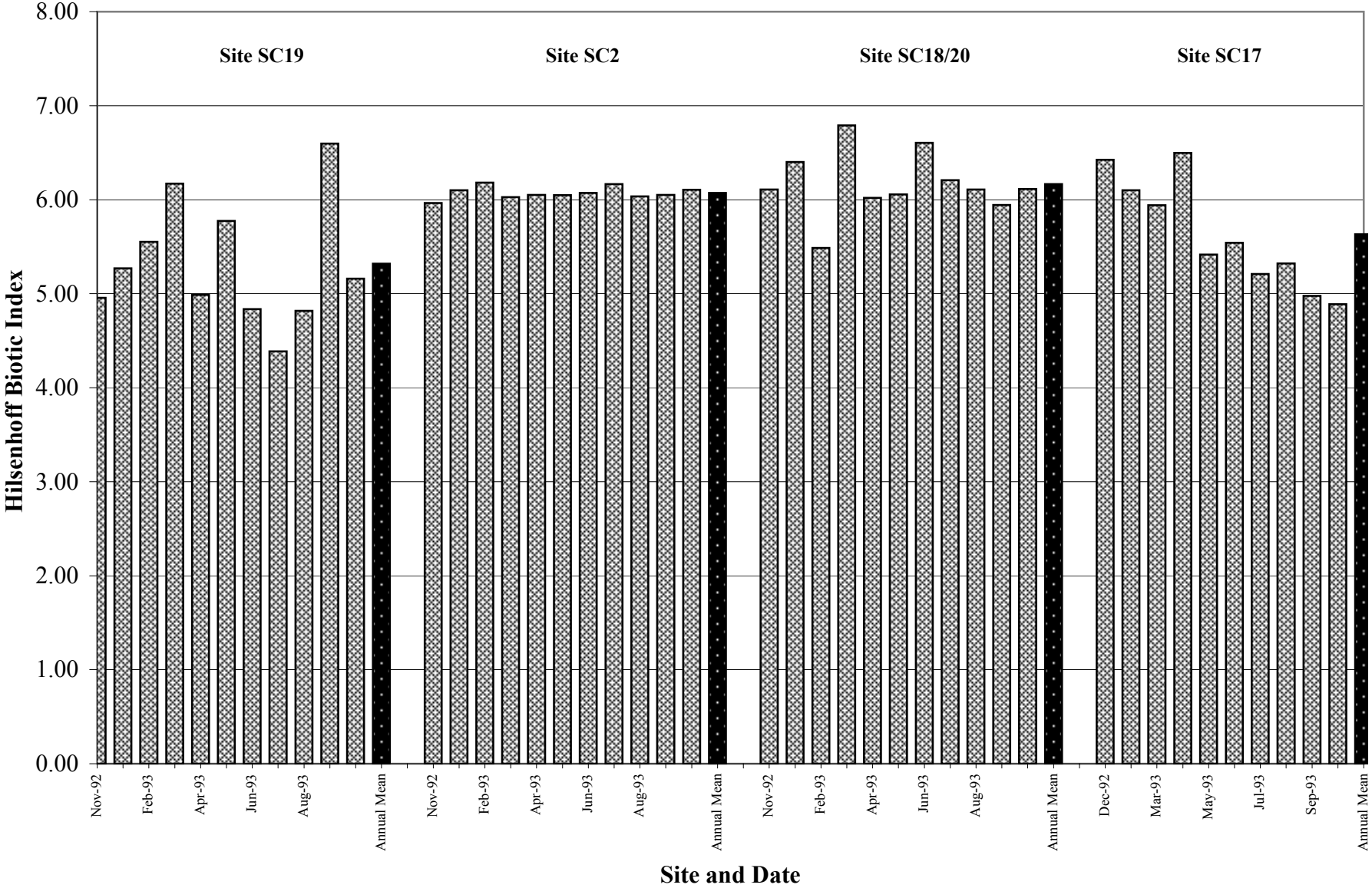


Figure C-2-21
Hilsenhoff Biotic Index
Family/Order Identification Level
Santa Cruz River Near Nogales, Arizona

but the effect was somewhat delayed with the lowest number of taxa not being reached until March or April 1993 when the highest flows ended. All sites then showed significant rebounds into early summer, but the number of taxa declined again at all sites in late summer to early fall (refer to **Figure C-2-19**).

An interesting by-product of monthly and seasonal sampling is an evaluation of the taxonomic pool that actually colonizes a stream. When samples are collected at the same time of year, only a snapshot is gathered of what actually lives in the stream. However, over a period of a year, different taxa may be present. **Figure C-2-22** illustrates the actual number of families collected over the period of a year as compared to the average number of families present on a given sample day. For example, at Site SC2, immediately below the discharge, the average number of families collected during a given month was less than 10. However, over the period of 12 months a total of 31 families was collected. If the total number of families per year is compared among sites, little difference is found among all three downstream sites with 31, 33, and 32 families at sites SC2, SC18 and SC20, and SC17, respectively. The pattern is the same at the site upstream of the discharge where 17 families were present in a given month, but the total number of families was 39 (**Figure C-2-22**).

HBI. The HBI results suggest that for most of the year site SC19, upstream of the discharge, has a macroinvertebrate community composed of a greater number of animals that are more intolerant of organic pollution than sites SC2, SC18, and SC20 (refer to **Figure C-2-20**). However, this finding must be qualified as "most of the year" because even at this site, significant month-to-month variation occurs such that during certain months the HBI value is actually higher than sites downstream of the discharge. With the exception of the most downstream site, site SC17, the sites downstream of the discharge are characterized by fairly constant month-to-month HBI values. A slight but temporary dip occurs at sites SC18 and SC20 following the January 1993 flood event, but the remainder of the year the HBI shows little month-to-month variation (refer to **Figure C-2-20**). The most downstream site had similar HBI values to other sites below the effluent discharge until May 1993. From May to October 1993 the HBI values at site SC17 were similar to the site upstream of the effluent discharge (refer to **Figure C-2-20**).

Overall, the HBI results from Lawson (1995a, 1995b) suggest that water quality upstream of the effluent discharge is variable, but overall better than water quality downstream of the effluent. The high variability upstream may be attributable to flow variability because months with the highest HBI scores are either post-flood or during periods of low flow. Flood events can cause temporary population shifts; in this example dominance shifts from baetid mayflies to more tolerant taxa (**Figure C-2-23**), and low-flow conditions can result in slack water conditions that are conducive to colonization by different insects (e.g., in this instance the population shifted from a dominance by baetid mayflies to dominance by mosquitoes).

The HBI results also suggest that by site SC17 water quality has improved somewhat as compared to water quality immediately below the NIWTP discharge. But again, the HBI value was variable changing from 6.00 or more at the beginning of the study to around 5.00 at the end of the study (refer to **Figure C-2-24**). The steady decline in the HBI value was caused by a

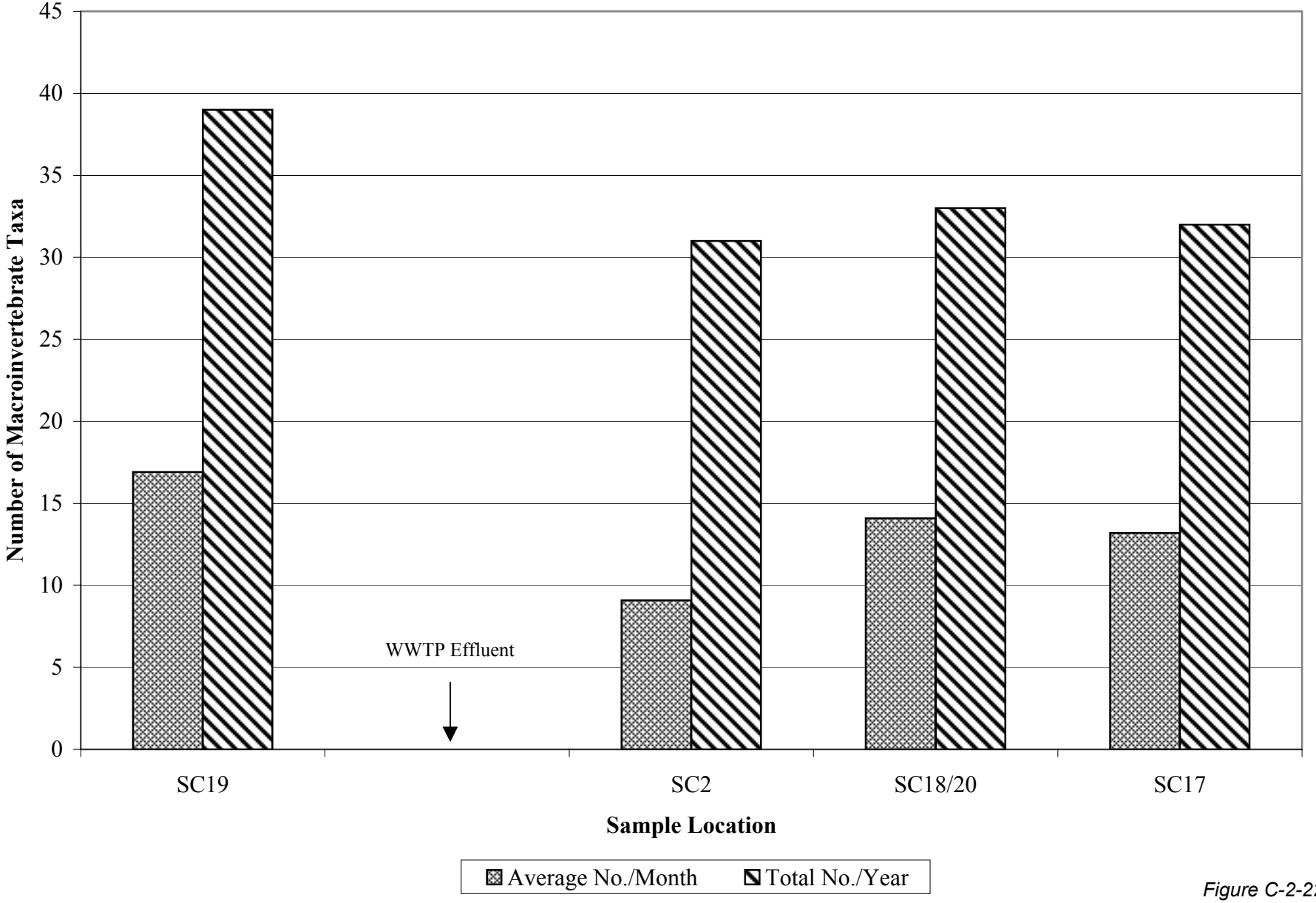


Figure C-2-22
Average Number of Macroinvertebrate Taxa per Month vs.
Total Number of Macroinvertebrate Taxa per Year (Lawson, 1995)
Santa Cruz River Near Nogales, Arizona

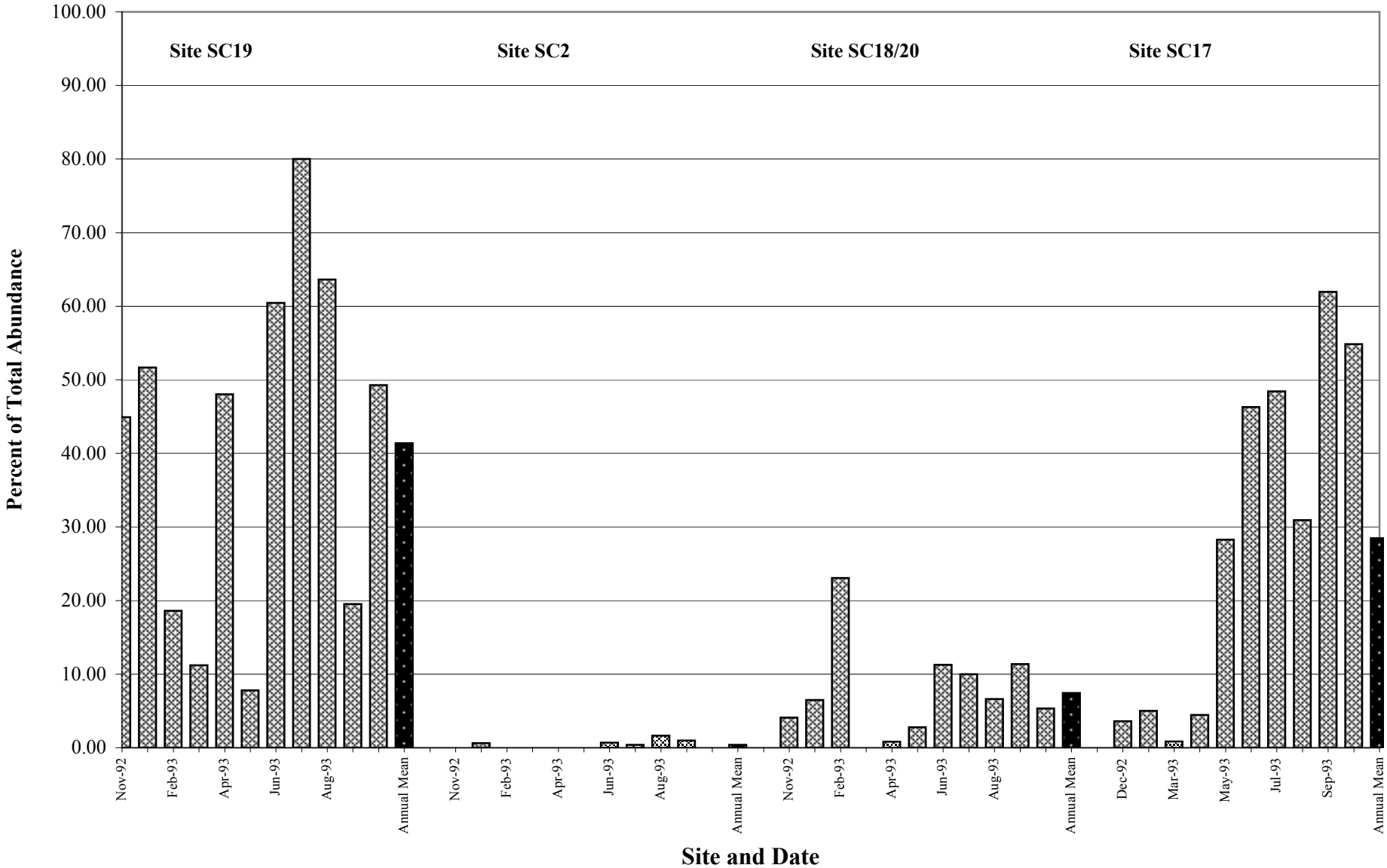


Figure C-2-23
Percent Myflies, Stoneflies and Caddisflies (EPT Taxa) (Lawson, 1995)
Santa Cruz River Near Nogales, Arizona

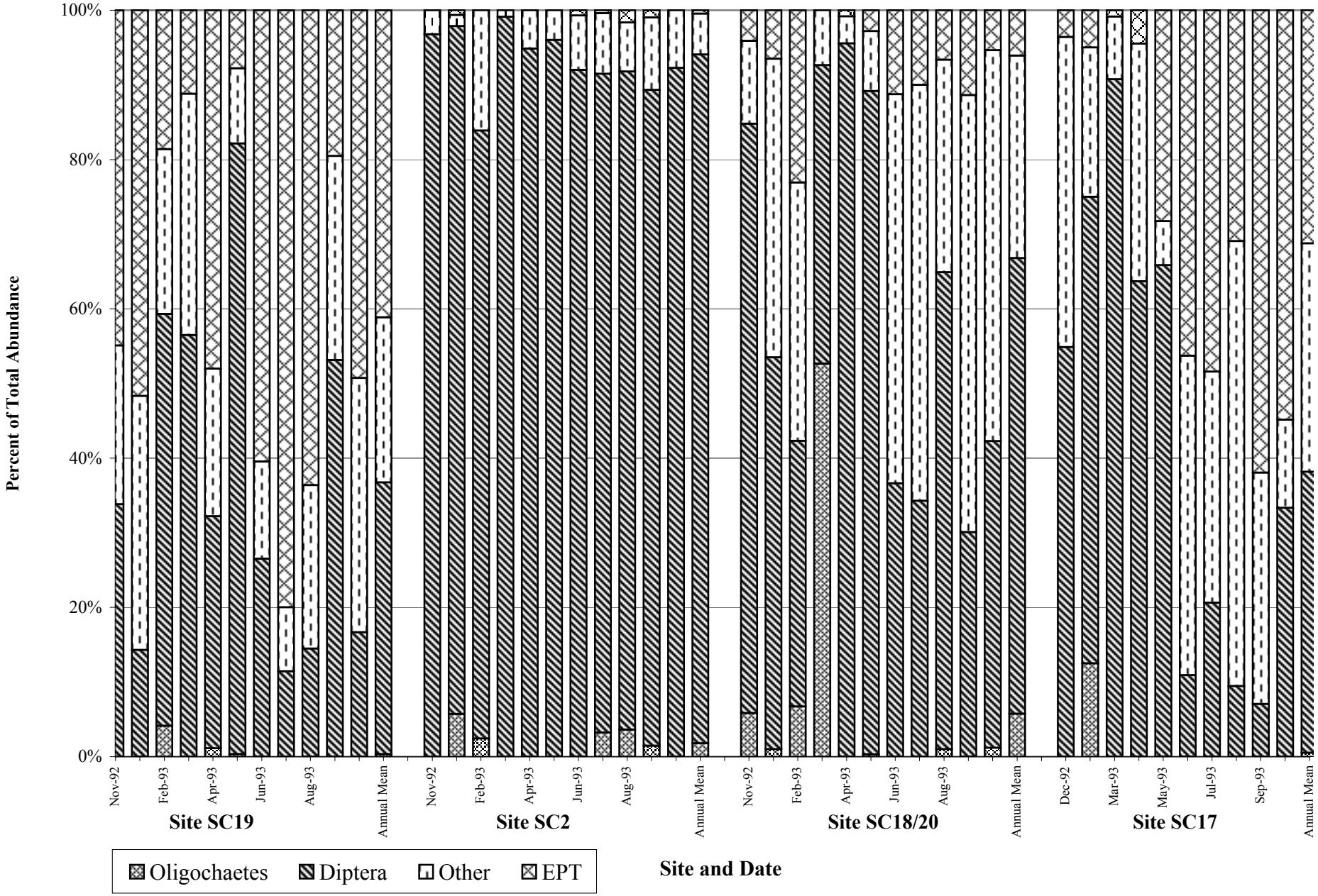


Figure C-2-24
Relative Abundance of Major Macroinvertebrate Groups (Lawson, 1995)
Santa Cruz River Near Nogales, Arizona

gradual increase in the dominance of baetid mayflies from late spring to fall (refer to **Figure C-2-23**).

Percent EPT. The relative abundance in mayflies, stoneflies, and caddisflies (EPT taxa) changes seasonally at most sites (refer to **Figure C-2-23**). [Note: Of the 10 EPT families collected by Lawson (1995a, 1995b) most of the families were only found at site SC19, and at all sites the majority of EPT taxa abundance was composed of baetid mayflies.] The exception to this finding was at site SC2 where EPT taxa were rarely collected during any month.

Relative Abundance. **Figure C-2-24** compares the relative abundance of four major taxonomic groups (Oligochaetes, Diptera, EPT taxa, and "Other" [i.e., everything else]) on a month-to-month basis. Evaluating relative abundance in the context of other measures (e.g., HBI or number of taxa) helps evaluate patterns, if any, in community structure. Evaluation of Lawson (1995a, 1995b) shows the following apparent patterns in the data:

- Community diversity is highest at site SC19, upstream of the discharge, and site SC17, the site farthest downstream of the discharge. Diversity is lowest immediately below the discharge.

- Although there are similar numbers of families present at all sites on an annual basis (refer to **Figure C-2-22**), the relative dominance of families constituting that richness varies among sites. For example, upstream of the discharge EPT taxa are an important component of the community, but downstream of the discharge, the community is dominated by *Diptera*, which typically are more tolerant of effluent than EPT taxa.

- There appears to have been a community composition shift at sites SC19, SC18, and SC20, and site SC17 in the early spring. This shift is most pronounced at the two most downstream sites where the community shifts to a temporary dominance by Diptera and/or Oligochaetes. This shift may have been a result of the flood event.

1.9.2.1.3 Longitudinal and Long-Term Temporal Patterns in Macroinvertebrate Community Structure

The discussion of seasonal patterns has already suggested that longitudinal patterns are apparent in the macroinvertebrate data collected by Lawson (1995a, 1995b). This section expands on that discussion by not only further evaluating data collected by Lawson (1995a, 1995b), but also evaluating other available data. However, because sample methods varied among studies, only overall patterns can be discussed, not specific results (e.g., 12 taxa versus 15 taxa at a given site). Evaluating the Lawson (1995a, 1995b) data in the context of the site reconnaissance data is problematical given that Lawson collected monthly data and the reconnaissance was a single sampling effort. We could compare May 1993 data with May 2000 data, but it appears likely that the Spring 1993 results were influenced by a flood event. Consequently, for the purposes of comparison, we have chosen to use mean monthly values for Lawson (1995a, 1995b).

Number of Families/Orders. The number of families showed similar patterns for Lawson (1995a, 1995b) and the site reconnaissance (i.e., with distance downstream of the NIWTP discharge, the number of families generally increased [**Figure C-2-25**]). Two other recorded samples, ADEQ (1994) and USGS (1998), were collected at single locations so no longitudinal evaluation is possible. However, the numbers of families collected by both efforts were similar to what was found at the same location on other dates by other studies (refer to **Figure C-2-25**). USGS had the highest number of families, but the USGS sampling method is intensive and likely to pick up taxa for which there are only a few individuals at a given site.

HBI Values. HBI values generally declined with distance downstream of the NIWTP facility for both Lawson (1995a, 1995b) and the site reconnaissance effort (**Figure C-2-26**). However, overall scores appear to be higher for the recent site reconnaissance effort. This may simply be the result of the comparison, which is comparing mean monthly values (Lawson 1995a, 1995b) with a snapshot in time (site reconnaissance). However, as noted below, the difference also may be an indication that there has been a change in the nature of taxa constituting the invertebrate community.

Percent EPT Taxa. Lawson (1995a, 1995b) found an increased abundance of EPT taxa with distance downstream of the NIWTP. When monthly values are averaged, the change with distance downstream is obvious (**Figure C-2-27**). Interestingly, the recent reconnaissance effort found no EPT taxa at any site regardless of distance downstream of the WWTP. The ADEQ 1994 sample found percent EPT to be essentially the same as that found at Lawson's SC18 and SC20 site (ADEQ's and Lawson's sites were in the same general area), but the USGS sample found no EPT taxa even though the sampling effort at that one site was intensive (refer to **Figure C-2-27**).

Relative Abundance. Longitudinal changes in relative abundance are obvious in both Lawson (1995a, 1995b) and site reconnaissance data (**Figure C-2-28**). Lawson (1995a, 1995b) found increased abundance of EPT and "other" taxa and decreased abundance of Diptera with distance downstream of the NIWTP. Oligochaetes were a minor component of all samples. The site reconnaissance found decreased abundance of "other taxa" and increased abundance of Oligochaetes with distance downstream of the NIWTP.

No EPT taxa were collected during site reconnaissance. Part of the difference, especially in the relative abundance of *Oligochaetes*, could be an artifact of the difference in sampling methods. Lawson only sampled submergent and emergent vegetation along stream edges, while we sampled all habitats including vegetation and mid-stream sandy substrates, the latter of which is favored by *Oligochaetes.* However, the complete lack of EPT taxa, especially baetid mayflies, cannot be explained by differences in sampled substrates. USGS (1998) also reported no EPT taxa as well as suggesting that the findings of the reconnaissance study are real (i.e., the field reconnaissance effort was not too cursory to find any of these taxa).

The ADEQ sample collected in 1994 was collected in the same general area as sites SC18 and SC20. The difference in invertebrate relative abundance between the Lawson (1995a, 1995b) and the ADEQ sample is pronounced. EPT taxa constituted the same proportion of the community, but the group "other" taxa (primarily *Crustacea*) were dominant rather than the *Diptera*.

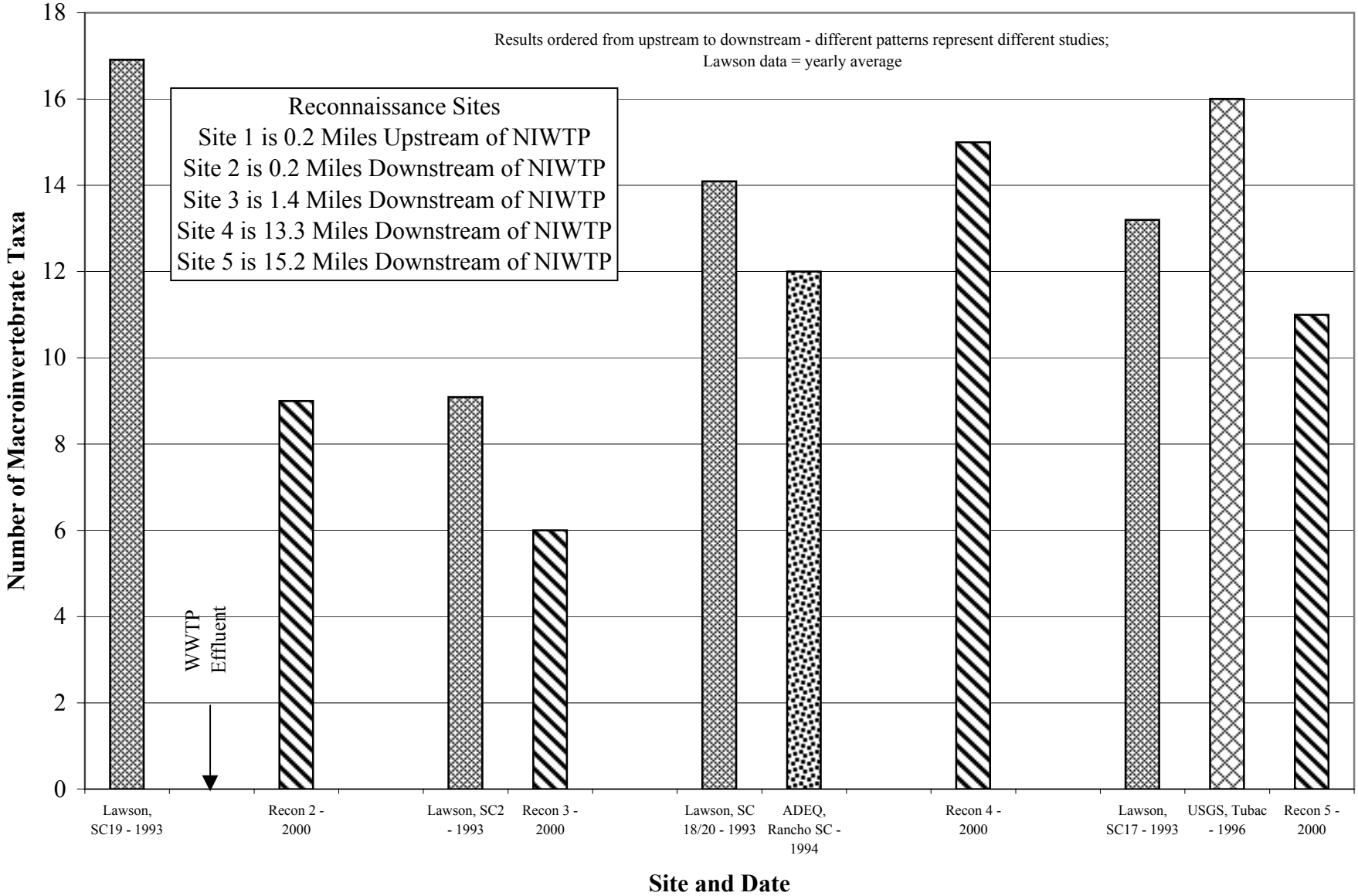
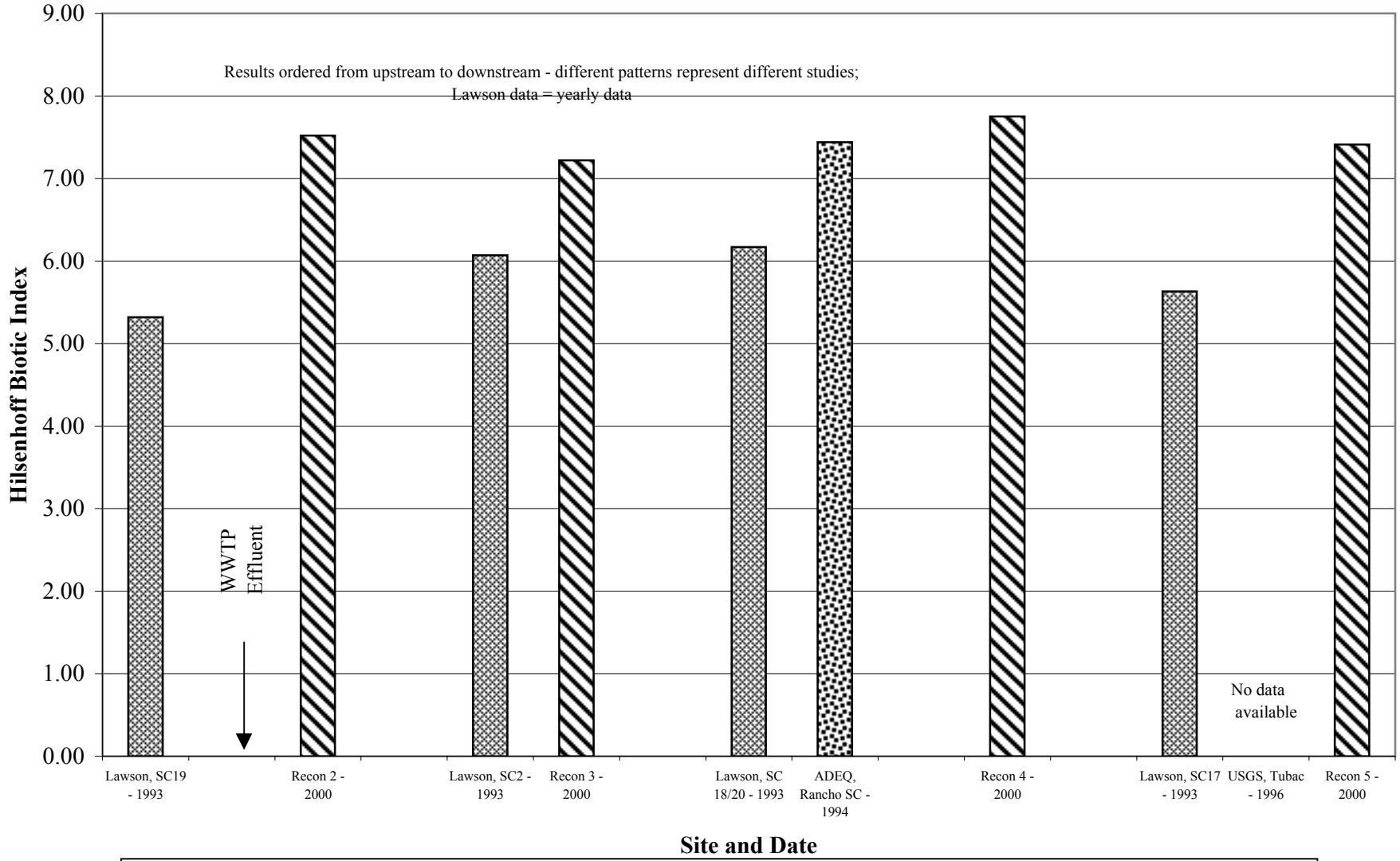


Figure C-2-25
Total Number of Taxa (Family/Order Identification Level)
Santa Cruz River Near Nogales, Arizona



Reconnaissance Sites: Site 1 is 0.2 Miles Upstream of NIWTP. Site 2 is 0.2 Miles Downstream of NIWTP. Site 3 is 1.4 Miles Downstream of NIWTP. Site 4 is 13.3 Miles Downstream of NIWTP. Site 5 is 15.2 Miles Downstream of NIWTP.

Figure C-2-26
Hilsenhoff Biotic Index
Family/Order Identification Level
Santa Cruz River Near Nogales, Arizona

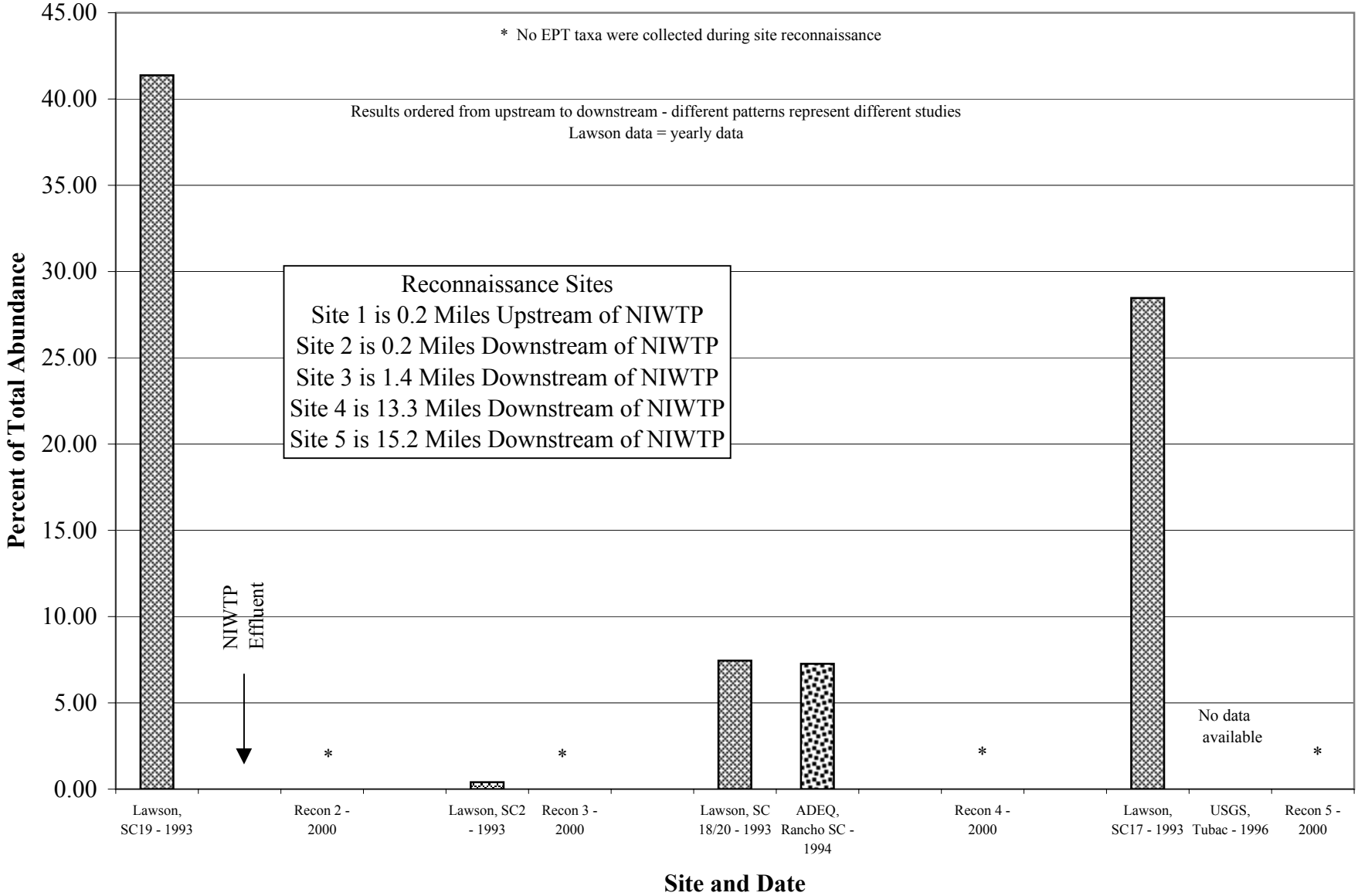


Figure C-2-27
Percent EPT Taxa
Santa Cruz River Near Nogales, Arizona

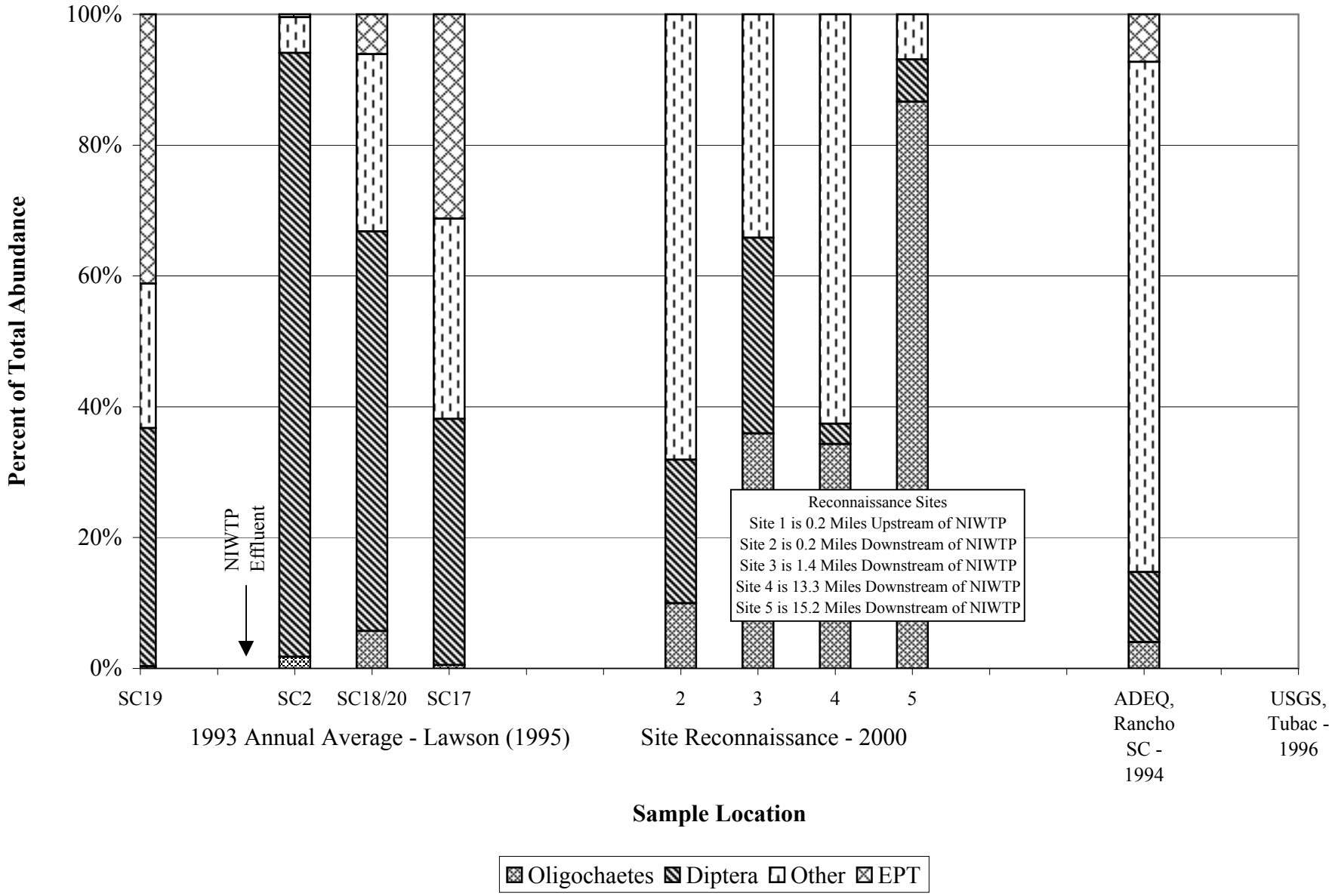


FIgure C-2-28
Relative Abundance of Major Taxonomic Groups
Santa Cruz River Near Nogales, Arizona

However, it must be kept in mind that the Lawson (1995a, 1995b) data on **Figure C-2-10** represents a monthly average. Referring back to **Figure C-2-24**, it is notable that what was found by ADEQ in 1994 in the area of sites SC18 and SC20 is similar to what was found by Lawson for all months except those immediately following the high flow, which appears to have modified the community at that site.

1.9.2.2 Fish Community

Two data sets, collected in 1993 and 1997, respectively, are available for analysis:

- Lawson (1995a, 1995b), in cooperation with the Arizona Game and Fish Department, surveyed the fish community at four sites (SC19, SC2, SC20, and SC17) in May and December 1993. Two replicate samples were collected along 80 feet of stream with electroshocking equipment.

- King et al. (1999) surveyed the fish community at six sites in the Santa Cruz River between March and July 1997. The six sites and their correspondence with Lawson (1995a, 1995b) are as follows:

  – Border – 14.7 miles upstream of the NIWTP (9.2 miles upstream of site SC19).

  – Rio Rico Bridge – same location as site SC2.

  – Rio Rico North – 3.1 miles downstream of Rio Rico Bridge, approximately halfway between sites SC2 and SC20.

  – Santa Gertrudis – same location as site SC20.

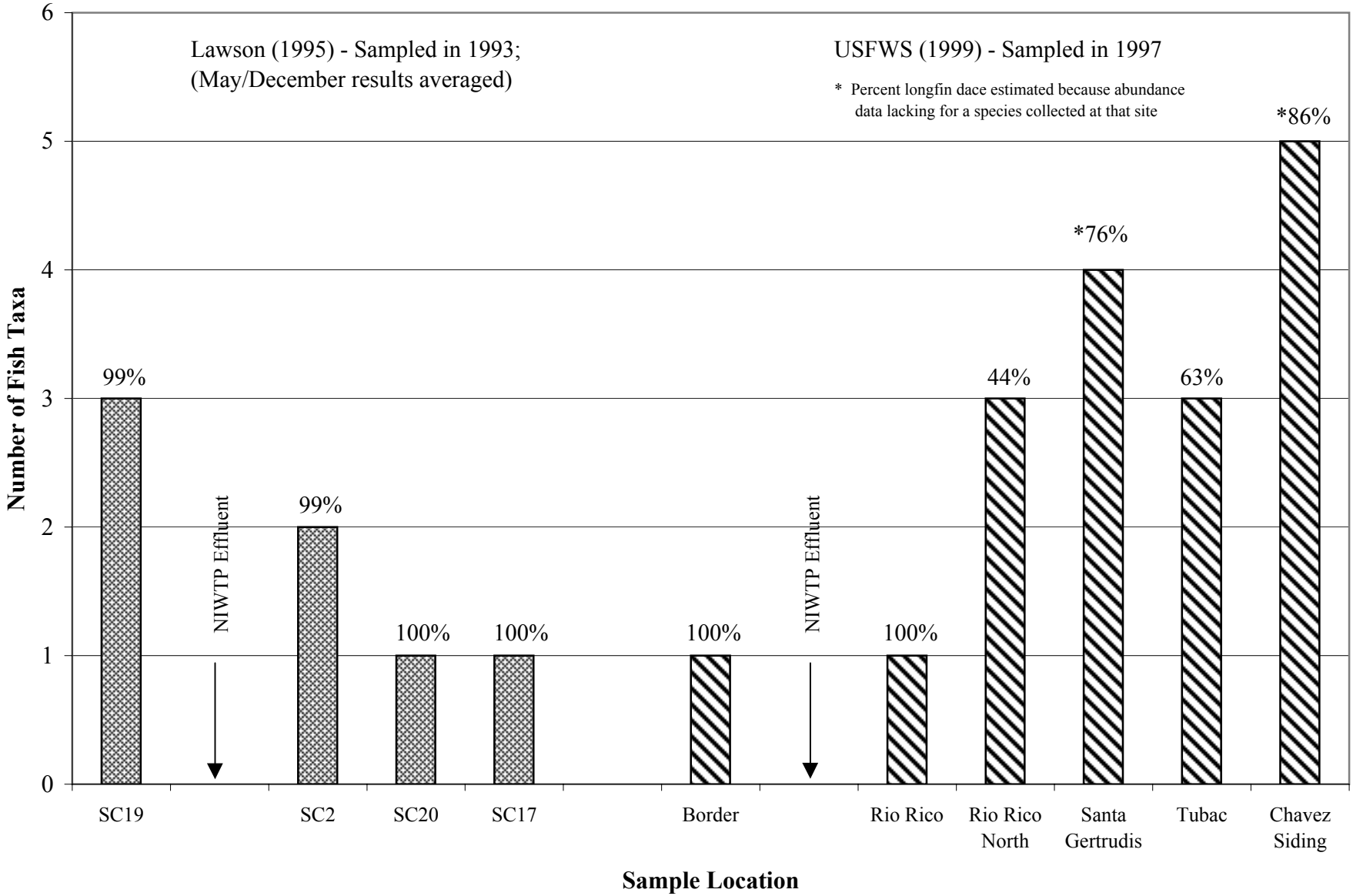
  – Tubac – 11.3 miles downstream of the NIWTP. Approximately halfway between sites SC20 and SC17.

  – Chavez Siding – same location as site SC17.

King et al. collected three or four replicates from all sites except the Border Site where only one replicate was collected. Timed samples were collected with an electroshocker so that abundance could be related on a per unit effort basis.

The Lawson (1995a, 1995b) and King et al. (1999) results cannot be directly compared since the units of sample measurement and numbers of replicates are different for each study (Lawson = spatial effort; King et al. = timed samples).

Lawson (1995a, 1995b) observed one to three fish species at any given site (**Figure C-2-29**). The most taxa (three) were collected at site SC19, upstream of the NIWTP discharge. Two species were collected at site SC2 and one species was collected at both sites SC20 and SC17. At all sites longfin dace (*Agosia chrysogaster*) constituted the majority of the fish (>99 percent of total abundance). In addition, a few Sonora sucker (*Catastomus insignis*) and mosquitofish (*Gambusia*



Percentage Above Column = Percent of Community Comprised fo Longfin Dace, *Agosia Chrysogaster*

Figure C-2-29
Fish Community
Santa Cruz River Near Nogales, Arizona

affinis) were observed at site SC19; one green sunfish (*Lepomis cyanellus*) was collected at site SC2.

King et al. (1999) observed one to five fish species at any given site (refer to **Figure C-2-29**). Only one species, longfin dace, was collect at the Border and Rio Rico sites. Three species were collected at two sites: Rio Rico North (longfin dace, Gila topminnow [*Poeciliopsis occidentalis*], and mosquitofish) and Tubac (longfin dace, Gila topminnow, and desert sucker [*Pantosteus clarki*]). Four species were collected at Santa Gertrudis (longfin dace, desert sucker, Sonora sucker, and Gila topminnow) and five species were collected at Chavez Siding (longfin dace, desert sucker, Sonora sucker, Gila topminnow, and mosquitofish).

Diversity was low (one species) at the Border Site, likely because, as King et al. (1999) notes, flow at this site is intermittent. The King et al. study found increased fish species diversity and less dominance by longfin dace (refer to **Figure C-2-29**) with increased distance downstream of the NIWTP discharge. This study also found Gila topminnow, a federally listed threatened and endangered species. [Note: During reconnaissance activities at Site 4, one Gila topminnow was collected in the macroinvertebrate kick sample; the specimen was returned to the river.] Abundance also increased downstream of the NIWTP discharge from 10 fish at Rio Rico to more than 500 fish at the last two downstream sites (King et al. 1999).

As indicated above, the two fish surveys cannot be directly compared. However, the results of the King et al. results suggest an improving fish community downstream of the NIWTP discharge. Gila topminnow, which were not collected in 1993 by Lawson (1995a, 1995b), were present at four downstream sites, with "relatively health population[s]…including breeding males" (King et al. 1999) present at Tubac and Chavez Siding. However, King et al. (1999) note that Gila topminnow populations have declined "precipitously" since 1993 when a survey found an abundant population including breeding males as far upstream as Rancho Santa Cruz (site SC18 in Lawson 1995a, 1995b) (Rector, ADEQ, unpublished data).

Both Lawson (1995a, 1995b) and King et al. (1999) recorded fish disease (any observable irregularity [e.g., lesion, deformity, discoloration, etc.]) in their respective studies. From sites SC19, SC2, SC20, and SC17, Lawson (1995a, 1995b) reported incidence of disease at 0 percent, 40 percent, 7 percent, and 6 percent, respectively. The study concluded that the "high incidence of disease at SC2 is not by chance, but dependent upon one or more environmental factors" (Lawson 1995a, 1995b). King et al. (1999) found lower frequencies of fish disease (up to 9.1 percent). Histological analyses were conducted but the results were inconclusive: "lesions and deformities were not related to the presence of the white grub and not enough fish with lesions were collected to assess the role of bacteria as a causative agent" (King et al. 1999).

Both Lawson (1995a, 1995b) and King et al. (1999) concluded that the presence of high levels of un-ionized ammonia near the wastewater treatment was the cause of fish mortality.

1.9.2.3 Habitat Quality

No habitat quality assessment had been conducted on the Santa Cruz River until the site reconnaissance effort in Spring 2000. Lawson (1995a, 1995b) did not use any habitat assessment techniques in conjunction with biological sampling.

The pattern of the habitat assessment scores was the same using both EPA, RBP, and Project habitat quality assessments (**Figure C-2-30**). Scores were lowest at Site 1, where no flow occurred on the day of sampling, gradually increased to Site 3, declined some at Site 4, but then rebounded at Site 5 to the same level as was found at Site 3. A regression between the scores obtained by both methods found a strong positive relationship (r2 = 0.995) (**Figure C-2-31**), meaning that regardless of the method used, the interpretation of habitat quality would be the same.

Additional analysis of factors within each scoring method again yielded similar results. The Project method can be broken down into three general habitat categories: instream habitat, channel morphology, and riparian zone characteristics. A review of the data shows that other than the obvious instream habitat difference between Sites 1 and 2 (absence or presence of water) the main factor varying among sites was the quality of the riparian habitat adjacent to the channel (**Figure C-2-32**). Minor fluctuations occurred in primary and secondary factors among Sites 2, 3, 4, and 5, but the fluctuation in the quality of the riparian habitat was more pronounced.

Similar results were obtained from a closer analysis of the RBP habitat scores. These scores are separated into three factors: instream habitat, channel morphology, and riparian zone. Again, other than the obvious flow difference between Site 1 and Site 2, which affect instream habitat, **Figure C-2-33** shows that riparian zone factors were considerably more variable among sites than other habitat factors.

1.10 TERRESTRIAL HABITAT AND SPECIES OVERVIEW

This section provides an overview of the historic records regarding terrestrial species and habitat along the Santa Cruz River near Nogales and provides a summary of the site reconnaissance effort. **Appendix O** contains a list of species that could occur near this site, a list of special status wildlife species, and a list of species that were observed during the site reconnaissance.

1.10.1 Historical Data Summary

Historically, the Santa Cruz River was perennial from its headwaters in the San Rafael Valley, south into Mexico where it looped back north and re-entered the United States approximately 5 miles east of Nogales, Arizona. The perennial flow continued from the Nogales area north to approximately Tubac, Arizona where the water went underground (Dobyns 1985; Tellman et al. 1997). The perennial water supported several plant communities that differed from the arid, semi-desert grassland surrounding the Santa Cruz River. Fremont cottonwood and Goodding's willow gallery forest was one of the dominant communities along the upper Santa Cruz River (Arizona Department of Water Resources [ADWR] 1994). This community was present within the main river channel to the edge of the low-flow channel, where groundwater levels were

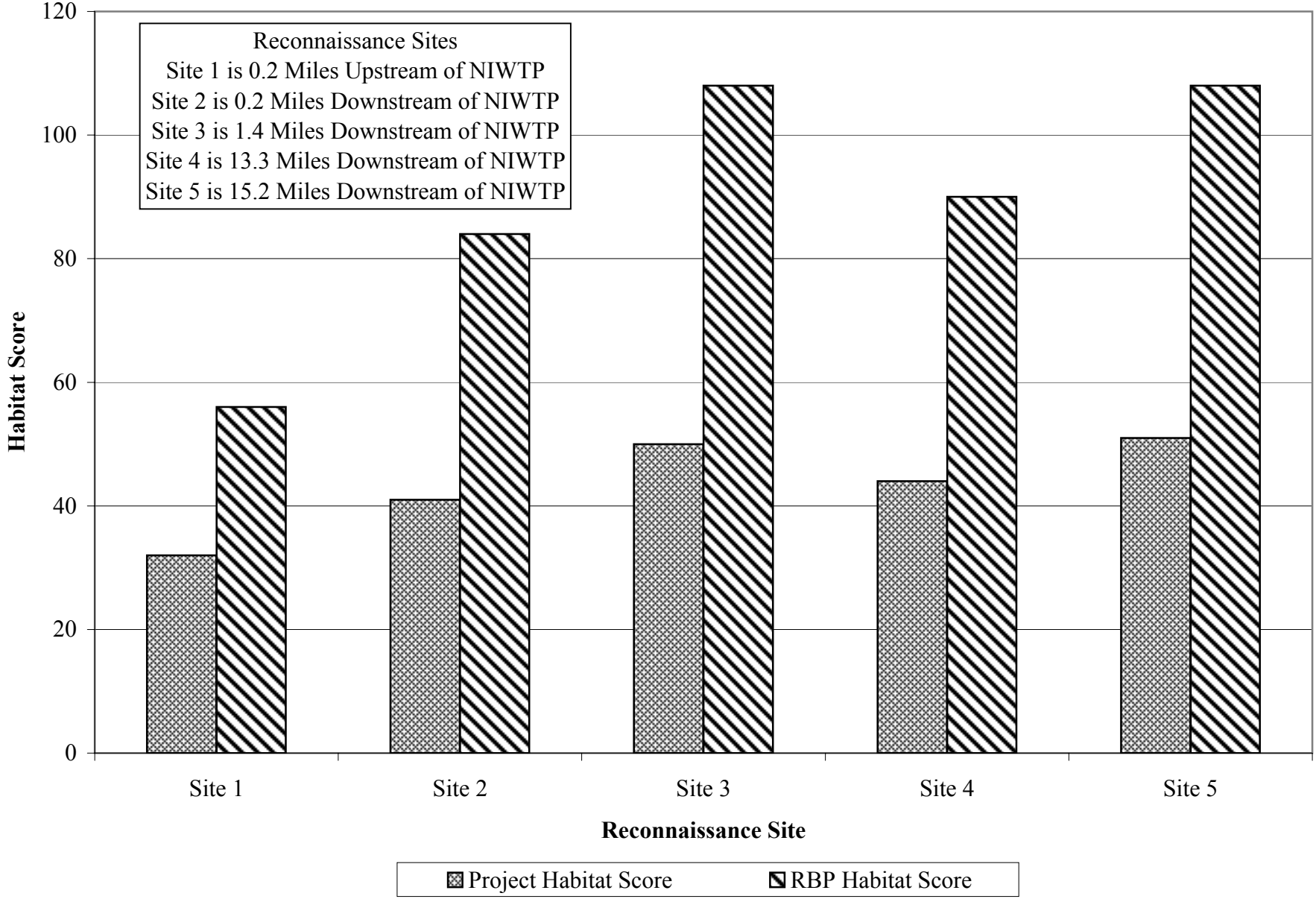


Figure C-2-30
Project Habitat vs. RBP Habitat Scores
Santa Cruz River Near Nogales, Arizona

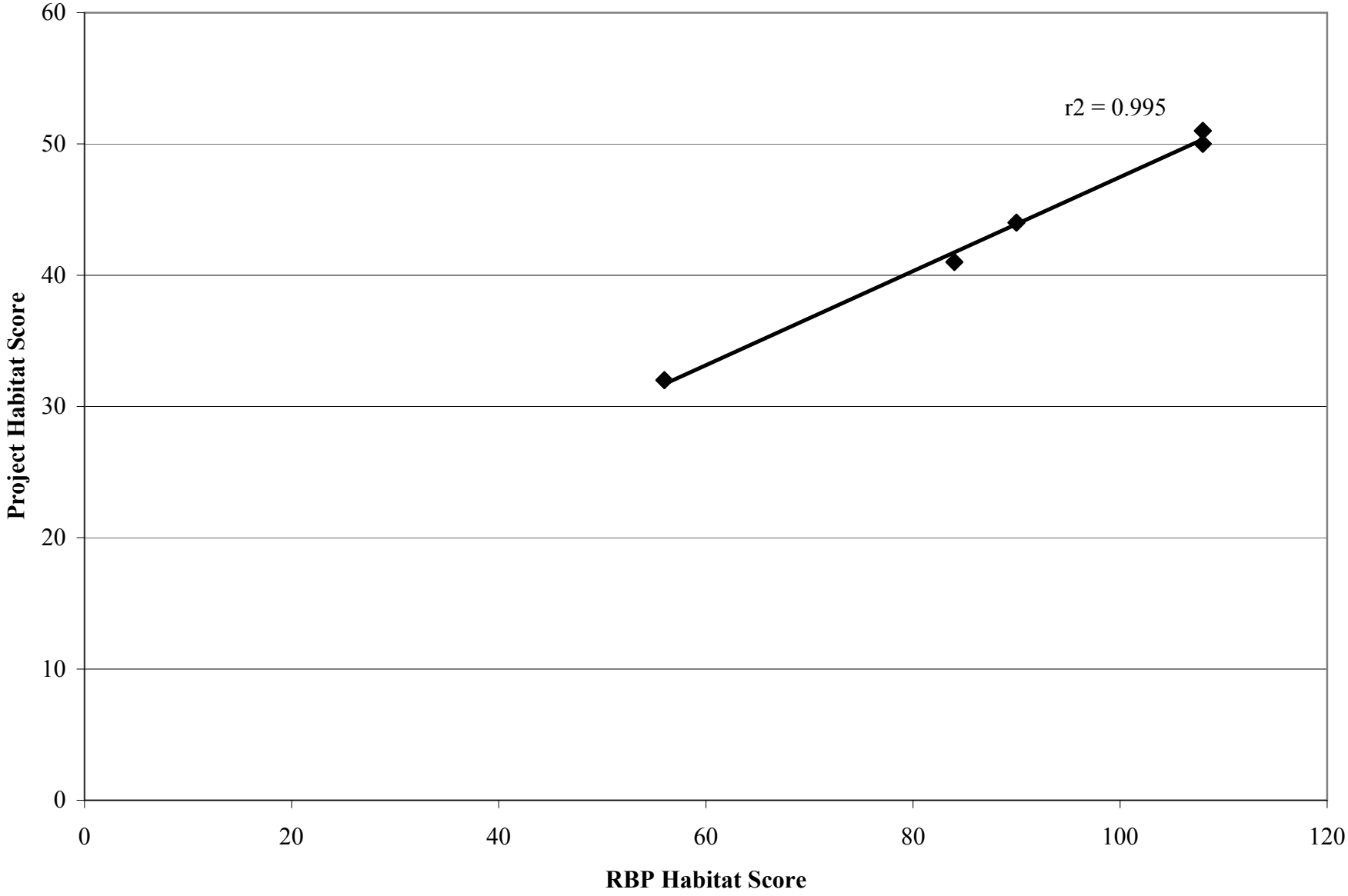


Figure C-2-31
Linear Regression RBP vs. Project Habitat Scores
Santa Cruz River Near Nogales, Arizona

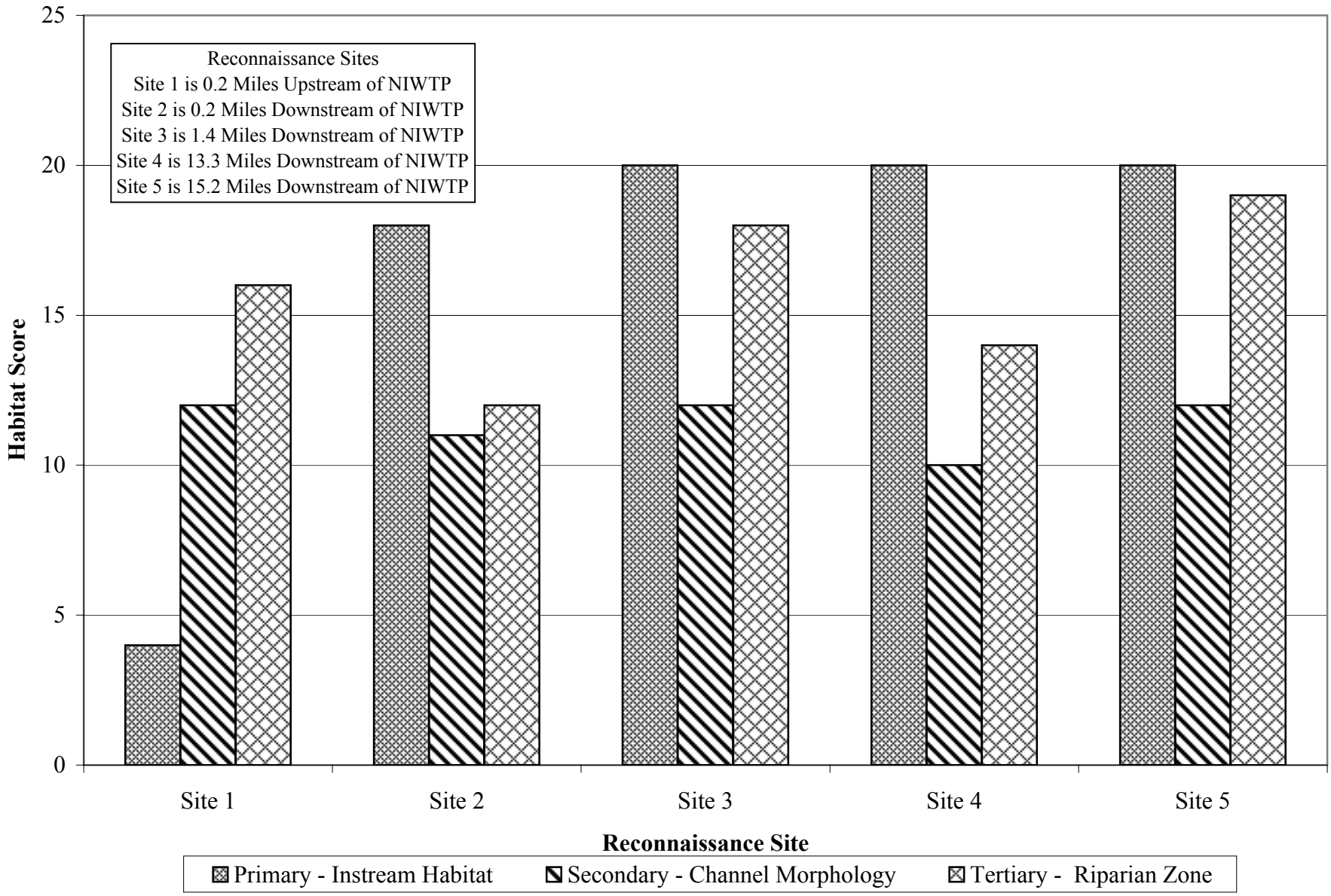


Figure C-2-32
Project Habitat Scores:
Comparison Among Primary, Secondary and Tertiary Factors
Santa Cruz River Near Nogales, Arizona

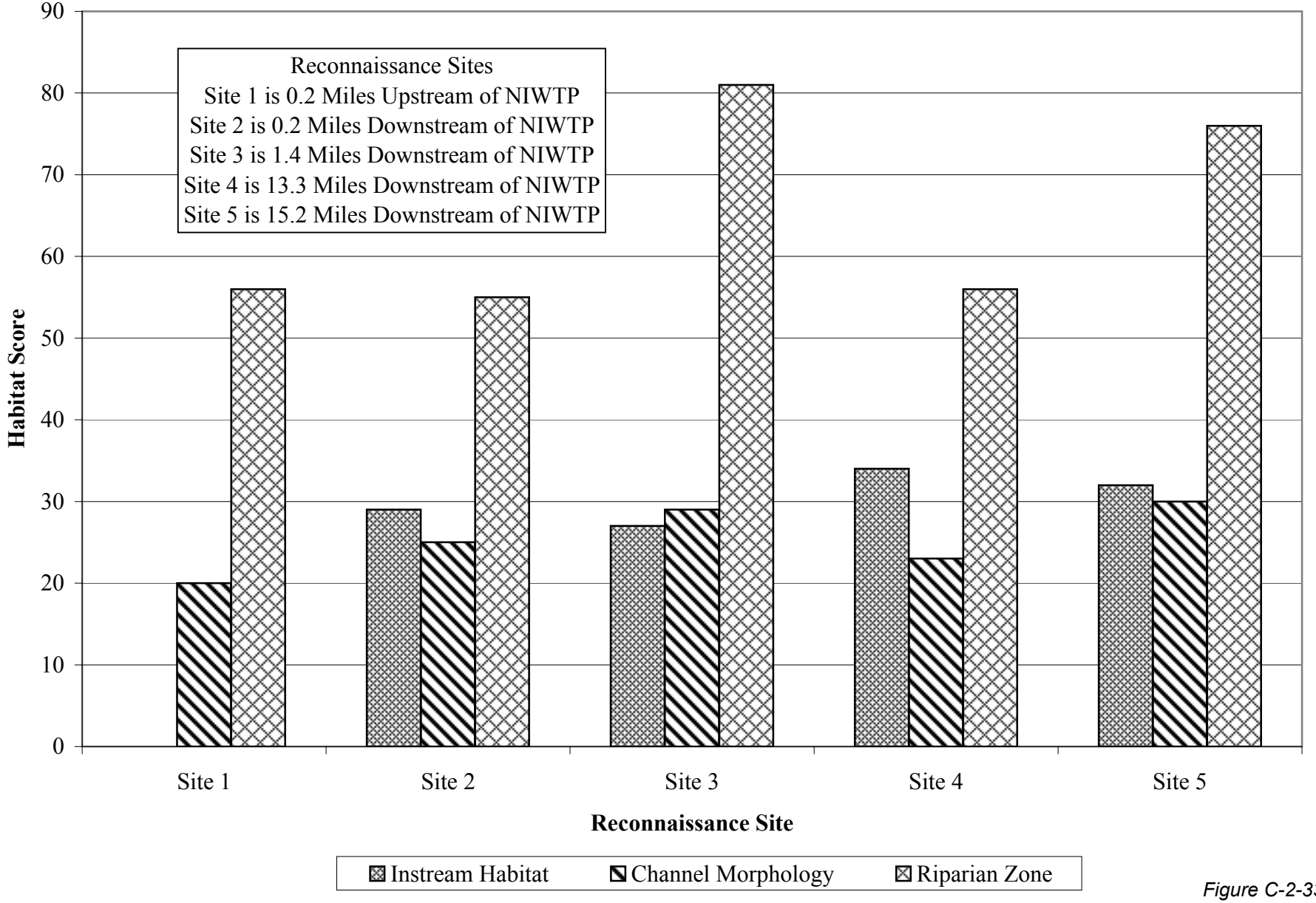


Figure C-2-33
RBP Habitat Scores:
Comparison Among Instream Habitat, Channel Morphology and Riparian Zone Factors
Santa Cruz River Near Nogales, Arizona

typically within 5 to 15 feet of the surface. Cienegas, or marshes, were also abundant along the Santa Cruz River in areas where groundwater was pushed to the surface by bedrock formations. Many cienega plants are wetland obligates and require water above or within approximately 1.5 feet of the ground surface (ADWR 1994). Bosques, composed of dense stands of large velvet mesquites, net-leaf hackberry, and Mexican elder, grew adjacent to the gallery forest on floodplains slightly higher than the main river channel (ADWR 1994). The floodplains provided areas for tree establishment where water was available to these deep-rooted species. Bosques were abundant along the upper Santa Cruz River and were the co-dominant riparian community.

Lush riparian vegetation disappeared from the region prior to the 1960s (Applegate 1981; ADWR 1994). Changes were brought about by increased pumping of groundwater, a dry period, and water table declines from the 1940s to the 1960s (ADWR 1994). After rain events, floods scour the river channel, removing vegetation and creating moist sand bars and sandy banks where Fremont cottonwood and willow seedlings can become established. Few floods occurred from the 1930s to the 1960s and water table levels had declined, so streambed conditions were not favorable for seedling establishment during this period. A series of floods beginning in the late 1960s provided the conditions required for Fremont cottonwood and willow establishment along the upper Santa Cruz (Applegate 1981). Increased water levels in the Santa Cruz River from the 1970s through the 1990s resulted from rain events recharging the aquifer during wet years beginning in the 1960s and from effluent discharge from the NIWTP beginning in 1972. The increased water levels provided the water needed for rapid growth of Fremont cottonwood and willow gallery forest.

Effluent discharge into the Santa Cruz River has created perennial streamflow from the outfall of the NIWTP downstream for approximately 12 miles (ADWR 1994). Stream water goes underground somewhere between Otero and Amado (Applegate 1981; ADWR 1994). Effluent discharge played a major role in raising water tables and thus re-establishing riparian vegetation (ADWR 1994).

Riparian vegetation dominated by Fremont cottonwood and willow gallery forest has become re-established along the Santa Cruz River since 1968 (Applegate 1981) and is well developed from NIWTP north to Amado, Arizona (ADWR 1994; Lawson 1995b). This vegetation community is currently the dominant riparian type (ADWR 1994). The historically co-dominant bosques have largely been cleared for agricultural production and are currently restricted to narrow areas along the perimeter of the Santa Cruz River (ADWR 1994).

Looking upstream on the dry channel of the Santa Cruz River from a railroad trestle immediately upstream of the Nogales International WWTP outfall. The bright green trees at left and right center are cottonwoods while most other trees shown are more xeric adapted mesquite.

The stream reach below the NIWTP supports the largest area of dense riparian vegetation along the portion of the Santa Cruz River from the Mexican border to Continental, Arizona (ADWR 1994). An exception to this is near the Rio Rico Bridge, where grazing of riparian

vegetation has prevented Fremont cottonwood and willow from growing above browse height (ADWR 1994).

Small areas of cienega have developed along the margins of the low flow channel downstream of the NIWTP (ADWR 1994; Lawson 1995b). Aquatic vegetation is confined to the water/bank interface and can be dense in some areas. Species present include watercress, water pennywort, and alligator weed with filamentous algae intertwined in aquatic vegetation (Applegate 1981; Lawson 1995b). Grasses, cattail, and knotweed border the low-flow channel (Applegate 1981). The largest remnant patch of cienega is located near Calabasas (Rio Rico) (ADWR 1994). This riparian community is dependent upon groundwater being at or near the surface and is sensitive to groundwater fluctuations (ADWR 1994).

Riparian vegetation provides habitat for many species of plants and animals, some of which are threatened, endangered, or otherwise sensitive (refer to **Appendix O**). Examples of these species include brown vine snake, gray hawk, thick-billed kingbird, southwestern willow flycatcher, and the Chiricahua leopard frog (CDM 1999; International Boundary Water Commission and EPA 1999). These and many other species depend upon the continued existence of riparian areas in Arizona and Sonora (CDM 1999).

1.11 TERRESTRIAL BIOLOGY ANALYSIS

A total of 43 species of birds, four species of lizards, a toad species, and two species of mammals were detected either visually, aurally, or through identification of other signs. Additionally, 34 species of plants were identified (**Appendix O**).

1.11.1 Site 1 – Reference Reach Upstream of the NIWTP Outfall

Upstream of the point where the NIWTP discharges into the Santa Cruz River, the streambed was dry. The riparian band is less than 50 feet wide at the sampling point. Riparian vegetation is dominated by deciduous trees including Fremont cottonwood, velvet mesquite, and Mexican elder. Small trees (diameter at breast height [dbh] <1 foot) are the most dense (canopy cover of less than 10 percent). Large trees (dbh >1 foot) are scattered along the stream bank. Understory vegetation is dominated by woody shrubs and saplings of Mexican elder and desert broom. Ground level vegetation is dominated by Bermuda grass with large areas of bare ground and sparse cover by woody shrubs. Dominant human influences observed at the site include a railroad bridge across the Santa Cruz River. Cattle grazing is also evident up to the banks of the stream. Surrounding land uses include agricultural fields, urban and commercial development, and mesquite grassland. Eleven species of birds were observed in the riparian area at this site. No mammals or reptiles were observed at this site.

With the riparian classification system, this site is described as a forested, mixed deciduous, community. The riparian vegetation characteristics score is relatively low because of moderate species diversity, relatively low percent cover in most vegetative layers, and no potential threatened or endangered species. The score for other habitat characteristics is also low because of discontinuous habitat, little contrast with non-riparian vegetation, few special habitat types or features, and a narrow riparian zone. The wildlife score is relatively low because few species in

any class were observed during the site visit, and there is potential habitat for relatively few threatened or endangered species. The score for disturbance characteristics is very low because of invasive plant species, high intensity grazing, and a high level of other human-caused disturbances in the riparian area and on adjacent land.

1.11.2 Site 2 – Below the NIWTP Outfall

The outfall from the NIWTP entering the dry channel of the Santa Cruz River. Trees shown here are wetland obligate Goodding's or black willow.

The canopy at Site 2 is composed primarily of Fremont cottonwood and Goodding's willow. Mexican elder and salt cedar are also present at this site, but are uncommon. The density of small and large trees is moderate. The understory is sparse and dominated by Goodding's willow. Ground cover is sparse and includes woody shrubs and herbaceous plants and grasses. Bare ground is moderately dense. Herbaceous plants present include common poolmat, curly dock, watercress, lupine, roughseed clammyseed, water pennywort, poison hemlock, hispid nama, monkey flower, and water speedwell. Grasses present include stinkgrass and Bermuda grass. Cattle grazing is apparent up to the banks of the stream.

Wildlife abundance is greater at this site than at Site 1, approximately 0.06 mile upstream. Twenty-two birds were observed at this site. Burrows of pocket gophers are present at this site and a tree lizard was observed.

With the riparian classification system, this site is described as a forested, mixed deciduous, community. The riparian vegetation score is low because of moderate species diversity, low percent cover in all layers, and little potential for threatened or endangered species. The score for other habitat characteristics is moderate because of discontinuous habitat, high contrast with adjacent vegetation, and some special habitat features. The wildlife score is relatively high because several bird, mammal, and reptile species were observed during the site visit, and there is potential habitat for several threatened, endangered, or sensitive species. The score for disturbance characteristics is very low because of invasive species, heavy grazing, and a high level of other disturbances.

1.11.3 Site 3 – Santa Cruz River at Rio Rico Road

NIWTP Site 3 at the Rio Rico Road Bridge looking downstream. Cottonwood, willow, tree tobacco, and seep willow are the dominant riparian species at this location. Also present at this site are poison hemlock, water speedwell, water cress, and yellow water plant.

Site 3 is immediately upstream of the bridge for Rio Rico Road that crosses the Santa Cruz River. The riparian band at this location is approximately

0.09 mile wide. Fremont cottonwood and Goodding's willow dominate the riparian area with a canopy cover of more than 25 percent. A few large trees are also present at this site, but provide less than 10 percent canopy cover. Riparian shrubs present in high density include seepwillow, tree tobacco, and salt cedar. Many herbaceous plants are present including common poolmat, Bermuda grass, curly dock, goosefoot, Mexican poppy, London rocket, watercress, blazing star, water pennywort, poison hemlock, hispid nama, verbena, datura, monkey flower, water speedwell, and cudweed.

The most notable human influences at this site include Rio Rico Road bridge crossing over the stream channel and livestock grazing. Wildlife are very abundant at this site. Twenty-one species of birds were observed at the site as well as a colony of free-tailed bats, a Sonoran whiptail lizard, another whiptail lizard, and a red-spotted toad.

With the riparian classification system, this site is described as a forested, mixed deciduous, community. The riparian vegetation score is relatively high because of moderate species diversity and high percent cover in the tree and herbaceous layers. The score for other habitat characteristics is very high because of high habitat continuity, high contrast with adjacent vegetation, and a wide riparian zone. The wildlife score is high because numerous birds, mammals, and reptiles were observed during the site visit, and there is potential habitat for several threatened or endangered species. The score for disturbance characteristics is relatively low because of heavy grazing and moderate levels of other disturbances.

An extremely dense growth of young (probably established after the floods of January 1993) cottonwood and willow at the Bridge Road site on the Santa Cruz River. Note the very large individual of poison hemlock at the left edge of the photo.

1.11.4 Site 4 – Santa Cruz River at Bridge Road

This site is immediately upstream of the Bridge Road bridge that crosses the Santa Cruz River. The right bank of the main channel at this site is reinforced with concrete, which limits the growth of riparian vegetation. The left bank of the river has three strands of riparian trees along old low flow channels. The riparian band on the left bank is approximately 0.05 mile wide. Fremont cottonwood and Goodding's willow trees are sparse along the right bank of the Santa Cruz, but are very dense (greater than 75 percent canopy cover) along the left bank. Tree and shrub densities immediately adjacent to the low-flow channel are thick enough to prevent pedestrian traffic (see photo). This dense growth of large

Looking upstream from the Bridge Road Bridge at Site 4 on the Santa Cruz River. The dense growth of young cottonwood and willow is so dense here as to nearly preclude a person walking through it.

Fremont cottonwood and willows saplings along the low-flow channel probably became established after the 1993 flood. This assumption is based on the fact that all Fremont cottonwood and willow tree saplings appeared to be about the same age. The 1993 flood probably scoured the vegetation from the site and created sandy banks that provided an ideal area for seedling establishment.

Herbaceous plants present within the main river channel include common poolmat, Bermuda grass, curly dock, watercress, water pennywort, poison hemlock, hispid nama, monkey flower, water speedwell, and common cocklebur. A well-developed mesquite bosque is present on upland sites at this location. Some of the mesquites in this bosque exceed 3 feet dbh. Human influences at this site are fairly abundant and include the road crossing the Santa Cruz River, trash along the left bank, and livestock grazing up to the bank of the river. Wildlife are common at this site and included 17 species of birds as well as the zebra-tailed lizard, greater earless lizard, and Sonoran whiptail.

With the riparian classification system, this site is described as a forested, mixed deciduous, community. The riparian vegetation score is moderate because of high species diversity but low percent cover in all layers. The score for other habitat characteristics is high because of high continuity, high contrast with adjacent vegetation, and a wide riparian zone. The wildlife score is high because numerous species of birds and reptiles were observed during the site visit, and there is potential habitat for several threatened or endangered species. The score for disturbance characteristics is low because of heavy grazing pressure and high levels of other disturbances, although the adjacent land is primarily natural vegetation.

1.11.5 Site 5 – Santa Cruz River at Chavez Siding Road

This point is immediately upstream of the Chavez Siding Road crossing of the Santa Cruz River. Small Fremont cottonwood and willow trees are moderately dense at this site and large trees are sparse. Fremont cottonwood and willows saplings and herbaceous plants are denser on the right bank than the left bank. Ground cover is very heavy on the left bank and heavy on the right bank, and bare ground is moderate on both banks. Herbaceous plants and grasses present at this site include common poolmat, common reed, timothy, curly dock, watercress, water pennywort, poison hemlock, hispid nama, monkey flower, water speedwell, cocklebur, and common sunflower.

Sampling Site 5 on the Chavez Siding Road on the Santa Cruz River. Cottonwood and Goodding willow are the dominant riparian trees and shrubs at this location. Most individual plants are young. Reed is also present in the riparian zone at this site. Streamside plants include water speedwell, water cress, yellow water plant, poison hemlock, and water foxtail. The spindly, dead plants at the right are the remains of the previous summer's growth of common sunflower.

Human influences present at this site include Chavez Siding Road (a dirt road that crosses the Santa Cruz River), trash along the banks of the river, and livestock grazing to the banks of the river.

Wildlife are abundant at this site. Twenty species of birds were observed. Other wildlife observations included burrows of pocket gophers and sightings of red-spotted toads, a greater earless lizard, and a Sonoran whiptail.

With the riparian classification system, this site is described as a forested, mixed deciduous, community. The riparian vegetation score is moderate because of moderate species diversity and low to moderate cover in most vegetative layers. The score for other habitat characteristics is high because of continuous riparian habitat, high contrast with adjacent vegetation, and a moderately wide riparian zone. The wildlife score is high because numerous birds, mammals, and reptiles were observed during the site visit, and there is potential habitat for several threatened, endangered, or sensitive species. The score for disturbance characteristics is very low because of heavy grazing pressure and high levels of other disturbances.