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Prepared as part of the Greater Everglades Priority Ecosystems Science initiative and in cooperation with the National Park Service

Flow Monitoring Along the Western Tamiami Trail Between County Road 92 and State Road 29 in Support of the Comprehensive Everglades Restoration Plan, 2007–2010

Data Series 831

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Bridge 71 along the western Tamiami Trail, between County Road 92 and State Road 29 (photograph by Lars Soderqvist, U.S. Geological Survey).

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

ADCP	acoustic Doppler current profiler
ADV	acoustic Doppler velocimeter
ADVM	acoustic Doppler velocity meter
SFWMD	South Florida Water Management District
SGGE	Southern Golden Gate Estates
TTI	Ten Thousand Islands
USGS	U.S. Geological Survey

Flow Monitoring Along the Tamiami Trail Between County Road 92 and State Road 29 in Support of the Comprehensive Everglades Restoration Plan, 2007–2010

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Abstract

The construction of U.S. Highway 41 (Tamiami Trail), the Southern Golden Gate Estates development, and the Barron River Canal has altered the flow of freshwater to the Ten Thousand Islands estuary of Southwest Florida. Two restoration projects, the Picayune Strand Restoration Project and the Tamiami Trail Culverts Project, both associated with the Comprehensive Everglades Restoration Plan, were initiated to address this issue. Quantifying the flow of freshwater to the estuary is essential to assessing the effectiveness of these projects.

The U.S. Geological Survey conducted a study between March 2006 and September 2010 to quantify the freshwater flowing under the Tamiami Trail between County Road 92 and State Road 29 in southwest Florida, excluding the Faka Union Canal (which is monitored by South Florida Water Management District). The study period was after the completion of the Tamiami Trail Culverts Project and prior to most of the construction related to the Picayune Restoration Project. The section of the Tamiami Trail that was studied contains too many structures (35 bridges and 16 culverts) to cost-effectively measure each structure on a continuous basis, so the area was divided into seven subbasins. One bridge within each of the subbasins was instrumented with an acoustic Doppler velocity meter. The index velocity method was used to compute discharge at the seven instrumented bridges. Periodic discharge measurements were made at all structures, using acoustic Doppler current profilers at bridges and acoustic Doppler velocity meters at culverts. Continuous daily mean values of discharge for the uninstrumented structures were calculated on the basis of relations between the measured discharge at the uninstrumented stations and the discharge and stage at the instrumented bridge. Estimates of daily mean discharge are available beginning in 2006 or 2007 through September 2010 for all structures. Subbasin comparison is limited to water years 2008–2010.

The Faka Union Canal contributed more than half (on average 60 percent) of the flow under the Tamiami Trail between State Road 29 and County Road 92 during water years 2008–2010. During water years 2008–2010, an average 9 percent of the flow through the study area came from west of the Faka Union Canal and an average 31 percent came from east of the Faka Union Canal. Flow data provided by this study serve as baseline information about the seasonal and spatial distribution of freshwater flow under the Tamiami Trail between County Road 92 and State Road 29, and study results provide data to evaluate restoration efforts.

Introduction

The construction of U.S. Highway 41, the Southern Golden Gate Estates (SGGE), and the Barron River Canal altered the flow of freshwater to the Ten Thousand Islands (TTI) estuary of southwest Florida (fig. 1) (U.S. Army Corps of Engineers, 1998). U.S. Highway 41, also known as the Tamiami Trail, was completed in 1928 to provide a southern route connecting the west coast of Florida (**Tam**pa) to the east coast (M**iami**) of Florida. The Tamiami Trail created a block to the natural drainage of the Picayune and Fakahatchee Strands (U.S. Army Corps of Engineers, 1998). Freshwater historically meandered south as sheet flow across the landscape, ultimately reaching the TTI estuary through a natural course of sloughs, wetlands, marshes, and rivers. With the completion of the Tamiami Trail, this flow was intercepted by a borrow canal (the Tamiami Canal) dug on the north side of the road. Water is conveyed under the road at only a few bridges and culverts, which were not always optimally positioned relative to the natural flow patterns. As a result, water is unevenly distributed, and the hydrology of the downstream wetlands and estuaries is affected by the addition or reduction in freshwater flows (U.S. Army Corps of Engineers, 1998).

The SGGE is an 86 square mile (mi^2) failed housing development built in the 1960s in the western part of the TTI watershed north of the Tamiami Trail. The Faka Union Canal System, consisting of four canals (Miller Canal, Faka Union Canal, Merritt Canal, and Prairie Canal), was built to drain the area for the SGGE project. Several roads, with adjacent drainage ditches, diverted sheet flow into the Faka Union

Canal System, accelerating drainage within the watershed and reducing wetland coverage, aquifer recharge, and base flow into the estuaries (South Florida Water Management District Big Cypress Basin and U.S. Department of Agriculture Natural Resources Conservation Services, 2003). As a result of the altered hydrologic environment, the intercepted sheet flow is discharged into the TTI estuary at a single point, Faka Union Bay, instead of being distributed throughout the system (fig. 2) (U.S. Army Corps of Engineers, 2008).

The Barron River Canal is a borrow canal built in the 1920s that parallels State Road 29 (S.R. 29) between Immokalee and Everglades City, a distance of 37 miles (South Florida Water Management District, 2006). The Barron River Canal is divided into two segments 2.5 miles north of the Tamiami Trail. These segments are reconnected just north of Everglades City, where the canal empties into the Barron River (fig. 2). The Barron River Canal has increased the amount of water discharged by the Barron River, resulting in a large single-point discharge of freshwater to the TTI estuary at Chokoloskee Bay (U.S. Army Corps of Engineers, 1998).

Seasonal salinity maps produced by the U.S. Geological Survey (USGS) between 2007 and 2010, as part of a broader monitoring program within the estuary, demonstrated the altered freshwater flows to the estuary. Freshwater plumes were evident in Faka Union and Chokoloskee Bays in many of the salinity maps. In addition, higher salinities were often observed in the inner bays west of the Faka Union Canal, particularly Pumpkin Bay, compared to the inner bays east of the Faka Union Canal (Soderqvist and Patino, 2010).

Two Comprehensive Everglades Restoration Plan projects were initiated to improve freshwater delivery to the TTI estuary: the Picayune Strand Restoration Project (formerly SGGE Restoration Project) and the Tamiami Trail Culverts Project. The goal of the Picayune Strand Restoration Project is to "restore historic hydroperiods and sheet-flow patterns in the study area to the extent possible, while maintaining the existing levels of flood protection for areas north of the SGGE" (U.S. Army Corps of Engineers, 2004). To meet this goal, the current plan calls for the removal of 227 miles of roads and the placement of 83 plugs within 42 miles of existing canals. In addition, three pump stations with downstream spreader channels are to be constructed to restore sheet flow through the region while maintaining flood control capacity for communities to the north (U.S. Army Corps of Engineers, 2008).

As of August 2012, plugs had been placed in the Prairie Canal, and roads between the Prairie and Merritt Canals were removed. The Merritt Pump station was near completion, and construction had begun on the Faka Union Pump station. The majority of road removal between the Faka Union and Miller Canals was also completed (Jennifer Carpenter, Florida Department of Environmental Protection, unpub. data, 2013).

The Tamiami Trail Culverts Project involved the construction of 16 culverts under the Tamiami Trail within the TTI watershed. The purpose of these culverts is to provide a path for the restored sheet flow exiting Picayune Strand to continue southward toward the estuary. The portion of the Tamiami Trail Culverts Project within the TTI watershed was completed in June 2006 (Wossenu and Ciuca, 2011).

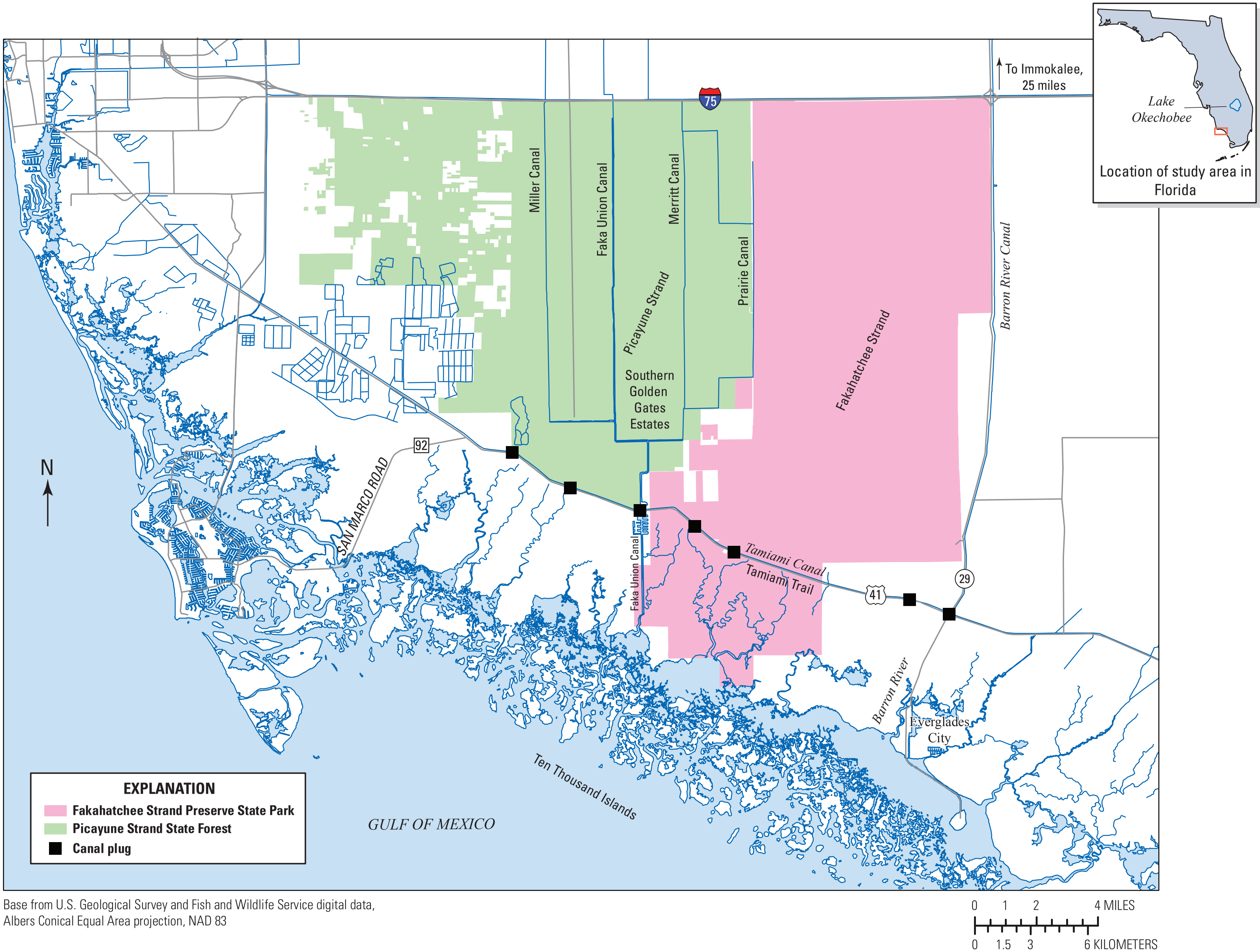
Quantifying discharge across the western part of the Tamiami Trail between County Road 92 (C.R. 92) and S.R. 29 was necessary to provide preliminary data to assess the effectiveness of these projects. Discharge for the Faka Union Canal at the Tamiami Trail is reported by the South Florida Water Management District (SFWMD); however, no flow data existed for the remaining structures. In March 2006, the USGS initiated a study, as part of the Greater Everglades Priority Ecosystems Science initiative, in cooperation with the National Park Service Critical Ecosystem Studies Initiative, U.S. Army Corps of Engineers, and SFWMD, to quantify the flow through the western Tamiami Trail, excluding the Faka Union Canal. The data presented herein provide information regarding the quantity and distribution of flow within the study area during 2007–2010. For the purpose of this report, years during the study period are referenced to water years (October 1 to September 30) and they are identified by the year in which the period ends. This study period occurred after the completion of the Tamiami Trail Culverts Project and prior to most of the construction related to the Picayune Restoration Project. The data complement seasonal salinity maps of the TTI estuary produced by the USGS between 2007–2010 as part of a broader monitoring program within the estuary (Soderqvist and Patino, 2010). The data also may be useful for calibration of local hydrologic models, such as the TTI-area model (Swain and Decker, 2009).

Purpose and Scope

The purpose of this report is to provide daily mean discharge data at 35 bridges and 16 culverts along the western Tamiami Trail between C.R. 92 and S.R. 29, excluding the Faka Union Canal. Data collection began in 2006 at structures west of the Faka Union Canal and in 2007 at structures east of the Faka Union Canal (table 1). Data collection continued at all locations through September 30, 2010. Data are not available for Subbasin 2 for 2007.

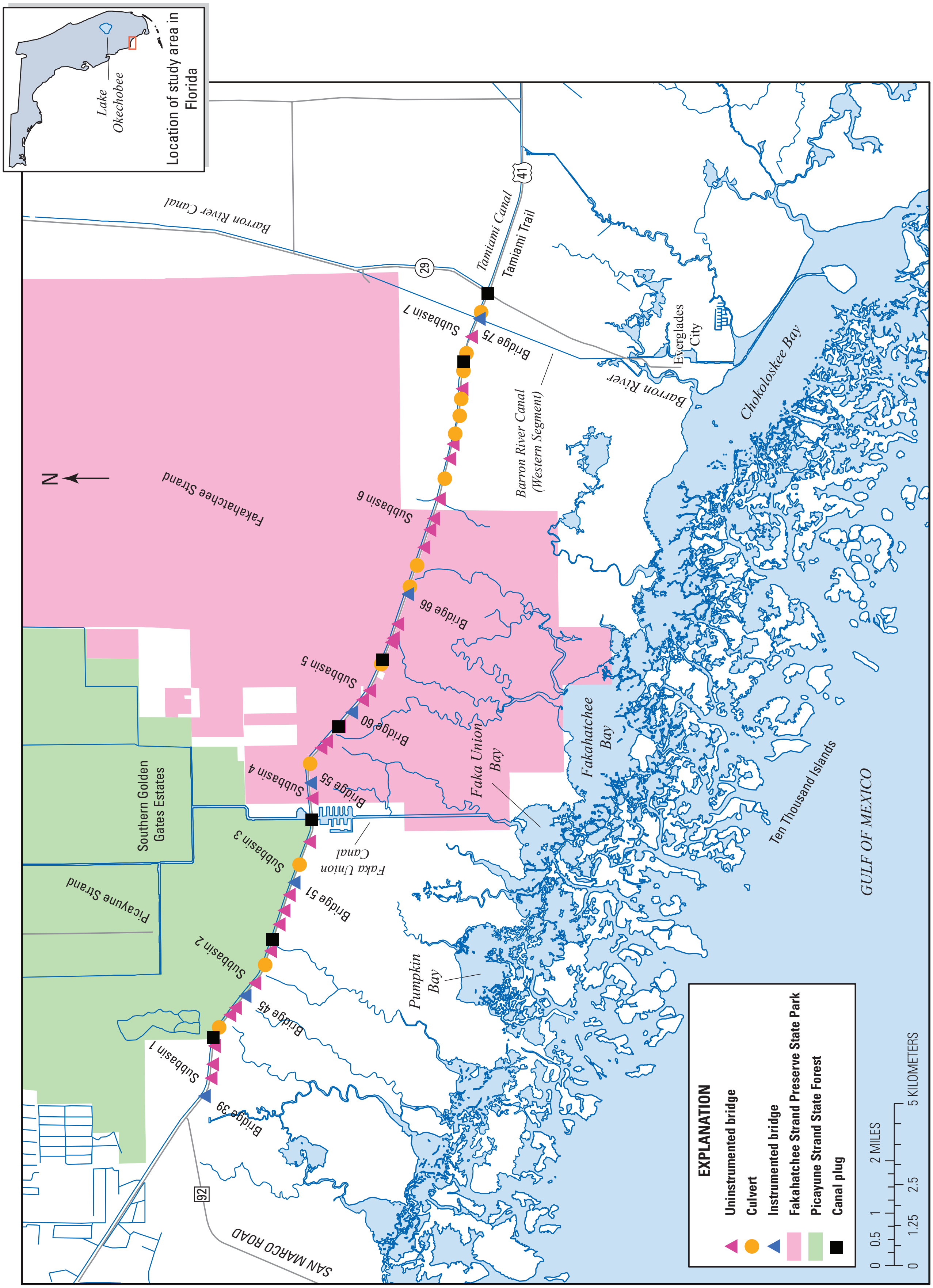
It was not cost effective to individually monitor the 51 structures within the study area continuously; therefore, the area was divided into seven subbasins, and one bridge within each subbasin was instrumented with a stream gage. Subbasins were delineated by plugs in the Tamiami Canal. Instrumented bridge stations provided 15-minute, and daily mean stage and discharge records. The daily mean value of discharge was calculated for the remaining structures within a subbasin on the basis of relations between instantaneous measured discharge at the uninstrumented structures and discharge and stage at the instrumented bridge.

A second purpose of this report is to describe the technique used to calculate discharge at uninstrumented structures. Data-collection methods, rating development techniques, data processing, seasonal and spatial flow distribution, limitations, and implications for future investigations are discussed.



Base from U.S. Geological Survey and Fish and Wildlife Service digital data,
Albers Conical Equal Area projection, NAD 83

Figure 1. Map of study area showing the Tamiami Canal and other major canals.



Base from U.S. Geological Survey and Fish and Wildlife Service digital data,
Albers Conical Equal Area projection, NAD 83

Figure 2. Enlarged map of study area showing instrumented and uninstrumented bridges, culverts, and canal plugs.

Table 1. Installation dates of stream gages at bridges monitored along the Tamiami Canal.

Bridge	USGS station number	Installation date
39	255923081351300	April 14, 2006
45	255843081333000	March 17, 2006
51	255754081314000	March 23, 2006
55	255738081300100	February 16, 2007
60	255656081285000	January 30, 2007
66	255601081265300	January 31, 2007
75	255449081221800	July 18, 2007

Description of Study Area

The study area includes 35 bridges and 16 culverts that convey flow under the western Tamiami Trail between C.R. 92 and S.R. 29. The study area is divided into seven subbasins. Each subbasin is constrained by plugs in the borrow canal on the north side of the Tamiami Trail. Within this report, subbasins are numbered from 1 to 7, from west to east (fig. 2). Structures located within each subbasin are listed in table 2.

Table 2. List of structures located within each subbasin.

Subbasin	Instrumented bridge	Uninstrumented bridges	Culverts
1	39	40, 41, 42	
2	45	43, 44, 46, 47	42A, 46A
3	51	48, 49, 50, 52	51A, 51B, 51C
4	55	54, 57, 58, 59	55A
5	60	61, 62	62A
6	66	63, 64, 65, 67, 68, 69, 70, 71, 72,73	66A, 66B, 70A, 72A, 72B, 72C, 73A
7	75	74	73B, 75A

Data-Collection Methods

Flow data were collected throughout the study area from March 2006 to September 2010. Data-collection methods are divided into three categories: instrumented bridges, uninstrumented bridges, and culverts. Instrumented bridges were selected in cooperation with local SFWMD personnel. In general, bridges with the highest visually observed flow were selected to be instrumented.

Instrumented Bridges

USGS stream gages were installed at the downstream side of seven Tamiami Trail bridges (Bridges 39, 45, 51, 55, 60, 66, and 75). Bridges 39, 45, 51, 55, and 66 were instrumented with an up-looking acoustic Doppler velocity meter (ADVM) to provide continuous measurements of index velocity and stage (fig. 3). Bridges 60 and 75 were instrumented with sidelooking ADVMs to provide continuous measurements of index velocity and a submersible vented pressure transducer to provide continuous measurements of stage. Stage was referenced to the North American Vertical Datum of 1988 based on optical survey levels measured from Florida Department of Transportation benchmarks. Power was supplied by a 26 amp-hour battery and 10-watt solar panel. Solar panels were later removed from all stations after several were stolen or vandalized. Velocity and stage were recorded at 15-minute intervals by the ADVMs and vented pressure transducers. Stations were visited every 3 to 6 weeks to download data, exchange batteries, perform stage verification measurements, and verify instrument performance. ADVM performance was verified following USGS protocols including in-field review of the data file, internal equipment diagnostics, and beam checks (Levesque and Oberg, 2012).

Between 13 and 136 discharge measurements were made at each instrumented bridge using a Teledyne RD Instruments (TRDI) Workhorse Rio Grande 1200 kHz acoustic Doppler current profiler (ADCP) or a TRDI Stream Pro 2000 kHz ADCP. Measurements were made periodically throughout each year, over the widest possible range of flow conditions, to develop and verify the relations (ratings) between the index velocity (as measured by the ADVM) and mean channel velocity (as measured by the ADCP) (appendix 1). A greater number of discharge measurements were made at Bridges 39 and 75 because they are tidally influenced; therefore, numerous discharge measurements could be made during each measurement session due to the continuously changing conditions.

Figure 3. Index velocity station at Bridge 55 (photograph by Lars Soderqvist, U.S. Geological Survey).

Uninstrumented Bridges

Between 7 and 12 ADCP discharge measurements were made at each uninstrumented bridge using a TRDI Workhorse Rio Grande 1200 kHz ADCP or a TRDI Stream Pro 2000 kHz ADCP and standard USGS protocols (appendix 2; Mueller and Wagner, 2009). Measurements were made periodically throughout each year, over the highest possible range of flow conditions, to develop and verify the relation (rating) between computed streamflow at the instrumented bridges and instantaneous streamflow measured at the uninstrumented bridges.

Culverts

Between 9 and 13 discharge measurements were made at each culvert (appendix 2). Culvert discharge was measured using nonstandard methods. An up-looking ADVM (Sontek Argonaut-SW) on a removable mount was deployed at the downstream end of the culvert (figs. 4, 5). The ADVM was deployed for 10–20 minutes, and the average discharge was computed using the ADVM's internal flow computations, which were configured for a 3-foot (ft) diameter culvert and 0.3-ft instrument elevation. Measurements were made periodically throughout each year, over the highest possible range of flow conditions, to develop and verify the relations (ratings) between computed flow at the instrumented bridges and the instantaneous flow measured at the culverts.

The technique of measuring culvert discharge was evaluated on September 17, 2008, at Culvert 73B by comparing the discharge computed by the ADVM to the discharge computed from the average of multiple point velocities measured by an Acoustic Doppler Velocimeter (ADV). During the evaluation, an ADVM was deployed for 20 minutes on the downstream side of the culvert prior to the ADV measurement, and then the ADVM was redeployed for 12 minutes afterward. A second ADVM was deployed at the upstream end of the culvert during the entire comparison period to monitor flow variability during the test. The ADV cross section was located immediately downstream from the culvert opening. The cross section was divided into eight vertical sections, and 9 to 15 point-velocity measurements were made in each section for a total of 91 velocity point measurements. Discharge from the ADV was computed using the average velocity multiplied by the cross-sectional area. The internally computed discharge from the ADVM agreed within 5 percent of the discharge computed from the ADV. The use of an ADVM appears to be a reliable method for measuring discharge from 3-ft diameter concrete culverts.

The deployment duration of this technique was also evaluated. Initially, a 20-minute duration was used for all ADVM culvert discharge measurements. The measurement duration was later reduced to 10 minutes after comparisons between the 10- and 20-minute sampling intervals were found to be within 0.6 cubic foot per second (ft^3/s) or 7 percent of one another.

Figure 4. ADVM removable mount for culvert discharge measurements (photograph by Lars Soderqvist, U.S. Geological Survey).

Figure 5. ADVM culvert installation (photograph by Lars Soderqvist, U.S. Geological Survey).

Rating Development

Rating development was divided into two categories: instrumented bridges, and uninstrumented bridges and culverts. All rating development analysis was completed in Microsoft Excel™ 2010. Two of the instrumented bridges (Bridges 39 and 75) were influenced by tides and required modified methods to relate the discharges between the instrumented and uninstrumented gages within each subbasin.

Instrumented Bridges

The index velocity method was used to compute discharge at all instrumented bridges, using standard USGS protocols (Morlock and others, 2002; Ruhl and Simpson, 2005; Levesque and Oberg, 2012). Regression equations and R^2 and standard error values can be found in appendix 1. The R^2 values ranged from 0.51 to 0.99, and standard error values ranged from 0.01 to 0.05 foot per second (ft/s). Daily mean values of discharge for all instrumented bridges can be found in the 2010 USGS Annual Water Data Report, which can be accessed at *http://wdr.water.usgs.gov/* and in appendix 3. Mean daily values of stage are included in appendix 3; these values were not previously published. Appendix 3 also includes additional estimates of discharge that were not included in the Annual Water Data Reports. These estimates were necessary to compare data across water years and subbasins. Estimates of discharge were determined by hydrographic comparison with neighboring structures and downstream tributaries.

Bridges 39 and 75 are tidally affected due to downstream canals that link them directly to the TTI estuary. According to USGS policy (U.S. Geological Survey, 2010), discharge record at these stations was first filtered using the Godin low-pass filter to remove tidal frequencies (Godin, 1972). Filtered discharge was then used to compute mean daily values of discharge.

Uninstrumented Bridges and Culverts

The relations between the stage and computed discharge at the instrumented bridges, and the discharge measurements from the uninstrumented bridges and culverts, were examined using regression analyses in order to calculate discharge at each uninstrumented structure. With the exception of Bridge 42, the analysis was restricted to structures that shared the same subbasin due to differences in stage between adjacent subbasins. Four linear regression scenarios were evaluated for each uninstrumented structure (table 3). In addition to linear regressions, stage-discharge relations were investigated using nonlinear trendlines. The rating equations that provided the best fit to the data were selected on the basis of statistical and graphical analysis. Rating equations, R^2 values, and standard error values for each structure are listed in appendixes 1 and 2. The R^2 values and standard error values ranged from 0.46 to 0.99 and 0.6 to 15.3 ft^3/s, respectively, for the uninstrumented bridges.

Table 3. Variables used in regression analyses performed for uninstrumented structures.

[Q, discharge; Qm, measured discharge]

Scenario	Independent variable (X) (data from instrumented bridge)	Dependent variable (Y) (data from uninstrumented structure)
1	Q	Qm
2	Stage	Qm
3	Q and Stage	Qm
4	Q with intercept forced through 0.00	Qm

Regression analysis determined that stage was a significant (p-value less than 0.05) variable (scenario 3 in table 3) in the rating equations for Subbasins 2–6. During periods of minimal flow, however, the discharge measurement computed from these ratings was unreliable as exemplified for the case of Bridge 44 in figure 6*A*. Using discharge and gage height at Bridge 45 to calculate discharge at Bridge 44 results in negative discharges greater than 40 ft^3/s. Negative discharges of this magnitude are not supported by data from the instrumented bridge located within the subbasin. To address this issue, the regression equation using instrumented bridge discharge forced through zero (scenario 4 in table 3) was used to compute discharge during periods of minimal flow. Analyses indicated that the stage at all structures must exceed a minimum value before downstream flow occurred; the relation between minimum stage and flow was apparent at Bridge 45 (fig. 6*B*), where the instrumented bridge did not show any substantial flow until stage was above 0.8 ft. In order to standardize the determination of the minimum stage, the daily mean stage at the instrumented bridge was plotted against the corresponding measured discharge from the uninstrumented structure (fig. 7). The intercept of the linear regression line for the stage discharge data determined the minimum stage, which in turn determined when each rating equation was used to compute discharge at the uninstrumented structure (fig. 8; appendix 2). In figure 8 the final discharge at Bridge 44 is derived using the equations with Bridge 45 discharge and stage as the input when the stage at Bridge 45 is greater than 0.8 ft and the equation using Bridge 45 discharge as the input (relationship forced through zero) when stage is less than or equal to 0.8 ft.

The technique described above resulted in an overcalculation of flow during minimal flow periods for the following uninstrumented structures: Bridges 40, 41, and 74, and Culvert 73B. The over-calculation is likely due to the tidal influence that occurs at the instrumented structure. To address this issue, flow was calculated as zero when the stage at the instrumented bridge was equal to or less than the minimum stage.

Bridge 42 was located in Subbasin 1; however, the relations between the measured discharge at Bridge 42 and the inputs from the instrumented structure were not optimal. Additional scenarios were explored and it was determined that the instrumented station in Subbasin 2 provided a better index for Bridge 42.

Seasonal and Spatial Distribution of Freshwater Flow

For the purpose of this report, total annual flow statistics are referenced to water years. Dry seasons typically span November to June, and wet seasons span July to October. Wet- and dry-season flow statistics were averaged over the entire study period.

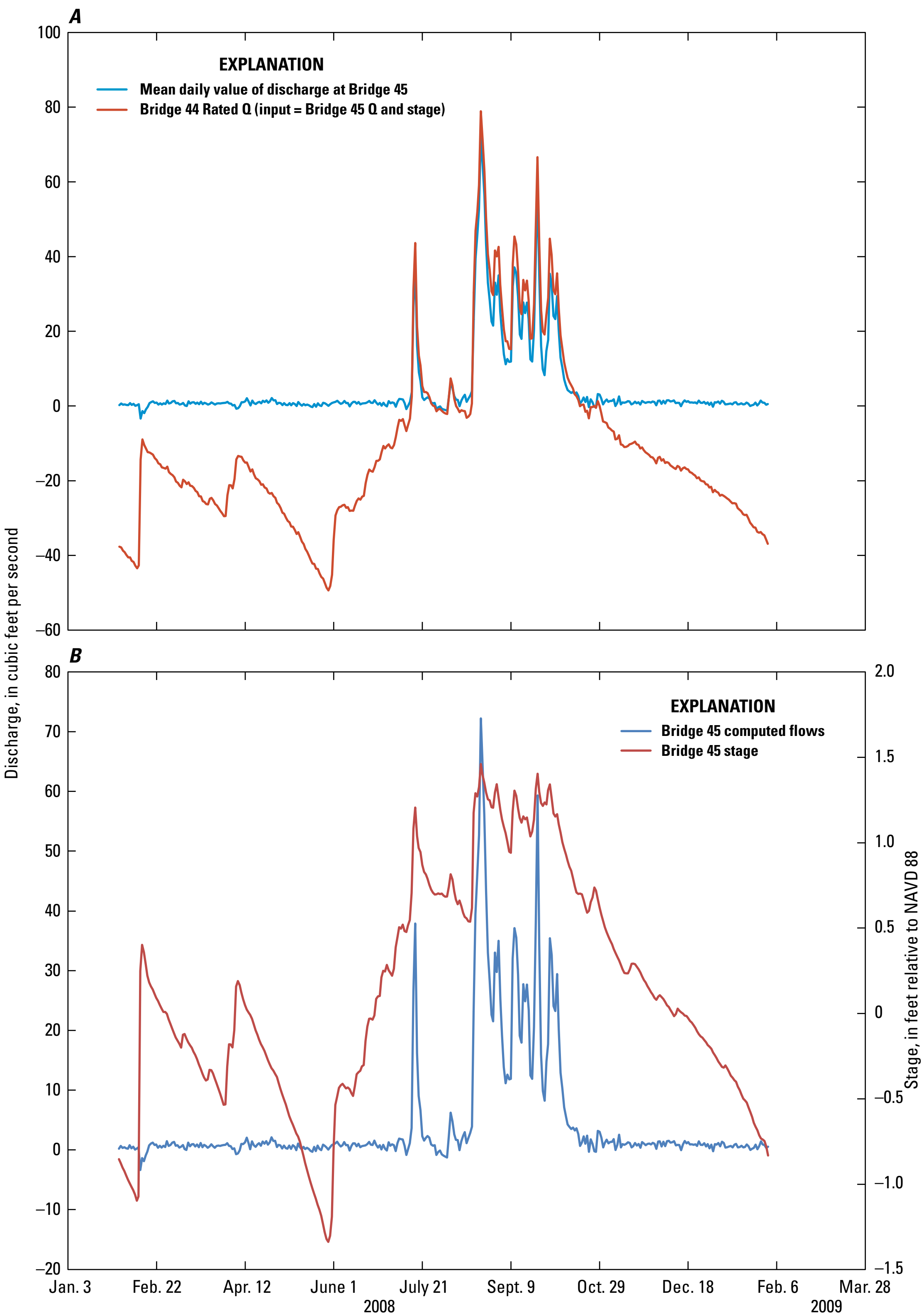


Figure 6. (*A*) Comparison of discharge ratings for Bridges 44 and 45, January 2008 to February 2009, and (*B*) comparison of mean daily values of discharge versus daily values of stage at Bridge 45, January 2008 to February 2009.

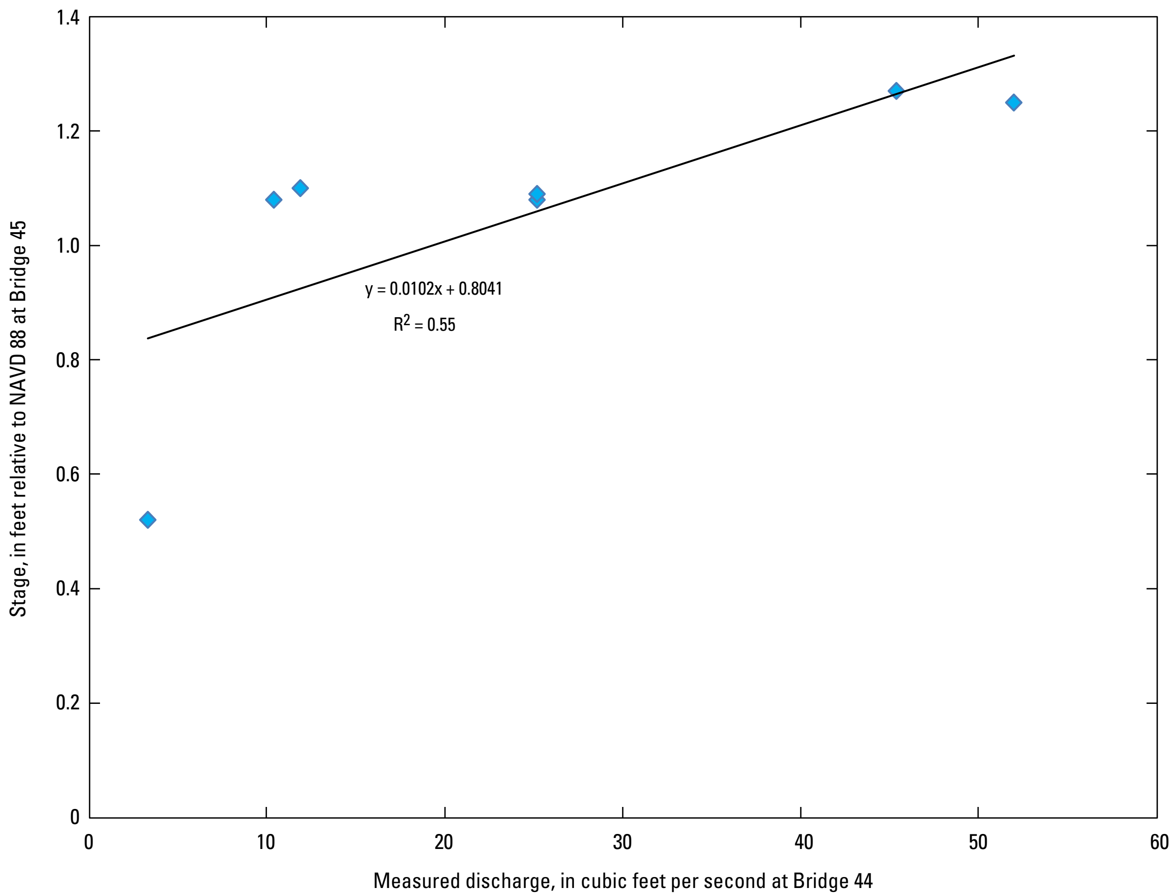


Figure 7. Measured discharge at Bridge 44 compared to stage at Bridge 45. The intercept from this regression determines the stage at which the stage-factor rating is used and when the discharge-only rating is used.

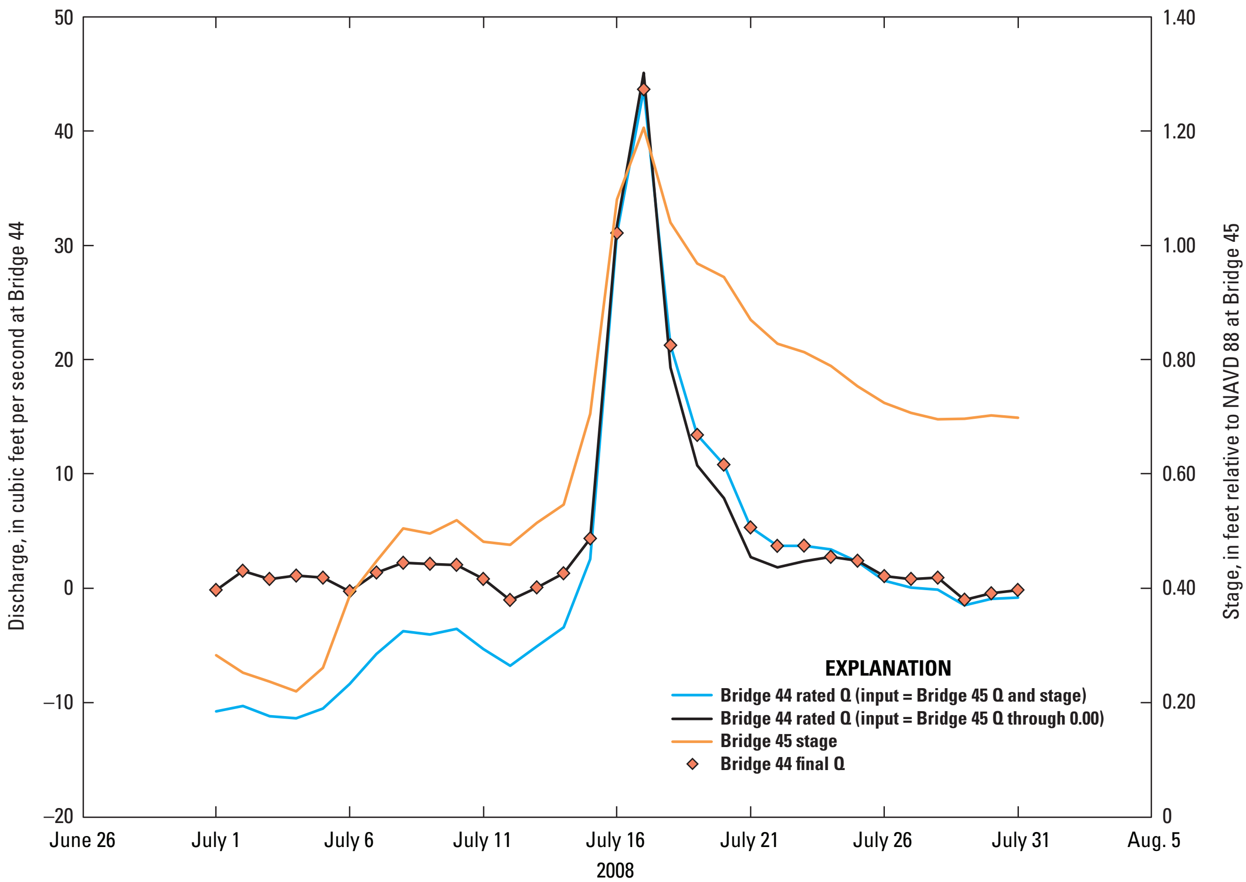


Figure 8. Bridge 44 discharge ratings including stage and not including stage as an input.

Subbasin 1

The highest computed total flow in Subbasin 1 occurred in 2008 (21,685 acre-feet), followed by 2009 (15,457 acre-feet), 2010 (13,026 acre-feet), and 2007 (2,814 acre-feet). The largest contributor to flow was Bridge 39 (fig. 9). In 2007, 51 percent of the flow in the subbasin was attributed to Bridge 39. Bridge 39 and Bridge 40 each contributed approximately 35 percent of the flow in the subbasin during 2008. During 2009 and 2010, Bridge 39 contributed 44 and 48 percent of the subbasin flow, respectively. The second largest contributor to flow was Bridge 40, followed by Bridges 41 and 42. During the study period (2007–2010) approximately 96 percent of the flow occurred during the wet seasons.

Subbasin 2

The highest computed total flow in Subbasin 2 occurred in 2008 (17,541 acre-feet), followed by 2009 (11,402 acre-feet), and 2010 (9,120 acre-feet). The largest contributor to flow in Subbasin 2 was Bridge 43, with approximately 27–28 percent of the flow. The next largest contributors to flow were Bridges 44 and 47 (44 in 2008 and 47 in 2009 and 2010), 45, and 46, and Culverts 42A and 46A (fig. 10). During 2007–2010, approximately 91 percent of flow occurred during the wet seasons.

Subbasin 3

The highest computed total flow in Subbasin 3 occurred in 2008 (10,271acre-feet), followed by 2009 (8,566 acre-feet), 2010 (5,765 acre-feet), and 2007 (3,441 acre-feet). The largest contributor to flow was Bridge 52, with approximately 23–24 percent of the flow. The next largest contributors to flow were Bridges 49 and 51 (51 in 2007), 48, and 50, and Culverts 51A, B, C (fig. 11). During 2007–2010, approximately 86 percent of the flow occurred during the wet seasons.

Subbasin 4

The highest computed total flow in Subbasin 4 occurred in 2008 (19,378 acre-feet), followed by 2009 (12,742 acre-feet) and 2010 (3,644 acre-feet). The largest contributor to flow in Subbasin 4 was Bridge 58 with approximately 31–48 percent of the flow. The next largest contributors to flow were Bridges 55, 59, 57, and 54, and Culvert 55A in 2008 and 2009 (fig. 12). During water year 2010, Bridge 58 was the greatest contributor to flow, followed by Bridges 59, 55, and 57, Culvert 55A, and Bridge 54. During 2008–2010, approximately 93 percent of the flow occurred during the wet seasons.

Subbasin 5

The highest calculated total flow in Subbasin 5 occurred in 2008 (7,736 acre-feet), followed by 2009 (5,453 acre-feet) and 2010 (2,643 acre-feet). The largest contributor to flow in Subbasin 5 was Bridge 62 with approximately 34–42 percent of the flow. The next largest contributors to flow were Bridges 61 and 60 (60 in 2008) and Culvert 62A (fig. 13). During 2008–2010, approximately 100 percent of flow occurred during the wet seasons.

Subbasin 6

The highest calculated total flow in Subbasin 6 occurred in 2009 (80,789 acre-feet), followed by 2010 (75,636 acre-feet) and 2008 (58,240 acre-feet) In 2009, 70,712 acre-feet were attributed to the bridge locations within Subbasin 6 followed by 65,482 acre-feet in 2010 and 51,029 acre-feet in 2008. In 2010 about 10,154 acre-feet were attributed to the culvert locations within the subbasin, followed by 10,077 acre-feet in 2009 and 7,211 acre-feet in 2008. Bridge 73 was the largest contributor to flow in the subbasin (approximately 20 percent), followed by Bridge 66 (approximately 10 percent). The remaining bridges and culverts each contributed 3–8 percent and 1–3 percent, respectively, of total flow from the subbasin (figs. 14, 15). During 2008–2010, approximately 87 percent of the flow occurred during the wet seasons.

Subbasin 7

The highest calculated total flow in Subbasin 7 occurred in 2010 (52,353 acre-feet); total flows were almost equal in 2008 (39,530 acre-feet) and 2009 (39,704 acre-feet). The largest contributor to flow was Bridge 75, which accounted for 77–82 percent of the annual flow. The second largest contributor to flow was Bridge 74, which accounted for 9–13 percent of the annual flow. Culvert 75A contributed 6–7 percent and Culvert 73B contributed 2–4 percent of total subbasin flow (fig. 16). During 2008–2010, approximately 63 percent of the flow occurred during the wet seasons.

Subbasin Comparisons

The total calculated discharge through the western Tamiami Trail (excluding the Faka Union Canal) was 174,361 acre-feet in 2008, 174,125 acre-feet in 2009, and 162,204 acre-feet in 2010. The largest flows in Subbasins 1 through 5 occurred in 2008; the largest flow in Subbasin 6 occurred in 2009, and the largest flow in Subbasin 7 occurred in 2010 (fig. 17).

The largest single contributor to discharge observed in this study (not including the Faka Union Canal) was Subbasin 6. Subbasin 6 is the largest subbasin and has the greatest number of structures. When flow from the Faka Union Canal is included (data available in the SFWMD DBHYDRO database) with the discharges computed for this study, 58–62 percent of flow is attributable to the Faka Union Canal, 13–20 percent of the flow is attributable to Subbasin 6, and 9–12 percent of the flow is attributable to Subbasin 7. Subbasin 7 is not large in size or number of structures compared to the other subbasins; however, the drainage area is large because of its connection to the Barron River Canal. The next largest contributor to flow was Subbasin 1 (3–5 percent of flow). Subbasins 2 through 5 contributed between 1 and 4 percent of flow (figs. 18–20).

During each year of this study, Subbasin 7 had more than twice the flow per bridge than any other subbasin (fig. 21*A*). Subbasin 7 also had the greatest flow per culvert on average (fig. 21*B*). In Subbasin 7, the average flow during 2008–2010 was 19,880 acre-feet per bridge, and 2,052 acre-feet per culvert. Bridge 75 was the second greatest single structure contributing to flow through the western Tamiami Trail between C.R. 92 and S.R. 29, exceeded only by the Faka Union Canal. Subbasin 6 had the next largest average flow per structure during this period; average flow was 5,673 acre-feet per bridge and 1,307 acre-feet per culvert. In contrast, Subbasin 3 had the lowest average flow per structure at 1,516 acre-feet per bridge and 207 acre-feet per culvert.

During 2008–2010, the majority of flow (58–62 percent) through the Tamiami Trail between S.R. 29 and C.R. 92 came through the Faka Union Canal (fig. 22). On average less than 10 percent (and ranging from 7–11 percent) of the flow for the entire basin came from west of the Faka Union Canal (Subbasins 1–3) during 2008–2010. On average, 31 percent (and ranging from 29–34 percent) of the flow for the entire basin came from east of the Faka Union Canal (Subbasins 4–7) during 2008–2010. The reduction in freshwater flows west of the Faka Union Canal is also indicated by salinity maps of the TTI estuary produced by the USGS (Soderqvist and Patino, 2010). The inner bays on the maps indicated higher salinities west of the Faka Union Canal, particularly Pumpkin Bay, compared to east of the Faka Union Canal. In addition, freshwater plumes were observed in Faka Union Bay and Chokoloskee Bay at the terminus of the Faka Union Canal System and Barron River Canals, respectively.

Limitations of the Study

Data quality at all structures depended on capturing a wide range of flow conditions with which to develop the regression equations. Subbasin flow was often limited to the peak of the wet season, which is a relatively short period of time. For example, during the first year of data collection at Bridge 60, the mean daily discharge exceeded 5 ft^3/s on only 16 days (fig. 23). As a result, ratings were developed with fewer discharge measurements, using a narrow range of flow conditions.

Improved discharge record at instrumented bridges could be obtained by adding telemetry. Quick response by technicians would reduce periods of missing record resulting from vandalism, equipment malfunction, and fouling from algae and sediments. Telemetry also would provide continuous information on stream conditions and would enable targeted measurements to capture a wider range of discharge at both instrumented and uninstrumented structures. Discharge record at instrumented bridges could also be improved by changing some of the station locations. For example, Bridge 51 had excessive data loss due to burial by sediments churned up by a boat launch adjacent to the station. Bridge 52, which conveyed more flow than Bridge 51, may provide better continuous flow and stage record for this subbasin. Any improvement to data quality at instrumented bridges would likely improve the quality of calculated discharge at the uninstrumented structures.

Upstream watershed diversions attributed to the Faka Union Canal System have reduced the historical flows to Subbasins 1 to 4. The quality of the ratings within these subbasins was lower due to the narrow range of conditions captured during discharge measurements.

An increased number of measurements during periods of reduced flow would increase the confidence in the ratings. At Bridge 75, which had reverse flow for a very short period of time each year, telemetry would be essential to capture those conditions. In addition, the use of tidally filtered stage record as an input could be evaluated. While the ratings for the uninstrumented structures within the tidally influenced subbasins had large uncertainties and decreased confidence during the low-flow periods, confidence in the ratings is increased during periods of higher flow.

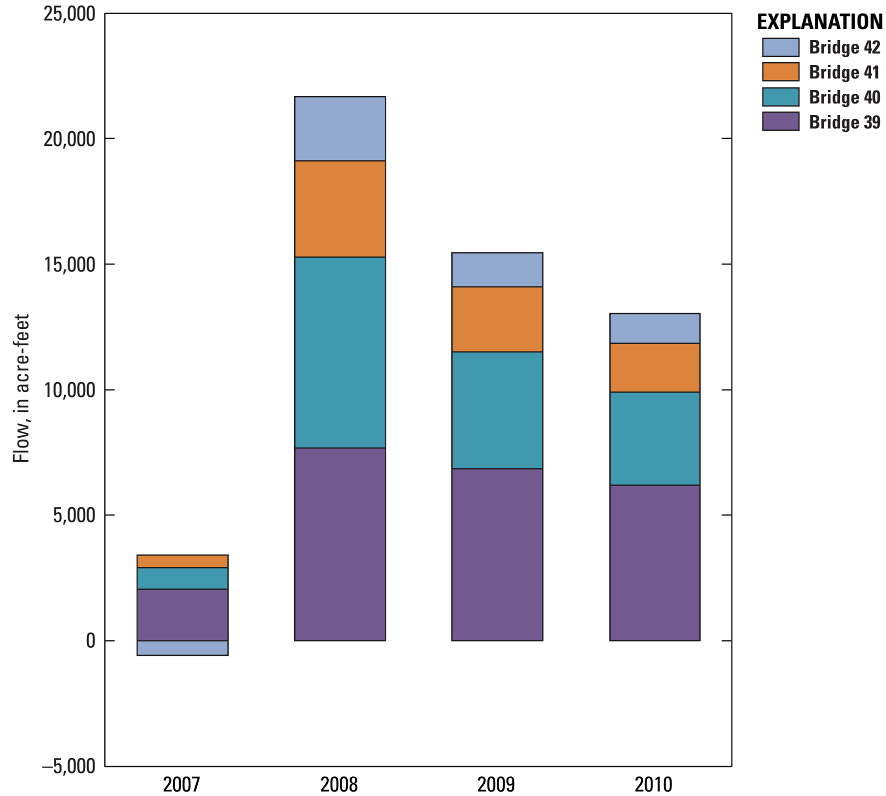


Figure 9. Distribution of flows for Subbasin 1, 2007–2010.

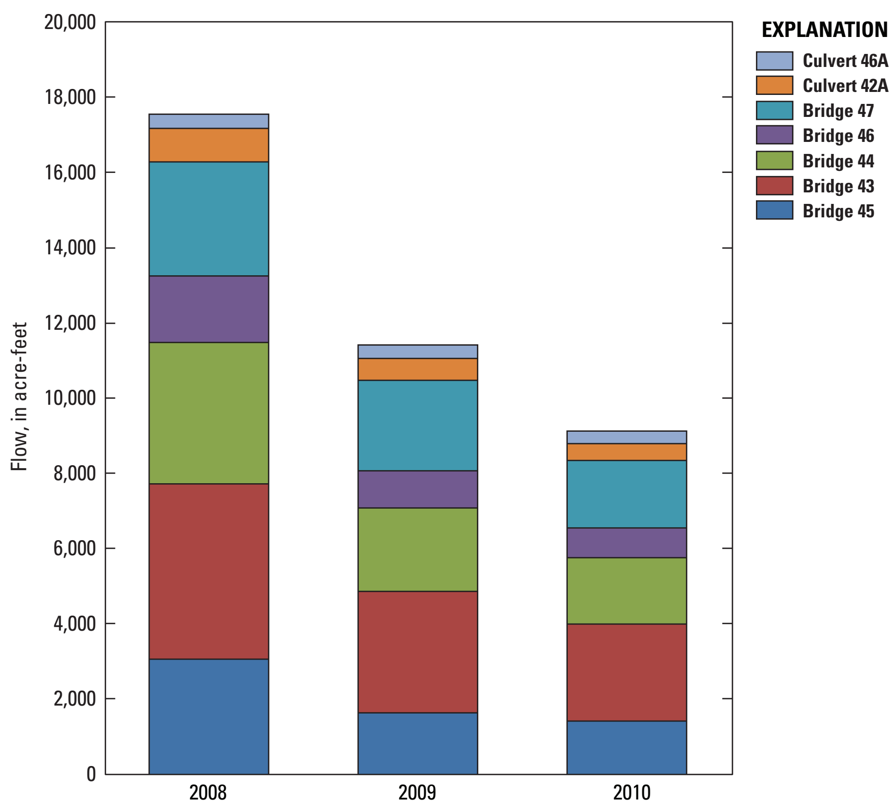


Figure 10. Distribution of flows for Subbasin 2, 2008–2010.

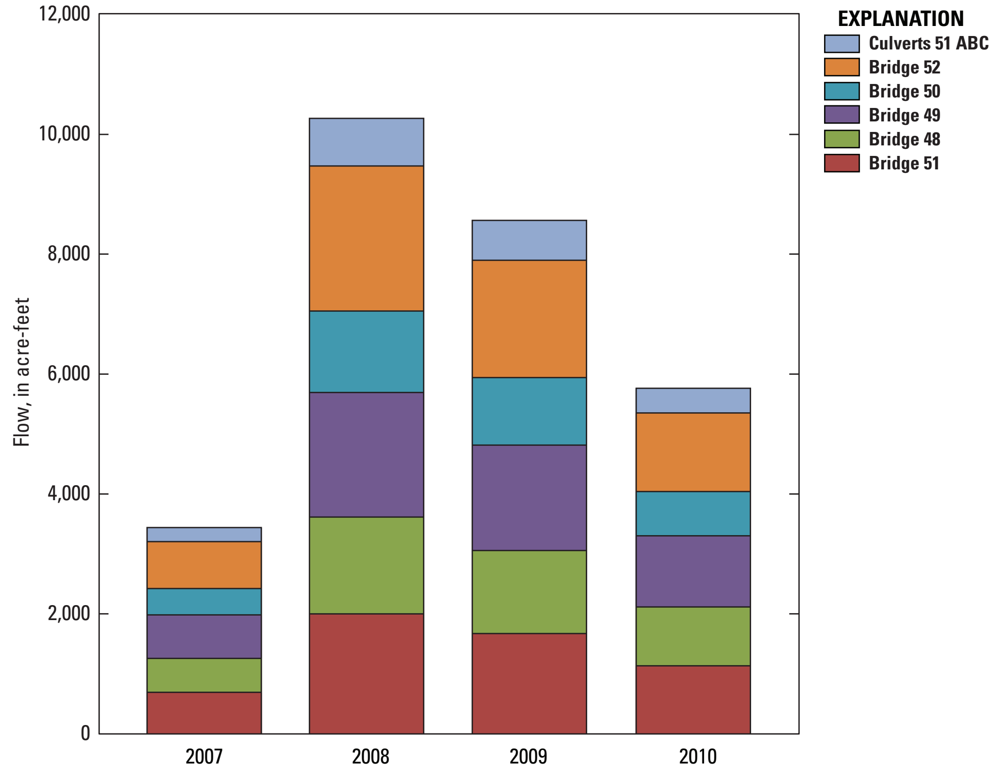


Figure 11. Distribution of flows for Subbasin 3, 2007–2010.

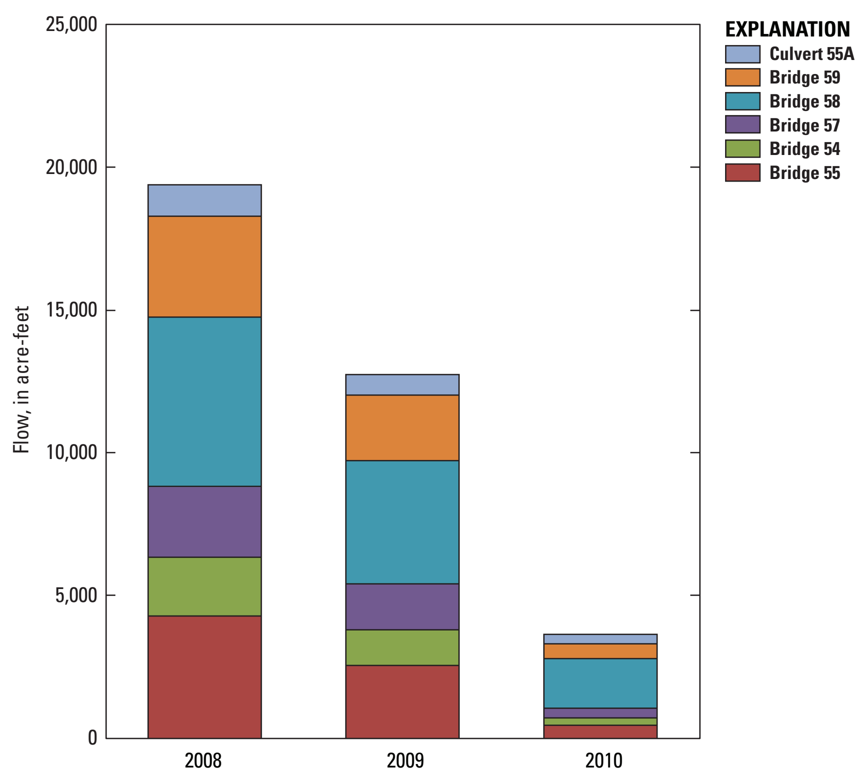


Figure 12. Distribution of flows for Subbasin 4, 2008–2010.

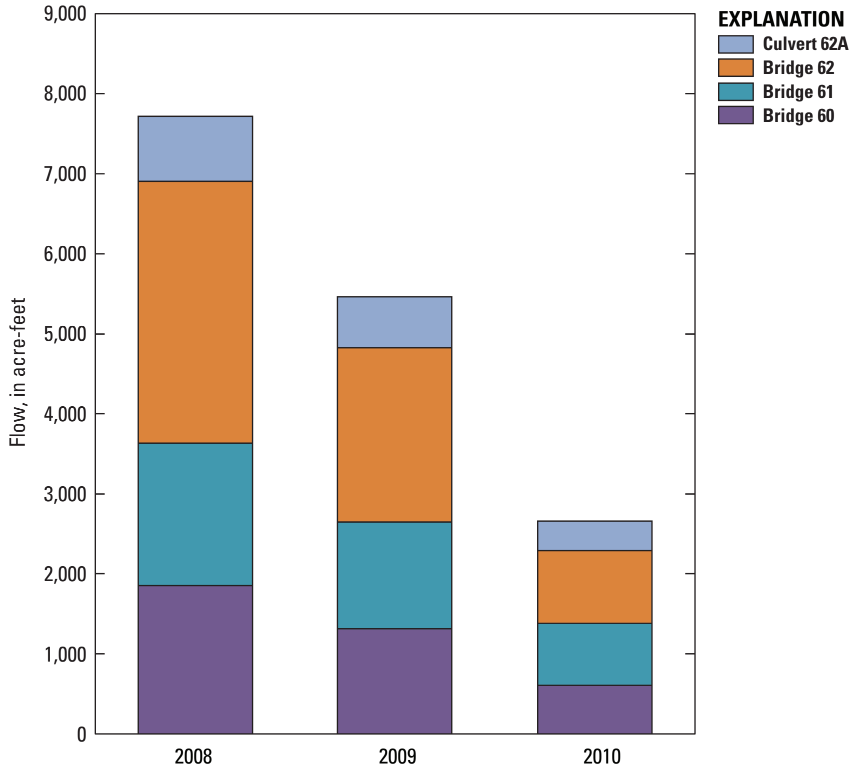


Figure 13. Distribution of flows for Subbasin 5, 2008–2010.

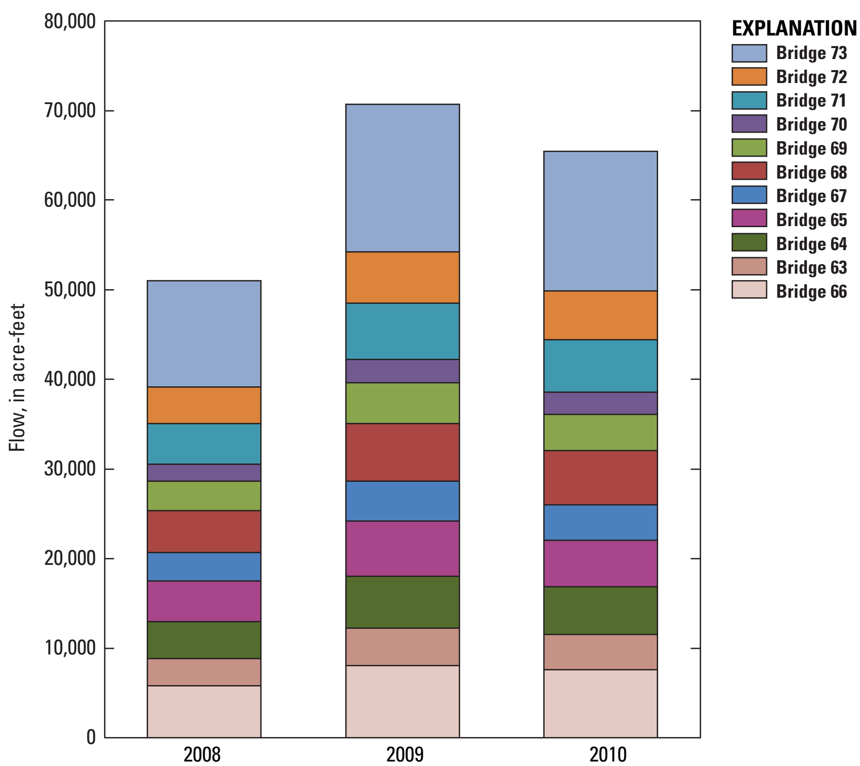


Figure 14. Distribution of flows for Subbasin 6 bridges, 2008–2010.

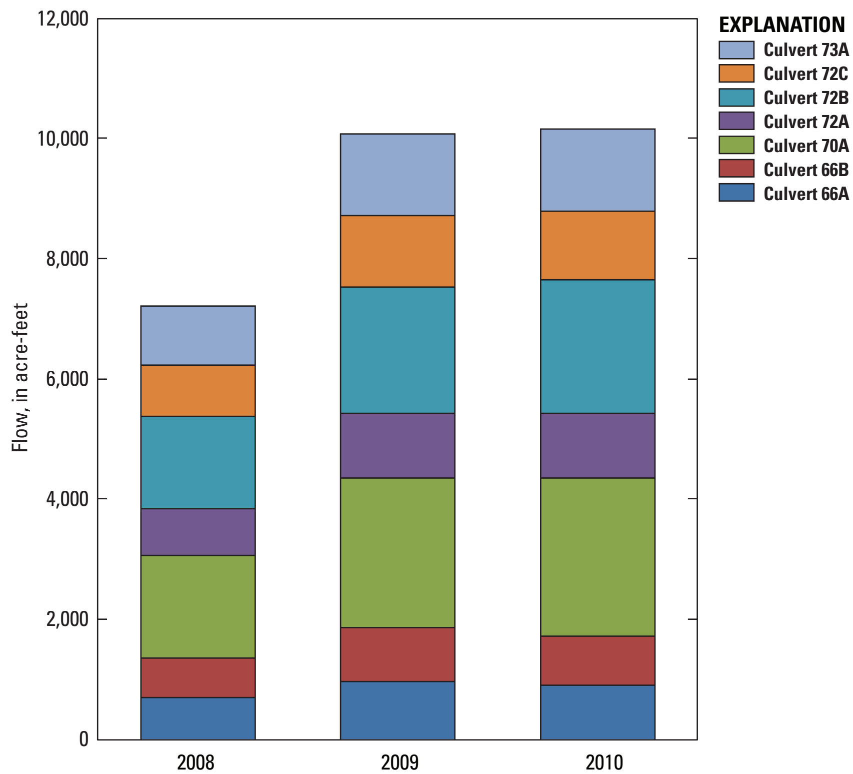


Figure 15. Distribution of flows for Subbasin 6 culverts, 2008–2010.

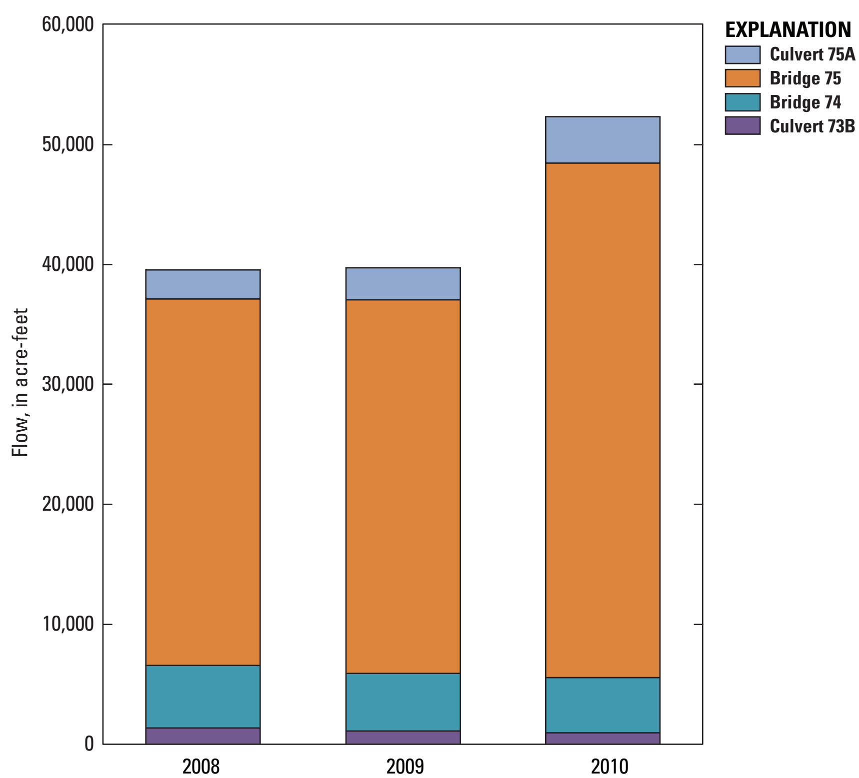


Figure 16. Distribution of flows for Subbasin 7, 2008–2010.

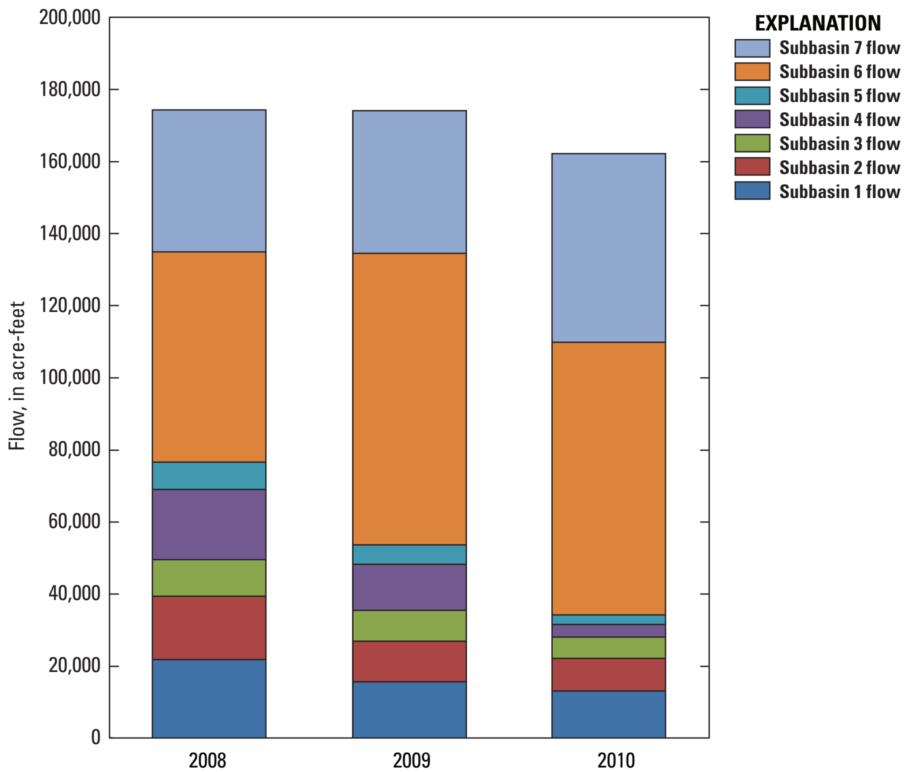
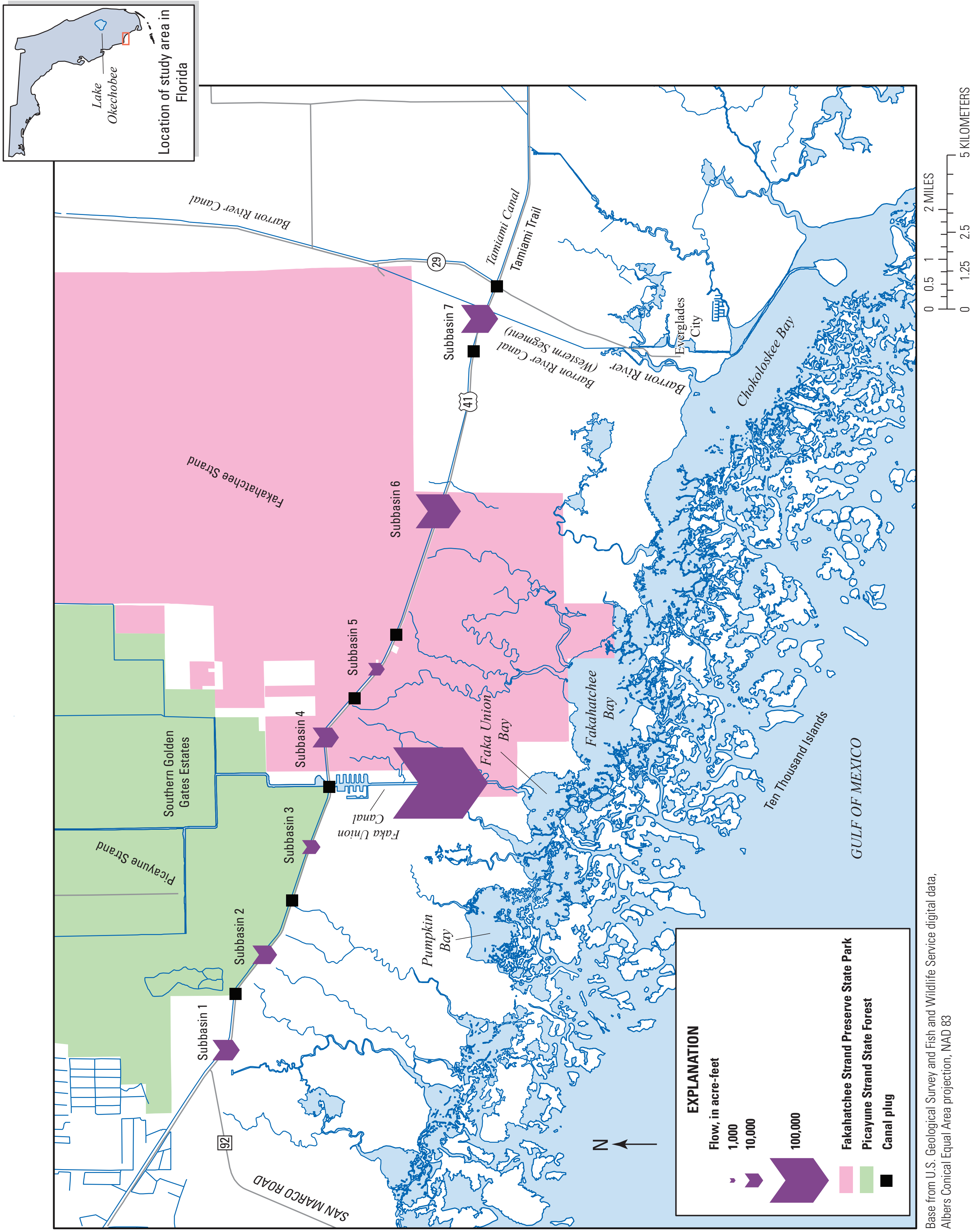
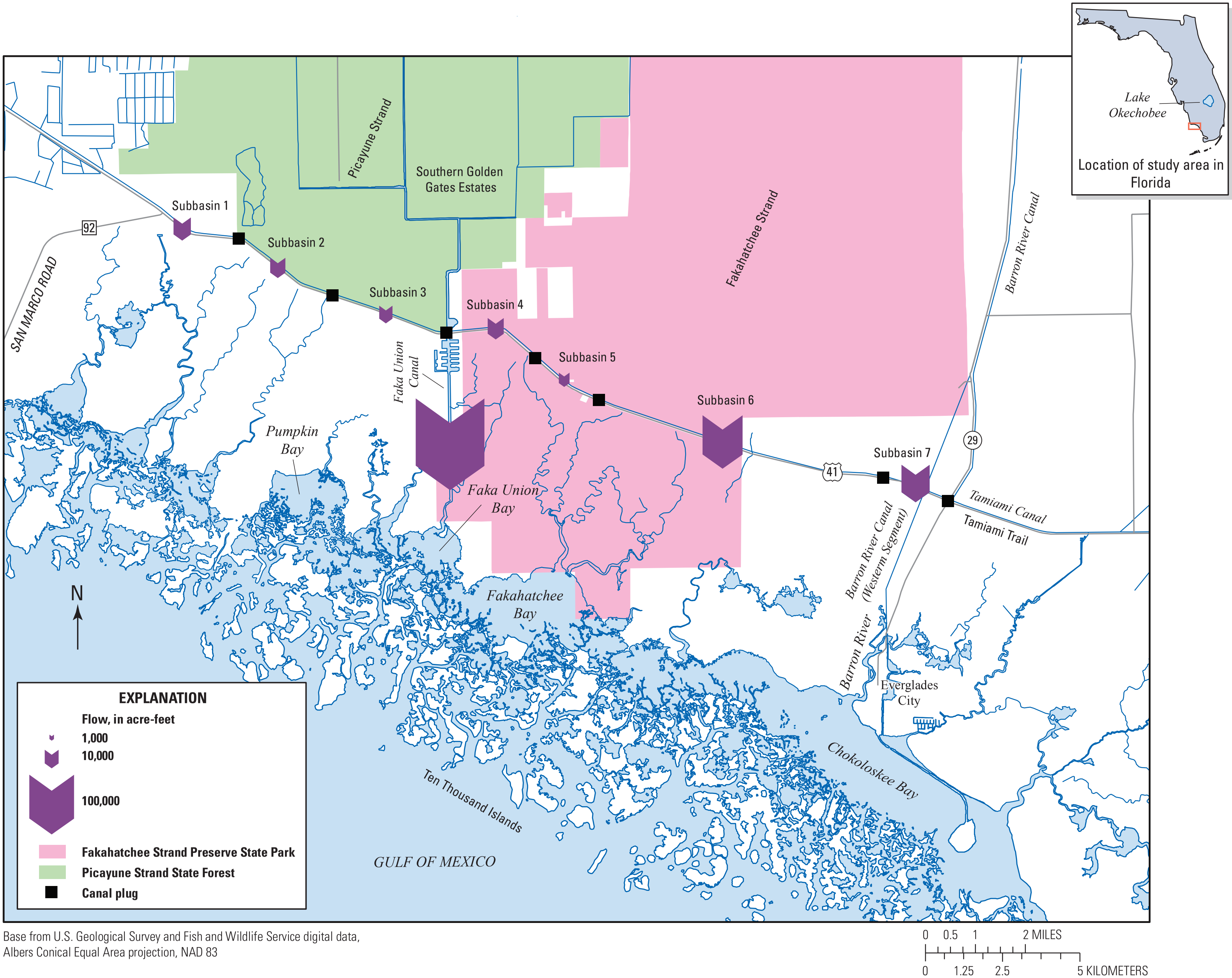


Figure 17 Subbasin total calculated flows through the western Tamiami Trail, excluding the Faka Union Canal, 2008–2010.



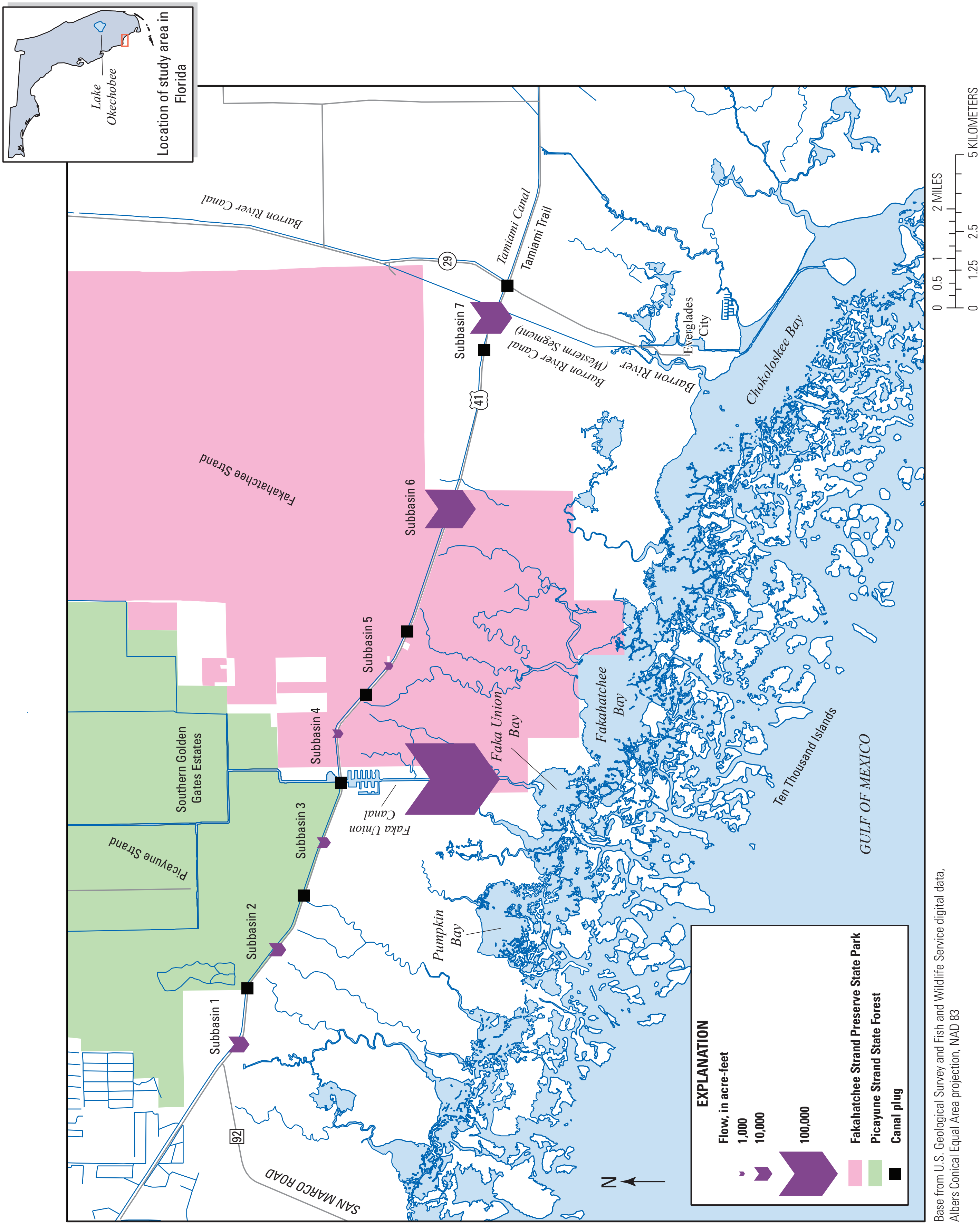
Base from U.S. Geological Survey and Fish and Wildlife Service digital data, Albers Conical Equal Area projection, NAD 83

Figure 18. Calculated flows by subbasin for 2008.



Base from U.S. Geological Survey and Fish and Wildlife Service digital data, Albers Conical Equal Area projection, NAD 83

Figure 19. Calculated flows by subbasin for 2009.



Base from U.S. Geological Survey and Fish and Wildlife Service digital data,
Albers Conical Equal Area projection, NAD 83

Figure 20. Calculated flows by subbasin for 2010.

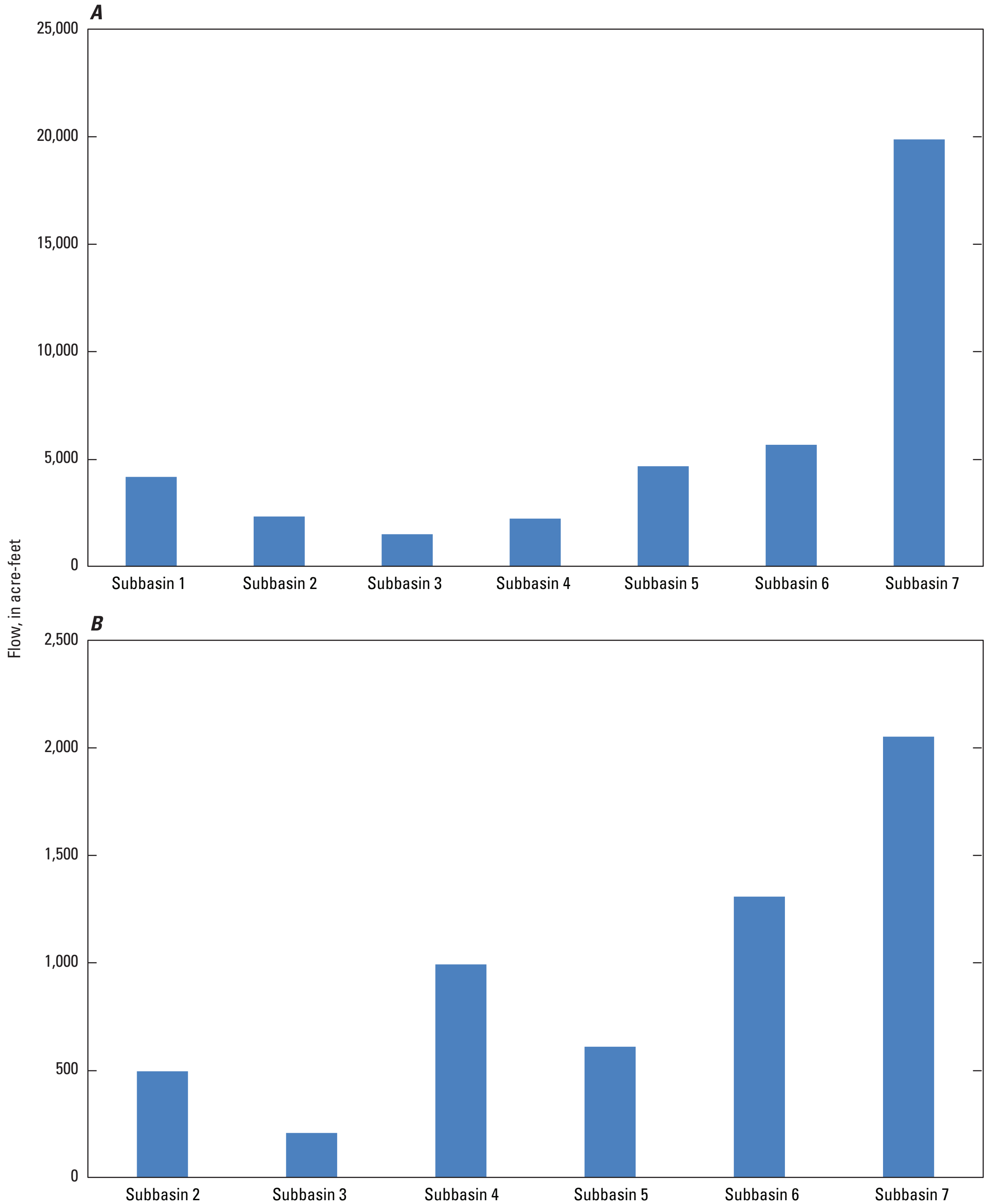


Figure 21. Average flow (*A*) per bridge and (*B*) per culvert by subbasin for 2007–2010.

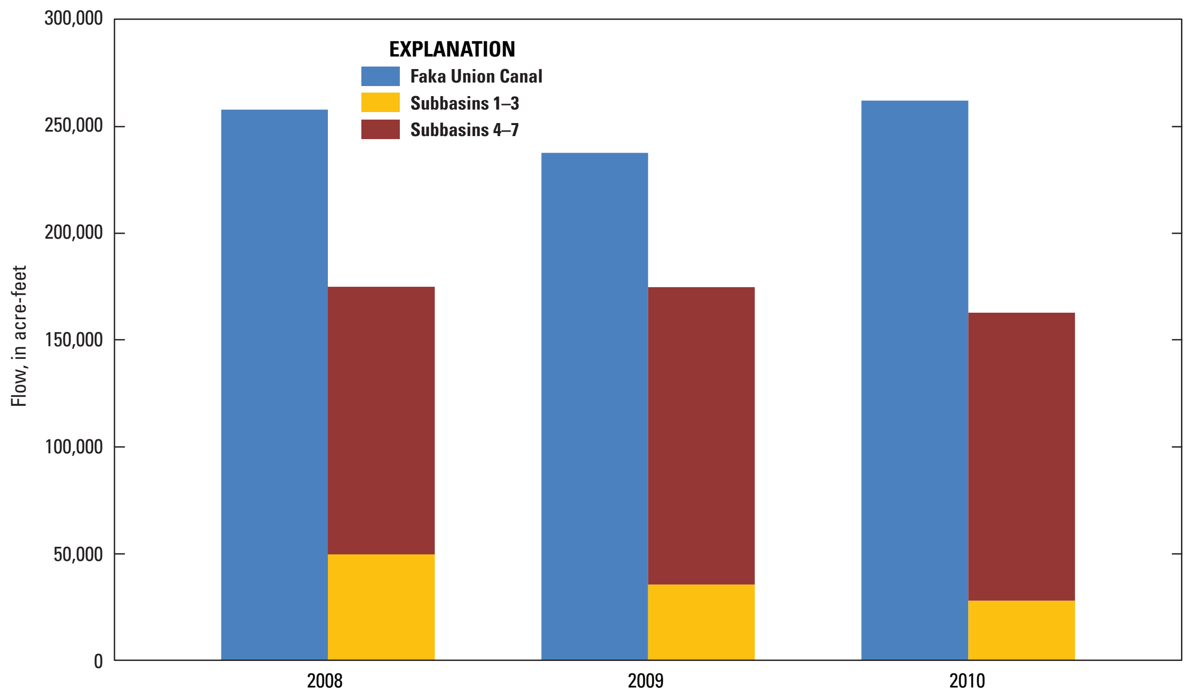


Figure 22. Comparison of discharge from the Faka Union Canal to the remainder of the basin.

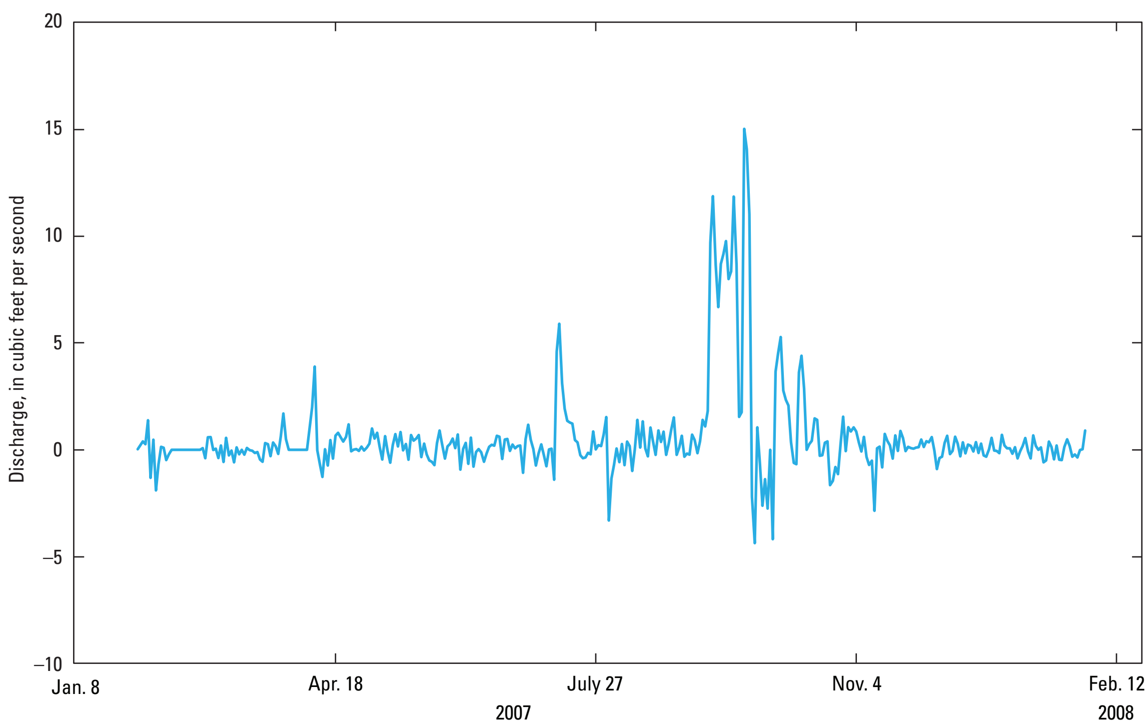


Figure 23. Daily mean discharge in cubic feet per second at Bridge 60 during the first year the station was operational.

Summary

The construction of the Tamiami Trail, the Southern Golden Gate Estates, and the Barron River Canal substantially altered freshwater delivery to the Ten Thousand Islands estuary, increasing flows in some areas while reducing flows in other areas. The Picayune Strand Restoration Project and the Tamiami Trail Culverts Project were implemented to improve freshwater delivery to the Ten Thousand Islands estuary. To monitor the effects of these restoration projects, the U.S. Geological Survey conducted a study between March 2006 and September 2010 to monitor flow through the Tamiami Trail between County Road 92 and State Road 29. This study period captures conditions after completion of the Tamiami Trail Culverts Project and prior to most of the construction associated with the Picayune Strand Restoration Project.

The western part of the Tamiami Trail between County Road 92 and State Road 29 was divided into seven subbasins, and one bridge per subbasin was instrumented with index-velocity and stage-measuring equipment for the determination of flow. Discharge at all instrumented and uninstrumented bridges were measured using acoustic Doppler current profilers. Culvert discharge was measured using an up-looking acoustic Doppler velocity meter on a removable mount. Flow was computed at each instrumented bridge according to standard U.S. Geological Survey index velocity discharge station methods. Daily mean values of flows for the remaining uninstrumented structures were computed from regression equations using discharge and gage height data from the instrumented bridge located within each subbasin (with the exception of Bridge 42).

During 2008–2010, more than half (58–62 percent) of the flow under the Tamiami Trail between County Road 92 and State Road 29 came from the Faka Union Canal System. Subbasin 6 conveyed the second largest amount of flow; Subbasin 6 also encompasses the largest area and has more structures than any other subbasin. Subbasins 7 and 1 were the next two largest contributors of flow, respectively. The total flow for Subbasin 7 has been increased through its connection to the Barron River Canal. An average of 9 percent of the flow for the study area, including the Faka Union Canal, came from west of the Faka Union Canal (Subbasins 1–3) during 2008–2010. An average of 31 percent of the flow for the study area, including the Faka Union Canal, came from east of the Faka Union Canal (Subbasins 4–7) during 2008–2010. The reductions in freshwater flows west of the Faka Union Canal also are documented by salinity maps of the Ten Thousand Island estuary produced as part of a related U.S. Geological Survey monitoring effort. The maps indicated higher salinities in the inner bays west of the Faka Union Canal, particularly Pumpkin Bay, compared to the inner bays east of the Faka Union Canal. In addition, freshwater plumes were observed in Faka Union Bay and Chokoloskee Bay, which are at the terminus of the Faka Union Canal System and Barron River Canals, respectively.

Daily mean discharge and stage data for instrumented bridges can be found in the 2010 U.S. Geological Survey Annual Water Data Report (*http://wdr.water.usgs.gov/*) and in appendix 3. Daily mean discharge data for uninstrumented structures can be found in appendix 3. The confidence in ratings used to calculate flow varied. The R^2 values ranged from 0.46 to 0.99, and standard error ranged from 0.6 to 15.3 cubic feet per second for the uninstrumented structures. The R^2 values and standard error ranged from 0.51 to 0.99 and 0.01 to 0.05 foot per second, respectively, for the instrumented bridges. Improved discharge record at instrumented bridges could be achieved by adding telemetry to the instrumented gages, increasing the number of measurements made, and selecting different measurement locations for some subbasins, preferably bridges with the highest amounts of flow.

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