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ST. LUCIE AND INDIAN RIVER COUNTIES WATER RESOURCES STUDY

FINAL SUMMARY REPORT

APPENDIX B

St. Lucie and Indian River Counties
Water Resources Study

WaSh Model Setup, Calibration and Validation
Deliverable 5

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1. INTRODUCTION

The South Florida and St. Johns River Water Management Districts co-sponsored a feasibility study in 2006 (Phase I Study) to evaluate the benefits and identify the constraints of restoring a hydraulic connection between basins in northern St. Lucie County and southern Indian River County (PBS&J, 2006). The hydraulic reconnection would provide increased storage, flexibility, and availability of alternative water supply; reduce the magnitude of freshwater flows to nearby estuaries; mitigate groundwater drawdown and saline intrusion; and improve coastal, surface water, and groundwater quality.

This report was prepared as a part of the St. Lucie and Indian River Counties Water Resources Study. The study is being prepared for the South Florida Water Management District (SFWMD) and St. Johns River Water Management District (SJRWMD). The report constitutes Deliverable 5 for Contract 4600000913 Work Order 2.

The rainfall-runoff simulation software WaSh (URS, 2008a) is being used to characterize the yield of the C-23, C-24, C-25, and C-25 extension basins (Figure 1). Simulation results will also be utilized to estimate flows for ungaged areas such as Basin 1 in eastern St. Lucie County (Figure 1). Results of long-term WaSh simulations will be used to evaluate potential water-storage alternatives. The C-25 model will be used to evaluate how restoring the connection between the SFWMD and SJRWMD will allow the diversion and storage of runoff from the C-25 Extension Basin. Stormwater runoff during major storm events currently flows northward into the Upper St. Johns River Basin Project where it exacerbates flooding (HDR, 2009b).

The purpose of this report is to generally describe the configuration of the WaSh software for the C-23, 24, and 25 Basins and to summarize the results of simulations made to calibrate and validate the basin models. Tables are provided with text; however all figures are provided at the end of the report. `

1.1 MODEL CONFIGURATION AND APPROACH

The spatial distribution of physical characteristics in the WaSh model is represented on a uniform Cartesian grid. The spatial distribution of land use, soil type, topography, canals, rivers and streams and control structures are required to configure each of the basin models. The distribution of each characteristic was obtained in the form of GIS shapefiles, the contents of which were mapped onto each model grid. For this application, the WaSh model uses an ArcMap 9 Graphical User Interface (GUI). Models were constructed using six input data shapefiles, including primary basins, secondary basins, soil type, hydrology, land use, and topography. For each of the models, a cell size was chosen that would maximize the resolution of basin drainage features without sacrificing model efficiency and run time. In this modeling approach, there is no differentiation between the gravity flows and pumping that occurs in the basins. The feasibility analysis of storage alternatives depends more on long-term basin yield and runoff volume than on short-term variations in runoff and peak discharge.

1.2 MODEL DOMAIN AND GRID

The study area is composed of three primary basins currently drained by an extensive network of canals and drainage ditches that discharge on the east coast into St. Lucie Estuary (SLE) and

Indian River Lagoon (IRL). The C-23 basin is located in St. Lucie, Martin and Okeechobee Counties and has a total surface area of approximately 177 mi^2 (square miles). The C-24 basin is located in St. Lucie and Okeechobee Counties and has a total surface area of approximately 138 mi^2. The C-24 and C-25 basins discharge into SLE. The C-25 basin is located in St. Lucie, Indian River and Okeechobee Counties and has a total surface area of 208 mi^2. It extends from State Road (SR) 15 on west side to SR 615 on the east and drains into IRL.

The basin boundary shapefile was used to define the extent and a Cartesian grid was constructed that covers the entire basin. Grid cells located outside the basin boundary were set as inactive. Cells that intersected the boundary were clipped to the basin boundary so that the total area of the basin was preserved in the model grid. A grid cell length of 2,000 ft was used for each basin, creating grid cells which cover an area of 4,000,000 square feet each. The C-23, C-24 and C-25 primary basin boundary and model grid are presented in Figures 1.1a, 1.1b and 1.1c respectively.

The C-25 basin model grid includes an area in the northwest corner referred to herein as the C-25 extension basin (Figure 1.1c). The basin has a drainage area of about 10,500 acres (C. Tai, SJRWMD, written communication, March 11, 2009). About 50% of this drainage basin is within SFWMD jurisdiction and the remaining drainage area is within SJRWMD jurisdiction.

Since 1980 runoff discharged by pumps and gravity flow from the C-25 extension basin (Figure 1a) has been directed north via the Ft. Drum Creek Flowway, Turnpike Canal, and C-52W canal into the C-52 canal (Figures 1b, 1c, 1d and 1e). The C-52 canal is formed by the congruence of the C-52W and C-52E canals just north of the parcel referred to as Evans Property (Figure 1a). C-52 discharge is controlled by structure S-253, a fixed-crest, sheet-pile weir that prevents reverse flow in the C-52 from entering the C-52W and C-52E canals. Prior to 1980, the C-52W and C-52E connected at the southeast corner of Evans Property and discharged southeast through a box culvert beneath the turnpike and into the C-25 extension canal (Figure 1e). The connection was plugged in the early 1980's.

Three parcels totaling about 11,500 acres (Greens Property, Florida Maid, and Coca Cola Co.) are permitted to discharge into both the C-25 extension canal and C-52E canal. The parcels are generally located in the triangular area between the C-25 extension canal and Florida Turnpike (Figure 1d). Runoff is typically discharged south into the C-25 extension canal, and excess runoff is discharged during extreme high-flow events north beneath the Florida Turnpike and into C-52E. For purposes of this analysis, the runoff from these three parcels is presumed to discharge into the C-25 extension canal.

1.3 GRID ATTRIBUTES

After defining the model grids and extents, each grid cell was assigned physical attributes controlling the runoff characteristics and hydrodynamics of the basin. This GIS shapefile mapping was achieved by using attributes from secondary basin, land use, soils, topography, and hydrology coverages.

1.3.1 Secondary Basin

The secondary basin boundary coverage is a polygon feature, which adds more control to the overland flow regime, or flow path, within each primary basin. During model generation, the secondary basins help to constrain the cell-to-cell surface flow paths based on documented drainage patterns. As resolution of the topographic data can often be too coarse or too subtle in South Florida for the model to distinguish, the assistance of additional secondary boundaries produces more accurate drainage patterns.

1.3.2 Soils

Soil types are used in model generation to guide the selection of model parameters that affect the run-off and/or infiltration processes within each grid cell. The Soil Survey Geographic (SSURGO) Database maintained by the Natural Resources Conservation Service (NRCS) was used to designate the soil type. The polygon feature of soils coverage includes the NRCS hydrologic soil group classes (A, B, C, D, A/B, C/D) which indicate runoff potential which are described as follows (NRCS, 1986):

Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This group represents soils with the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

The distributions of soil types within the C-23, C-24 and C-25 basins are shown in Figures 1.2a, 1.2b and 1.2c respectively. The relative distribution of soils within each basin is illustrated as a pie chart for C-23, C-24 and C-25 basins in Figures 1.6a, 1.6b and 1.6c, respectively. It can be observed from 1.6a, 1.6b and 1.6c that soil group "D" is more predominant in C-23 and C-24 basins, while the dual-group classification "B/D" is more predominant in C-25 basin. The first letter in a dual hydrologic group represents drained areas and the second letter is for undrained areas. Soils have been mapped to a depth of 80 inches and consist of predominantly fine sand, sand, and loamy sand with small areas of muck (SCS, 1977).

1.3.3 Land Use

Each grid cell was attributed with a land-use designation, a key parameter controlling the selection of model parameters that primarily affect hydrology and to a lesser extent irrigation practices and water quality runoff concentrations. The 2004 Florida Land Use, Land Cover Classification (FLUCCS) land-use coverage was used for attributing the grid, as it provides the most recent dataset available for current land-uses. These codes are used to differentiate between the urban, agricultural and other types of land use. Land cover/land use data are interpreted from CIR (color infrared), RGB (red, green, blue) and stereo panchromatic aerial photography. The classification is a three-digit code that categorizes land use into nine different categories the primary ones of which are 100 (Urban), 200 (Agriculture), 300 (Rangeland), 400 (Upland Forest), 500 (Water), 600 (Wetlands), 700 (Barren Land), and 800 (Transportation). The land use coverages were subject to quality assurance reviews by SFWMD and SJRWMD. C-23, C-24 and C-25 basin land use is illustrated in Figures 1.3a, 1.3b and 1.3c, respectively.

Upon model generation, the WaSh model assigns to each grid cell the most dominant land-use classification within that cell. When dominant land uses are assessed basin-wide, the smaller land use polygon features can be overlooked by the model and, therefore, under-represented in each model basin. For example, this could happen if the wetlands within a basin consist of small patches distributed throughout a forested area or pasture land. The small patches may not dominate the cell area and would be overlooked, resulting in an under-representation of the wetlands in the model configuration.

One method to reduce the influence of this artifact of the grid discretization is to use smaller grid cells. An alternate approach is to manually alter the land use classification in individual cells so that the grid-based designation preserves a representative distribution of land use within each basin. The current 2000-foot grid resolution and WaSh-generated land-use classification were deemed sufficient to model the flow volumes to be considered in the feasibility analysis of alternative storage plans. No further refinements in land-use classification were prepared.

1.3.4 Topography

A Digital Elevation Model (DEM) was used to assign elevation to the model grid. This file contains a raster grid with elevation data in feet at the centroid of each grid cell. DEM data were obtained from SFWMD and SJRWMD. The vertical datum of this file sets the project datum and all other vertical information, such as weir crest elevations and tidal elevations, which should be referenced to the same datum. Elevations in datasets prepared for the study basins are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

1.4 HYDROLOGY AND HYDRAULICS

1.4.1 Canals, Rivers and Streams

The hydrology coverage is a polyline layer that identifies both natural and man-made drainage features. This coverage includes rivers, streams, and primary, secondary and tertiary canals. The coverage was updated to differentiate the tertiary canals and the primary canals, rivers and streams that are explicitly represented in the reach network. The C-23, C-24 and C-25 basin hydrology mapped to the model grids is shown in Figures 1.4a, 1.4b and 1.4c respectively. The tertiary canal coverage was mapped onto the grid cells with the attribute of total length of canals. The canal widths and bottom elevations were obtained from previous calibration effort for the C-23 and C-24 basins (URS, 2008b), and discussions with local sources knowledgeable of site conditions within the C-25 basin. The coverages for primary canals, rivers and streams were used to develop the reach network. The arcs designated as primary reaches, rivers or streams were digitized to create the reach network. Geometric data for the rivers, streams, and primary canals were obtained from online District data sources, consultation with District personnel and others familiar with local conditions, and from aerial photographs.

1.4.2 Groundwater and Surface Water Interactions

The WaSh model requires additional cell attributes to represent the connection between reach segments, cells, cells with tertiary canals, and connections with the groundwater table. The connections are identified in the WaSh model by a cell attribute that controls the physical interactions that are applied to each cell. The available cell attributes and their influence on the hydrology and hydrodynamic simulations are described in Table 1-1. The WaSh GUI provides a tool for mapping the cell-type attribute onto each cell. This tool was applied to each of the three models (C-23, C-24, and C-25). The results of the digitizing of the reach network and the cell-type mapping are shown in Figures 1.4a, 1.4b, and 1.4c for the C-23, C24, and C-25 basin models, respectively.

Table 1-1. Water Routing Operations for Each Cell Type.

Cell-Type	Flow Routing Operations
Free	Infiltration is directed to cell groundwater Surface water is directed to a nearby cell's canals, reach or reservoir*
Canal	Infiltration is directed to cell groundwater Surface water is directed to cell canals Groundwater and canal surface water allowed to exchange
Free-Reach	Infiltration is directed to cell groundwater Surface water is directed to the cell's reach or nearby cell's canals Groundwater and reach surface water allowed to exchange
Canal-Reach	Infiltration is directed to cell groundwater Surface water is directed to cell canals Groundwater can be exchanged with canal surface water and with reach surface water Canal and reach surface water can be exchanged
Free-Reservoir	Infiltration is directed to cell groundwater Surface water is directed to the cell's reservoir or nearby cell's canals ** Groundwater and reservoir surface water allowed to exchange
Canal-Reservoir	Infiltration is directed to cell groundwater Surface water is directed to cell canals Groundwater can be exchanged with canal surface water and with reservoir surface water
* A nearby canal cell or reach is determined by the flow network which is discussed in the next section. ** The surface water does not necessarily have to drain to the coincident reach in a free-reach cell, for instance, in the case that a dike separates the reach from surface water runoff.	

1.4.3 Overland Flow Routing

The overland flow simulated by WaSh is designated by cell-to-cell connections which guide the direction that runoff is routed. The flow continues from cell-to-cell until it reaches a surface-water body -- cells with either tertiary canals, a segment of the reach network, or a reservoir. The WaSh GUI provides a tool that estimates the overland flow paths based on topographic gradients. Drainage of surface water will be routed from each cell to another, down-gradient cell.

Due to the flat terrain and the intense canal network characteristic of South Florida, the automated flow-routing pathway generator in WaSh that utilizes DEM data can sometimes misrepresent flow paths. Flow paths were compared with the secondary basin boundaries and hydrology coverage as guidelines. Flow directions for select grid cells were manually realigned to provide an accurate representation of the actual overland drainage patterns using a WaSh model GUI tool. Overland flow drainage developed for C-23, C-24 and C-25 basin models are shown in Figures 1.5a, 1.5b and 1.5c, respectively.

1.4.4 Structures

Four types of structures can be explicitly represented using WaSh -- gates, weirs, culverts, and pumps. The operating rules for gated structures and pumps have a profound effect on the daily discharges, and the proper representation of these rules is critical to a successful calibration. Of the four available types, gates and weirs are represented in the C-23, C-24 and C-25 basins. The structures at the outfalls of the C-23, C-24 and C-25 canals (S-48, S-49 and S-50) and S-253 on the C-52 canal were explicitly represented in the models, and the published operational criteria were used to configure the gate model parameters. However, the gates are not always operated according to the published criteria and adjustments are made manually to their operation in anticipation of large rainfall events and projected droughts. These types of gate operations cannot be modeled accurately; therefore the occasional occurrence of manual overrides of gate operations must be considered in the interpretation of the calibration and validation results.

1.4.5 Rainfall and Potential Evapotranspiration

Rainfall data were obtained from two sources. A rainfall database developed for SFWMD regional modeling was used for the period 1965 through 2000. Daily time series data processed from over 860 rainfall stations within the Natural Systems Regional Simulation Model (NSRSM) domain resulted in temporal and spatial distribution of rainfall representative of the simulated period of record (1965-2000). The daily records were disaggregated into time series of hourly records based on a pattern hyetograph determined by URS for earlier WaSh models of the C-23 and C-24 basins.

NEXRAD (Next Generation Radar) is a network of doppler weather radars operated by the U.S. Weather Service. SFWMD has updated and corrected the NEXRAD database such that hourly data are available for the modeling areas. Hourly NEXRAD data were used for the period from 2001 through 2008.

The ESRI GIS software was used to find the nearest NEXRAD cell for each of the WaSh model cells. Each model grid cell was attributed with appropriate NEXRAD rainfall station index ID through a spatial join. Figure 1.6 shows a color-coded mapping of the WaSh model cells indicating which NEXRAD cell rainfall data is used for each cell in C-24 basin model. There are 45 NEXRAD stations used in the C-24 basin model. This mapping was applied to all three models and the results were used to create the rainfall input file for each of the basin models.

Daily values of potential evapotranspiration (PET) were obtained from the SFWMD's South Florida Water Management Model (SFWMM) for the period 1965 to 2000 (SFWMD, 1996). The dataset was extended to 2008 with PET data stored in the SFWMD DBHYDRO database.

1.4.6 Reservoirs/Stormwater Treatment Areas

Reservoirs can exist as natural or manmade water bodies. Examples of reservoirs include lakes, ponds, stormwater treatment areas (STAs), detention ponds, utilities holding ponds, and even canals regulated by control structures. Reservoirs can be introduced into the model via a shapefile defining the aerial extent or by digitizing them directly in the model grid. Reservoirs and their representation for C-23, C-24 and C-25 are shown in Figures 1.4a, 1.4b and 1.4c respectively. These reservoirs were configured to discharge water when water-surface elevation exceeds 4 feet above natural grade, and the groundwater exchange coefficient was set to zero. During the model simulation, the occasional runoff generated from the neighboring areas (i.e. light grey cells) during runoff events would accumulate in the reservoir. When the reservoir water-surface elevation exceeds the critical elevation of 4.0 feet above natural grade, water is discharged from the storage system.

2. CALIBRATION AND VALIDATION

2.1 C-23, C-24 AND C-25 BASINS

The model calibrations and validations for the C-23, C-24 and C-25 basin models are based on a comparison of simulated and measured flows daily at the primary basin outfall structures. Flow records for SFWMD structures were downloaded from DBHYDRO. Stage records for C-52 canal at S-253 database were provided by Dr. Charles Tai (SJRWMD). The comparisons were made using time series graphs, flow frequency curves, seasonal and annual bar charts, and cumulative mass curves. Quantitative metrics were calculated to make comparisons between the calibration and validation results and ensure that the simulation of the validation period is comparable to accuracy of the calibration period.

2.2 SIMULATION PERIODS

Records of daily flow at the outflow structures for the C-23, C-24 and C-25 basins are available from 1965 through present. Summary statistics of the historic flow records available for these structures were prepared in an earlier phase of this study (HDR, 2009a). However, the entire period of record was not used for the flow calibration and validation for two primary reasons. First, land use has changed in the basins over the 40 year period, and secondly there is a general consensus that the data used for developing the models should represent current conditions.

A recent 11-year period was selected for the combined calibration and validation of C-23 and C-24 basin models consistent with earlier WaSh calibrations by URS (2008). Model calibrations were completed for the calendar years 1995 through 2000, and validations were completed for the period 2001 through 2005. For the C-25 basin model, the period 2004 through 2008 was chosen as the calibration period because of particular interest in high flows that occurred in August/September 2008 due to Tropical Storm Fay. The period from 1998-2003 was used for validation.

Table 2-1. Summary of Model Calibration and Validation Periods.

Basin	Characteristic	Calibration Period	Validation Period	Gage Location
C-23	Daily Flow	1995-2000	2001-2005	S-48
C-24	Daily Flow	1995-2000	2001-2005	S-49
C-25	Daily Flow	2004-2008	1998-2003	S-50

There are insufficient data to develop representative initial conditions for all of the model grid cells. A 'spin-up' period consisting of two years of hydrometeorologic data immediately prior to the calibration and validation periods is simulated to establish antecedent moisture and hydraulic conditions that are in numerical equilibrium. The 'spin-up' period reduces the impact of assumed initial conditions on the simulated output for periods of interest.

A spin-up period from 1993 through 1994 was prescribed for the C-23 and C-24 basin models consistent with the earlier work of URS. The period 1996 through 1997 was prescribed for the C-25 basin model.

The fundamental time step for the model is one day, and output from the model is provided in daily increments. However, certain model algorithms operate at shorter time steps (30 minutes to one hour), which are required to provide accurate representations of physical processes and provide numerical stability.

The general approach for the calibration is to use a consistent set of model parameters for all three models, adjusting individual values for a basin only when the characteristics of a basin warranted the adjustment. Many of the parameters determined from previous WaSh studies in the C-23 and C-24 basins were used as initial estimates for the C-25 basin model.

There are numerous sets of model parameters that need to be set for the model operation. The parameters are grouped into four categories:

- Hydrology parameters for infiltration, runoff and evapotranspiration
- Groundwater parameters for hydraulic conductivity and conductance
- Canal parameters for friction and pump rates
- Irrigation practices

2.3 MODEL PARAMETERS

The calibration process consisted of iteratively adjusting key model parameters in a succession of model simulations until reasonable agreement between the measured and simulated flows was obtained. The primary parameters that were adjusted include the infiltration capacity, the interflow fraction and recession constant, the global evapotranspiration (ET) parameter, the fraction of daily irrigation demand that is supplied and the gate operation criteria.

The first three parameters control the amount of base flow and both direct and indirect surface runoff. They also help to reduce the period over which base flow continues to drain from the basins. Prior to the adjustment of the irrigation module, the application of the entire demand in one day would sometimes overwhelm the infiltration capacity of the soils creating unrealistic surface runoff during the dry season. The adjustment reduced the application rate and eliminated the spurious runoff events. Finally, the global evapotranspiration parameter scales the daily potential evapotranspiration and affects the total annual discharge from each basin. This parameter was adjusted slightly during the calibration process because the adjustments made to each of the other parameters would alter the total discharge.

Soil hydraulic conductivity is not considered in the cell-by-cell calculation of infiltration, percolation and surface runoff. However, the horizontal hydraulic conductivity of the surficial aquifer is considered in the calculation of lateral groundwater flow. Values of of 25 ft/day for the C-23 and C-25 Basins and 50 ft/day fro the C-25 Basin was prescribed for the three models.

The land-use dependent final model parameters are listed in Tables 2-2 through 2-5. The parameters were either set for each land use or for each basin, depending on their implementation. For instance, whereas the hydrology parameters are related to land use, the irrigation practices vary from basin to basin and therefore the parameter values vary for each basin model. The tables list other parameters in addition to the primary calibration parameters described above. Values for these parameters were determined during earlier WaSh studies of the C-23 and C-24 basin and are based to the extent possible on data obtained from SFWMD, SJRWMD, and local knowledge.

A detailed description of the function of each model parameter can be found in the WaSh model documentation (URS, 2008c). Processes representing surface hydrology are based on algorithms in the rainfall-runoff simulation software HSPF (AQUA TERRA, 2001). The parameters in Table 2-2 are defined as follows:

CEPSC: Interception storage capacity

UZSN: Upper soil-moisture zone storage capacity representing pore water that percolates under the influence of gravity

NSUR: Manning's roughness coefficient (n) for overland flow

INTFW: Scaling parameter for separating the soil moisture available to the land surface into what infiltrates and what goes to interflow

LZETP: Scaling parameter for determining amount of vegetation transpiration from lower soil-moisture zone

LZSN: Lower soil-moisture zone storage capacity representing pore water that can only be removed by transpiration

INFILT: Infiltration rate

Table 2-2. WaSh Model Calibrated Hydrologic Parameters.

Parameter	Tree Crops	Cattle Feeding	Wetlands	Forest	Urban (Excludes Correctional)
CEPSC (in)	0.15	0.15	0.03	0.1	0.1
UZSN (in)	0.25	0.25	0.19	0.23	0.08
NSUR ($ft^{1/6}$)	0.4	0.4	0.4	0.4	0.25
INTFW (in)	0.875	0.875	0.875	0.875	0.875
LZETP	0.95	0.95	0.64	0.76	0.28
LZSN (in)	2.1	2.1	1.6	1.9	0.7
INFILT (in/hr)	0.09	0.09	0.09	0.09	0.09

Another set of calibration parameters relate to the amount of irrigation demand associated with citrus land-use areas. There are no measured data to estimate the amount of irrigation demand; however, based on the results of previous modeling, and discussions with Dr. Y. Wan of the SFWMD, a target annual demand of 10 inches was adopted. Table 2-3 lists some of the irrigation parameters used in the model which are defined as follows:

IRATE: Irrigation rate

AZRI: Fraction of irrigation demand (i.e. total moisture deficiency) that will be met

MIN_CAP: Minimum fractional moisture content that will trigger an irrigation demand

D_R: Depth of root zone

Macro_Pore: Porosity of soil in vadose zone that will drain by gravity unless drainage is inhibited

Micro_Pore: Porosity of soil in vadose zone that holds water by cohesion; approximately the difference between wilting point and field capacity

Table 2-3. Calibrated Irrigation Demand Module Parameters Applied to Citrus Land Use.

Parameter	C-23	C-24	C-25
IRATE (in/hr)	0.01	0.01	0.01
AZRI (%)	85	85	85
MIN_CAP (%)	45	45	45
D_R (ft)	2	2	2
Macro_Pore (in/in)	0.1	0.1	0.1
Micro_Pore (in/in)	0.15	0.15	0.15

The irrigation module for HSPF that was developed by AQUA TERRA was incorporated into WaSh with some modifications (URS, 2008c). The modifications were applied to simplify the interaction between the groundwater and the moisture zone. Table 2-4 lists some of the additional irrigation parameters used in the model which are defined as follows:

Canal Source: Proportion of irrigation demand to be supplied by withdrawal from canals

Shallow Aquifer Source: Proportion of irrigation demand to be supplied by withdrawal from the shallow aquifer

External Source: Target proportion of irrigation demand to be supplied by source(s) external to the model domain (e.g. Floridan Aquifer) which will be used only if the proportions designated for the other sources are not available

Spray Application: Proportion of irrigation water applied by spray to land surface

Surface Application: Proportion of irrigation water applied by other means to land surface

Upper Zone Application: Proportion of irrigation water applied to upper soil moisture zone

Lower Zone Application: Proportion of irrigation water applied to lower soil moisture zone

Table 2-4. Calibrated Irrigation Supply and Application Model Parameters.

Parameter	C-23	C-24	C-25
Canal Source	100 %	100 %	100 %
Shallow Aquifer Source	0%	0%	0%
External Source	0%	0%	0%
Spray Application	20%	20%	20%
Surface Application	0%	0%	0%
Upper Moisture Zone Application	15%	15%	15%
Lower Moisture Zone Application	65%	65%	65%

Tertiary canals represent the intense network of finger canals, small drainages, creeks, streams, and irrigation ditches which facilitate the exchange of surface water within a cell with the primary reaches and surface reservoirs. WaSh allows for the designation of different tertiary canal properties based on land use and which are defined as follows:

Depth: Distance below grade to canal bottom

Width: Top-of bank width

Pumping Rate: Capacity of pump used to discharge water from tertiary canal to primary canal during wet periods, or to pump water from primary canal or reservoir into tertiary canal during periods of irrigation demand

Conductance: A factor that is multiplied times the difference in elevations of groundwater and water in the canal to determine the flow between the canal and aquifer

Table 2-5. Calibrated Tertiary Canal Properties for Each Land Use.

Land Use	Depth (ft)	Width* (ft)	Pumping Rate (inches/day)	Conductance (ft/day)		
	All	All	All	C-23	C-24	C-25
Tree Crops	8	52	1.075	0.06	0.06	0.06
Wetlands	1	3.9	0.55 or 0.725	0.06	0.06	0.06
Urban (excludes	5.5	15.6	1.1	0.06	0.06	0.06

Land Use	Depth (ft)	Width* (ft)	Pumping Rate (inches/day)	Conductance (ft/day)		
	All	All	All	C-23	C-24	C-25
cemeteries)						
Forest	5.5	15.6	0.725	0.06	0.06	0.06

2.4 RESULTS

The results of the final flow calibration are summarized in Figures 2.1 through 2.15. The time series data (Figures 2.1 through 2.3) indicate a reasonable simulation of daily flow patterns with flows from isolated rainfall events as well as continuous flows developing during the wet seasons when rainfall occurs more often.

The flow frequency curves (Figures 2.4 through 2.6) indicate that the distribution of daily flow is well represented, especially the relatively large number of days with zero flow. The shape of the distribution in the region where the daily flow distribution goes to zero is sensitive to the gate operation criteria. The annual variations (Figures 2.7 through 2.9) and the seasonal patterns in discharges (Figures 2.10 through 2.12) are also well represented. The total discharge simulated during the calibration period for the C-23 and C-24 basins exceeds total measured flow by about 6 percent (Tables 2-6 and 2-7; Figures 2.13 and 2.14). By comparison, the total discharge simulated for the C-25 basin was 5.4% less than total measured flow (Table 2-8; Figure 2.15).

Table 2-6. Summary Statistics for C-23 Basin Calibration Period (1995 – 2000).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	174	184	-10
Standard Error	9.42	9.07	.034
Median	0	0	0
Standard Deviation	441	425	16
Range	4550	4720	-170
Minimum	0	0	0
Maximum	4550	4720	-170
Sum	380,695	403,004	-22,309

Table 2-7. Summary Statistics for C-24 Basin Calibration Period (1995 – 2000).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	220	234	-14
Standard Error	8.82	10.13	-1.31
Median	0	0	0
Standard Deviation	413	474	-61
Range	3900	5730	-1830
Minimum	0	0	0
Maximum	3900	5730	-1830
Sum	482,877	512,000	-29,123

Table 2-8. Summary Statistics for C-25 Basin Calibration Period (2004 – 2008).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	223	211	12
Standard Error	11.50	10.97	0.53
Median	26.39	11.34	15.05
Standard Deviation	492	469	23
Range	4566	4464	102
Minimum	0	0	0
Maximum	4566	4464	102
Sum	406,680	384,687	21,993

The maximum difference for a single day is 1,830 cfs for C-24 basin (Table 2-7). The cause of this difference was not evaluated, but it is likely attributable to a deviation during actual operations from the typical operating gate operating rule for S-49.

In general, the comparisons of daily measured flow with flow simulated during the validation periods are similar to the calibration results. The results of the model validations are shown in Figures 2.16 through 2.30 and Tables 2-9 through 2-11 for the C-23, C-24, and C-25 basin models.

Table 2-9. Summary Statistics for C-23 Basin Validation Period (2001 – 2005).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	238	221	17
Standard Error	11.80	10.59	1.2
Median	0	0	0
Standard Deviation	504	453	51
Range	5166	3513	1653
Minimum	0	0	0
Maximum	5166	3513	1653
Sum	434,136	403,956	30,180

Table 2-10. Summary Statistics for C-24 Basin Validation Period (2001 – 2005).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	279	232	47
Standard Error	12.04	10.22	1.82
Median	0.135	0	0.135
Standard Deviation	514.33	436.57	77.76
Range	4004	4200	-196
Minimum	0	0	0
Maximum	4004	4201	-197
Sum	509,015	423,190	85,825

Table 2-11. Summary Statistics for C-25 Basin Validation Period (1998 – 2003)

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	196	215	-19
Standard Error	7.99	7.62	0.36
Median	17.14	41.26	-24.11
Standard Deviation	374	357	17
Range	3111	2615	496
Minimum	0	0	0
Maximum	3111	2615	496
Sum	429,977	470,751	-40,774

As the purpose of the model validation is to show that a calibration is robust and applicable to other conditions, a quantitative assessment of the calibration and validation results was made (Table 2-12). For the time series data, the root-mean-square (RMS) error and the Nash-Sutcliffe coefficient were calculated from the data. The RMS errors for the flow time series were in the range of 250 to 320 cfs. These values are above the mean flows for each basin. However, as most of the flows are near zero for a large percentage of the time, a better scale for evaluating the RMS error is the range of daily flows. A review of the flow frequency curves shows that the range of the daily flows for the 40 to 50% time when flow occurs is about 2,000 cfs. Thus, using 2,000 cfs and the full range, the RMS errors for each basin are about 15% of the full range.

The Nash-Sutcliffe coefficient ranges between 0.4 and 0.7 for the C-23 and C-24 basins, indicating a moderately strong correlation. These values are likely indicative of the model representing the strong wet/dry seasonal patterns in the flow data.

Generally, the errors between the measured and simulated results for the validation were similar to those obtained for the calibration period, indicating that the model calibrations are robust and reliable. Summary statistics for measured and simulated flows during the combined 11-year periods for calibration and validation are provided in Tables 2-13 through 2-15.

Table 2-12. Time Series Metrics for Model Calibrations and Validations of Daily Flow.

	C23		C24		C25	
Metric	**Calibration**	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**
RMS Error (cfs)	246	302	313	293	264	292
NS Coefficient	0.68	0.64	0.42	0.68	0.71	0.39
Percent Error	-5.86	6.95	-6.03	16.9	5.4	-9.48
***Wet Season Percent Error**	-7.49	7.90	-11.0	19.0	4.49	-10.6
^Dry Season Percent Error	2.18	-3.76	13.1	-2.59	14.3	-3.19

*June – November ^December – May

Table 2-13. Summary Statistics for C-23 Basin Simulation Period (1995 – 2005).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	203	201	2
Standard Error	7.44	6.91	0.53
Median	0	0	0
Standard Deviation	472	438	34
Range	5166	4720	446

Minimum	0	0	0
Maximum	5166	4720	446
Sum	814,831	806,961	7870

Table 2-14. Summary Statistics for C-24 Basin Simulation Period (1995 – 2005).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	247	233	14
Standard Error	7.30	7.2	0.08
Median	0	0	0
Standard Deviation	463	458	5
Range	4004	5731	-1727
Minimum	0	0	0
Maximum	4004	5731	-1727
Sum	991,892	935,190	56,702

Table 2-15. Summary Statistics for C-25 Basin Simulation Period (1998 – 2008).

Statistic	Measured Flow (cfs)	Simulated Flow (cfs)	Difference (cfs)
Mean	208	213	-5
Standard Error	6.8	6.49	0.31
Median	21.6	24.24	-2.65
Standard Deviation	432	411	20
Range	4566	4464	102
Minimum	0	0	0
Maximum	4566	4464	102
Sum	836,667	855,559	-18,892

The water budgets for the combined calibration and validation periods considered for each basin demonstrate reasonable numerical balances with relative differences ranging from 2.1% of total inflow for the C-24 basin to -4.1% of total inflow for the C-25 basin model (Table 2-16). Rainfall accounted for nearly all of the source water with very small amounts of external source water being simulated in basins C-23 and C-25 to meet irrigation demands that could not be met by water in the system of tertiary canals and surface storage reservoirs. Evapotranspiration accounted for most of the outflow from each basin, ranging from an average 39.3 to 36.5 inches per year. The remaining outflows from the systems were as surface discharge which ranged from an annual average of 10.65 to 16.96 inches and as groundwater discharge which ranged from 4.49 to 8.10 inches per year.

Table 2-16. Annual Average Water Budgets for the C-23, C-24 and C-25 Basin Models.

Characteristic	Inflow (I) Outflow (O)	C-23 (1995-2005)	C-24 (1995-2005)	C-25 (1998-2008)
Rainfall (inches)	I	50.92	53.49	51.40
External Irrigation Supply (inches)	I	0.01	0	0.28
Total Inflow	I	50.93	53.49	51.68
Evapotranspiration (inches)	O	33.63	29.30	36.53
Surface Discharge (inches)	O	13.91	16.96	10.65
Groundwater Discharge (inches)	O	4.49	7.47	8.10
Total Outflow	O	52.03	53.73	55.28
Change in Storage*	dS	-1.61	-1.37	-1.47
Balance	I – O – dS	0.51	1.13	-2.13
Relative Difference	Balance/Total Inflow	1.0%	2.1%	-4.1%

*Change in storage represents the difference in beginning and ending soil moisture and groundwater elevation, where positive values indicate that the final groundwater elevation is lower than the initial elevation. Most of the change is due to groundwater elevation changes.

Simulated irrigation demand ranged from an average 1.61 to 8.05 inches per year assuming a uniform distribution over the entire basin area for the 11 year combined calibration and validation periods (Table 2-17). As indicated in the preceding table, almost all of this demand was simulated as being met using surface-water sources. Considering just the areas with a land use with a potential demand for irrigation water, the average demand ranged from 7.29 to 14.8 inches per year. This is comparable to the annual 10 inch target assumed for the irrigated portion of the basins.

Table 2-17. Simulated Annual Average Irrigation Demand.

Characteristic	C-23 (1995-2005)	C-24 (1995-2005)	C-25 (1998-2008)
Irrigation Demand, All Cells (inches)	2.73	1.61	8.05
Irrigated Cell Average (inches)	8.92	7.29	14.8

2.5 C-25 EXTENSION BASIN

Historic records of streamflow are lacking for the C-52 canal at S-253 thus the modeling results for the C-25 extension basin are described in more qualitative terms. However, C-52 stage data are available for both the upstream and downstream sides of S-253. Downstream stage records were used to represent a hydrodynamic boundary condition representing the current outfall of the C-25 extension basin at S-253.

The reasonableness of simulation results for the C-25 extension basin were reviewed by evaluating simulated stage on the upstream side of S-253 for an extended period of time and the simulated discharge during two recent floods, including Tropical Storm Faye in the fall of 2008. Simulated stages during periods of no to moderate flow are consistently about 0.3 to 0.4 feet lower than reported stages (Figure 2.31). The weir crest elevation is reportedly 25.2 feet NGVD29. This relatively consistent bias suggests that the elevation of the gage datum for the stage recorders at the structure and the weir crest elevation should be verified by field survey.

The historic stage record indicates that upstream stages typically vary within a range of about 0.5 to 0.6 feet (Figure 2.31). The typical range in simulated stages is comparable except during brief periods of relatively high flow and floods. Simulated high-flow stages during the calibration/ validation period of 1998-2008 exceed the recorded stage by as much as 2 feet. The cause of this deviation is not know and has not been evaluated because is occurs infrequently. One explanation may be that the width of the flowway increases beyond the width of the weir crest at extreme high flow thus increasing channel conveyance capacity.

On three occasions during the past 5 years, the simulated discharge of the C-52 at S-253 exceeds 500 cfs. Two separate events during 2004 are associated with simulated peak discharge of about 500 cfs (Figure 2.32). The first occurs in early September during the time when Hurricane Frances made landfall on the east-central Florida coast. A second event with simulated peak discharge of about 500 cfs occurs about 3 weeks later as a revived Hurricane Ivan passed over the area en route to a final destination on the Louisiana coast. The discharge simulated during Tropical Storm Faye in late August 2008 peaks at about 600 cfs (Figure 2.33). These simulated peak discharges compare reasonably well with information provided by SJRWMD (C. Tai, written communication, March 11, 2009) which indicated that a major storm event could produce a maximum flow from the C-52W canal into the C-52 canal of about 515 cfs.

The simulation results determined for the C-25 extension basin are sufficient to conclude the model can be used to simulate the long-term yield of the basin. The daily flow record determined from such long-term simulation will reflect current land use and effectively support the evaluation of potential water-storage alternatives which contemplate the hydraulic re-connection of basins in northern St. Lucie County and southern Indian River County.

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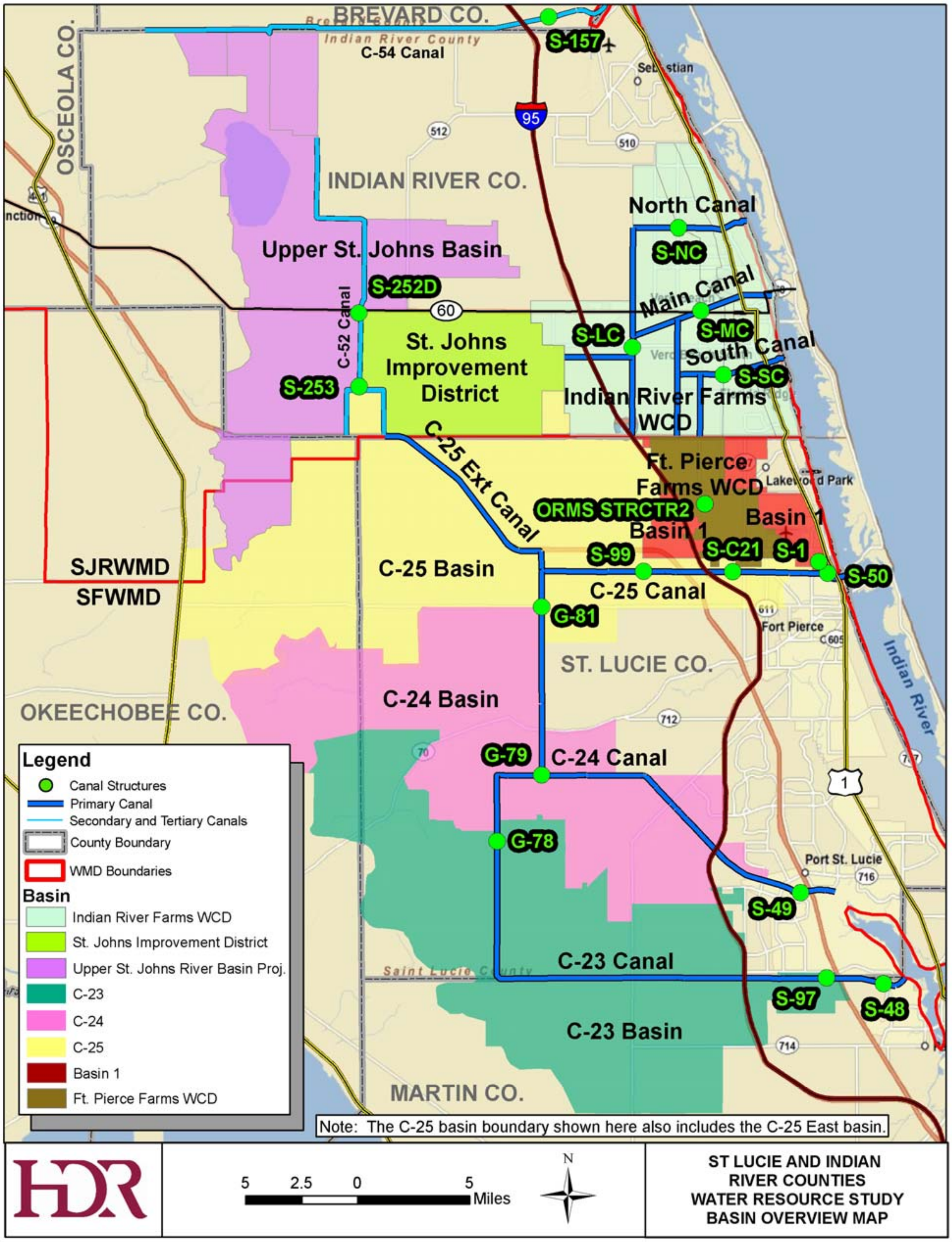

Figure 1. Study Basin Overview Map

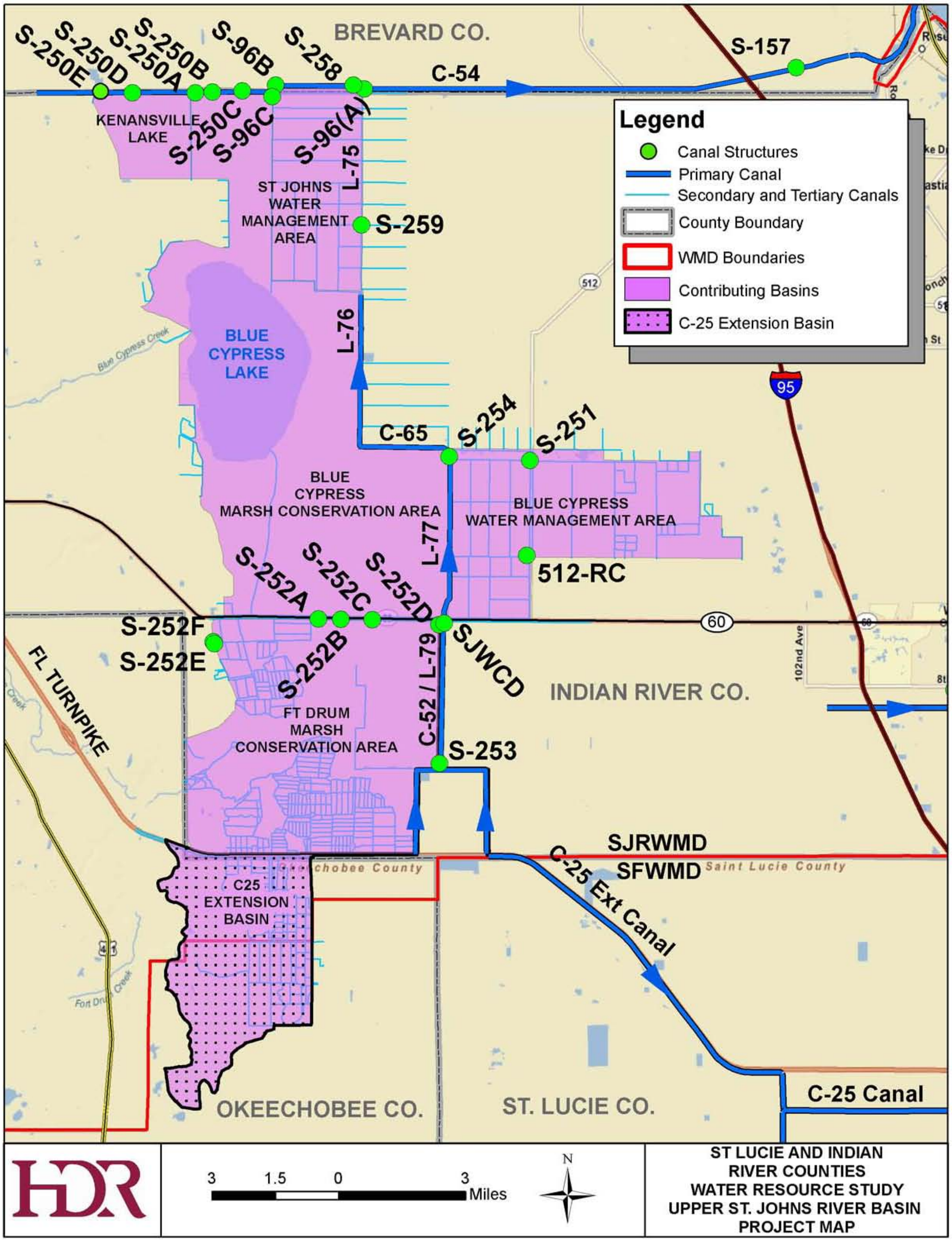

Figure 1a. C-25 Extension Basin, the Upper St. Johns River Basin Project, and C-25 Extension Canal.

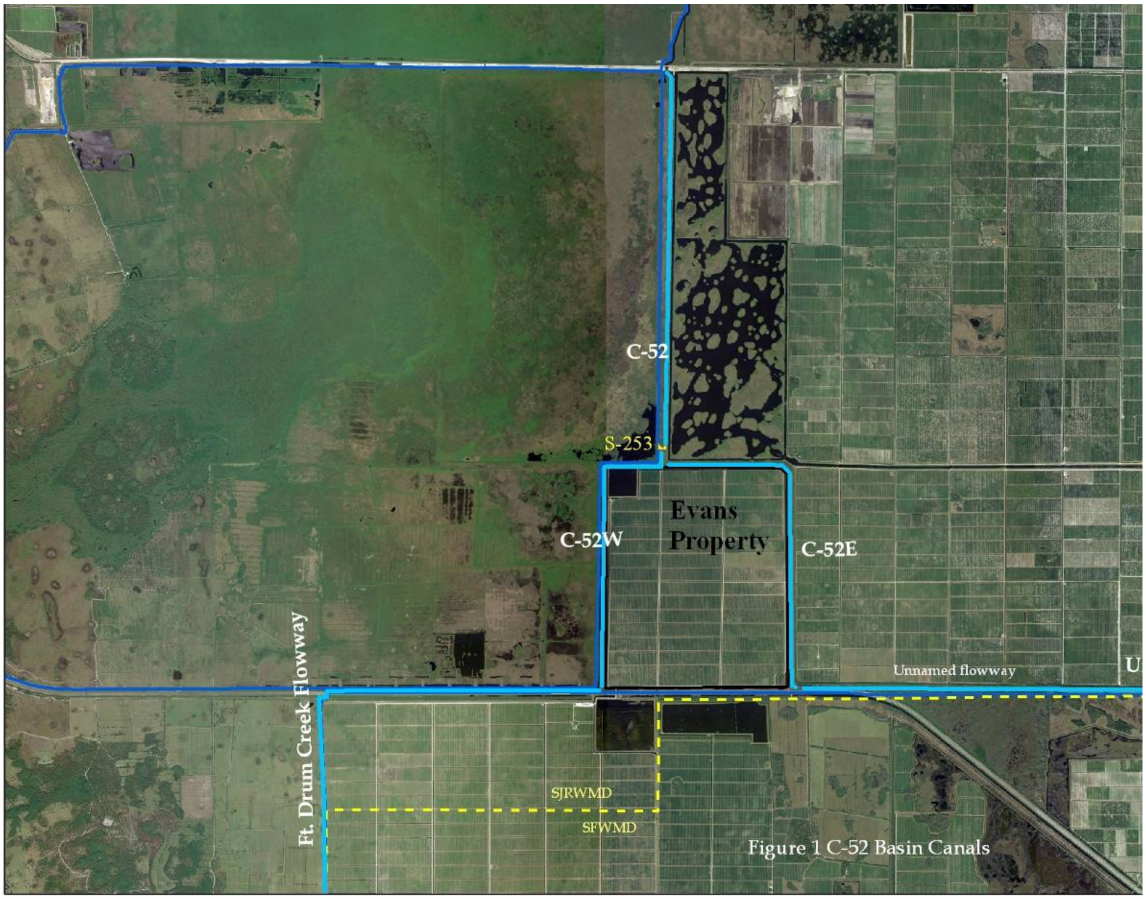

Figure 1b. Location of C-52 Basin Canals.
[Source: C. Tai, SJRWMD, 2009]

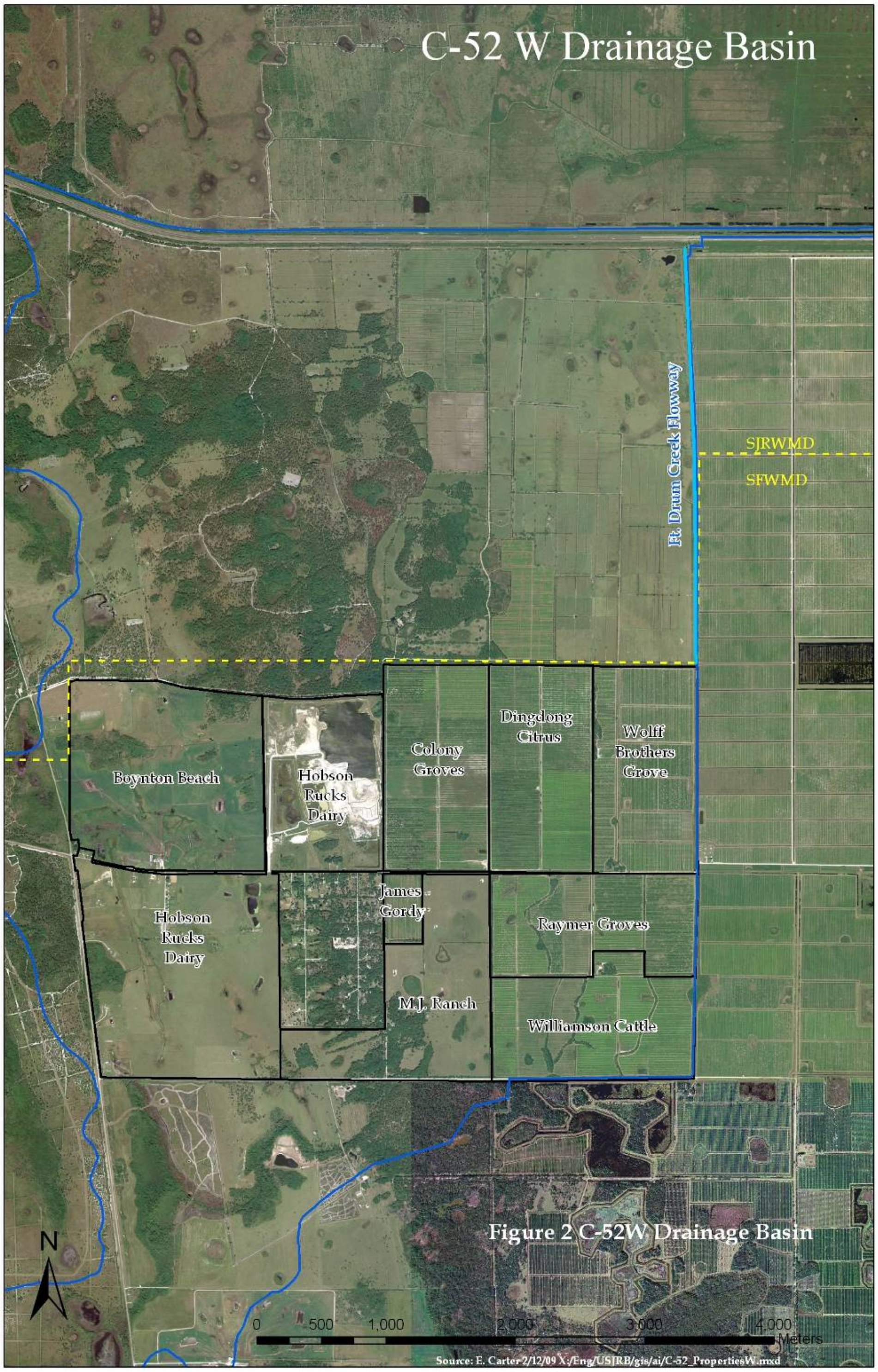

Figure 1c. Location of parcels within C-25 extension basin permitted to discharge into Upper SJR Basin via C-52W Canal.

[Source: C. Tai, SJRWMD, 2009]

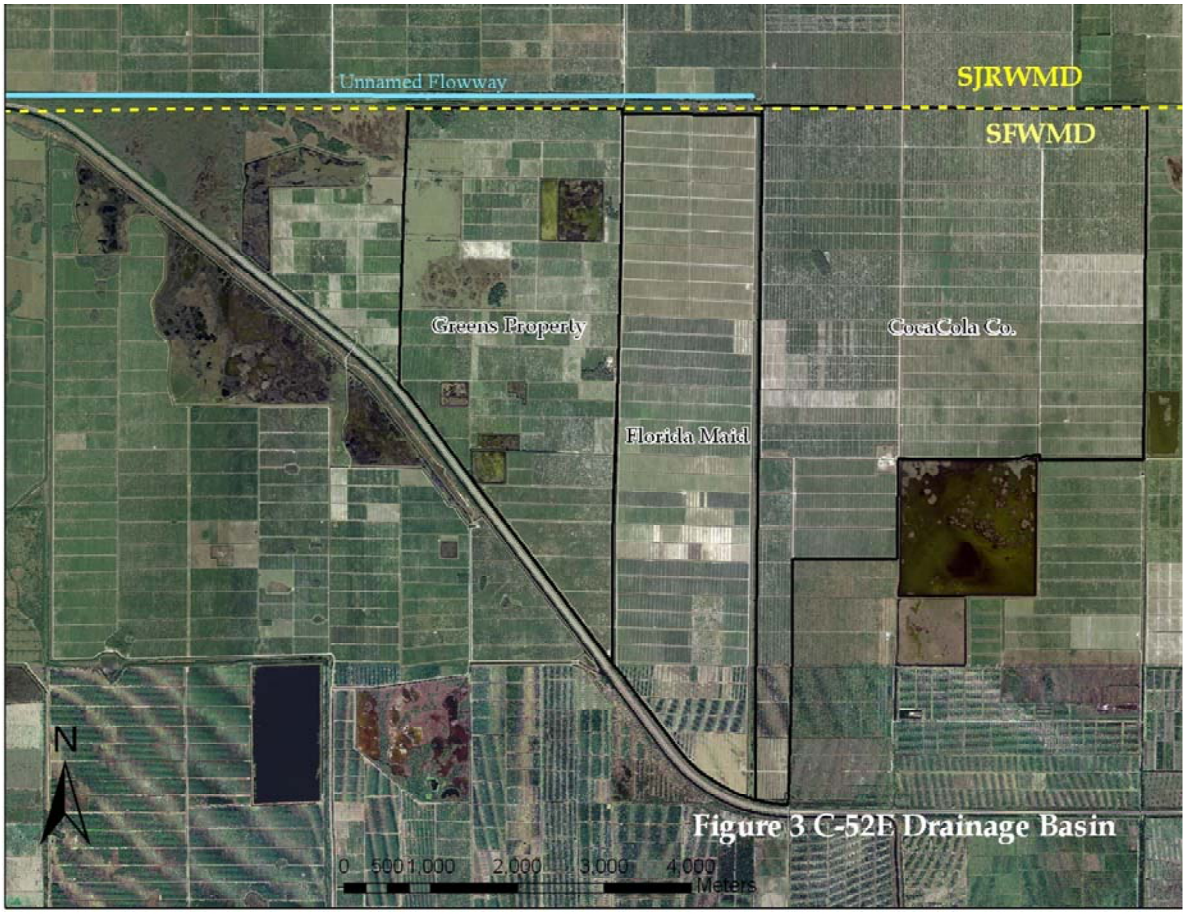

Figure 1d. Location of parcels within C-25 Basin permitted to discharge into Upper SJRB via C-52E Canal.

[Source: C. Tai, SJRWMD, 2009]

Figure 1e. Location of plug near southeast corner of Evans Property.
[Source: C. Tai, SJRWMD, 2009]

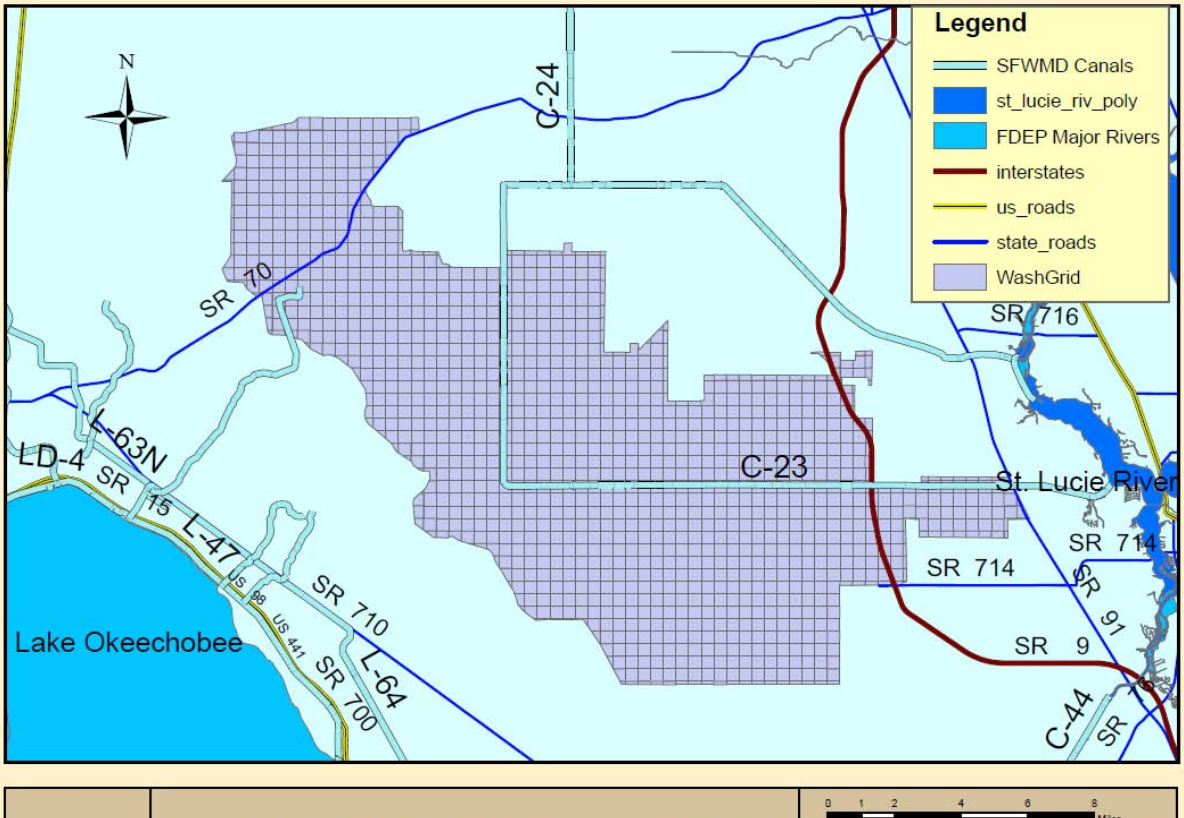

Figure 1.1a. Wash Model Grid for the C-23 Basin

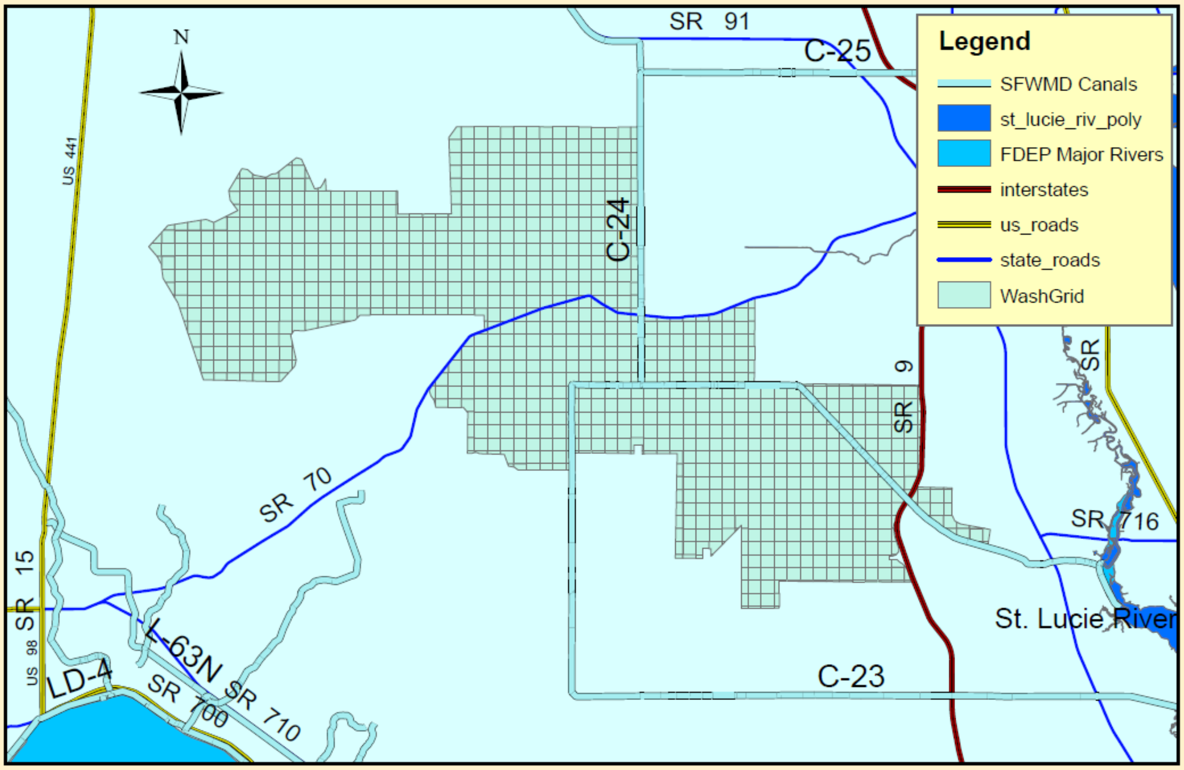

Figure 1.1b. Wash Model Grid for the C-24 Basin

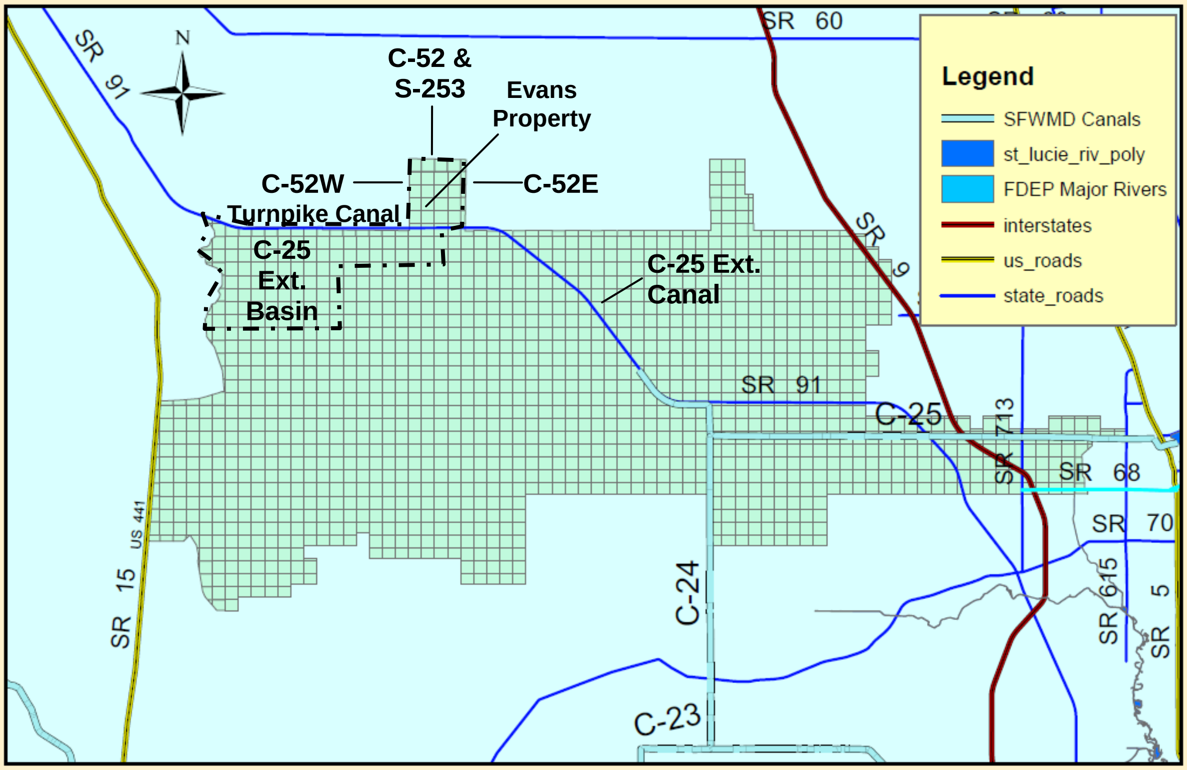

Figure 1.1c. Wash Model Grid for C-25 Basin

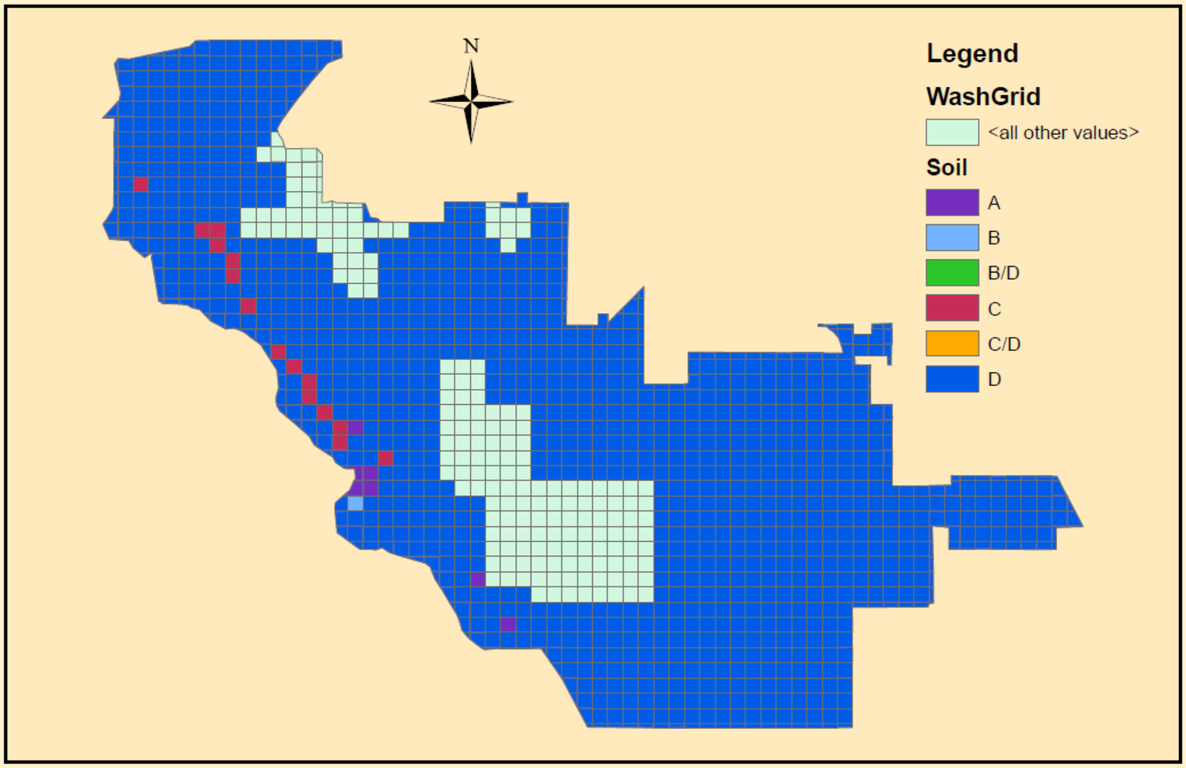

Figure 1.2a. Wash Model Representation of Soils in C-23 Basin

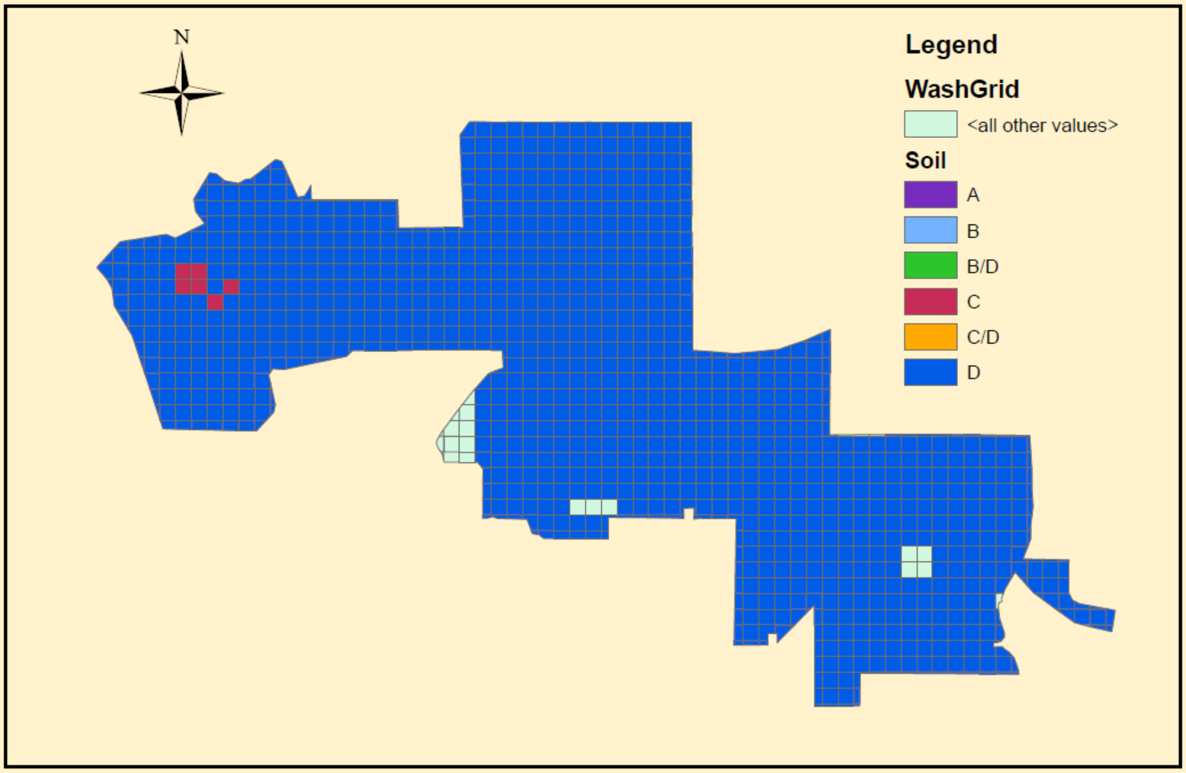

Figure 1.2b. Wash Model Representation of Soils in C-24 Basin

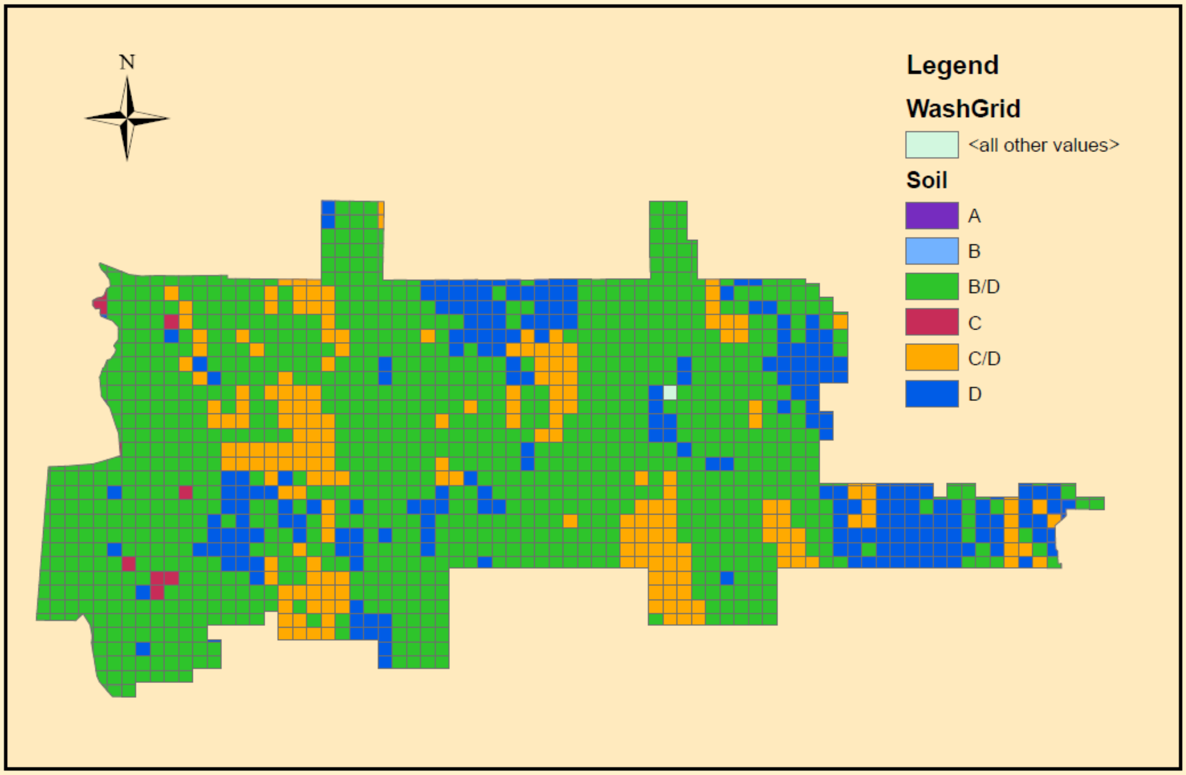

Figure 1.2c. Wash Model Representation of Soils in C-25 Basin

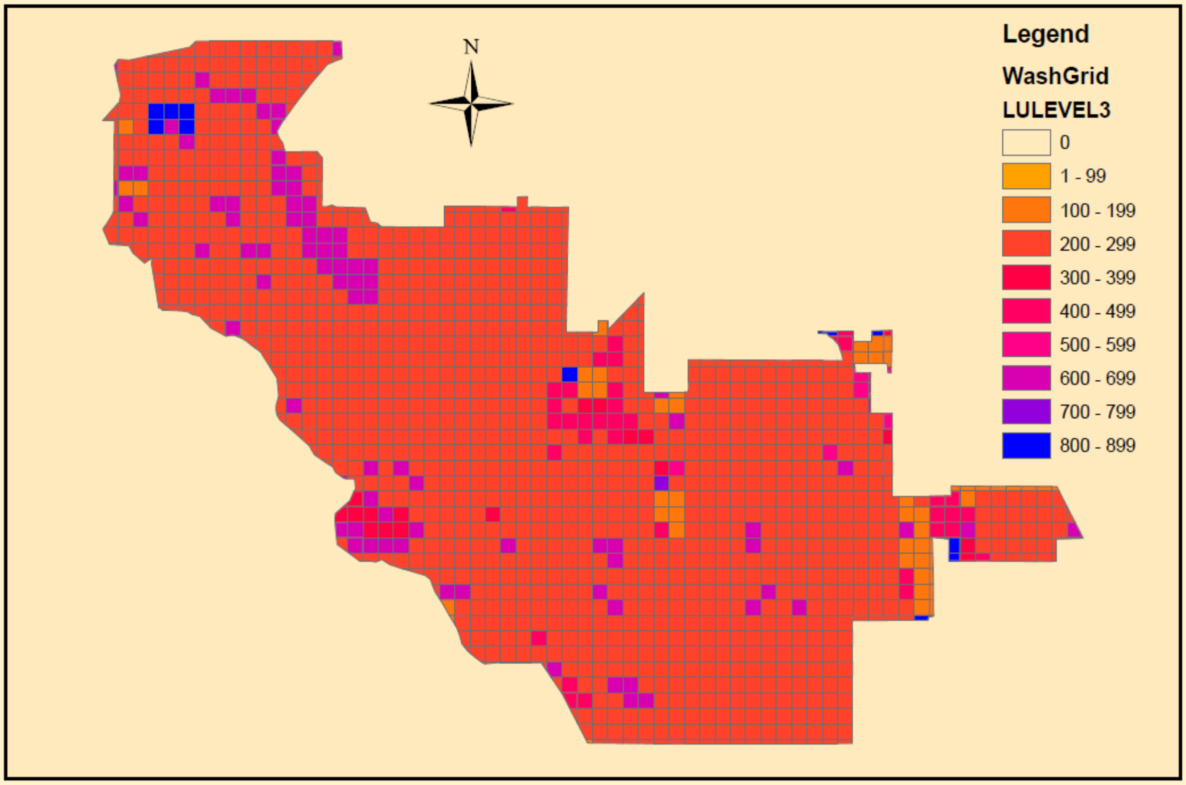

Figure 1.3a. Wash Model Representation of Landuse in C-23 Basin

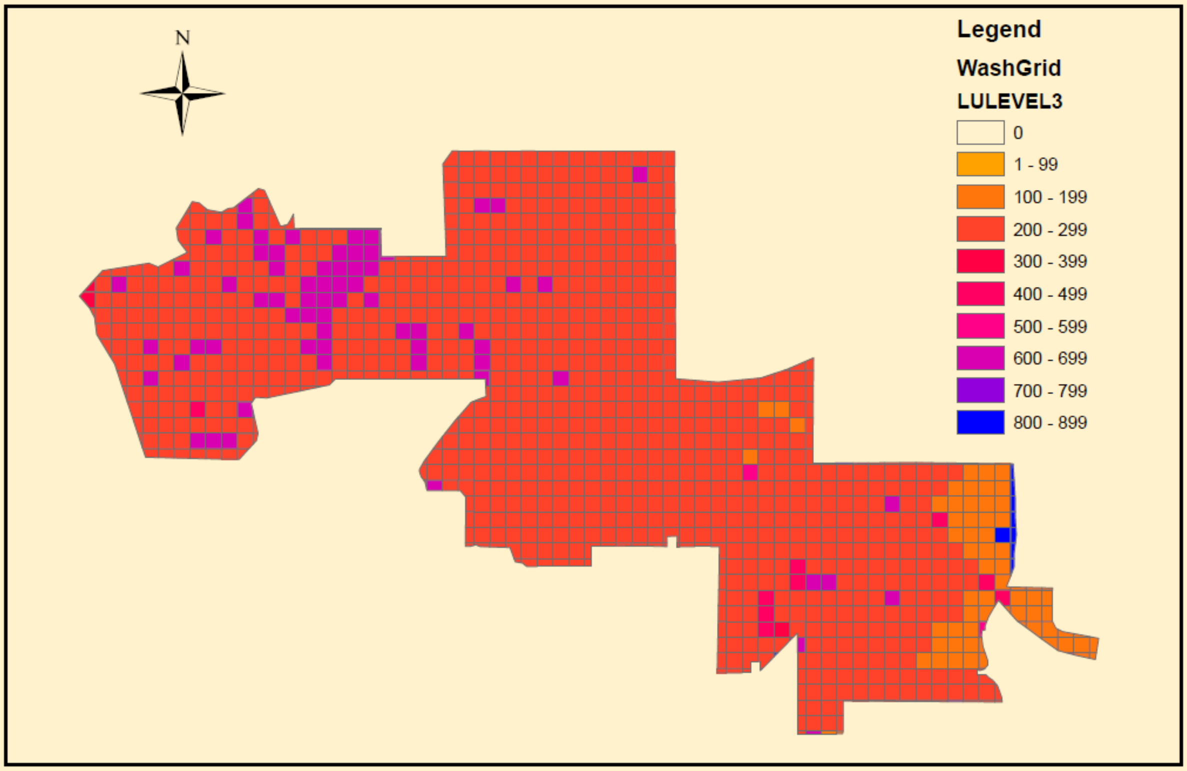

Figure 1.3b. Wash Model Representation of Landuse in C-24 Basin

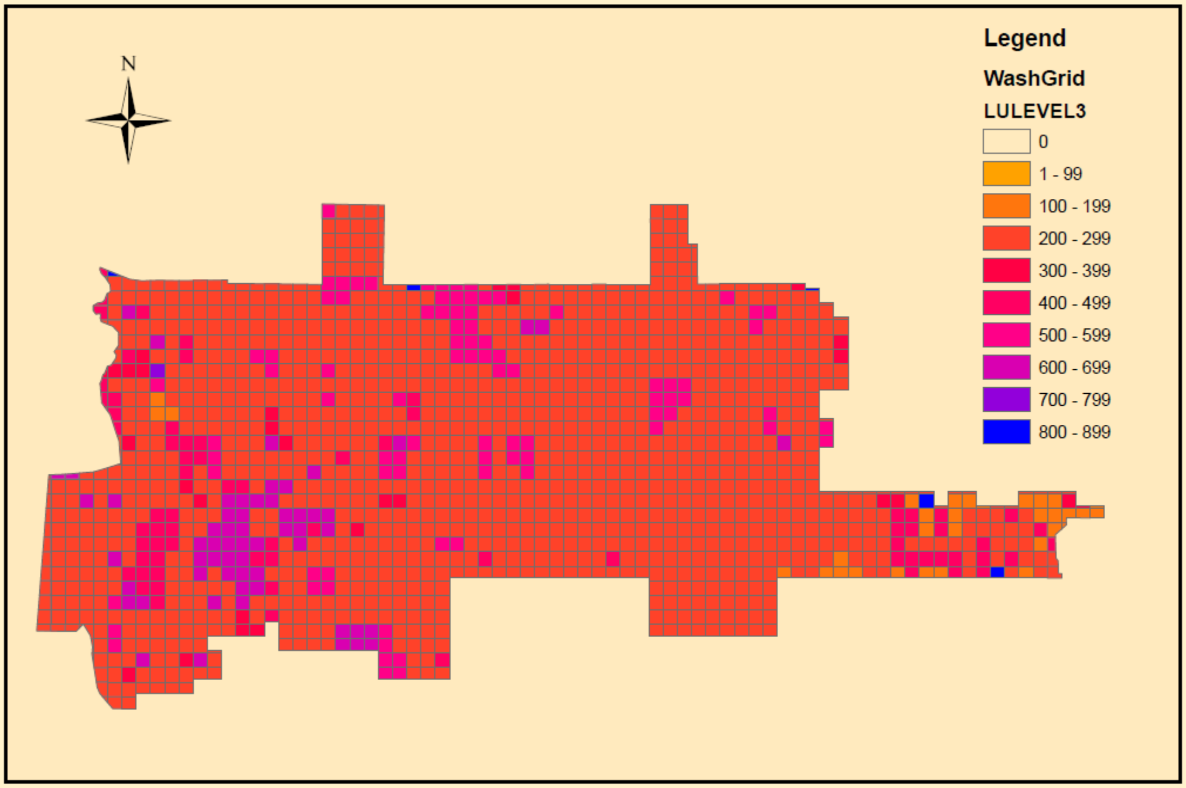

Figure 1.3c. Wash Model Representation of Landuse in C-25 Basin

0 0.5 1 2 3 4 Miles

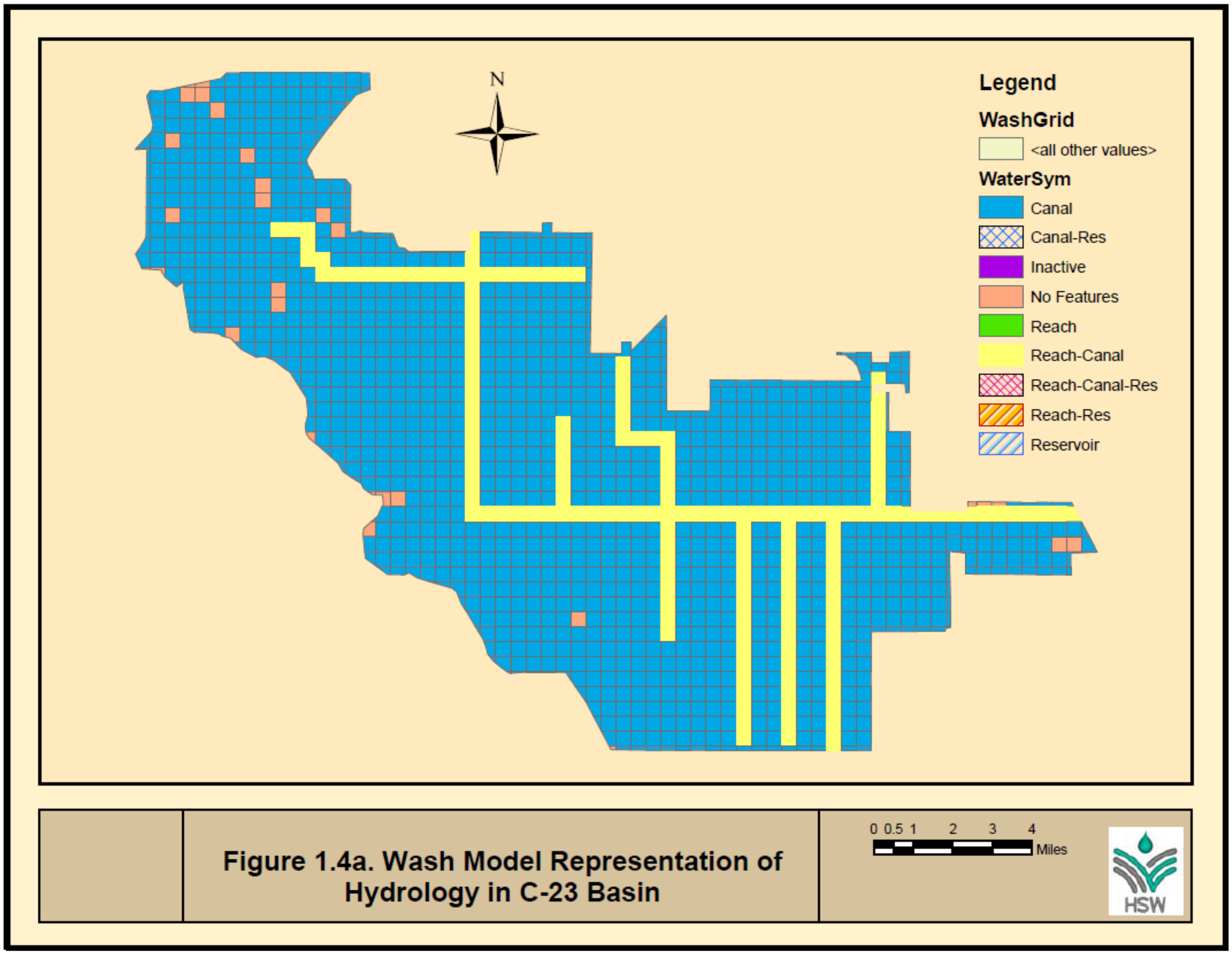

Figure 1.4a. Wash Model Representation of Hydrology in C-23 Basin

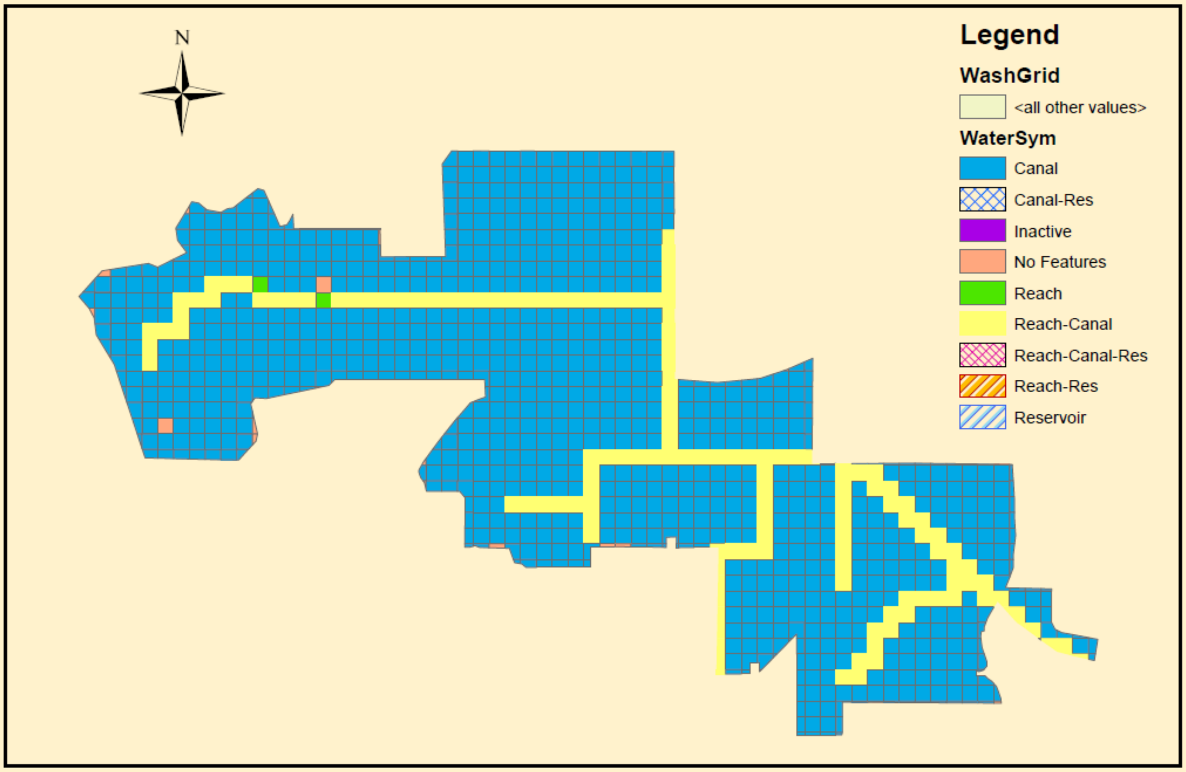

Figure 1.4b. Wash Model Representation of Hydrology in C-24 Basin

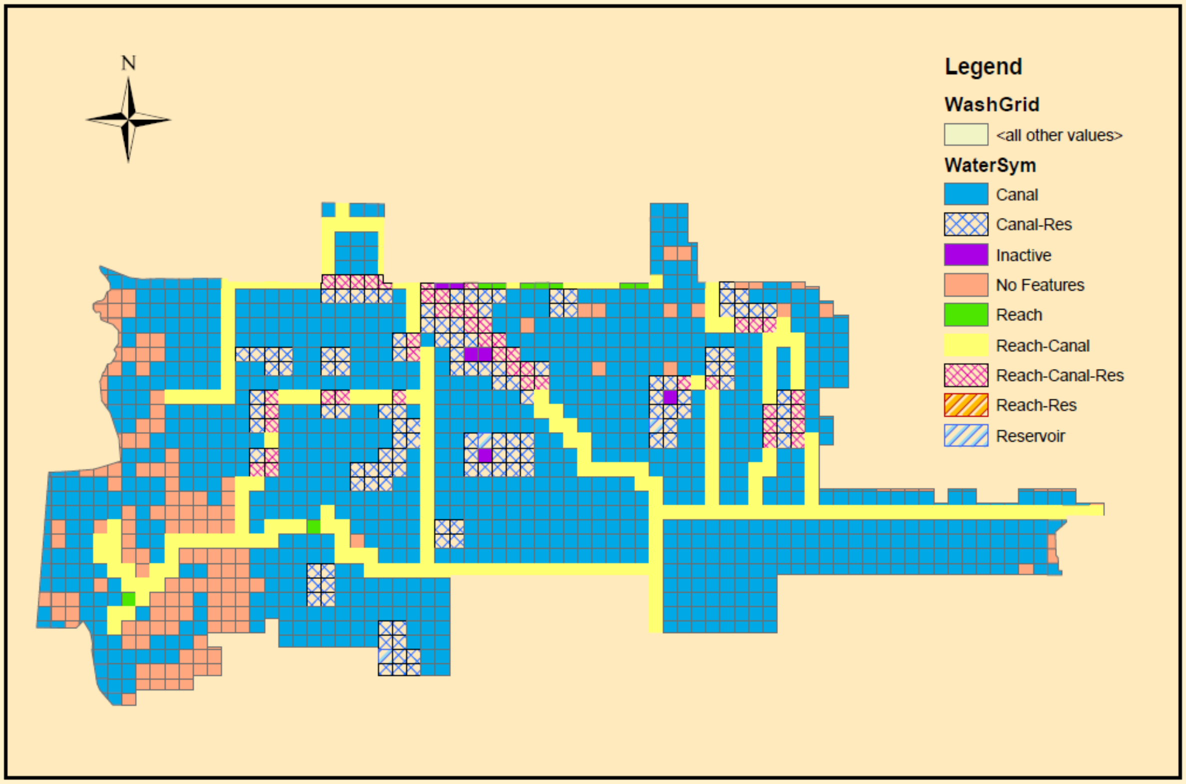

Figure 1.4c. Wash Model Representation of Hydrology in C-25 Basin

0 0.5 1 2 3 4 Miles

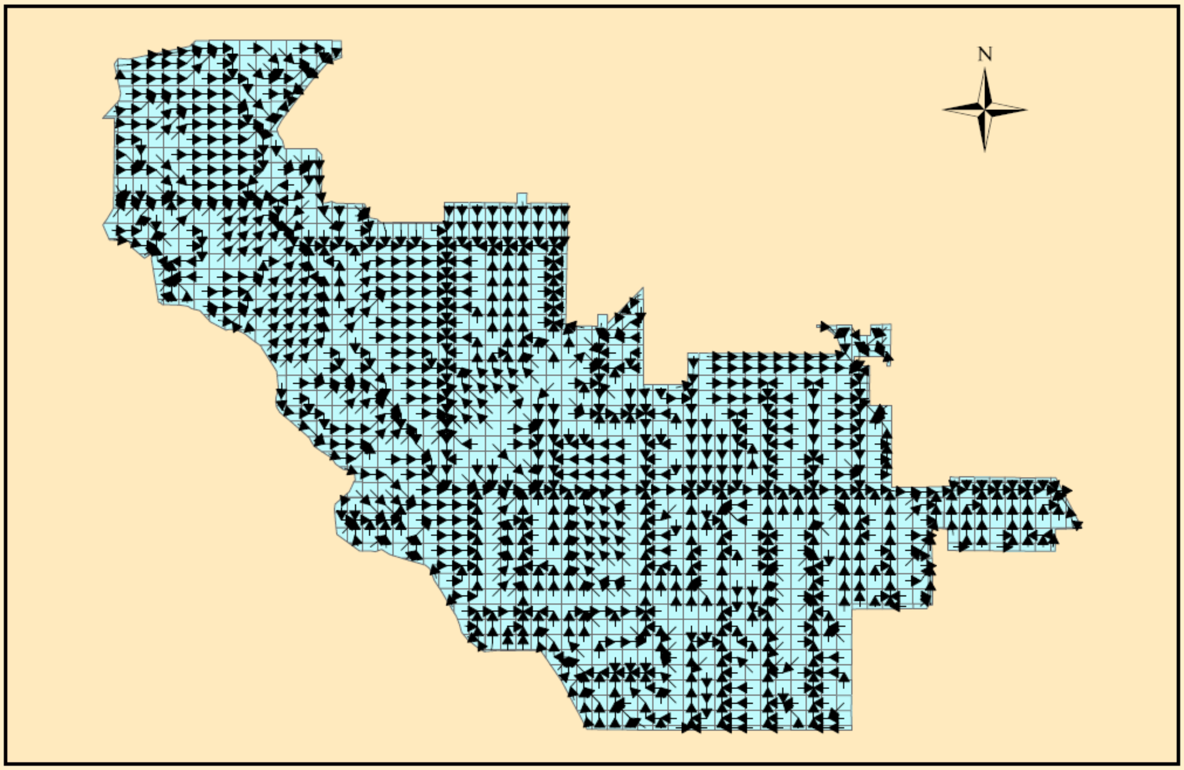

Figure 1.5a. Wash Model Representation of Overland Flow Paths in C-23 Basin

0 0.5 1 2 3 4 Miles

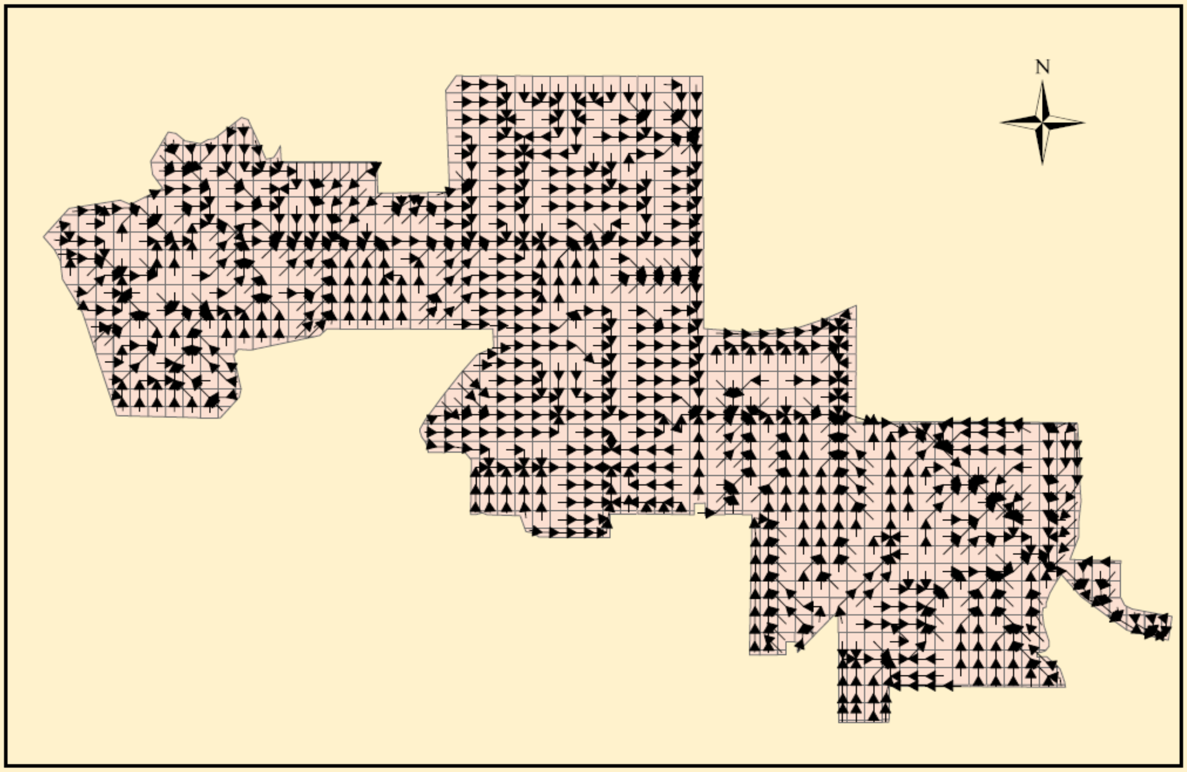

Figure 1.5b. Wash Model Representation of Overland Flow Paths in C-24 Basin

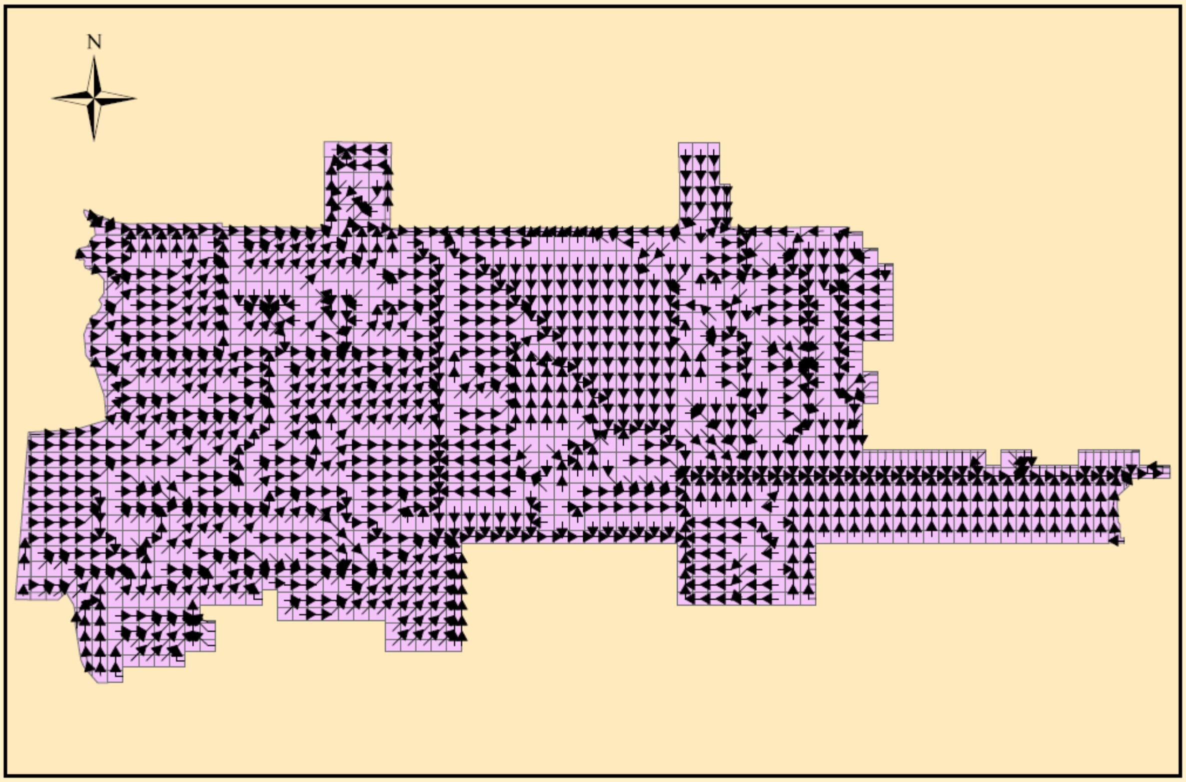

Figure 1.5c. Wash Model Representation of Overland Flow Paths in C-25 Basin

Figure 1.6a. Soil Group Distribution for C-23 Basin.

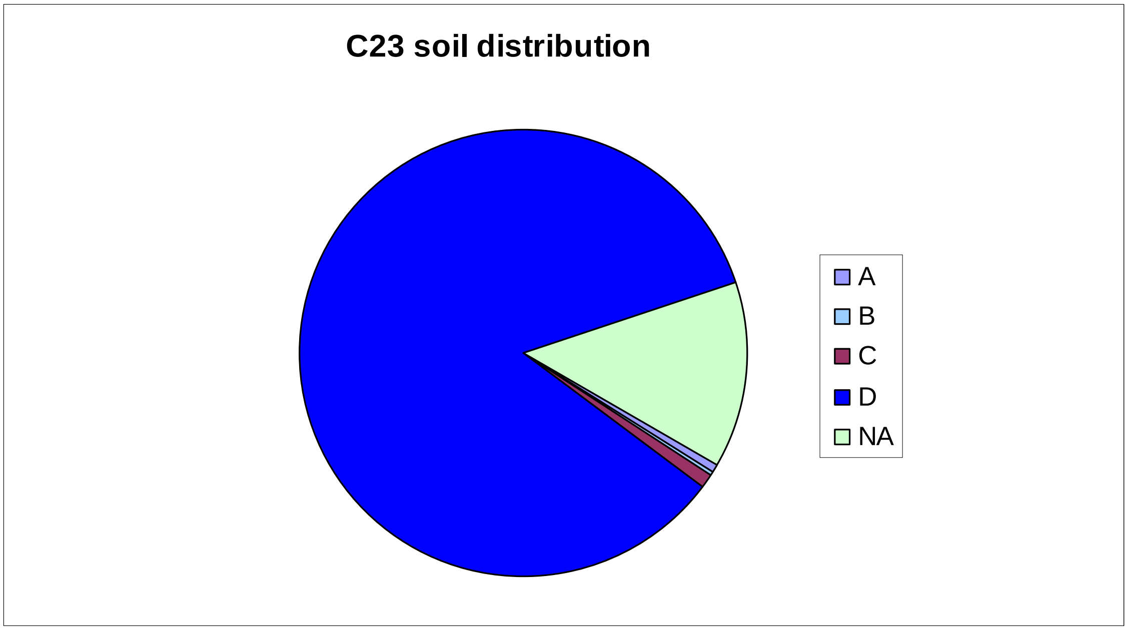

Figure 1.6b. Soil Group Distribution for C-24 Basin.

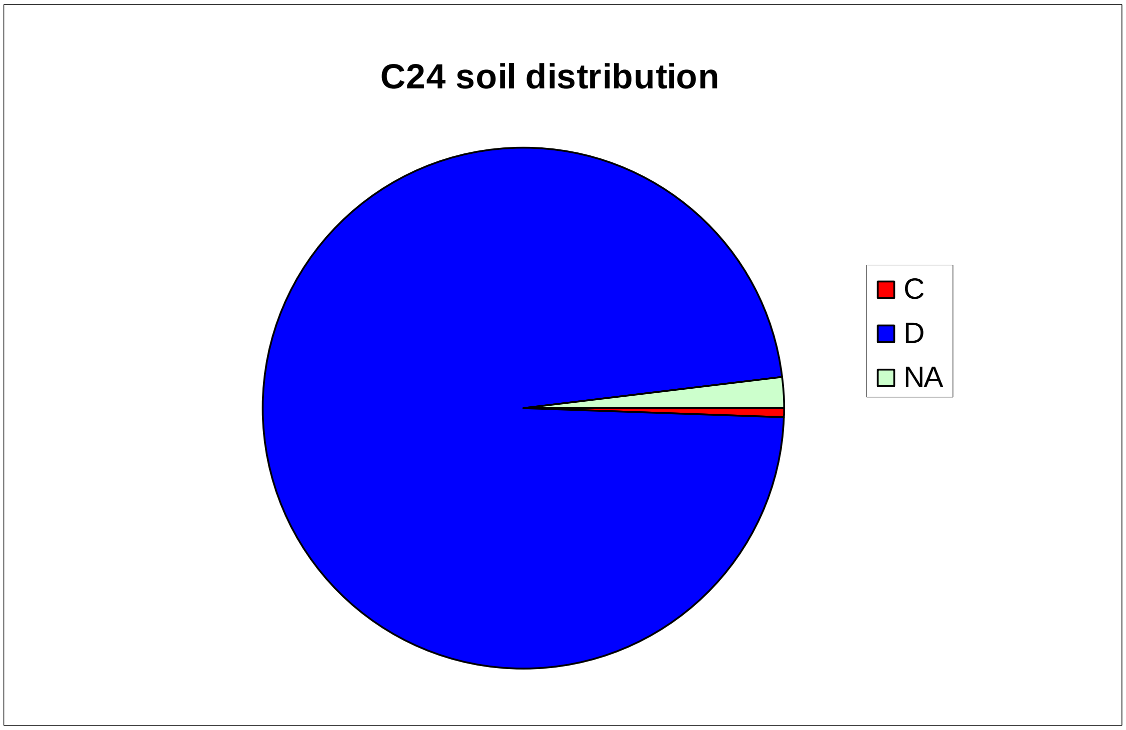

Figure 1.6c. Soil Group Distribution for C-25 Basin.

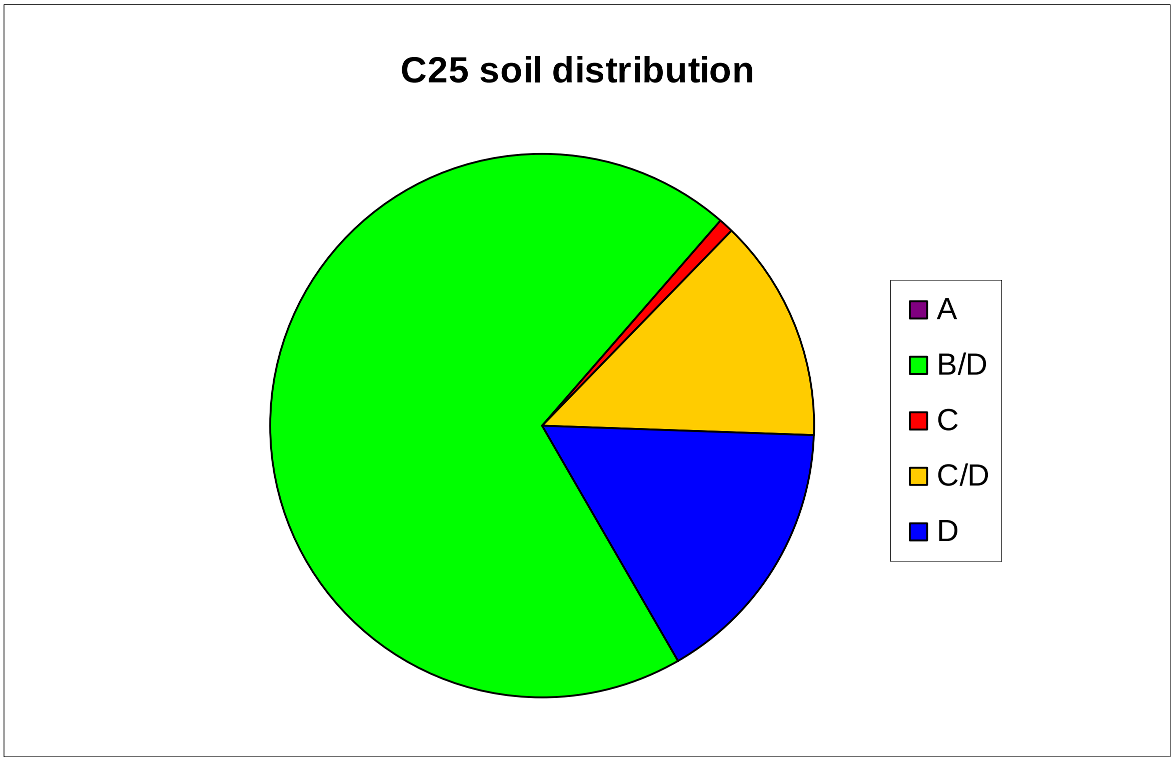

Figure 1.7. Mapping of NEXRAD Stations To WaSh Model C-24 Basin Grid Cells.

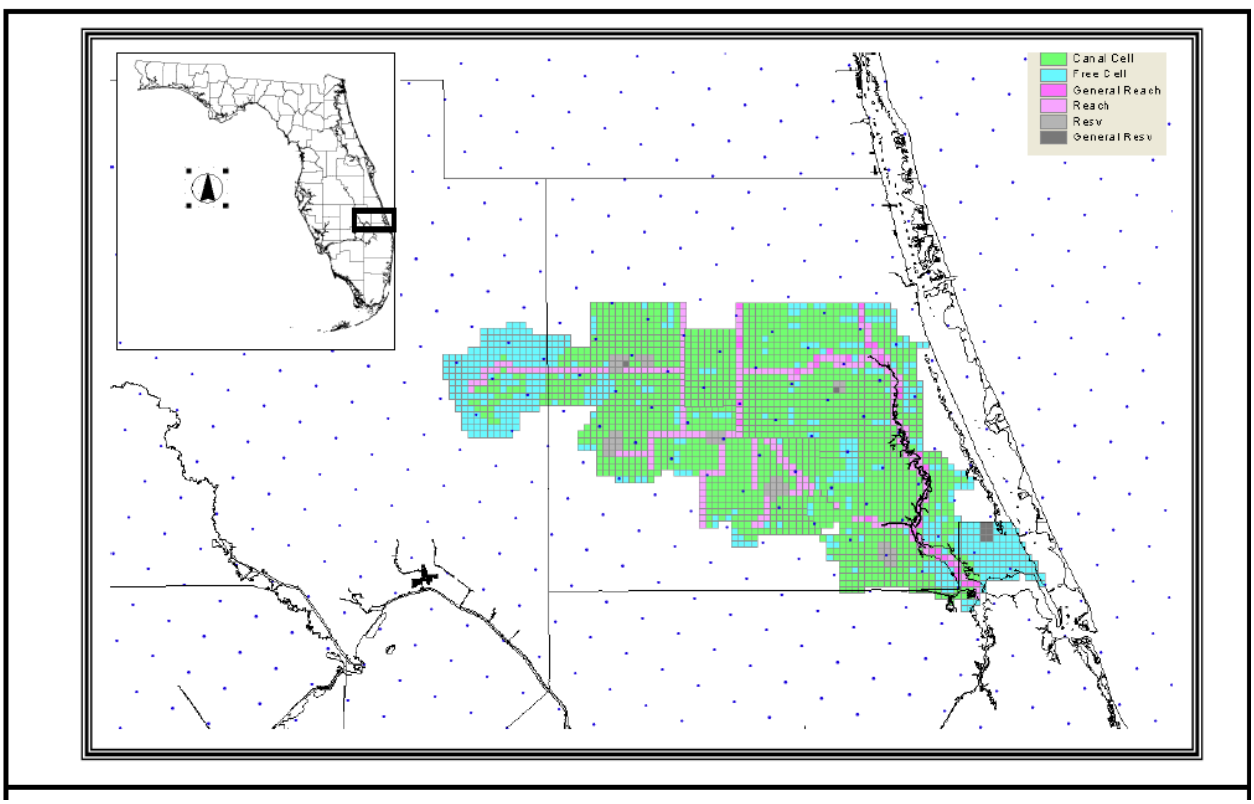

Figure 2.1. C-23 Daily Average Flow During Calibration Period 1995-2000.

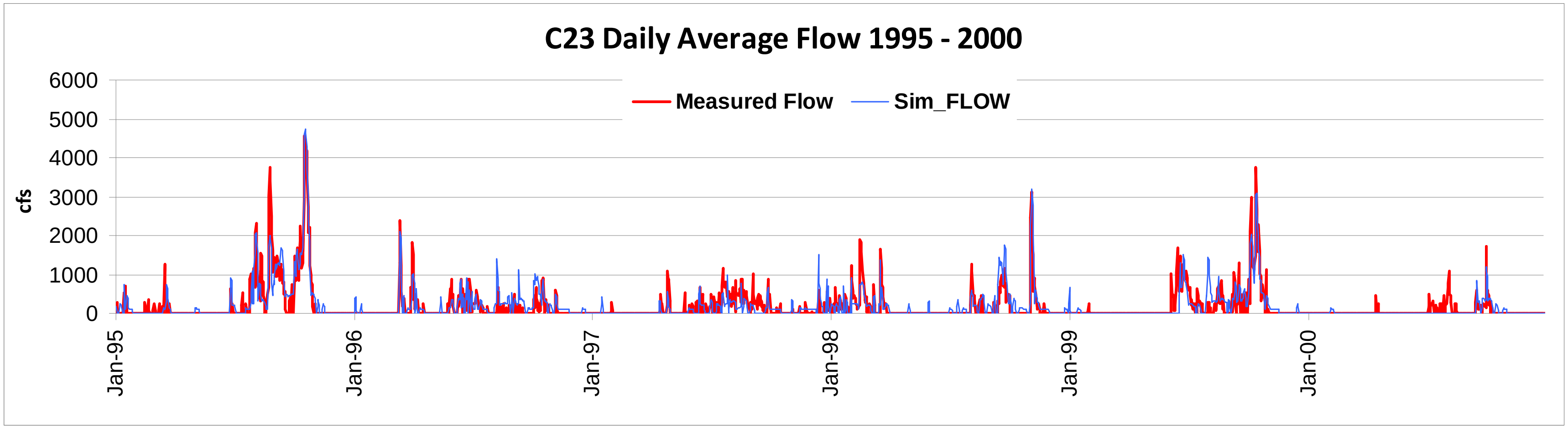

Figure 2.2. C-24 Daily Average Flow During Calibration Period 1995-2000.

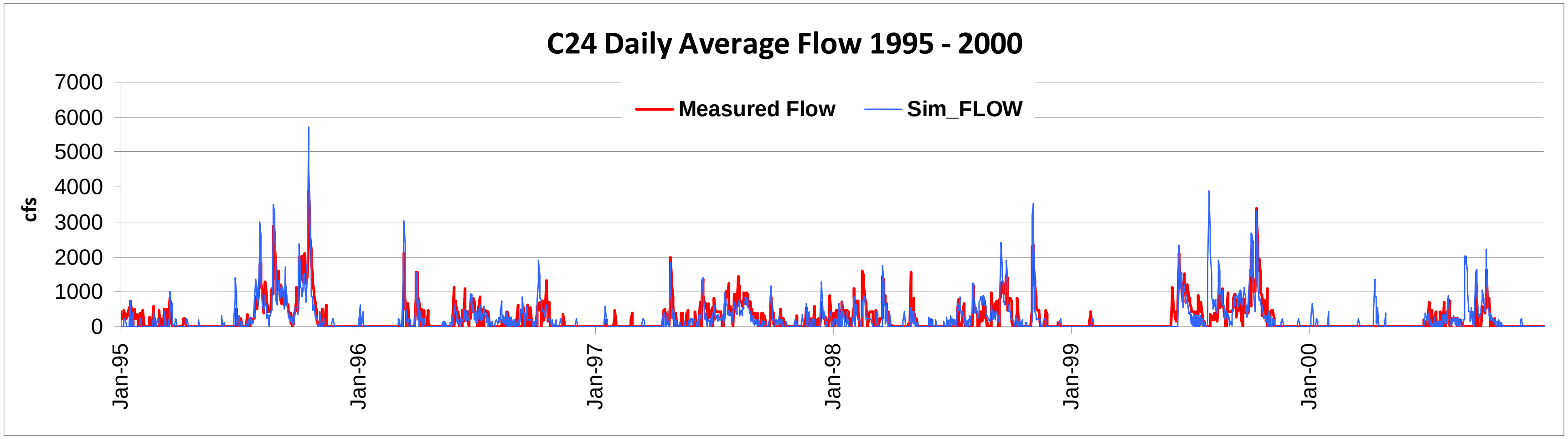

Figure 2.3. C-25 Daily Average Flow During Calibration Period 2004-2008.

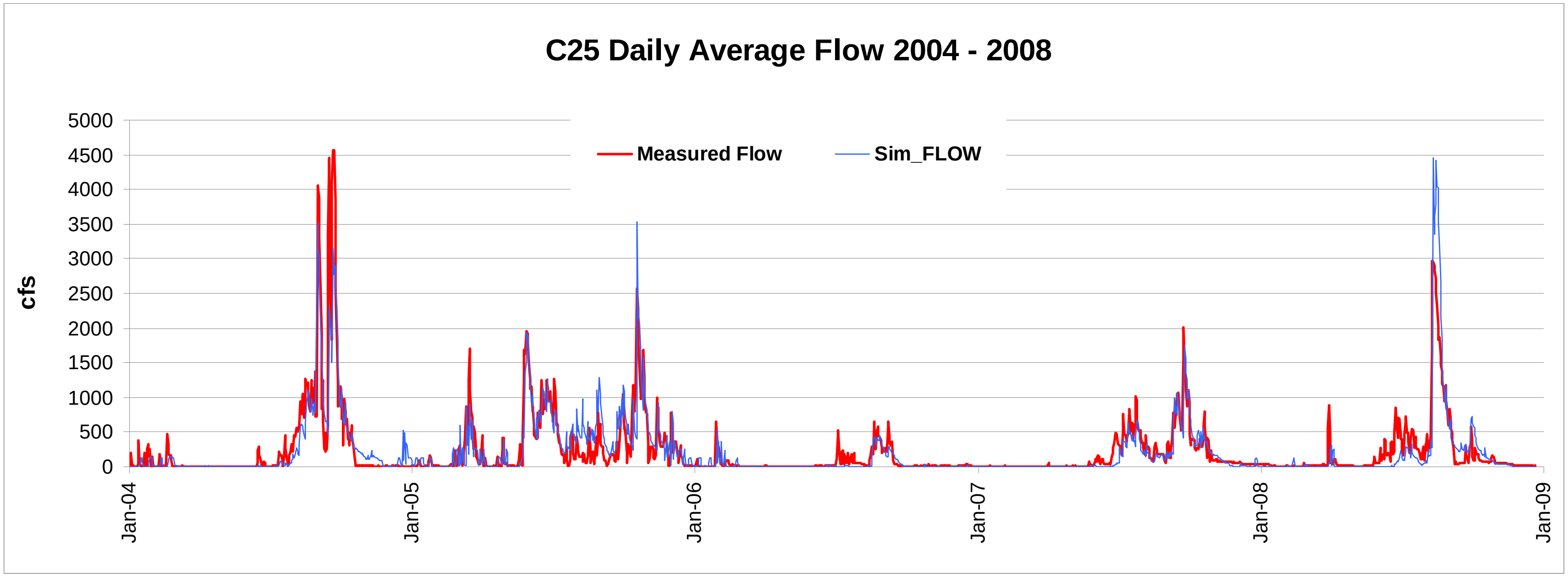

Figure 2.4. C-23 Daily Average Flow Frequency During Calibration Period 1995-2000.

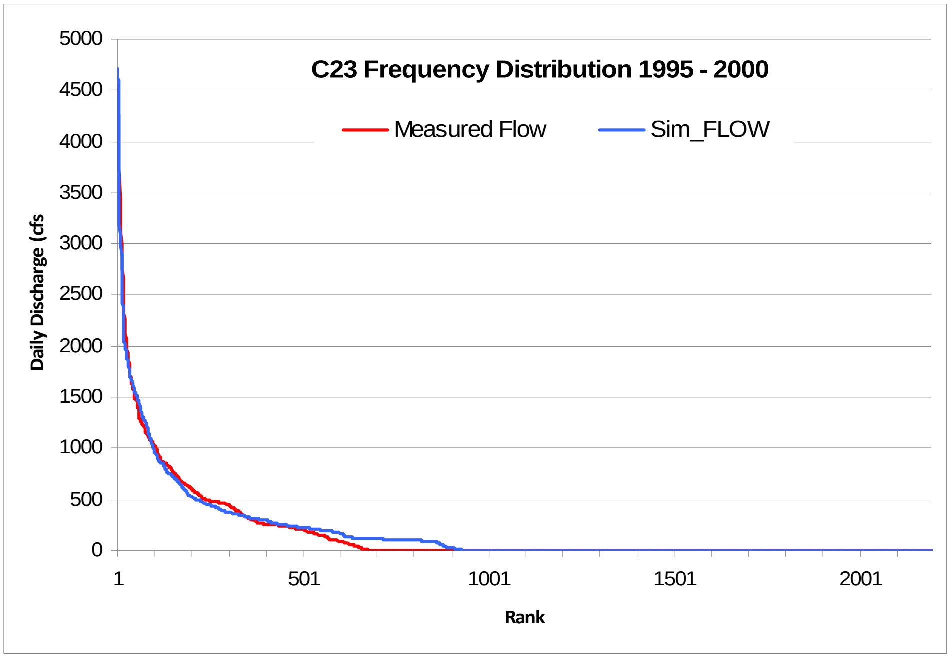

Figure 2.5. C-24 Daily Average Flow Frequency During Calibration Period 1995-2000.

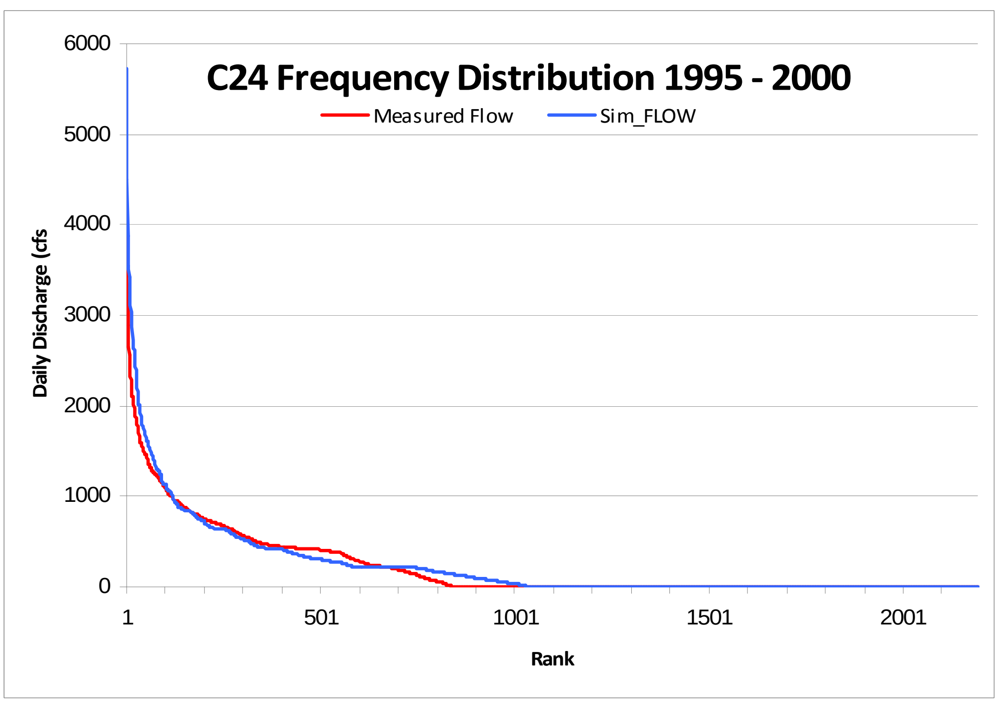

Figure 2.6. C-25 Daily Average Flow Frequency During Calibration Period 2004-2008.

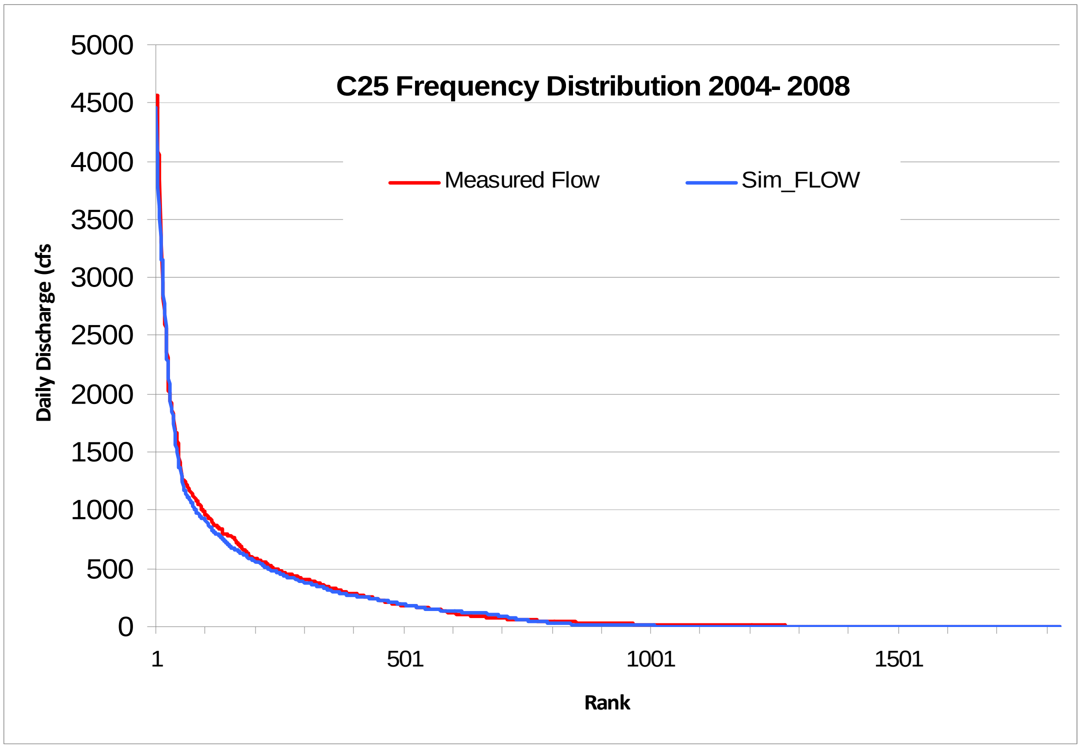

Figure 2.7. C-23 Annual Flow During Calibration Period 1995-2000.

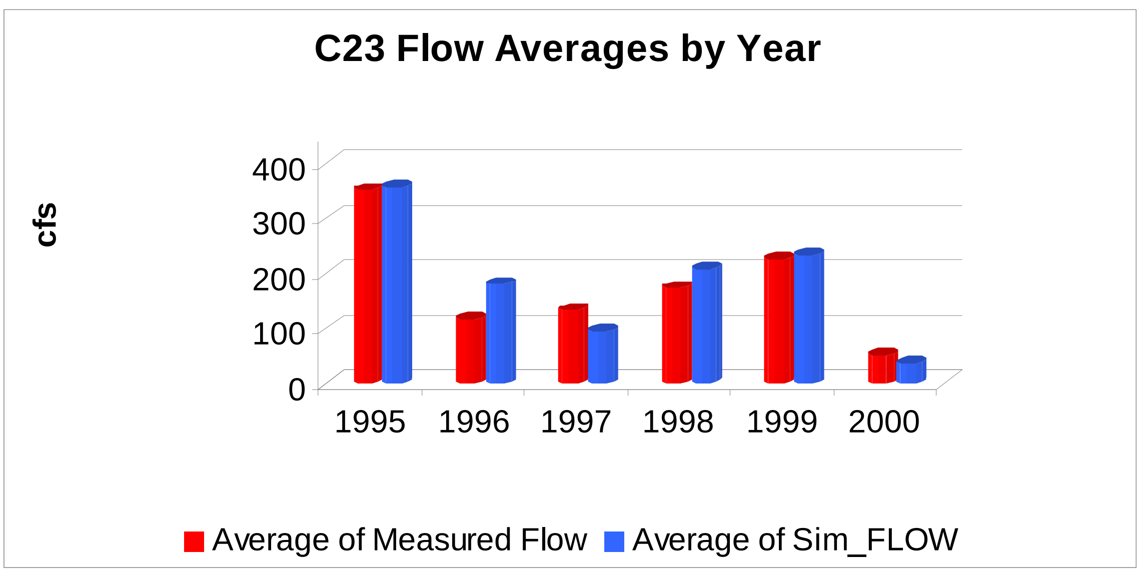

Figure 2.8. C-24 Annual Flow During Calibration Period 1995-2000.

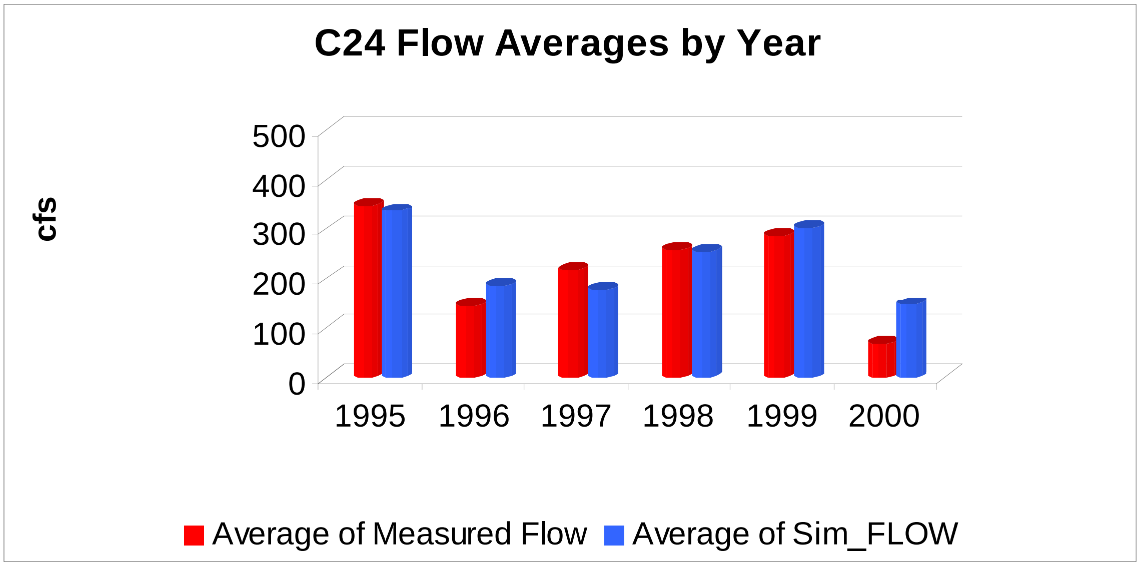

Figure 2.9. C-25 Annual Flow During Calibration Period 2004-2008.

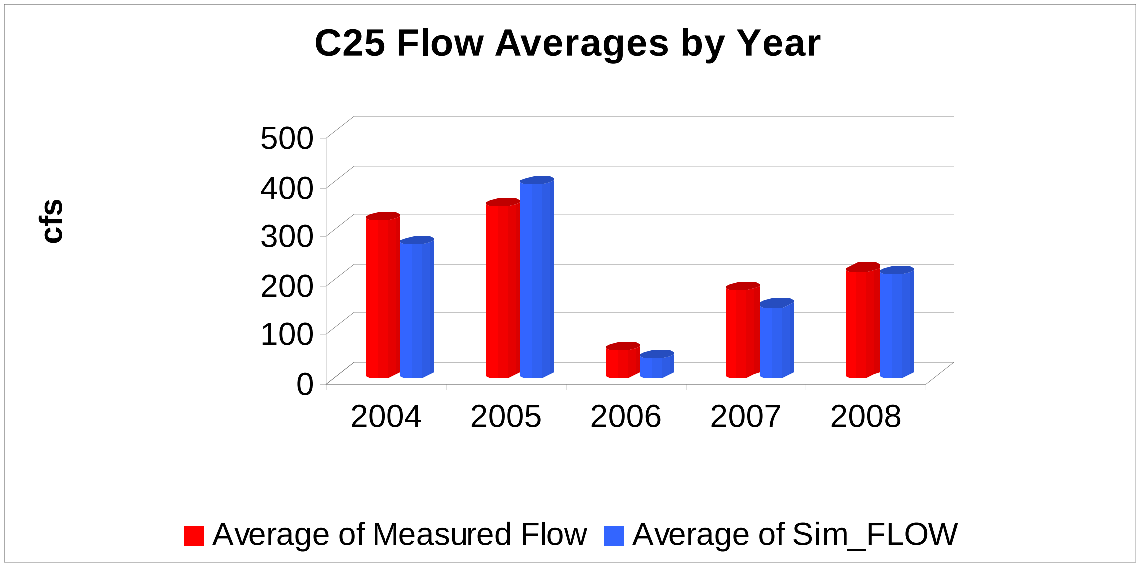

Figure 2.10. C-23 Monthly Average Flow During Calibration Period 1995-2000.

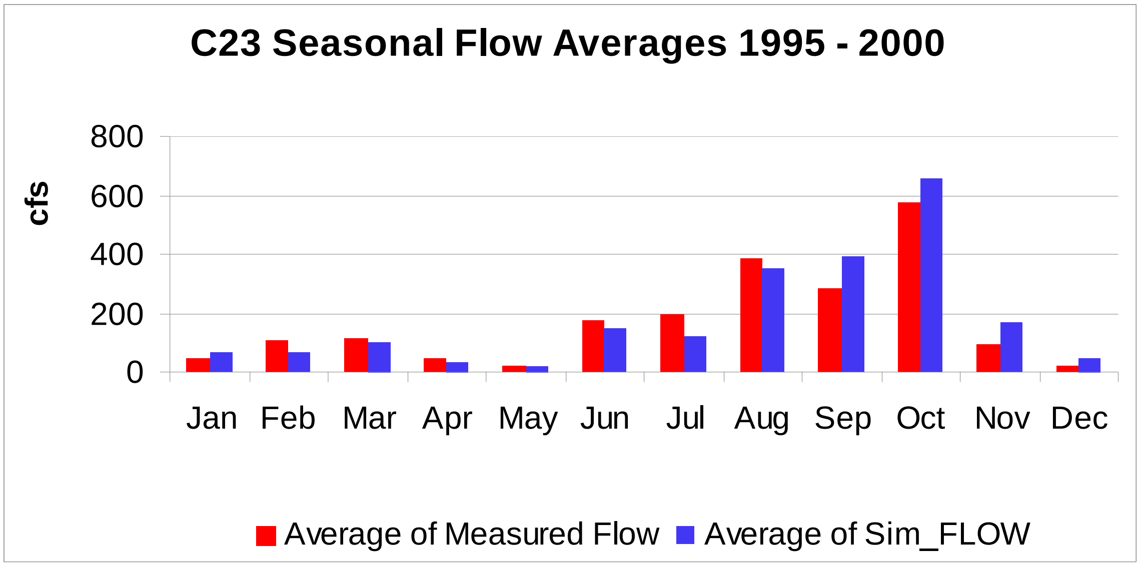

Figure 2.11. C-24 Monthly Average Flow During Calibration Period 1995-2000.

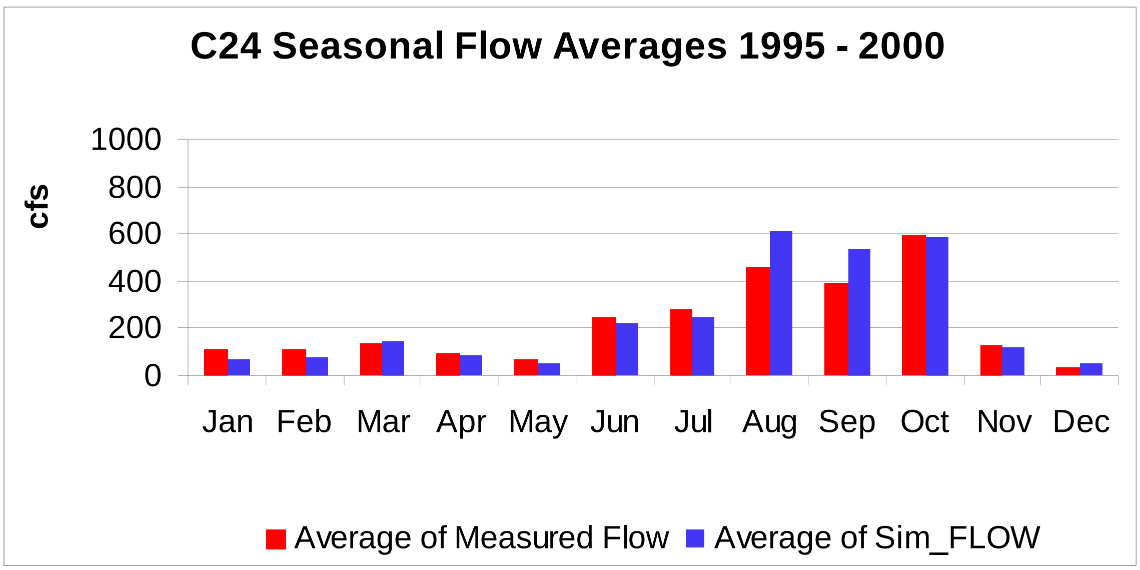

Figure 2.12. C-25 Monthly Average Flow During Calibration Period 2004-2008.

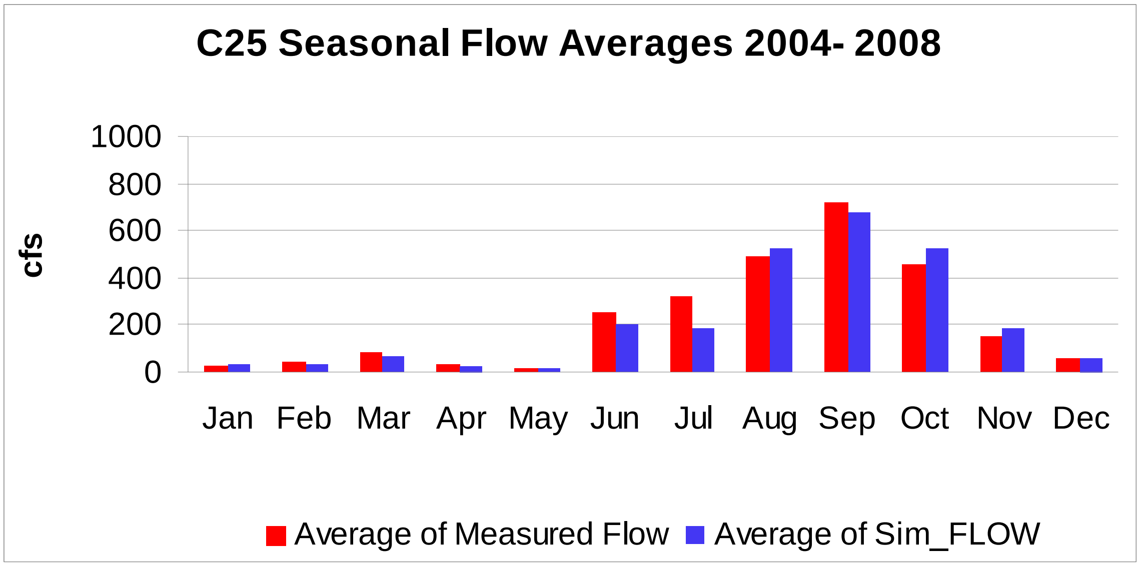

Figure 2.13. C-23 Cumulative Daily Flow During Calibration Period 1995-2000.

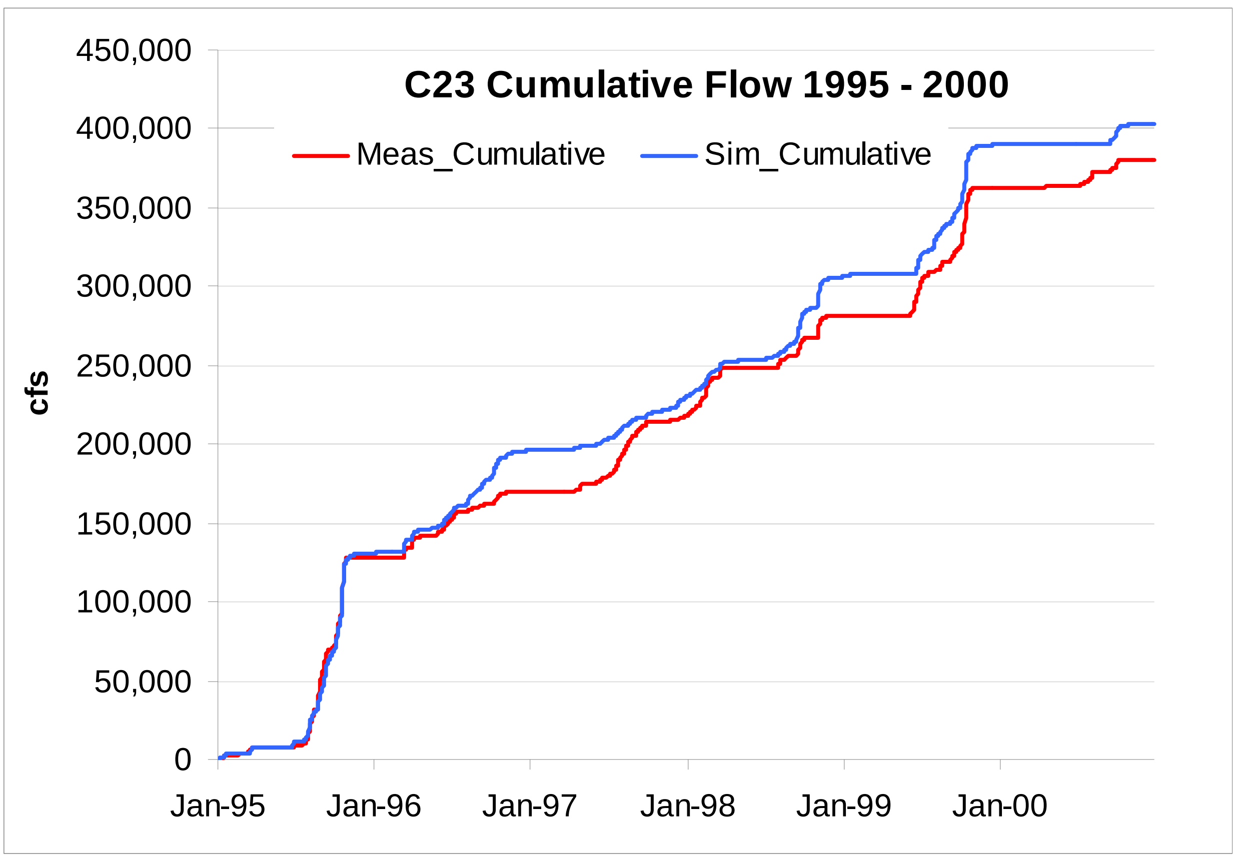

Figure 2.14. C-24 Cumulative Daily Flow During Calibration Period 1995-2000.

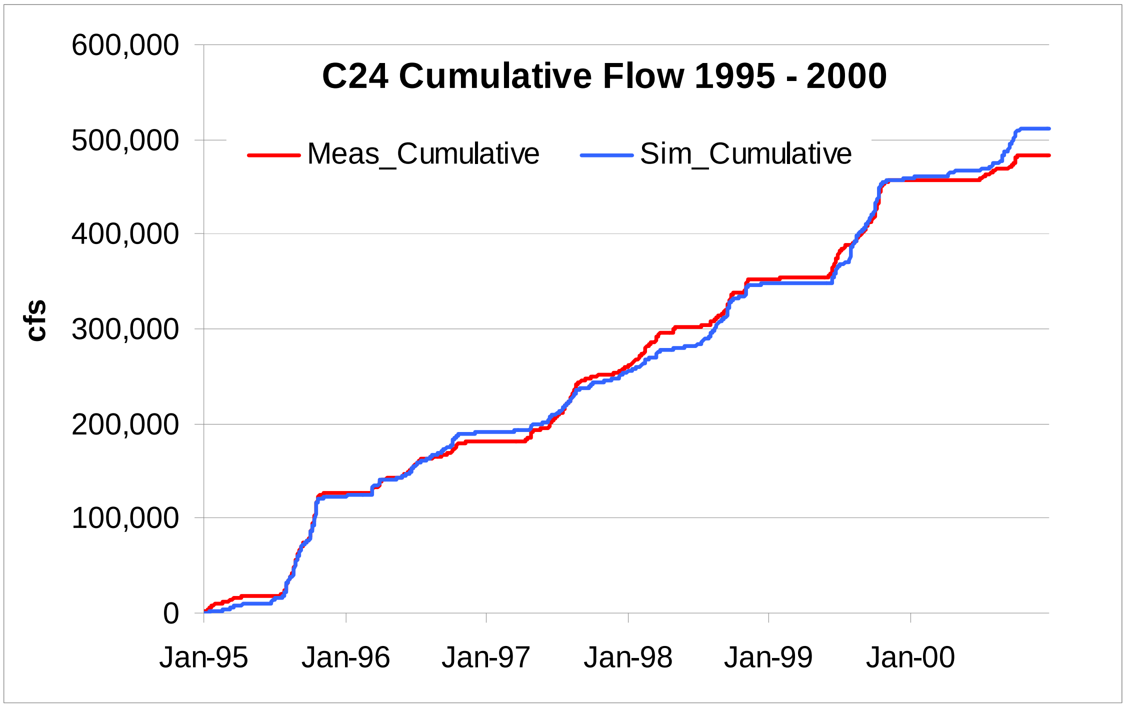

Figure 2.15. C-25 Cumulative Daily Flow During Calibration Period 2004-2008.

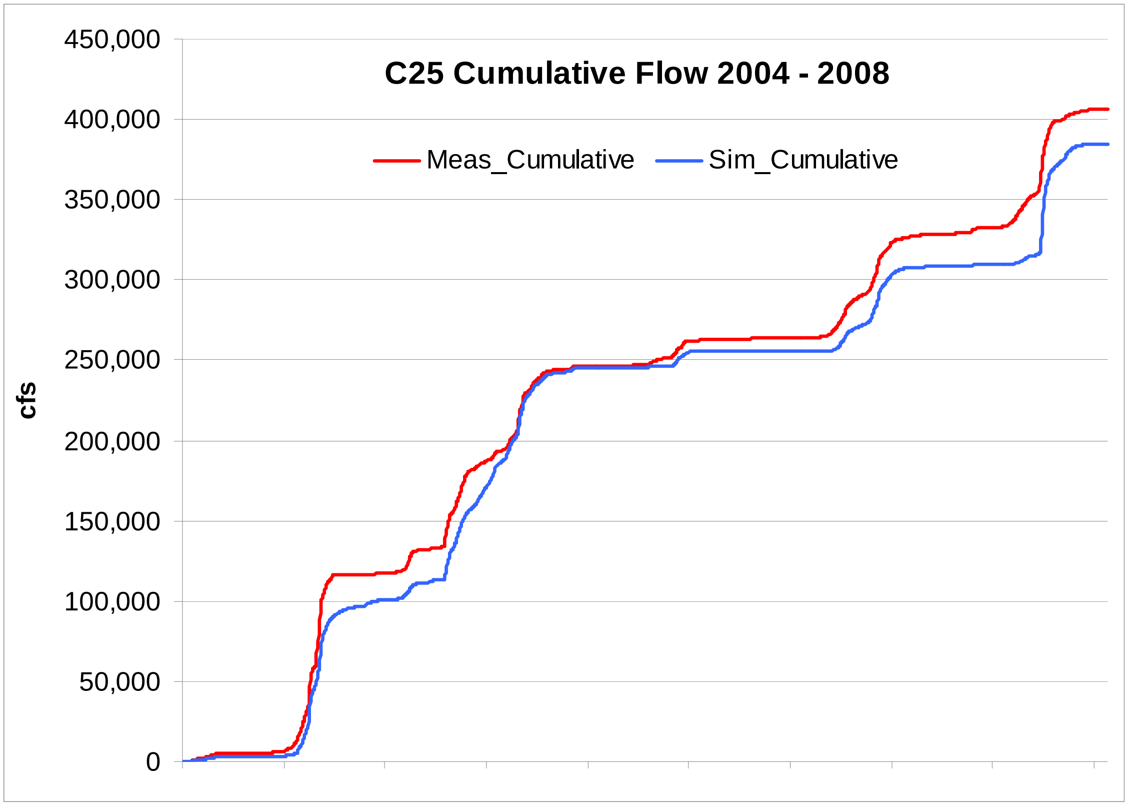

Figure 2.16. C-23 Daily Average Flow During Validation Period 2001-2005.

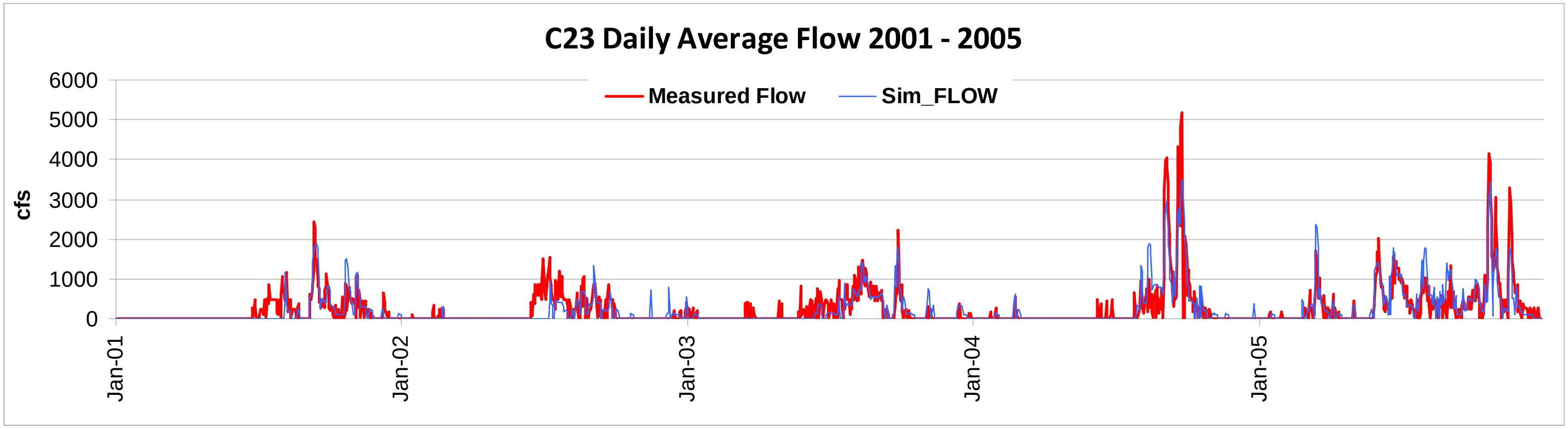

Figure 2.17. C-24 Daily Average Flow During Validation Period 2001-2005.

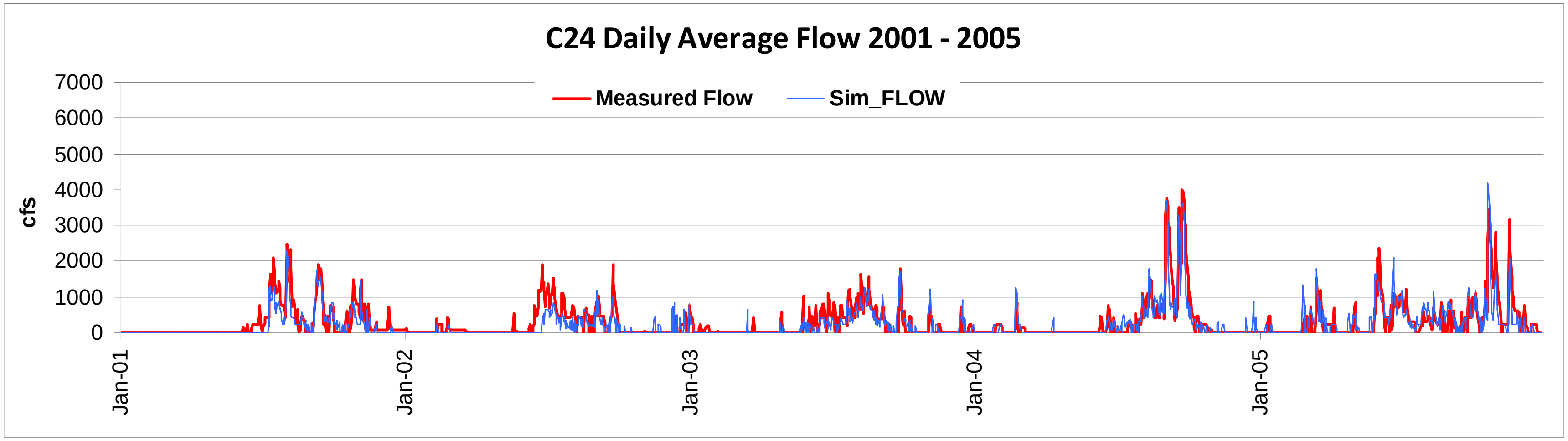

Figure 2.18. C-25 Daily Average Flow During Validation Period 2001-2005.

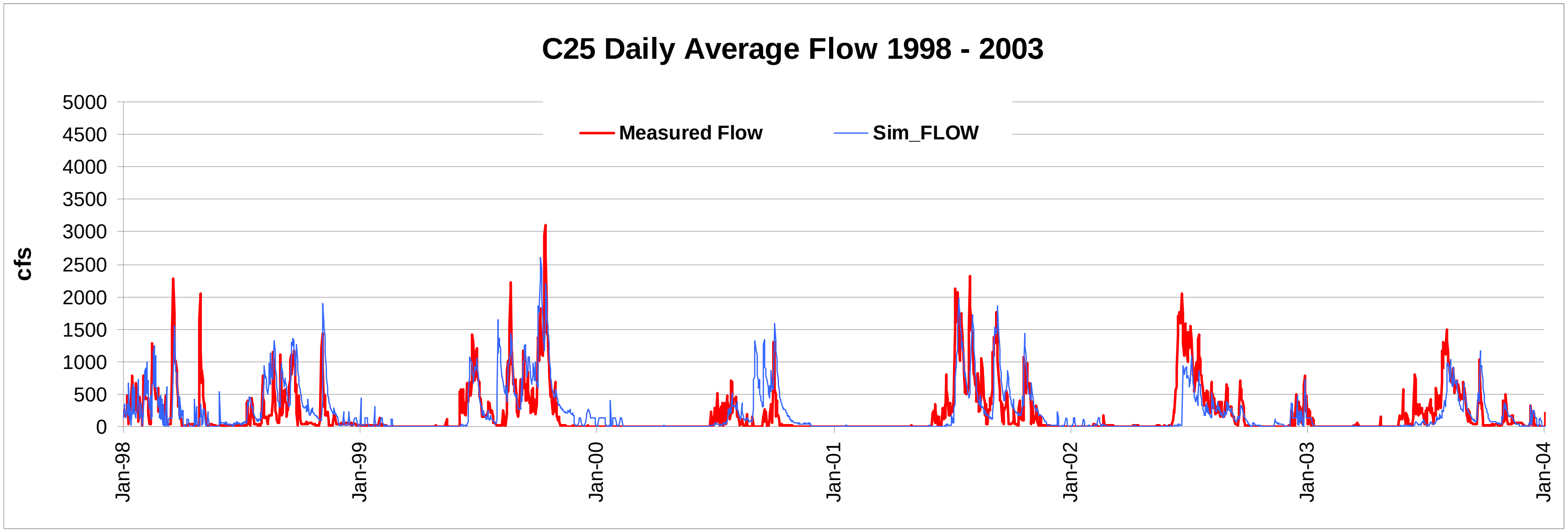

Figure 2.19. C-23 Daily Average Flow Frequency During Validation Period 2001-2005.

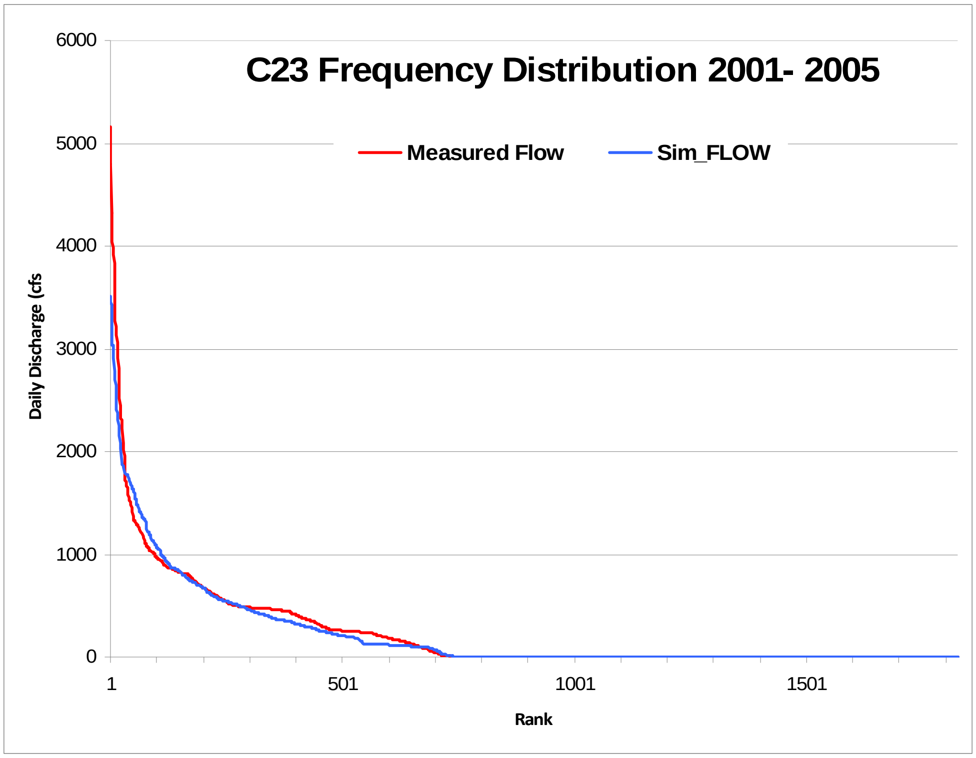

Figure 2.20. C-24 Daily Average Flow Frequency During Validation Period 2001-2005.

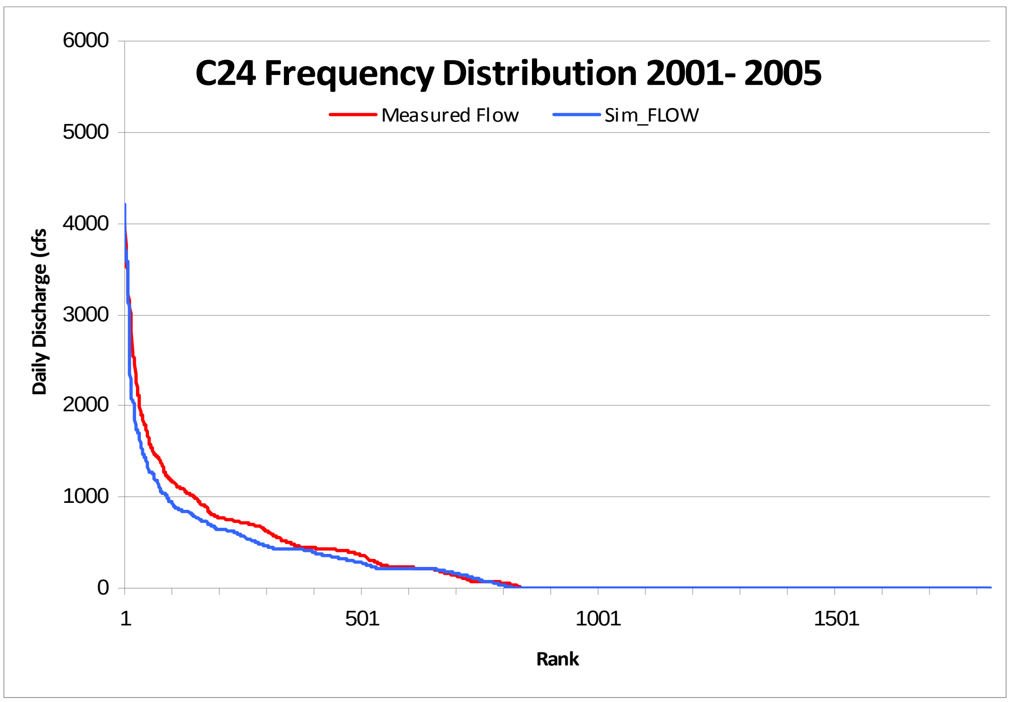

Figure 2.21. C-25 Daily Average Flow Frequency During Validation Period 1998-2003.

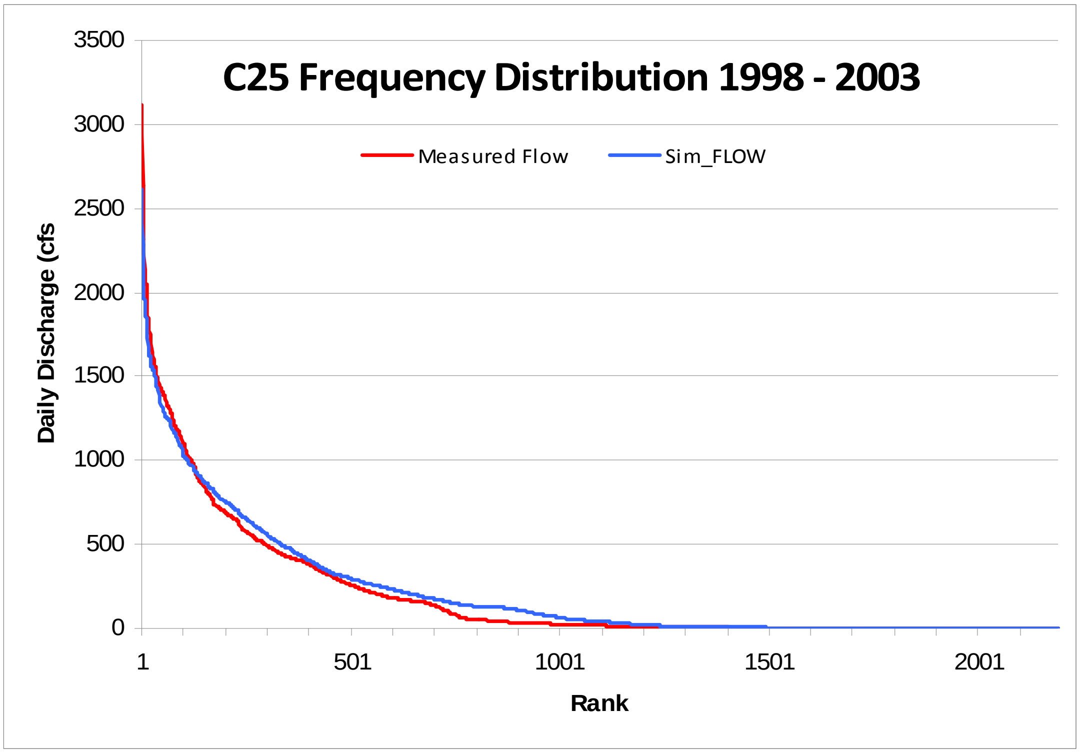

Figure 2.22. C-23 Annual Average Flow During Validation Period 2001-2005.

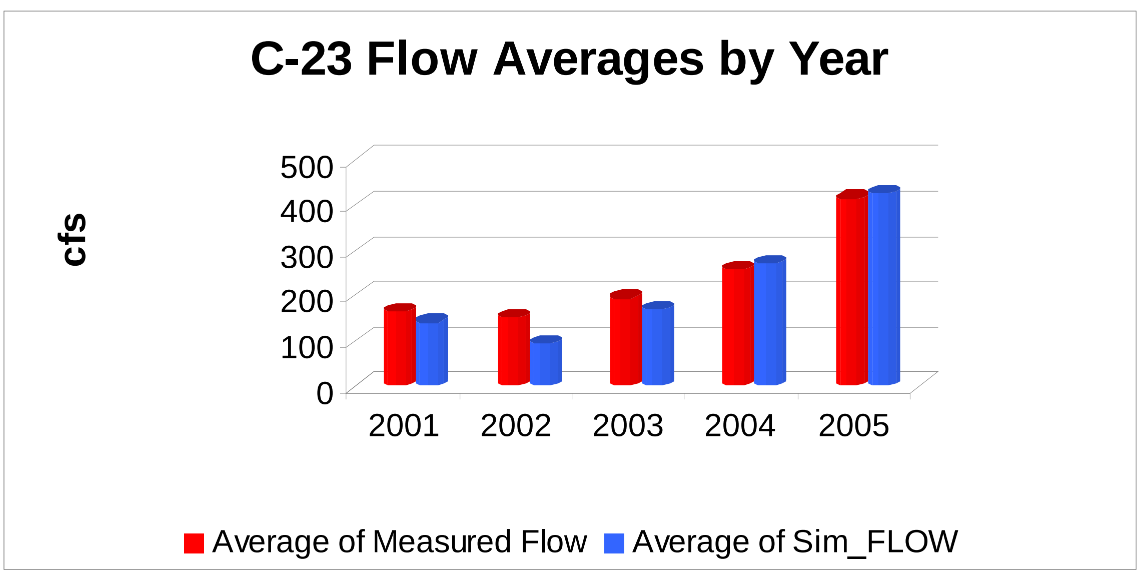

Figure 2.23. C-24 Annual Average Flow During Validation Period 2001-2005.

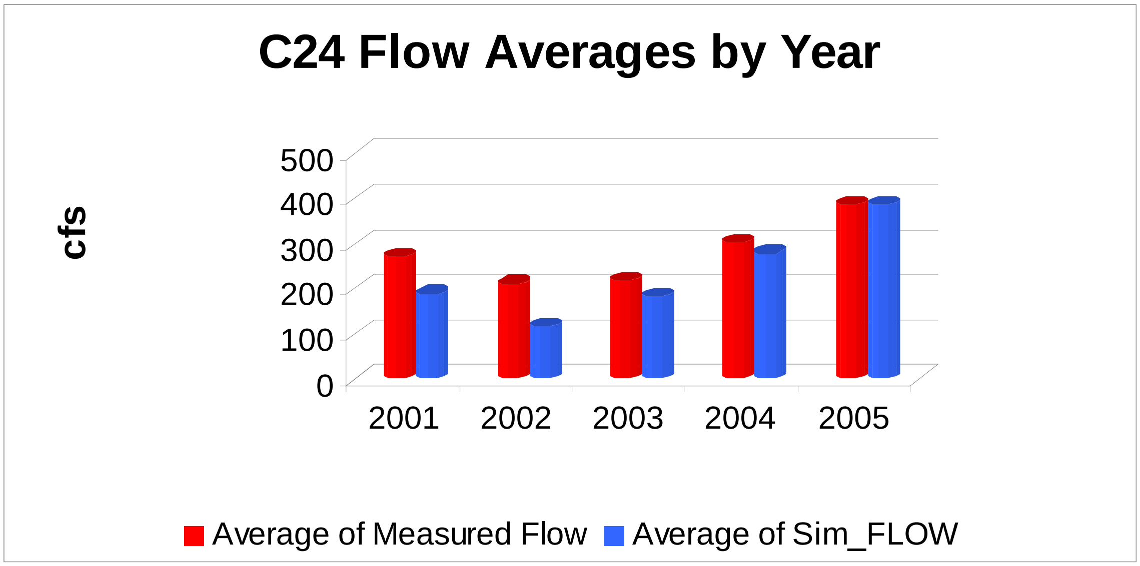

Figure 2.24. C-25 Annual Average Flow During Validation Period 1998-2003.

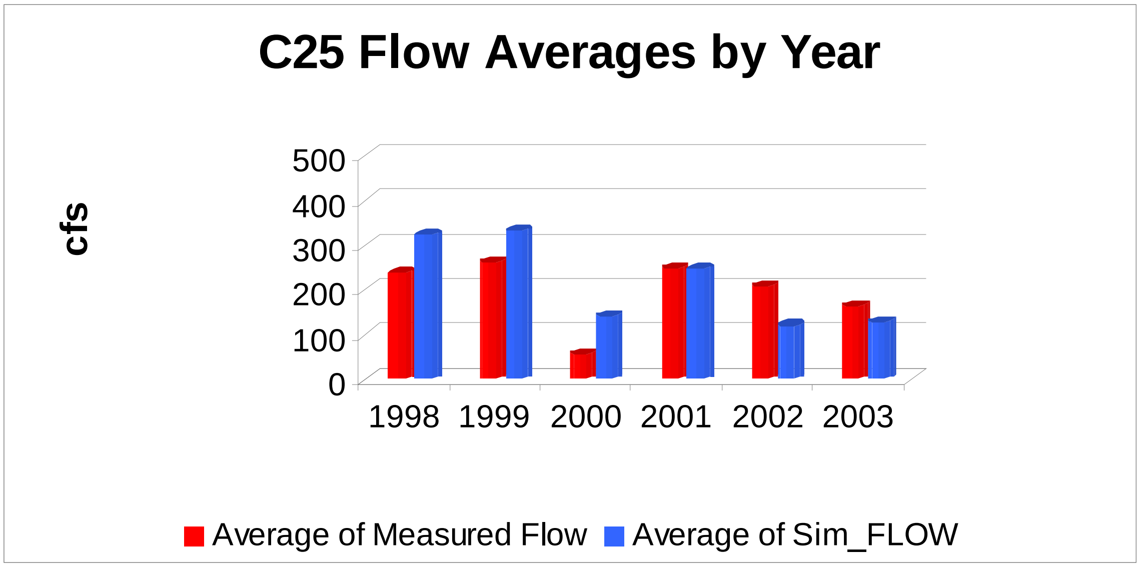

Figure 2.25. C-23 Monthly Average Flow During Validation Period 2001-2005.

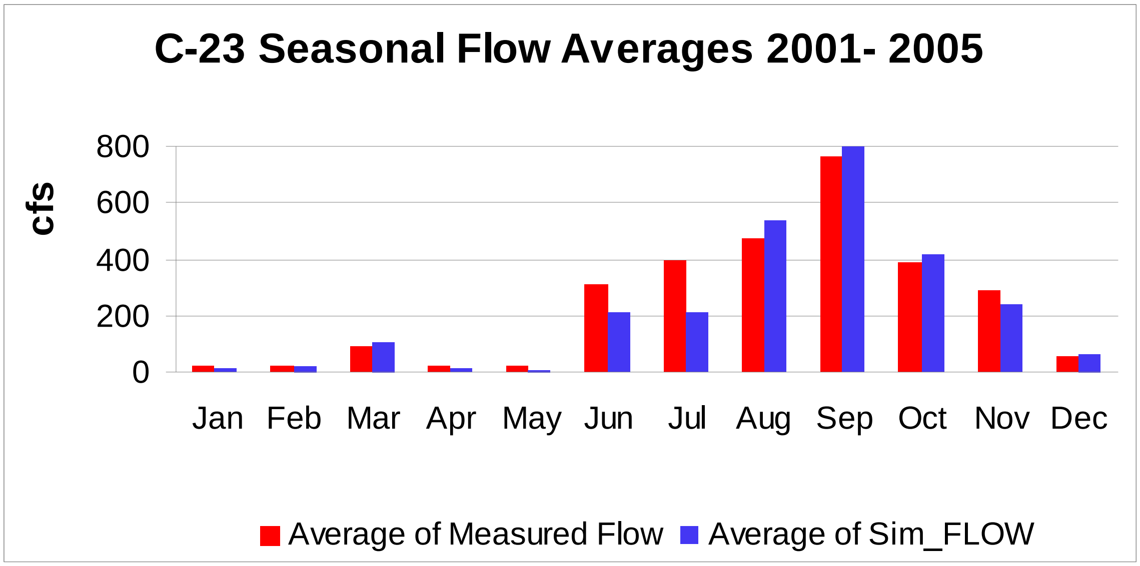

Figure 2.26. C-24 Monthly Average Flow During Validation Period 2001-2005.

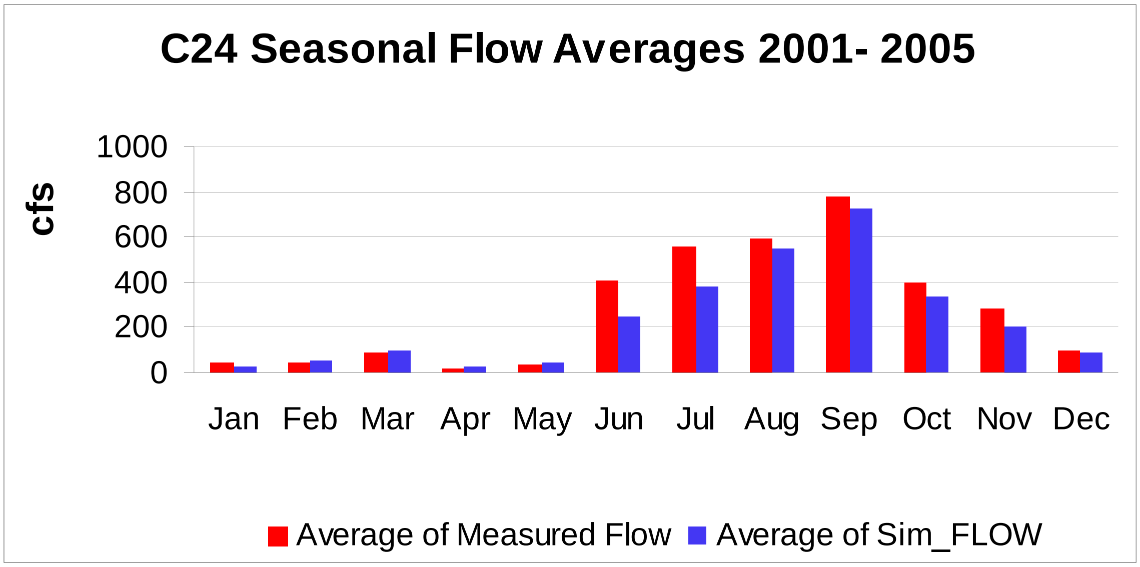

Figure 2.27. C-25 Monthly Average Flow During Validation Period 1998-2003.

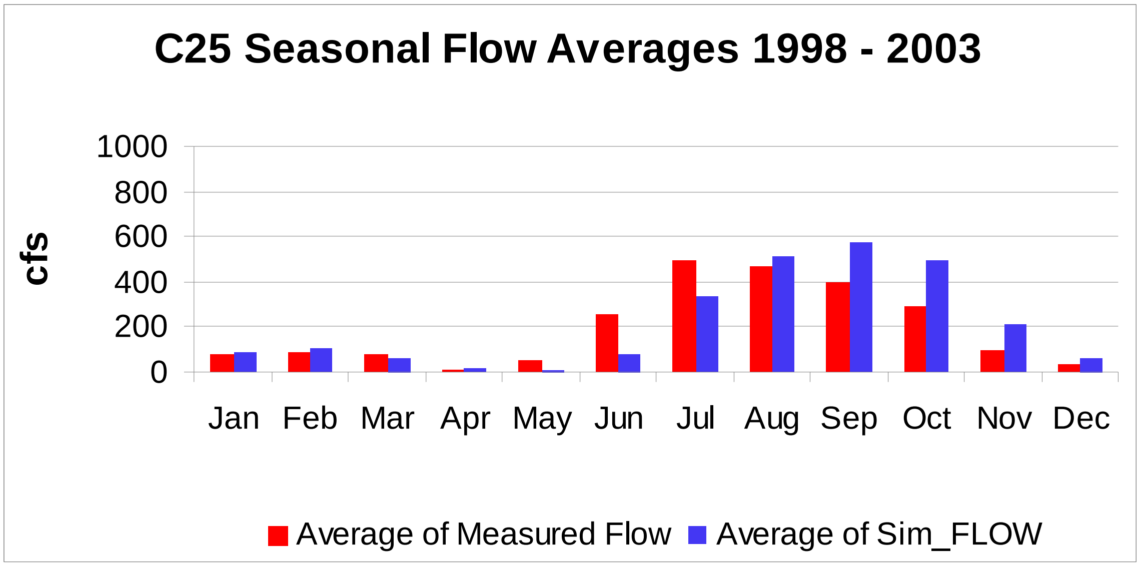

Figure 2.28. C-23 Cumulative Flow During Validation Period 2001-2005.

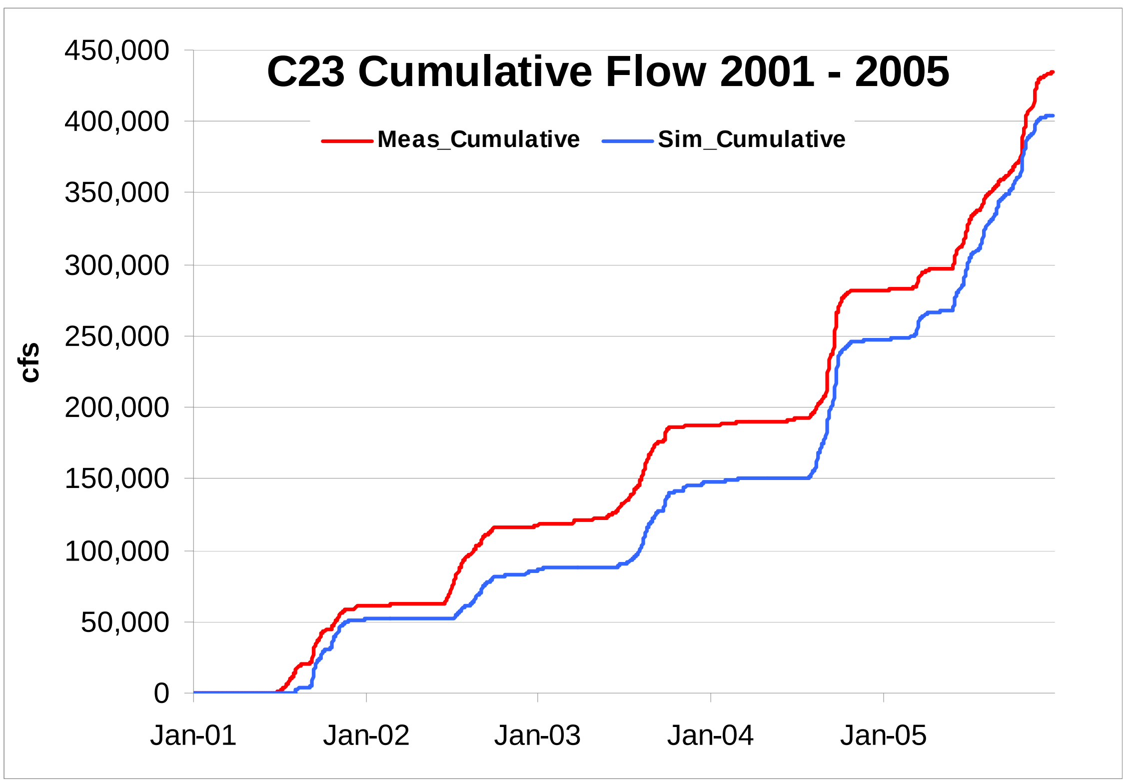

Figure 2.29. C-24 Cumulative Flow During Validation Period 2001-2005.

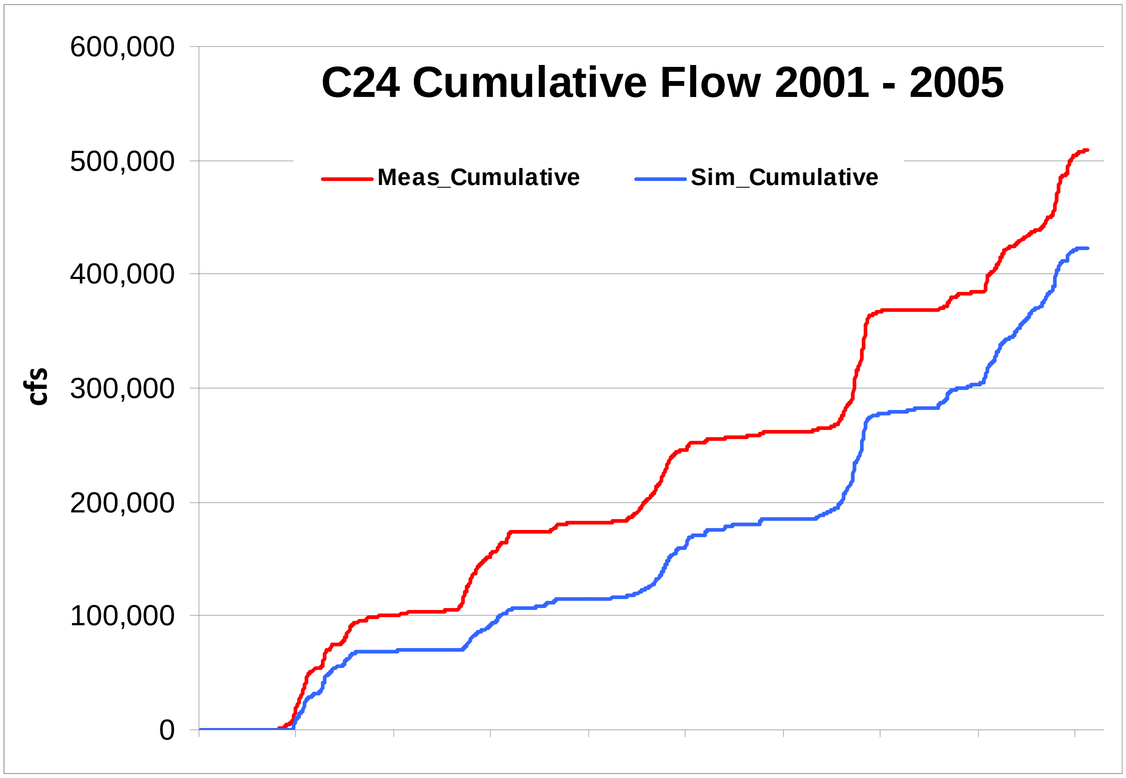

Figure 2.30. C-25 Cumulative Flow During Validation Period 1998-2003.

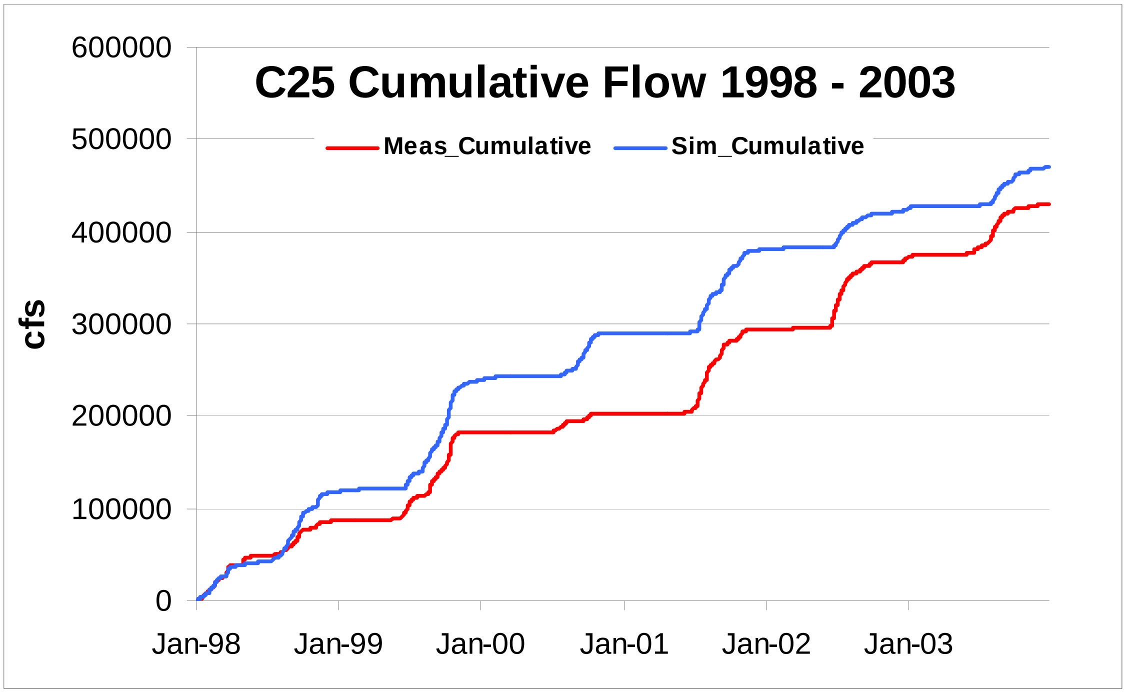

Figure 2.31. Observed and Simulated Upstream Stage at S-253.

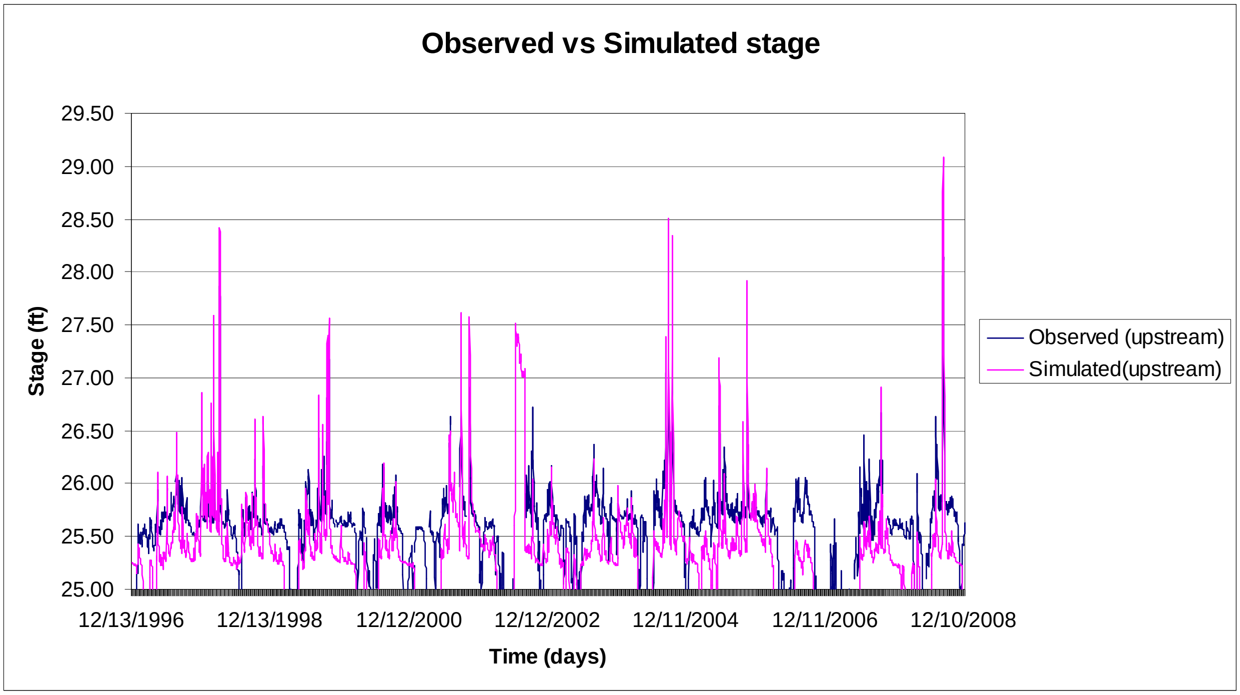

Figure 2.32. Simulated and Observed Flows at S-253 and S-50 During 2004.

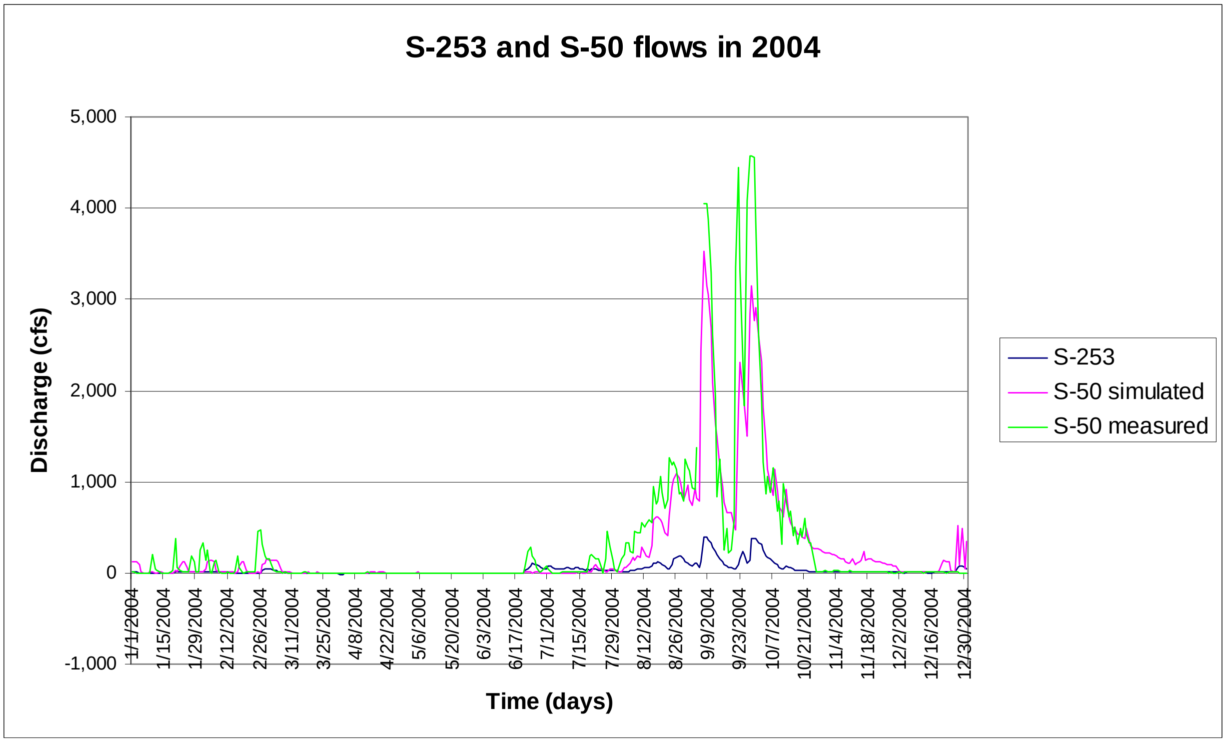

Figure 2.33. Simulated and Observed Flows at S-253 and S-50 During 2008.