Generalized Delta Conservative Constituent Modeling using Artificial Neural Networks

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ACRONYMS

ANN Artificial Neural Network

CAL Calaveras

CCF Clifton Court Forebay

CCWD Contra Costa Water District

DCC Delta Cross Channel

DICU Delta Island Consumptive Use

DOC Dissolved Organic Carbon

DSM2 Delta Simulation Model II

EC Electric Conductivity

HOR Head of Old River

LM Levenberg-Marquardt

MLP Multi-layer Perceptron

MOK Mokelumne

MTZ Martinez

NBA North Bay Aqueduct

SAC Sacramento

SCG Scale Conjugated Gradient

SJR San Joaquin River

Yolo Yolo Bypass

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EXECUTIVE SUMMARY

The modeling of water quality in the Delta, for conservative and non-conservative constituents, has been performed extensively using the Delta Simulation Model (DSM2). The DSM2 model represents the mixing of freshwater and saltwater flows, and exchanges across islands, through the complex channel network in the Delta. Using a set of boundary flows and concentrations, DSM2 can compute the resulting concentrations across space and time within the Delta. Sometimes, however, the modeling has a different goal: Given a location in the Delta with concentration data, we need to know the relative contribution of the different boundary flows to that location, termed “fingerprinting.” The fingerprints of different flows, multiplied by constituent concentrations in those flows, can also be used to compute in-Delta water quality. The water quality calculation works best for conservative, non-reactive constituents, such as major cations and anions. While the DSM2 fingerprinting approach is a stable tool and has been in existence for more than a decade, it requires a fairly high level of user expertise to run, limiting its application among the larger community of individuals concerned with water quality management in the Delta.

The goal of this work was the development of an easy-to-use tool that could relate the input flows to the Delta to volumetric contributions at in-Delta locations, with the ability to then incorporate the boundary concentrations to compute in-Delta concentrations. This was done using Artificial Neural Networks (ANNs), an empirical modeling approach that has had success representing complex functions, including some prior applications in the Delta.

In this work, the Delta Simulation Model (DSM2) was first used to simulate volumetric contributions from boundary sources to given locations in the Delta. These results form the targets to which the ANNs were trained to. A total of 10 scenarios with different combination of exports, operation of agricultural barriers and DCC gates were simulated. The DSM2 model was run for a period of 19.6 years from 1990–2010.

ANN were trained using input flows and gate conditions to reproduce the volumetric contribution of individual flows. The ANN models were trained for 17 pre-specified locations within the Delta.

The ANN fitted and DSM2 simulated volumetric contributions over time were compared through time series plots and scatter plots. The results demonstrate a relatively good fit of ANN models to the DSM2 results (correlation coefficient, $r > 0.90$).

The use of trained ANN models to predict EC, bromide, and DOC at Delta locations also showed very good fits, and the ANN tool offers promise as an emulator of the DSM2 model that is accessible with considerably less user expertise and learning time than required to run the DSM2 model. Therefore, the ANN can be considered as a substitute for DSM2 for many situations where the operation of the full DSM2 model is not suitable, such as for use by non-modelers for exploring scenarios, or when multiple runs need to be performed to rapidly evaluate different inflow conditions, or as a precursor to performing more detailed DSM2 runs.

1 INTRODUCTION

Simulations of dissolved and conservative constituents such as electrical conductivity (EC), individual cations and anions, and dissolved organic carbon (DOC) are important for the purpose of managing water quality in the Delta, and are tied to one or more beneficial uses for Delta waters. The modeling of water quality in the Delta, for conservative and non-conservative constituents, has been performed extensively using the Delta Simulation Model (DSM2). The DSM2 model represents the mixing of freshwater and saltwater flows, and exchanges across islands, through the complex channel network in the Delta. Using a set of boundary flows and concentrations, DSM2 can compute the resulting concentrations across space and time within the Delta. Sometimes, however, the modeling has a different goal: Given a location in the Delta, we need to know the relative contribution of the different boundary flows to that location, termed “fingerprinting.” A representation of the fingerprinting concept is shown in Figure 1-1, where the resulting concentration at a receptor or output location is shown as a mix of inputs from multiple sources.

Because the channel paths in the Delta are complex and water residence times highly variable, attribution of a water quality constituent at a given receptor location, say a pumping station for an aqueduct, to a specific source or boundary is challenging. To address this need an additional DSM2 module has been developed that allows for fingerprinting of individual sources across the Delta (Anderson, 2002). The fingerprint module allows for estimation of the volumetric contribution by source, and when coupled with boundary concentration values—and assuming that the constituent in conservative, or can approximately be considered conservative—be used to relate the constituent contribution by source. Typical uses of the fingerprint model, for example, might be to estimate the contribution of San Francisco Bay inputs of salinity to the Clifton Court pumping intake, or the contribution of organic carbon from agricultural return flows in the Delta to locations of drinking water quality interest. The assumption behind the fingerprint calculation in DSM2, when used for calculating the concentration of a constituent, is that it is conservative and does not change during transport as a result of any reactions (such as decomposition, volatilization, or other transformation). Theoretically, the approach is applicable for electrical conductivity and many major cations and anions, such a Na, Ca, or Cl, and approximately valid for a constituent such as dissolved organic carbon (DOC), which can be assumed to be minimally reactive.

The fingerprint concept can also be stated mathematically. At any given location in the Delta, the water volume will be a mixture of contributions from the boundary flows. The contributions may be from the current time step and/or from previous time steps. The constituent concentrations can be calculated at each Delta location as the sum of the products of volumetric contributions and boundary concentrations as defined in the equation below:

$$C_j = \sum_t \sum_i V_{it} * BC_{it} \ \forall j \ (1)$$

$$\sum_t \sum_i V_{it} = 1$$

C_j = constituent concentration at Delta location j

V_i = volumetric contribution from source i (i.e. fingerprint) provided by ANN models

BC_i = water quality boundary condition at source i

t = lag index

This allows a fingerprint model to be used to simulate conservative constituent transport through the Delta.

The purpose of this work was to develop a general numeric model that can emulate the functionality of the DSM2 fingerprint model. The model approach described here uses the artificial neural network (ANN) methodology trained using DSM2 simulation data. The ANN approach was identified because of its success in emulating the complex processes in the Delta for salinity and turbidity (Finch and Sandhu, 1995; Sandhu et al., 1999; Seneviratne et al., 2008; Chen and Roy, 2014), as well as the extensive body of literature demonstrating its use in similar water resources applications, with complex, non-linear relationships between inputs and outputs (Maier et al., 2010; Wu et al., 2014). The primary benefit of the use of an ANN approach is the development of a fingerprint response that can be operated relatively quickly and with limited user expertise and learning time compared to the operation of the DSM2 model. This allows the emulator to be applied by a wider audience, and can also serve as a test-bed prior to detailed DSM2 simulations being performed. Other benefits include improved understanding of the influence of hydrologic conditions on salinity constituent relationships; improved methodologies for developing long-term planning tools; and the ability to quickly fit model results to water quality observation by manipulating assumed boundary conditions.

Figure 1-1 Conceptual representation of fingerprinting of chemical constituents in the Delta. In a fingerprint estimate, the goal is to find out the contribution of individual sources at an output location.

An ANN basically consists of a set of nodes, in one or more layers, that connect various input and outputs using mathematical functions. At its most general, ANNs can be used to approximate any general function (Bishop, 1995), and were thus considered for use in this work. Given a set of inputs and outputs, the parameters associated with the ANN nodes (termed weights and biases) are fitted using an error minimization function. In the ANN literature, this is called "training" and is analogous to model calibration by adjusting parameters as commonly done in water resources modeling.

In this work, for emulating the Delta fingerprinting model by DSM2, the inputs were the time series of daily flows at the different boundaries as well as the status of various gates in the Delta channels. The outputs were the DSM2-calculated monthly volumetric fingerprint for each input at various pre-specified locations. The task of ANN training was to define a reasonable network structure (number of nodes in the hidden layer) and the best fit weights and biases, such that the inputs when passed through the ANN emulated the output volumetric concentrations obtained from DSM2. The specific inputs that were used are as follows:

- Delta Inflows
    - Sacramento River flow at Freeport
    - San Joaquin River flow at Vernalis

  - Mokelumne River flow at Benson's Ferry
  - Cosumnes River flow
  - Calaveras River flow
  - Yolo Bypass flow
- Delta agricultural return flow
- Martinez tide (stage)
- Delta Gate & Barrier Operations
  - Grant Line Canal temporary barrier
  - Middle River temporary barrier
  - Old River at Tracy temporary barrier
  - Head of Old River temporary barrier
  - Delta Cross Channel (DCC) gate
- Delta combined exports

The specific output locations for which ANNs were trained are shown in Figure 1-2 and discussed in more detail in Chapter 2.

The inputs and outputs were selected based on an identification of the major drivers of Delta hydrodynamics. ANNs for all output locations were given the same inputs, with the expectation that the training would filter out the most important contributors to volumetric fingerprint at each location.

The ANN training process is shown schematically in Figure 1-3. First, a set of hydrologic conditions were defined and the DSM2 model was run using these inputs to produce the values of volumetric fingerprints at the locations shown in Figure 1-2. This is represented in the left limb of the schematic diagram in Figure 1-3. The same hydrologic inputs were given to an ANN and the training performed to match the DSM2 output data. Multiple ANNs were used to represent each station and the volumetric fingerprint associated with each of the major sources. This is shown on the right limb of Figure 1-3. The training process resulted in a set of ANNs that emulated the response at the seventeen pre-defined locations. The ANN part of this work was focused only on estimating the volumetric fingerprint. Once estimated, the volumetric fingerprint was associated with the constituent concentrations at the boundaries, through a matrix multiplication as represented in Equation 1, to calculate the resulting concentrations at the output locations.

The remainder of this report describes the approach used for developing the ANNs in greater detail (Chapter 2), the results from the trained ANNs (Chapter 3), and a summary of the key findings of this approach (Chapter 4). The data set associated with this effort is large, and to be efficient, key information is presented in tables in the main body of the report, with supporting plots presented in Appendices A through D.

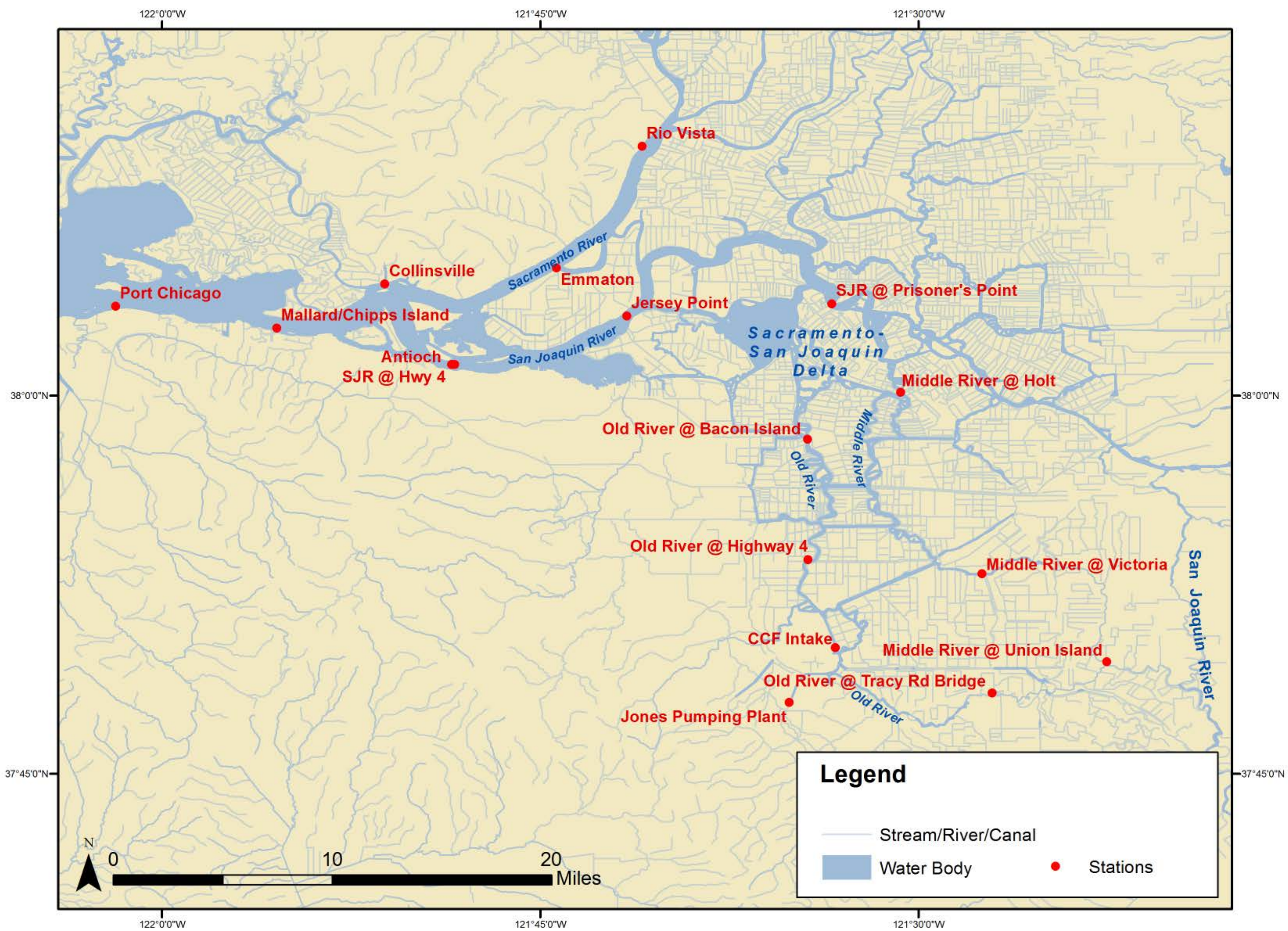


Figure 1-2 Output locations used for training the ANN models.

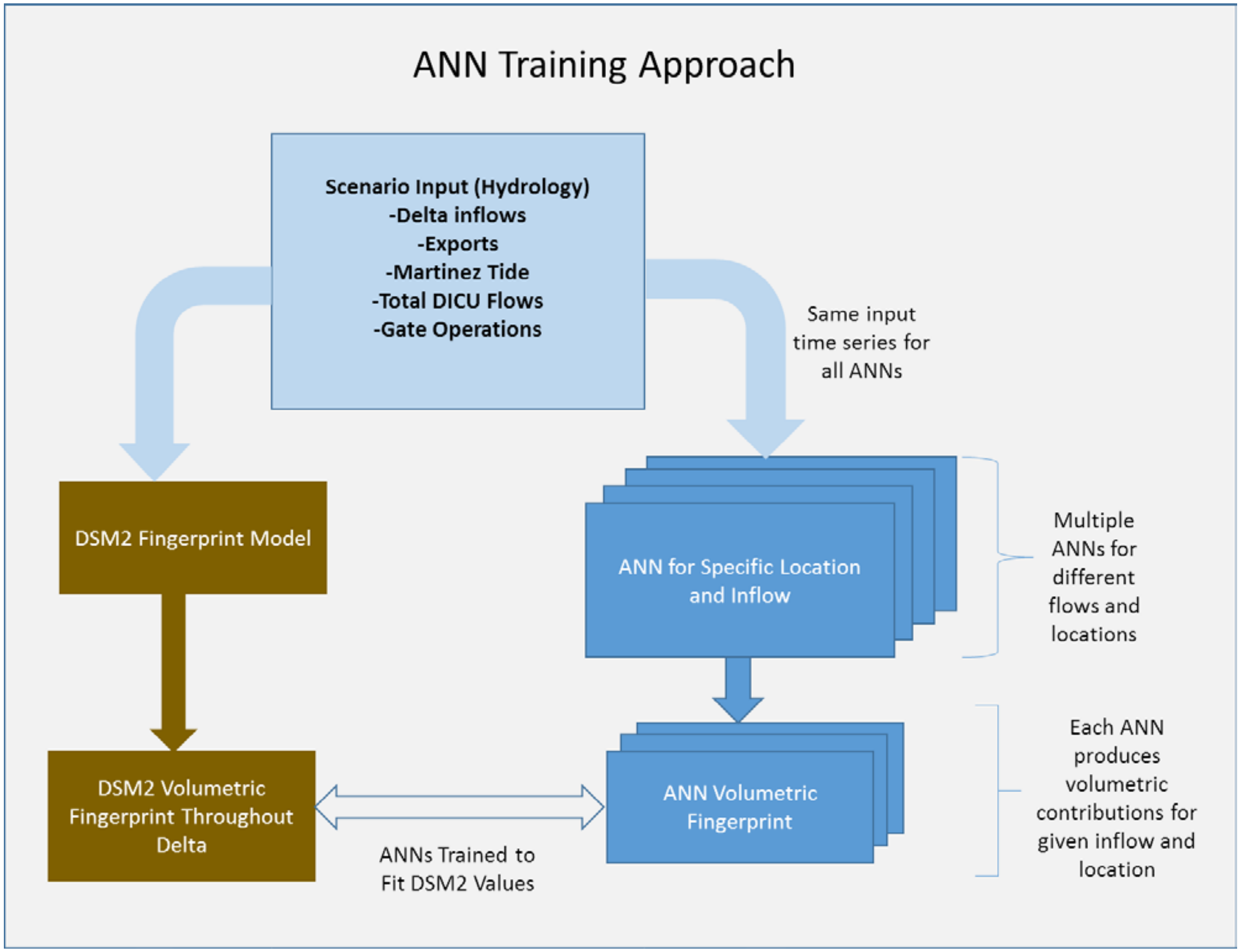


Figure 1-3 Approach used for training the ANN models using outputs from DSM2.

2 APPROACH

2.1 OVERALL APPROACH

The goal of this work was to develop numeric models that predict concentrations of any conservative constituent within the Delta using the concept of volumetric fingerprinting. A set of DSM2 studies, with a range of gate conditions and with Delta water exports included or excluded, were developed to represent the volumetric fingerprint of the boundary flows. The volumetric fingerprint results at selected locations were then associated to the inputs and gate conditions using a set of ANNs. The trained ANNs are basically an empirical representation of the underlying hydrodynamics of the DSM2 model. In order to predict concentrations of any conservative constituent, the ANN models can be used to estimate the volumetric fingerprint of individual sources, and by multiplying with the corresponding concentrations at these sources, they may be used to compute the concentrations of conservative constituents at selected output locations. Importantly, the volumetric contribution of all sources is time-varying, as is the boundary concentration. The concentration calculation needs to take into account the time-stamp associated with the volumetric fingerprint. Below we describe the steps used in this work, including the DSM2 fingerprinting runs performed and ANN training approach.

2.2 DSM2 FINGERPRINTING RUNS

The first step in this work, prior to the development of ANNs, was the creation of a set of DSM2 studies using reasonable boundary inputs that would provide a data set of volumetric contribution over time at multiple output locations across the Delta. The specific conditions used for these DSM2 runs are described below.

2.2.1 DSM2 MODEL AND FINGERPRINTING METHODOLOGY

The DSM2 is a one-dimensional mathematical model that simulates hydrodynamics, water quality and particle tracking in the Sacramento–San Joaquin Delta. Simulated Delta hydrodynamics and water quality conditions have been validated against hydrodynamics and EC data in the Delta, and the model calibration continues to evolve.[1] This work is based on DSM2 model version 8.0.6.

A methodology exists within DSM2, referred to as fingerprinting, that allows for simulation of volumetric contributions from boundary sources for any given location within the Delta (Anderson, 2002; Anderson and Wilde, 2005). When applying the model

[1] Current updates are available at http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm. The most recent version of DSM2 is labeled as 8.1.2.

in the fingerprinting mode, different tracers are associated with the boundary sources. The model calculates the relative volumetric contributions from each source. Ideally, the volumetric contributions to a given location from all sources should all sum up to 100%, although small discrepancies are possible. The DSM2 model can be used to calculate:

- Volumetric fingerprinting – determine the relative contributions of water sources to the volume at any specified location
- Volumetric and timing fingerprinting – in addition to determining the relative contributions of water sources to the volume at any specified location, the time period during which that water entered the system is also recorded.

Because the Delta is a complex system with long residence times due to tidal influences and varying boundary conditions, the residence time of constituents in the Delta could be up to six months. Flow from a certain boundary six months ago could still contribute to concentrations at locations in the Delta at a point in time. For this application, volumetric fingerprinting with time within DSM2 was used.

When applying the DSM2 model using fingerprinting with time, concentrations of a conservative constituent can be estimated by summing the volume of each source for each time period multiplied by concentrations of the constituent associated with that source for that time period.

$$C_{cc}(t) = \sum_{i=1}^{n} \sum_{j=0}^{m} \frac{V\%_{i,-j}}{100} C_{i,-j} \quad (2)$$

Where,

$C_{cc}(t)$ = concentration of a conservative water quality constituent at a specified location and time,

$C_{i,-j}$ = concentration of a conservative water quality constituent from source i at time –j (predicted by the DSM2 model),

n = total number of sources,

m = length of the system memory (assumed to be up to 6 months), and

$V\%_{i,-j}$ = percent volume at a specified location from source i at time –j.

Note that once the volumetric contribution from different inflows has been obtained from DSM2, for each defined output location, the calculation of concentration is only a matrix multiplication, and does not require the DSM2 water quality model to be run.

2.2.2 Number of Tracers Used

The fingerprinting runs used for ANN training calculate volumetric contributions from six major sources (Sacramento River, San Joaquin River, Mokelumne River, Calaveras River, Martinez and Yolo Bypass) and nine DICU regions. Fingerprinting with time is typically conducted on a monthly basis in DSM2 (Anderson, 2002). Within DSM2, the calculation of volumetric concentration by source is performed by using a tracer. A conservative tracer constituent, identified by a number, is assigned to each source location for each month, and the concentration of this tracer tracked to calculate the volumetric contribution of the corresponding source. Different months are assigned different tracers, even for the same location. The Delta region is considered to have a system memory of six months or less, therefore the contribution of any tracer beyond the previous six months was not considered, and it is assumed that after six months the concentrations of the tracer are diluted to near zero levels. Therefore, in a long-duration run, after the six month period, the numeric tracer for a given location was re-assigned to a new time. Therefore, the same tracer was used for the months of January and July, months of February and August and so on. Using this method, each source location is associated with six tracers, with each tracer associated with two months of the year (January and July, February and August etc.). With a total of 15 source locations (6 major tributaries and 9 DICU regions), a total of 15 x 6 = 90 tracers were used in the DSM2 fingerprinting simulation. The specification of tracers for each source with time is listed in Table 2-1.

Table 2-1
Specified tracers for volume and time fingerprinting in the Delta

Location\time	Jan/July	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
Sacramento River	1	2	3	4	5	6
San Joaquin River	7	8	9	10	11	12
Martinez	13	14	15	16	17	18
Yolo Bypass	19	20	21	22	23	24
Mokelumne River	25	26	27	28	29	30
Calaveras River	31	32	33	34	35	36
DICU Region 1	37	38	39	40	41	42
DICU Region 2	43	44	45	46	47	48
DICU Region 3	49	50	51	52	53	54
DICU Region 4	55	56	57	58	59	60
DICU Region 5	61	62	63	64	65	66
DICU Region 6	67	68	69	70	71	72
DICU Region 7	73	74	75	76	77	78
DICU Region 8	79	80	81	82	83	84
DICU Region 9	85	86	87	88	89	90

2.2.3 -Definition of Nine DICU Regions

The Delta islands and tracts are a source of agricultural return flows with relatively high levels of dissolved constituents, including DOC and EC, and potentially other solutes of general interest in the Delta. This discussion is presented in the context of DOC and EC, constituents with concentrations that have been characterized for Delta islands as part of the normal DSM2 setup, although it should be recognized that the formulation presented here applies to any conservative constituent present in the DICU flows. The ANN formulation allows the assignment of concentrations to nine groups of DSM2 nodes that correspond to inputs developed for the model.

DOC concentrations in the agricultural return flows can be generally characterized in three ranges: 1) low (less than 15 mg/L), 2) mid-range (16 -30 mg/L), and 3) high (> 30 mg/l). These ranges of inputs are associated with different regions. Higher inputs of DOC are generally associated with the Central Delta, and lower DOC inputs are generally associated with southern and northern Delta, with mid-range DOC inputs associated with regions in between. Within DSM2, three sets of DOC values were assigned to the Delta islands (Table 2-2).

Similar to DOC, EC values have been represented by three levels in the agricultural return flows (three regions; Table 2-3; Figure 2-2). The spatial distributions of these three EC regions are different from DOC. High levels of EC in agricultural return flow are found in the southern and western Delta. Low EC values were found in northern Delta. The combination of three DOC regions and three EC regions form a total of nine DICU regions that have a unique combination of DOC and EC concentrations. The possible regions are shown in Table 2-4 as well as in Figure 2-2.

Table 2-2
DOC values from DICU regions in DSM2

DOC regions	Mean (mg/L)	Range (mg/L)	Number of nodes
1	5.4	5.4	97
2	9.3	7.5-12.0	88
3	22.3	15.0-36.0	72

Table 2-3
EC values from DICU regions in DSM2

EC regions	Mean (µS/cm)	Range (µS/cm)	Number of nodes
1	987	720-1350	154
2	1272	950-1900	32
3	571	350-820	71

Table 2-4
Composite regions, consisting of DSM2 nodes, representing different EC and DOC values

Composite region	DOC region	EC region	Count of DSM2 Nodes in this Category
1	1	1	45
2	2	1	65
3	3	1	44
4	1	2	10
5	2	2	11
6	3	2	11
7	1	3	42
8	2	3	12
9	3	3	17

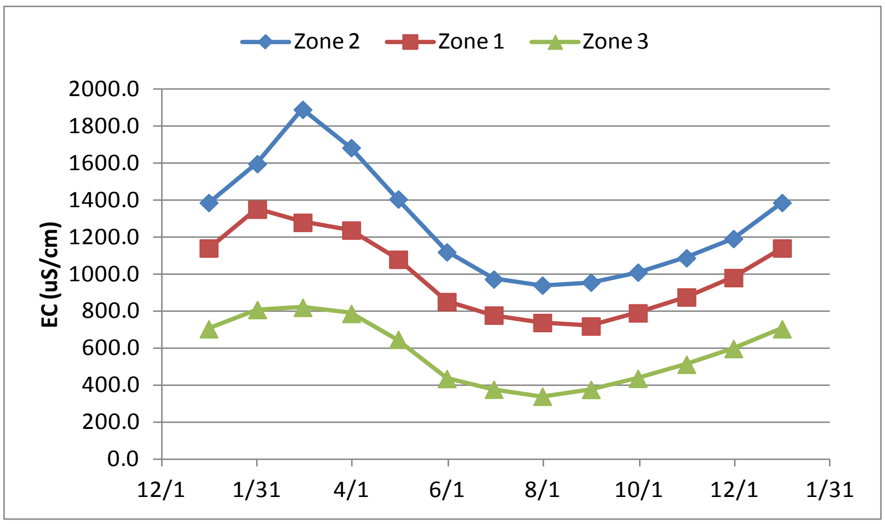


Figure 2-1 EC concentrations used in DSM2 model.

2.2.4 DSM2 Scenarios

The DSM2 model was run in the fingerprinting mode to simulate volumetric contributions from a set of boundary locations. The model was run for a period of 19.6 years from 1990–2010 (10/1/1990 – 4/26/2010; 7,147 days). A total of 10 scenarios with different combination of exports, operation of agricultural barriers and DCC gates were simulated (Table 2-5). The first scenario represented the historical condition, using inflows and gate settings that have occurred in the past. The nine additional scenarios represented conditions that included various adjustments to the historical inputs. The reason for developing multiple DSM2 studies was to create a large training data set for the ANNs, and to provide a wide range of conditions for training. The underlying idea behind this approach is that ANNs, like other empirical formulations, perform best at representing conditions that are within their training horizon, and their performance outside this range is not well defined. For the DSM2 simulations, the following assumptions apply:

- The DSM2 volumetric fingerprint simulations were customized to allow for unique boundary definitions listed in Section 1. Agricultural return flow regions defined at the intersection of the three salinity DICU regions and the three organic carbon DICU regions were used as boundary sources.
- Exclude Head of Old River (HOR) barrier installation from all DSM2 simulations outlined in Table 2-5.
- Exclude North Bay Aqueduct (NBA) and Contra Costa Water District (CCWD) diversions from all DSM2 simulations outlined in Table 2-5.

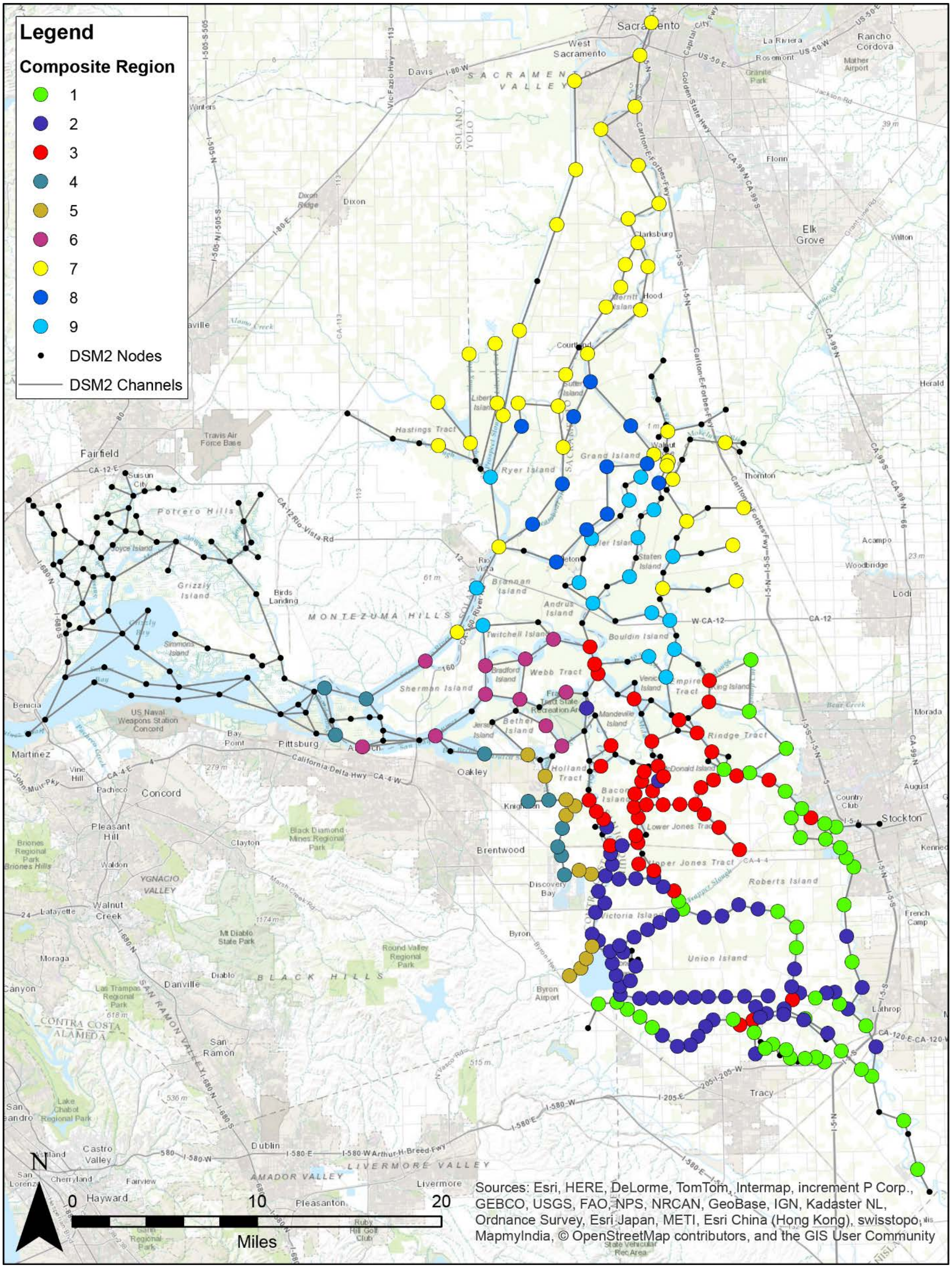


Figure 2-2 DSM2 nodes by DICU region, classified into 9 categories as listed in Table 2-4.

Table 2-5
DSM2 Fingerprinting Simulation Scenarios

Run #	Temporary Barriers	DCC	S. Delta Exports
1	Historical	Historical	Historical
2	In	Open	Historical
3	Out	Open	Historical
4	In	Closed	Historical
5	Out	Closed	Historical
6	Historical	Historical	None
7	In	Open	None
8	Out	Open	None
9	In	Closed	None
10	Out	Closed	None

2.3 Artificial Neural Networks

Using the volumetric fingerprint output from the multiple runs, the next step was to represent the outputs using one or more ANNs. The following describes the methodology employed to structure the ANNs for this work.

2.3.1 Model Inputs

For the ANN model training, a set of flow and tide input variables, corresponding to the source locations in the DSM2 fingerprinting runs were used (Figure 2-3). These input variables are considered to be the main boundary conditions that influence constituent dynamics within Delta. These inputs are:

- Sacramento River flow at Freeport
- San Joaquin River flow at Vernalis
- Mokelumne River flow at Benson’s Ferry
- Cosumnes River flow
- Calaveras River flow
- Yolo Bypass flow
- Delta agricultural return flow
- Martinez tide

For the DSM2 scenarios listed in Section 2.2.4 (Table 2-5), assumptions were made for operation of the temporary barriers, DCC gates and the south Delta exports. In order to best represent these scenarios, in addition to the flow and tide boundaries, operation of south Delta agricultural barriers (0 = closed; 1 = open), DCC gates (0 = closed; 1 = one gate open; 2 = two gates open) and south Delta exports were also included in the ANN model inputs. These inputs are time series data of:

- GL_CN: Grant Line Canal barrier operation, 0 or 1
- MID_R: Middle River near Tracy barrier operation, 0 or 1
- OLD_R: Old River at Tracy barrier operation, 0 or 1
- ORHRB: Head of Old River barrier operation, 0 or 1
- DCC gate: DCC gates operation, 0, 1, or 2
- Delta combined exports

The Martinez tide value is the historical mean sea level data at Martinez. The Delta combined exports are total exports of SWP, CVP, Contra Costa Canal (CCC) and Contra Costa Los Vaqueros (LVR). As a result, a total of 14 input variables (Table 2-6) were used as the ANN model inputs. Values of these 14 input variables were derived from DSM2 model inputs. Because the model inputs are primarily based on historical observed values, they are easier to derive when applying the ANN models for future simulations. The application of the ANN model will not depend on other models (e.g. DSM2) to derive the inputs.

Table 2-6
Inputs for ANN model development

Model Input	Units
Sacramento River flow at Freeport	cfs
San Joaquin River flow at Vernalis	cfs
Mokelumne River flow at Benson’s Ferry	cfs
Cosumnes River flow	cfs
Calaveras River flow	cfs
Yolo Bypass Flow	cfs
Delta agricultural return flow	cfs
Martinez tide (msl)	ft
Grant Line Canal barrier operation	0,1
Middle River near Tracy operation	0,1
Old River at Tracy barrier operation	0,1
Head of Old River barrier operation	0,1
DCC gates	0,1,2*
Delta combined exports	cfs

*0: Gate is fully closed; 1: One gate is fully open; 2: two gates are fully open

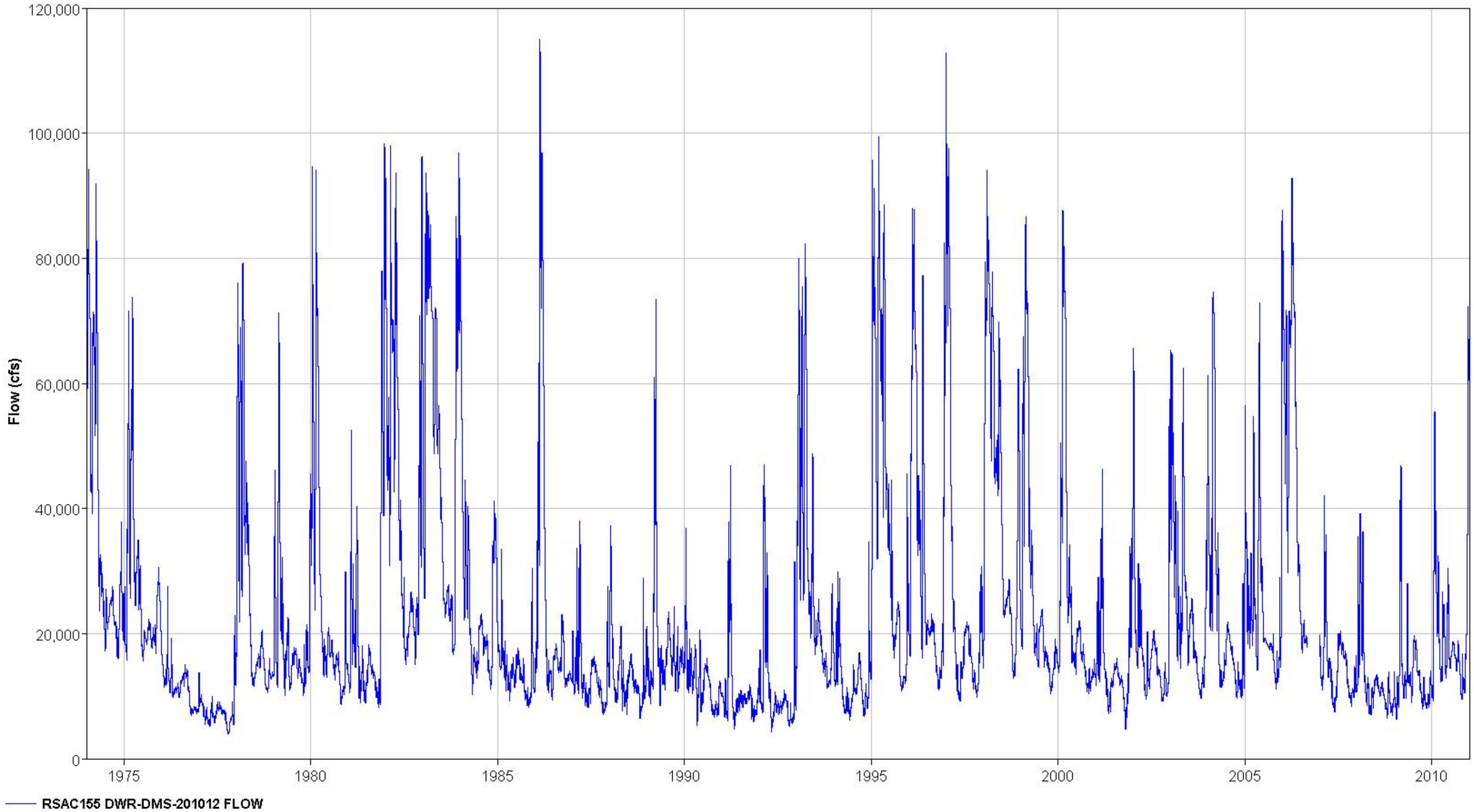


Figure 2-3a Sacramento River

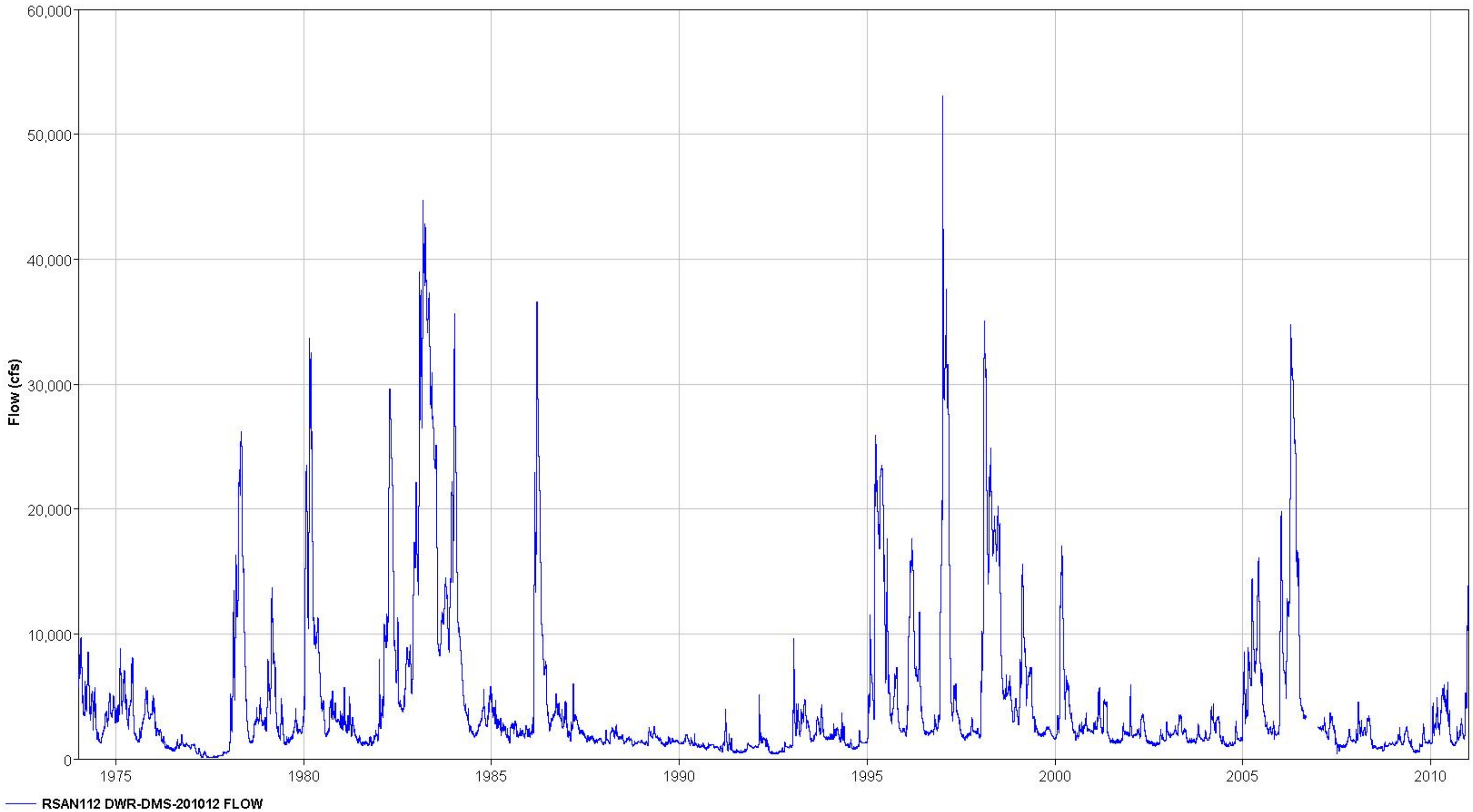


Figure 2-3b San Joaquin River

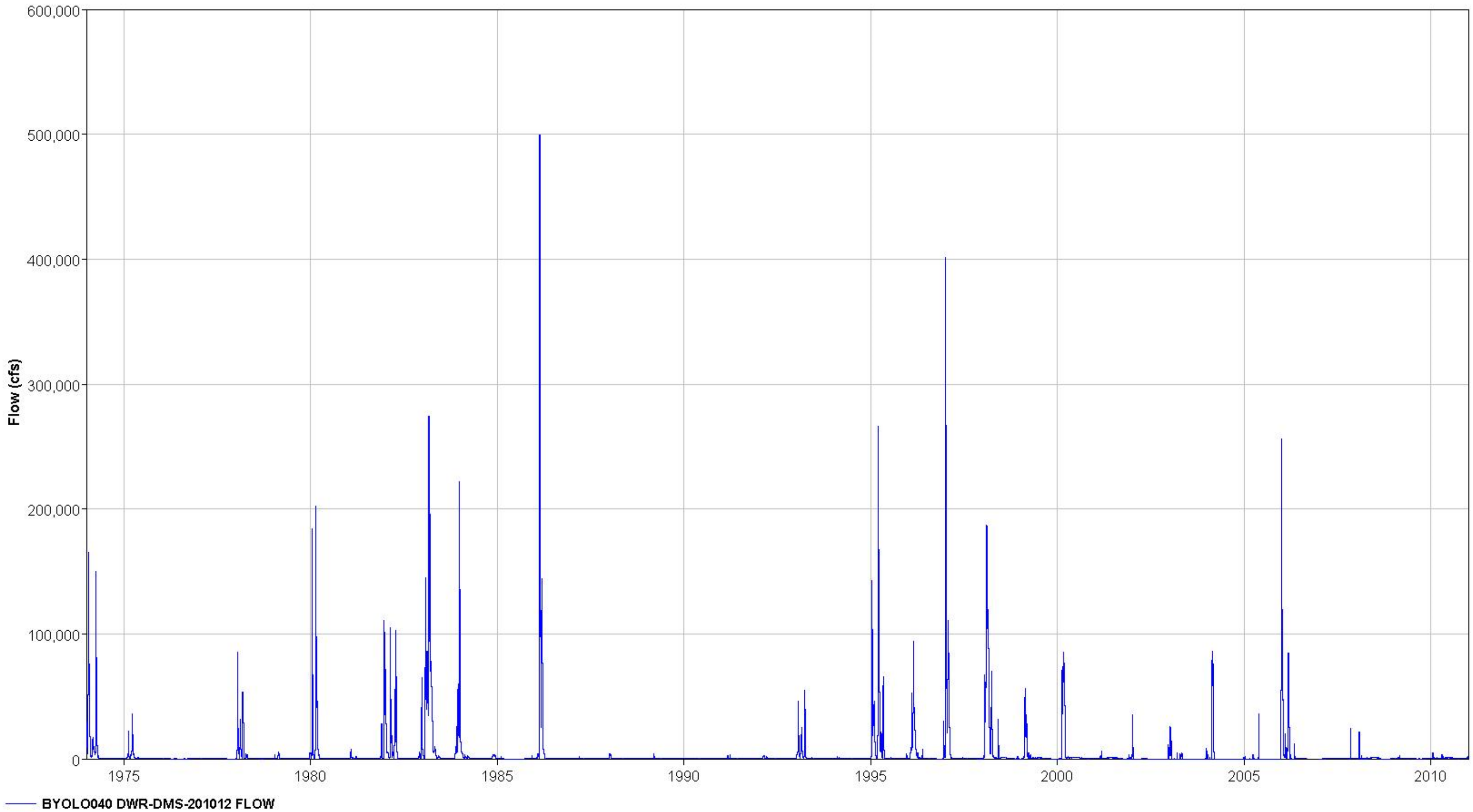


Figure 2-3c Yolo Bypass

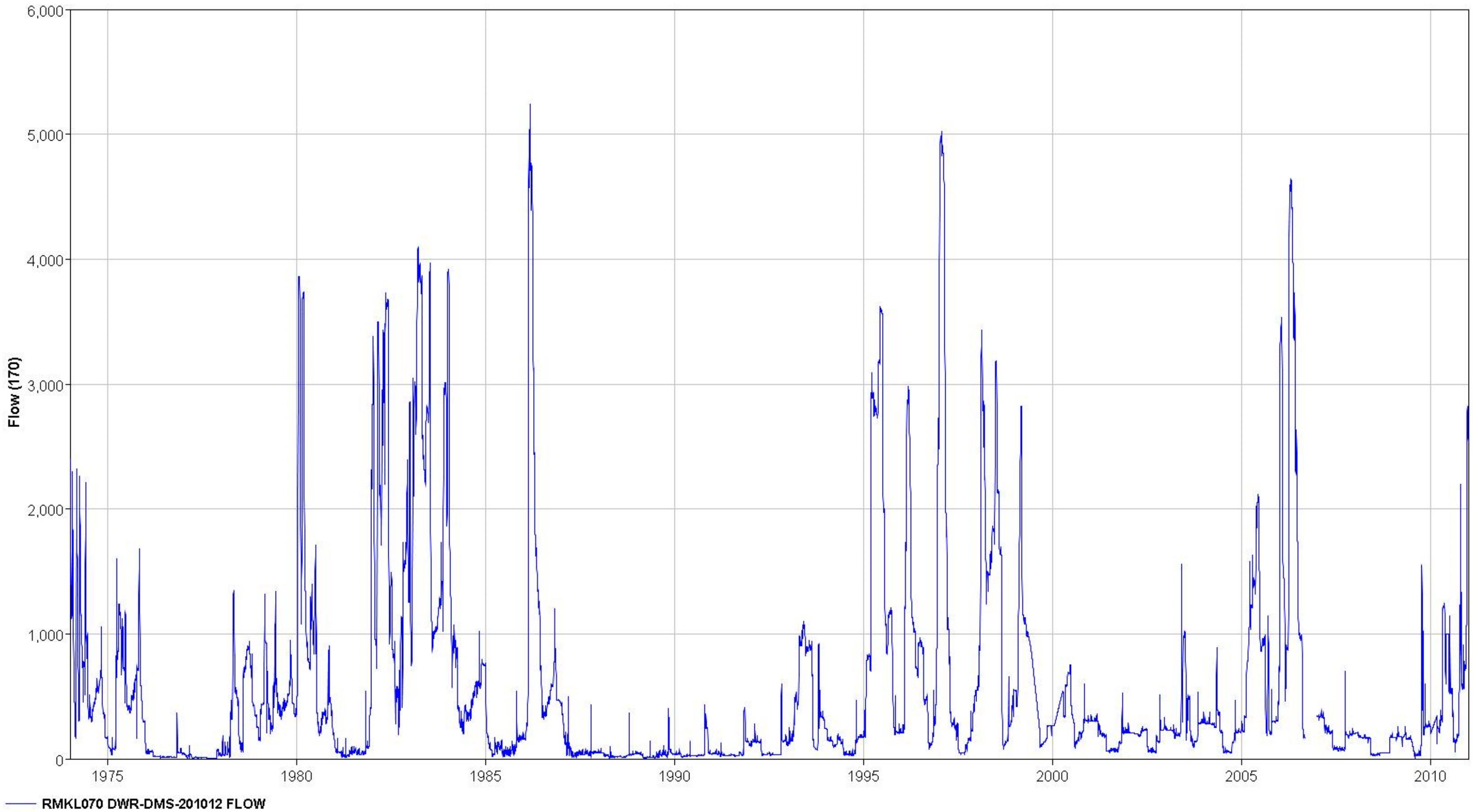


Figure 2-3d Mokelumne River

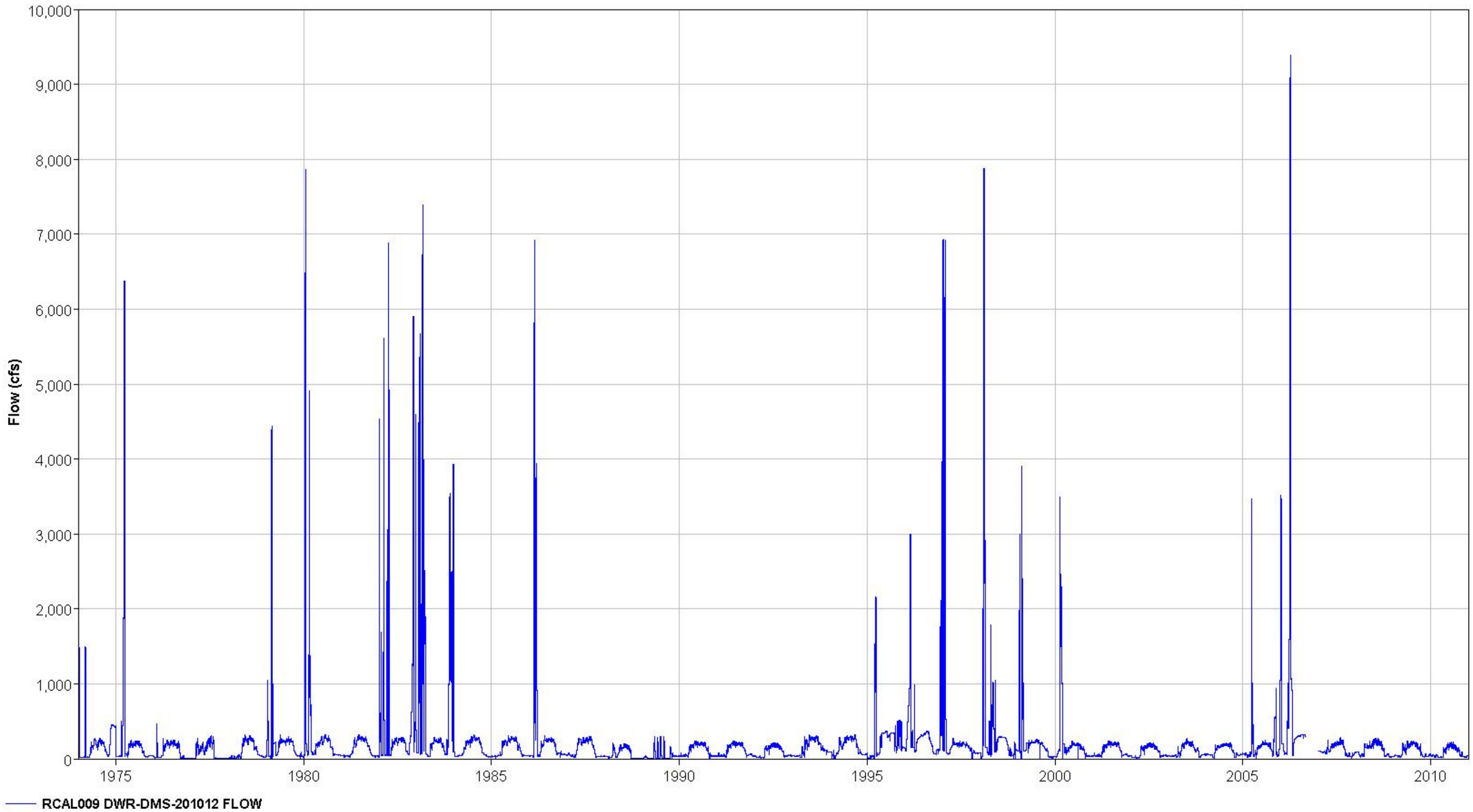


Figure 2-3e ANN inputs of flow from boundaries at: a) Sacramento River, b) San Joaquin River, c) Yolo Bypass, d) Mokelumne River, and e) Calaveras River.

2.3.2 ANN Output Locations

The DSM2 model was used to simulate the volumetric contributions of flow from six boundary locations (Sacramento River, San Joaquin River, Yolo Bypass, Calaveras River, Mokelumne River and Cosumnes River combined, and Martinez flows) and nine DICU regions to the 17 output locations (Figure 1-2; Table 2-7). The results from DSM2 simulations are volumetric contributions from these 15 sources (six boundaries and nine DICU regions) with time stamps associated for a six month period. For each location therefore, and in each month, we obtain from DSM2, the volumetric fingerprint from a source for the current month (termed V1%), the preceding month (termed V2%), and so on till the sixth month (V6%). The simulated volumetric contributions from the 90 tracers (15 sources with 6 time stamps) for each of these 17 locations were used in the ANN training. As a specific example, if we are considering the CCF intake station, the ANNs would compute the volumetric fingerprint for all 15 sources (Sacramento River, San Joaquin River, Yolo Bypass, Calaveras River, Mokelumne River and Cosumnes River combined, and Martinez flows and nine DICU regions) with a time stamp for each of the 15 sources. So, for a given month, we would know the percentage of water contributed by the Sacramento River at the current and previous five months of flows.

2.3.3 ANN Model Structure

The dynamic nature of flow and mixing in the Delta is best represented by a network structure that allows for a time series input, with current and previous values of inputs being considered. This is done using an architecture called the multi-layer perceptrons (MLPs). Although other network structures have received attention in the recent literature, MLPs are by far the most popular network structure used in similar water resources applications, and represent more than 90% of peer-reviewed applications in the water resources field (Maier et al. 2010). For this reason, the feedforward MLP network was selected in this study, and is shown schematically in Figure 2-4.

All ANNs had the same inputs but were trained for different outputs. We trained the ANNs for each of the six tracers for Sacramento River at Freeport volume percent (6 separate ANNs), DICU flow volume percent (9 separate ANNs), Vernalis volume percent (1 ANN), Calaveras volume percent (1 ANN), Mokelumne+Cosumnes volume percent (1 ANN), Yolo volume percent (1 ANN), Martinez volume percent (1 ANN). This forms a total of 20 ANNs for each output location. Other than the Sacramento River ANNs, each of the other ANNs have 6 outputs for each of the 6 tracers corresponding to that inflow; thus, the Vernalis ANN produces the output for V1% through V6% for tracers originating at Vernalis. For the 17 target locations in Table 2-7, we used 17x20 ANNs.

Table 2-7
ANN Model Output Locations

Model Output Location	Code	Channel No	Distance
Port Chicago	RSAC064	452	190
Mallard/Chipps Island	RSAC075	437	11108
Collinsville	RSAC081	436	5733
Antioch	RSAN007	52	366
Emmaton	RSAC092	434	435
Rio Vista	RSAC101	430	9684
Jersey Point	RSAN018	83	4213
Old River @ Bacon Island	ROLD024	106	2718
Old River @ Highway 4	ROLD034	90	3021
CCF Intake	CHSWP003	82	286
Jones Pumping Plant	CHDMC004	181	0
SJR @ Prisoner's Point	RSAN037	42	286
Middle River @ Holt	RMID005	156	140
Middle River @ Victoria	RMID027	230	0
Old River @ Tracy Rd Bridge	ROLD059	71	3116
Middle River @ Union Island	RMID041	125	1700
SJR @ Hwy 4 nr. Antioch	RSAN008	52	0

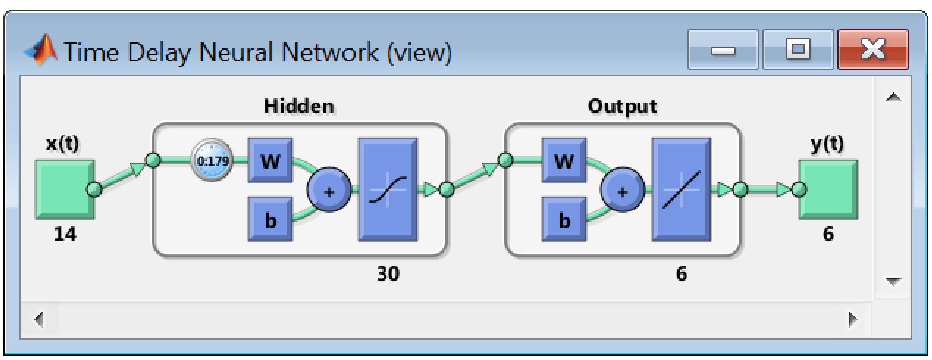


Figure 2-4 Feed-forward ANN model structure (inputs = 14 boundaries, hidden neurons = 30; time delay = 180 days; outputs: volumetric contribution for 6 time steps). x(t) represents the input, y(t) the output, and W and b represents the weights and biases.

In this network, the input layer, termed *x(t)* contains time series of fourteen input variables (flows and gate status). The hidden layer uses 30 neurons, which is formulated based on input variables using a set of weights (W) and biases (b). For the 30 neurons and 14 input variables, this yielded a total of 420 weights and 420 bias parameters that were adjusted during training. An input time delay of 180 days was used, given the long residence time in the Delta that could be up to 6 months. The output layer, *y(t)*, contains the volumetric contributions over 6 months. As described above, a single ANN was used to train for a single source of flow. The hidden layer is converted to the output layer through another set of weights and biases. All weights and biases are estimated during the ANN training process.

2.3.4 Training Technique and Dataset Division

With the large dataset used in the training (outputs from 14 sources at 6 time steps, 17 output locations, and 10 DSM2 scenarios), the training was conducted separately for different stations and sources. Each scenario consisted of approximately 19.5 years x 365 day/year = 7148 data points. A typical training is for contributions from one source to one location. The inputs are time series data of flow from 14 sources and the outputs are volumetric contribution from one source to one location at six time steps (six columns) for the 10 scenarios. This requires generally a total of 20 ANNs at each location (with Sacramento River source trained at each time tracer individually). Because of the large dataset and the long time delay (180 days) involved in the training, the requirements for computer system memory and speed were large. For this work, the Scaled Conjugated Gradient (SCG) approach was used in the training, which has been shown to provide much faster convergence than other error minimization approaches (Beale et al. 2012).

For each training run, the data were divided in the following manner: 70%, 15%, and 15% was used for training, validation and testing, respectively. The data points for training, validation and testing were randomly selected from the entire dataset for each training cycle. Because the training outputs are six variables representing volumetric contribution from six time periods, the output values can be very different among the six variables depending on location and time of the year. It is not unusual for the volumetric contribution from one time period to be much greater than other time periods. The DSM2 simulated volumetric contribution could vary from 90% to less than 1%. Given the large range in the six output variables, the error minimization approach used for the training is mean standard error (mse) with ‘percent’ normalization. Using this normalization, the error was normalized to the range of [-1, +1] during training (Beale et al. 2012).

2.4 Proposed Application

Once ANNs have been trained to calculate the volumetric contribution of different sources using hydrology at the boundaries, they can be used to compute concentrations at the output locations. This is done by multiplying the percent volume of each source/time stamp with the concentration associated with that source/time stamp (schematic representation in Figure 2-5). For example, if at a station we have a volumetric concentration from the San Joaquin River over a six month period, the volume percentages for each of the six monthly intervals would be multiplied by the concentration at the San Joaquin River in that month. This process would be repeated for each of the sources to compute the total concentration of any constituent.

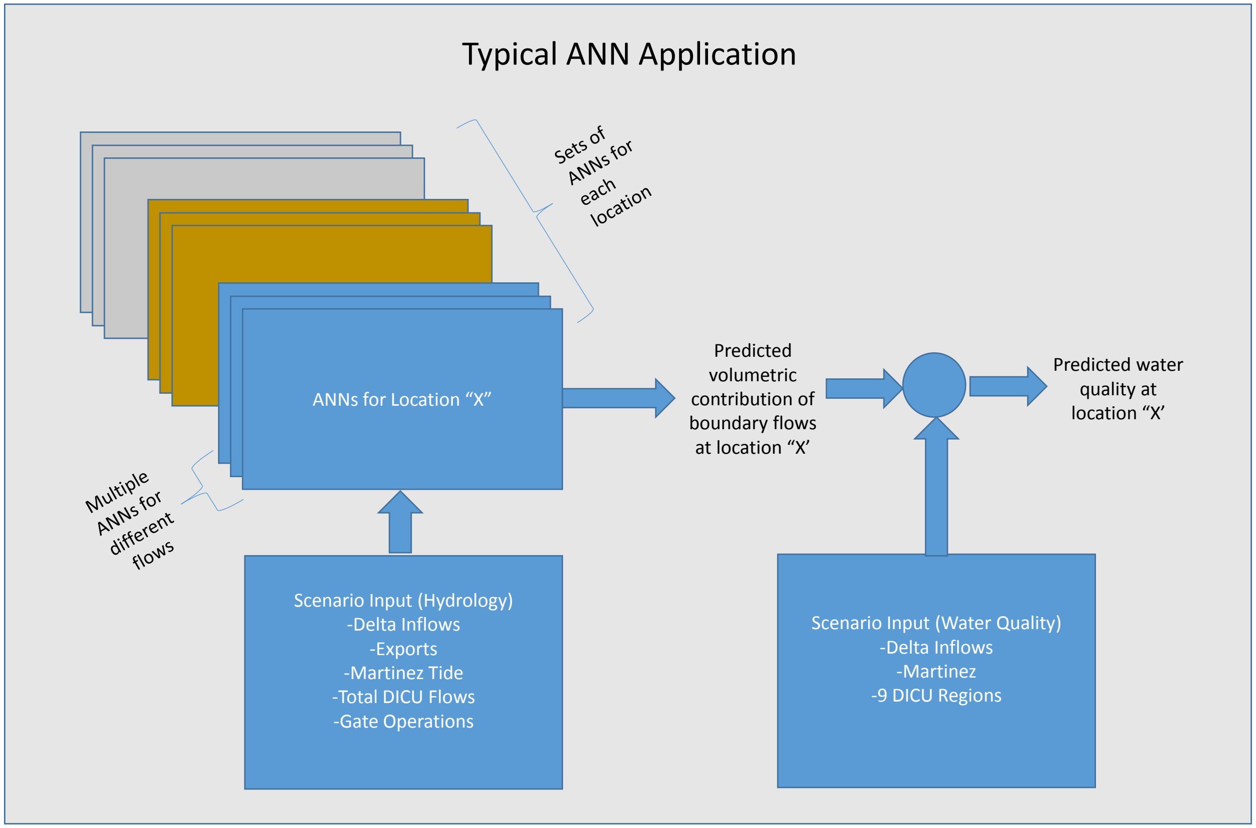


Figure 2-5 Typical application of fingerprint ANN model.

3 RESULTS

3.1 DSM2 SIMULATED VOLUMETRIC CONTRIBUTION AT TARGET LOCATIONS

The DSM2 model was run for 10 scenarios described in Chapter 2, for a time period from 1990-2010. The simulated daily volumetric contributions are available at 17 target locations. An example of these results is shown in Appendix A for one location (Clifton Court Forebay, CCF) and for one scenario (Scenario 10). Similar results could be plotted for each of the 17 output locations and for the 10 DSM2 scenarios, but are not shown for brevity.

3.2 PRELIMINARY VALIDATION RESULTS

Prior to the ANN training, the DSM2 fingerprinting results were first validated against DSM2 simulated EC at six locations (Table 3-1):

- Jones Pumping Plant,
- CCF intake,
- Old River at Bacon Island,
- San Joaquin River at Jersey Point,
- Sacramento River at Mallard Island, and
- Old River at Highway 4.

This validation exercise is primarily a test of the fingerprint model, averaged daily, to represent values calculated through DSM2 operating in the normal mode. For each location, the DSM2 simulated volumetric contribution from boundary sources, along with EC concentrations at boundaries, was used to predict EC at the above validation locations. EC concentrations were calculated as the sum of the products of volumetric contributions and boundary concentrations (including lagged terms) as shown in Equation 2.

The estimated EC from DSM2 finger printing results were compared to DSM2 simulated EC at the six validation locations. The results suggested good agreement between fingerprinting results and the DSM2 simulated EC (Appendix B). However, due to the tidal effects, EC concentrations vary substantially at Martinez over the course of a day. Usually lower EC is associated with high volumetric contribution from Martinez during the day.

Because the finger printing results were output at a daily time step, a daily average EC at Martinez often over estimated EC at validation locations. An average of EC during flood tide better represents EC contributions from Martinez. Therefore in these validation results, an average of EC during flood tide multiplied by a factor of 0.9 was used for EC at Martinez, and matched the normal DSM2 results very well.

Table 3-1
Summary of Locations of Six Validation Stations

Location	DSM2 Channel Name	DSM2 Channel
CCF Intake	CHSWP003	82
Jones Pumping Plant	Chdmc004	216
Old River at Bacon Island	ROLD024	106
Sacramento River at Mallard Island	RSAC075	437
San Joaquin River at Highway 4	RSAN063	15
San Joaquin River at Jersey Point	RSAN018	83

3.3 ANN TRAINING RESULTS

The ANN training was conducted using the feedforward network with a time delay of 180 days. The ANN fitted and DSM2 simulated volumetric contribution at six time steps were compared through time series plots and scatter plots. Results of these comparisons as time series and scatter plots are shown in Appendix C for two sample locations (CCF and Antioch). The DSM2 simulated and ANN fitted volumetric contribution for the entire time period were also compared for CCF and Antioch (Figure 3-1 and Figure 3-2). The DSM2 simulated and ANN fitted volumetric contribution from different flow components are shown for a few years from 1996-1999 in Figure 3-4 to Figure 3-14. The correlation between ANN-fitted and DSM2-simulated volumetric contribution was also calculated (Table 3-2). Results are shown here for the six largest volumetric contributors: Calaveras (CAL), Mokelumne+Cosumnes (MOK), San Joaquin (SJR), Martinez (MTZ), and the Sacramento River (SAC). To keep the table and evaluation to a manageable size, the nine individual DICU flows (which are a smaller volumetric source) are not shown. Slopes and intercepts of regressions between ANN fitted and DSM2 simulated results were also calculated (Table 3-3 and Table 3-4). The fit in terms of correlation coefficient is usually above 0.9 with a few exceptions. Generally stations on the Sacramento River and San Joaquin River tributaries have better fits than stations located at Old River and Middle River. This is probably due to stations at Sacramento and San Joaquin Rivers being more highly influenced by ANN model inputs of a single input (either Sacramento or San Joaquin River flow). Old River at Union Island showed good fit for SJR contribution but has poor fit for other sources. This is because the SJR is dominant source and contribution from other sources is very small and more difficult to fit.

Additional time series plots at different scales provide additional insight into the operation of the ANN models. Thus, Figure 3-1 and Figure 3-2 show the comparison of DSM2 and ANN calculated fingerprints from the different volumetric sources at two different locations, Antioch and CCF. In general it appears that the ANNs capture the main characteristics of the variation over time. Figure 3-3 through Figure 3-14 present a more detailed examination of the DSM2 results and the ANN emulation. Results are shown for contributions to the CCF and Antioch locations for single components of flow. In general, the ANNs appear to emulate the DSM2 signal with fairly high accuracy.

Table 3-2
Correlation (r) between ANN fitted and DSM2 simulated volumetric contribution from six major boundaries at 17 locations with six time steps (Highlighted cells indicate r > 0.9)

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
SJR@HWY4	CAL	0.965	0.967	0.946	0.939	0.963	0.925
	MOK	0.942	0.957	0.953	0.948	0.974	0.965
	SJR	0.97	0.956	0.97	0.974	0.976	0.962
	MTZ	0.955	0.958	0.961	0.95	0.957	0.938
	Yolo	0.962	0.956	0.976	0.933	0.931	0.702
	SAC	0.989	0.982	0.99	0.984	0.988	0.986
SJR@ Jersey Point	CAL	0.964	0.958	0.916	0.927	0.968	0.95
	MOK	0.936	0.954	0.954	0.96	0.971	0.959
	SJR	0.971	0.965	0.958	0.972	0.975	0.975
	MTZ	0.942	0.953	0.945	0.901	0.924	0.918
	Yolo	0.949	0.947	0.971	0.898	0.933	0.891
	SAC	0.986	0.975	0.986	0.986	0.986	0.987
SJR @ Prisoner’s Point	CAL	0.956	0.97	0.936	0.912	0.954	0.938
	MOK	0.856	0.884	0.851	0.893	0.904	0.846
	SJR	0.952	0.946	0.956	0.961	0.966	0.949
	MTZ	0.951	0.959	0.959	0.949	0.927	0.947
	Yolo	0.973	0.937	0.927	0.911	0.907	0.915
	SAC	0.988	0.987	0.978	0.983	0.99	0.986
Emmaton	CAL	0.931	0.946	0.932	0.918	0.937	0.943
	MOK	0.902	0.912	0.925	0.918	0.923	0.934
	SJR	0.944	0.851	0.925	0.958	0.954	0.956
	MTZ	0.955	0.928	0.969	0.956	0.944	0.925
	Yolo	0.988	0.99	0.992	0.933	0.899	0.939
	SAC	0.98	0.981	0.981	0.982	0.988	0.991
Rio Vista	CAL	0.91	0.951	0.915	0.947	0.911	0.931
	MOK	0.839	0.908	0.9	0.824	0.911	0.929
	SJR	0.87	0.874	0.876	0.919	0.921	0.91
	MTZ	0.964	0.949	0.968	0.802	0.917	0.904
	Yolo	0.984	0.984	0.989	0.969	0.868	0.908
	SAC	0.988	0.987	0.99	0.989	0.988	0.988
Collinsville	CAL	0.952	0.956	0.912	0.916	0.955	0.925

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	MOK	0.881	0.908	0.869	0.929	0.945	0.943
	SJR	0.928	0.907	0.951	0.975	0.965	0.952
	MTZ	0.939	0.901	0.947	0.941	0.922	0.942
	Yolo	0.986	0.989	0.993	0.966	0.899	0.913
	SAC	0.987	0.975	0.987	0.985	0.989	0.991
Mallard/Chipps	CAL	0.969	0.969	0.932	0.94	0.97	0.935
	MOK	0.939	0.936	0.93	0.955	0.973	0.968
	SJR	0.971	0.966	0.954	0.975	0.978	0.969
	MTZ	0.925	0.924	0.921	0.929	0.944	0.931
	Yolo	0.987	0.99	0.992	0.969	0.811	0.931
	SAC	0.986	0.968	0.984	0.988	0.988	0.987
Port Chicago	CAL	0.977	0.966	0.936	0.959	0.963	0.933
	MOK	0.95	0.953	0.955	0.956	0.98	0.965
	SJR	0.97	0.954	0.972	0.981	0.981	0.952
	MTZ	0.911	0.889	0.862	0.908	0.92	0.917
	Yolo	0.991	0.993	0.996	0.975	0.9	0.743
	SAC	0.986	0.985	0.987	0.99	0.987	0.987
Old River Tracy	CAL	0.817	0.77	0.913	0.837	0.904	0.914
	MOK	0.939	0.629	0.676	0.862	0.859	0.864
	SJR	0.895	0.881	0.88	0.885	0.889	0.877
	MTZ	0.835	0.915	0.889	0.892	0.866	0.909
	Yolo	0.945	0.873	0.711	0.899	0.782	0.755
	SAC	0.909	0.946	0.969	0.965	0.954	0.968
Old River @ HWY4	CAL	0.892	0.828	0.775	0.925	0.927	0.956
	MOK	0.954	0.933	0.948	0.922	0.914	0.905
	SJR	0.93	0.936	0.925	0.928	0.945	0.912
	MTZ	0.901	0.92	0.874	0.862	0.846	0.932
	Yolo	0.969	0.916	0.893	0.943	0.902	0.93
	SAC	0.985	0.982	0.992	0.987	0.993	0.992
Old River @ Bacon	CAL	0.812	0.871	0.556	0.911	0.931	0.919
	MOK	0.936	0.937	0.932	0.951	0.961	0.938
	SJR	0.959	0.955	0.962	0.961	0.969	0.952
	MTZ	0.917	0.888	0.926	0.852	0.872	0.868
	Yolo	0.963	0.913	0.869	0.952	0.937	0.936
	SAC	0.99	0.986	0.987	0.99	0.986	0.991
Middle River @ Union Island	CAL	0.074	0.811	0.360	0.270	0.292	0.070
	MOK	0.007	0.006	0.248	0.463	0.351	0.250

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	SJR	0.941	0.927	0.921	0.948	0.943	0.943
	MTZ	0.018	0.112	0.465	0.346	0.586	0.464
	Yolo	0.051	-0.13	0.494	0.695	0.819	0.563
	SAC	0.714	0.959	0.579	0.832	0.771	0.179
Middle River @ Holt	CAL	0.876	0.932	0.867	0.952	0.944	0.91
	MOK	0.909	0.915	0.93	0.901	0.922	0.918
	SJR	0.946	0.936	0.952	0.958	0.963	0.947
	MTZ	0.864	0.867	0.867	0.86	0.836	0.926
	Yolo	0.974	0.946	0.909	0.911	0.899	0.942
	SAC	0.991	0.99	0.992	0.985	0.987	0.991
Middle River @ Victoria	CAL	0.864	0.768	0.826	0.885	0.897	0.899
	MOK	0.923	0.943	0.938	0.886	0.922	0.924
	SJR	0.928	0.937	0.927	0.927	0.926	0.921
	MTZ	0.865	0.935	0.907	0.885	0.909	0.936
	Yolo	0.966	0.936	0.933	0.93	0.859	0.936
	SAC	0.992	0.986	0.988	0.988	0.982	0.986
Jones Pumping	CAL	0.949	0.943	0.962	0.941	0.964	0.97
	MOK	0.956	0.968	0.944	0.927	0.947	0.96
	SJR	0.951	0.951	0.957	0.969	0.959	0.96
	MTZ	0.966	0.965	0.966	0.961	0.971	0.968
	Yolo	0.974	0.946	0.905	0.872	0.864	0.938
	SAC	0.993	0.991	0.992	0.98	0.991	0.988
CCF Intake	CAL	0.85	0.919	0.945	0.867	0.906	0.957
	MOK	0.949	0.948	0.916	0.829	0.917	0.935
	SJR	0.94	0.908	0.931	0.916	0.944	0.934
	MTZ	0.945	0.946	0.933	0.931	0.928	0.912
	Yolo	0.961	0.939	0.874	0.9	0.891	0.912
	SAC	0.992	0.991	0.99	0.989	0.99	0.991
Antioch	CAL	0.969	0.967	0.937	0.943	0.967	0.938
	MOK	0.945	0.966	0.956	0.934	0.971	0.96
	SJR	0.968	0.96	0.971	0.977	0.978	0.971
	MTZ	0.945	0.95	0.96	0.944	0.927	0.939
	Yolo	0.956	0.955	0.977	0.95	0.932	0.926
	SAC	0.987	0.978	0.976	0.986	0.987	0.988

CAL: Calaveras River; MOK: Mokelumne River; SJR: San Joaquin River; MTZ: Martinez; Yolo: Yolo Bypass; SAC: Sacramento River. %V1-V6: volumetric contributions from six time periods (i.e., months of January and July, months of February and August, months of March and September and so on). Shaded cells have correlations greater than 0.9.

Table 3-3
Slope for linear regression of ANN fitted and DSM2 simulated volumetric contribution from six major boundaries at 17 locations with six time steps

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
SJR@HWY4	CAL	0.933	0.943	0.914	0.887	0.928	0.841
	MOK	0.893	0.914	0.913	0.896	0.955	0.930
	SJR	0.945	0.914	0.938	0.954	0.969	0.935
	MTZ	0.922	0.932	0.924	0.901	0.926	0.879
	Yolo	0.920	0.920	0.955	0.871	0.862	0.505
	SAC	0.980	0.965	0.978	0.966	0.975	0.971
SJR@ Jersey Point	CAL	0.934	0.927	0.820	0.870	0.941	0.905
	MOK	0.873	0.923	0.908	0.928	0.939	0.924
	SJR	0.939	0.937	0.916	0.946	0.953	0.958
	MTZ	0.878	0.908	0.913	0.808	0.858	0.848
	Yolo	0.906	0.889	0.943	0.800	0.867	0.815
	SAC	0.972	0.953	0.972	0.972	0.971	0.974
SJR @ Prisoner's Point	CAL	0.921	0.943	0.877	0.824	0.907	0.878
	MOK	0.749	0.784	0.707	0.811	0.824	0.705
	SJR	0.906	0.896	0.919	0.924	0.933	0.907
	MTZ	0.906	0.931	0.922	0.890	0.866	0.899
	Yolo	0.948	0.866	0.856	0.830	0.827	0.832
	SAC	0.976	0.974	0.957	0.967	0.979	0.975
Emmaton	CAL	0.849	0.898	0.878	0.855	0.867	0.899
	MOK	0.827	0.848	0.849	0.851	0.841	0.893
	SJR	0.904	0.719	0.855	0.926	0.917	0.923
	MTZ	0.916	0.869	0.940	0.923	0.888	0.860
	Yolo	0.977	0.979	0.988	0.864	0.811	0.882
	SAC	0.965	0.965	0.962	0.967	0.977	0.985
Rio Vista	CAL	0.821	0.907	0.842	0.905	0.827	0.868
	MOK	0.708	0.840	0.800	0.683	0.838	0.884
	SJR	0.768	0.766	0.759	0.851	0.848	0.838
	MTZ	0.928	0.904	0.953	0.630	0.845	0.812
	Yolo	0.965	0.966	0.980	0.949	0.752	0.806
	SAC	0.978	0.975	0.980	0.979	0.978	0.978
Collinsville	CAL	0.914	0.901	0.844	0.852	0.911	0.858

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	MOK	0.766	0.832	0.751	0.883	0.897	0.894
	SJR	0.872	0.834	0.905	0.959	0.929	0.912
	MTZ	0.888	0.811	0.903	0.885	0.857	0.905
	Yolo	0.975	0.984	0.988	0.942	0.794	0.853
	SAC	0.974	0.957	0.976	0.972	0.978	0.986
Mallard/Chipps	CAL	0.934	0.940	0.866	0.888	0.946	0.867
	MOK	0.877	0.885	0.866	0.925	0.949	0.938
	SJR	0.949	0.942	0.903	0.948	0.962	0.934
	MTZ	0.860	0.869	0.848	0.868	0.891	0.867
	Yolo	0.976	0.976	0.986	0.939	0.659	0.881
	SAC	0.973	0.941	0.970	0.979	0.978	0.977
Port Chicago	CAL	0.956	0.937	0.874	0.909	0.930	0.863
	MOK	0.894	0.916	0.910	0.928	0.960	0.938
	SJR	0.950	0.922	0.943	0.970	0.966	0.914
	MTZ	0.832	0.793	0.773	0.848	0.857	0.849
	Yolo	0.983	0.992	0.996	0.948	0.808	0.514
	SAC	0.973	0.970	0.975	0.980	0.975	0.972
Old River Tracy	CAL	0.673	0.594	0.838	0.705	0.829	0.839
	MOK	0.887	0.393	0.477	0.747	0.722	0.753
	SJR	0.816	0.772	0.783	0.781	0.793	0.768
	MTZ	0.724	0.861	0.792	0.793	0.764	0.826
	Yolo	0.899	0.765	0.480	0.816	0.598	0.593
	SAC	0.829	0.894	0.941	0.935	0.919	0.937
Old River @ HWY4	CAL	0.803	0.701	0.621	0.853	0.874	0.914
	MOK	0.913	0.867	0.905	0.851	0.838	0.835
	SJR	0.871	0.882	0.865	0.875	0.887	0.835
	MTZ	0.807	0.842	0.792	0.732	0.737	0.859
	Yolo	0.930	0.826	0.811	0.896	0.808	0.868
	SAC	0.973	0.964	0.986	0.975	0.987	0.984
Old River @ Bacon	CAL	0.667	0.763	0.313	0.837	0.867	0.844
	MOK	0.877	0.882	0.868	0.906	0.927	0.878
	SJR	0.935	0.918	0.928	0.918	0.943	0.905
	MTZ	0.857	0.797	0.855	0.700	0.780	0.761
	Yolo	0.931	0.835	0.730	0.897	0.897	0.865
	SAC	0.978	0.971	0.975	0.982	0.974	0.981
Middle River @ Union Island	CAL	0.020	0.759	0.414	0.075	0.075	0.007
	MOK	0.004	0.002	0.085	0.178	0.086	0.089

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	SJR	0.893	0.861	0.866	0.910	0.882	0.907
	MTZ	0.003	0.027	0.207	0.113	0.373	0.216
	Yolo	0.034	-0.05	0.253	0.568	0.629	0.355
	SAC	0.528	0.924	0.318	0.676	0.579	0.042
Middle River @ Holt	CAL	0.767	0.890	0.742	0.910	0.898	0.831
	MOK	0.826	0.853	0.868	0.810	0.852	0.847
	SJR	0.901	0.882	0.907	0.920	0.926	0.897
	MTZ	0.783	0.750	0.762	0.744	0.688	0.852
	Yolo	0.953	0.885	0.822	0.812	0.838	0.883
	SAC	0.983	0.980	0.982	0.970	0.974	0.982
Middle River @ Victoria	CAL	0.770	0.615	0.662	0.794	0.808	0.818
	MOK	0.861	0.900	0.884	0.773	0.852	0.845
	SJR	0.864	0.879	0.875	0.868	0.866	0.851
	MTZ	0.745	0.891	0.818	0.784	0.848	0.862
	Yolo	0.928	0.880	0.863	0.865	0.746	0.873
	SAC	0.985	0.973	0.976	0.973	0.964	0.972
Jones Pumping	CAL	0.912	0.900	0.922	0.887	0.932	0.938
	MOK	0.910	0.941	0.898	0.860	0.893	0.929
	SJR	0.910	0.907	0.921	0.938	0.922	0.922
	MTZ	0.943	0.936	0.938	0.919	0.946	0.930
	Yolo	0.951	0.880	0.835	0.769	0.731	0.878
	SAC	0.985	0.982	0.985	0.959	0.981	0.980
CCF Intake	CAL	0.713	0.852	0.895	0.753	0.833	0.927
	MOK	0.908	0.910	0.833	0.659	0.841	0.893
	SJR	0.890	0.823	0.875	0.832	0.897	0.886
	MTZ	0.913	0.893	0.899	0.847	0.863	0.825
	Yolo	0.936	0.869	0.752	0.820	0.810	0.832
	SAC	0.983	0.981	0.980	0.976	0.982	0.985
Antioch	CAL	0.937	0.938	0.873	0.891	0.932	0.894
	MOK	0.897	0.942	0.920	0.871	0.943	0.932
	SJR	0.945	0.928	0.945	0.958	0.957	0.947
	MTZ	0.905	0.902	0.915	0.898	0.850	0.884
	Yolo	0.920	0.922	0.960	0.900	0.863	0.861
	SAC	0.976	0.958	0.950	0.972	0.975	0.978

CAL: Calaveras River; MOK: Mokelumne River; SJR: San Joaquin River; MTZ: Martinez; Yolo: Yolo Bypass; SAC: Sacramento River. %V1-V6: volumetric contributions from six time periods (i.e., months of January and July, months of February and August, months of March and September and so on).

Table 3-4
Intercept for linear regression of ANN fitted and DSM2 simulated volumetric contribution from six major boundaries at 17 locations with six time steps

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
SJR@HWY4	CAL	0.004	0.006	0.008	0.012	0.006	0.012
	MOK	0.052	0.039	0.061	0.068	0.024	0.030
	SJR	0.086	0.050	0.067	0.137	0.090	0.106
	MTZ	0.246	0.246	0.246	0.246	0.246	0.246
	Yolo	0.399	0.399	0.399	0.399	0.399	0.399
	SAC	0.280	0.280	0.280	0.280	0.280	0.280
SJR@ Jersey Point	CAL	0.391	0.391	0.391	0.391	0.391	0.391
	MOK	0.273	0.273	0.273	0.273	0.273	0.273
	SJR	0.342	0.342	0.342	0.342	0.342	0.342
	MTZ	0.063	0.098	0.132	0.092	0.066	0.091
	Yolo	0.040	0.037	0.019	0.021	0.027	0.113
	SAC	0.007	0.008	0.021	0.017	0.006	0.007
SJR @ Prisoner's Point	CAL	0.083	0.053	0.076	0.051	0.030	0.045
	MOK	0.032	0.019	0.027	0.051	0.031	0.027
	SJR	0.383	0.383	0.383	0.383	0.383	0.383
	MTZ	0.644	0.644	0.644	0.644	0.644	0.644
	Yolo	0.383	0.383	0.383	0.383	0.383	0.383
	SAC	0.412	0.412	0.412	0.412	0.412	0.412
Emmaton	CAL	0.322	0.322	0.322	0.322	0.322	0.322
	MOK	0.262	0.262	0.262	0.262	0.262	0.262
	SJR	0.097	0.111	0.197	0.166	0.083	0.059
	MTZ	0.043	0.015	0.027	0.025	0.019	0.034
	Yolo	0.023	0.014	0.052	0.063	0.034	0.039
	SAC	0.229	0.167	0.324	0.184	0.155	0.223
Rio Vista	CAL	0.005	0.005	0.004	0.005	0.004	0.004
	MOK	0.235	0.235	0.235	0.235	0.235	0.235
	SJR	0.253	0.253	0.253	0.253	0.253	0.253
	MTZ	0.397	0.397	0.397	0.397	0.397	0.397
	Yolo	0.230	0.230	0.230	0.230	0.230	0.230
	SAC	0.137	0.137	0.137	0.137	0.137	0.137
Collinsville	CAL	0.250	0.250	0.250	0.250	0.250	0.250

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	MOK	0.409	0.407	0.564	0.499	0.469	0.426
	SJR	0.002	0.006	0.006	0.003	0.004	0.005
	MTZ	0.004	0.003	0.004	0.007	0.004	0.002
	Yolo	0.014	0.017	0.025	0.030	0.026	0.014
	SAC	0.033	0.031	0.018	0.024	0.036	0.038
Mallard/Chipps	CAL	0.488	0.488	0.488	0.488	0.488	0.488
	MOK	0.524	0.524	0.524	0.524	0.524	0.524
	SJR	0.679	0.679	0.679	0.679	0.679	0.679
	MTZ	0.516	0.516	0.516	0.516	0.516	0.516
	Yolo	0.324	0.324	0.324	0.324	0.324	0.324
	SAC	0.200	0.200	0.200	0.200	0.200	0.200
Port Chicago	CAL	0.033	0.091	0.076	0.048	0.050	0.030
	MOK	0.024	0.013	0.026	0.052	0.062	0.039
	SJR	0.001	0.001	0.001	0.001	0.001	0.000
	MTZ	0.004	0.003	0.007	0.016	0.005	0.002
	Yolo	0.001	0.001	0.001	0.011	0.003	0.003
	SAC	0.402	0.402	0.402	0.402	0.402	0.402
Old River Tracy	CAL	0.300	0.300	0.300	0.300	0.300	0.300
	MOK	0.356	0.356	0.356	0.356	0.356	0.356
	SJR	0.333	0.333	0.333	0.333	0.333	0.333
	MTZ	0.307	0.307	0.307	0.307	0.307	0.307
	Yolo	0.300	0.300	0.300	0.300	0.300	0.300
	SAC	0.012	0.013	0.028	0.023	0.012	0.009
Old River @ HWY4	CAL	0.039	0.032	0.010	0.029	0.120	0.089
	MOK	0.003	0.006	0.009	0.008	0.004	0.004
	SJR	0.037	0.029	0.084	0.034	0.027	0.024
	MTZ	0.187	0.331	0.145	0.270	0.343	0.212
	Yolo	0.329	0.329	0.329	0.329	0.329	0.329
	SAC	0.554	0.554	0.554	0.554	0.554	0.554
Old River @ Bacon	CAL	0.352	0.352	0.352	0.352	0.352	0.352
	MOK	0.344	0.344	0.344	0.344	0.344	0.344
	SJR	0.211	0.211	0.211	0.211	0.211	0.211
	MTZ	0.119	0.119	0.119	0.119	0.119	0.119
	Yolo	0.076	0.101	0.105	0.064	0.069	0.053
	SAC	0.038	0.021	0.016	0.013	0.056	0.040
Middle River @ Union Island	CAL	0.006	0.000	0.002	0.007	0.012	0.013
	MOK	0.001	0.005	0.014	0.010	0.007	0.006

Station	Source	%V1	%V2	%V3	%V4	%V5	%V6
	SJR	1.619	2.288	2.043	1.356	1.806	1.269
	MTZ	0.000	0.000	0.000	0.002	0.002	0.001
	Yolo	0.000	0.000	0.001	0.000	0.000	0.000
	SAC	0.053	0.013	0.049	0.046	0.082	0.177
Middle River @ Holt	CAL	0.003	0.004	0.007	0.006	0.002	0.004
	MOK	0.021	0.022	0.042	0.024	0.014	0.015
	SJR	0.419	0.362	0.560	0.683	0.515	0.488
	MTZ	0.290	0.290	0.290	0.290	0.290	0.290
	Yolo	0.643	0.643	0.643	0.643	0.643	0.643
	SAC	0.417	0.417	0.417	0.417	0.417	0.417
Middle River @ Victoria	CAL	0.204	0.204	0.204	0.204	0.204	0.204
	MOK	0.193	0.193	0.193	0.193	0.193	0.193
	SJR	0.268	0.268	0.268	0.268	0.268	0.268
	MTZ	0.036	0.059	0.097	0.052	0.040	0.039
	Yolo	0.035	0.027	0.009	0.010	0.074	0.032
	SAC	0.002	0.002	0.004	0.003	0.001	0.003
Jones Pumping	CAL	0.014	0.013	0.020	0.014	0.007	0.010
	MOK	1.515	1.827	1.821	1.547	1.483	1.350
	SJR	0.211	0.211	0.211	0.211	0.211	0.211
	MTZ	0.217	0.217	0.217	0.217	0.217	0.217
	Yolo	0.191	0.191	0.191	0.191	0.191	0.191
	SAC	0.136	0.136	0.136	0.136	0.136	0.136
CCF Intake	CAL	0.128	0.128	0.128	0.128	0.128	0.128
	MOK	0.170	0.170	0.170	0.170	0.170	0.170
	SJR	0.024	0.045	0.040	0.022	0.020	0.038
	MTZ	0.011	0.011	-0.009	0.007	0.029	0.075
	Yolo	0.029	0.019	0.011	0.019	0.016	0.016
	SAC	0.006	0.031	0.045	0.025	0.035	0.017
Antioch	CAL	0.007	0.004	0.006	0.007	0.006	0.003
	MOK	0.388	0.388	0.388	0.388	0.388	0.388
	SJR	0.182	0.182	0.182	0.182	0.182	0.182
	MTZ	0.098	0.098	0.098	0.098	0.098	0.098
	Yolo	0.161	0.161	0.161	0.161	0.161	0.161
	SAC	0.124	0.124	0.124	0.124	0.124	0.124

CAL: Calaveras River; MOK: Mokelumne River; SJR: San Joaquin River; MTZ: Martinez; Yolo: Yolo Bypass; SAC: Sacramento River. %V1-V6: volumetric contributions from six time periods (i.e., months of January and July, months of February and August, months of March and September and so on).

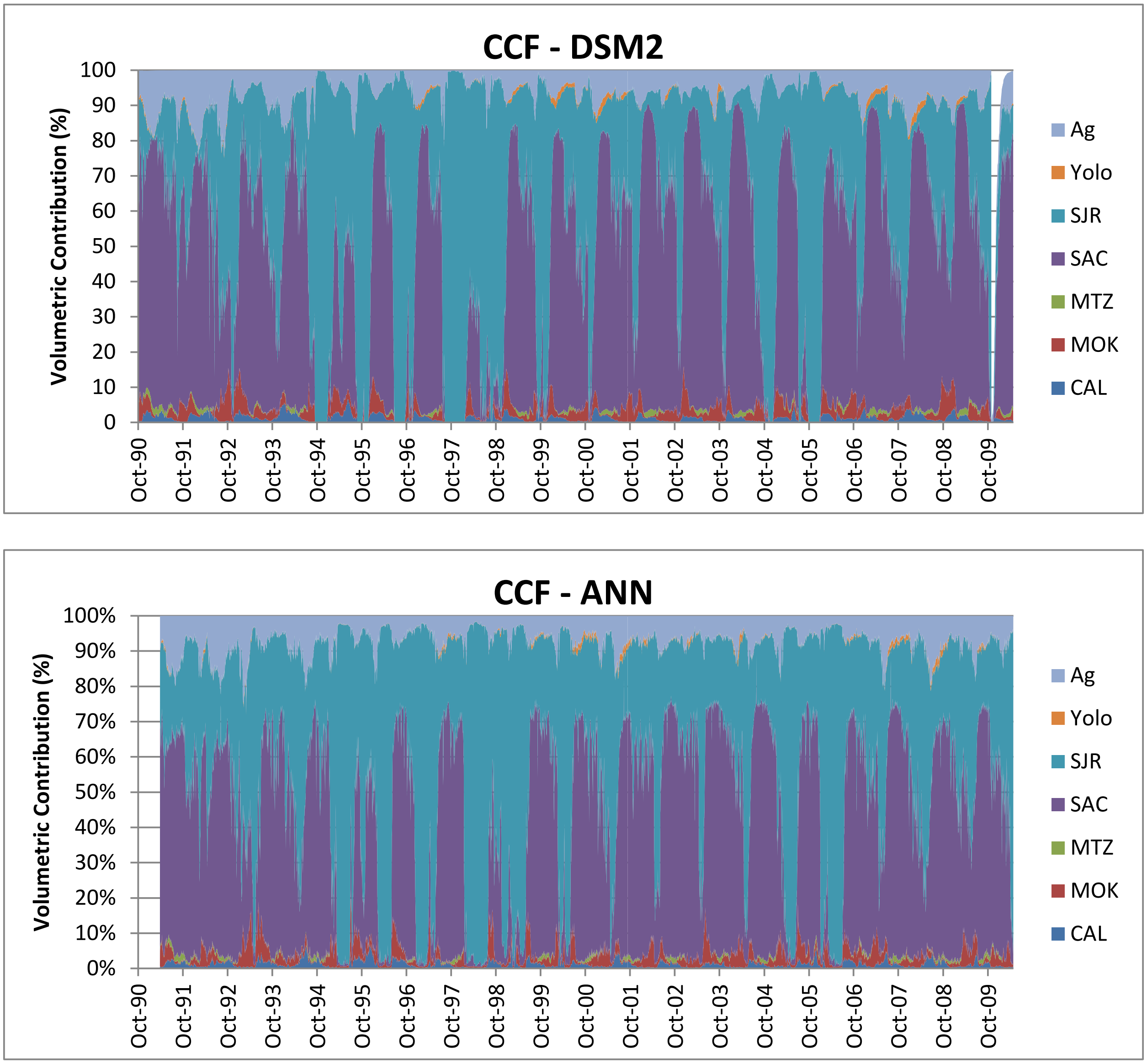
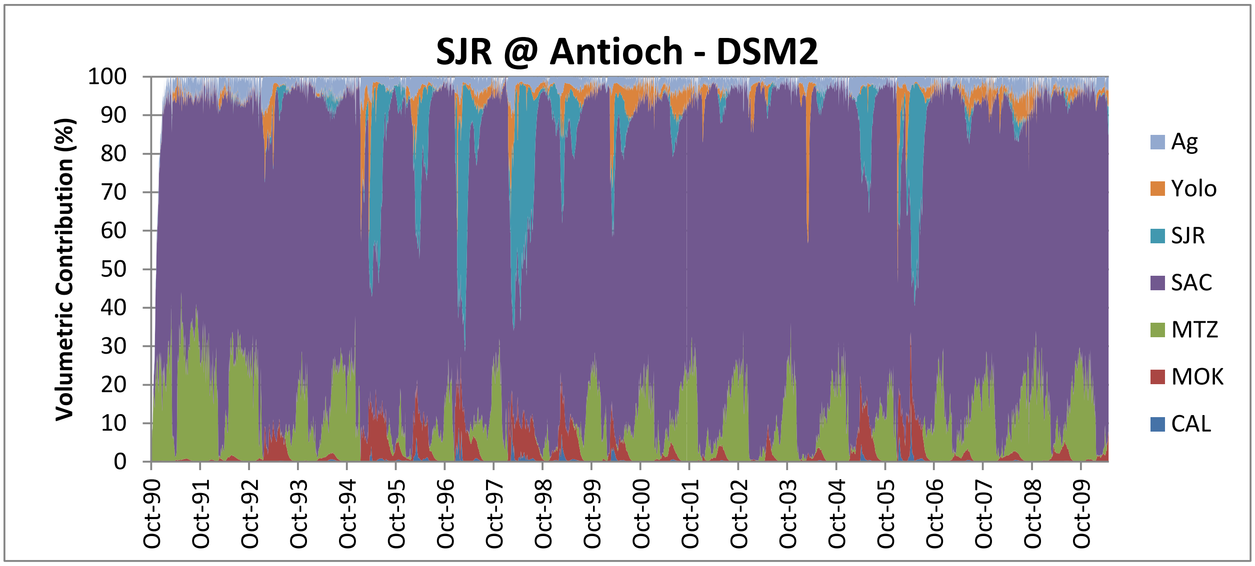


Figure 3-1 DSM2 simulated and ANN fitted volumetric contribution at CCF



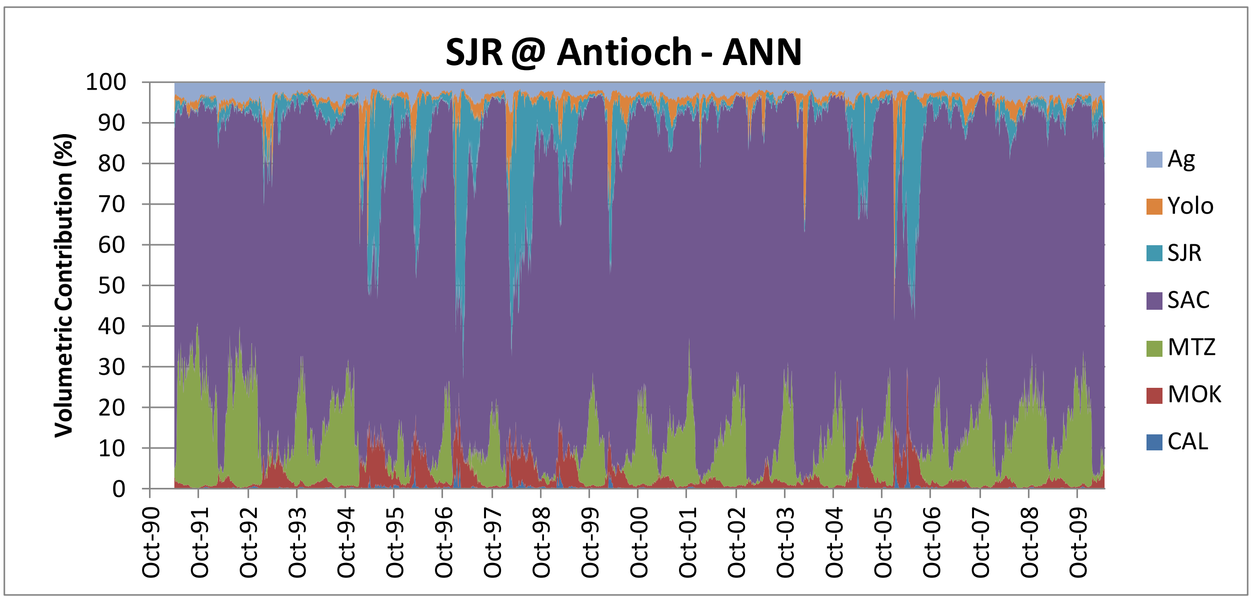


Figure 3-2 DSM2 simulated and ANN fitted volumetric contribution at Antioch

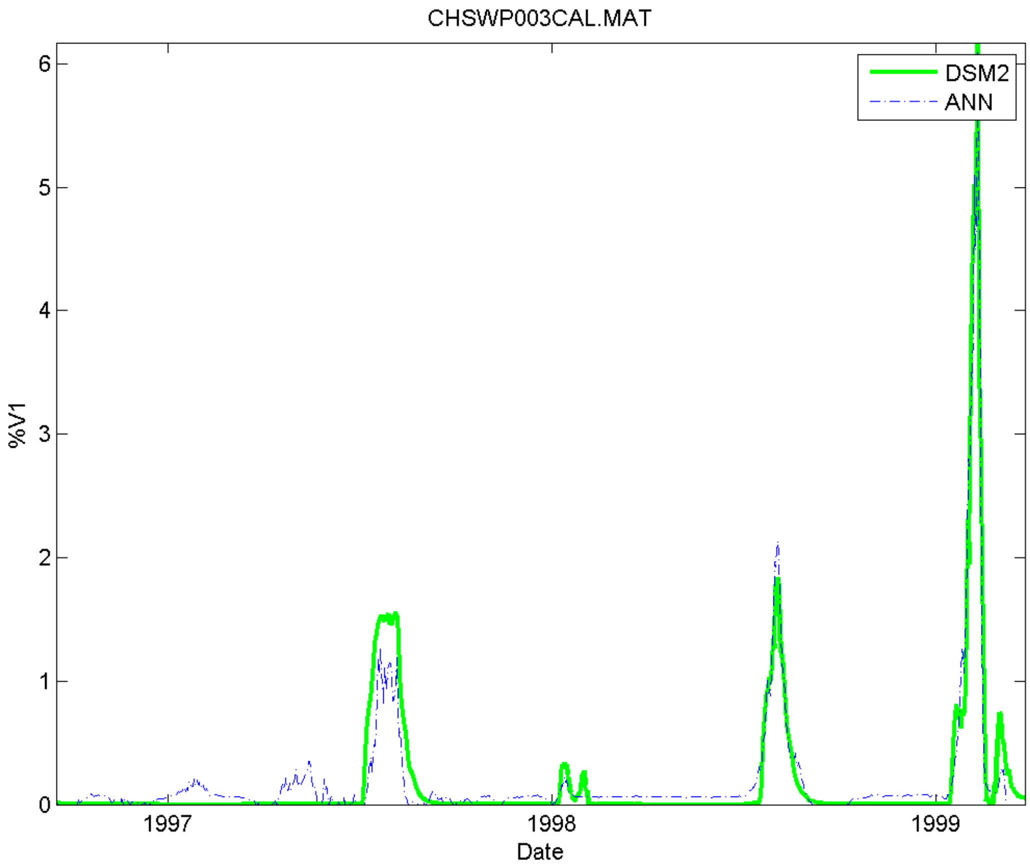


Figure 3-3 DSM2 simulated and ANN fitted volumetric contributions from Calaveras River to CCF (09/1996-03/1999)

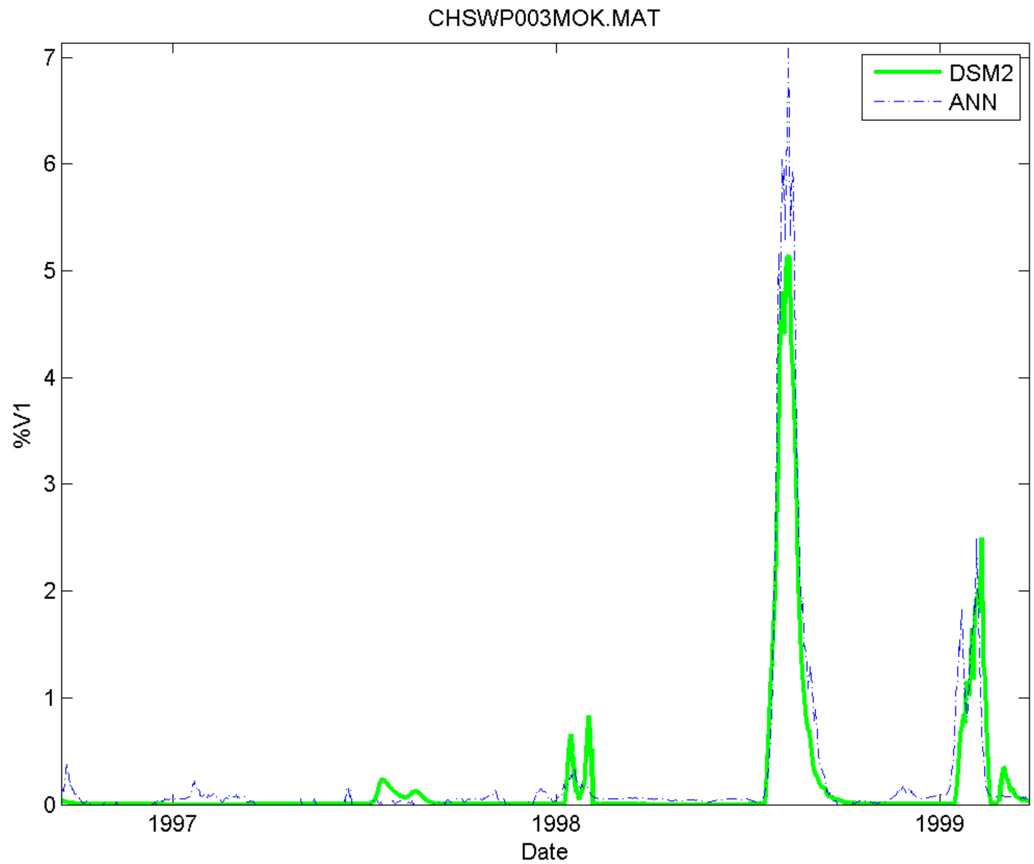


Figure 3-4 DSM2 simulated and ANN fitted volumetric contributions from Mokelumne River to CCF (09/1996-03/1999)

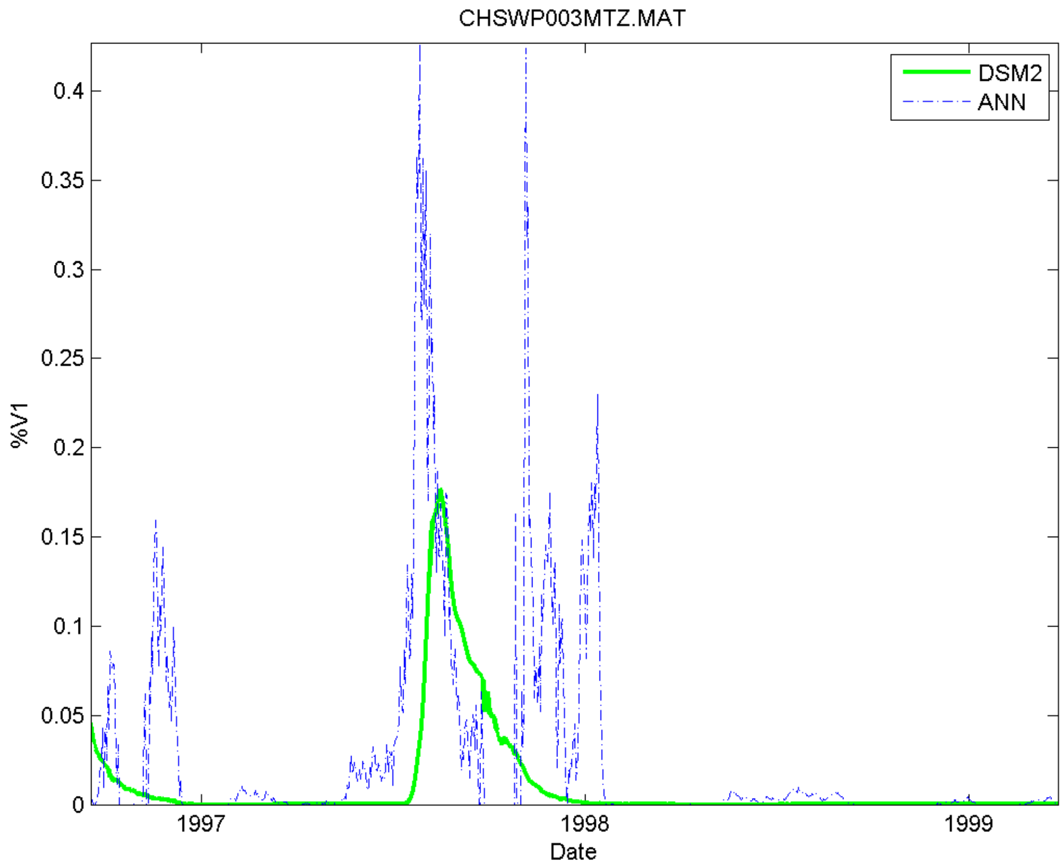


Figure 3-5 *DSM2 simulated and ANN fitted volumetric contributions from Martinez to CCF (09/1996-03/1999)*

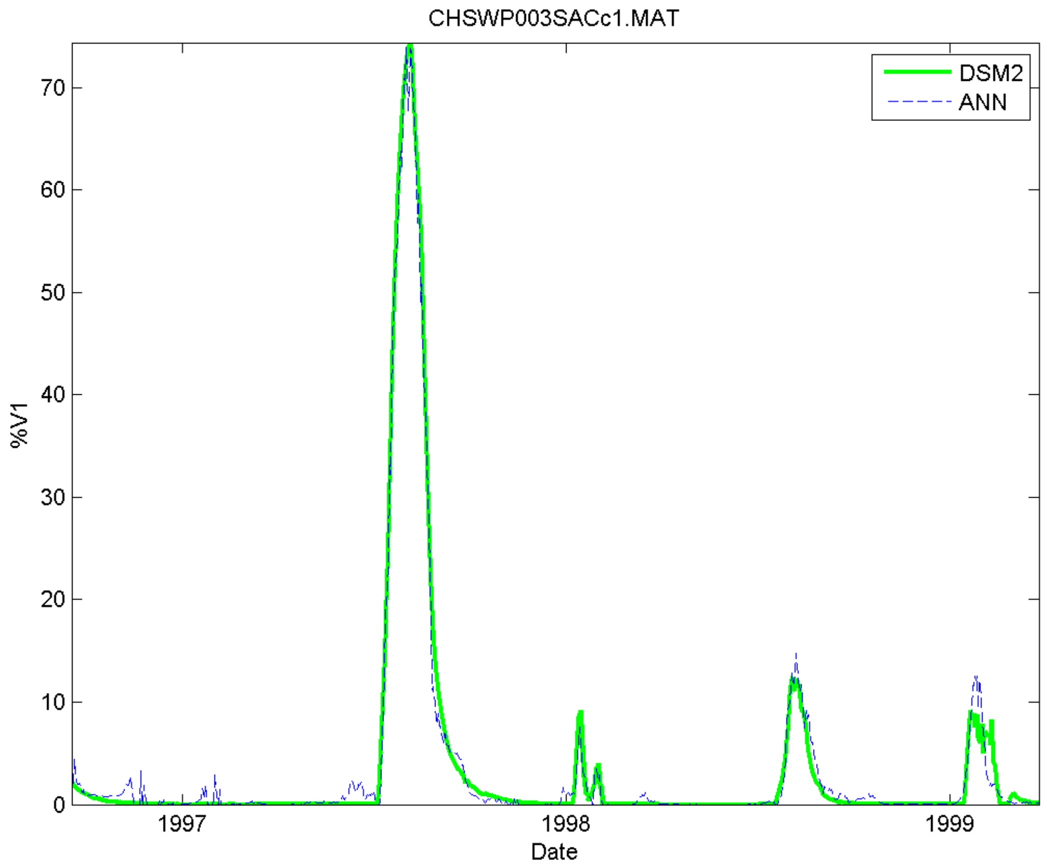


Figure 3-6 DSM2 simulated and ANN fitted volumetric contributions from Sacramento River to CCF (09/1996-03/1999)

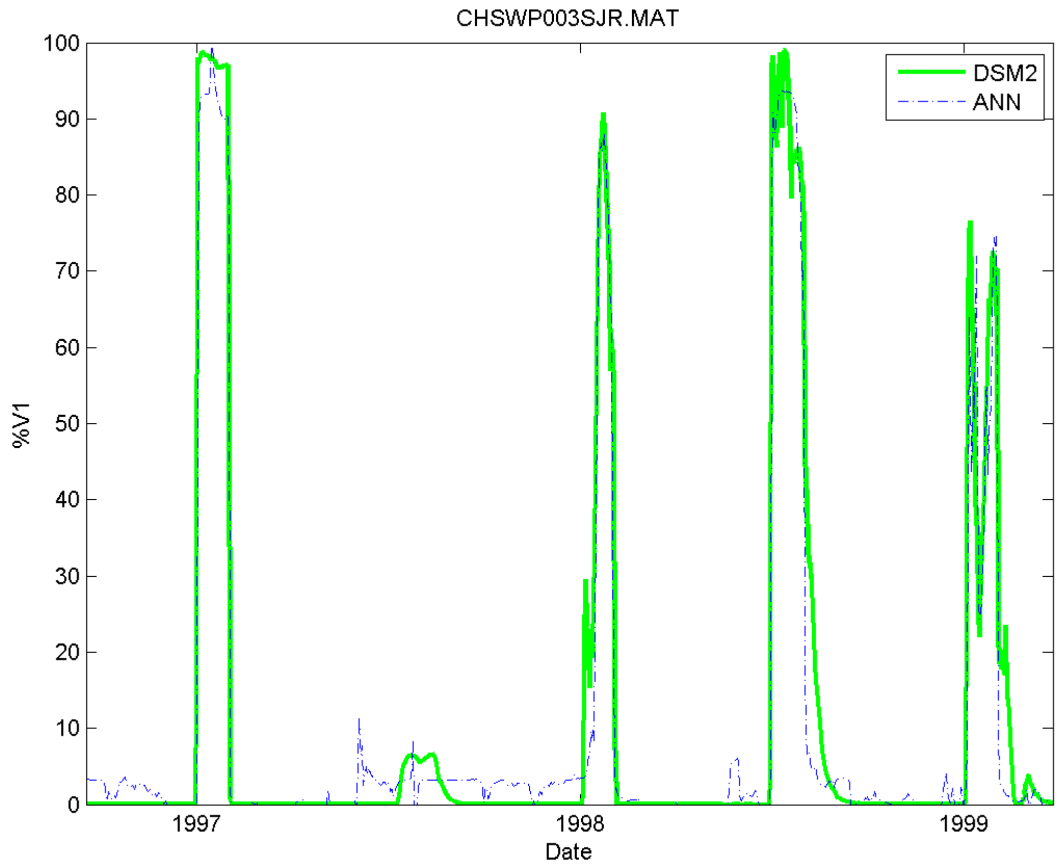


Figure 3-7 DSM2 simulated and ANN fitted volumetric contribution from San Joaquin River to CCF (09/1996-03/1999)

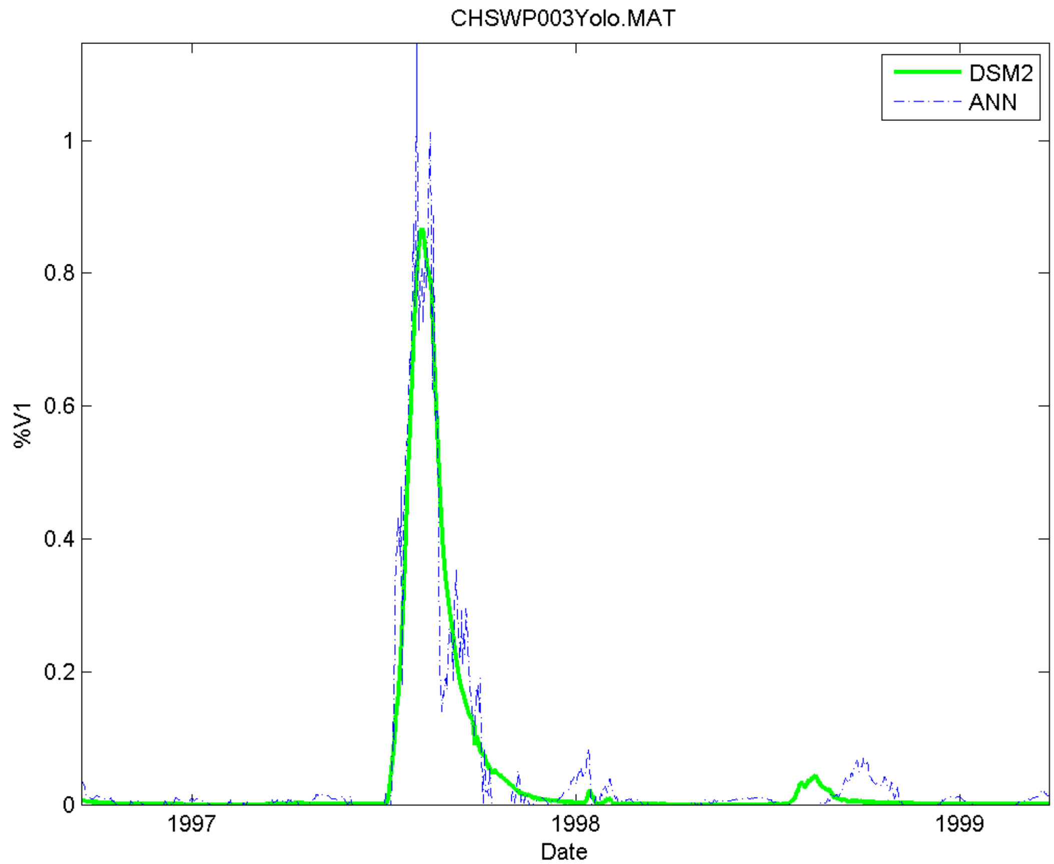


Figure 3-8 DSM2 simulated and ANN fitted volumetric contribution from Yolo Bypass to CCF (09/1996-03/1999)

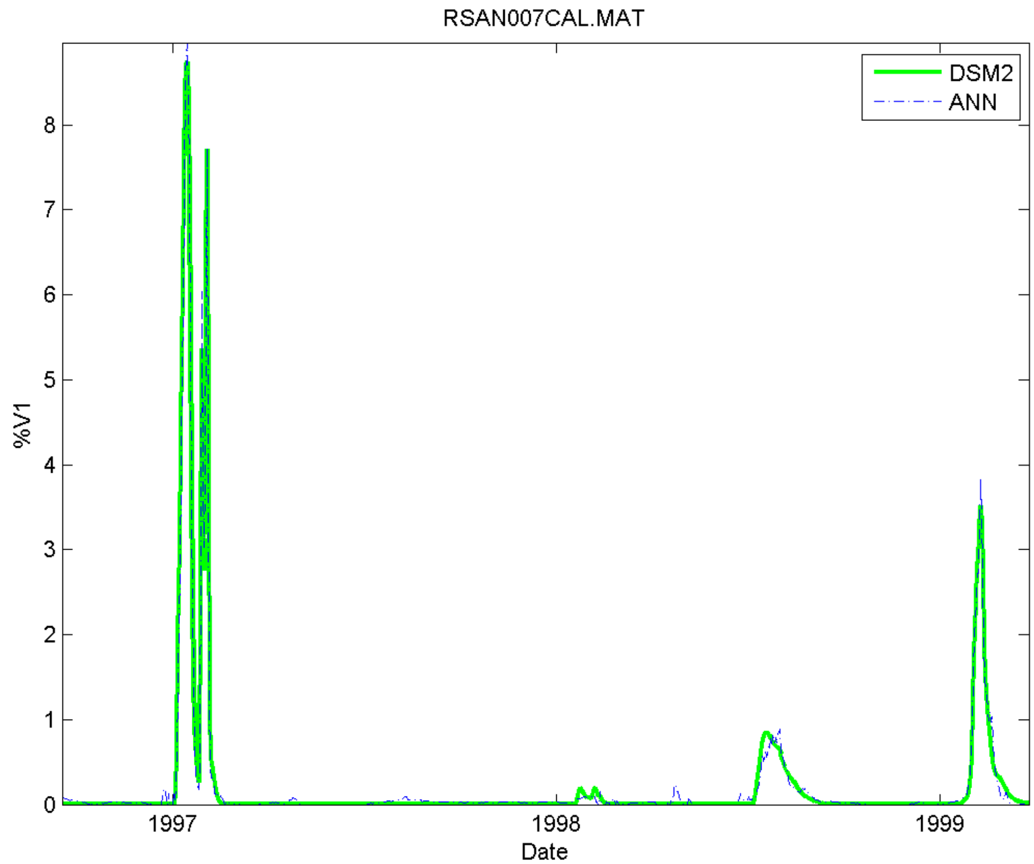


Figure 3-9 DSM2 simulated and ANN fitted volumetric contribution from Calaveras River to Antioch (09/1996-03/1999)

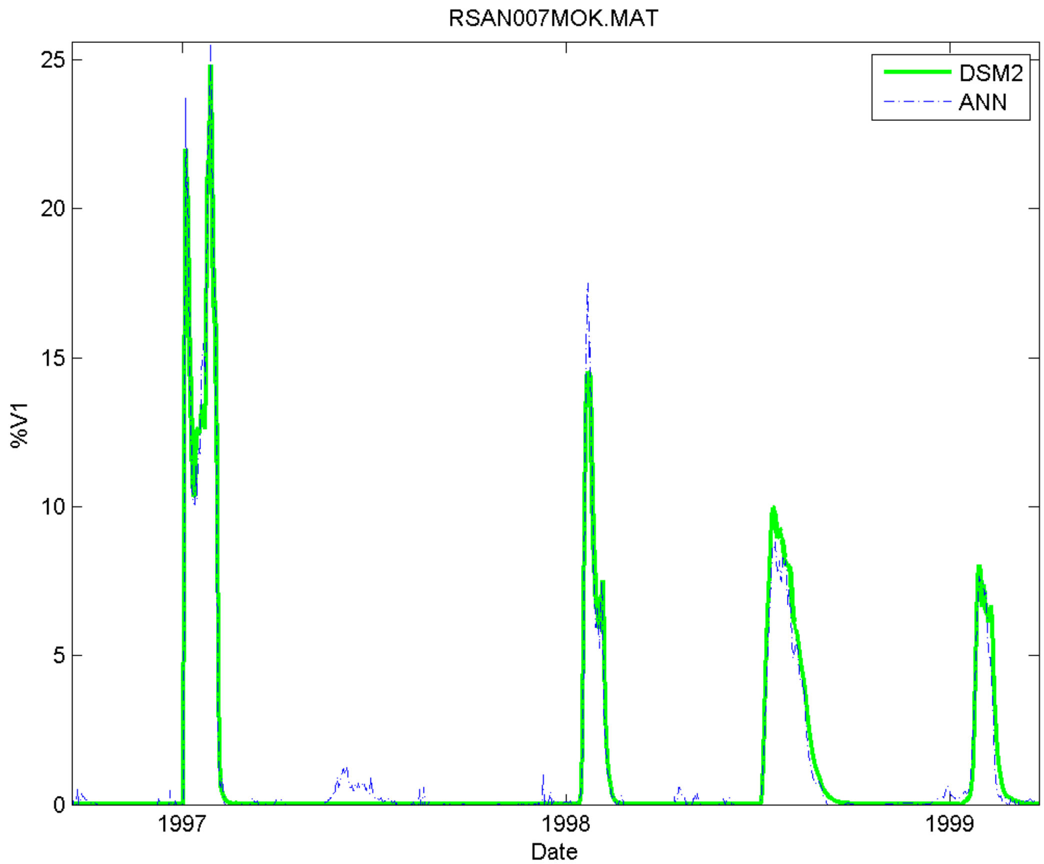


Figure 3-10 DSM2 simulated and ANN fitted volumetric contribution from Mokelumne River to Antioch (09/1996-03/1999)

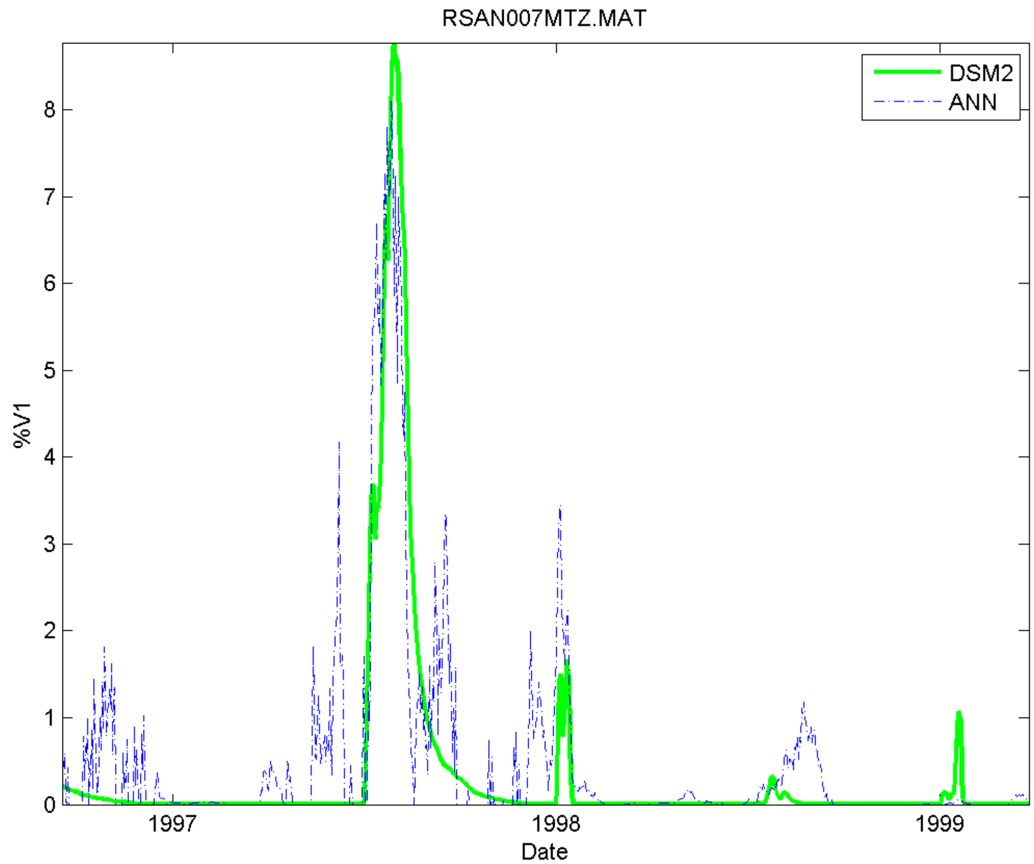


Figure 3-11 DSM2 simulated and ANN fitted volumetric contribution from Martinez to Antioch (09/1996-03/1999)

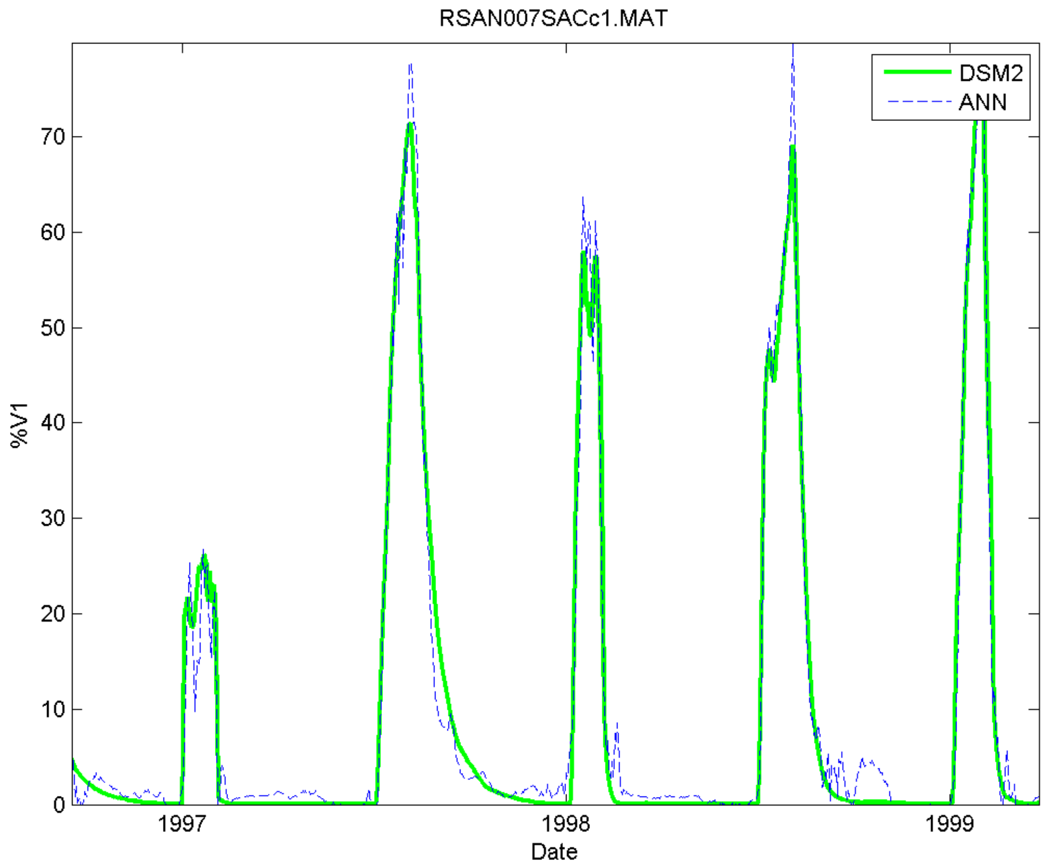


Figure 3-12 DSM2 simulated and ANN fitted volumetric contribution from Sacramento River to Antioch (09/1996-03/1999)

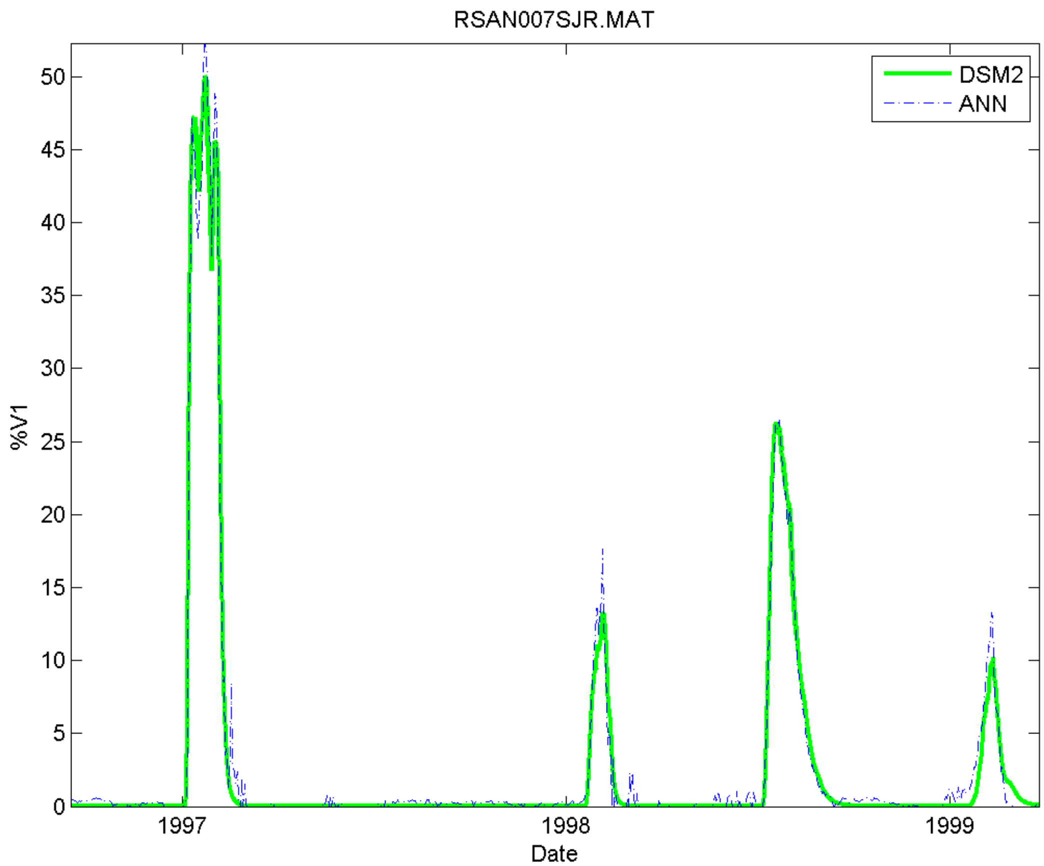


Figure 3-13 DSM2 simulated and ANN fitted volumetric contribution from San Joaquin River to Antioch (09/1996-03/1999)

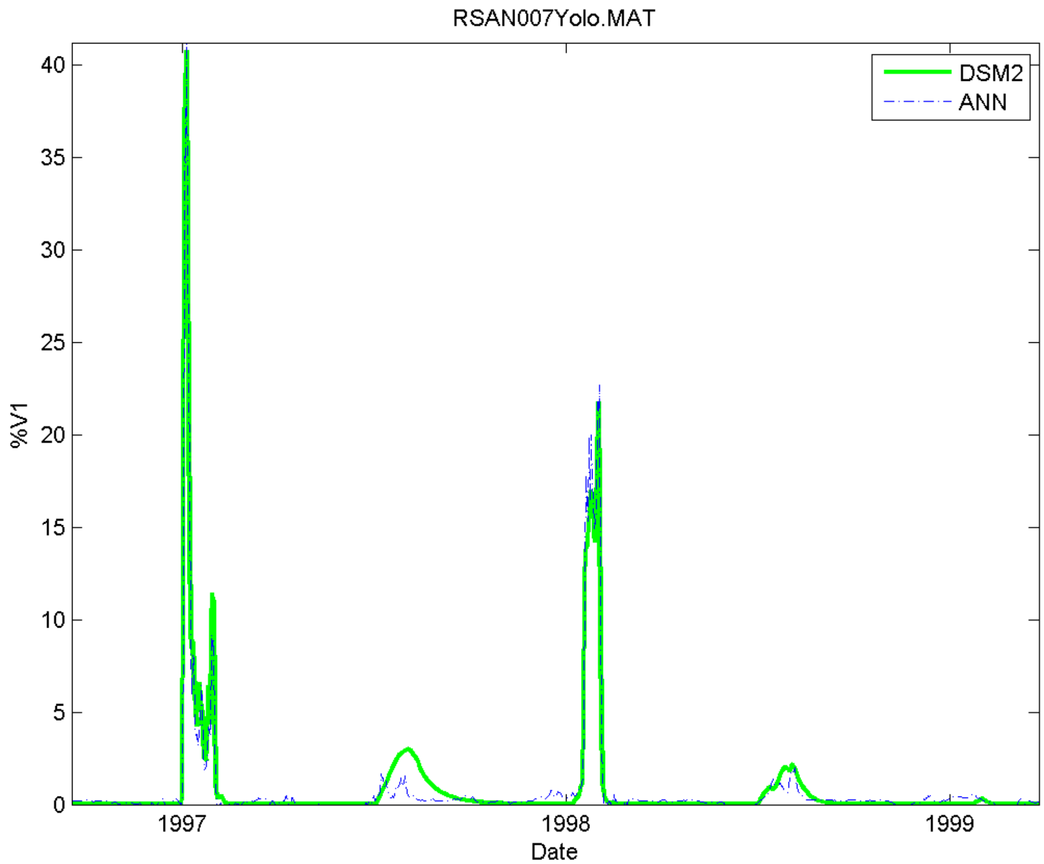


Figure 3-14 DSM2 simulated and ANN fitted volumetric contribution from Yolo Bypass to Antioch (09/1996-03/1999)

3.4 ANN APPLICATION RESULTS

The trained ANN results were applied to simulate EC at different locations within the Delta, and the results were compared to EC derived from the DSM2 simulated volumetric contribution using the same calculation method (Table 3-5). For each location, the ANN-estimated and DSM2-simulated volumetric contribution from each source, along with EC concentrations at source locations were used to calculate EC at predicted locations within the Delta. EC concentrations were calculated as the sum of the products of volumetric contributions and boundary concentrations (including lagged terms) as defined in Chapter 1.

The EC estimated from the ANN and DSM2 simulated volumetric contribution was compared. The results suggest good agreement between EC estimated from ANN and DSM2 estimated volumetric contribution, which is expected given the quality of the volumetric fingerprint fits presented in the prior section. Scatter plots of ANN- and DSM2-estimated EC are shown in Appendix D. EC concentrations at boundaries used in the calculations are derived from DSM2 model inputs. Similar to DSM2, EC concentrations assigned to three EC DICU regions were used as inputs. As in DSM2, EC concentrations from east side tributaries were assigned at constant of 125 µS/cm.

A similar application was conducted for bromide (Br) and dissolved organic carbon (DOC). Similarly good agreement between ANN and DSM2 simulated concentrations (of Br and DOC) were found (Table 3-6 and Table 3-7).

Table 3-5
Comparison of EC estimated from volumetric contribution simulated by ANN and DSM2

Location	DSM2 Channel Name	Slope	Intercept	r
SJR @HWY4	RSAN008	0.94	110	0.976
SJR @ Jersey Point	RSAN018	0.95	44	0.972
SJR @ Prisoner's Point	RSAN037	0.91	42	0.977
Emmaton	RSAC092	0.98	54	0.978
Rio Vista	RSAC101	0.90	25	0.962
Collinsville	RSAC081	0.94	280	0.971
Mallard/Chipps	RSAC075	0.93	530	0.975
Port Chicago	RSAC064	0.89	1300	0.972
Old River Tracy	Rold059	0.85	98	0.963
Old River @ HWY4	Rold034	0.87	79	0.947
Old River @ Bacon	Rold024	0.92	47	0.956
Middle River @ Union Island	Rmid041	0.9	62	0.978
Middle River @ Holt	Rmid005	0.89	61	0.966
Middle River @ Victoria	Rmid027	0.9	65	0.958
Jones Pumping	Chdmc004	0.93	33	0.977
CCF Intake	CHSWP003	0.92	51	0.962
Antioch	RSAN007	0.94	160	0.976

Table 3-6
Comparison of Br estimated from volumetric contribution simulated by ANN and DSM2

Location	DSM2 Channel Name	Slope	Intercept	r
SJR @HWY4	RSAN008	0.94	0.11	0.976
SJR @ Jersey Point	RSAN018	0.95	0.04	0.972
SJR @ Prisoner's Point	RSAN037	0.90	0.02	0.969
Emmaton	RSAC092	0.98	0.06	0.978
Rio Vista	RSAC101	0.88	0.01	0.949
Collinsville	RSAC081	0.94	0.32	0.971
Mallard/Chipps	RSAC075	0.93	0.60	0.975
Port Chicago	RSAC064	0.89	1.5	0.972
Old River Tracy	Rold059	0.79	0.049	0.924
Old River @ HWY4	Rold034	0.80	0.048	0.928
Old River @ Bacon	Rold024	0.91	0.027	0.947
Middle River @ Union Island	Rmid041	0.89	0.026	0.973
Middle River @ Holt	Rmid005	0.82	0.034	0.922
Middle River @ Victoria	Rmid027	0.85	0.033	0.941
Jones Pumping	Chdmc004	0.93	0.017	0.971
CCF Intake	CHSWP003	0.88	0.025	0.961
Antioch	RSAN007	0.94	0.17	0.976

Table 3-7
Comparison of DOC estimated from volumetric contribution simulated by ANN and DSM2

Location	DSM2 Channel Name	Slope	Intercept	r
SJR @HWY4	RSAN008	0.96	0.15	0.991
SJR @ Jersey Point	RSAN018	0.95	0.17	0.991
SJR @ Prisoner's Point	RSAN037	0.92	0.35	0.978
Emmaton	RSAC092	0.96	0.10	0.996
Rio Vista	RSAC101	0.97	0.07	0.997
Collinsville	RSAC081	0.96	0.11	0.991
Mallard/Chipps	RSAC075	0.94	0.13	0.986
Port Chicago	RSAC064	0.83	0.26	0.966
Old River Tracy	Rold059	0.79	0.94	0.942
Old River @ HWY4	Rold034	0.86	0.55	0.956
Old River @ Bacon	Rold024	0.91	0.39	0.967
Middle River @ Union Island	Rmid041	0.85	0.55	0.965
Middle River @ Holt	Rmid005	0.88	0.55	0.973
Middle River @ Victoria	Rmid027	0.84	0.57	0.954
Jones Pumping	Chdmc004	0.90	0.39	0.978
CCF Intake	CHSWP003	0.87	0.51	0.969
Antioch	RSAN007	0.95	0.15	0.992

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4 SUMMARY

The volumetric fingerprint approach in the DSM2 model allows an evaluation of the contribution of different inflows to any location in the Delta. Using this information, and knowledge of inflow concentrations, one can determine the chemical concentration at any location using a matrix multiplication, and without the need to re-run DSM2. This basic concept was applied in this work, with the use of ANNs to emulate DSM2.

ANN models were developed to predict volumetric contributions from six major boundary sources and nine DICU regions to 17 pre-specified locations within Delta. The DSM2 model was first applied under the fingerprinting mode to simulate volumetric contributions from the six boundaries and nine DICU regions for a set of 10 scenarios with variable input conditions. The DSM2 simulation results provided the data set that was used to train the ANN models. Because of the complexity of the response, a large number of ANNs were needed to accomplish this task. For each location, separate ANN models were developed to simulate the volumetric contribution from the Sacramento, San Joaquin, Calaveras, Mokelumne+Cosumnes Rivers, Yolo Bypass, Martinez and agricultural regions. We trained the ANNs for each of the six tracers for Sacramento River at Freeport volume percent (6 separate ANNs), DICU flow volume percent (9 separate ANNs), Vernalis volume percent (1 ANN), Calaveras volume percent (1 ANN), Mokelumne+Cosumnes volume percent (1 ANN), Yolo volume percent (1 ANN), Martinez volume percent (1 ANN). This formed a total of 20 ANNs for each output location, or 20x17 (340) ANNs for the entire exercise. An interface was developed that provides wrapper around the individual ANNs such that a user does not need to deal with the specifics of the ANN to be used for a particular application.

The training results generally suggested very good agreement between the DSM2 and ANN-predicted volumetric contribution, with a correlation coefficient of generally above 0.85. Better fits was found for Sacramento River and San Joaquin River tributary locations than central Delta locations.

The simulated volumetric contribution from the ANN models, in conjunction with concentrations at the boundary, can be used to predict concentrations of any conservative constituent for the 17 trained locations within Delta.

In the application of the trained ANN models, the ANN- and DSM2-simulated volumetric contribution from different boundaries and DICU regions, along with EC concentrations at these sources, were used to predict EC at trained locations. The results from the ANN and DSM2 models were compared and showed good agreement (with correlation coefficient of > 0.9). Similar comparisons showed good results for Br and DOC, strongly supportive of the concept of using a DSM2 emulator for modeling conservative constituents in a manner that runs faster and with less specialized skill than required for operating the full DSM2 model. It is envisioned that this approach will find use among a broader community of users who want to explore the effects of individual boundary sources on specific locations, to understand relationships under varying conditions, and also to pre-screen scenarios before embarking on full-fledged DSM2 runs.

5 REFERENCES

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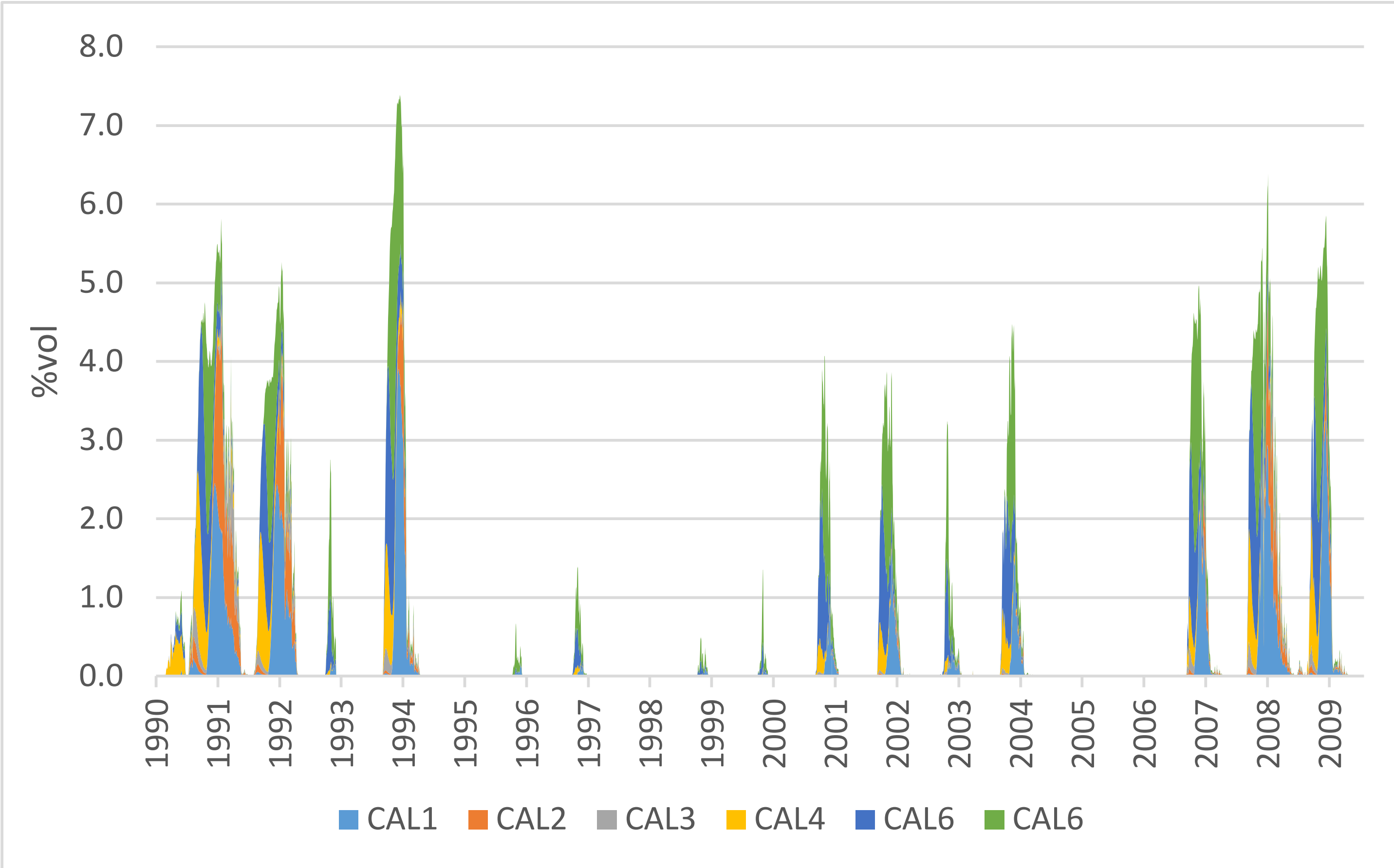
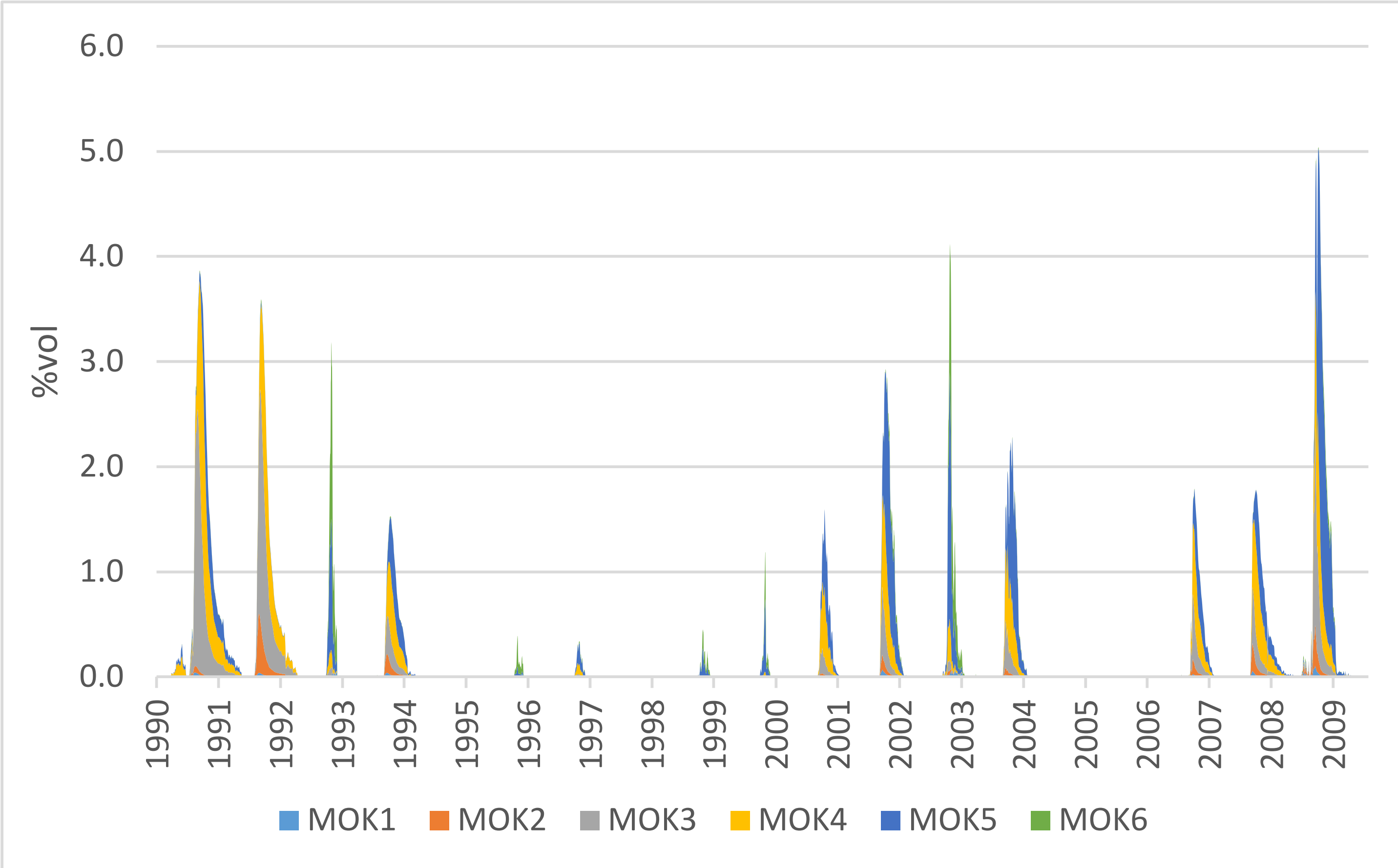
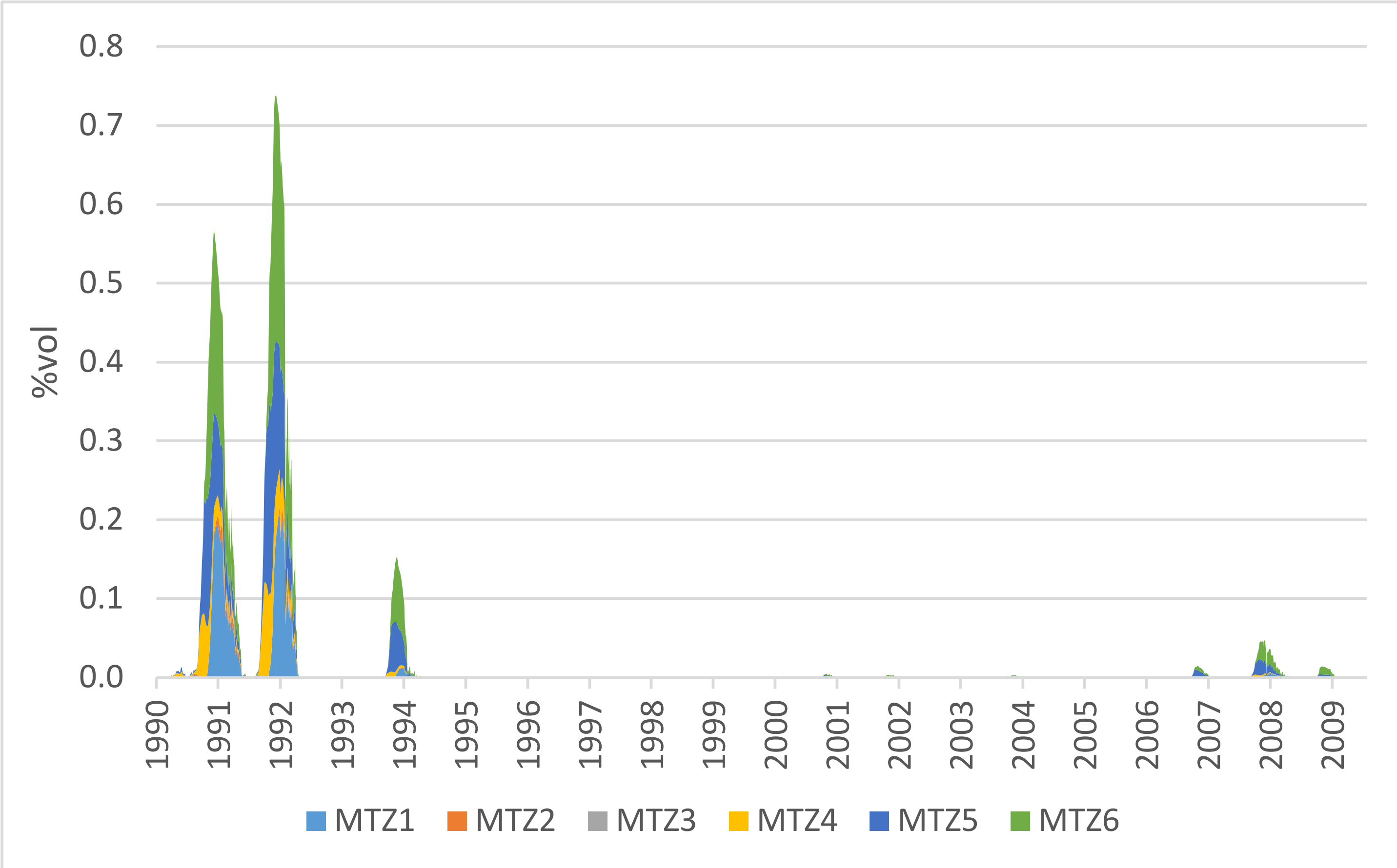
APPENDIX A
DSM2 SIMULATED VOLMETRIC CONTRIBUTION FROM BOUNDARY SOURCES TO CLIFTON COURT FOREBAY (CHSWP003)



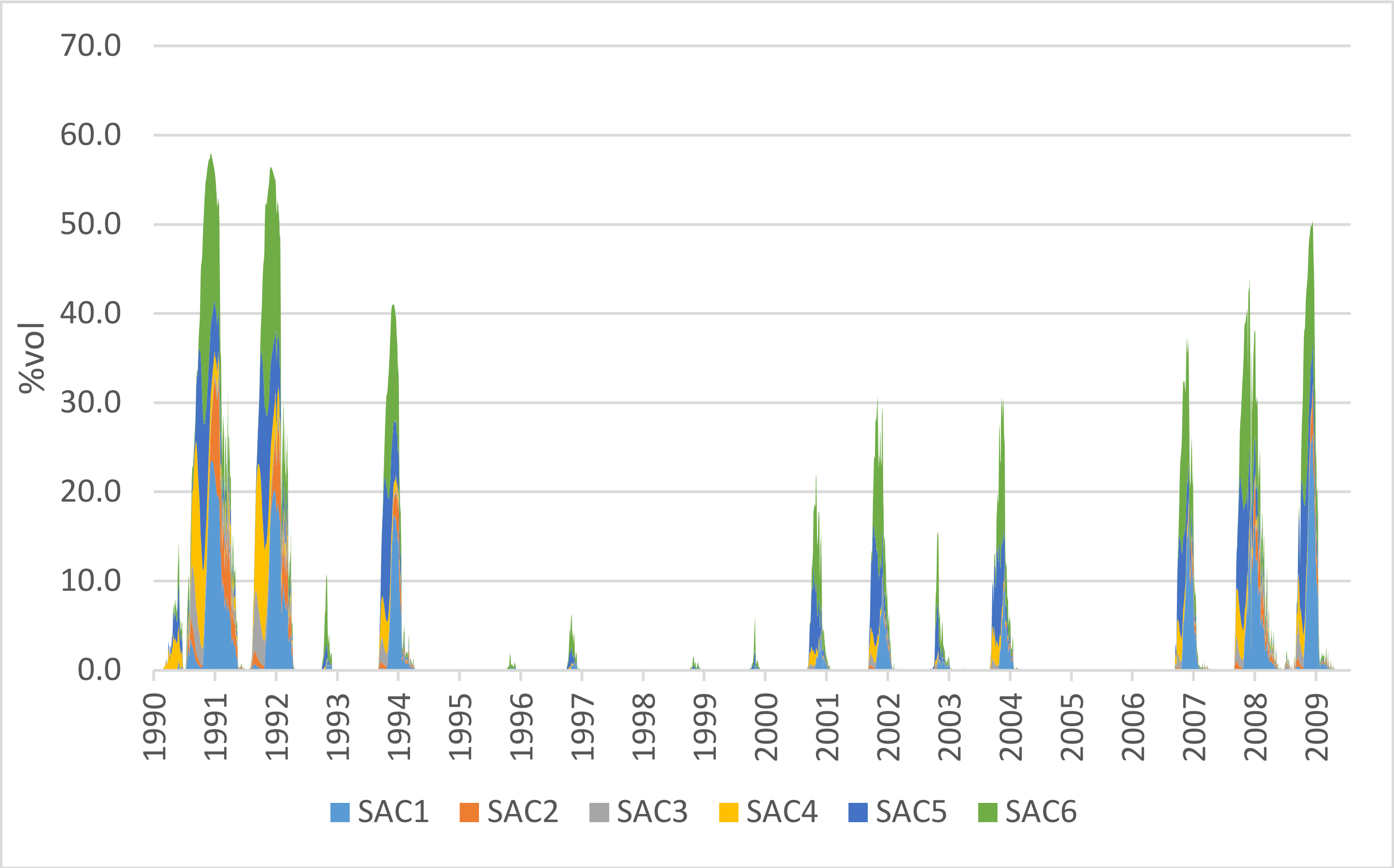
a) Contribution from Calaveras River



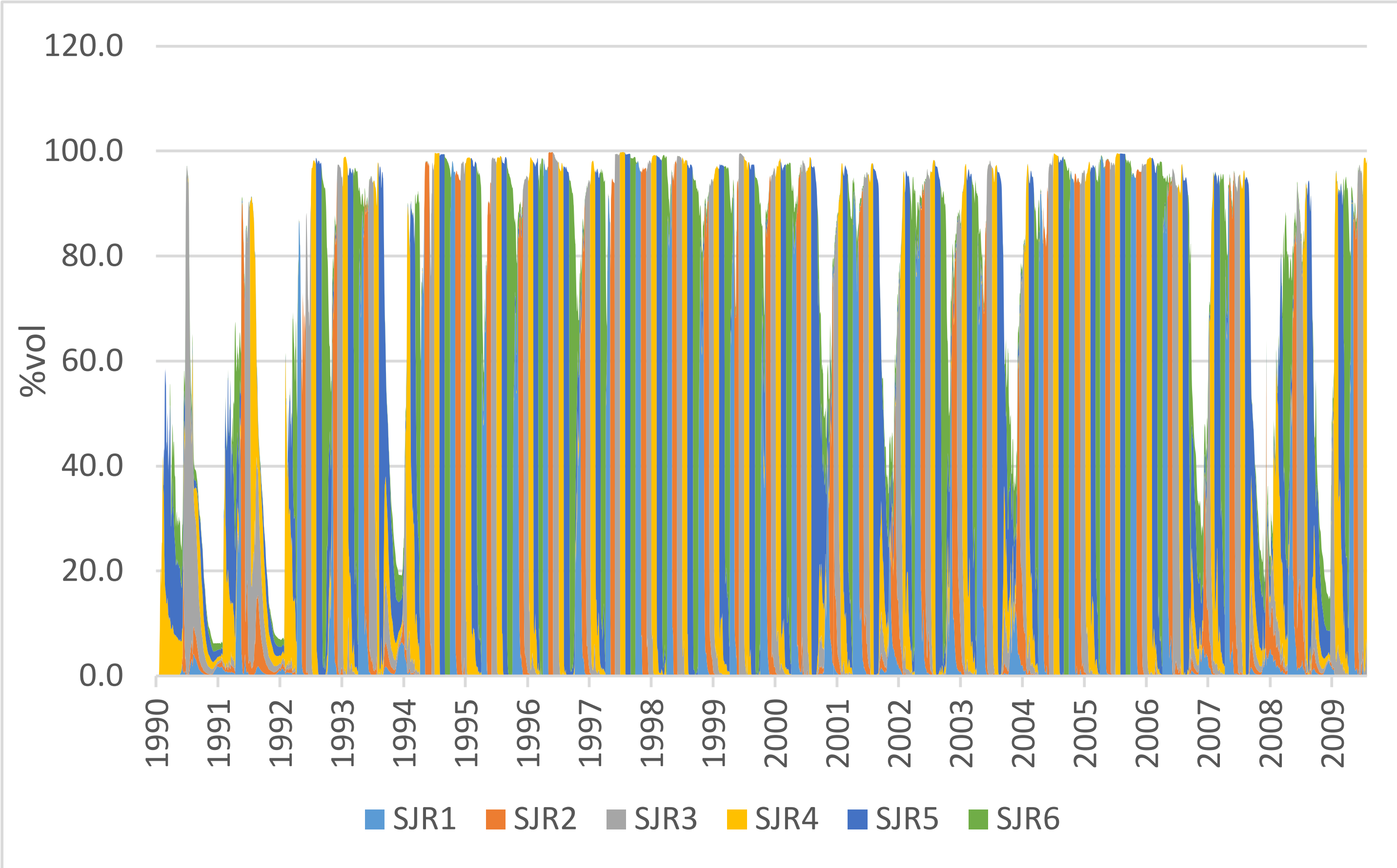
b) Contribution from Mokelumne River



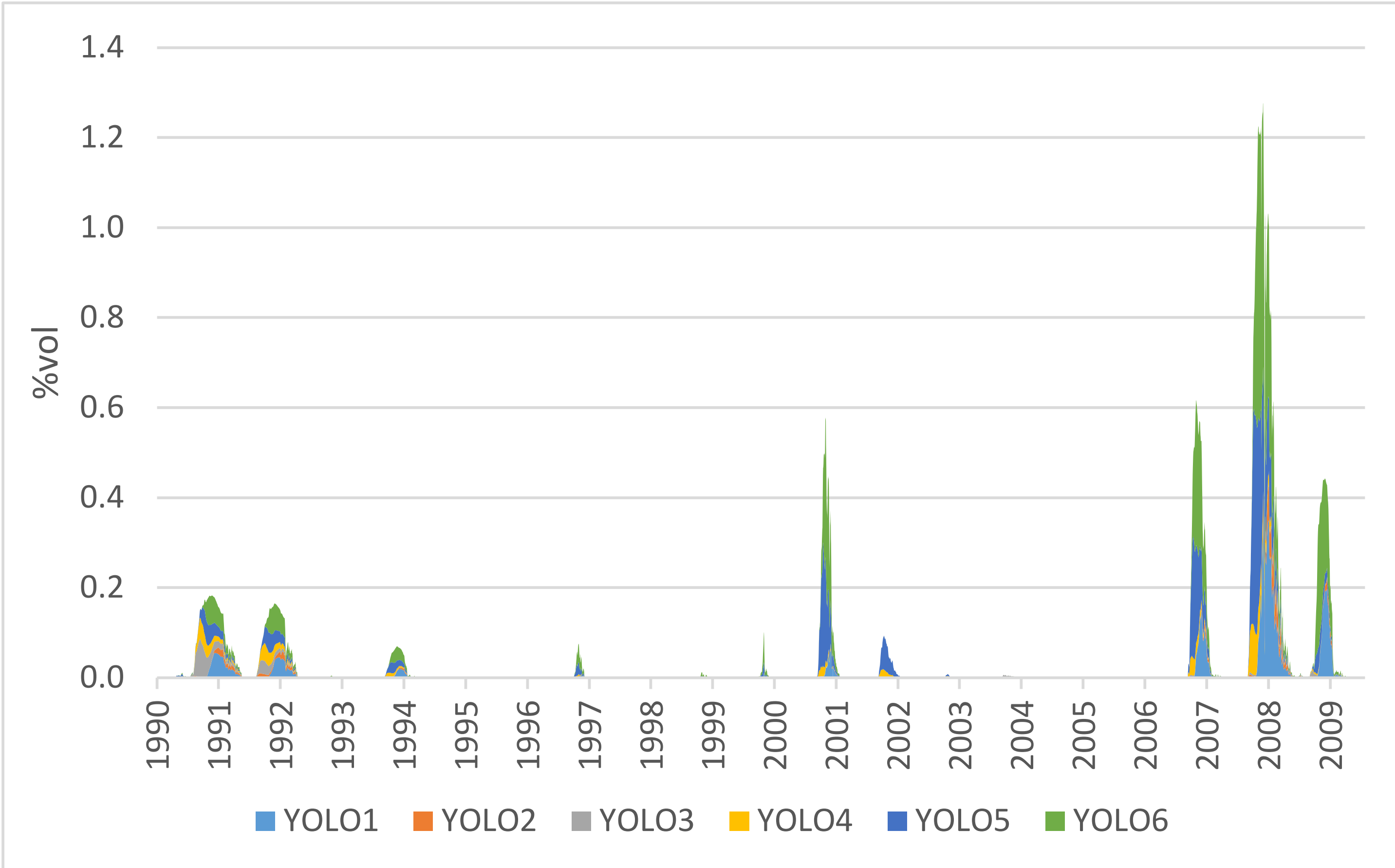
c) Contribution from Martinez



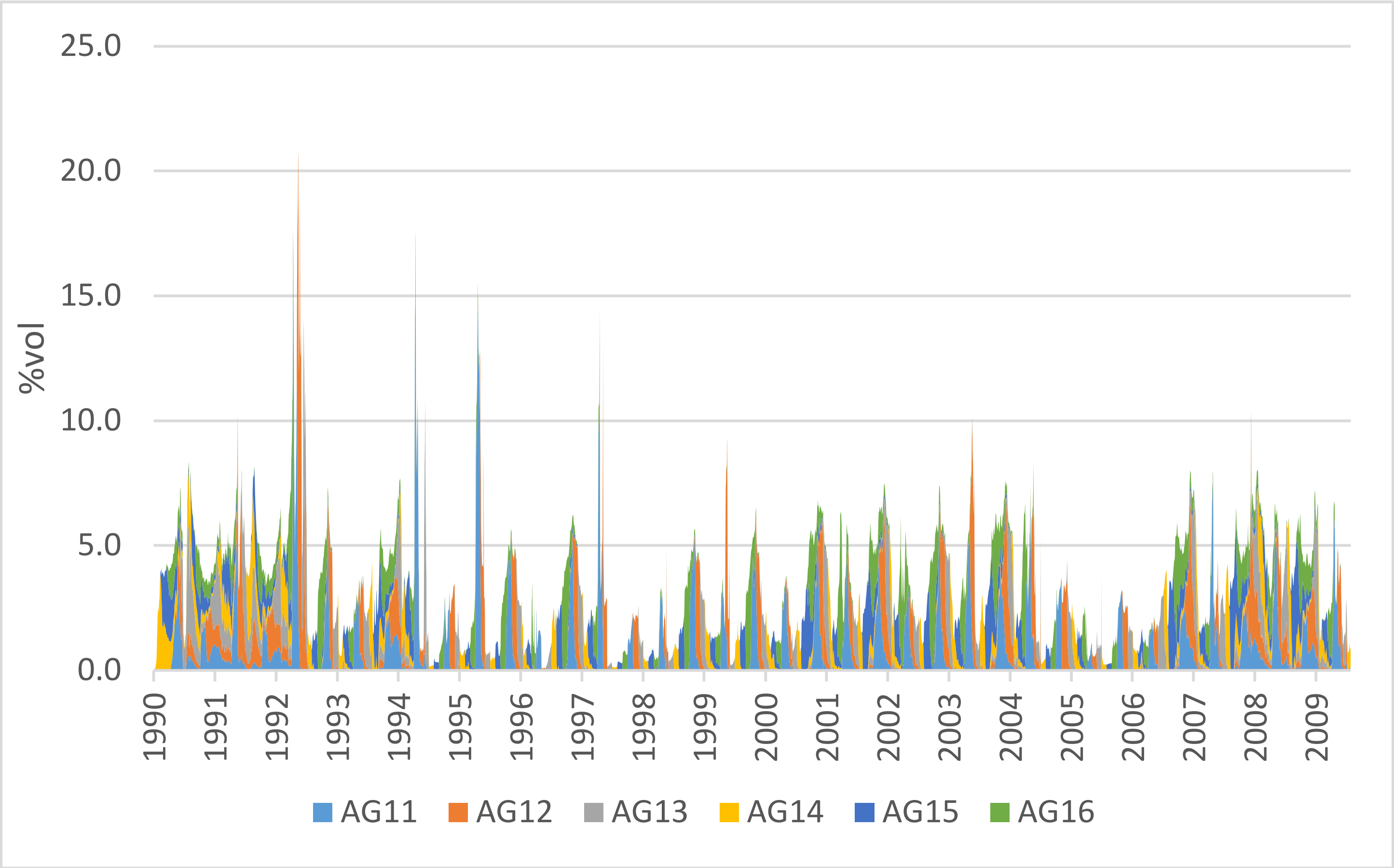
d) Contribution from Sacramento River



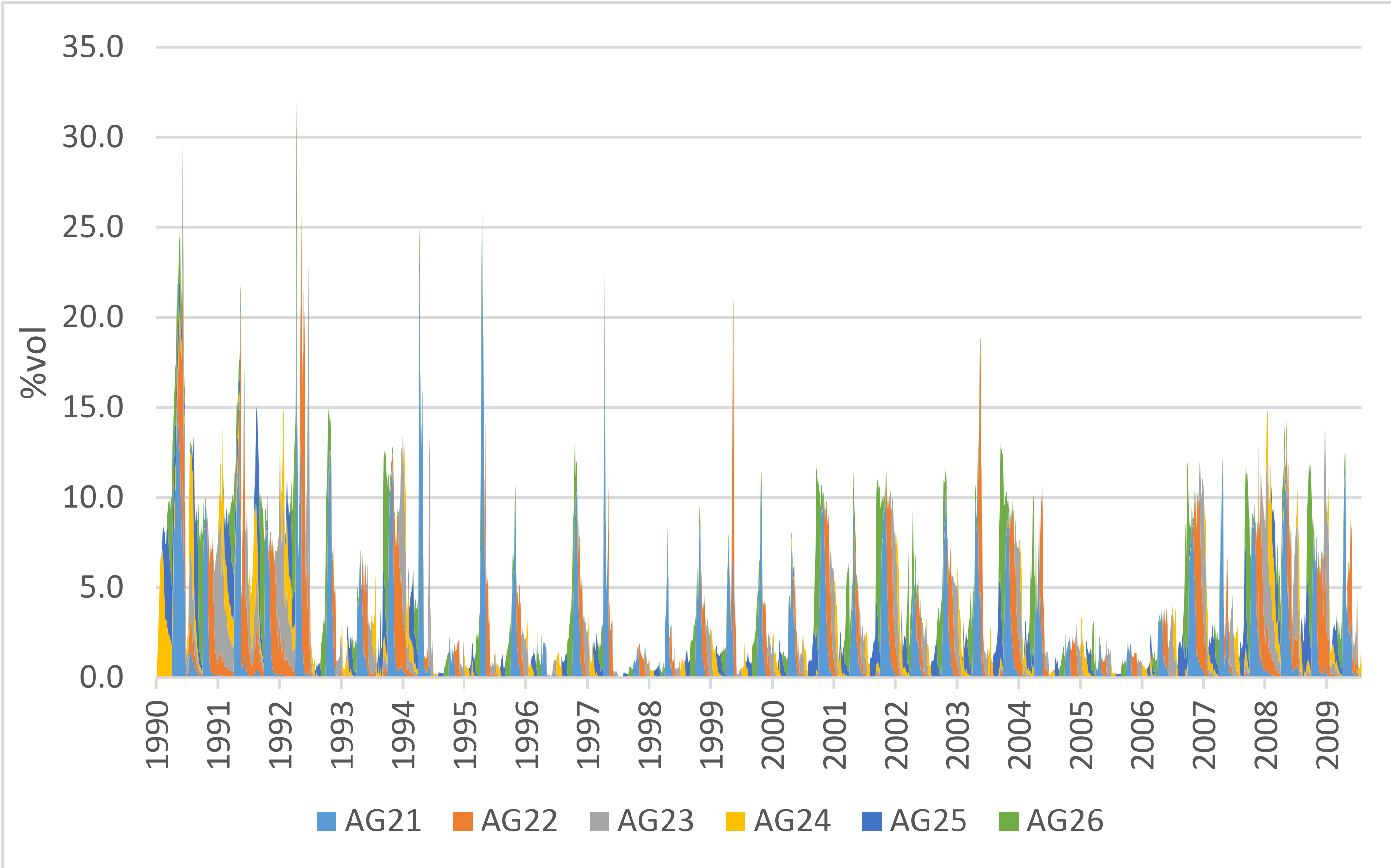
e) Contribution from San Joaquin River



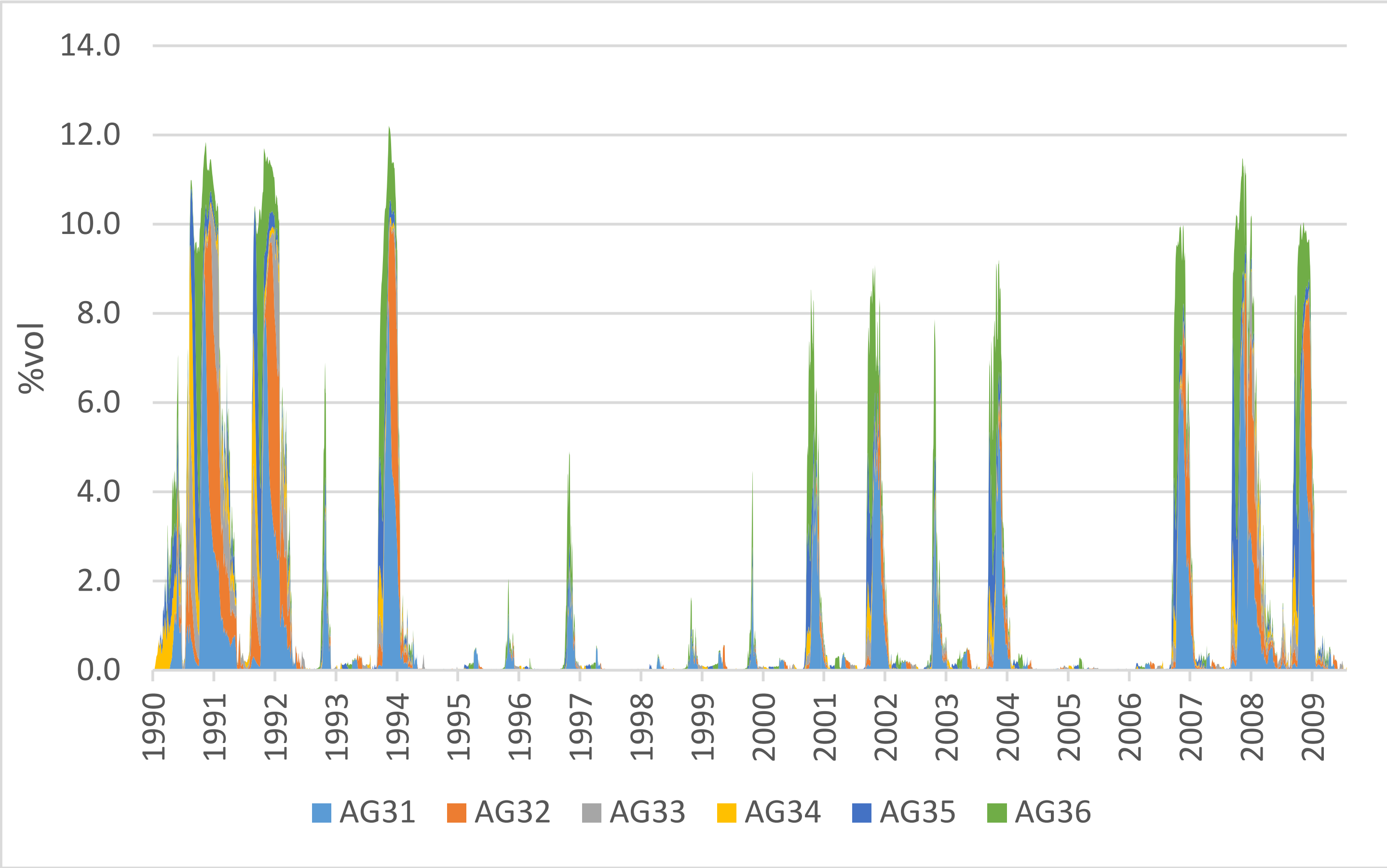
f) Contribution from Yolo Bypass



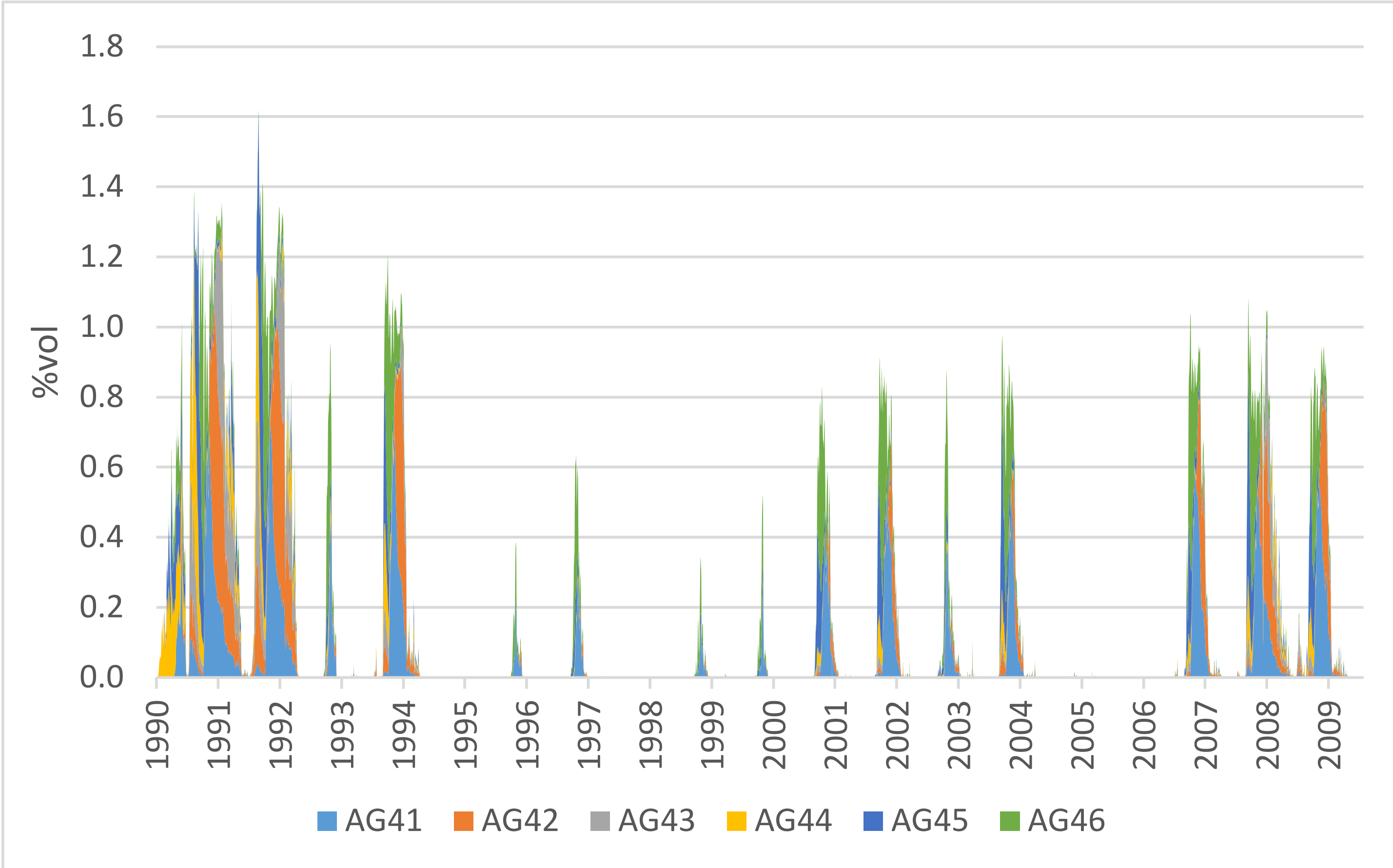
g) Contribution from DICU region 1



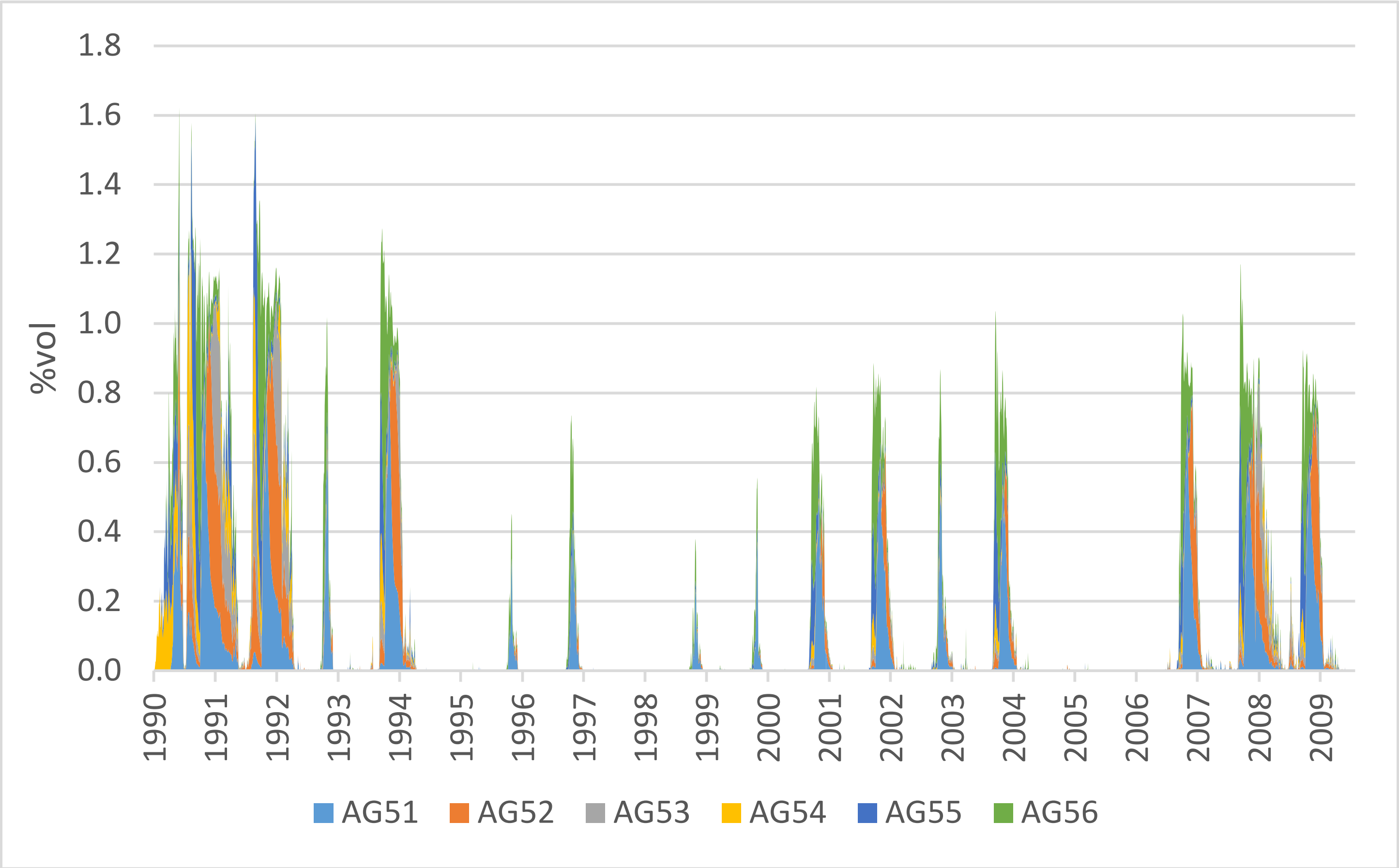
h) Contribution from DICU region 2



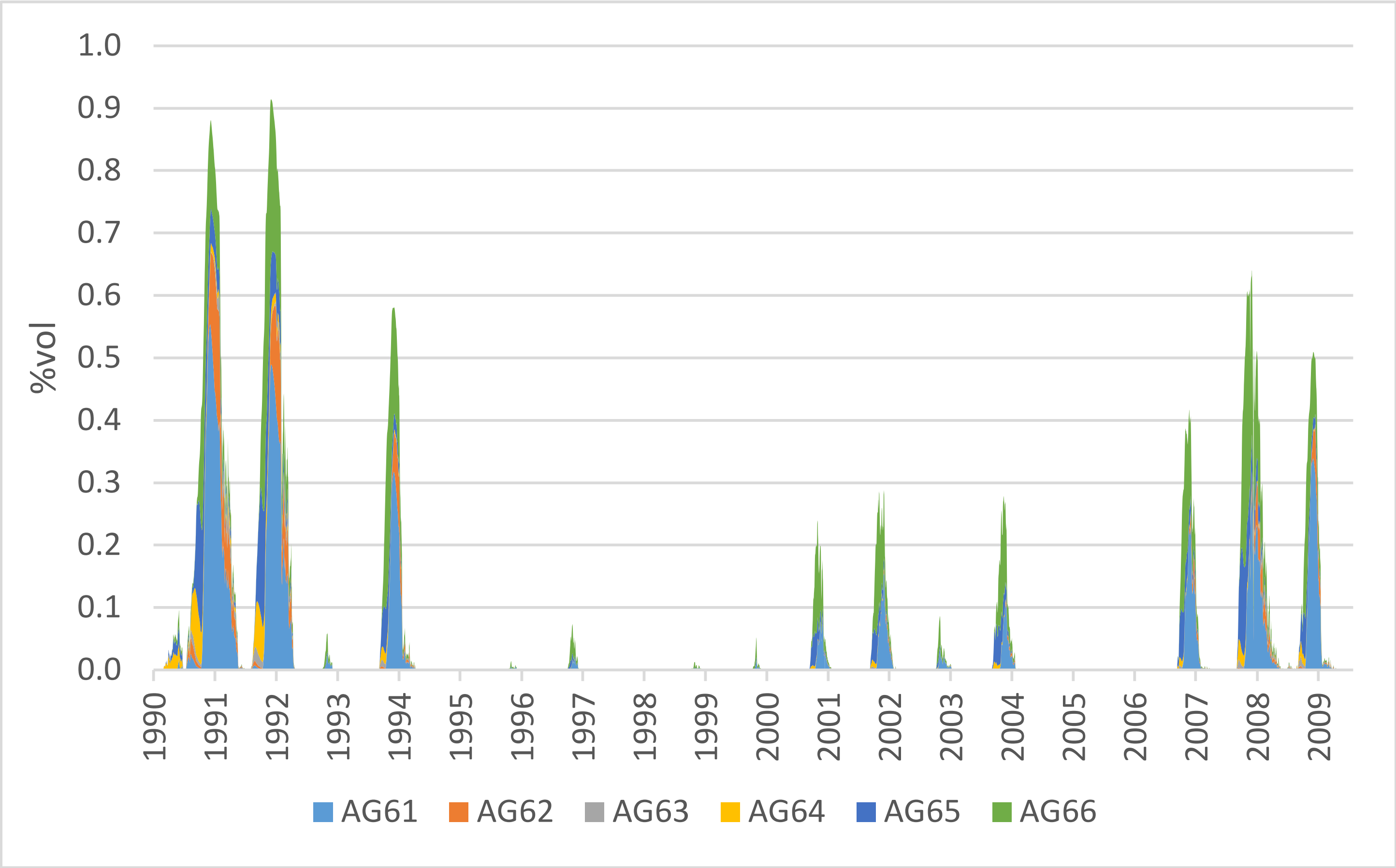
i) Contribution from DICU region 3



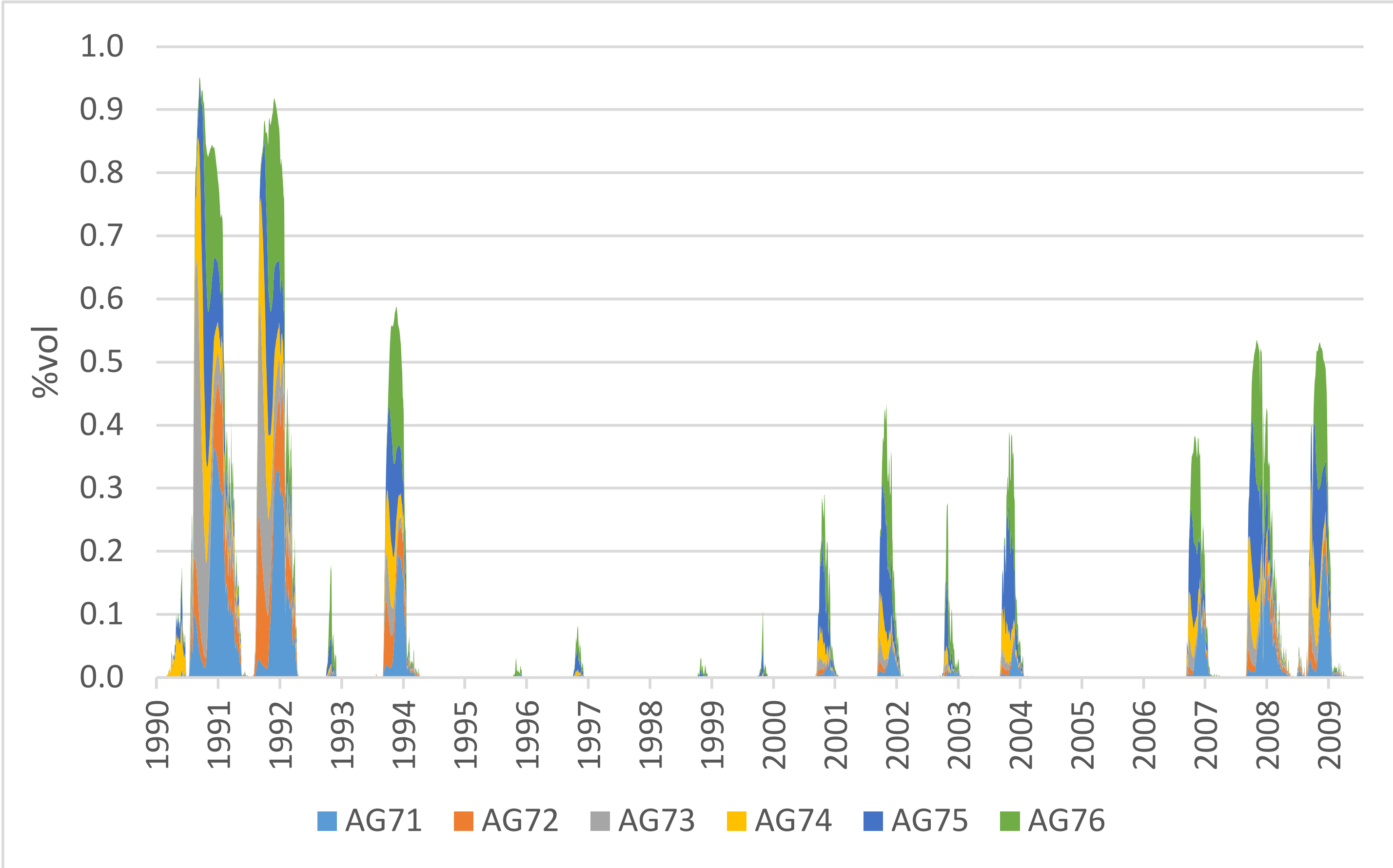
j) Contribution from DICU region 4



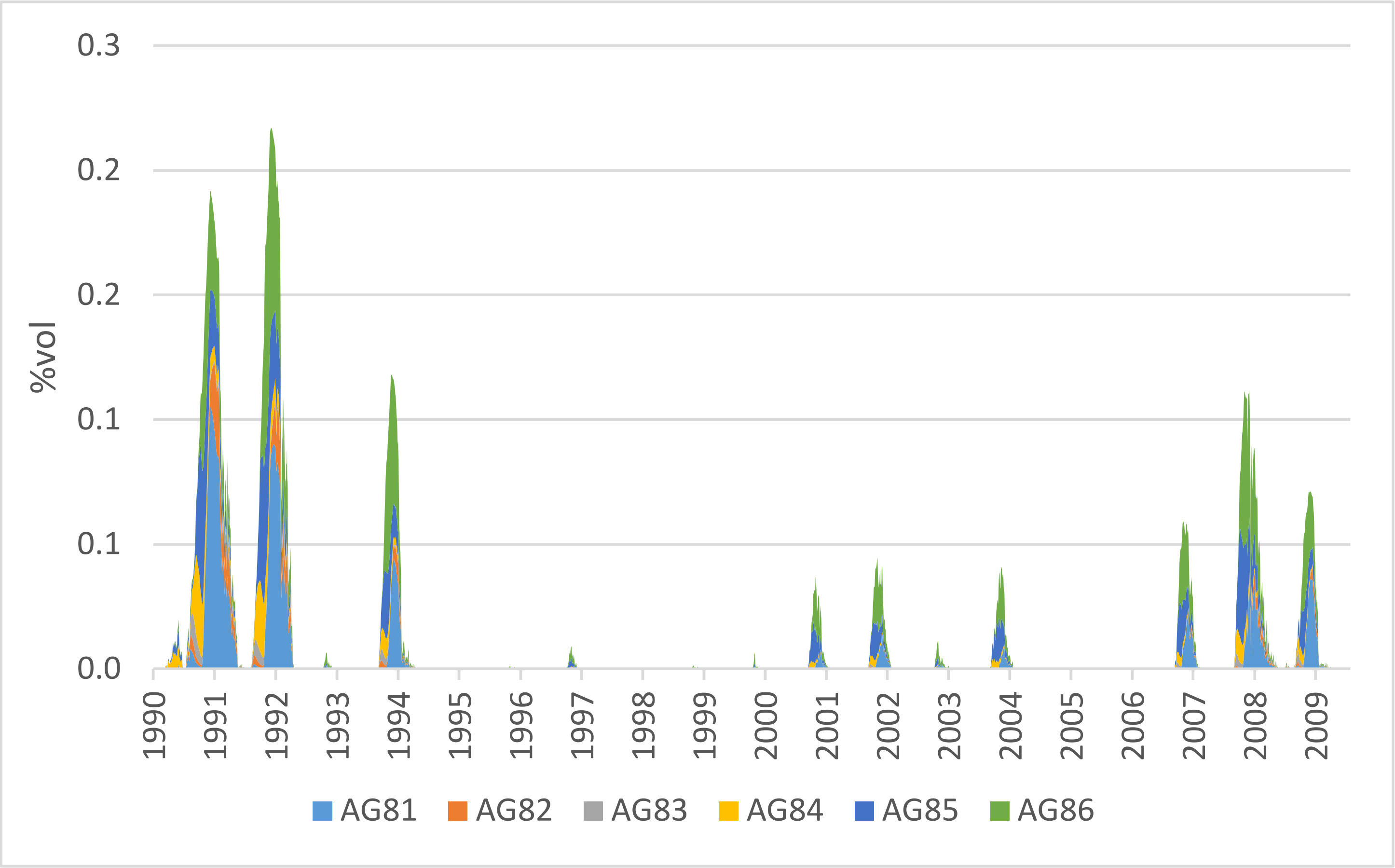
k) Contribution from DICU region 5



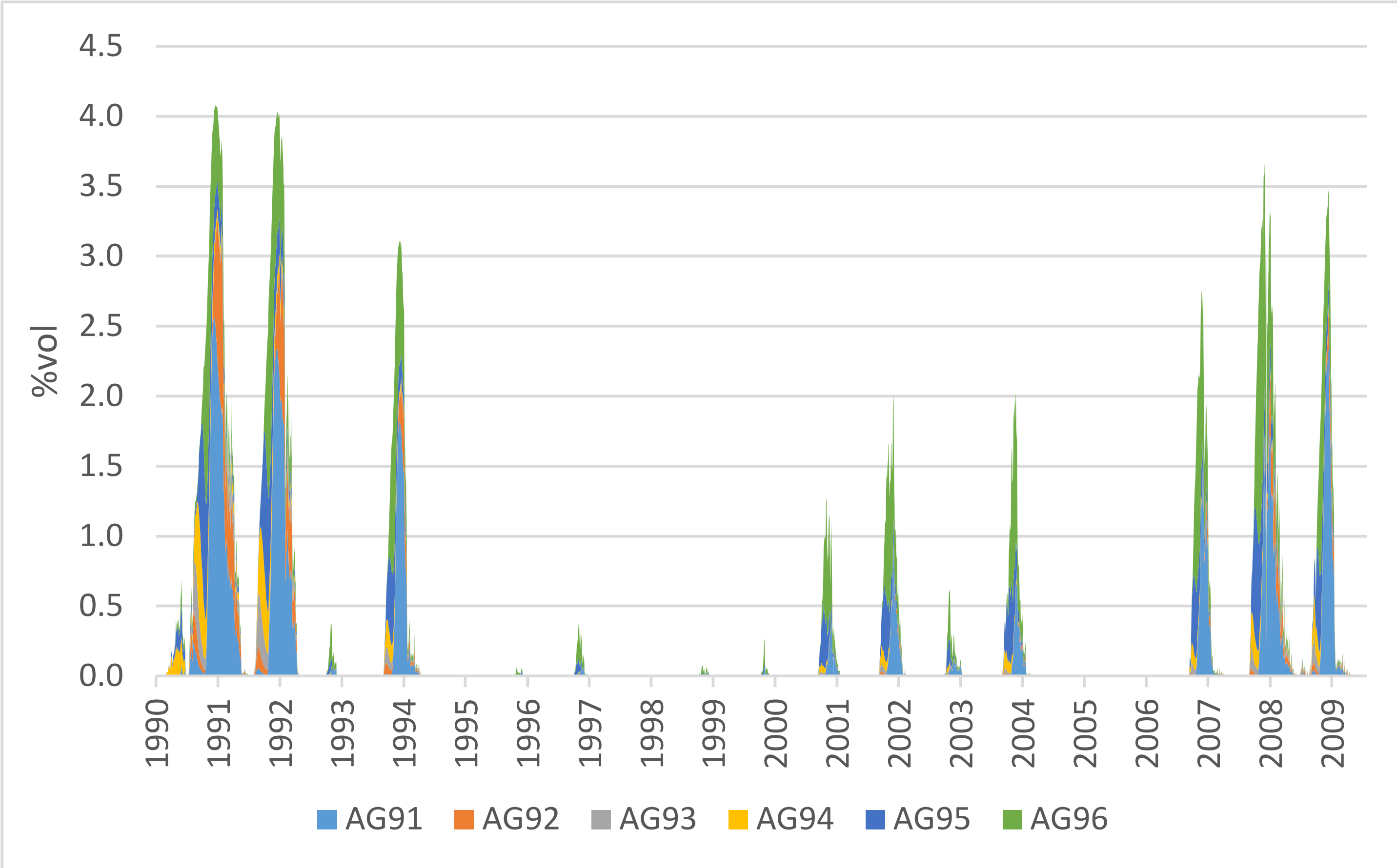
l) Contribution from DICU region 6



m) Contribution from DICU region 7



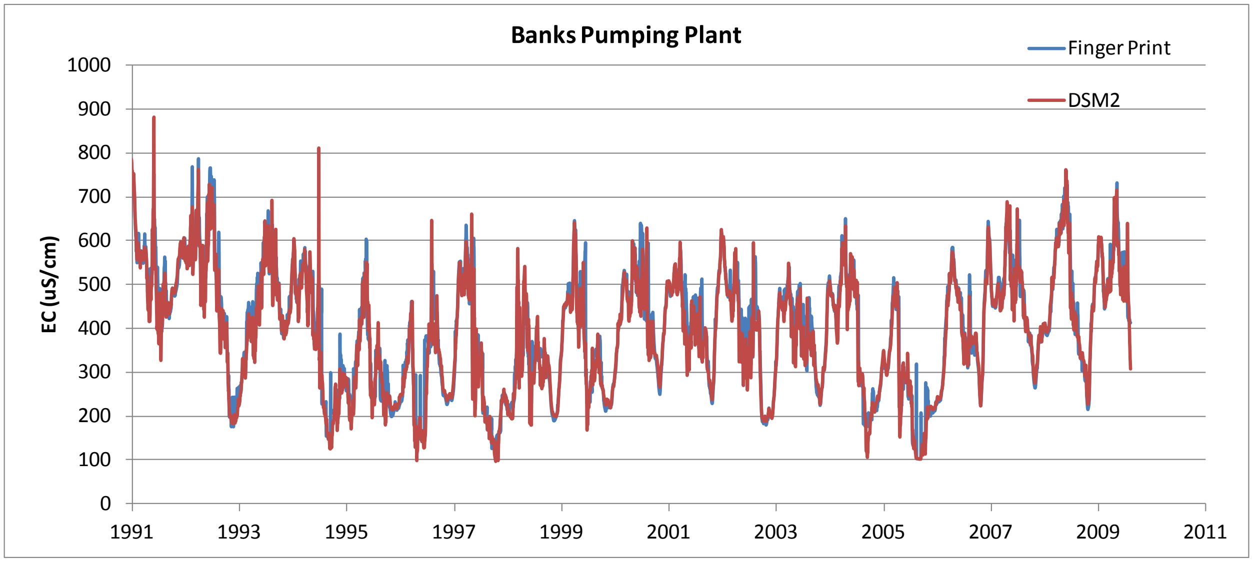
n) Contribution from DICU region 8



o) Contribution from DICU region 9

Figure A-1 *DSM2 simulate contribution to CHSWP (CCF) from: a) Calaveras River; b) Mokelumne River; c) Martinez; d) Sacramento River; e) San Joaquin River; f) Yolo Bypass, g) DICU region 1, h) DICU region 2, i) DICU region 3, j) DICU region 4, k) DICU region 5, l) DICU region 6, m) DICU region 7, n) DICU region 8, and o) DICU region 9 at six time steps.*

APPENDIX B
VALIDATION OF DSM2 FINGER PRINTING RESULTS VS DSM2 SIMULATED EC



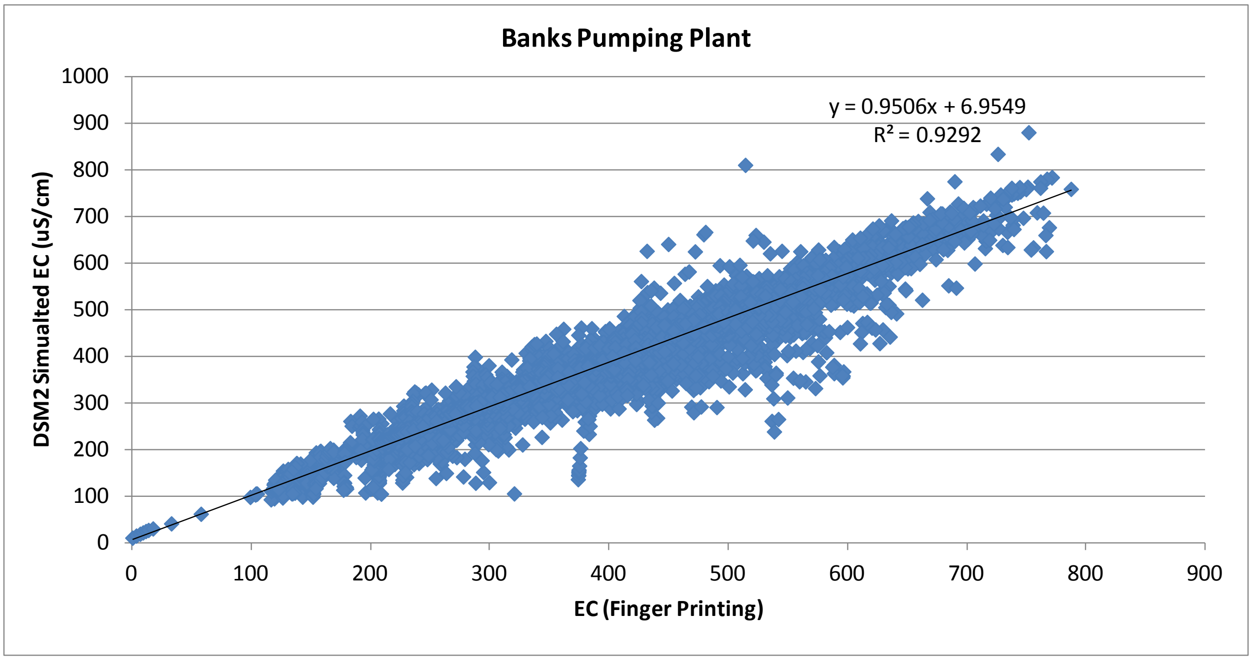
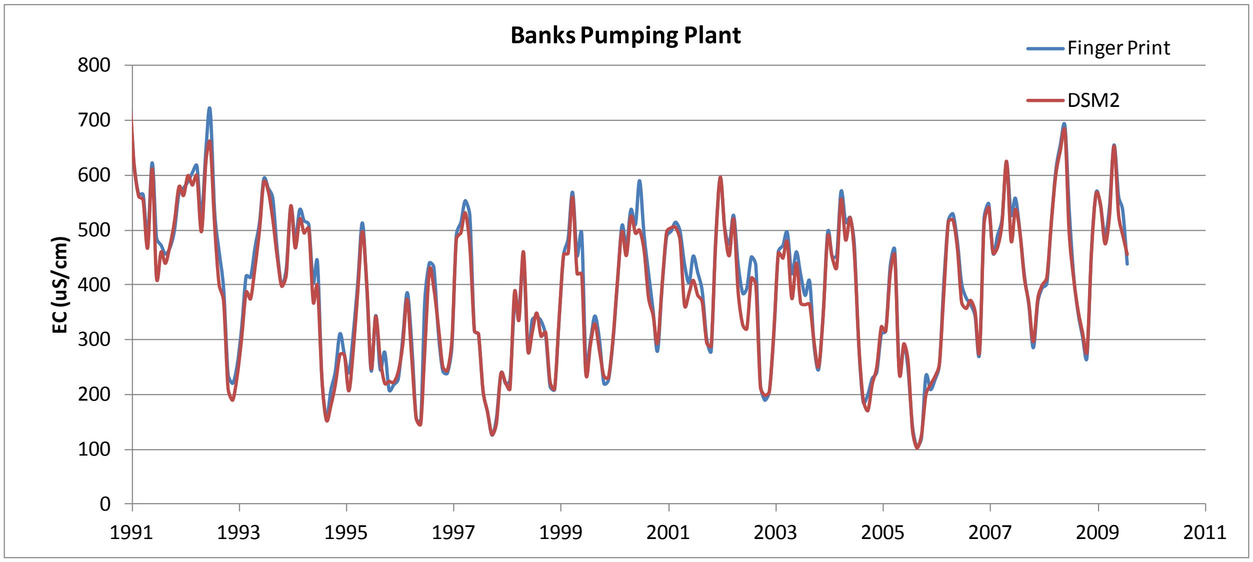


Figure B-1 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at CCF Intake (Banks Pumping Plant) (daily results)



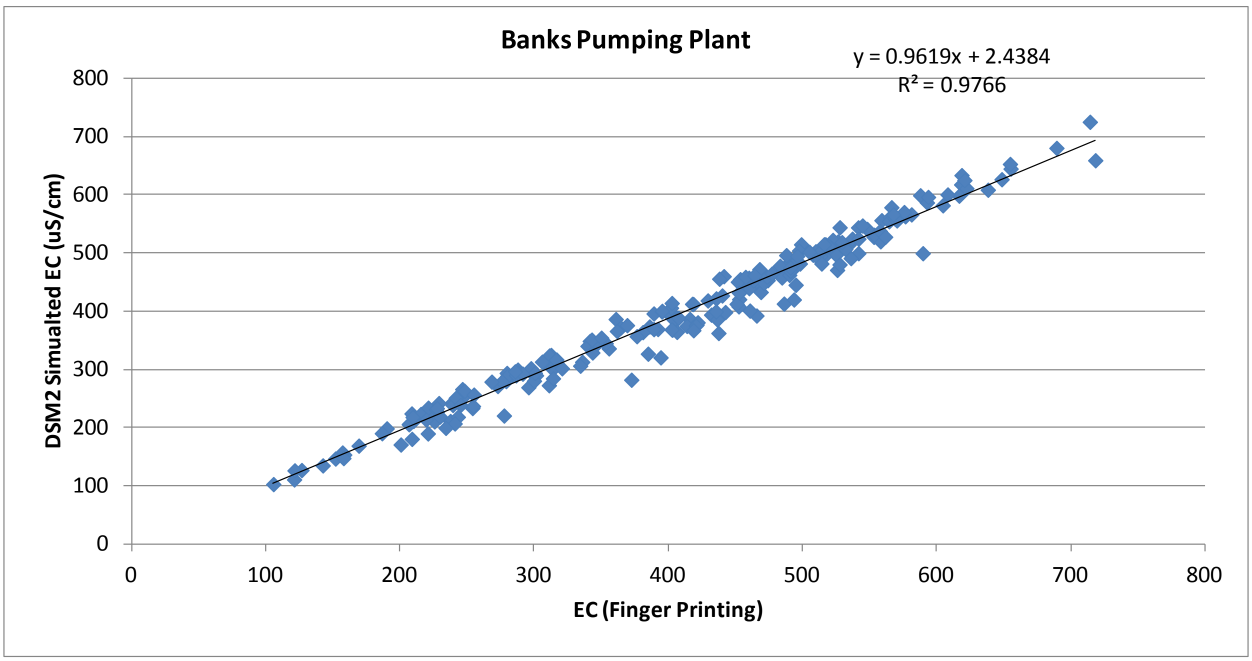
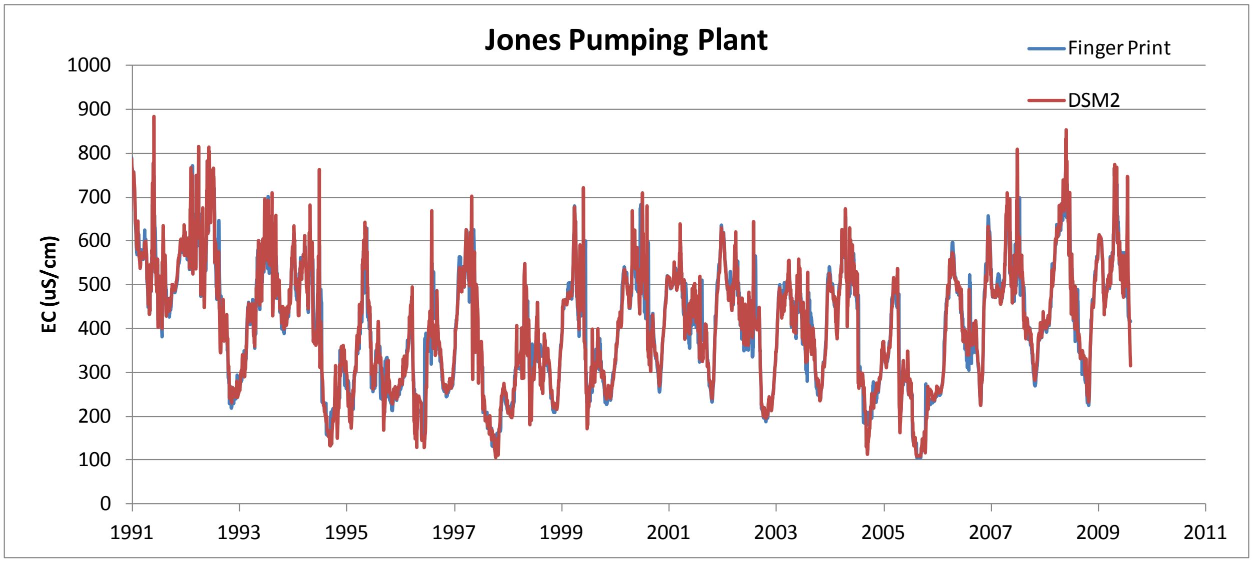


Figure B-2 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at CCF Intake (Banks Pumping Plant) (monthly results)



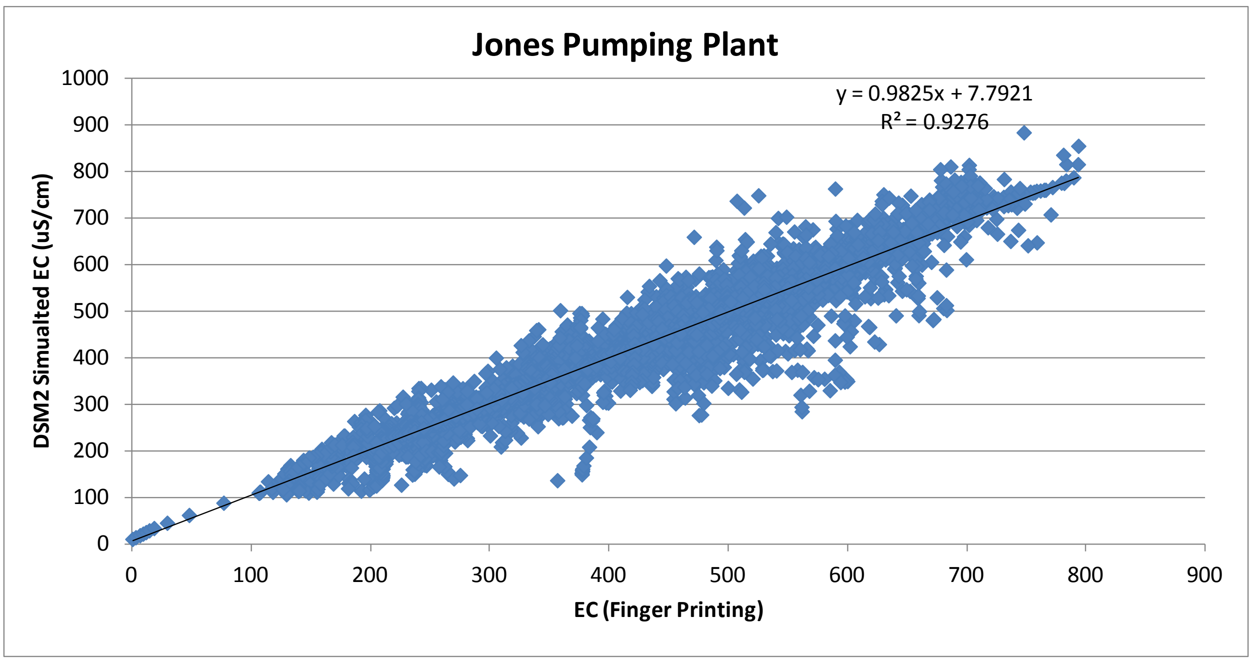
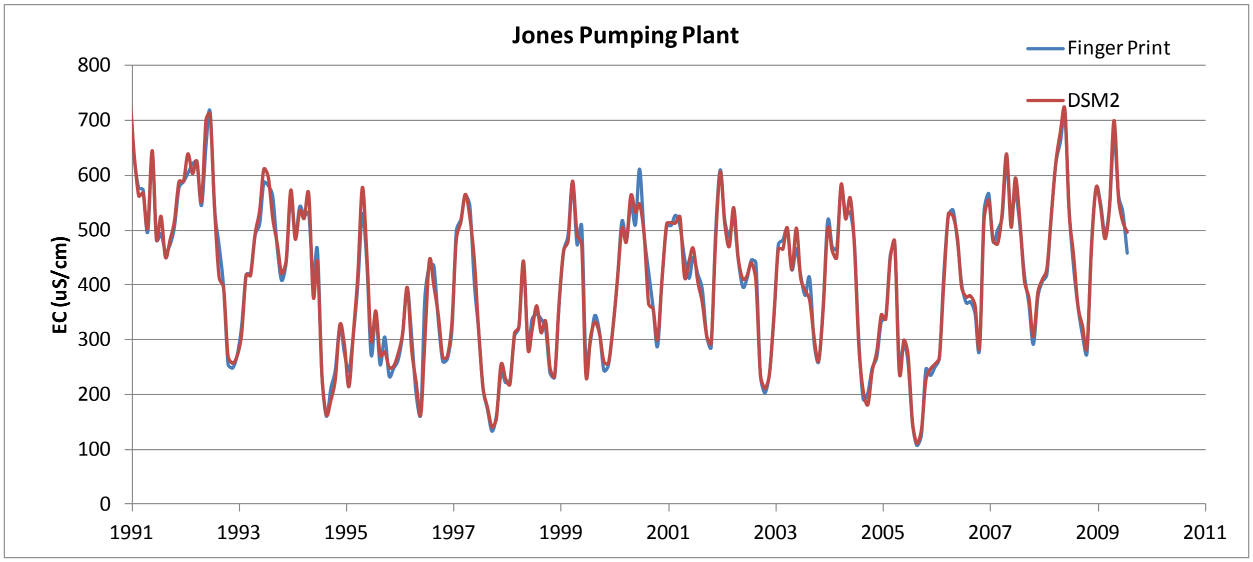


Figure B-3 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Jones Pumping Plant (daily results)



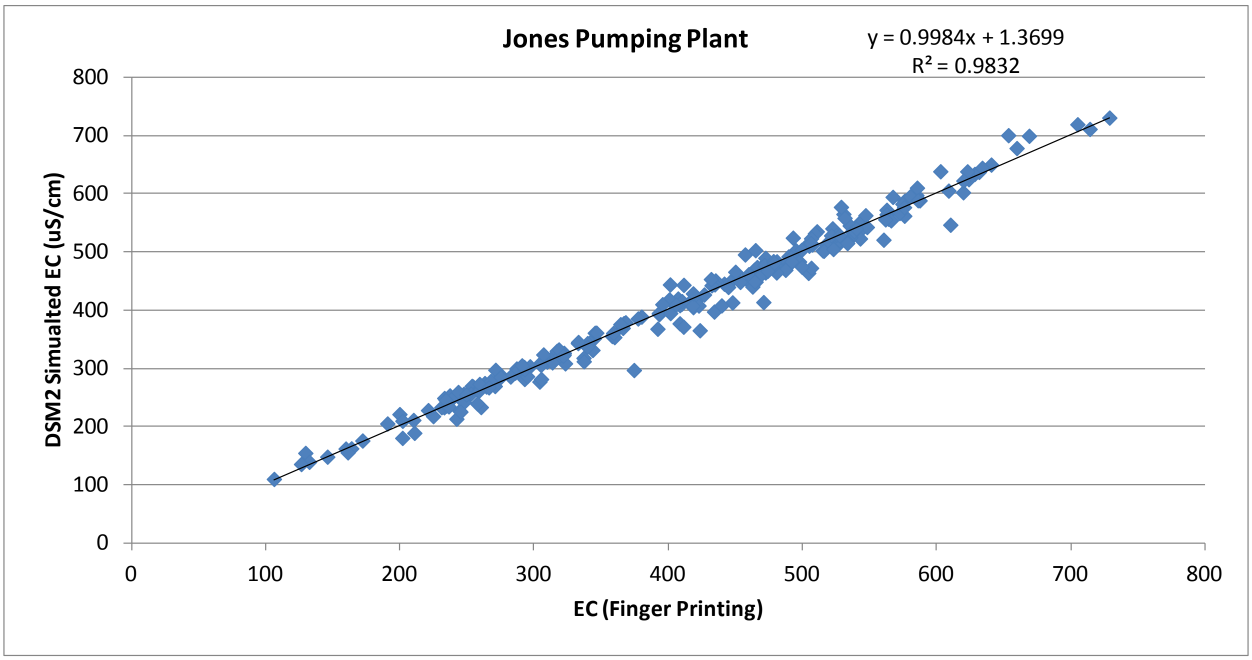
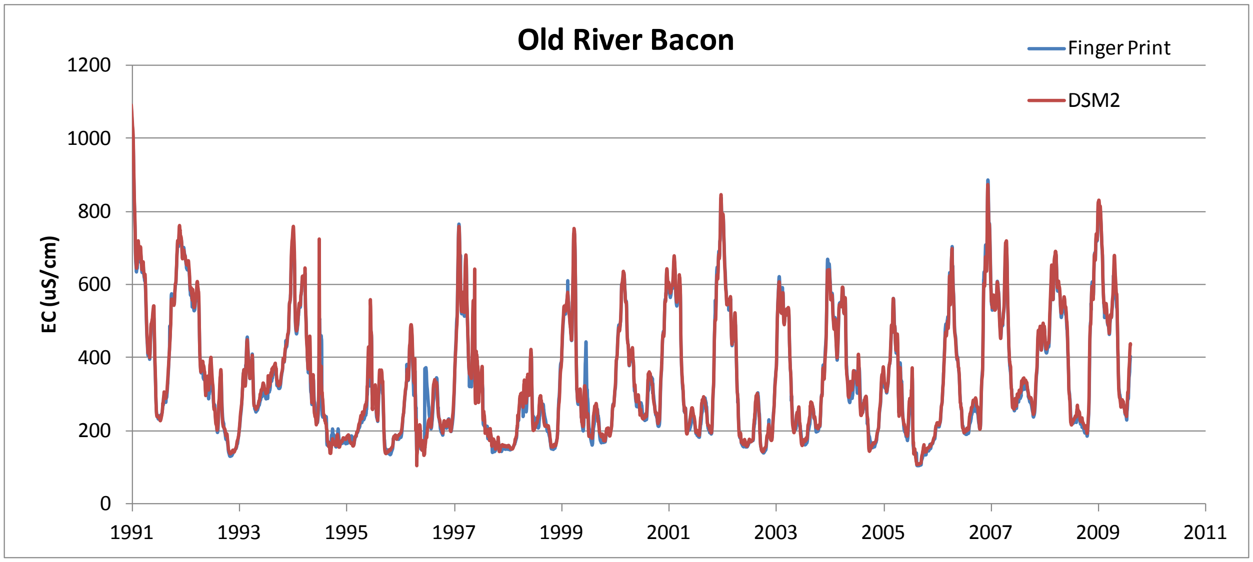


Figure B-4 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Jones Pumping Plant (monthly results)



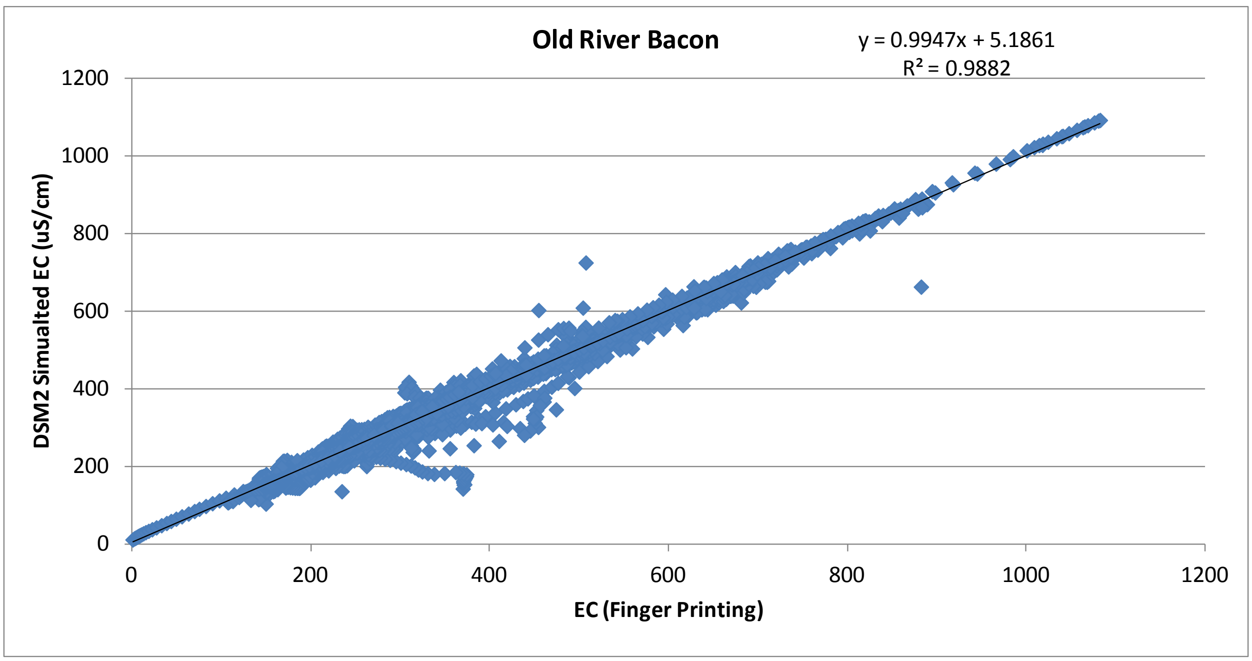
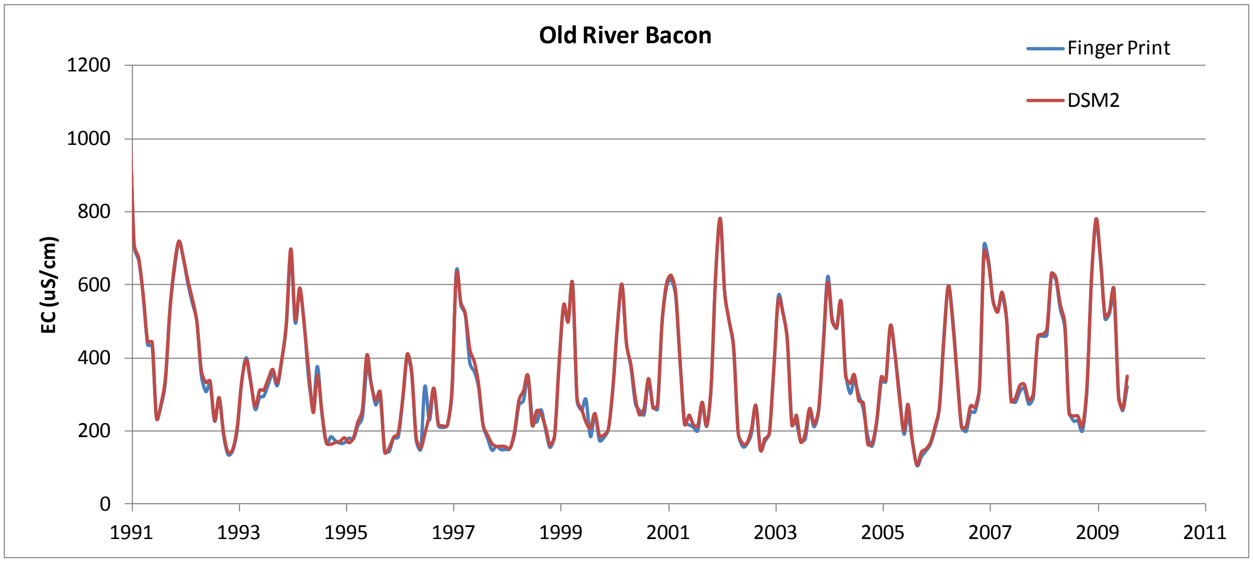


Figure B-5 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Old River Bacon (daily results)



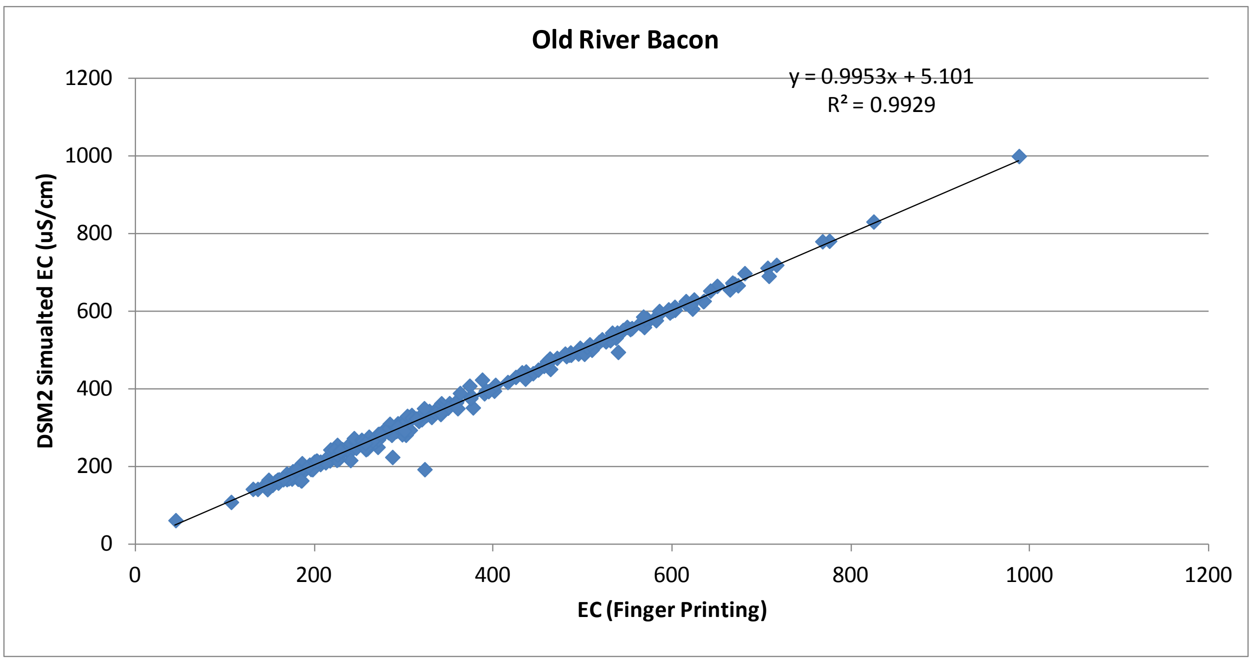


Figure B-6 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Old River Bacon (monthly results)

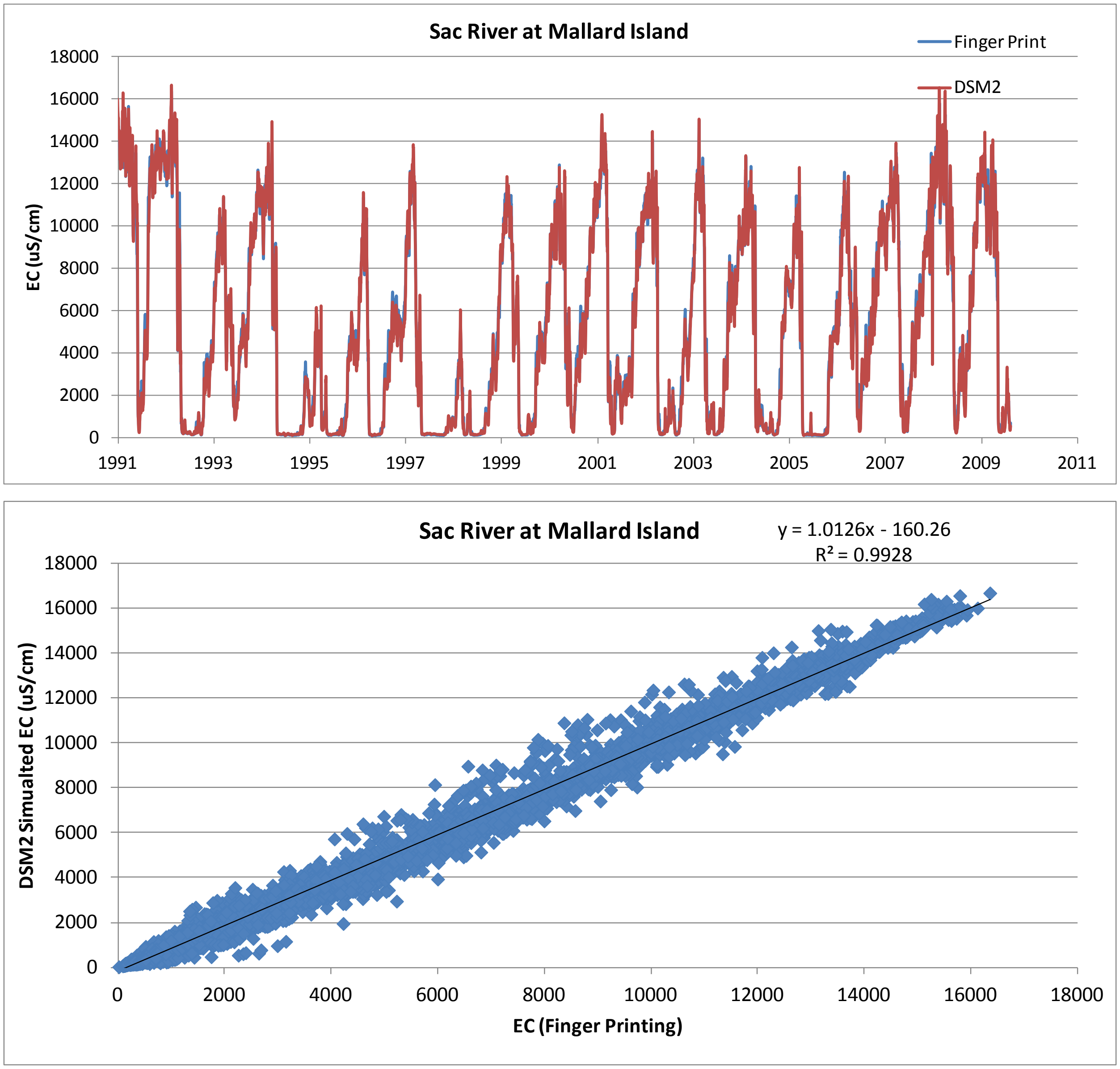
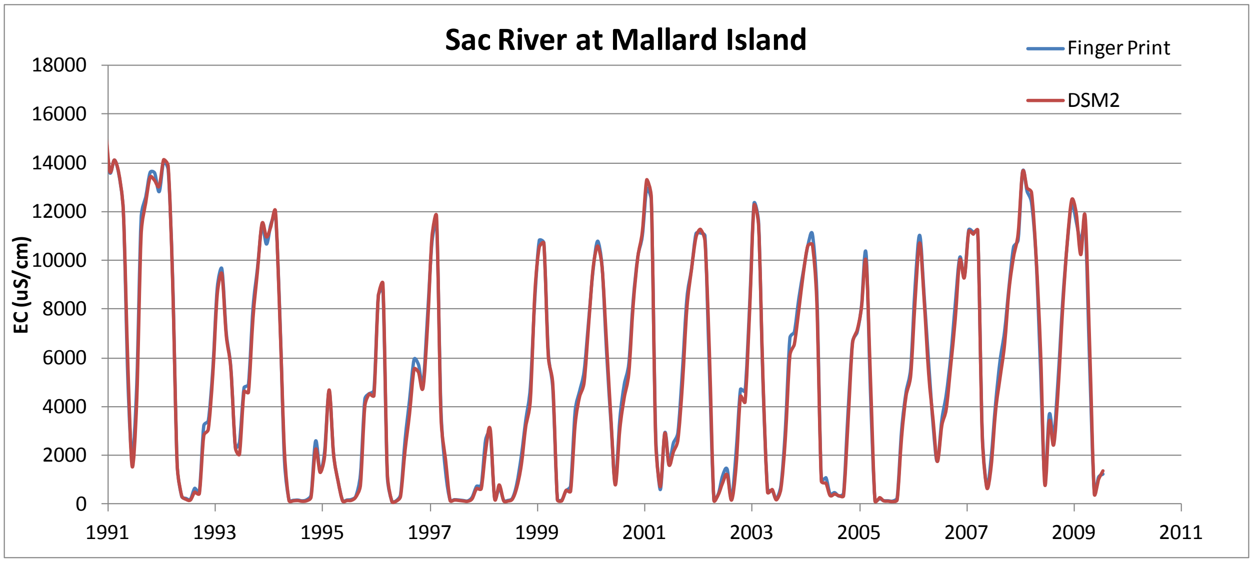


Figure B-7 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Sacramento River at Mallard Island (daily results)



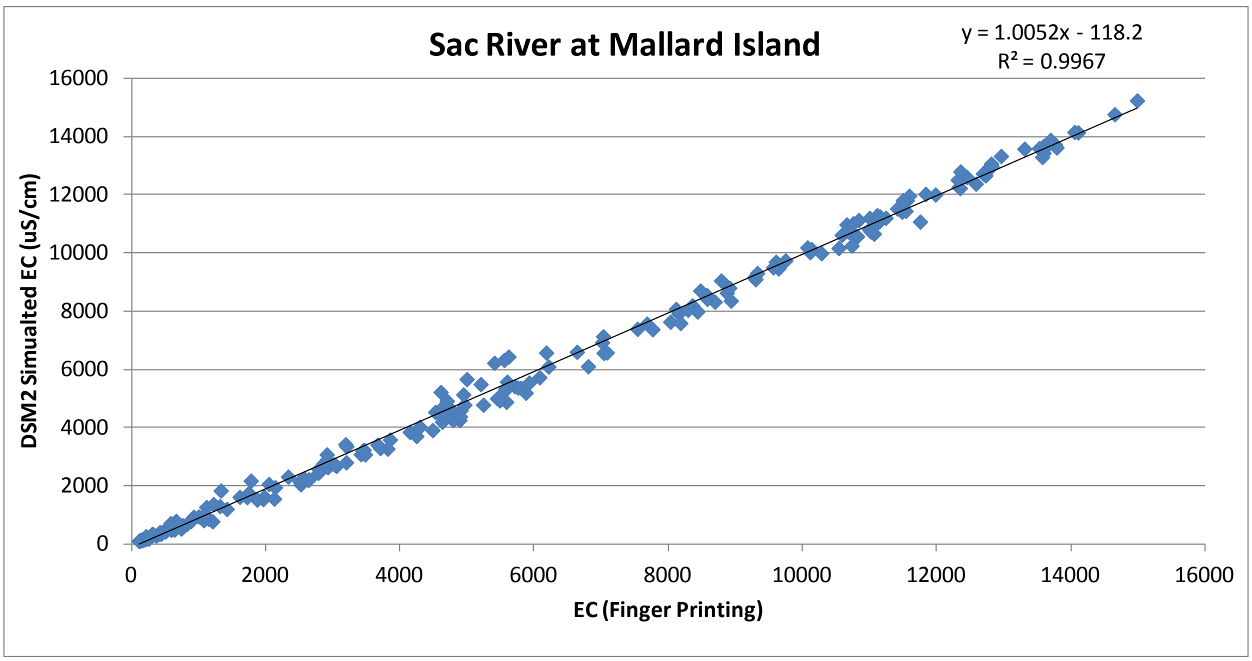


Figure B-8 *Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at Sacramento River at Mallard Island (monthly results)*

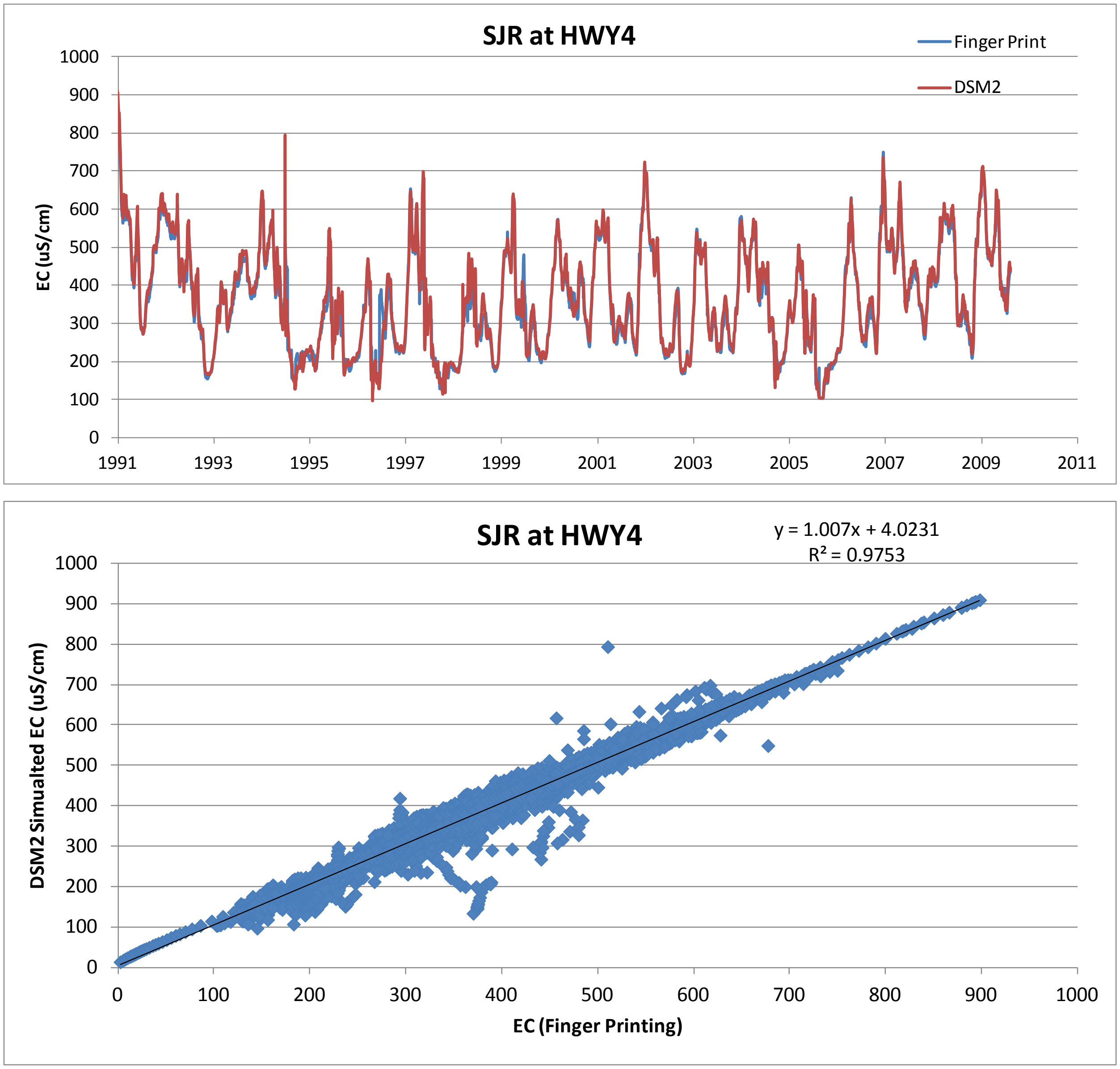
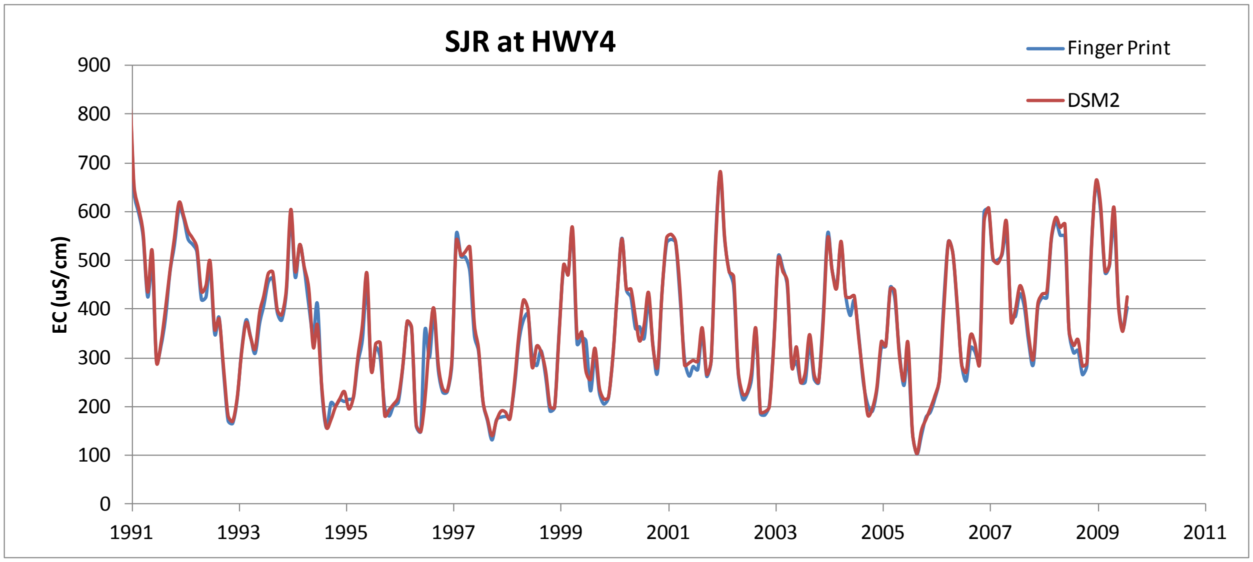


Figure B-9 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at San Joaquin River at Highway 4 (daily results)



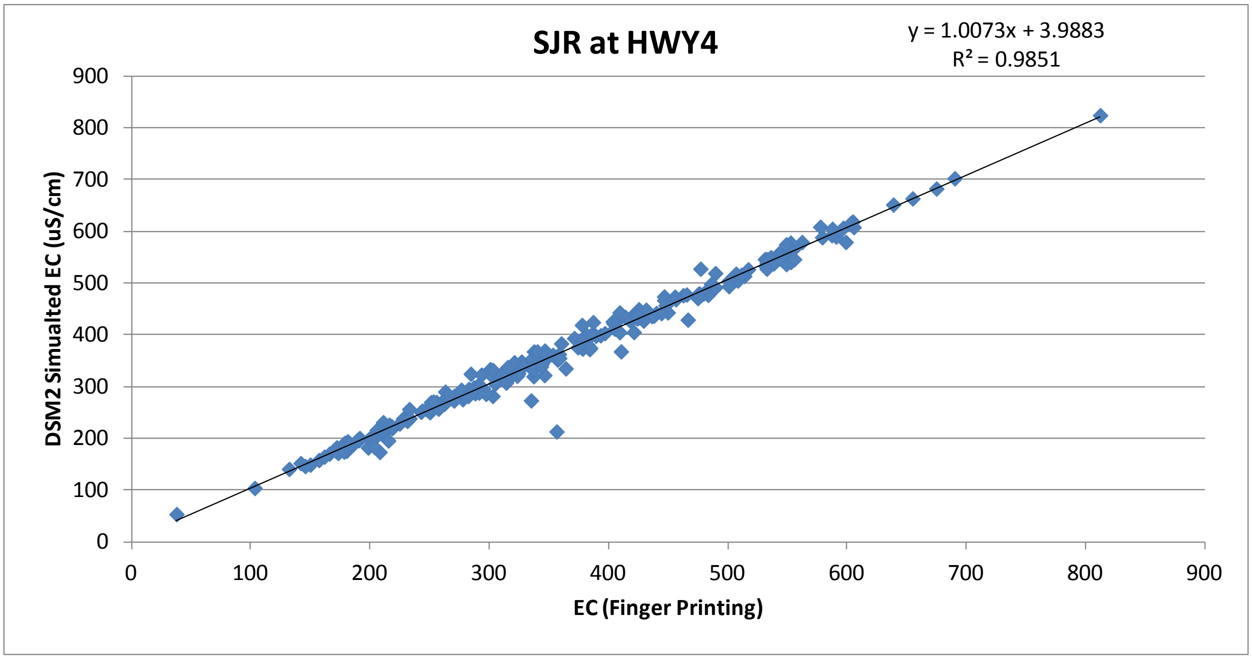
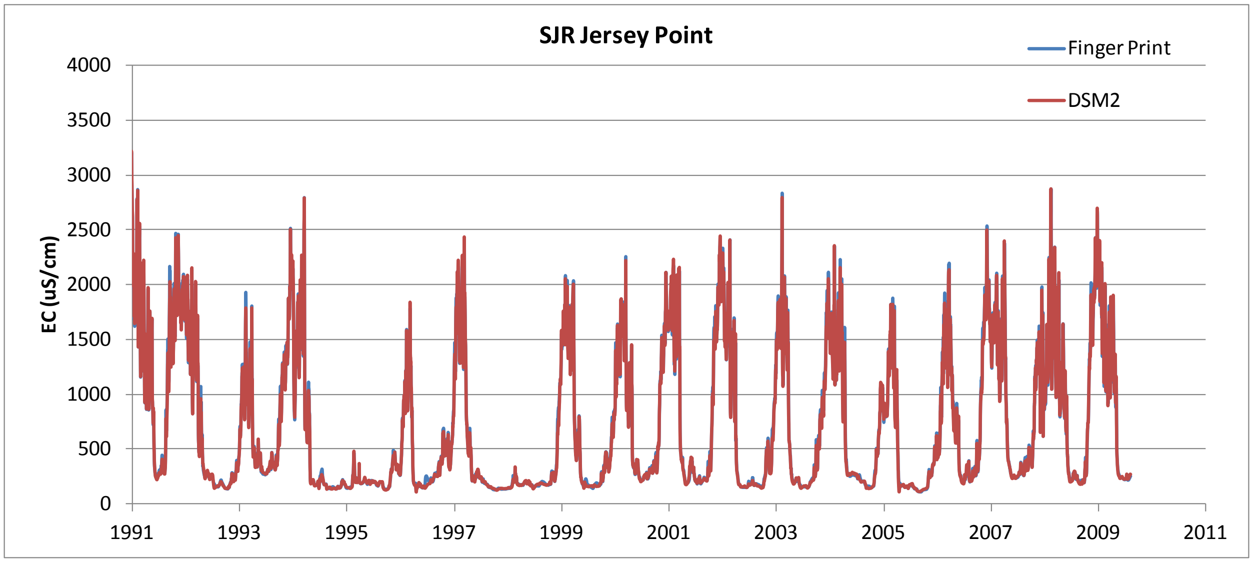


Figure B-10 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at San Joaquin River at Highway 4 (monthly results)



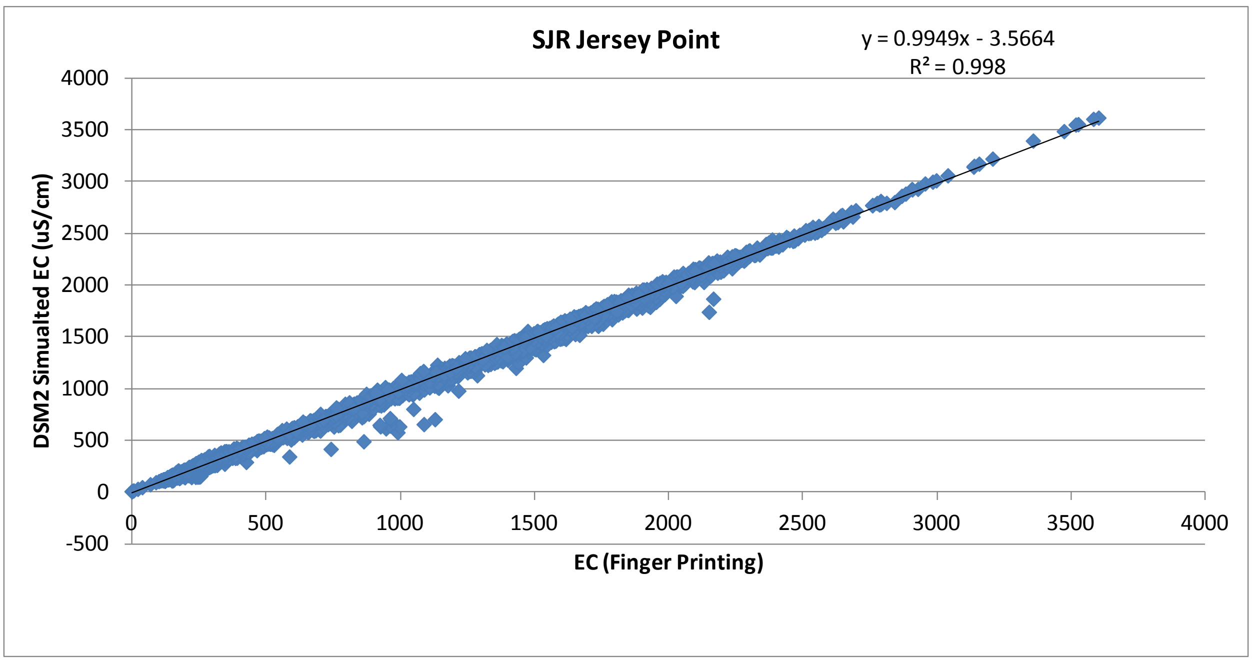
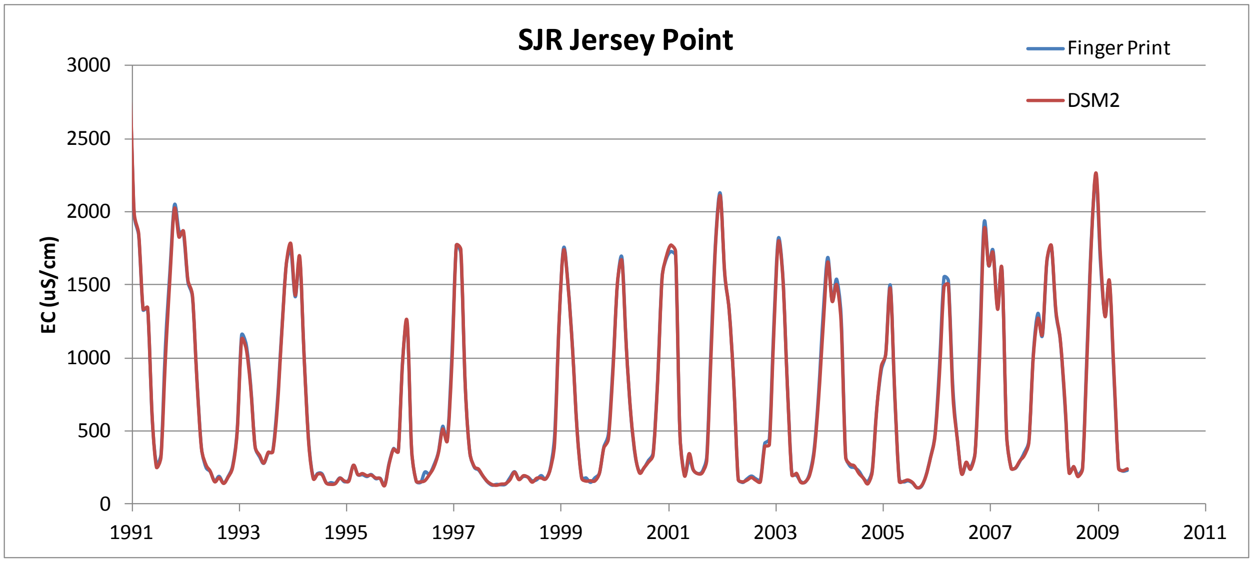


Figure B-11 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at San Joaquin River at Jersey Point (daily results)



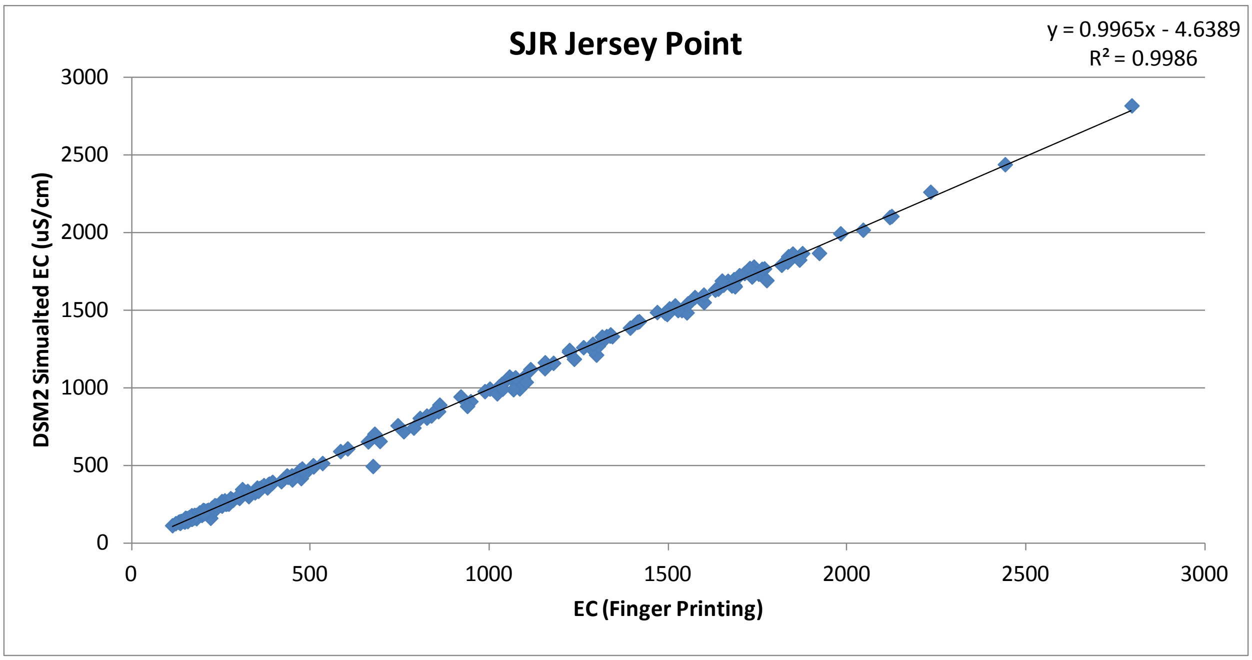


Figure B-12 Validation of EC estimated from DSM2 finger printing results against DSM2 simulated EC at San Joaquin River at Jersey Point (monthly results)

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APPENDIX C
COMPARISON OF ANN AND DSM2 SIMULATED VOLUMETRIC CONTRIBUTION AT TWO EXAMPLE LOCATIONS (CCF AND ANTIOCH)

This appendix presents time series and scatterplot comparisons of DSM2 results and ANN output for two of the 17 locations for which we developed ANNs. Results are shown for DSM2 Run 1 (identified in Table 2-5 in the main document). ANN outputs are presented as-is, with some incidences of negative predictions where the actual DSM2-computed value is near zero. Negative values of volumetric contribution are not physically plausible and in the application of the fingerprint model, all negative outputs are replaced with a zero value.

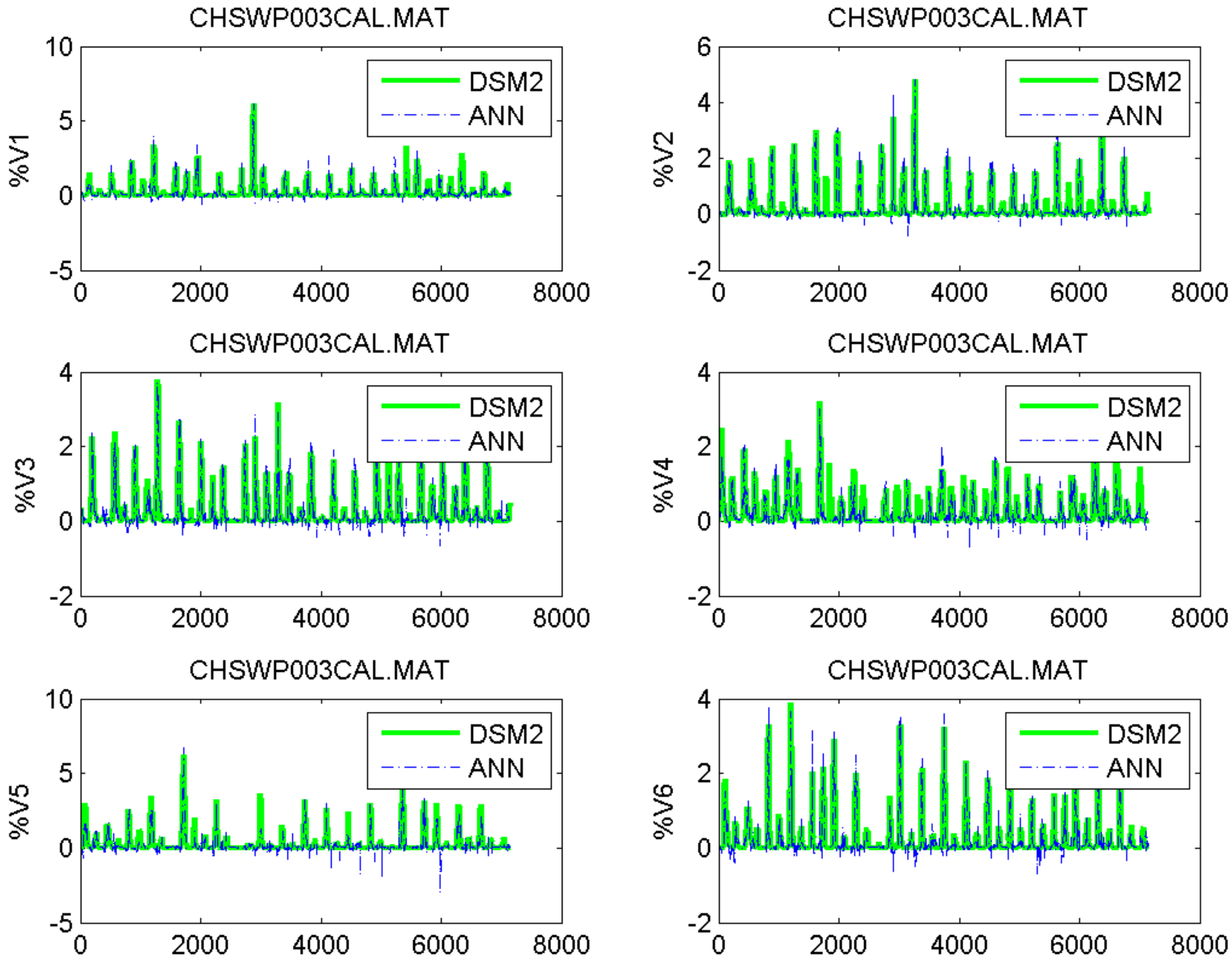

Figure C-1 ANN vs. DSM2 simulated time series of volumetric contribution from Calaveras River to CHSWP003 (CCF) for different time steps

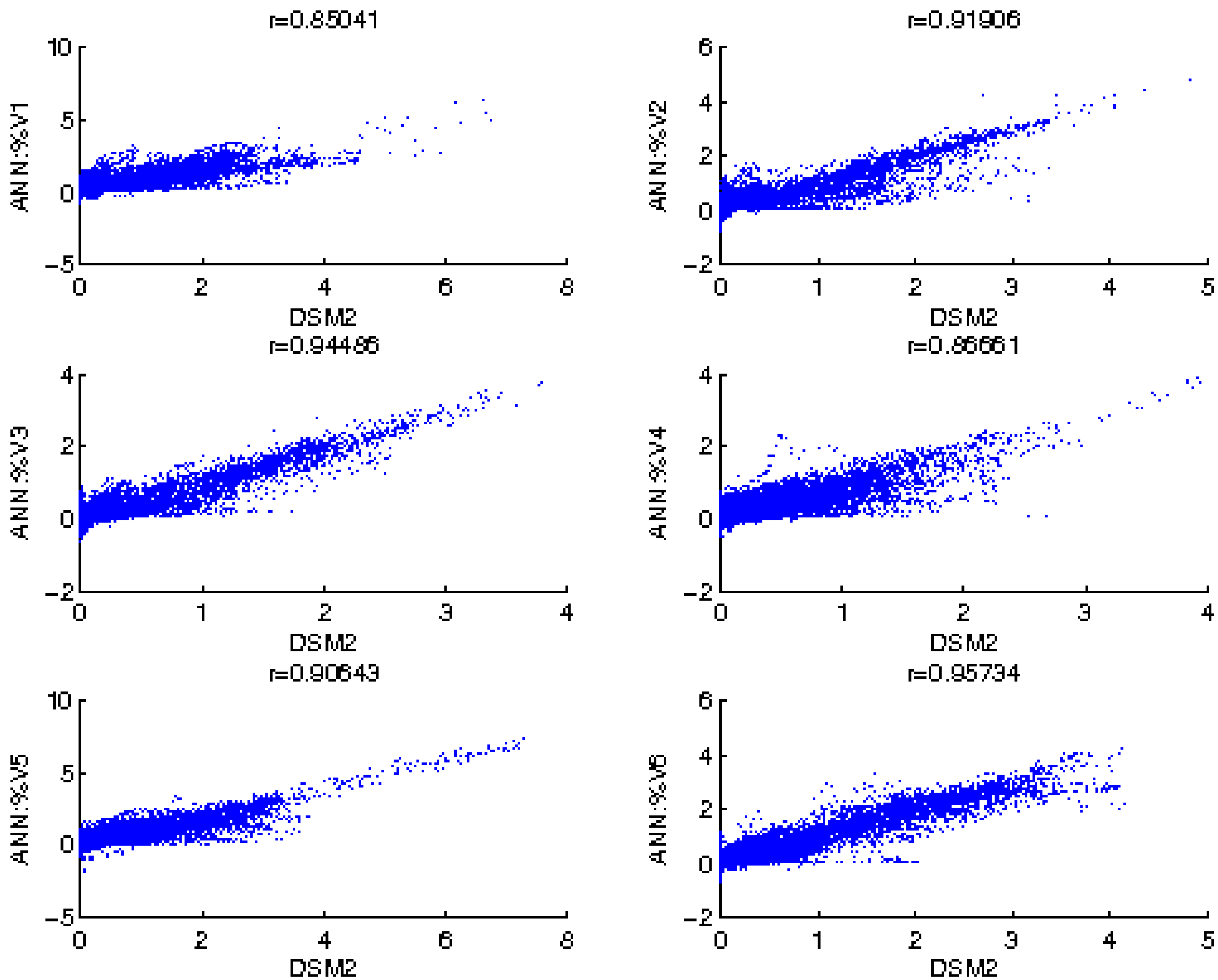

Figure C-2 ANN vs. DSM2 simulated volumetric contribution from Calaveras River to CHSWP003 (CCF) at different time steps

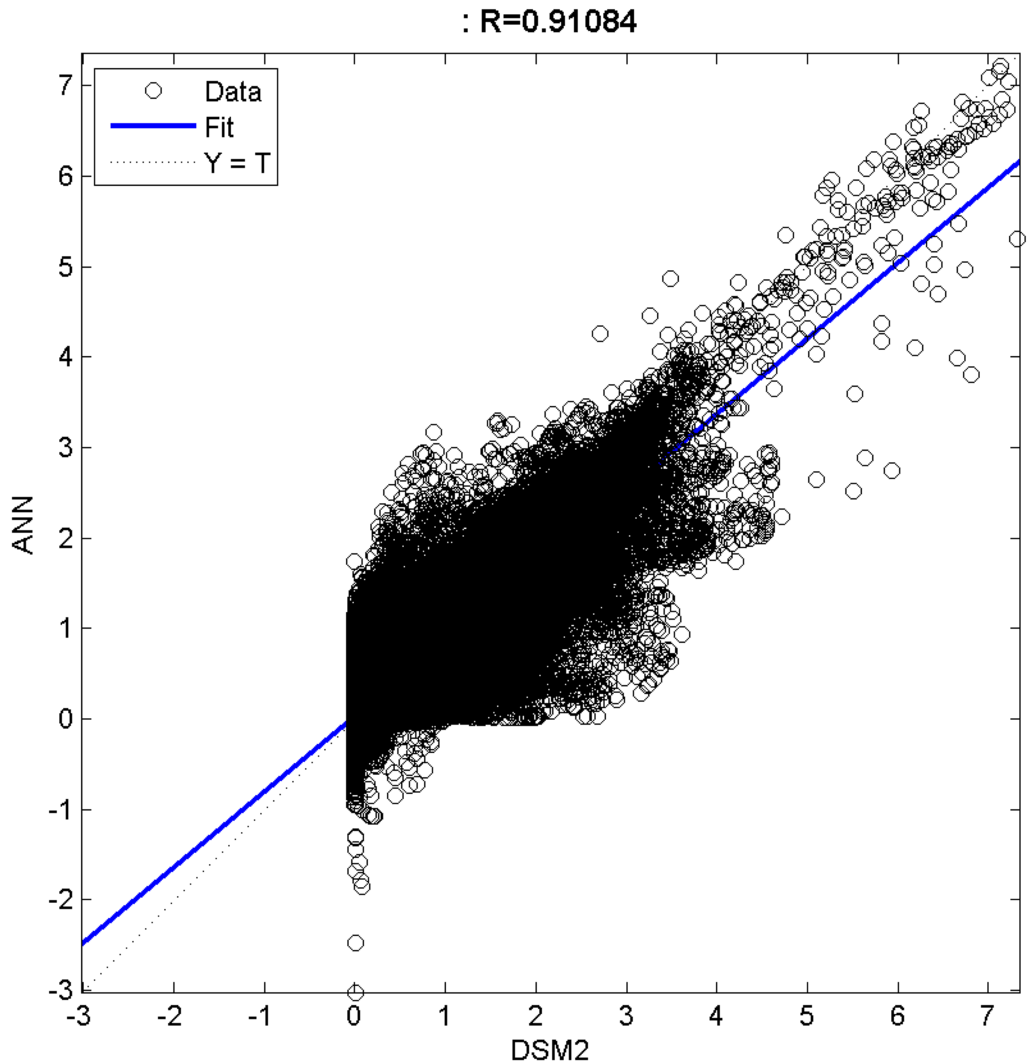

Figure C-3 ANN vs. DSM2 simulated volumetric contribution from Calaveras River to CHSWP003 (CCF)

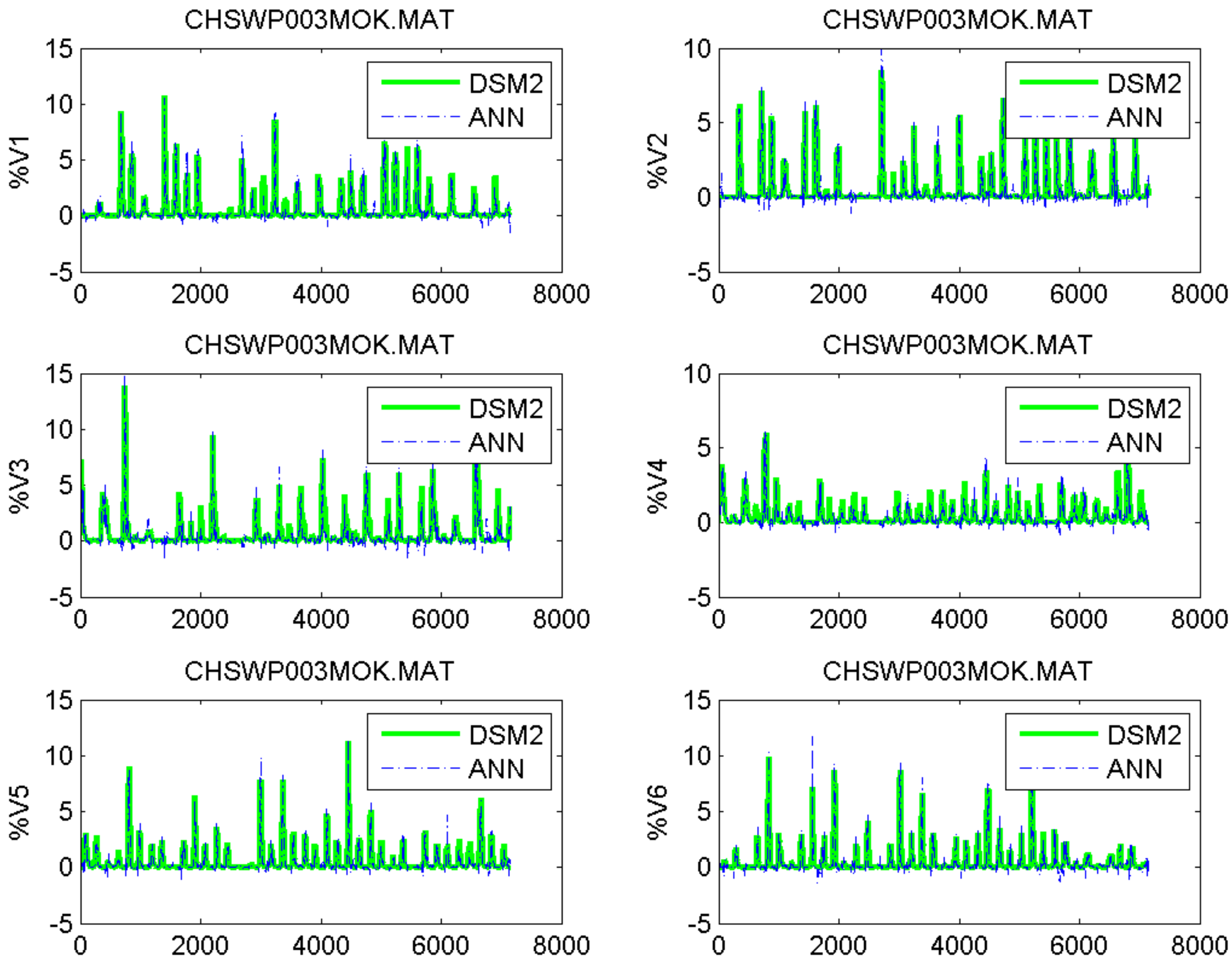

Figure C-4 ANN vs. DSM2 simulated time series of volumetric contribution from Mokelumne River to CHSWP003 (CCF) at different time steps

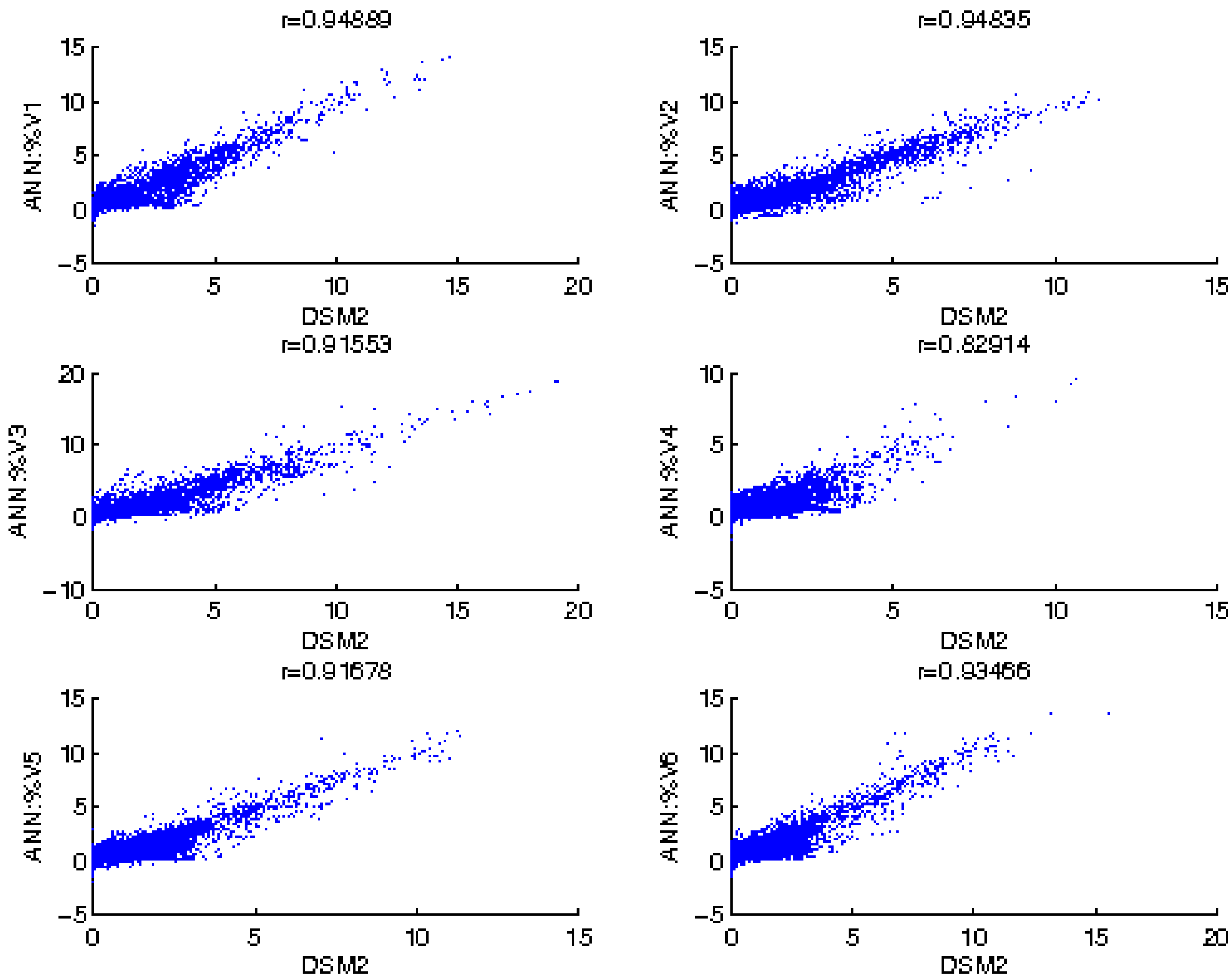

Figure C-5 ANN vs. DSM2 simulated volumetric contribution from Mokelumne River to CHSWP003 (CCF) at different time steps

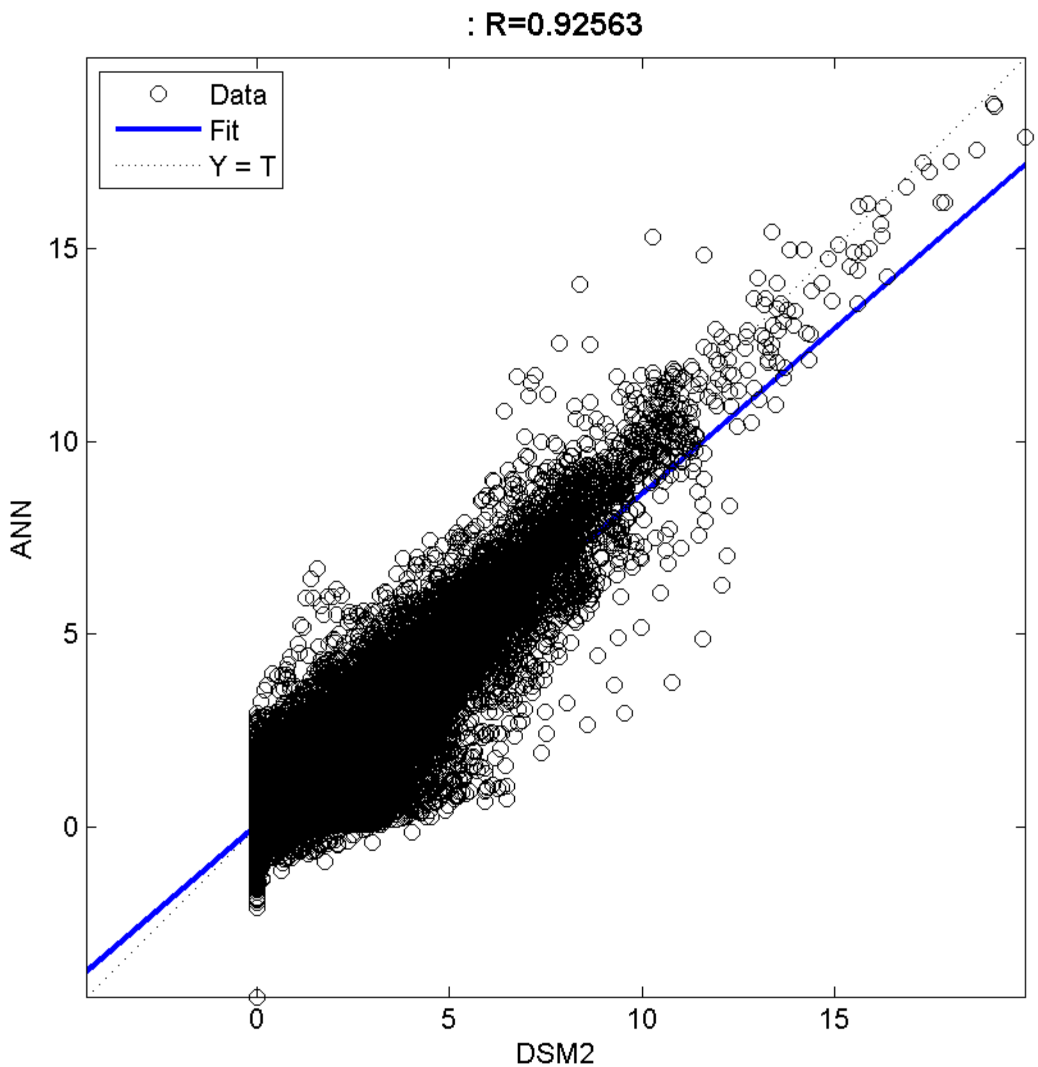

Figure C-6 ANN vs. DSM2 simulated volumetric contribution from Mokelumne River to CHSWP003 (CCF)

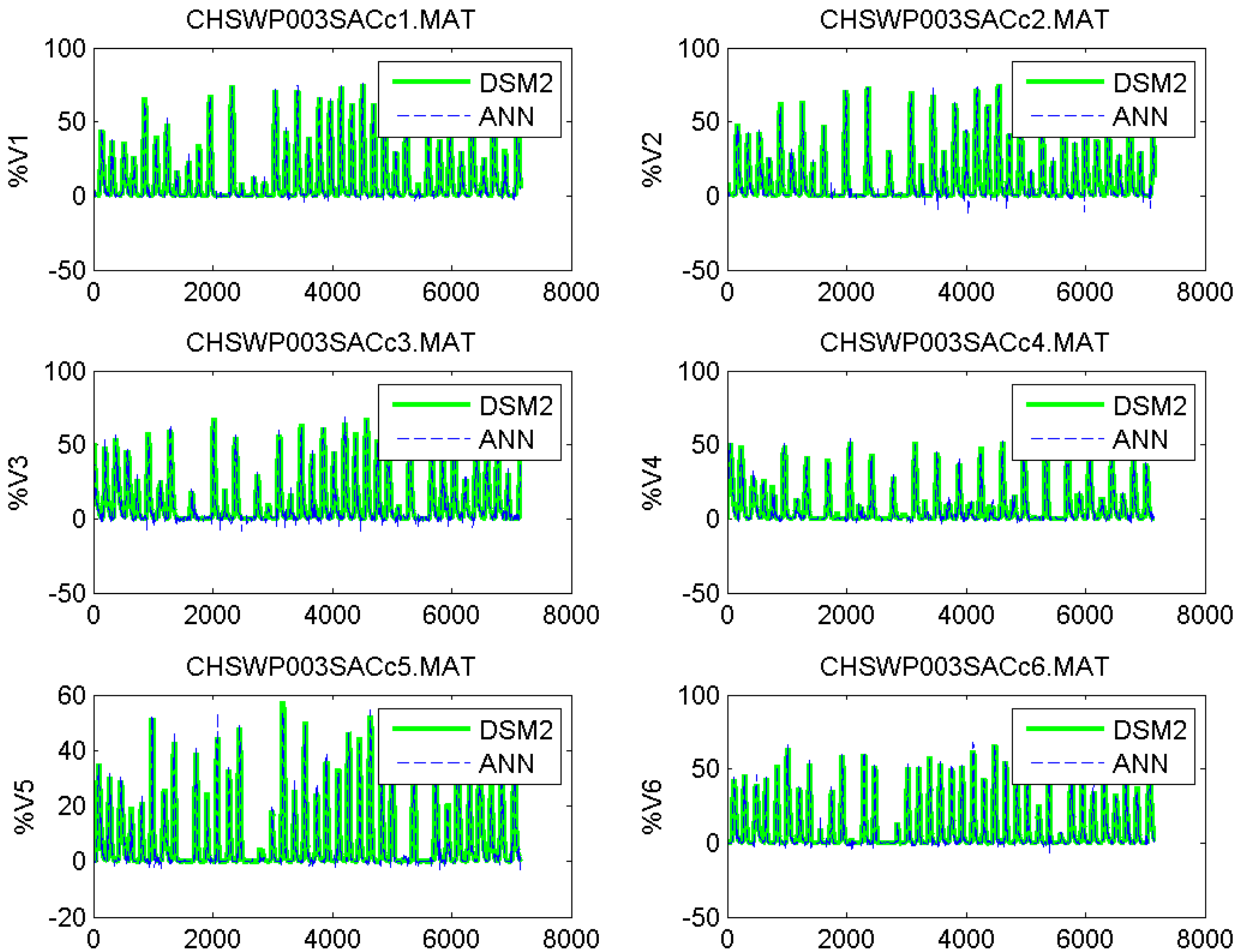

Figure C-7 *ANN vs. DSM2 simulated time series of volumetric contribution from Sacramento River to CHSWP003 (CCF) at different time steps*

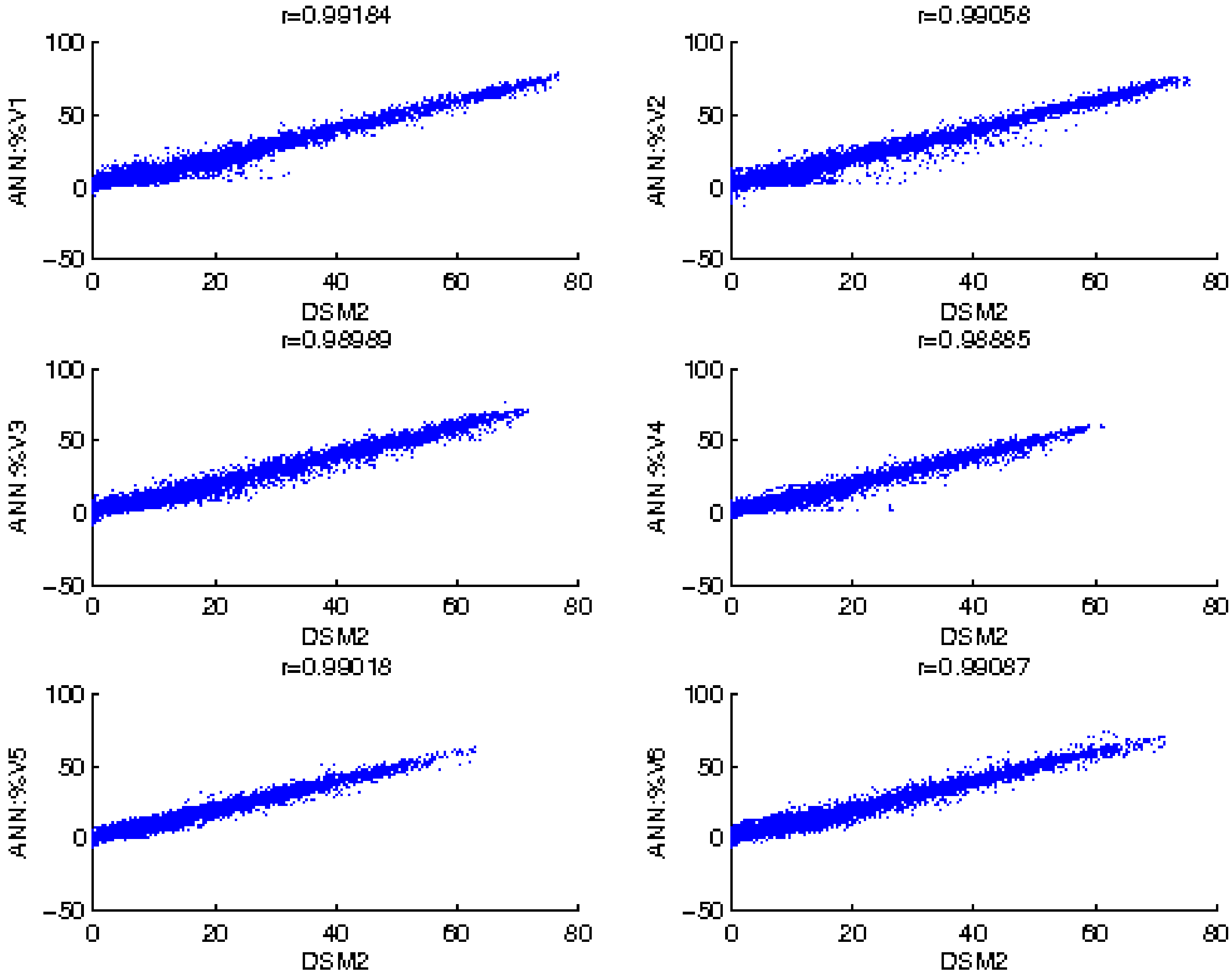

Figure C-8 ANN vs. DSM2 simulated volumetric contribution from Sacramento River to CHSWP003 (CCF) at different time steps

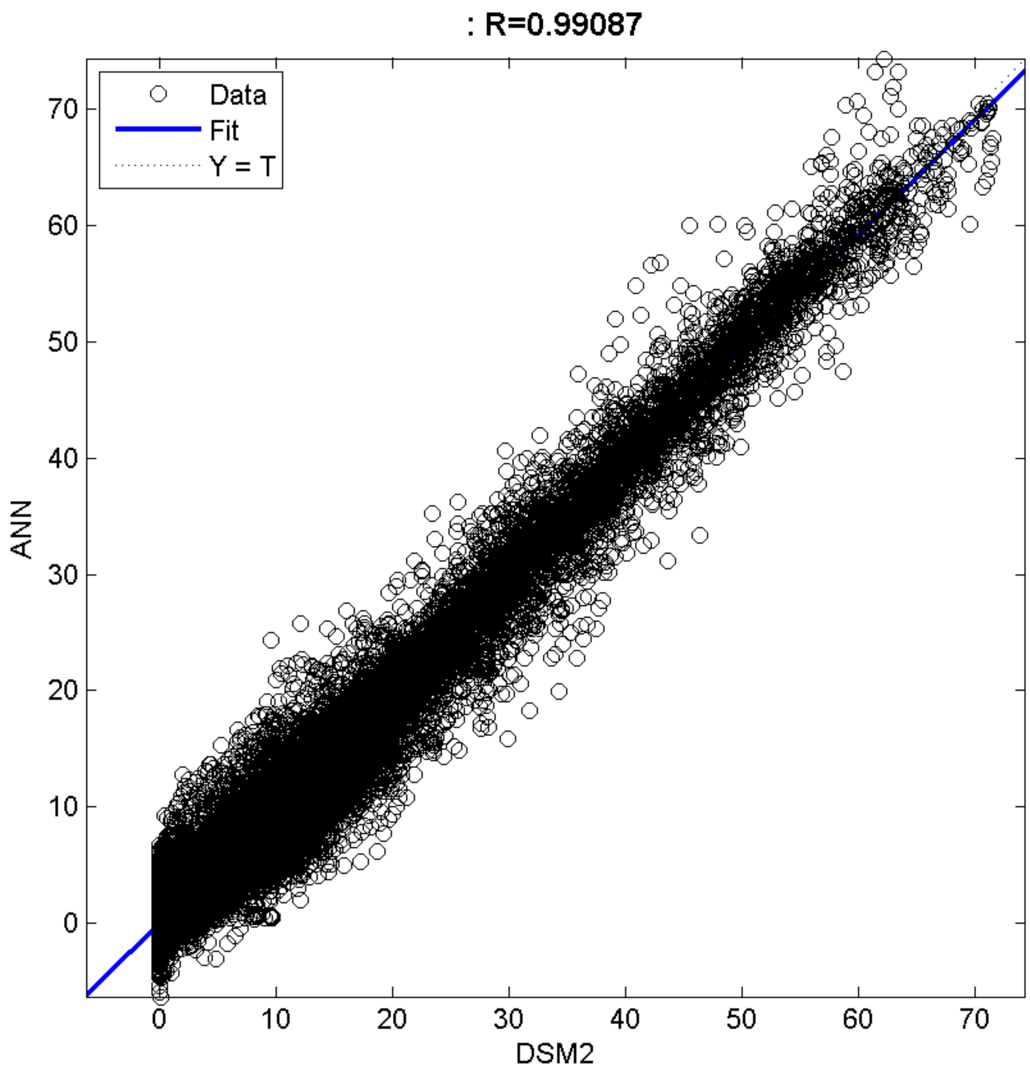

Figure C-9 ANN vs. DSM2 simulated volumetric contribution from Sacramento River to CHSWP003 (CCF)

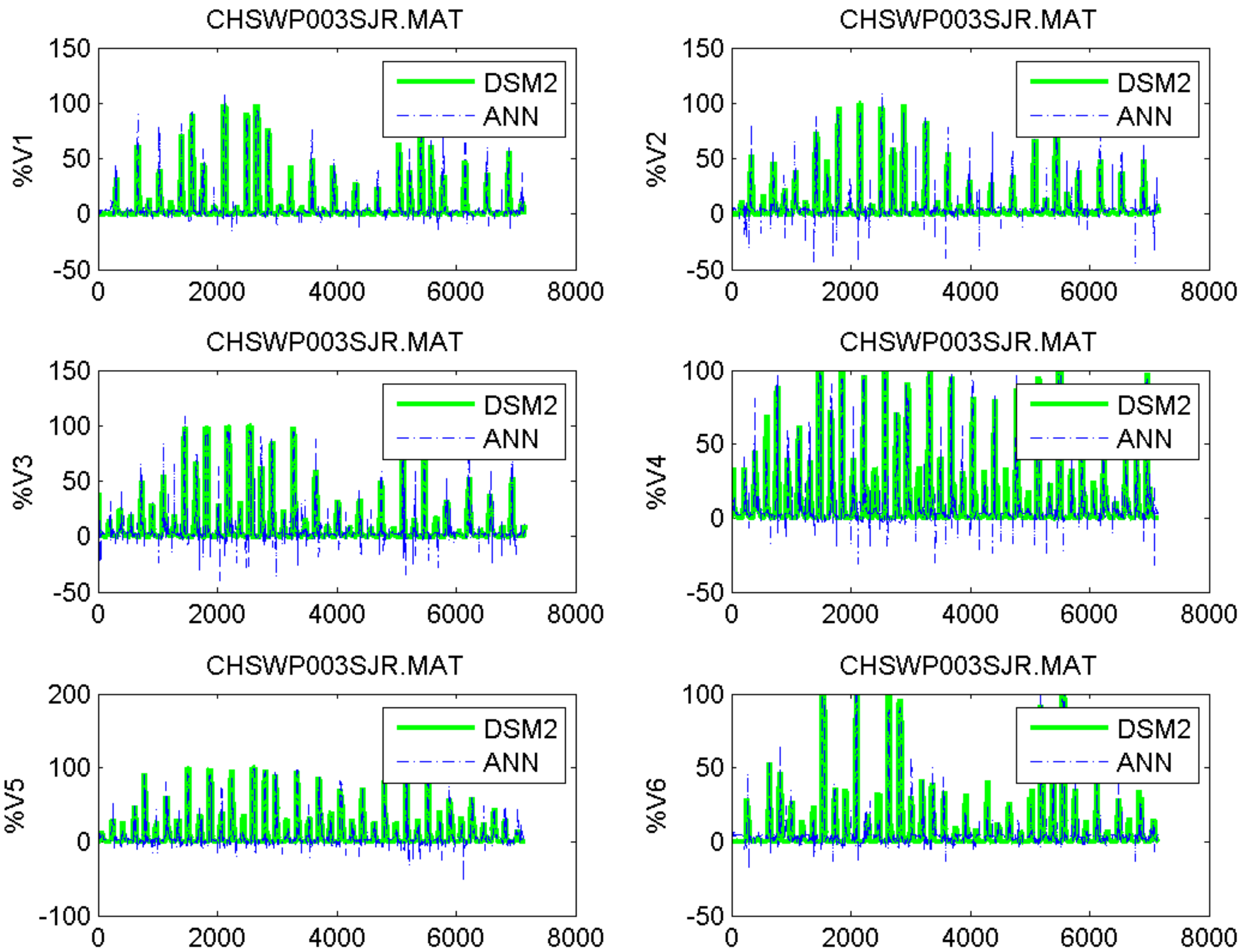

Figure C-10 ANN vs. DSM2 simulated time series of volumetric contribution from San Joaquin River to CHSWP003 (CCF) at different time steps

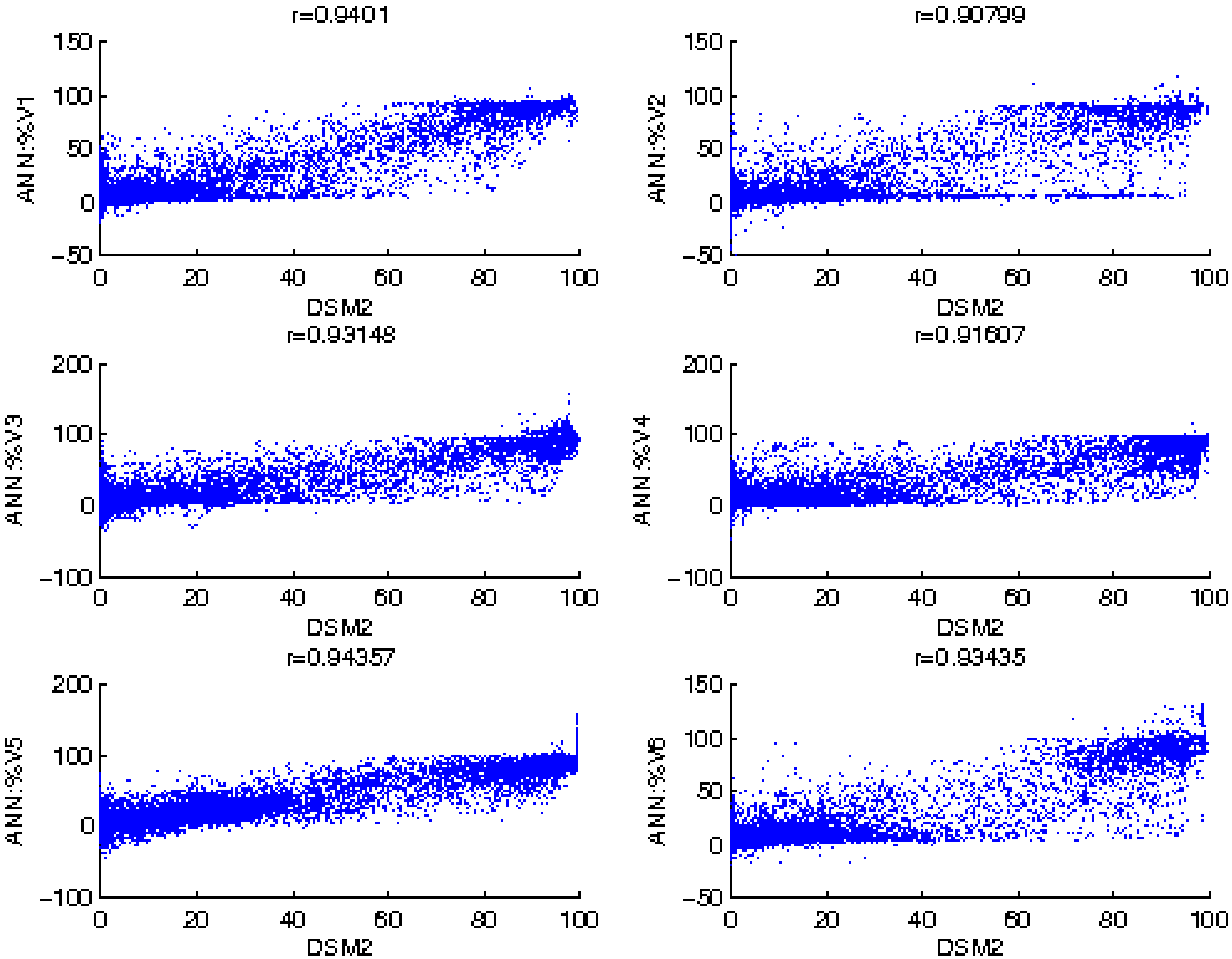

Figure C-11 ANN vs. DSM2 simulated volumetric contribution from San Joaquin River to CHSWP003 (CCF) at different time steps

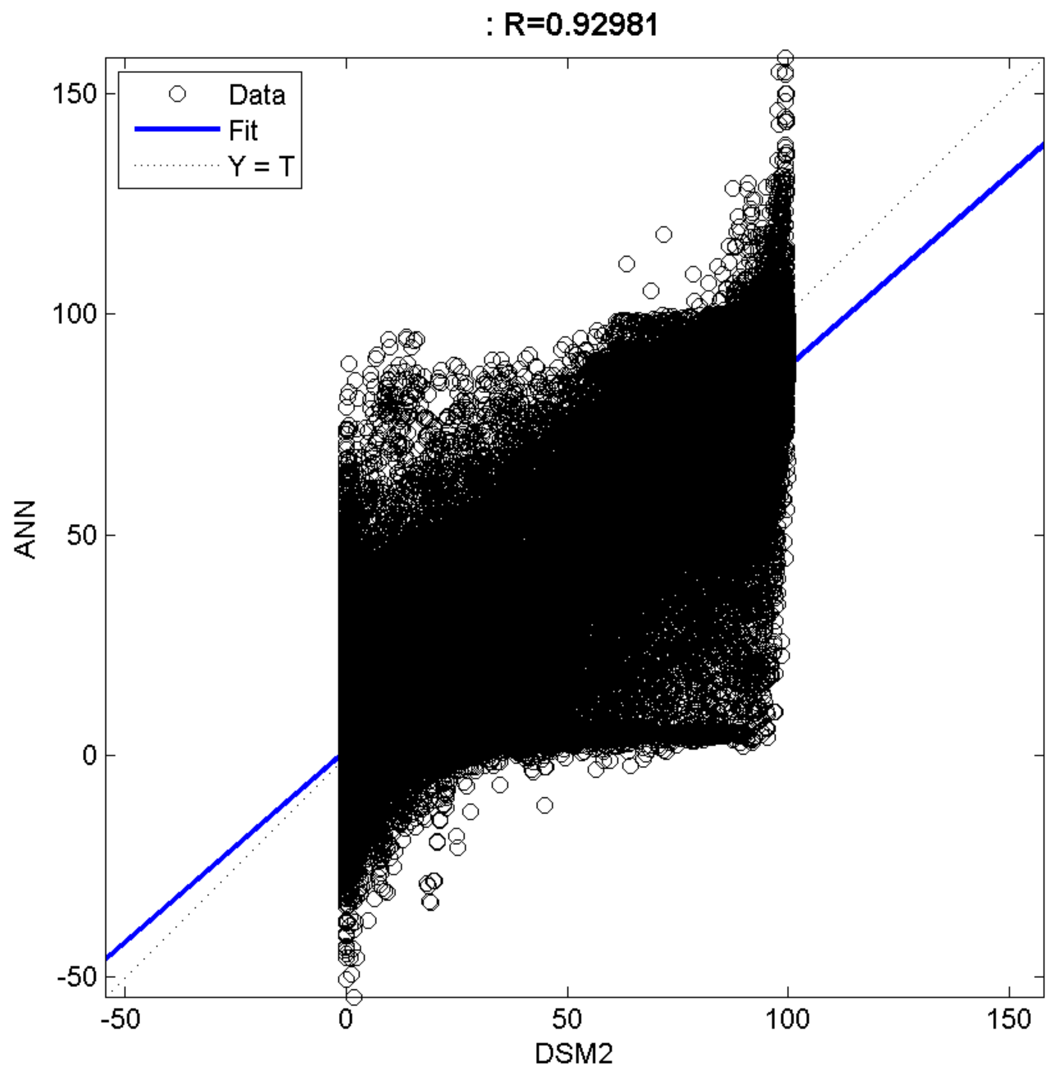

Figure C-12 ANN vs. DSM2 simulated volumetric contribution from San Joaquin River to CHSWP003 (CCF)

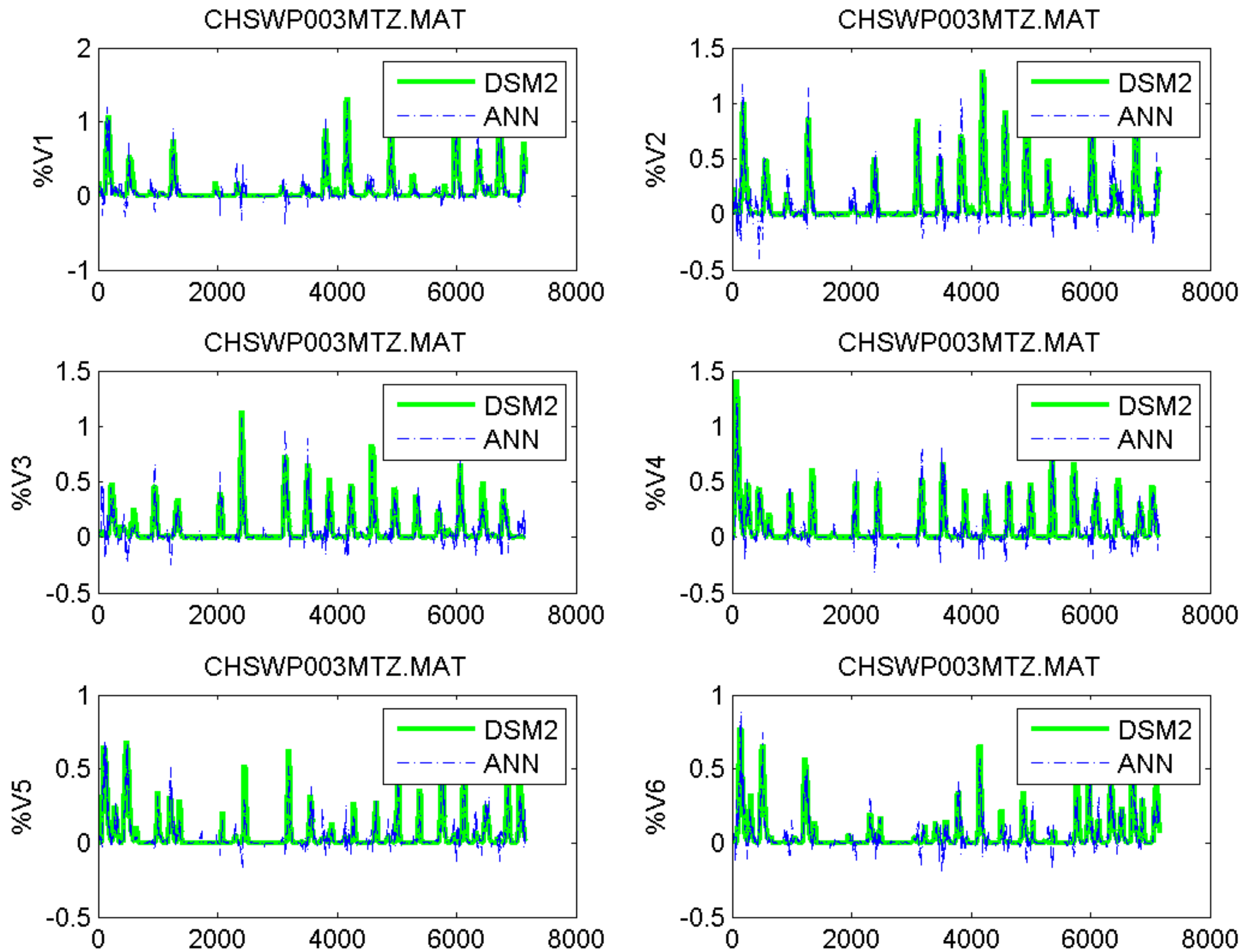

Figure C-13 ANN vs. DSM2 simulated time series of volumetric contribution from Martinez to CHSWP003 (CCF) at different time steps

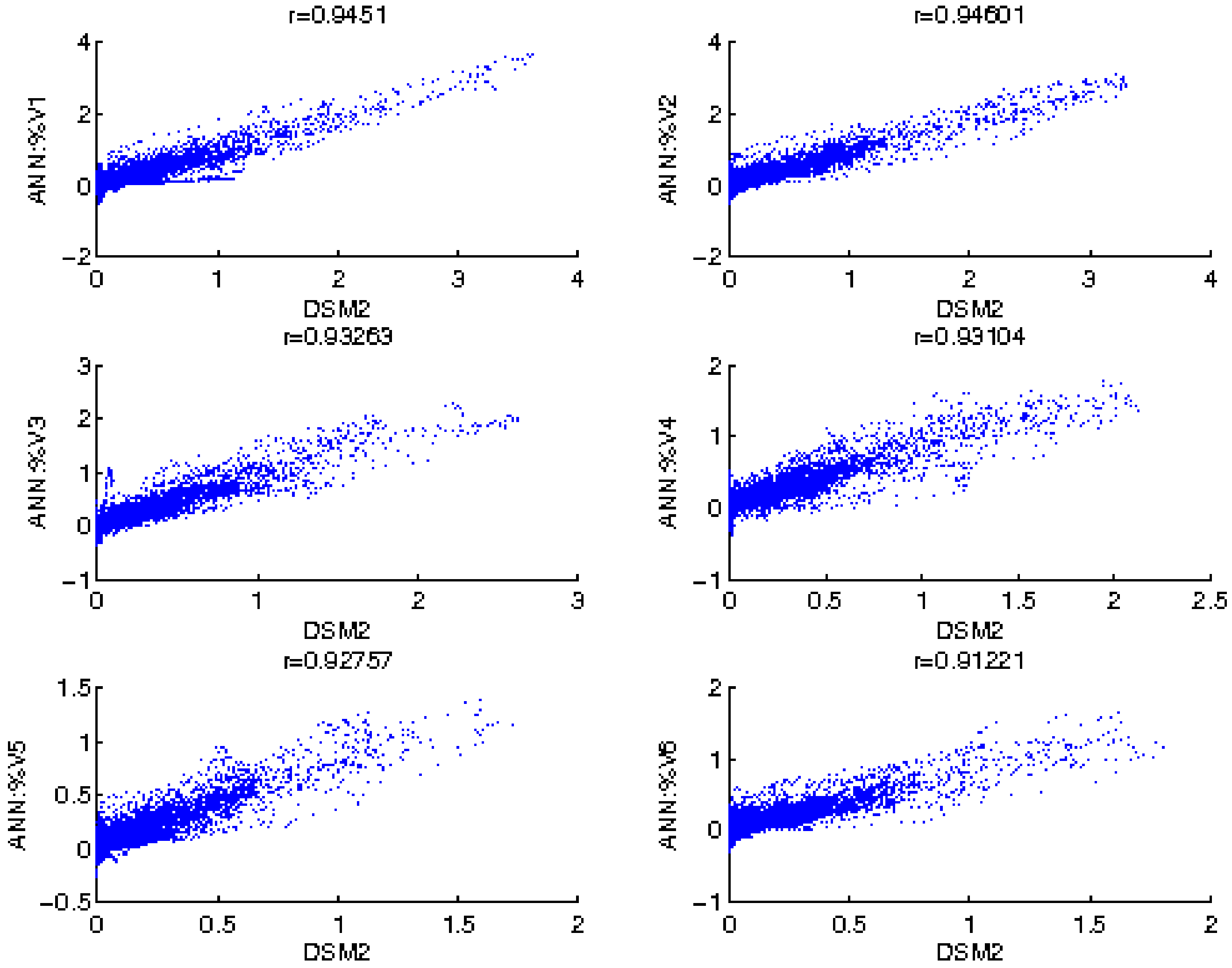

Figure C-14 ANN vs. DSM2 simulated volumetric contribution from Martinez to CHSWP003 (CCF) at different time steps

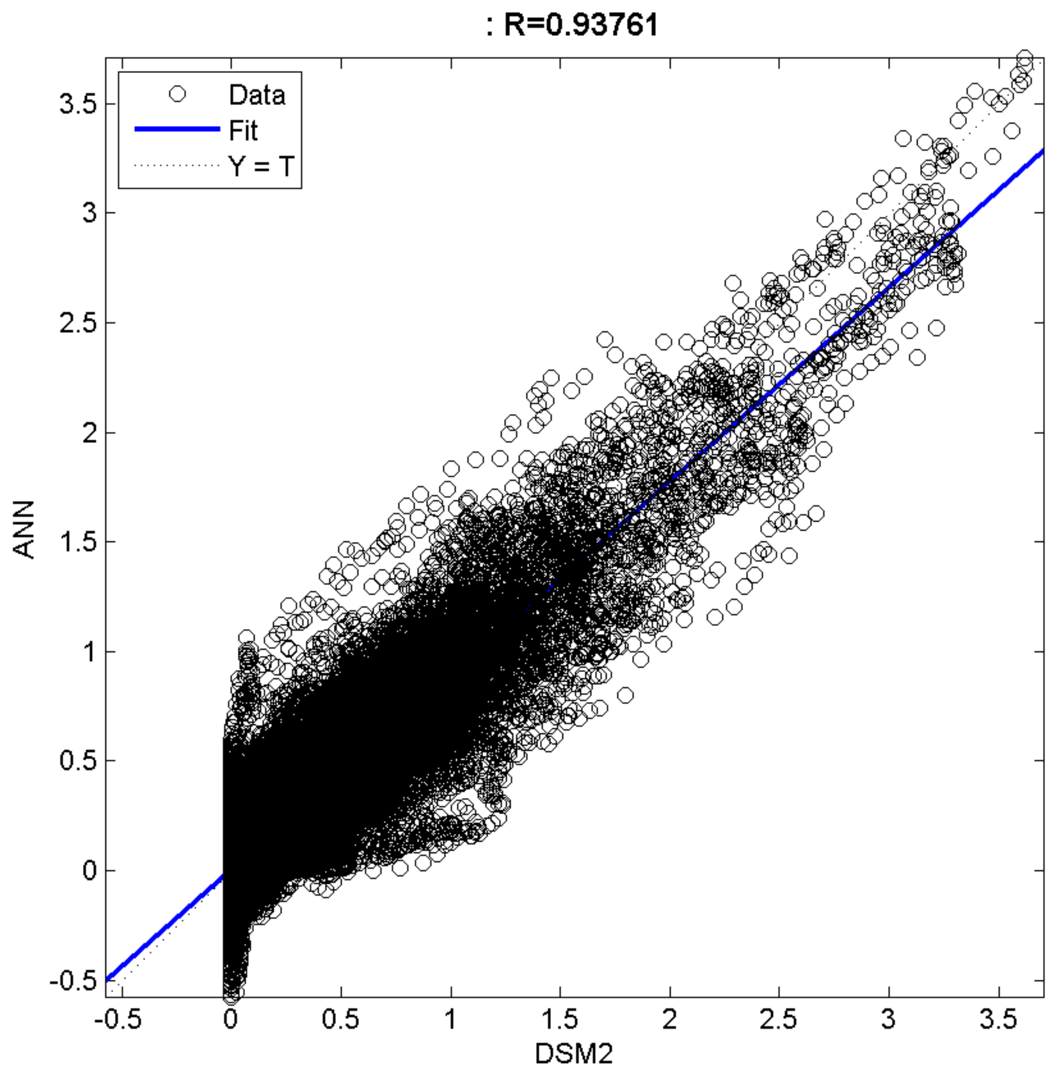

Figure C-15 ANN vs. DSM2 simulated volumetric contribution from Martinez to CHSWP003 (CCF)

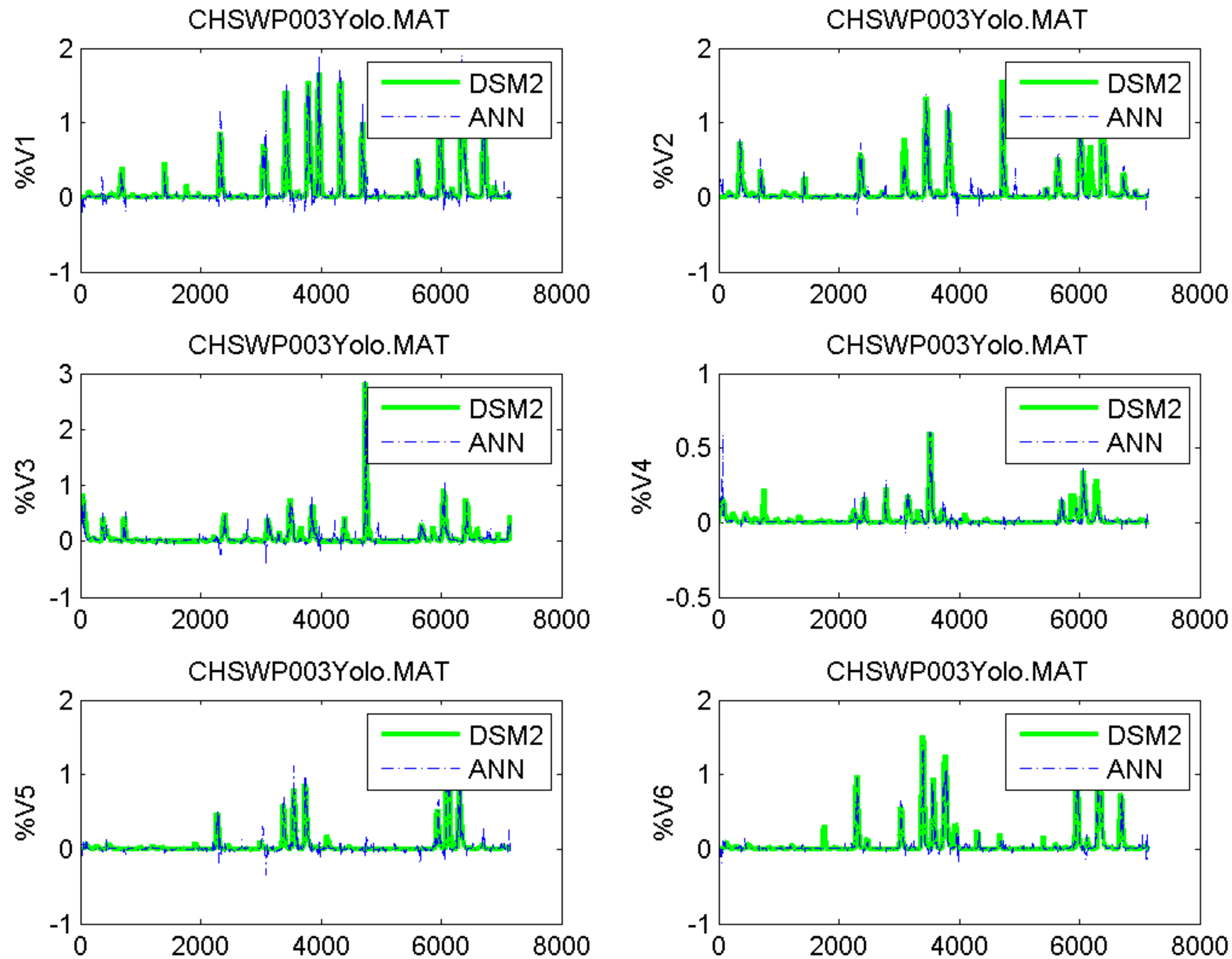

Figure C-16 ANN vs. DSM2 simulated time series of volumetric contribution from Yolo to CHSWP003 (CCF) at different time steps

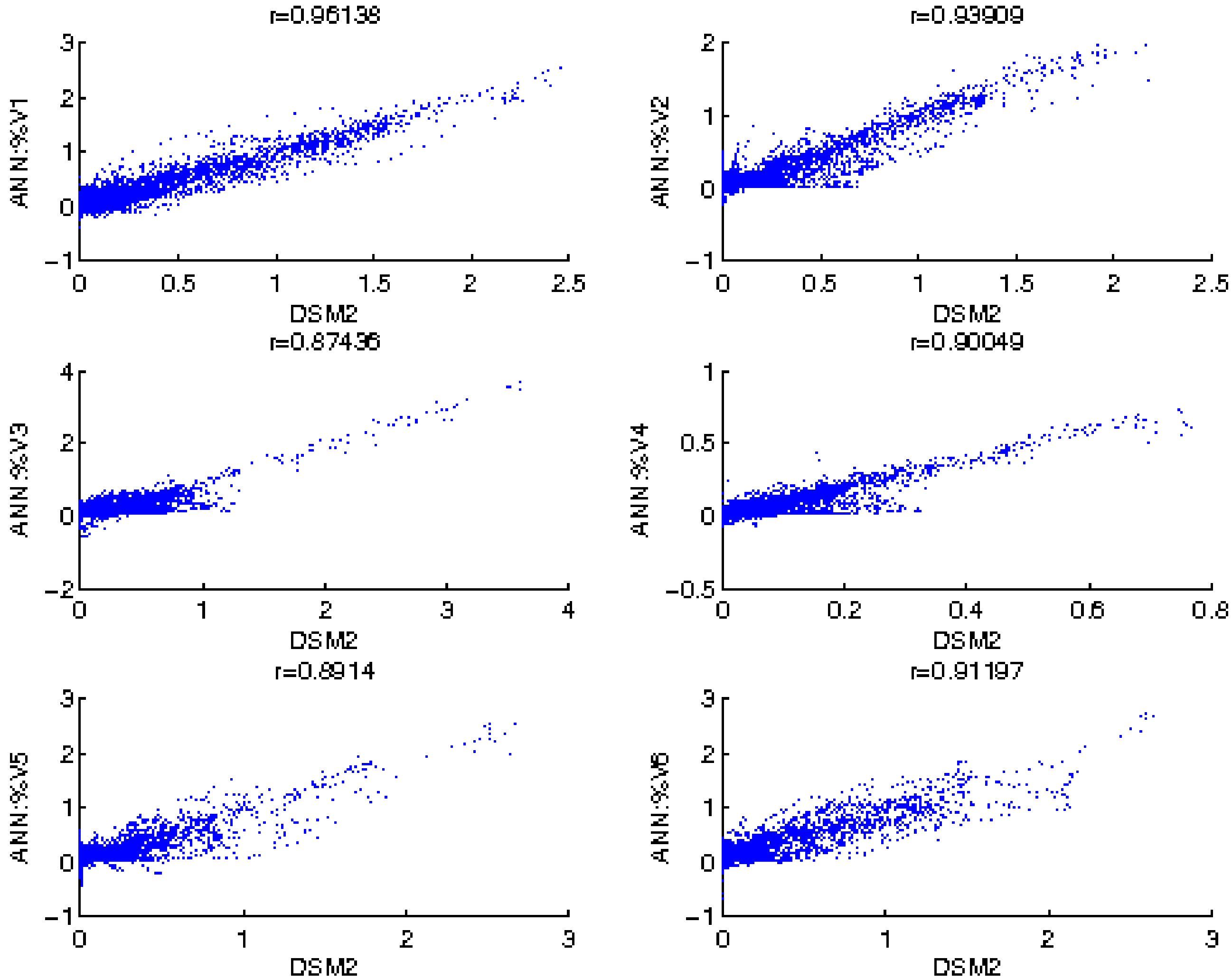

Figure C-17 ANN vs. DSM2 simulated volumetric contribution from Yolo to CHSWP003 (CCF) at different time steps

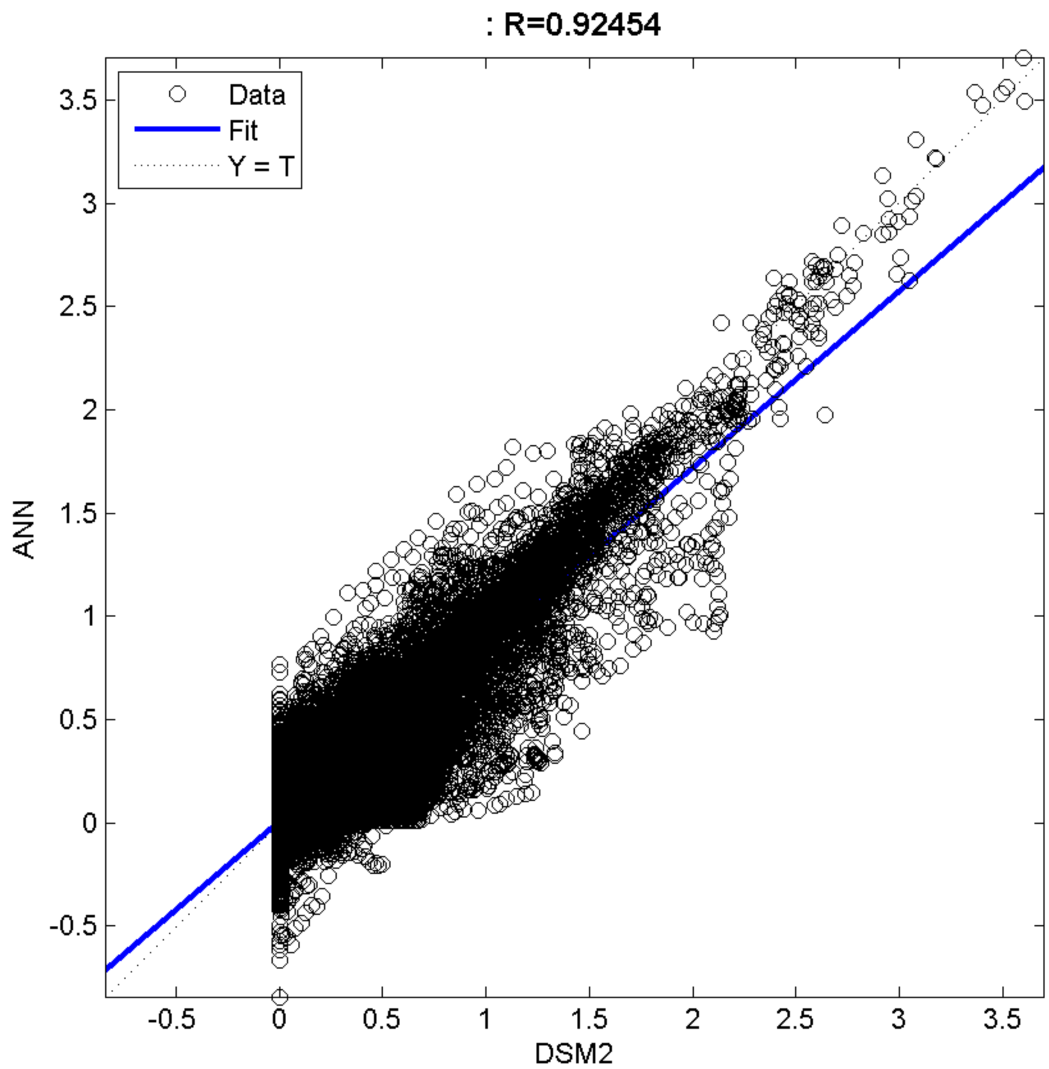

Figure C-18 ANN vs. DSM2 simulated volumetric contribution from Yolo to CHSWP003 (CCF)

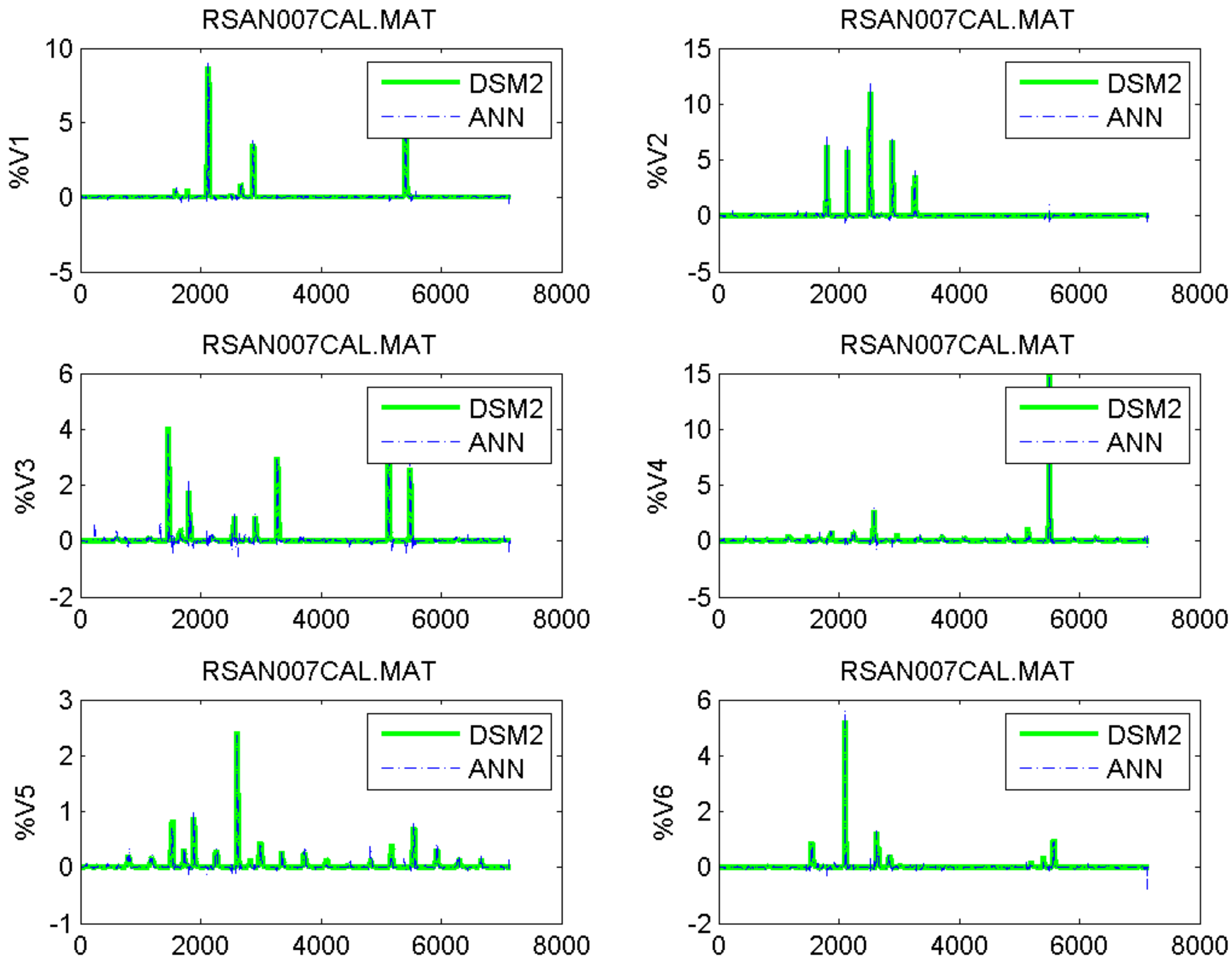

Figure C-19 ANN vs. DSM2 simulated time series of volumetric contribution from Calaveras River to RSAN007 (Antioch) at different time steps

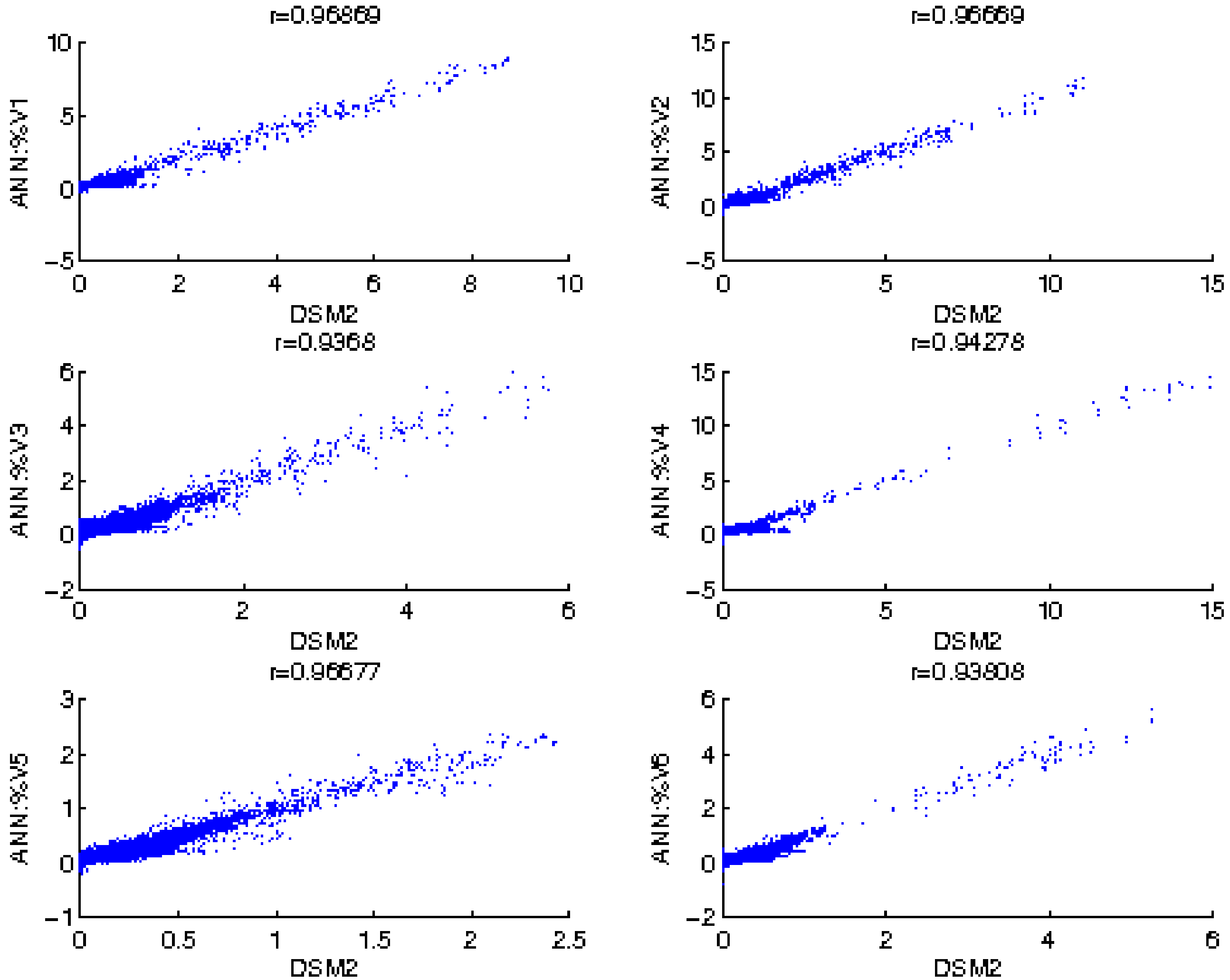

Figure C-20 ANN vs. DSM2 simulated volumetric contribution from Calaveras River to RSAN007 (Antioch) at different time steps

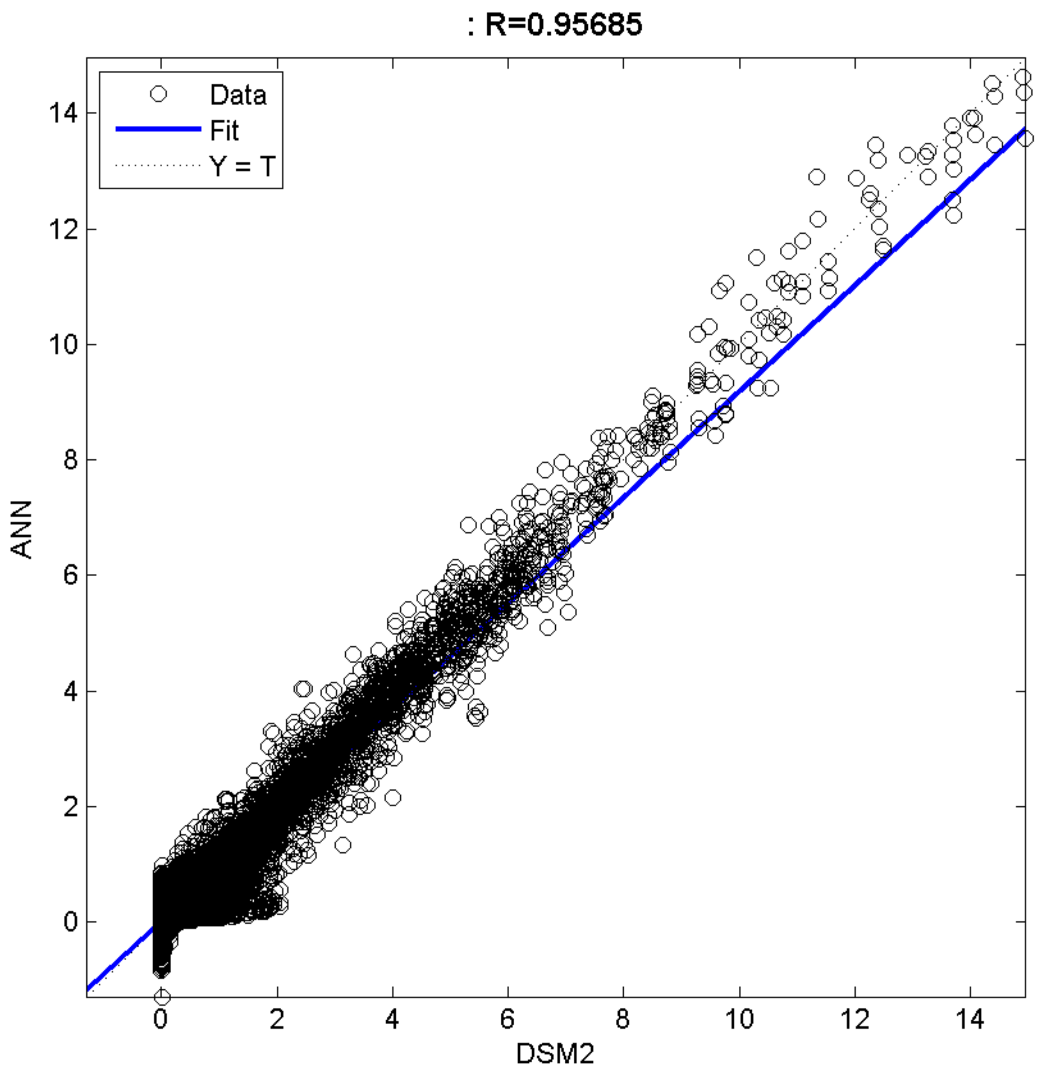

Figure C-21 ANN vs. DSM2 simulated volumetric contribution from Calaveras River to RSAN007 (Antioch)

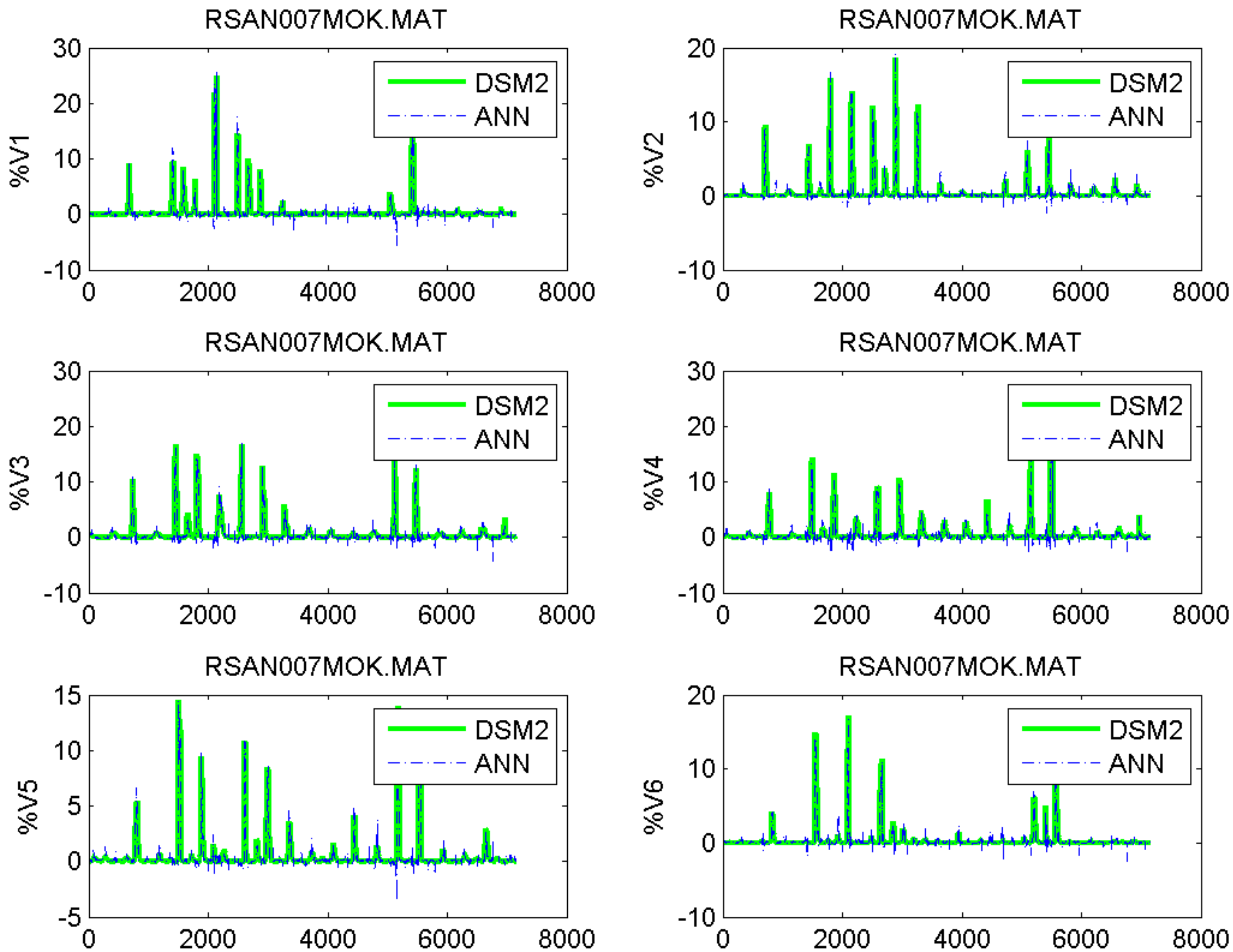

Figure C-22 ANN vs. DSM2 simulated time series of volumetric contribution from Mokelumne River to RSAN007 (Antioch) at different time steps

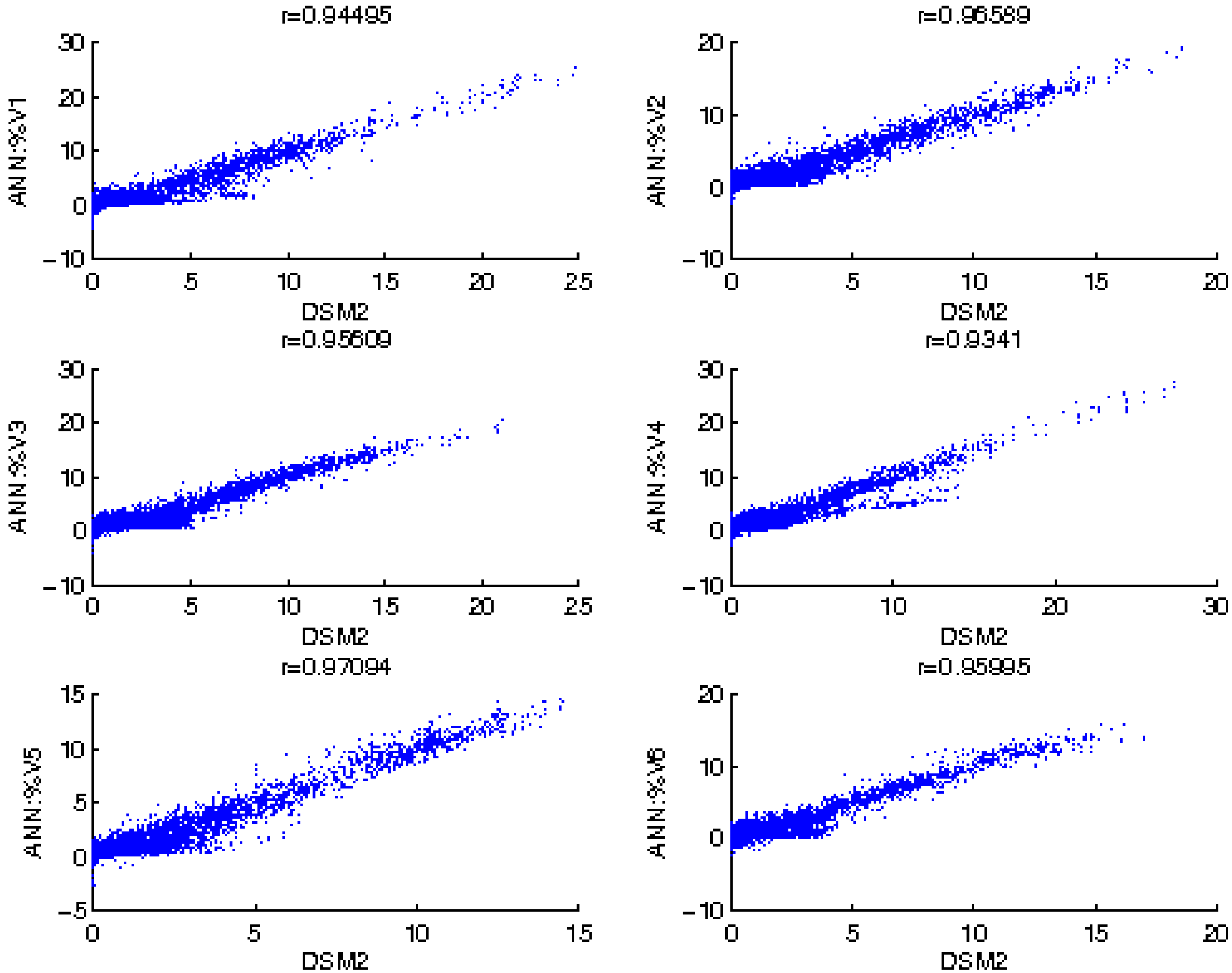

Figure C-23 ANN vs. DSM2 simulated volumetric contribution from Mokelumne River to RSAN007 (Antioch) at different time steps

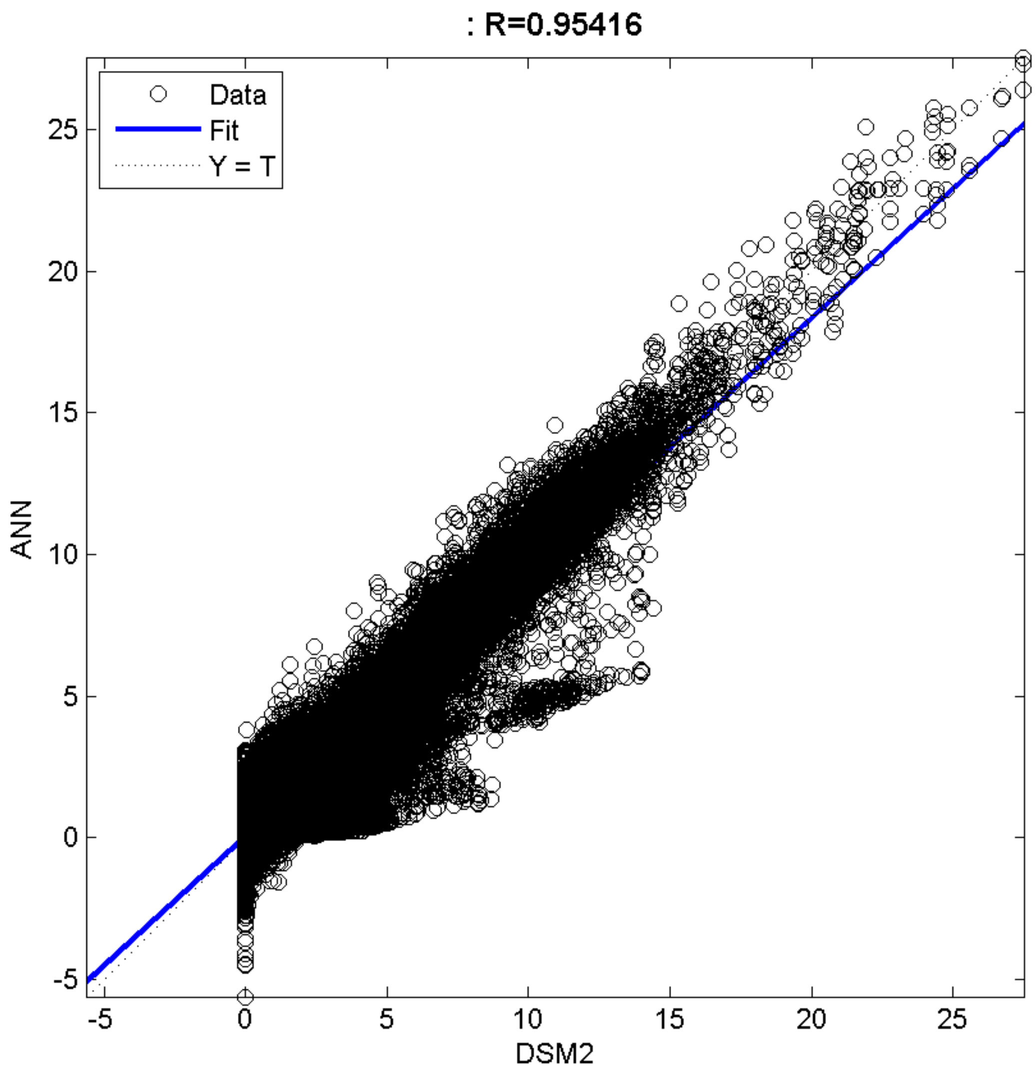

Figure C-24 ANN vs. DSM2 simulated volumetric contribution from Mokelumne River to RSAN007 (Antioch)

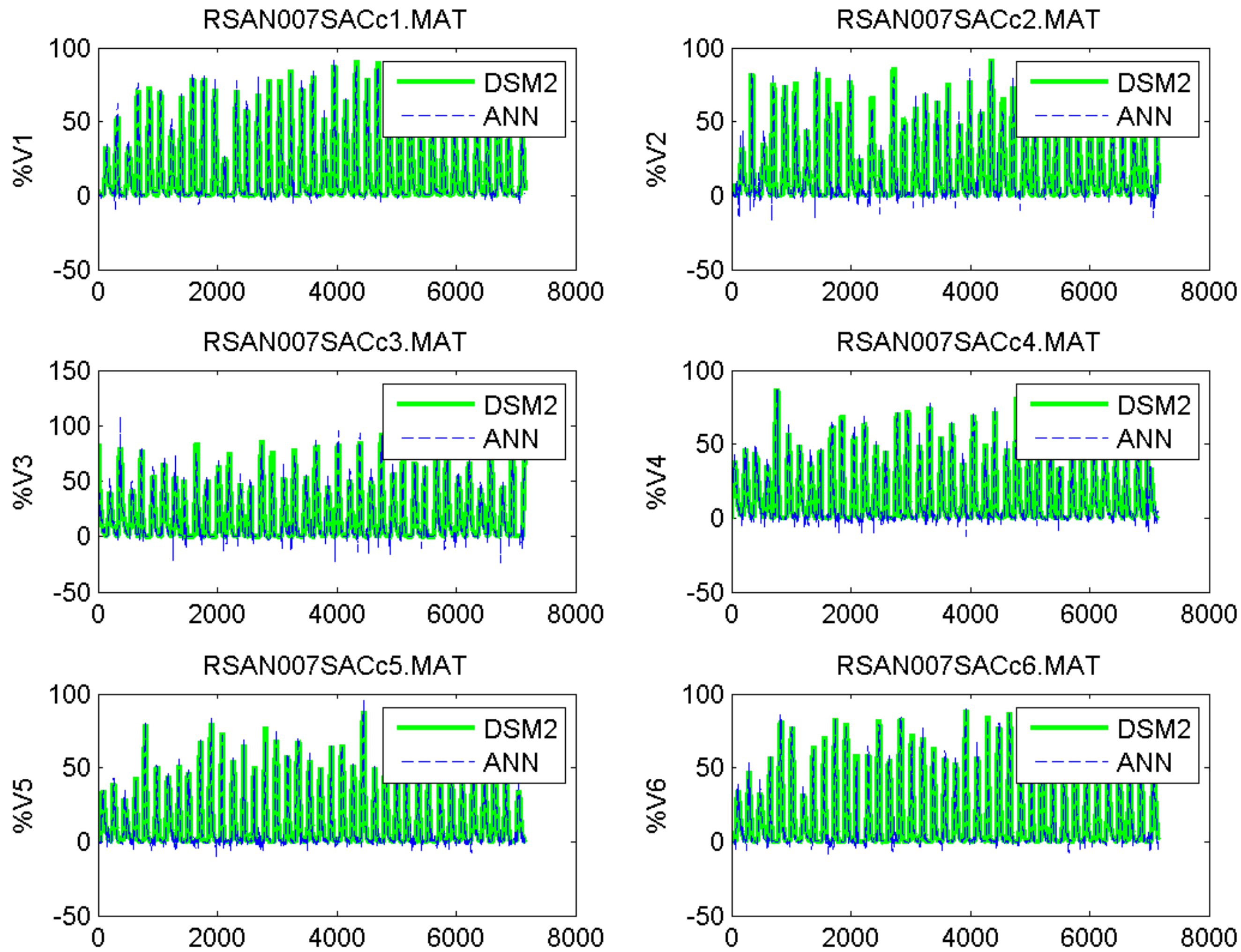

Figure C-25 ANN vs. DSM2 simulated time series of volumetric contribution from Sacramento River to RSAN007 (Antioch) at different time steps

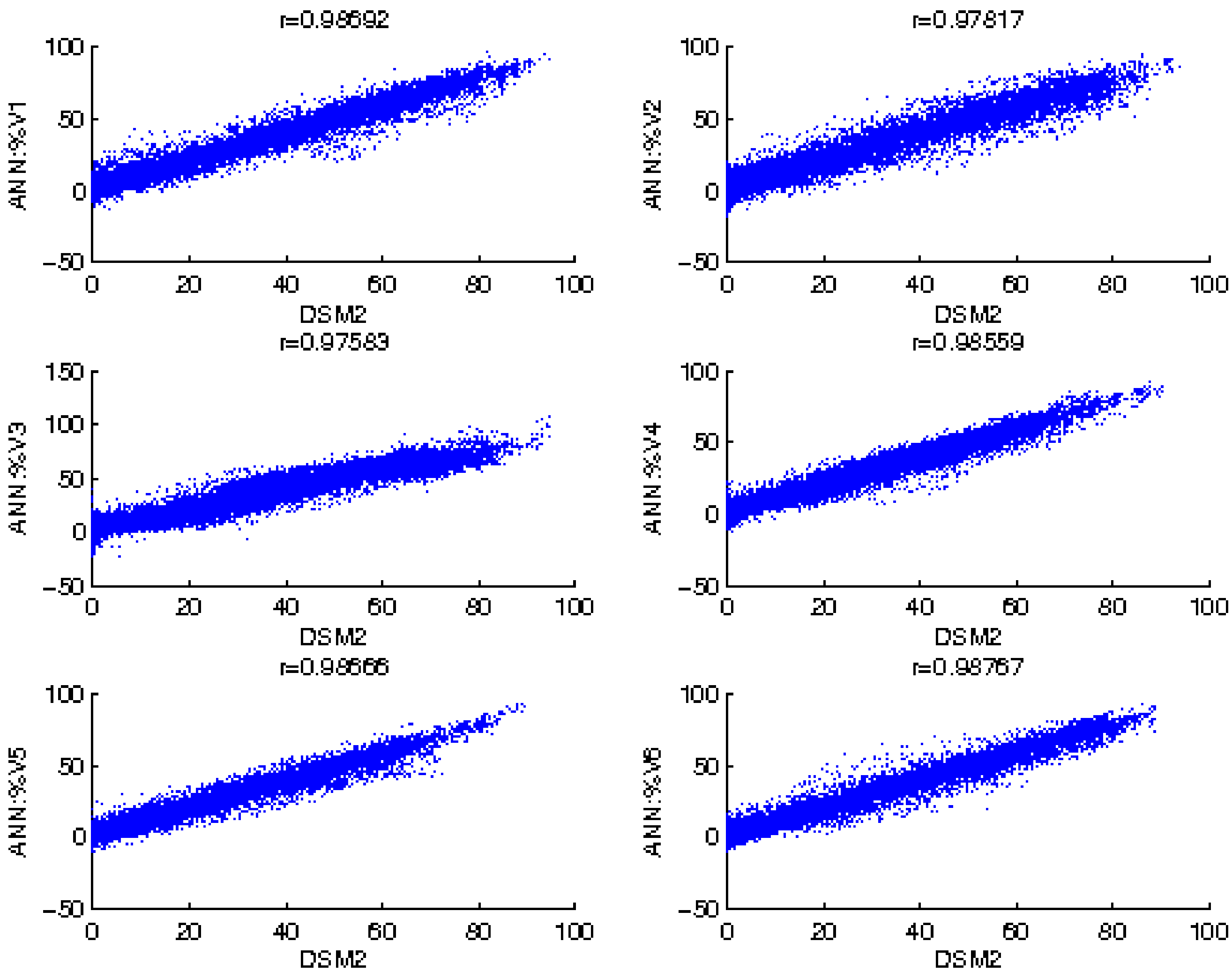

Figure C-26 ANN vs. DSM2 simulated volumetric contribution from Sacramento River to RSAN007 (Antioch) at different time steps

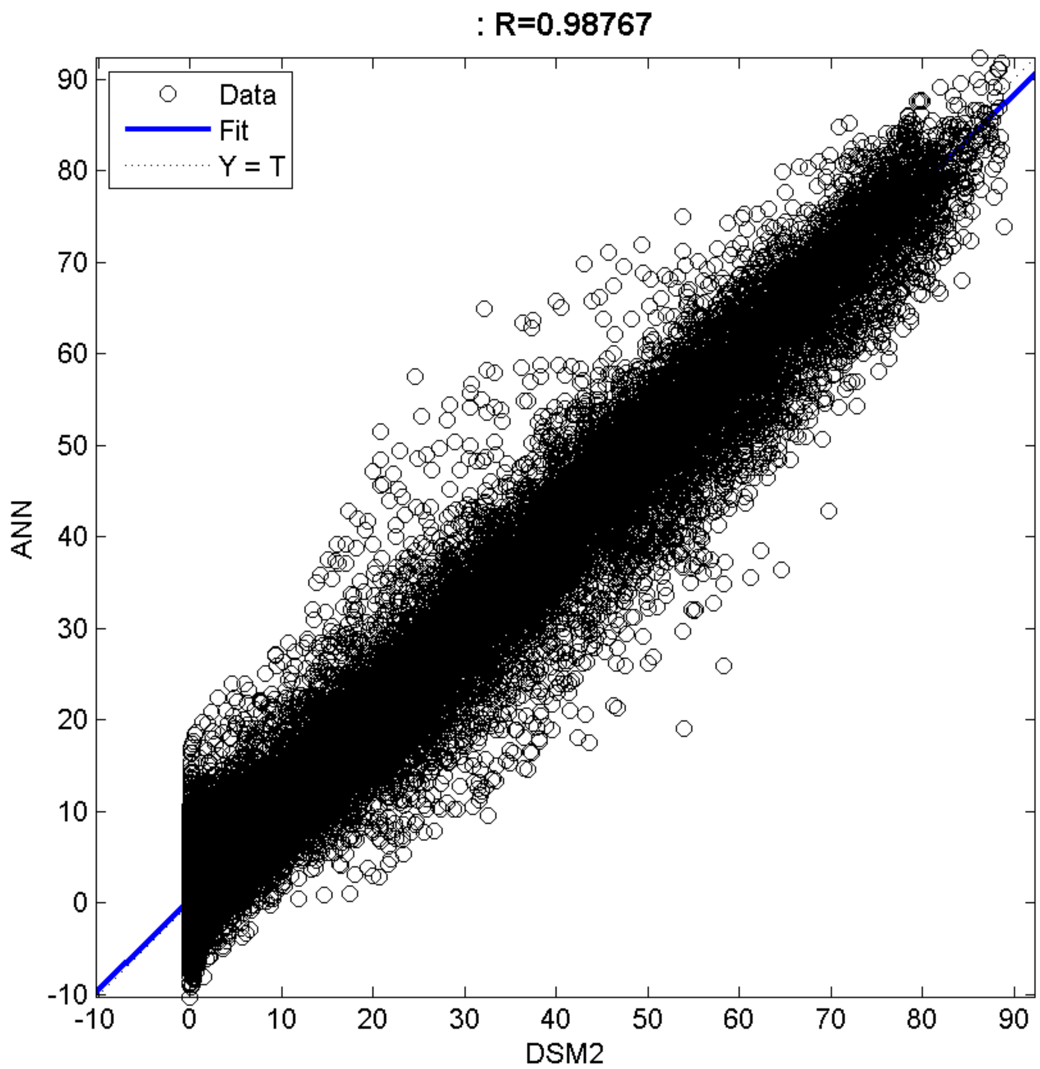

Figure C-27 ANN vs. DSM2 simulated volumetric contribution from Sacramento River to RSAN007 (Antioch)

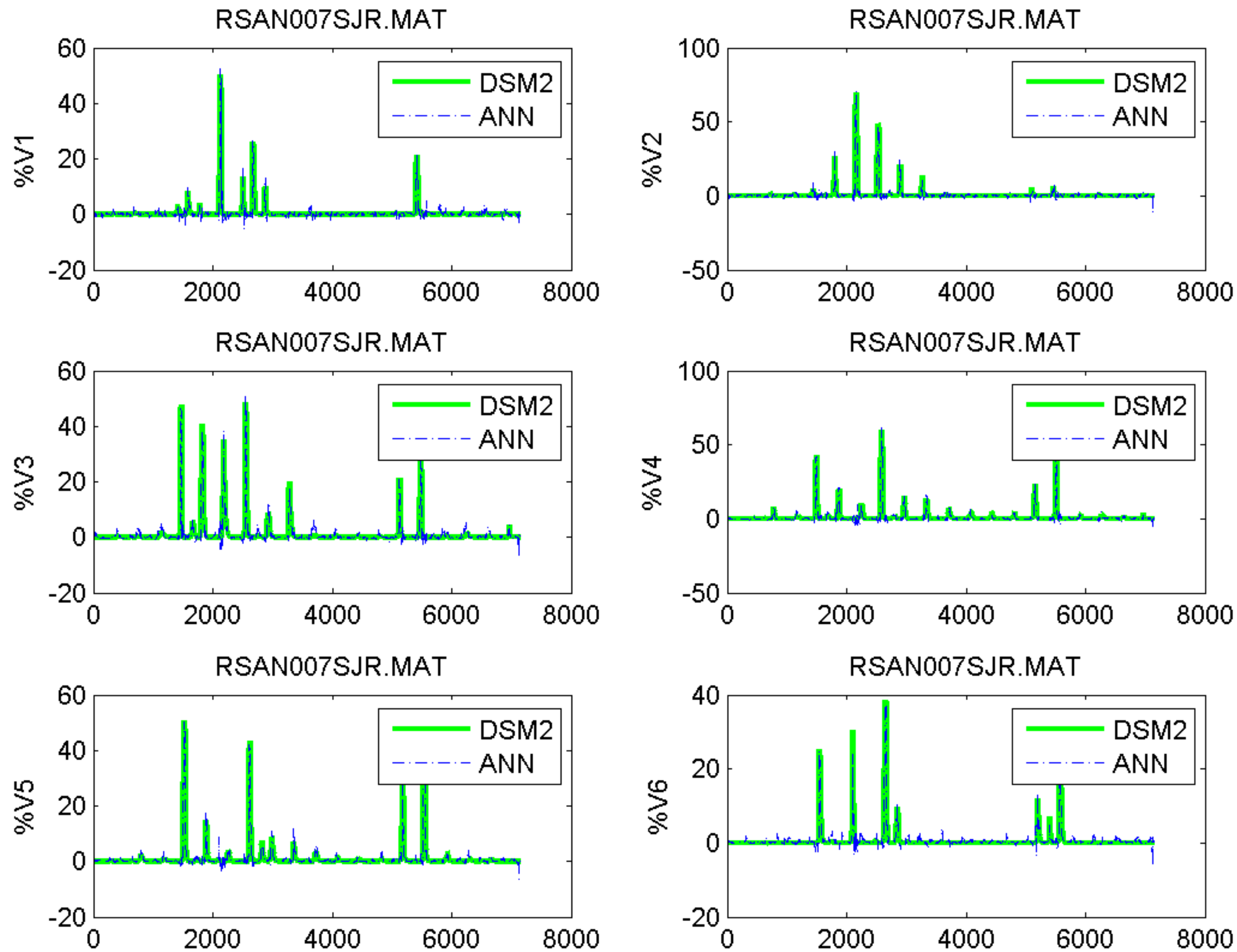

Figure C-28 ANN vs. DSM2 simulated time series of volumetric contribution from San Joaquin River to RSAN007 (Antioch) at different time steps

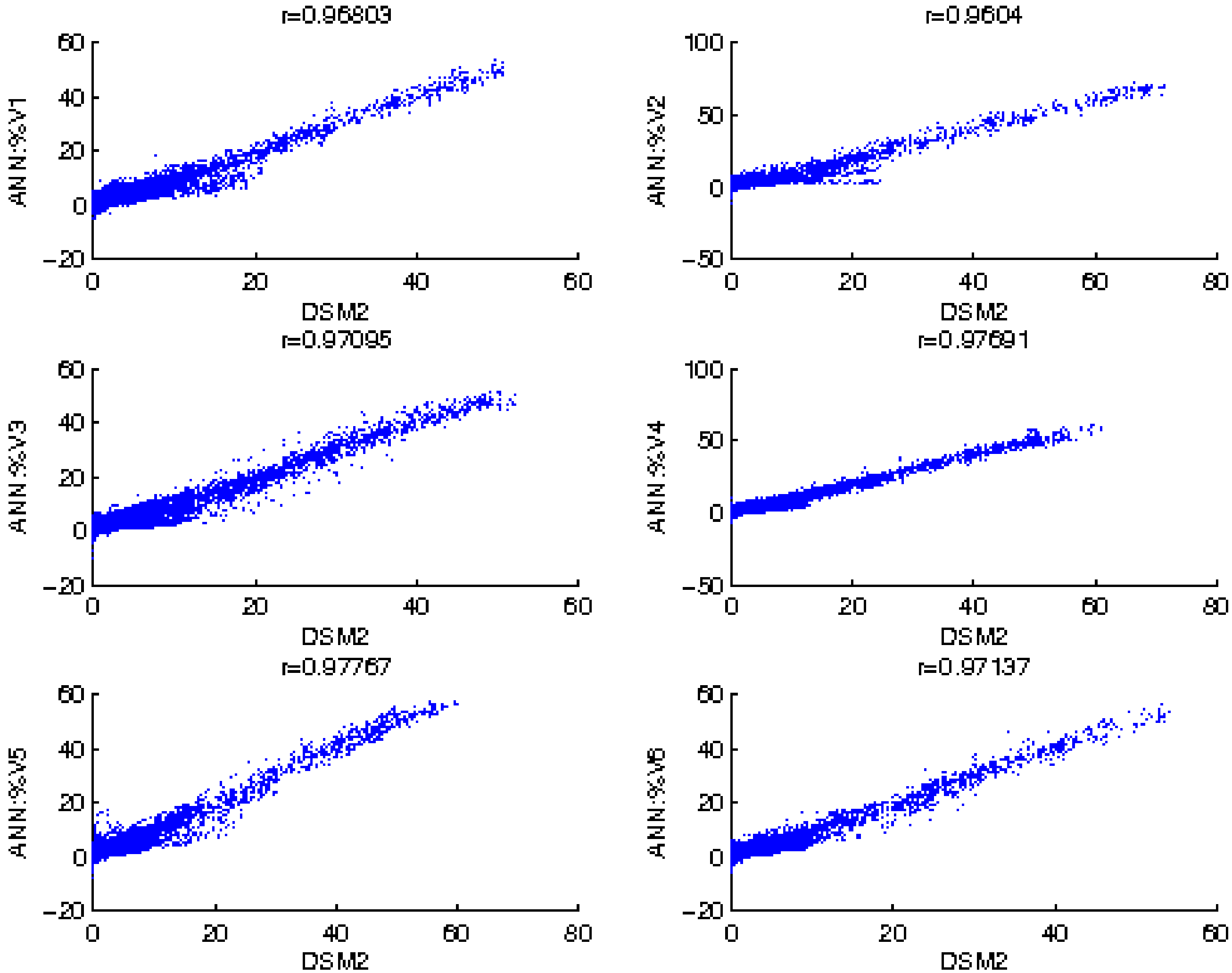

Figure C-29 ANN vs. DSM2 simulated volumetric contribution from San Joaquin River to RSAN007 (Antioch) at different time steps

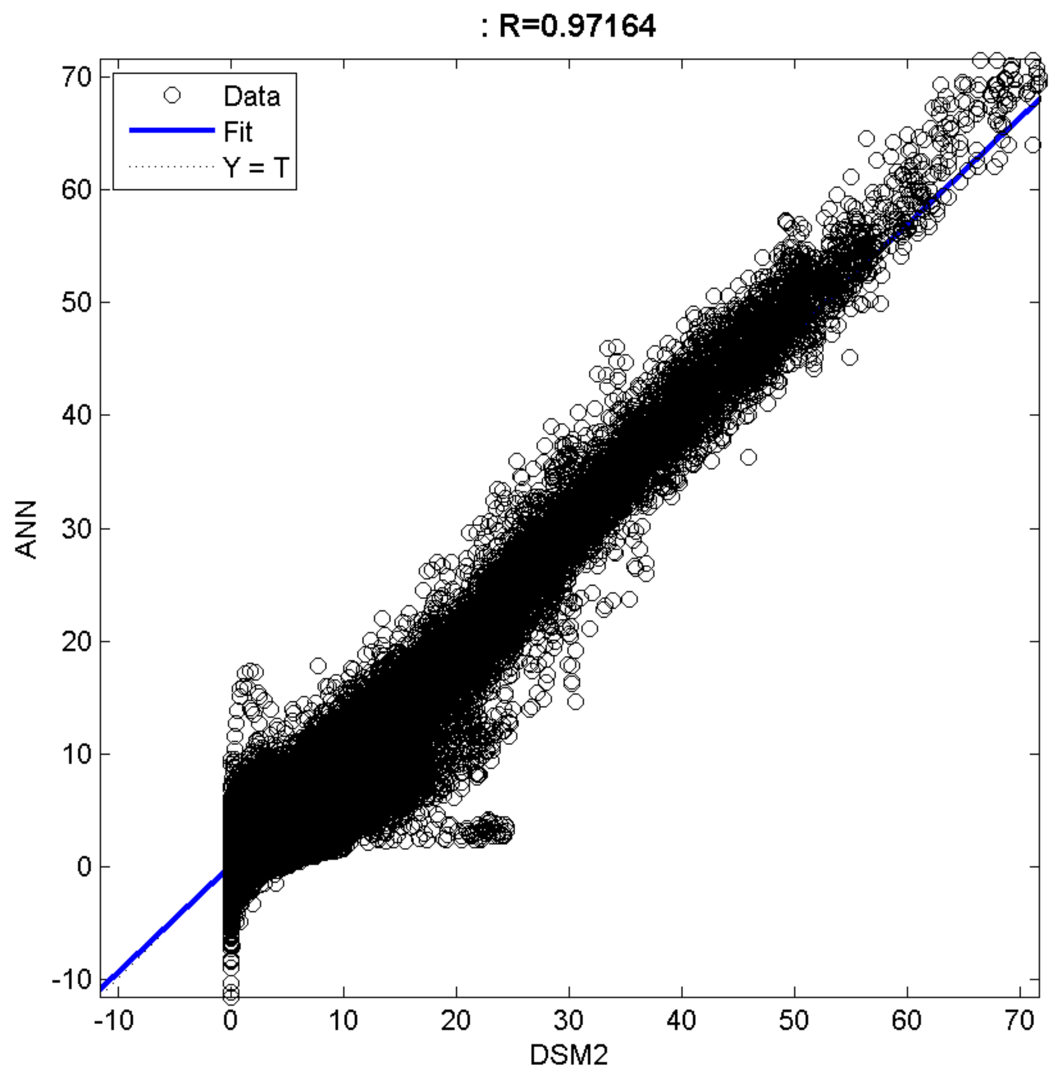

Figure C-30 ANN vs. DSM2 simulated volumetric contribution from San Joaquin River to RSAN007 (Antioch)

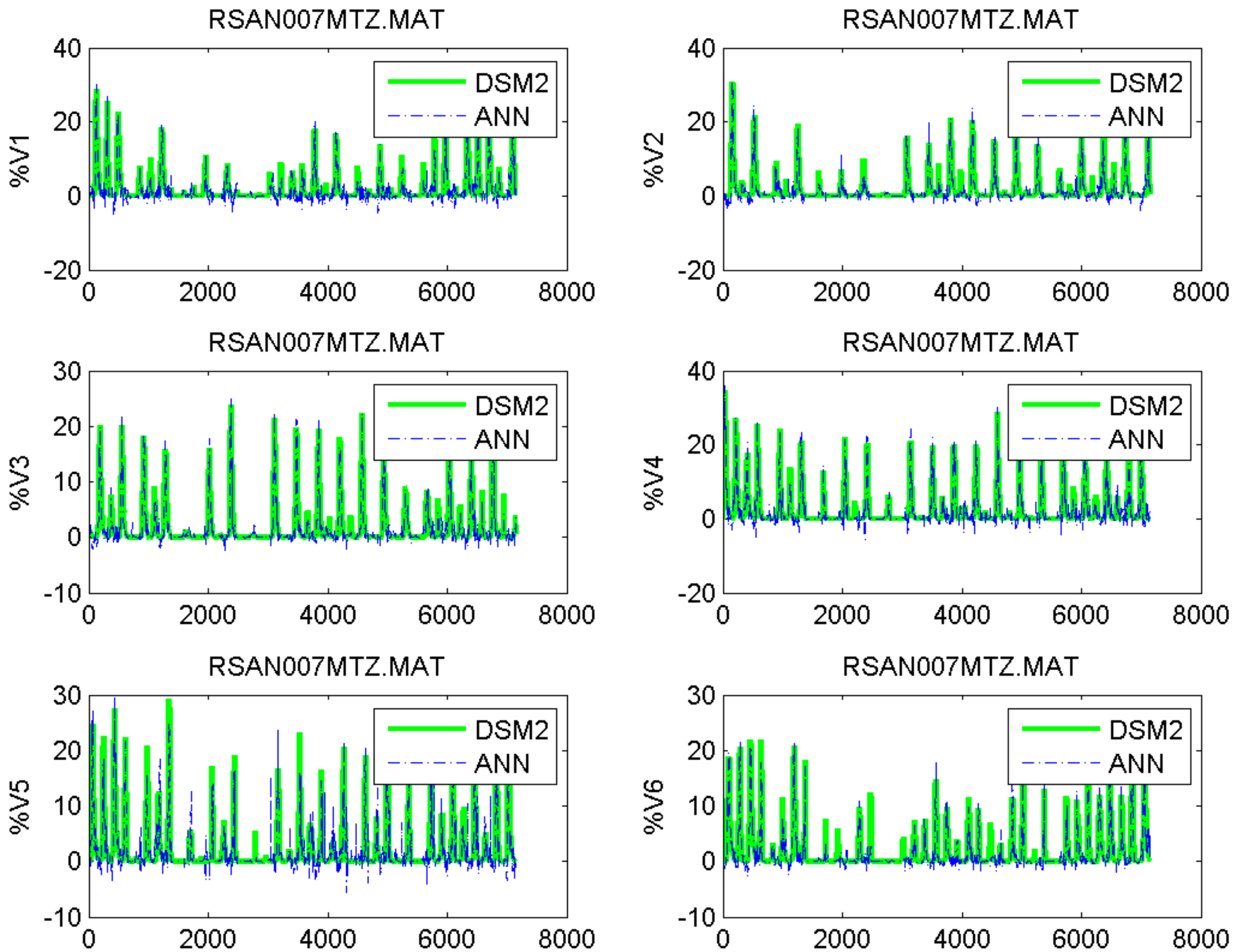

Figure C-31 ANN vs. DSM2 simulated time series of volumetric contribution from Martinez to RSAN007 (Antioch) at different time steps

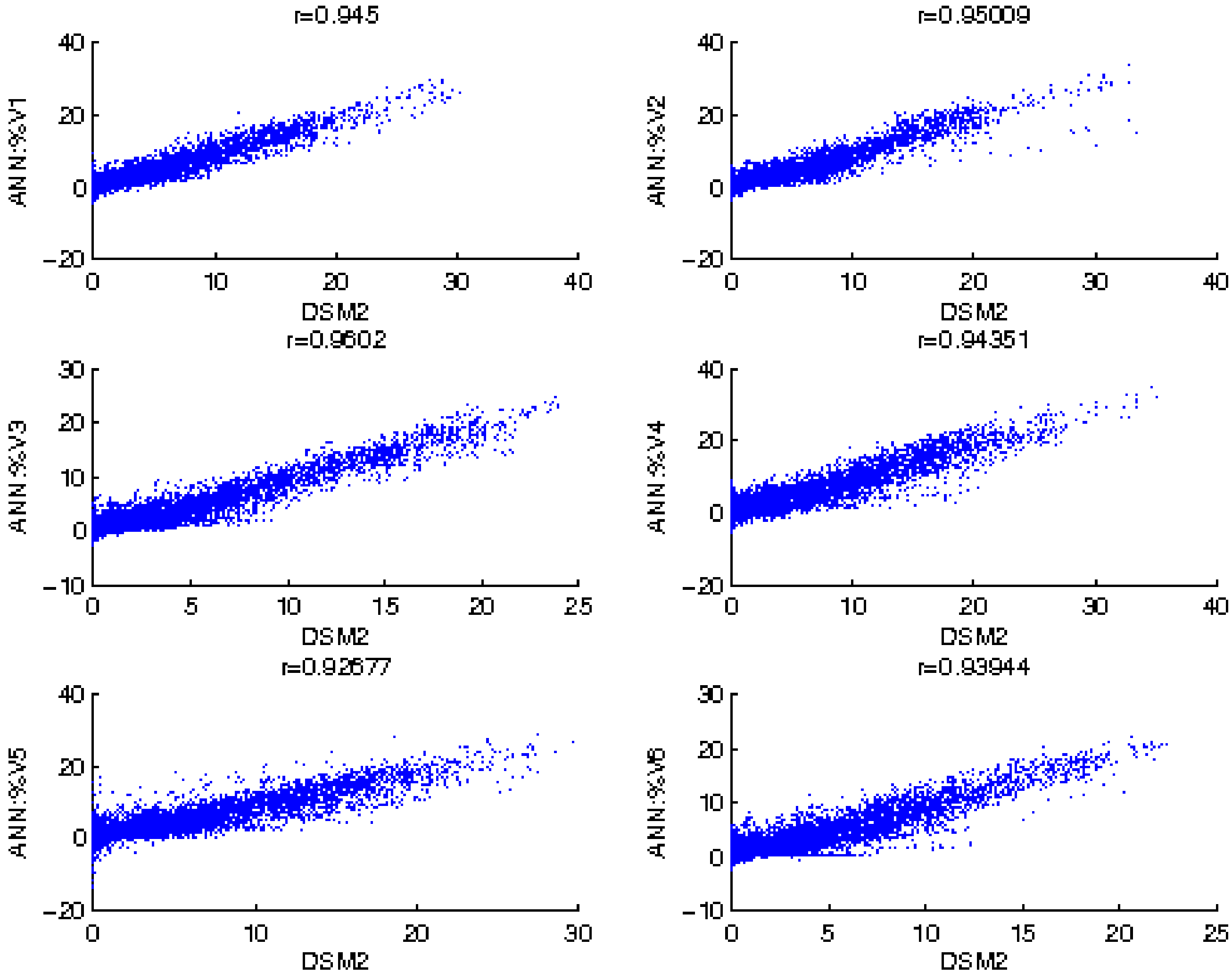

Figure C-32 ANN vs. DSM2 simulated volumetric contribution from Martinez to RSAN007 (Antioch) at different time steps

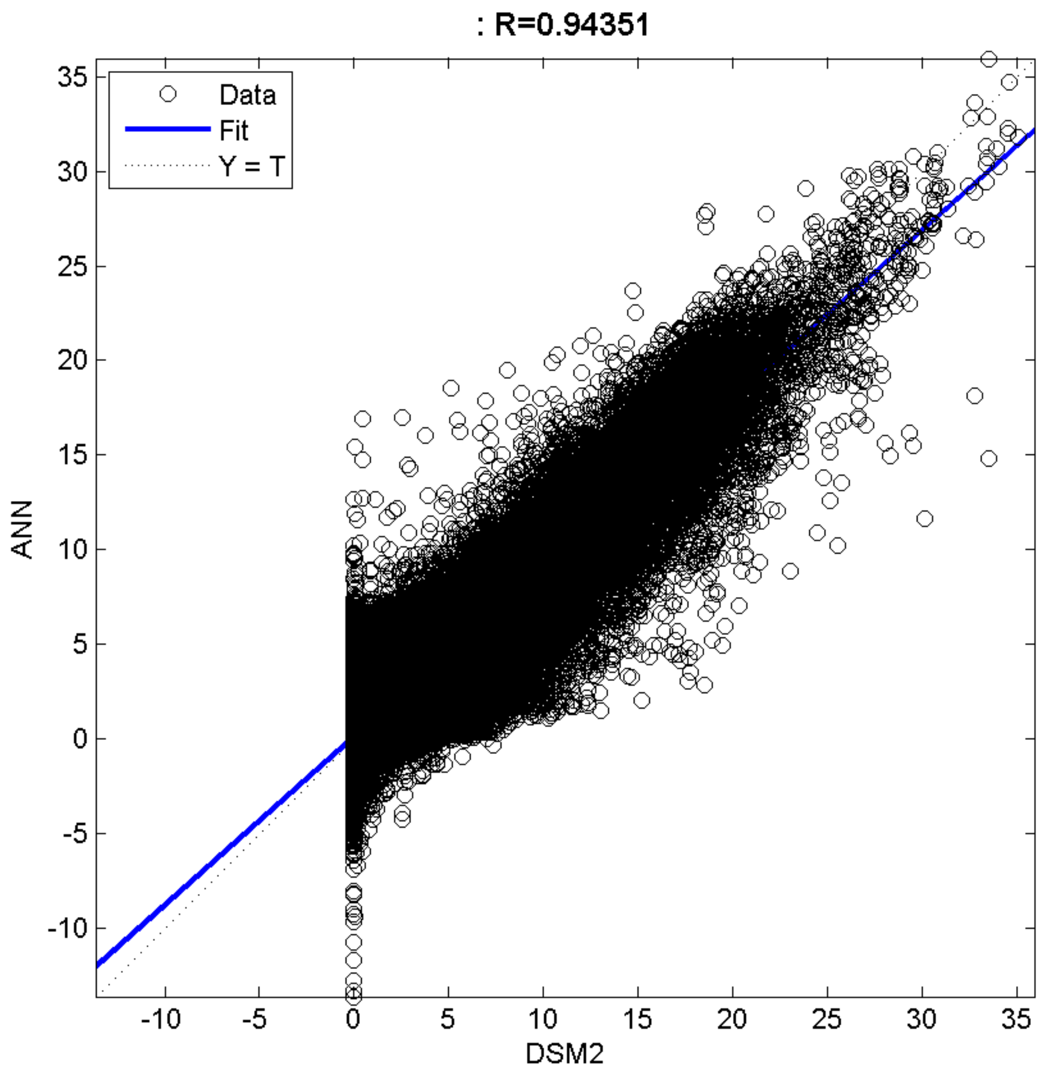

Figure C-33 ANN vs. DSM2 simulated volumetric contribution from Martinez to RSAN007 (Antioch)

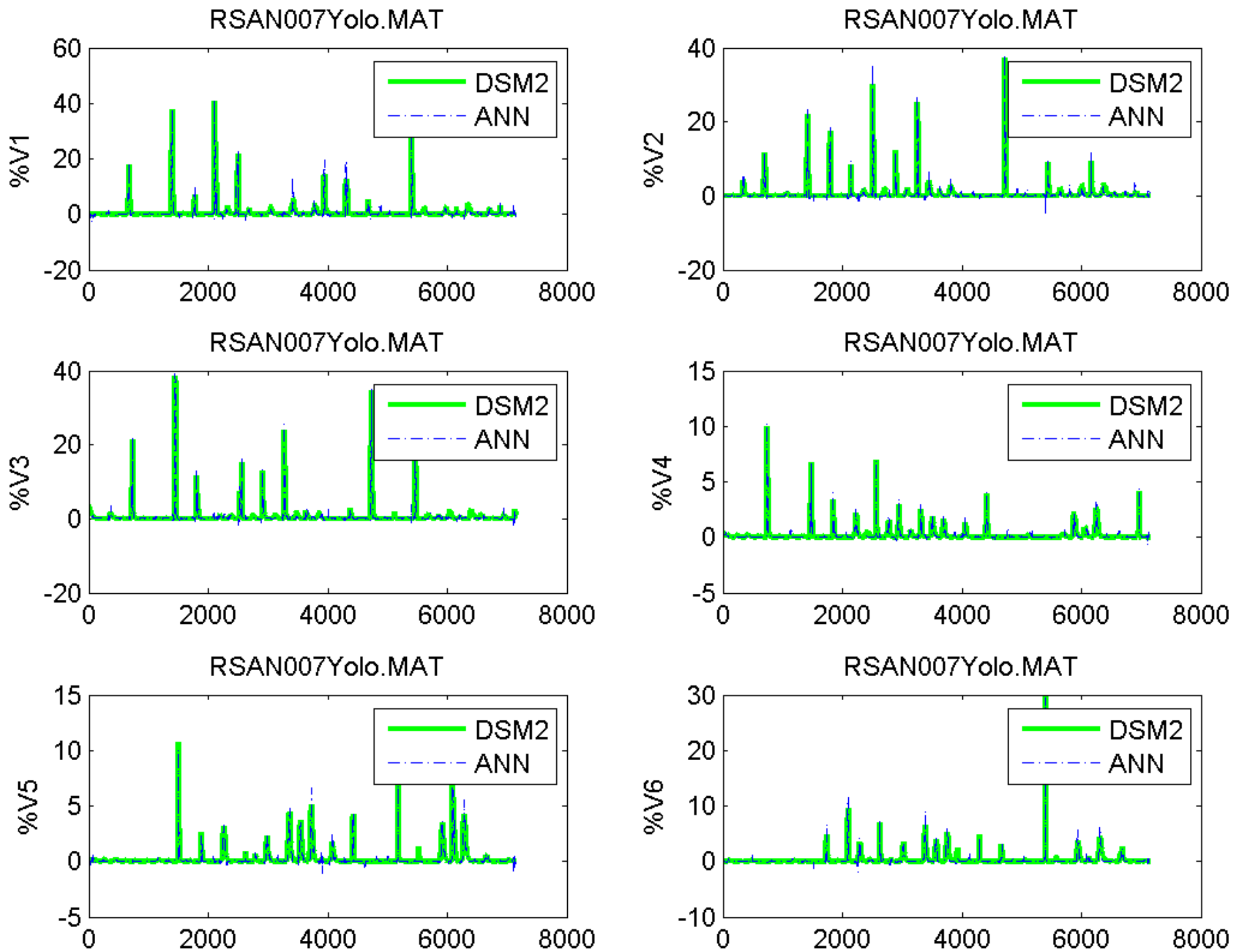

Figure C-34 ANN vs. DSM2 simulated time series of volumetric contribution from Yolo to RSAN007 (Antioch) at different time steps

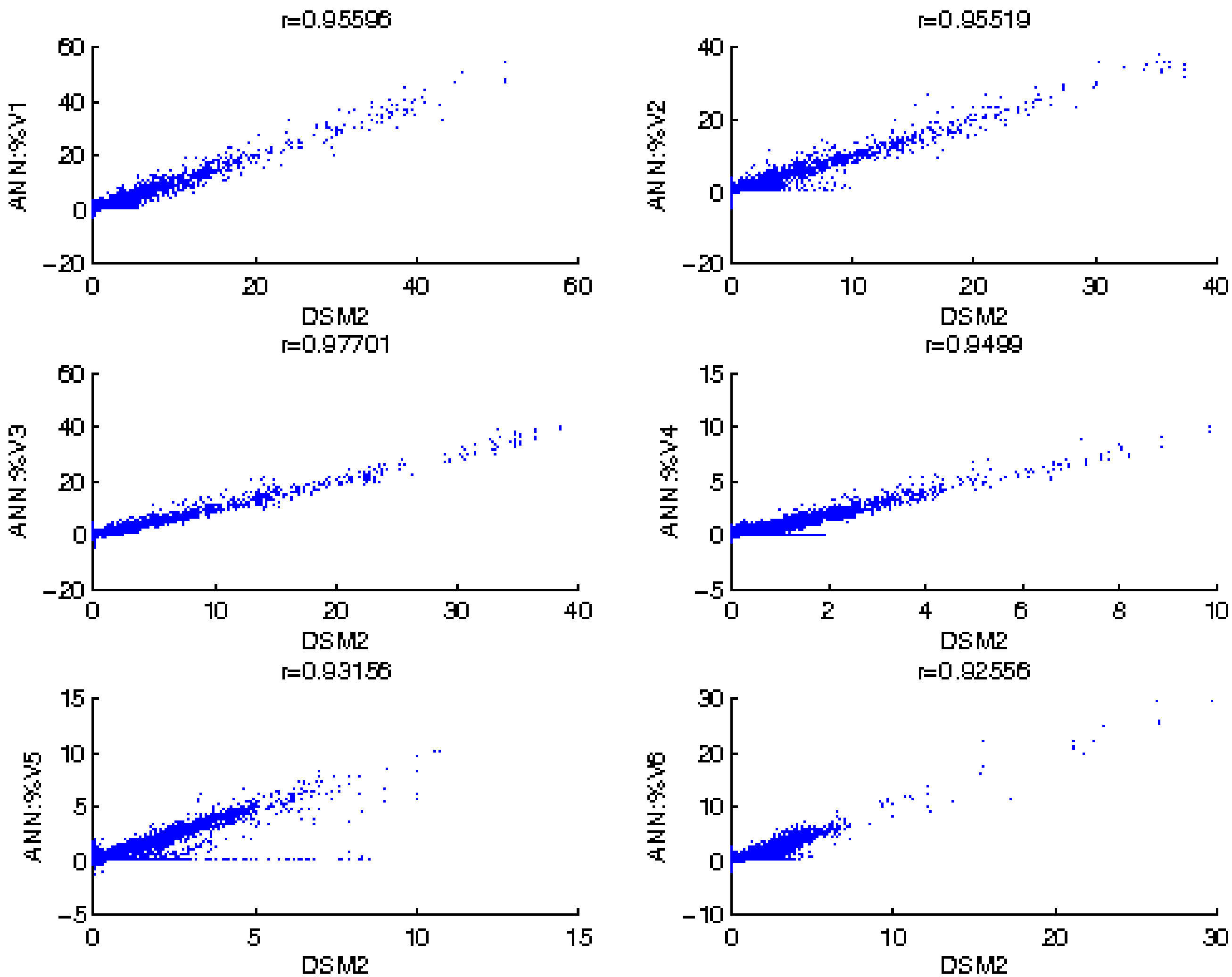

Figure C-35 ANN vs. DSM2 simulated volumetric contribution from Yolo to RSAN007 (Antioch) at different time steps

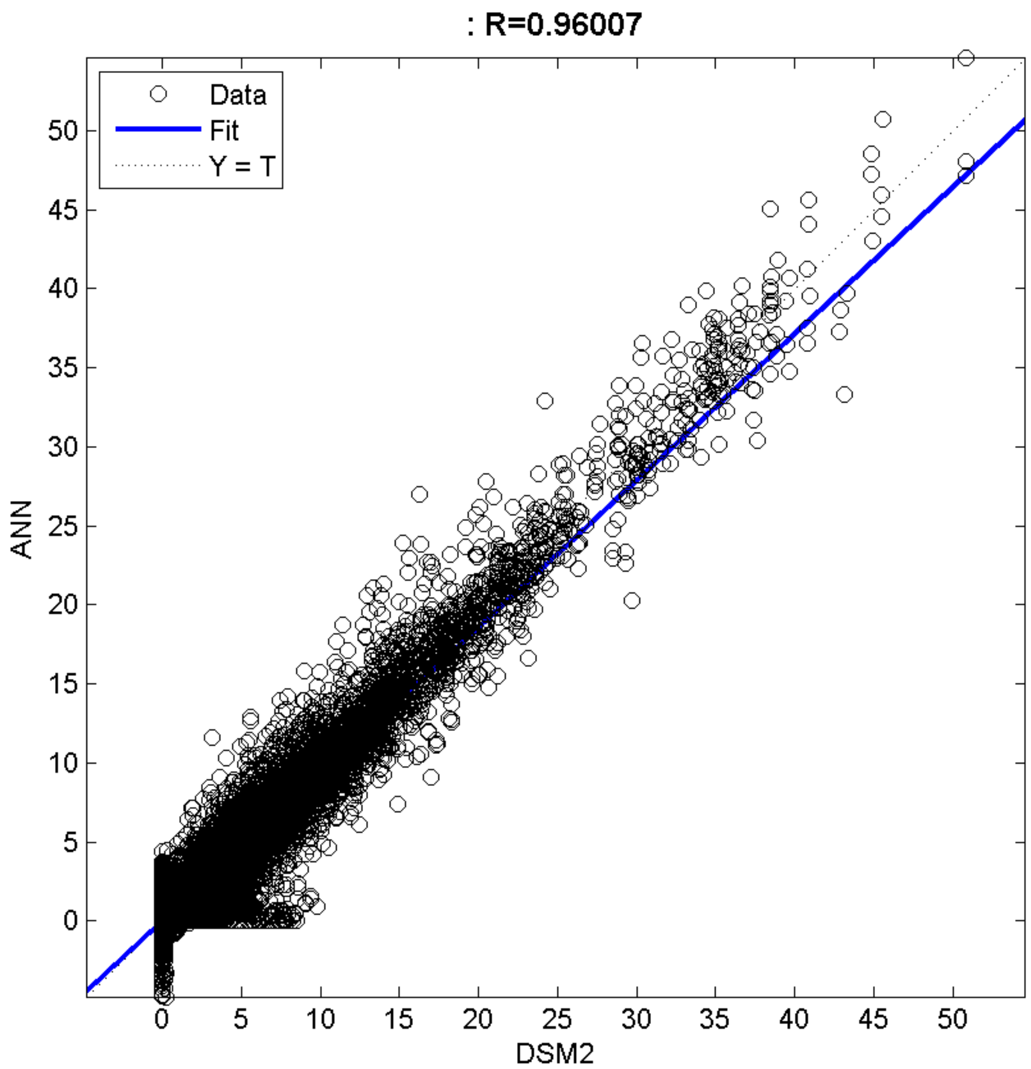

Figure C-36 ANN vs. DSM2 simulated volumetric contribution from Yolo to RSAN007 (Antioch)

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APPENDIX D
COMPARISON OF EC, BR, AND DOC ESTIMATED FROM ANN AND DSM2 SIMULATED VOLUMETRIC CONTRIBUTION

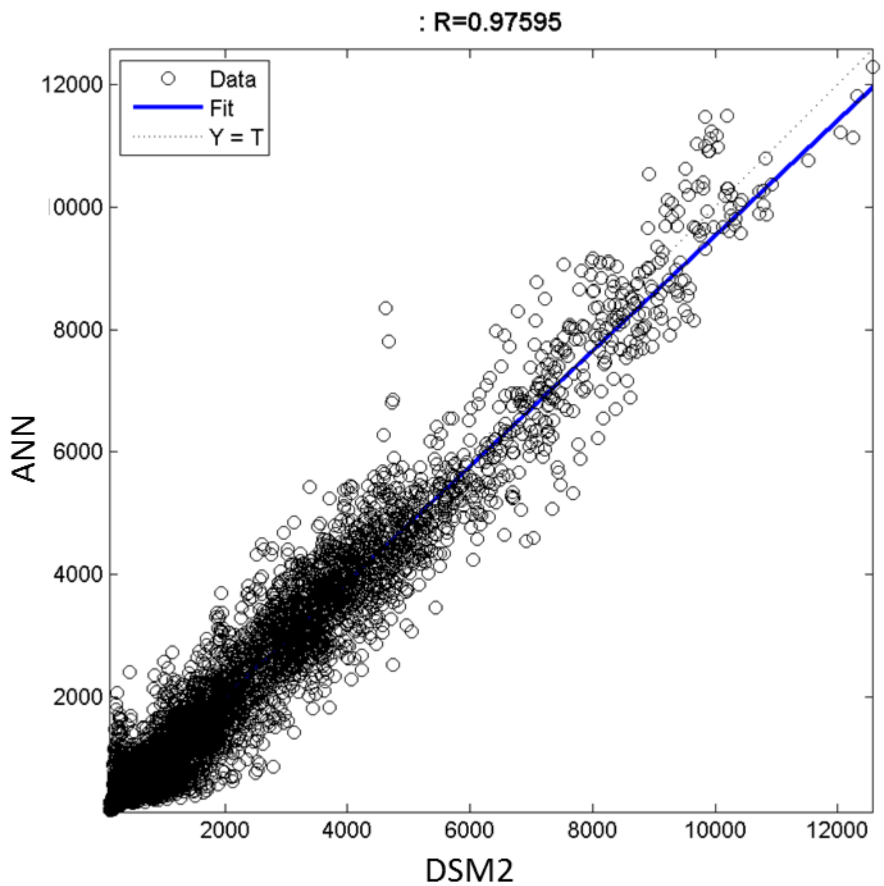

Figure D-1 ANN vs. DSM2 simulated EC at SJR @ HWY4 (RSAN008)

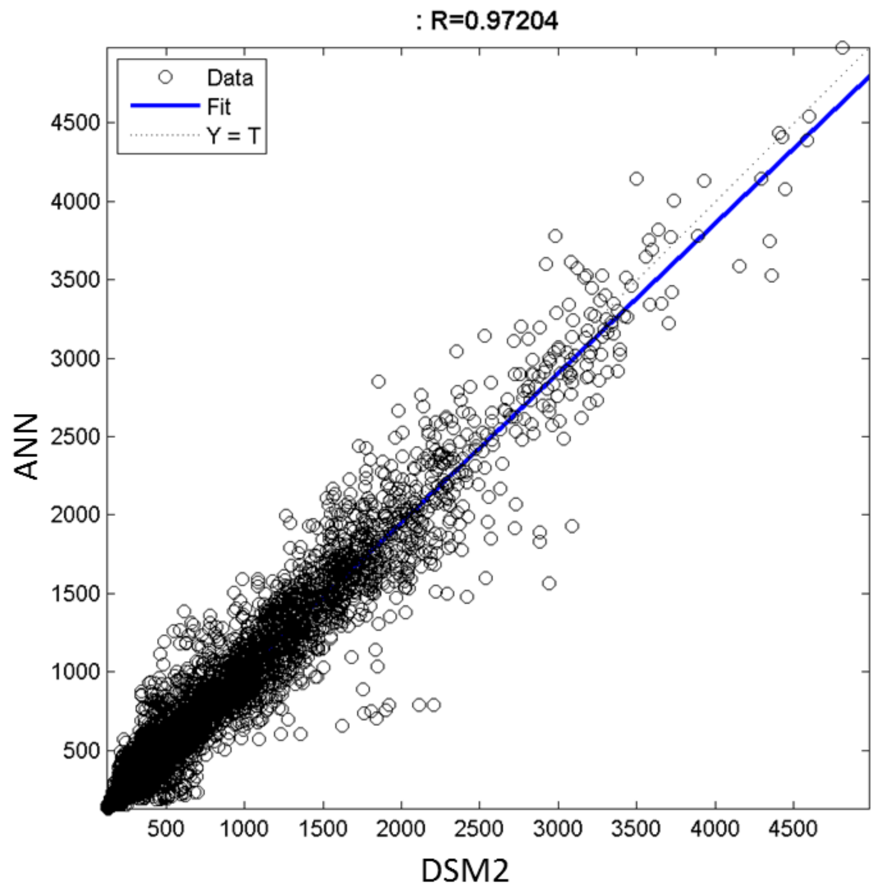

Figure D-2 ANN vs. DSM2 simulated EC at SJR @ Jersey Point (RSAN018)

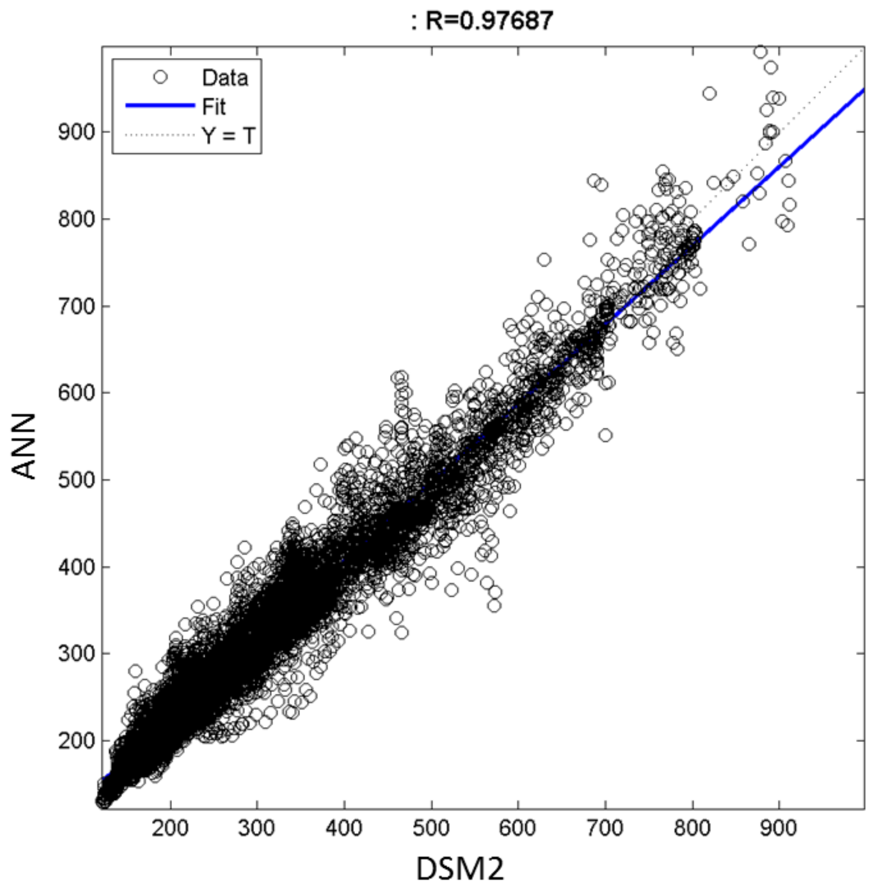

Figure D-3 ANN vs. DSM2 simulated EC at SJR @ Prisoner's Point (RSAN037).

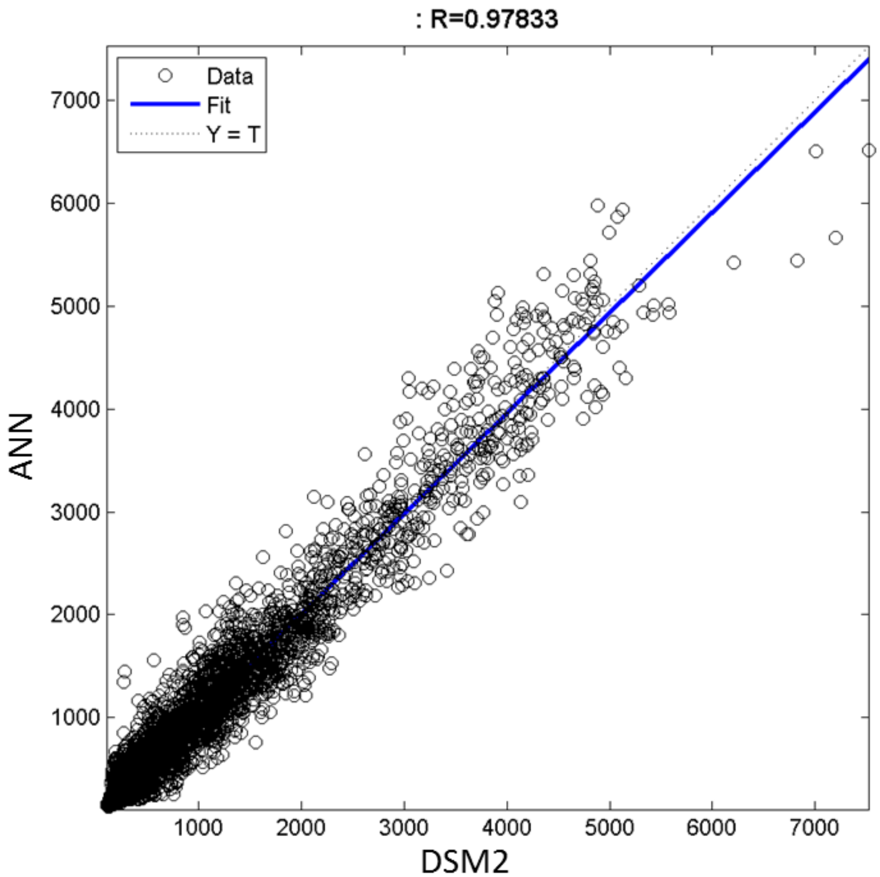

Figure D-4 ANN vs. DSM2 simulated EC at Emmaton (RSAC092).

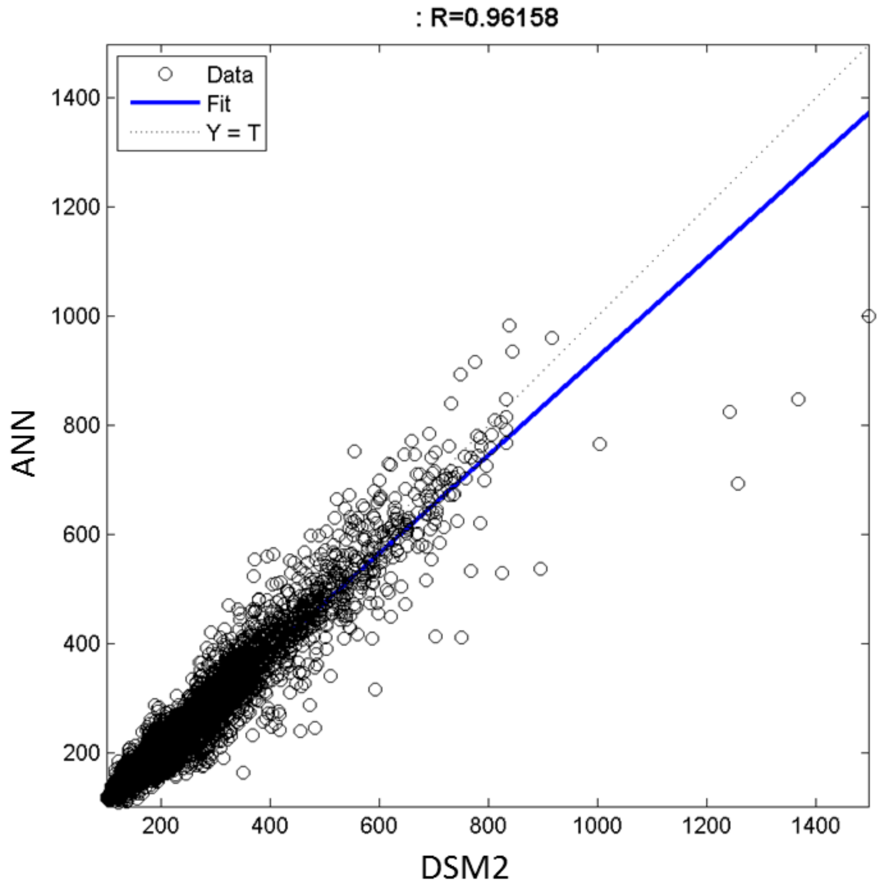

Figure D-5 ANN vs. DSM2 simulated EC at Rio Vista (RSAC101).

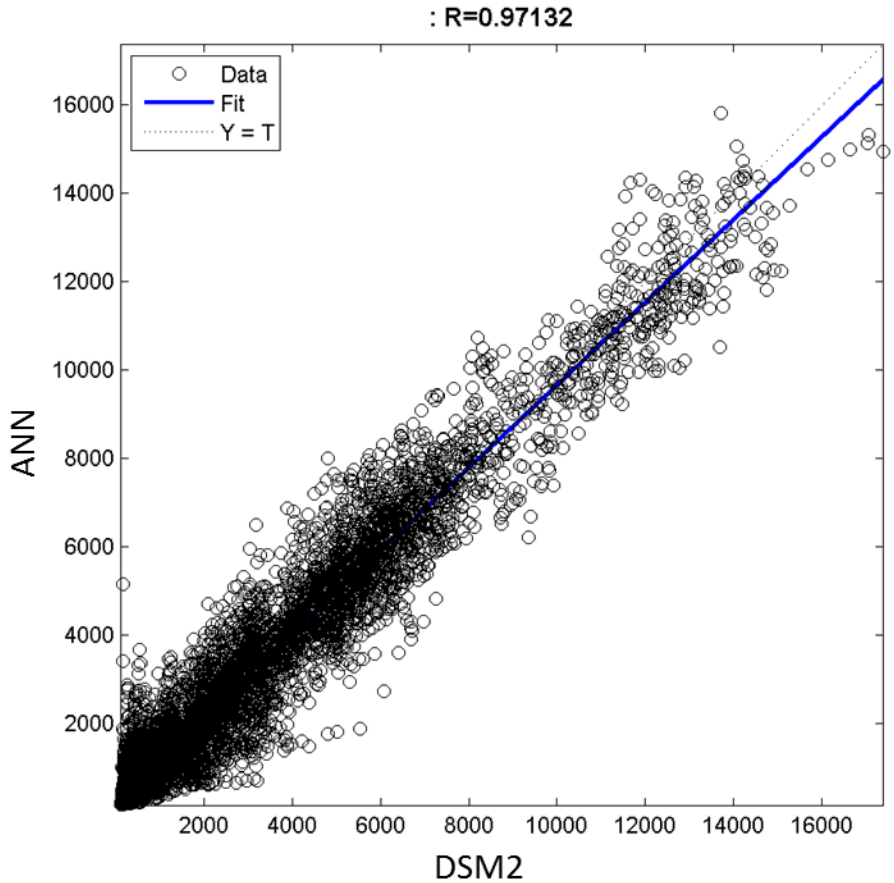

Figure D-6 ANN vs. DSM2 simulated EC at Collinsville (RSAC081).

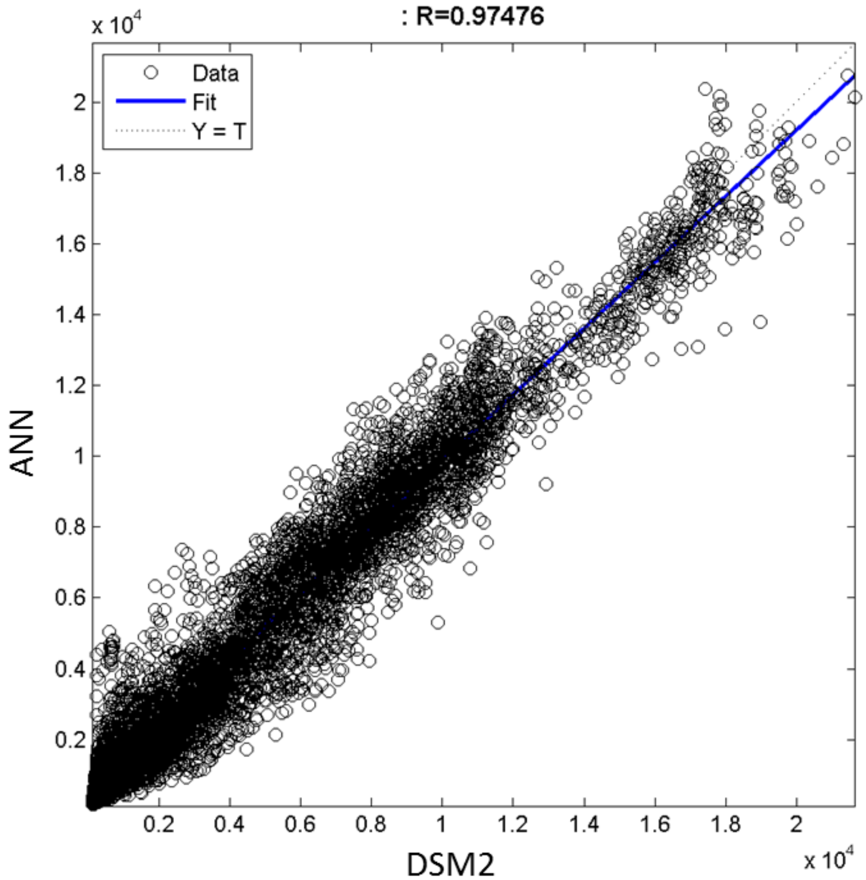

Figure D-7 ANN vs. DSM2 simulated EC at Mallard (RSAC075).

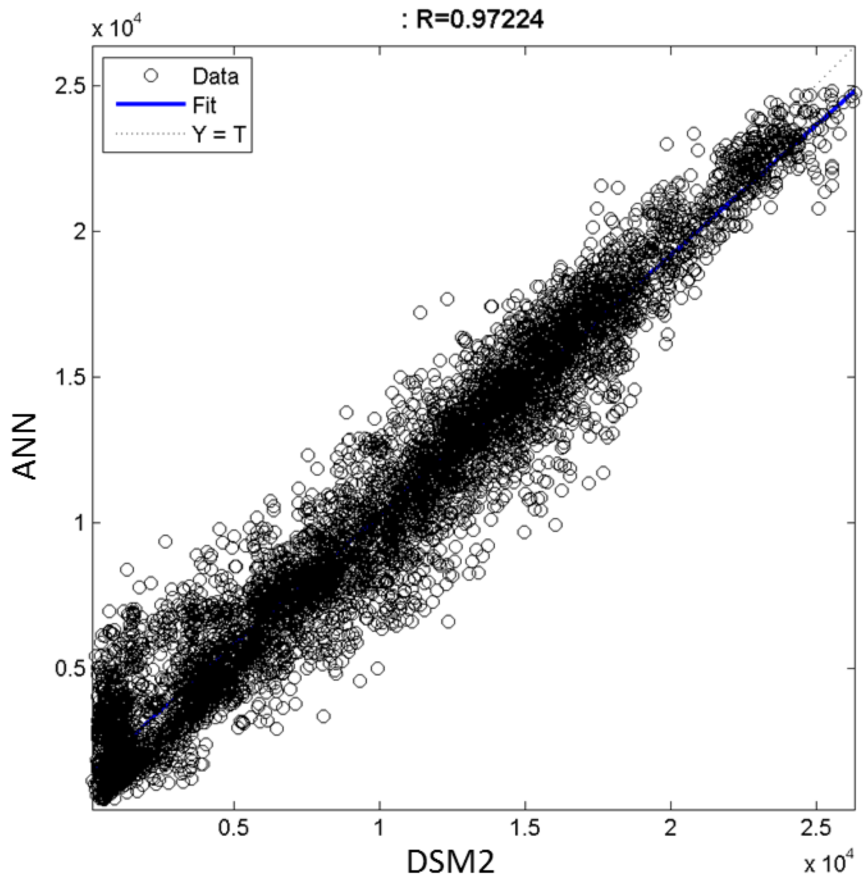

Figure D-8 ANN vs. DSM2 simulated EC at Port Chicago (RSAC064).

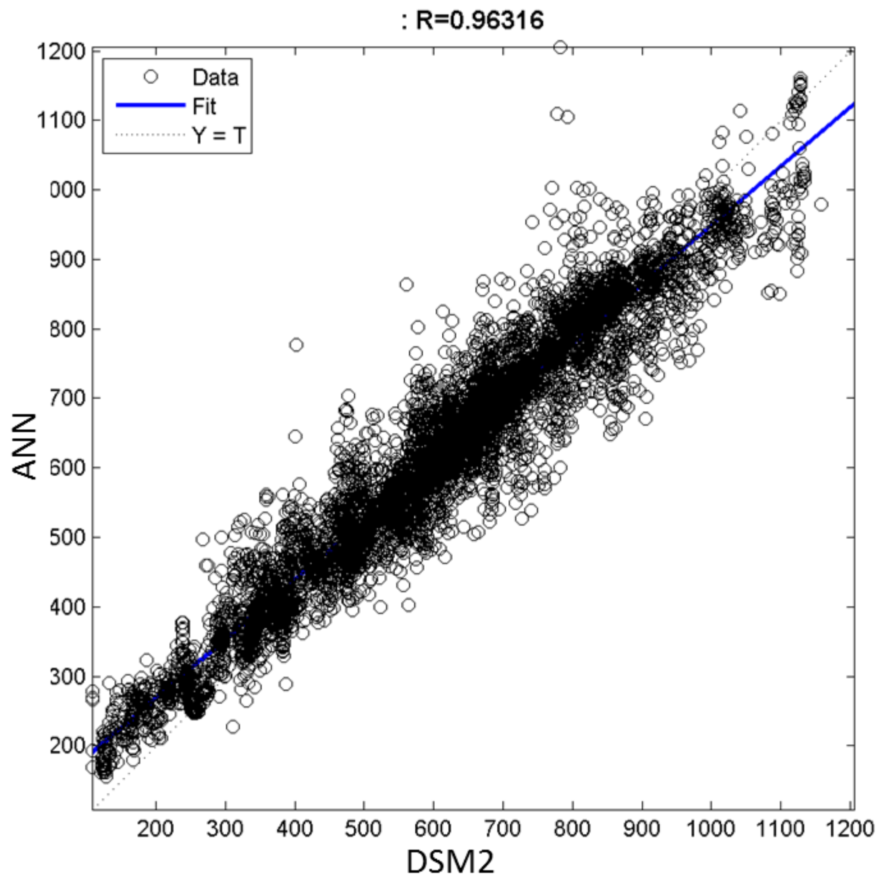

Figure D-9 ANN vs. DSM2 simulated EC at Old River Tracy (Rold059).

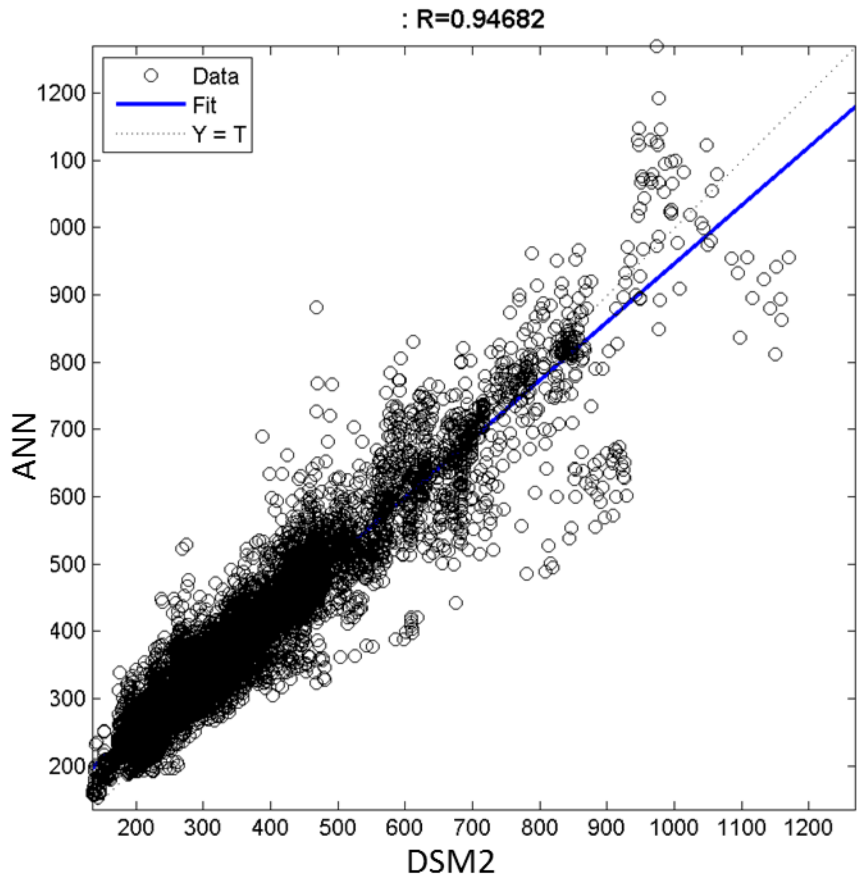

Figure D-10 ANN vs. DSM2 simulated EC at Old River @ HWY4 (Rold034).

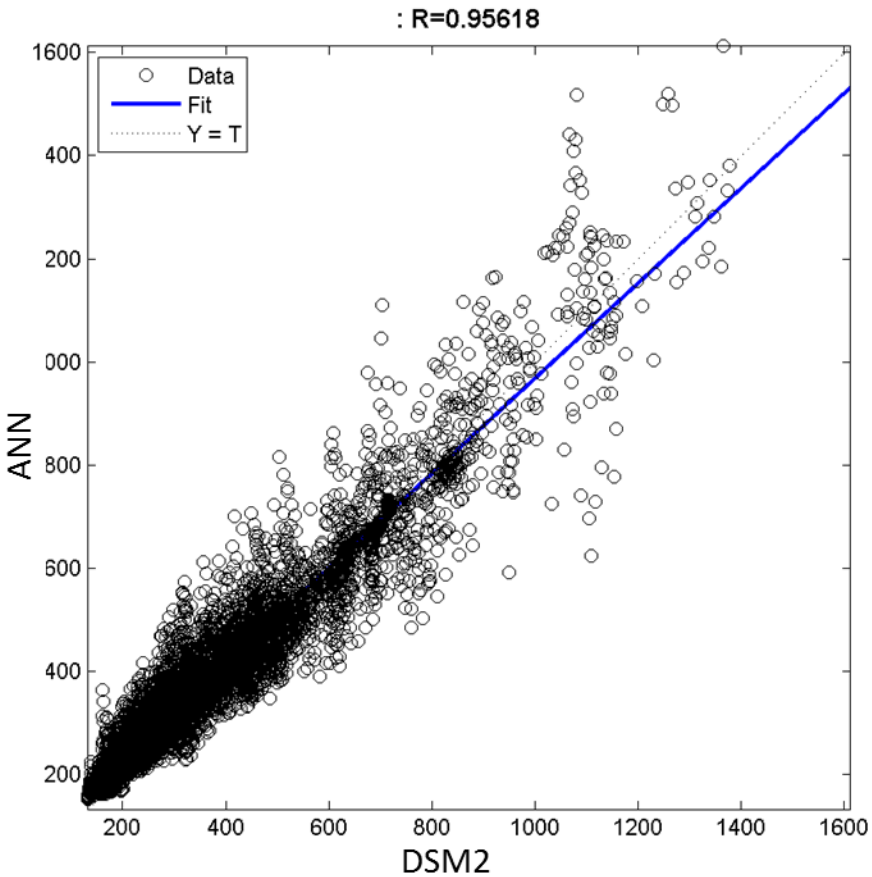

Figure D-11 ANN vs. DSM2 simulated EC at Old River @ Bacon (Rold024).

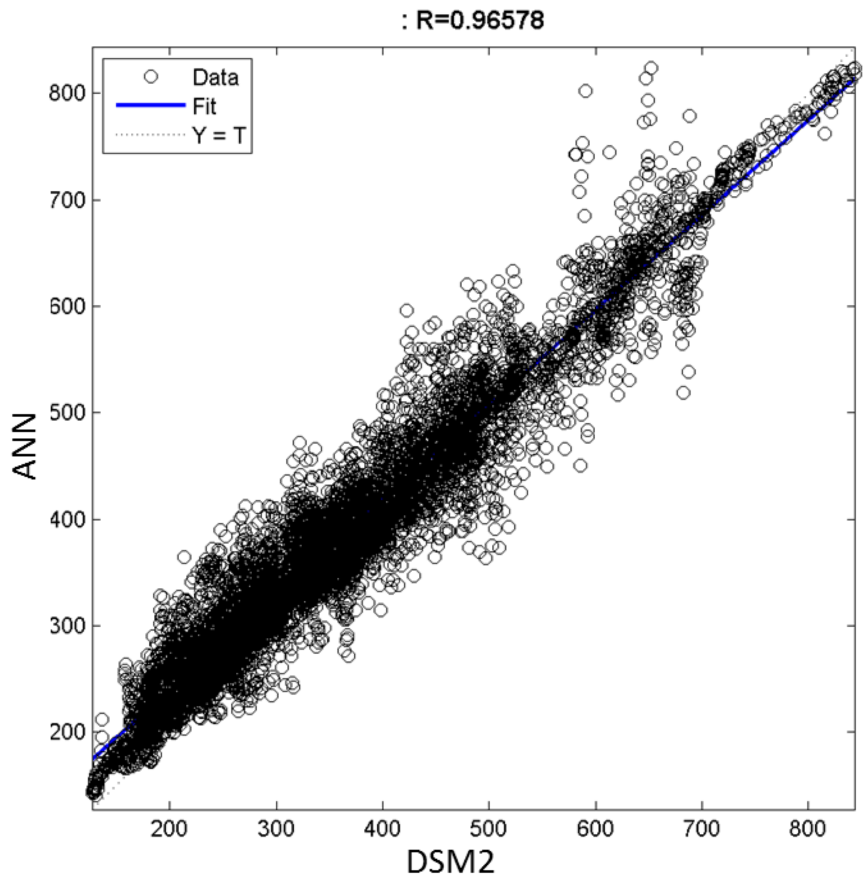

Figure D-12 ANN vs. DSM2 simulated EC at Middle River @ Holt (Rmid005).

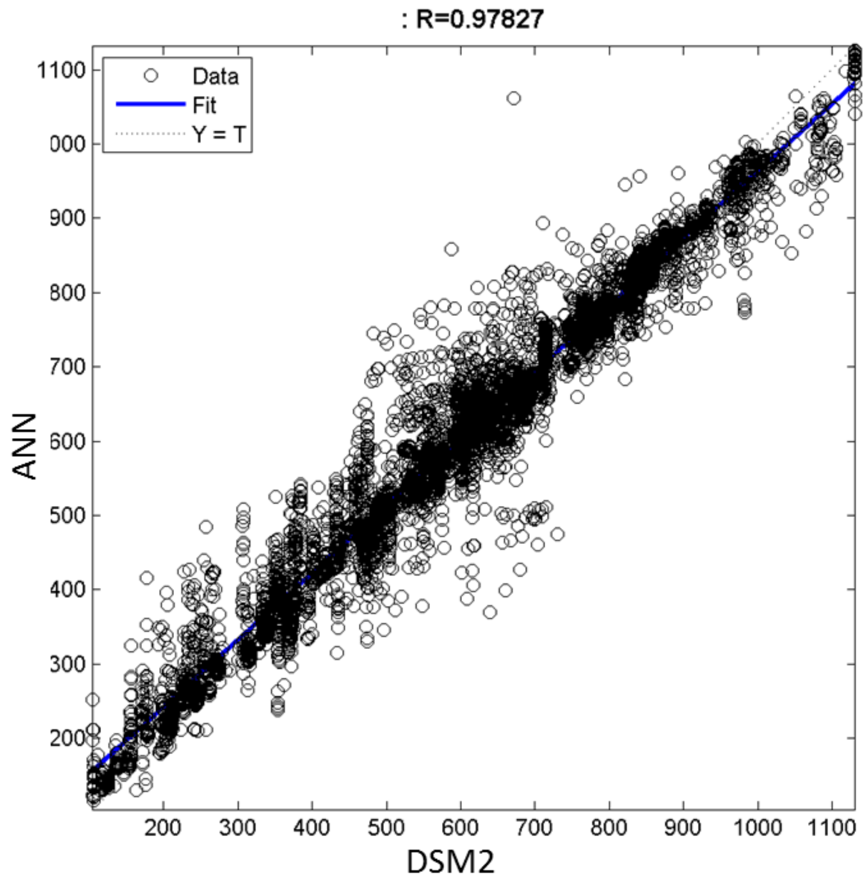

Figure D-13 ANN vs. DSM2 simulated EC at Middle River @ Union Island (Rmid041).

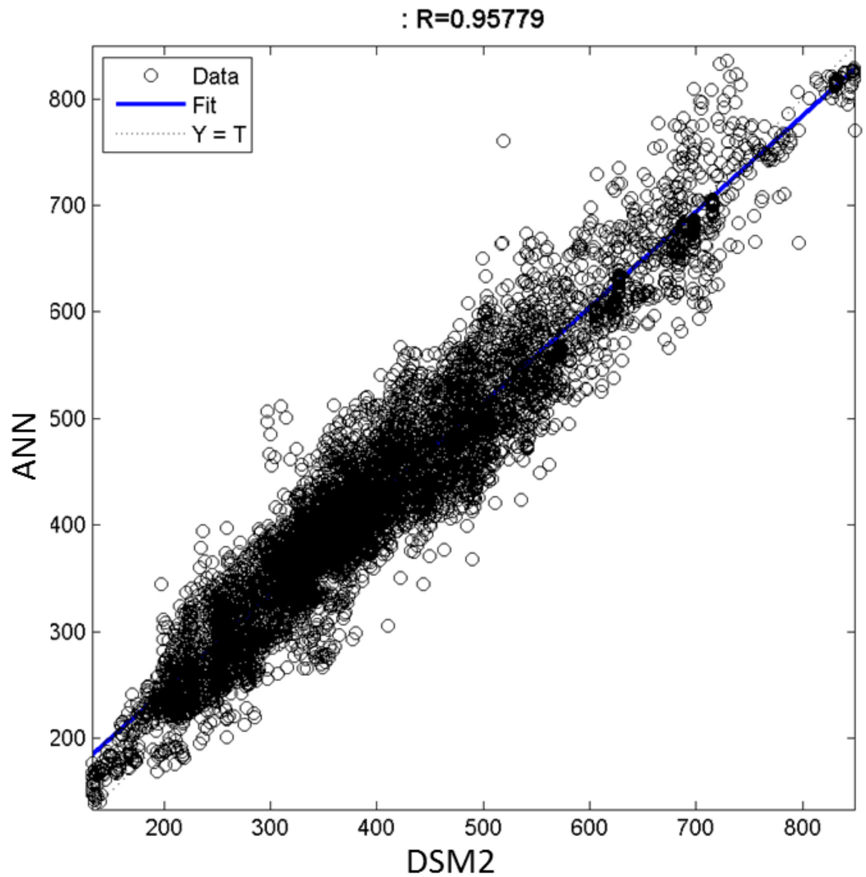

Figure D-14 ANN vs. DSM2 simulated EC at Middle River at Victoria Canal

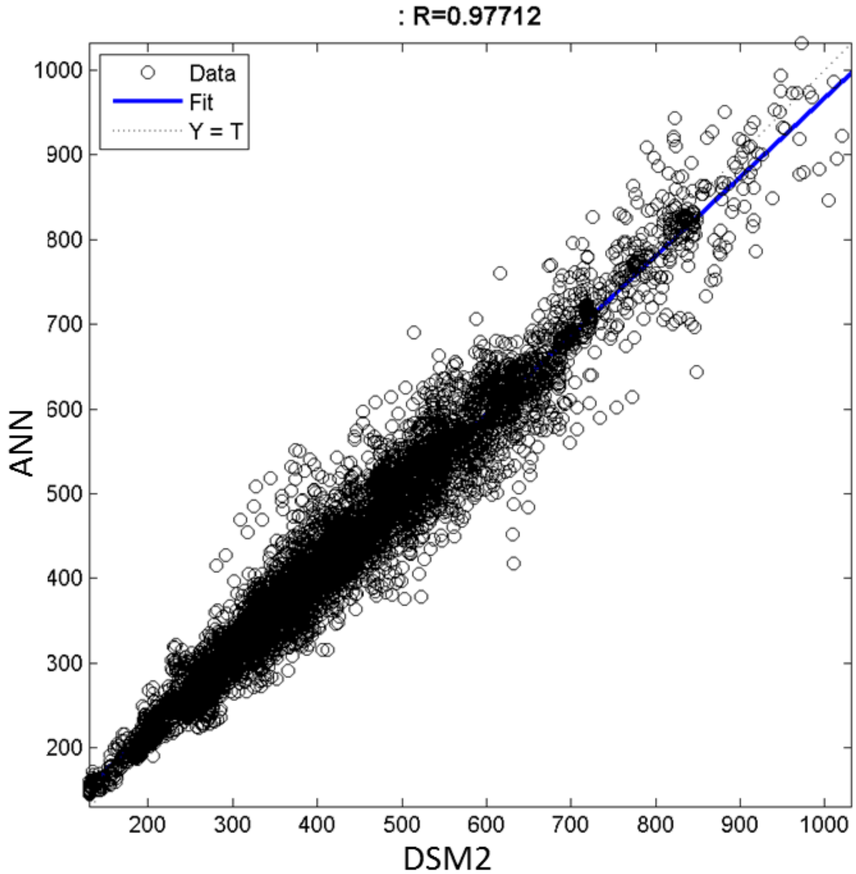

Figure D-15 ANN vs. DSM2 simulated EC at Jones Pumping

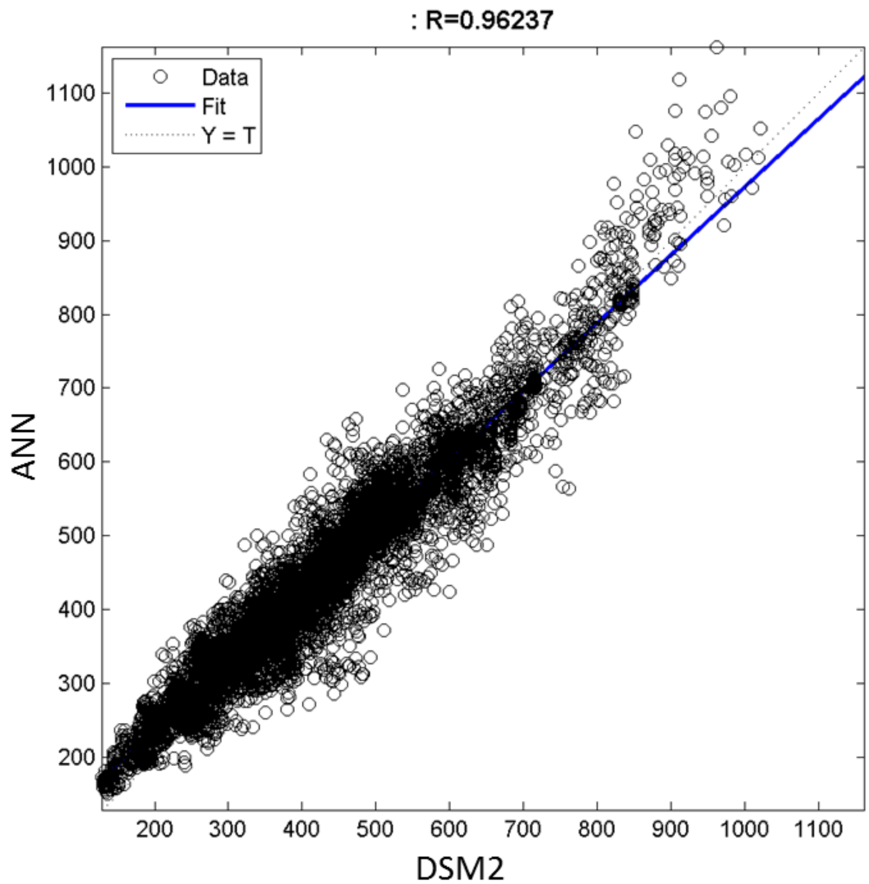

Figure D-16 ANN vs. DSM2 simulated EC at CCF Intake (CHSWP003).

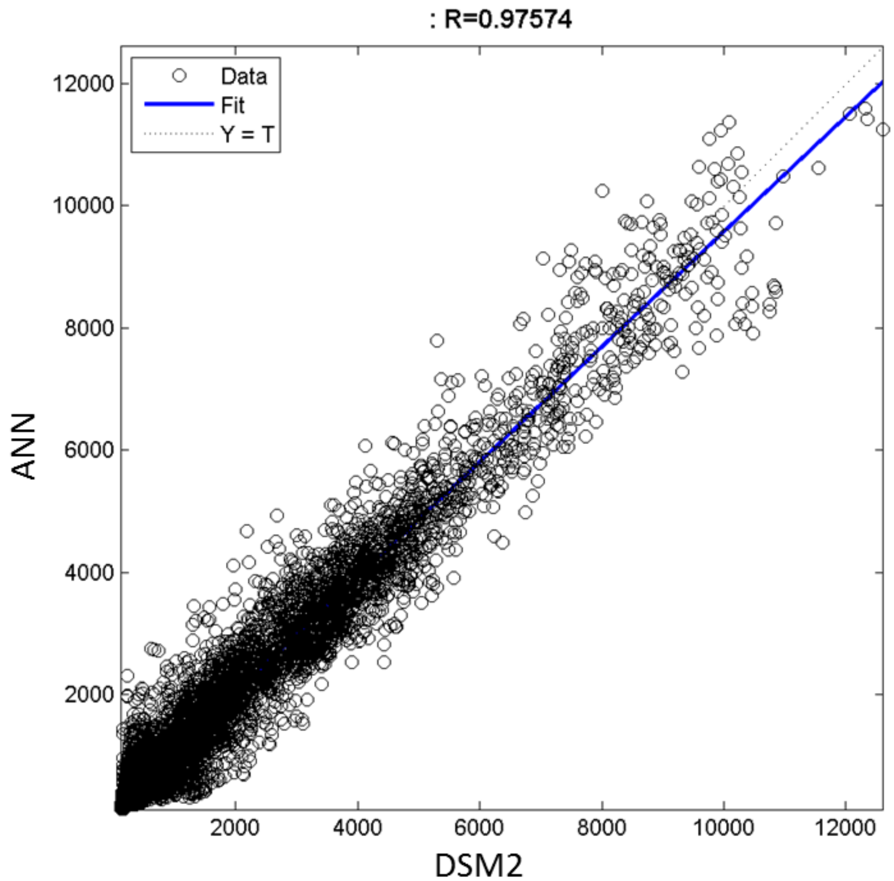

Figure D-17 ANN vs. DSM2 simulated EC at Antioch (RSAN007).

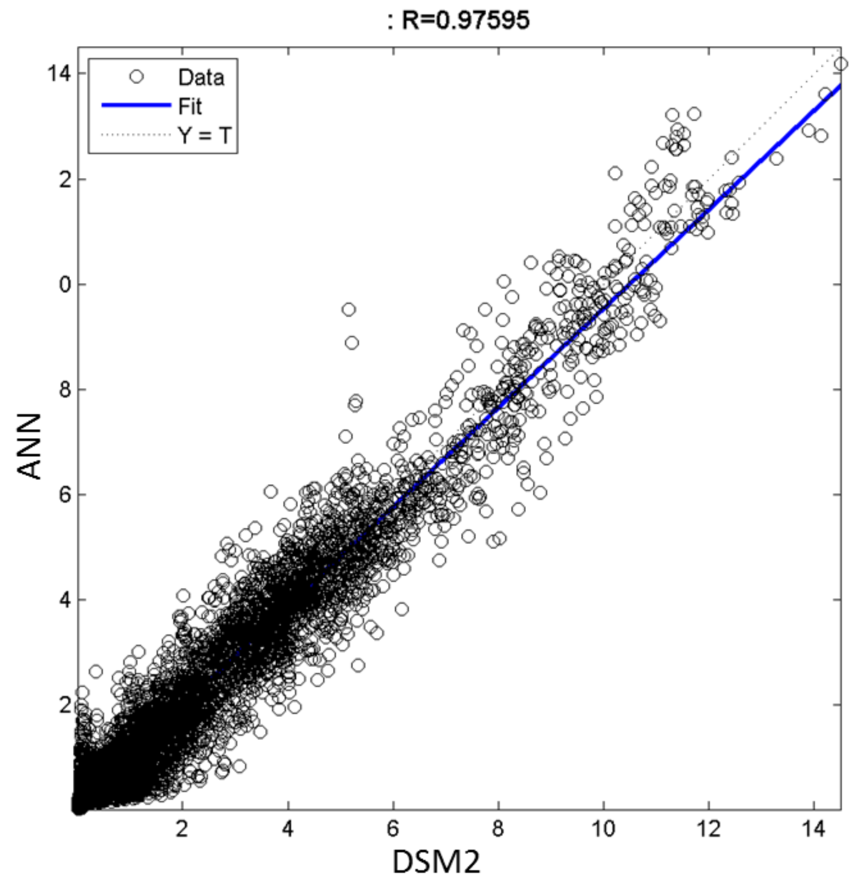

Figure D-18 ANN vs. DSM2 simulated Br at SJR @ HWY4 (RSAN008)

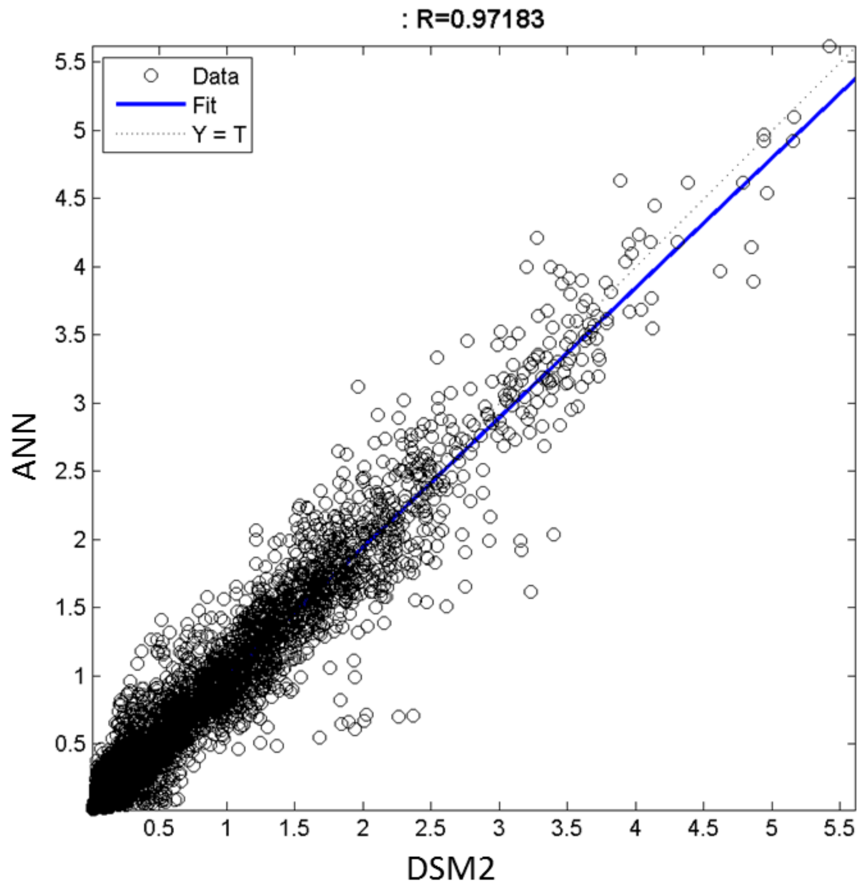

Figure D-19 ANN vs. DSM2 simulated Br at SJR @ Jersey Point (RSAN018)

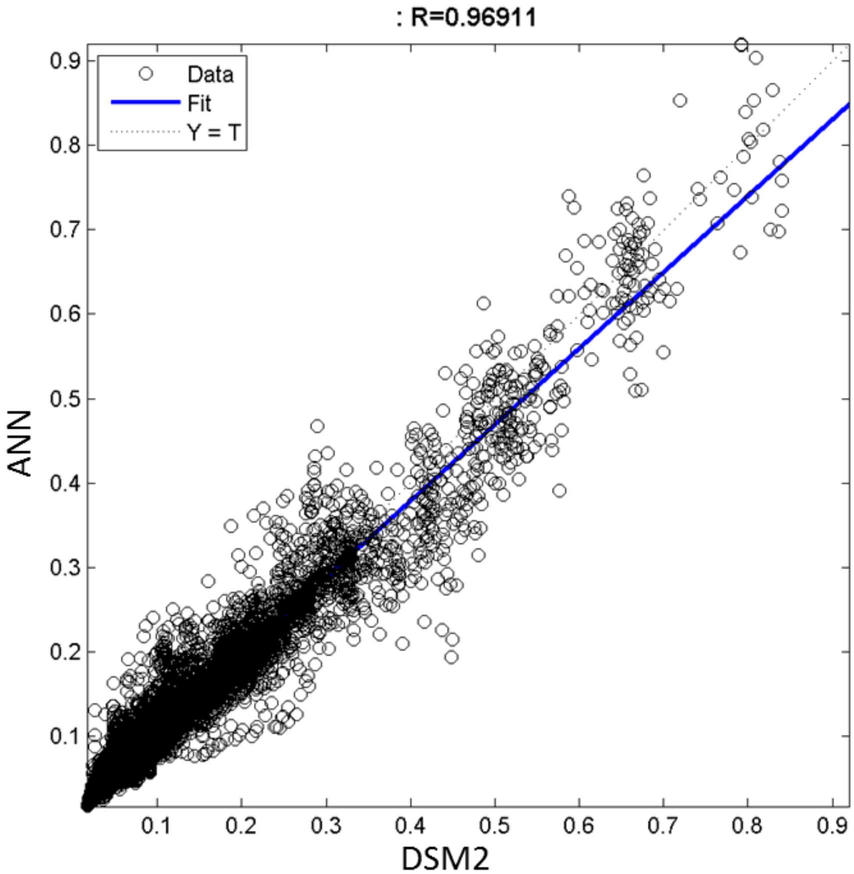

Figure D-20 ANN vs. DSM2 simulated Br at SJR @ Prisoner's Point (RSAN037).

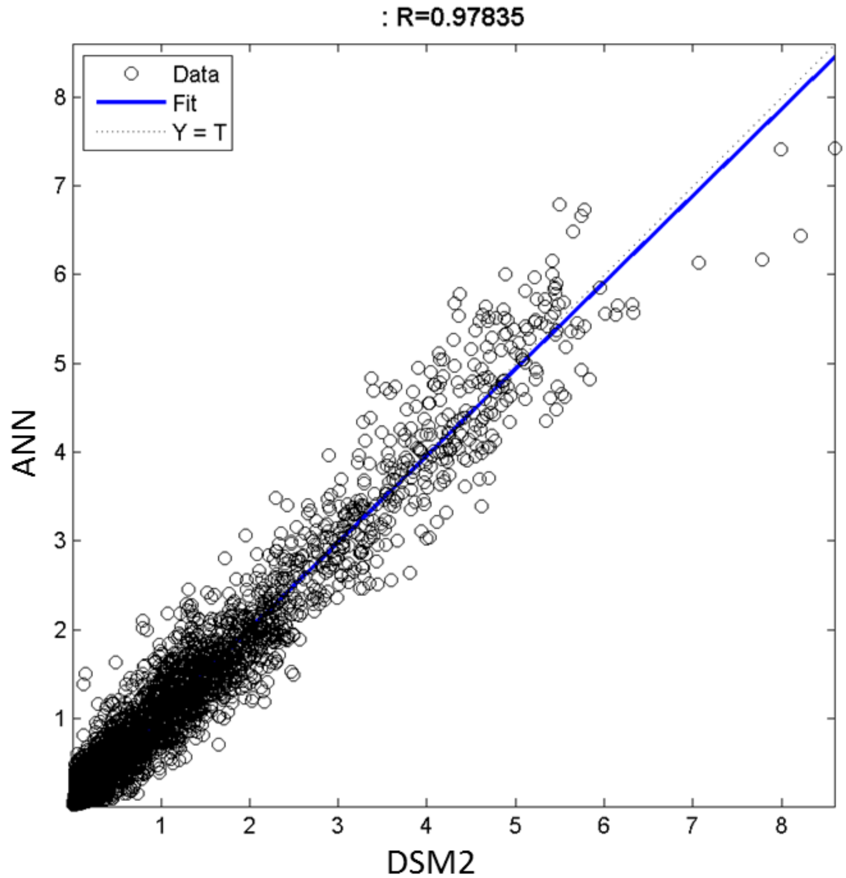

Figure D-21 ANN vs. DSM2 simulated Br at Emmaton (RSAC092).

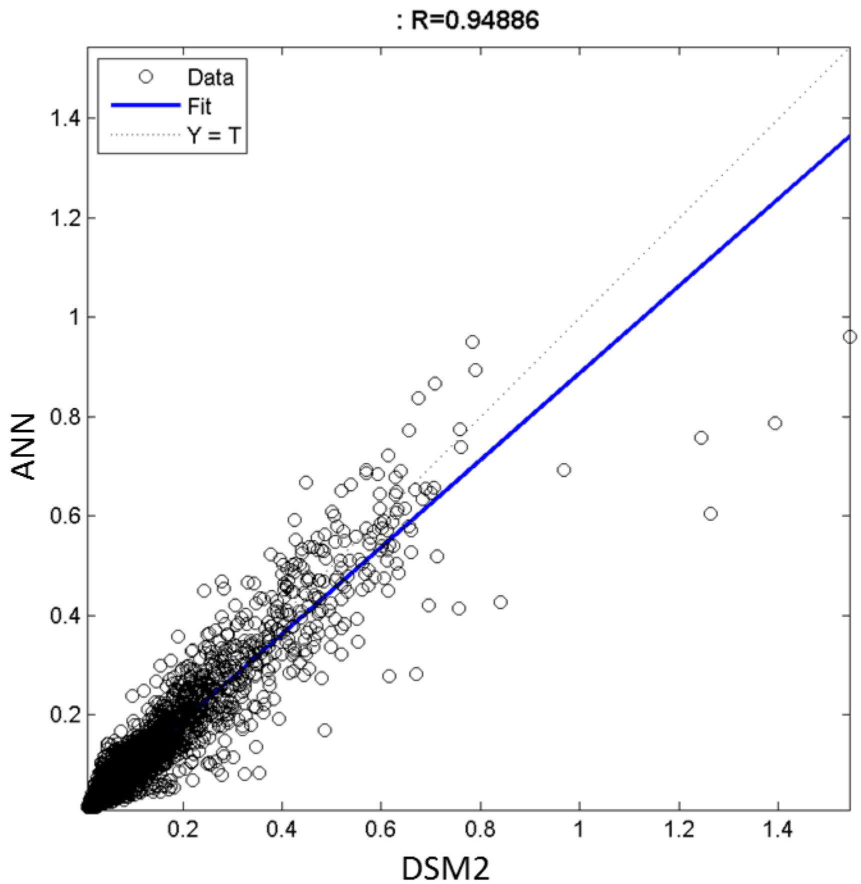

Figure D-22 ANN vs. DSM2 simulated Br at Rio Vista (RSAC101).

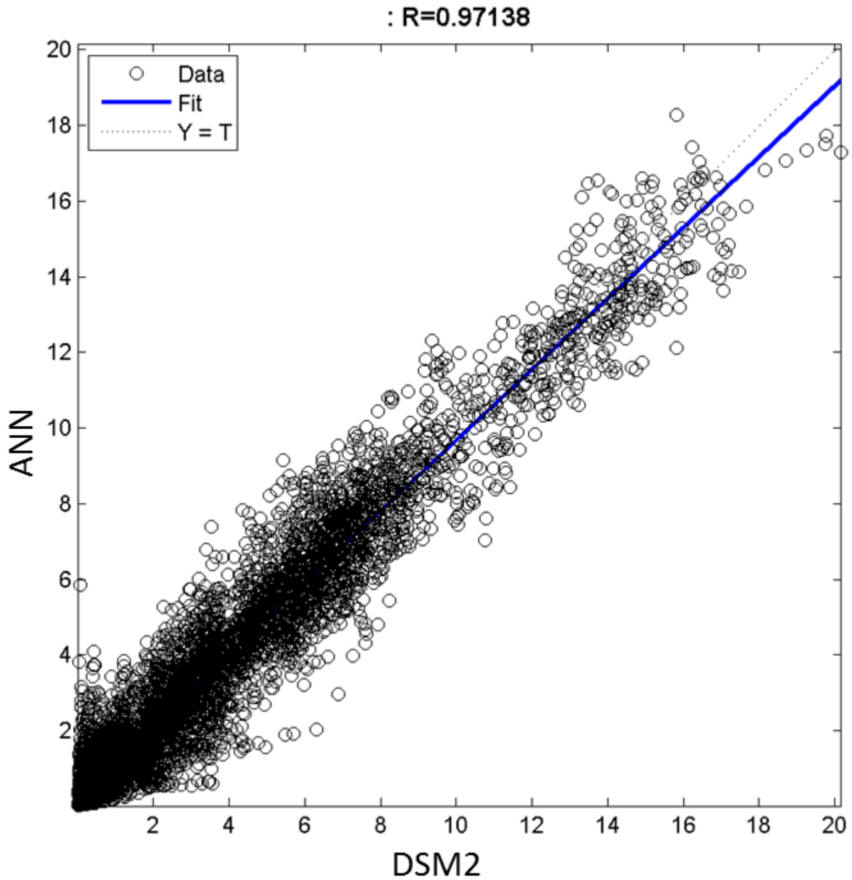

Figure D-23 ANN vs. DSM2 simulated Br at Collinsville (RSAC081).

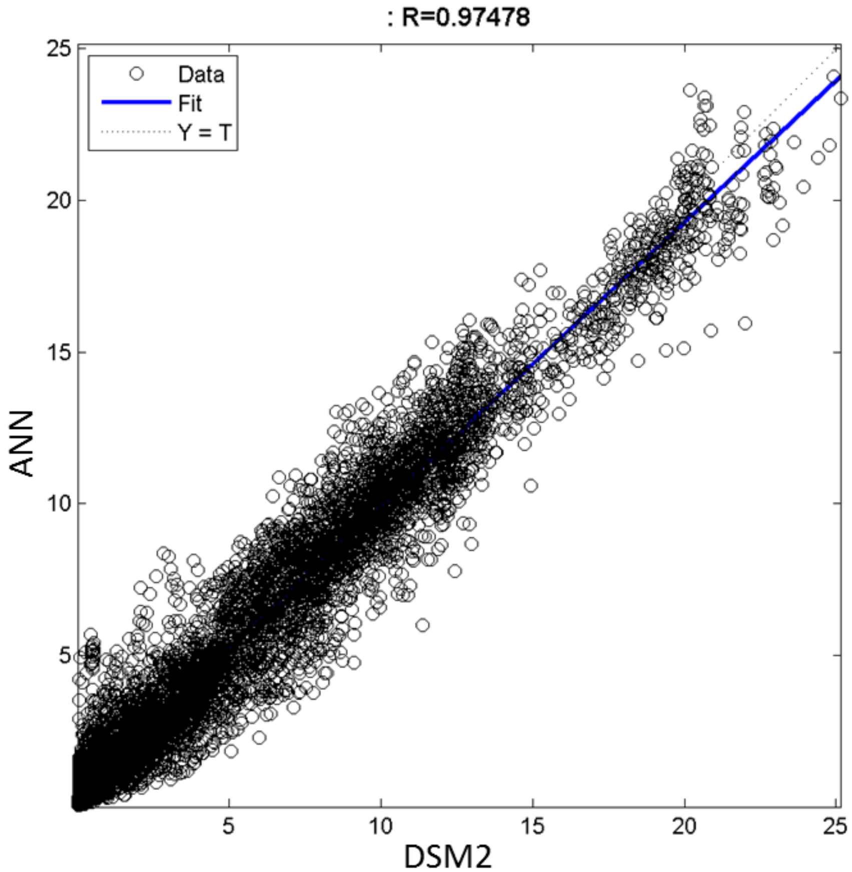

Figure D-24 ANN vs. DSM2 simulated Br at Mallard (RSAC075).

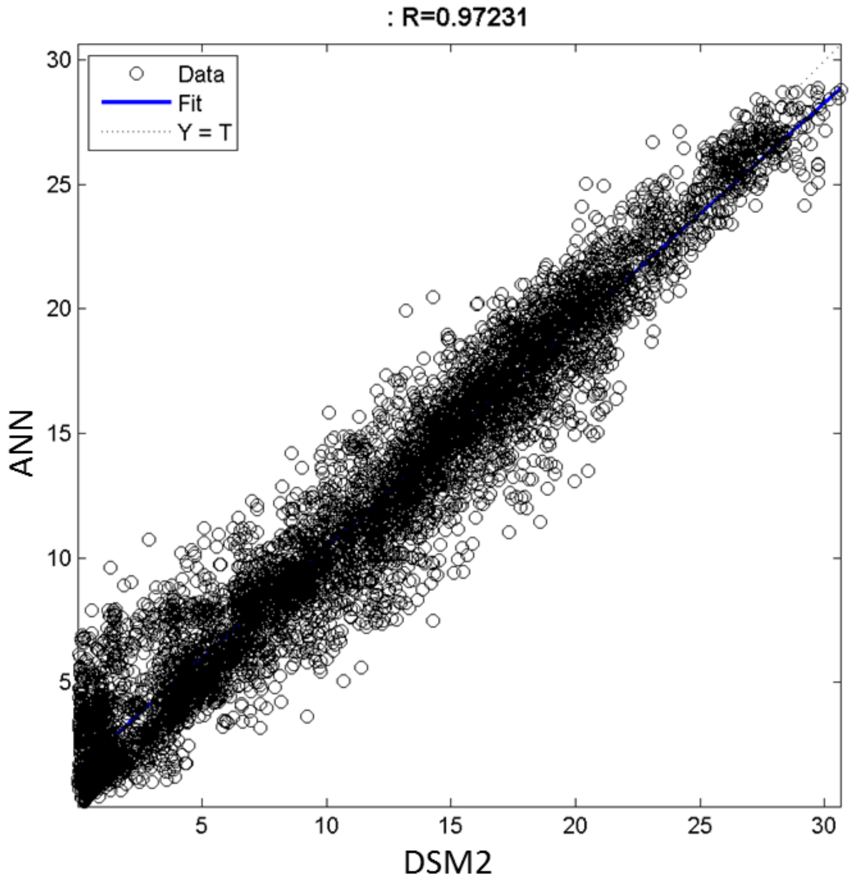

Figure D-25 ANN vs. DSM2 simulated Br at Port Chicago (RSAC064).

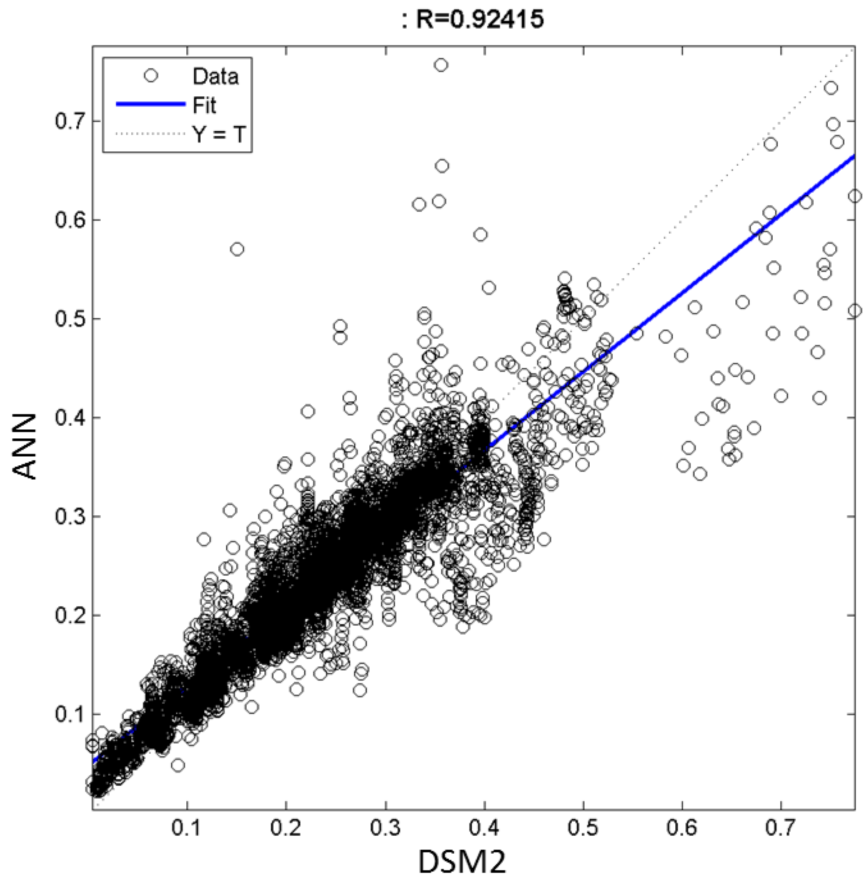

Figure D-26 ANN vs. DSM2 simulated Br at Old River Tracy (Rold059).

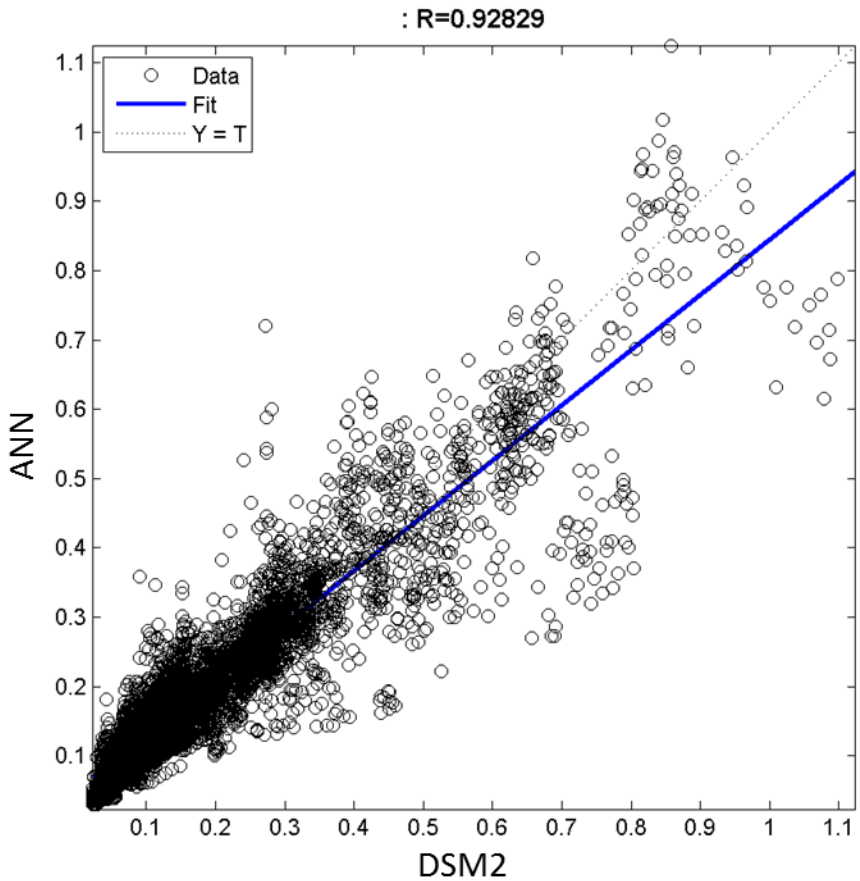

Figure D-27 ANN vs. DSM2 simulated Br at Old River @ HWY4 (Rold034).

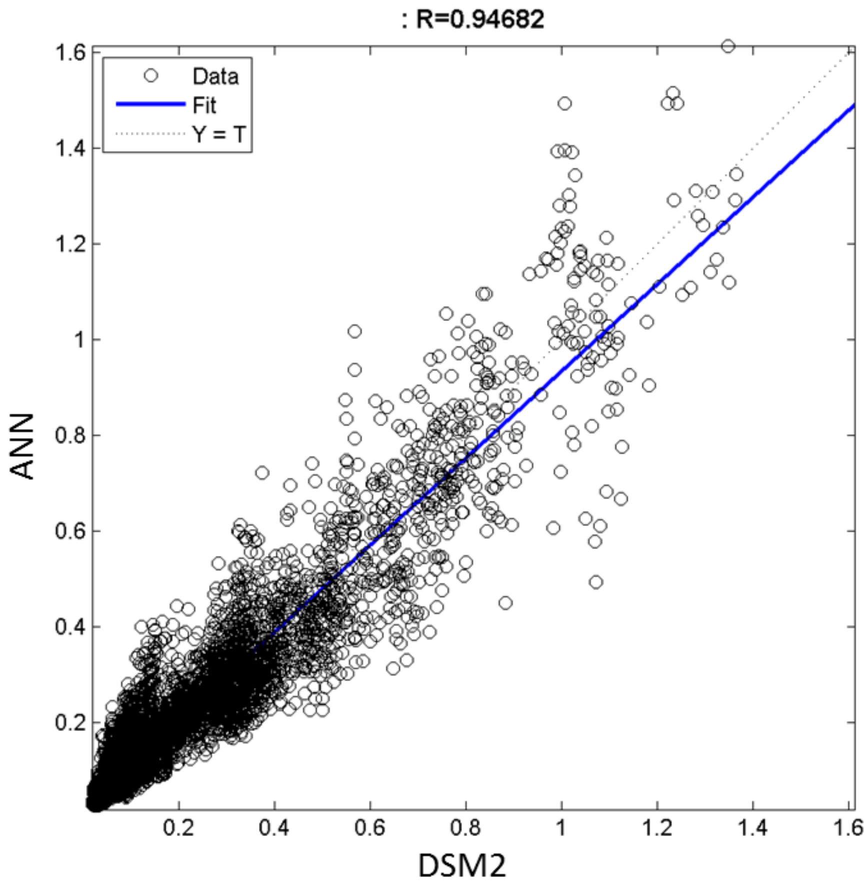

Figure D-28 ANN vs. DSM2 simulated Br at Old River @ Bacon (Rold024).

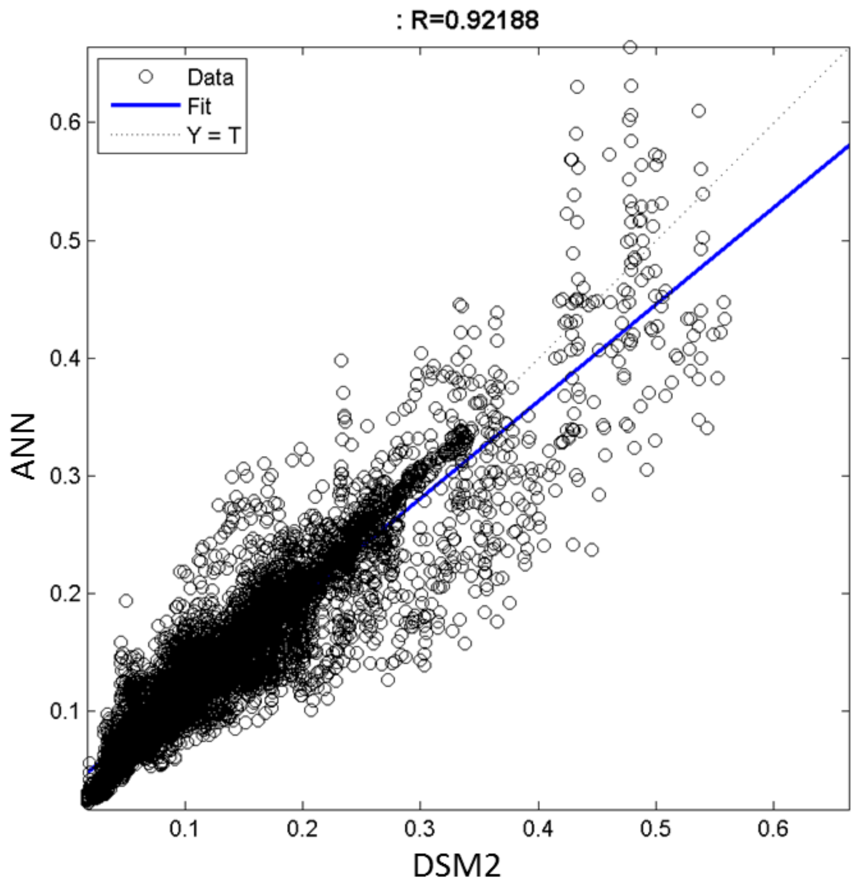

Figure D-29 ANN vs. DSM2 simulated Br at Middle River @ Holt (Rmid005).

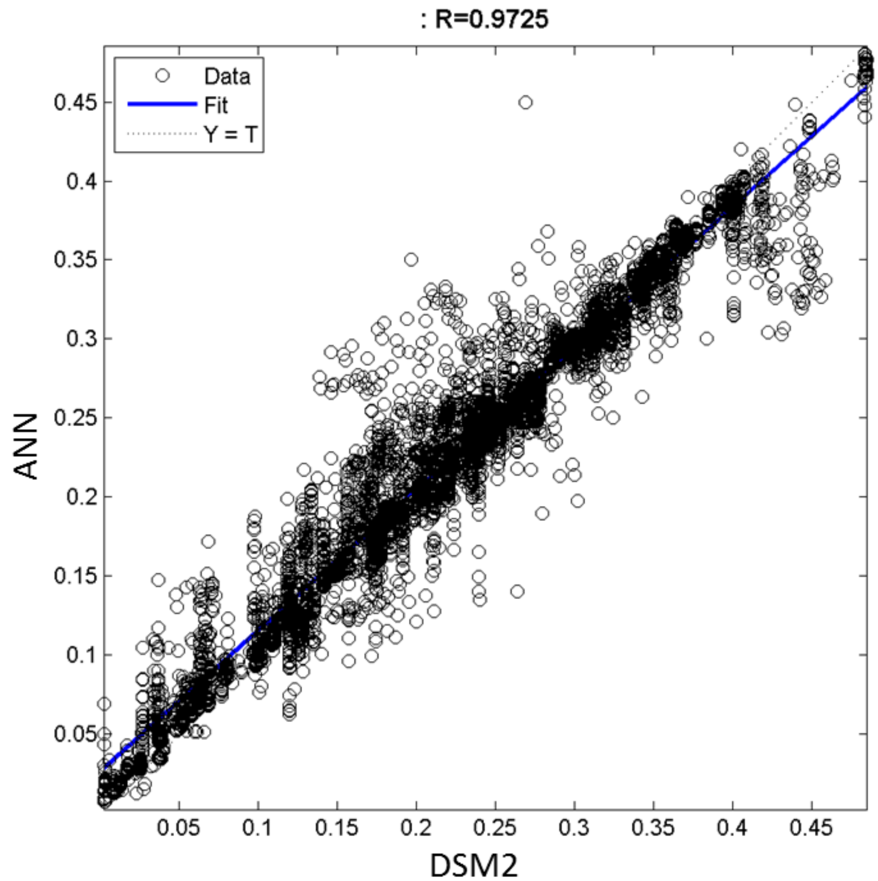

Figure D-30 ANN vs. DSM2 simulated Br at Middle River @ Union Island (Rmid041).

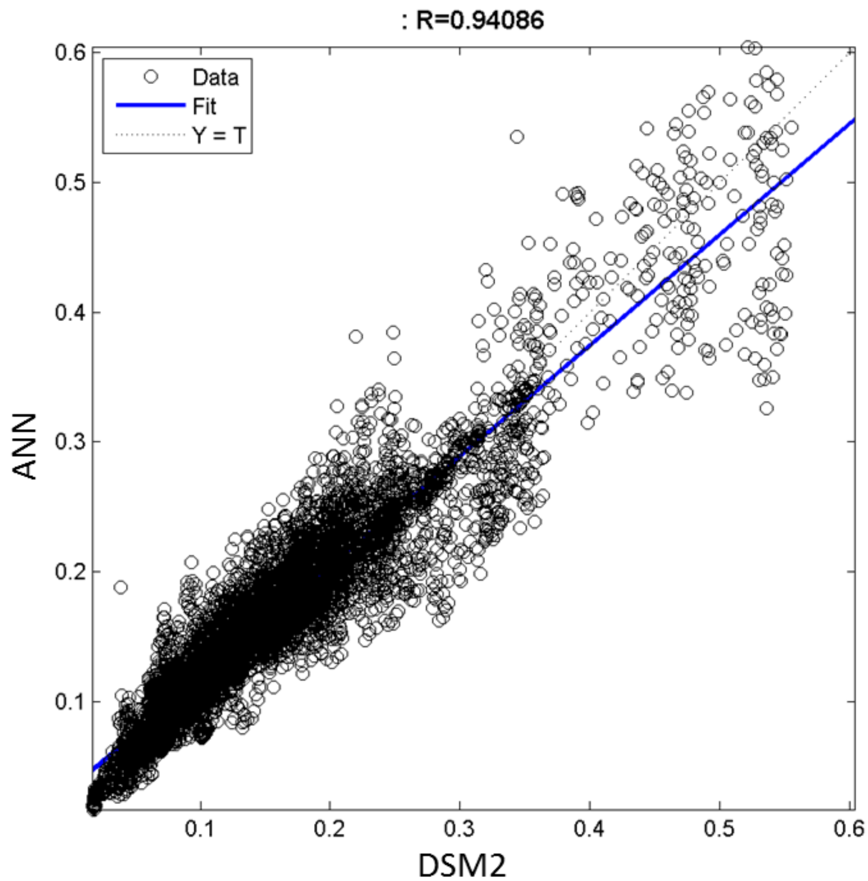

Figure D-31 ANN vs. DSM2 simulated Br at Middle River at Victoria Canal

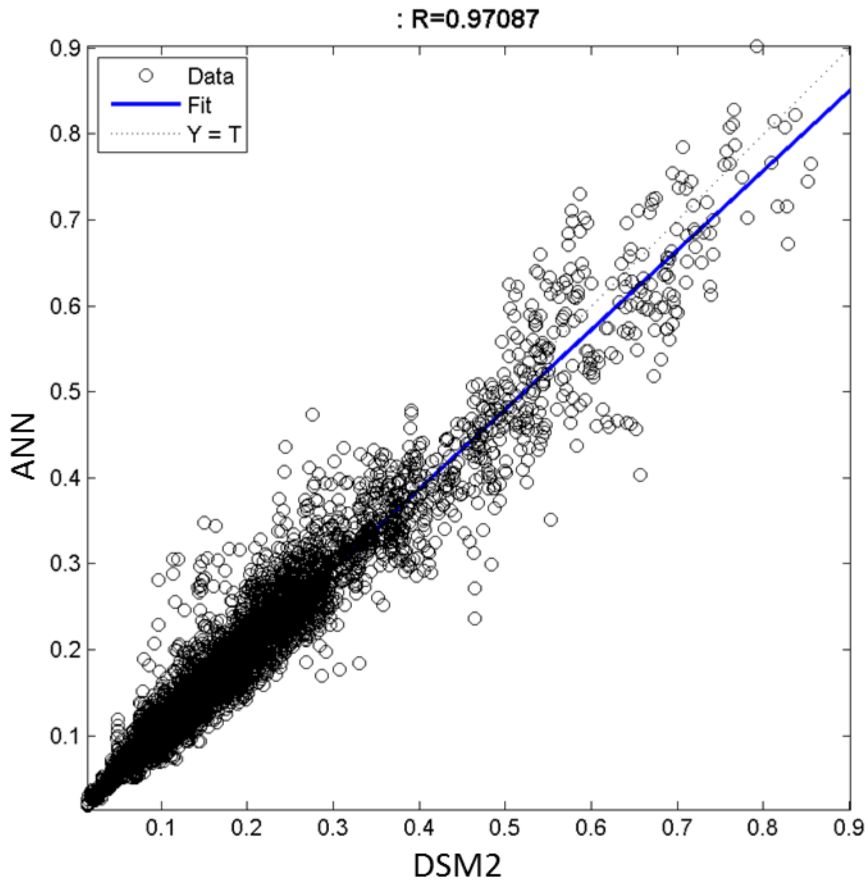

Figure D-32 ANN vs. DSM2 simulated Br at Jones Pumping

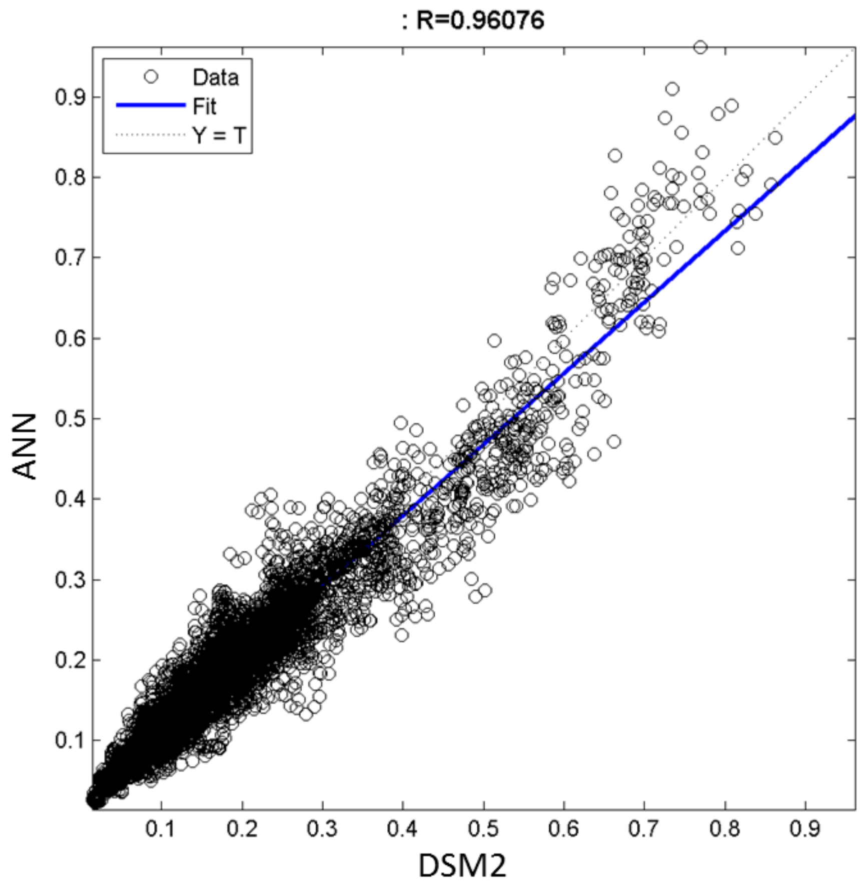

Figure D-33 ANN vs. DSM2 simulated Br at CCF Intake (CHSWP003).

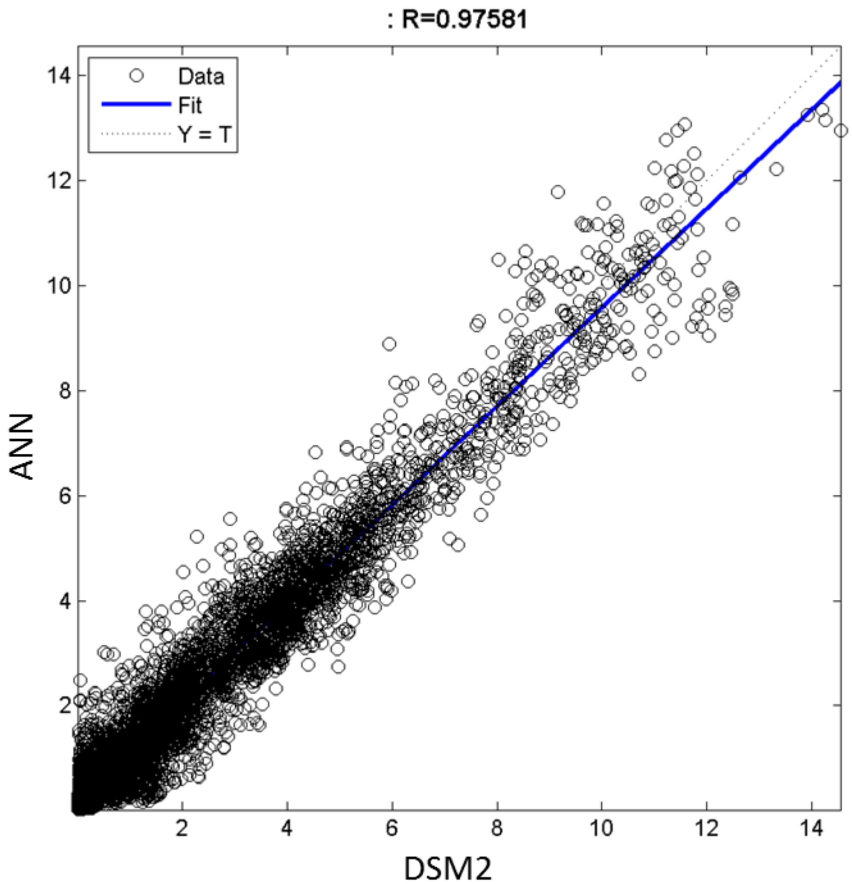

Figure D-34 ANN vs. DSM2 simulated Br at Antioch (RSAN007).

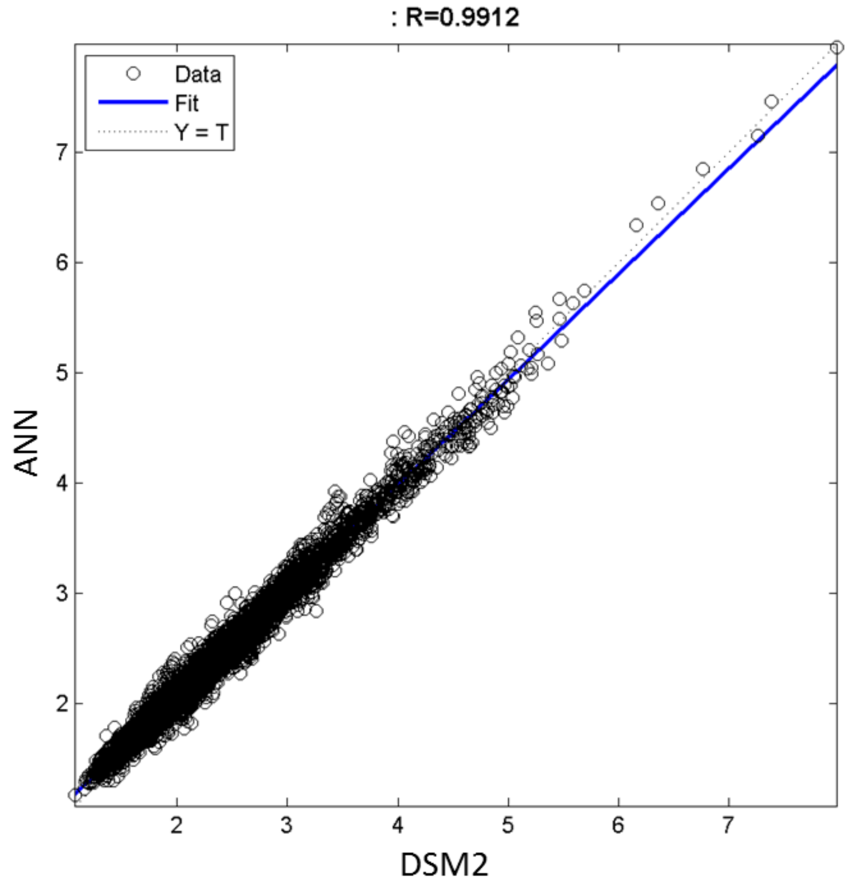

Figure D-35 ANN vs. DSM2 simulated DOC at SJR @ HWY4 (RSAN008)

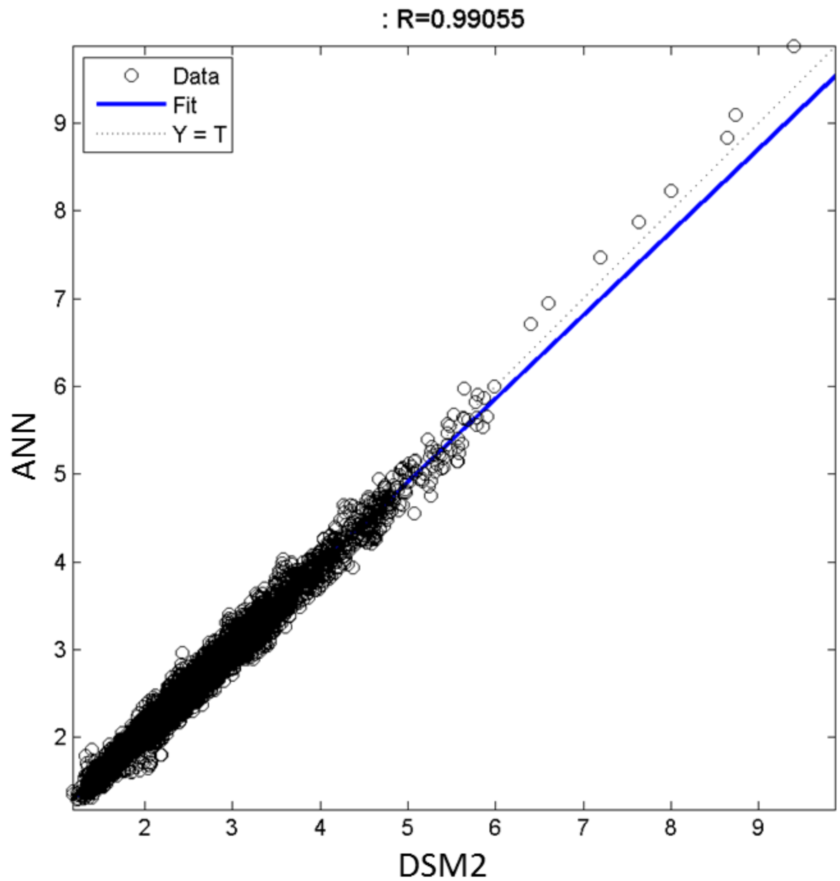

Figure D-36 ANN vs. DSM2 simulated DOC at SJR @ Jersey Point (RSAN018)

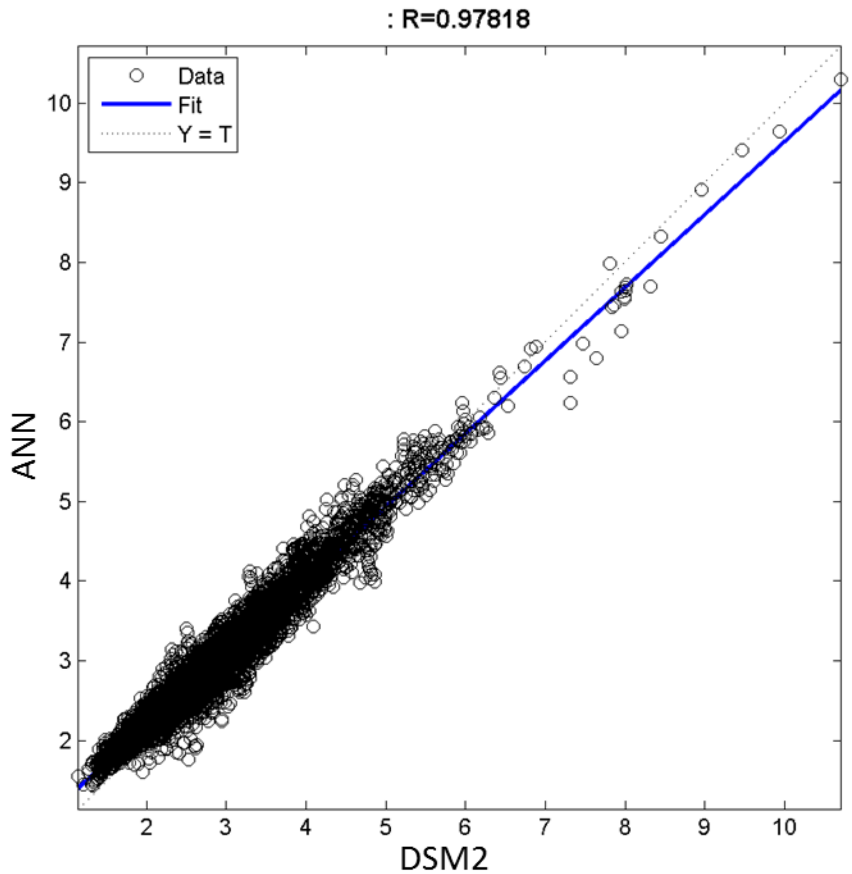

Figure D-37 ANN vs. DSM2 simulated DOC at SJR @ Prisoner's Point (RSAN037).

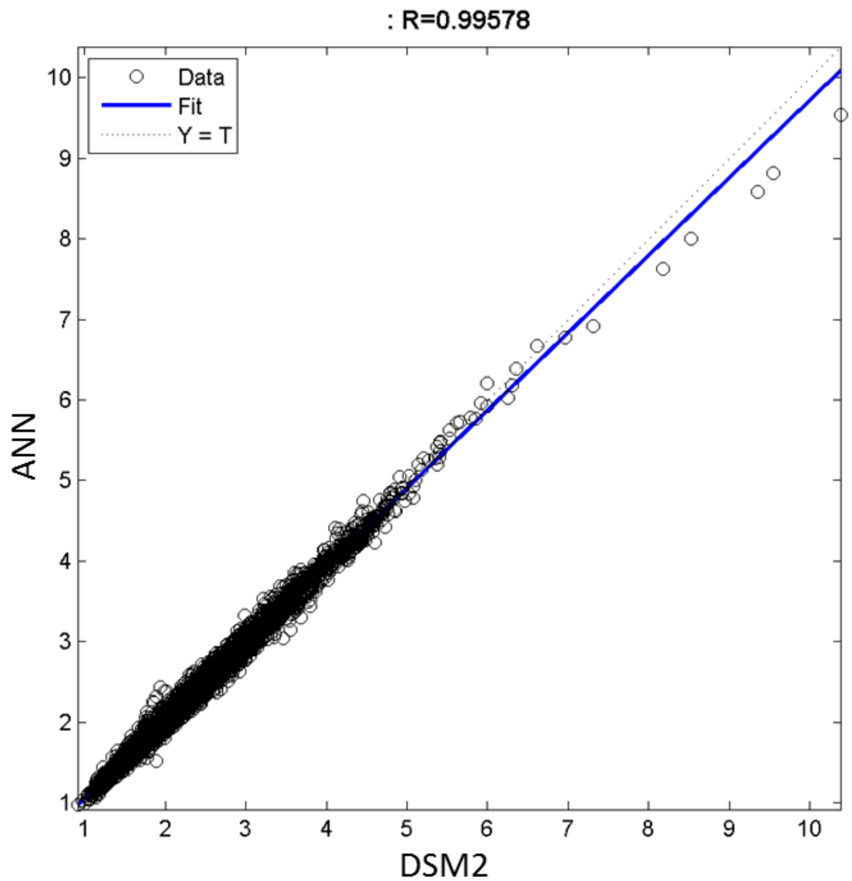

Figure D-38 ANN vs. DSM2 simulated DOC at Emmaton (RSAC092).

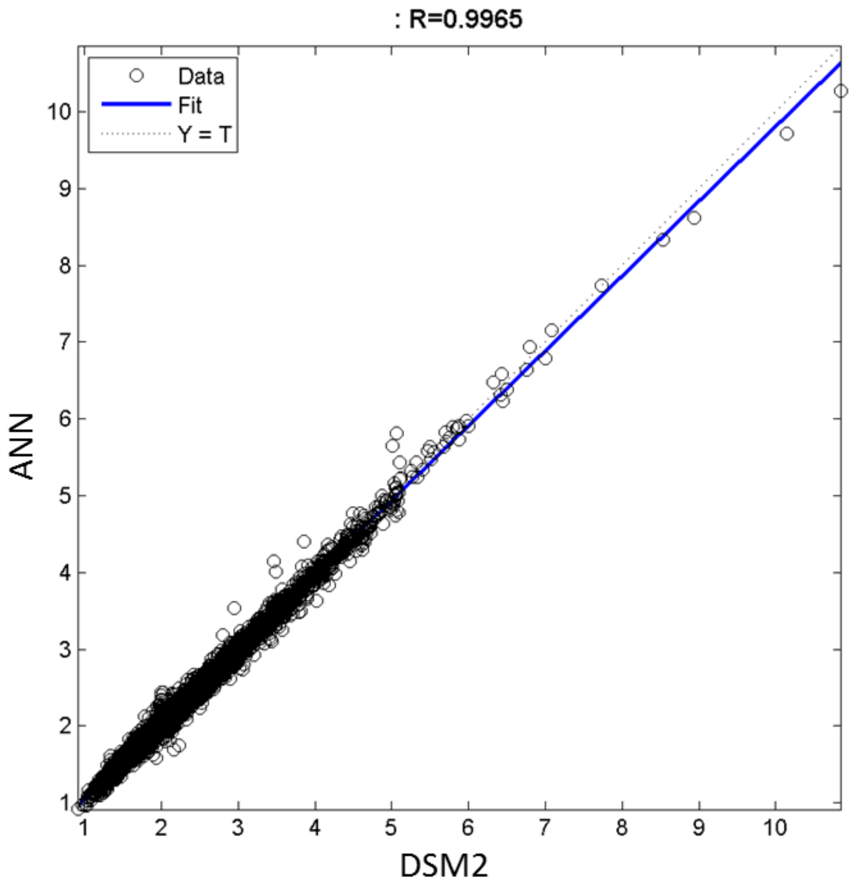

Figure D-39 ANN vs. DSM2 simulated DOC at Rio Vista (RSAC101).

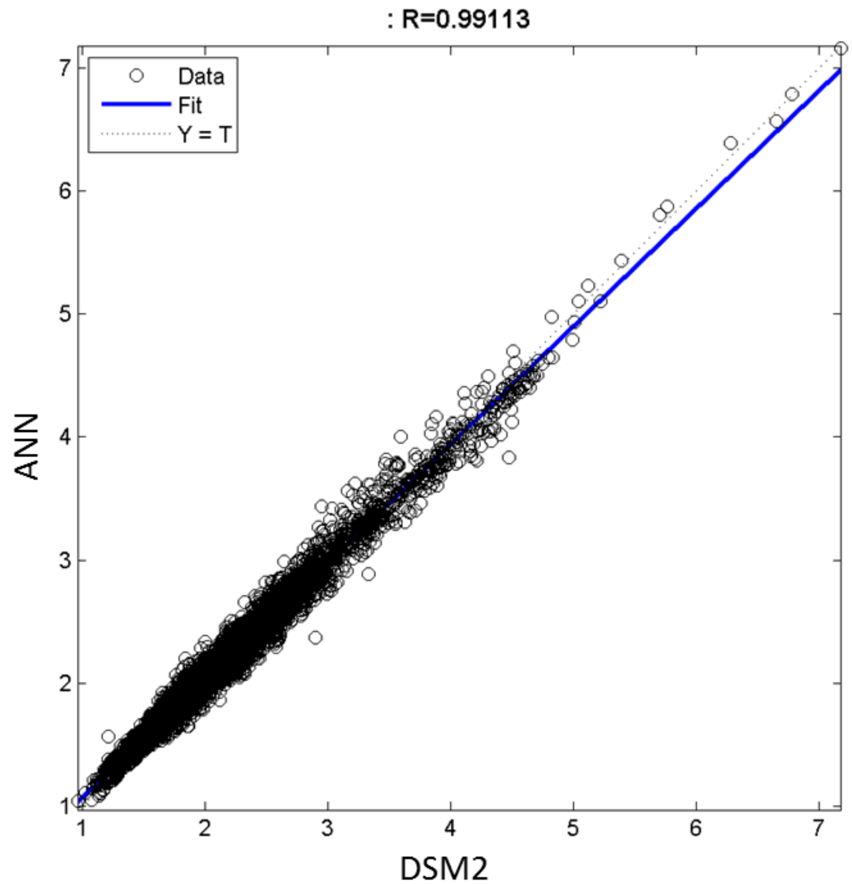

Figure D-40 ANN vs. DSM2 simulated DOC at Collinsville (RSAC081).

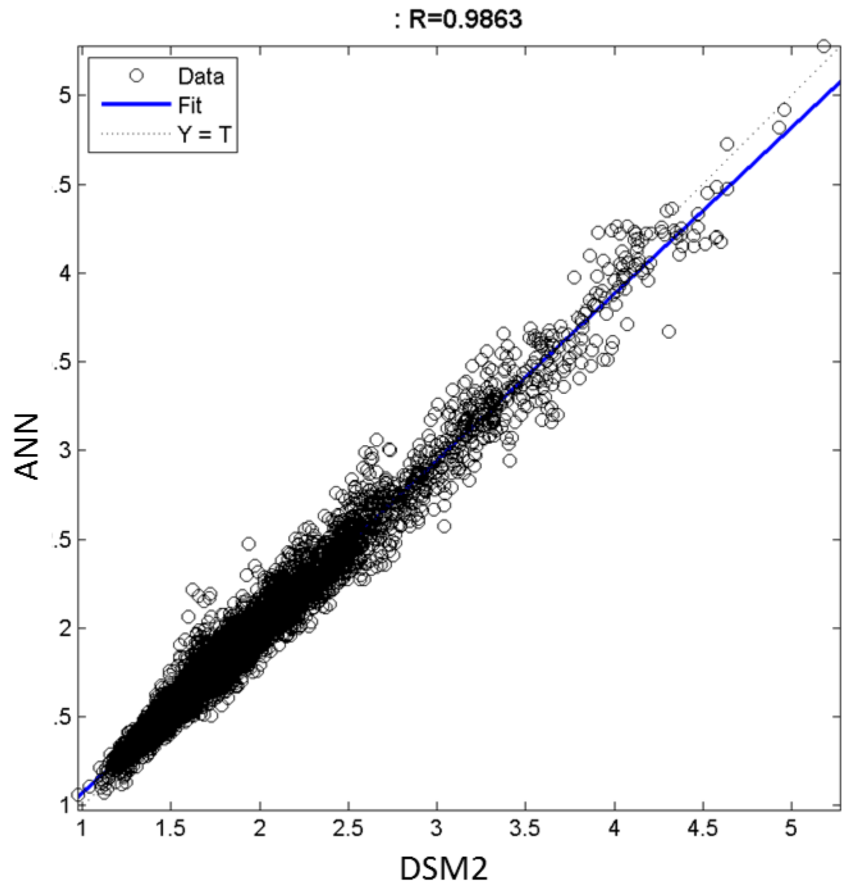

Figure D-41 ANN vs. DSM2 simulated DOC at Mallard (RSAC075).

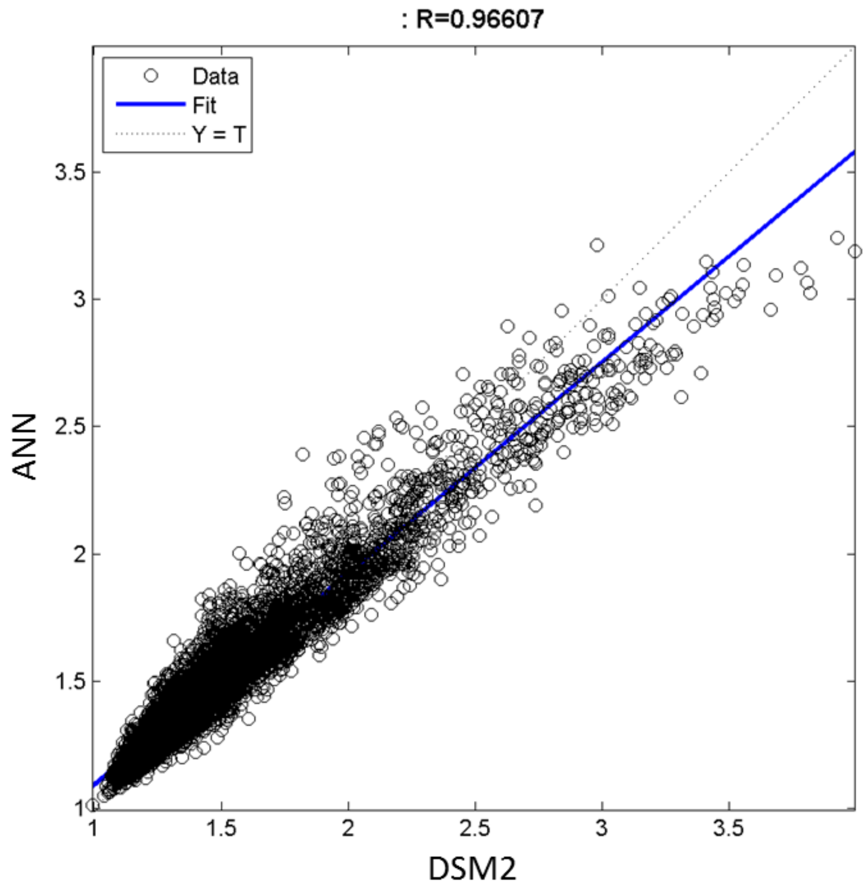

Figure D-42 ANN vs. DSM2 simulated DOC at Port Chicago (RSAC064).

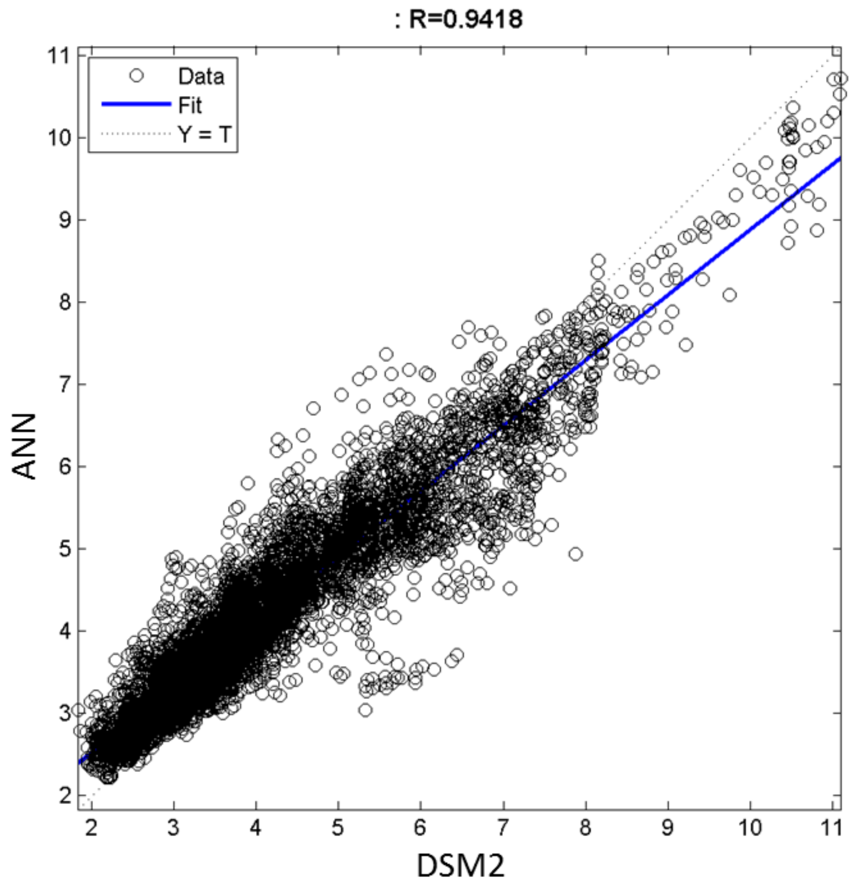

Figure D-43 ANN vs. DSM2 simulated DOC at Old River Tracy (Rold059).

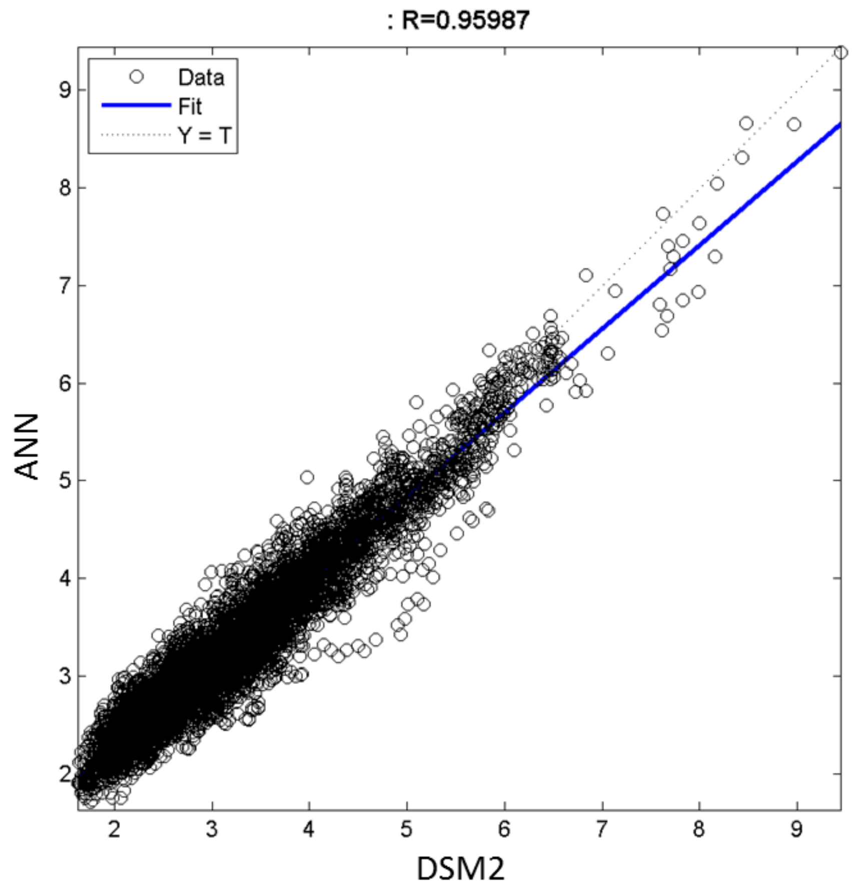

Figure D-44 ANN vs. DSM2 simulated DOC at Old River @ HWY4 (Rold034).

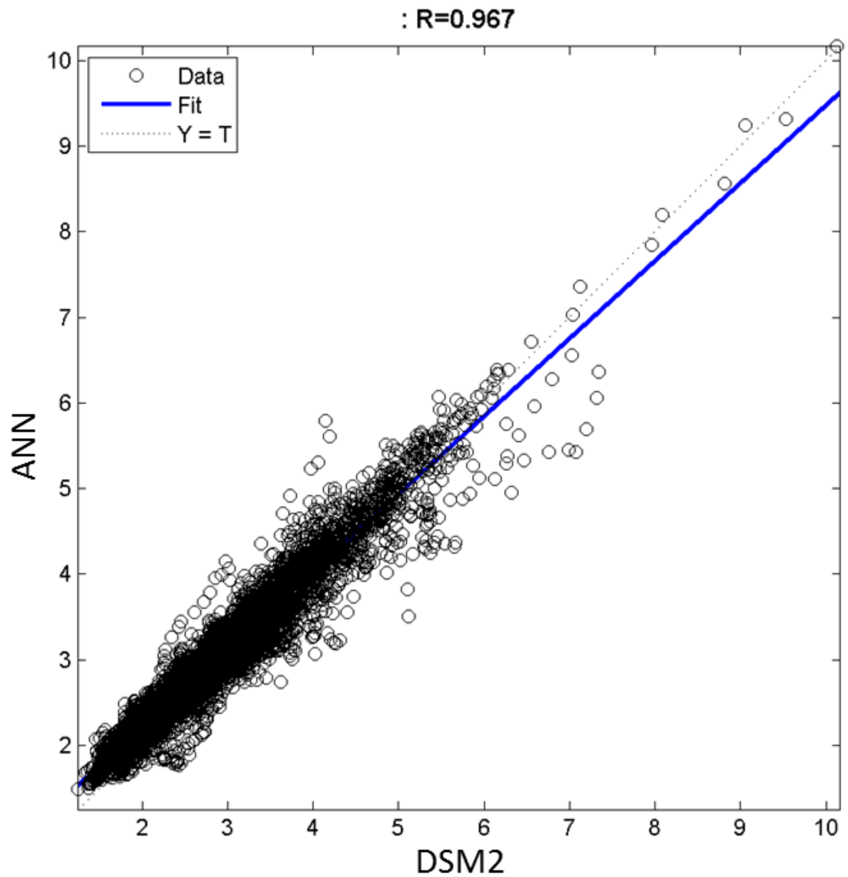

Figure D-45 ANN vs. DSM2 simulated DOC at Old River @ Bacon (Rold024).

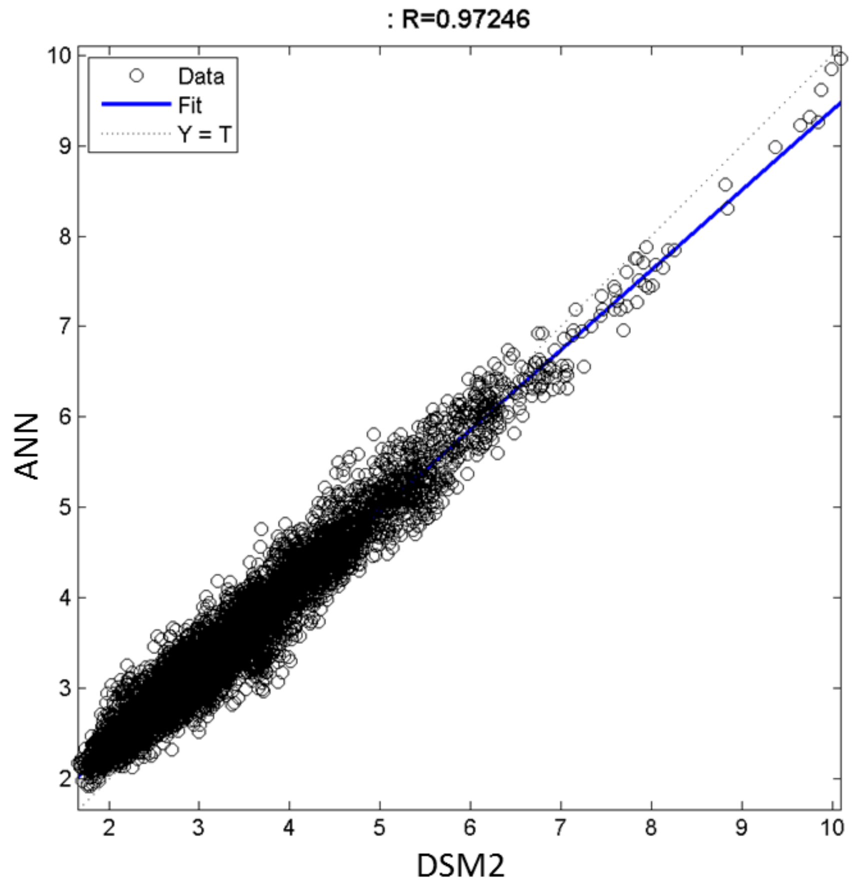

Figure D-46 ANN vs. DSM2 simulated DOC at Middle River @ Holt (Rmid005).

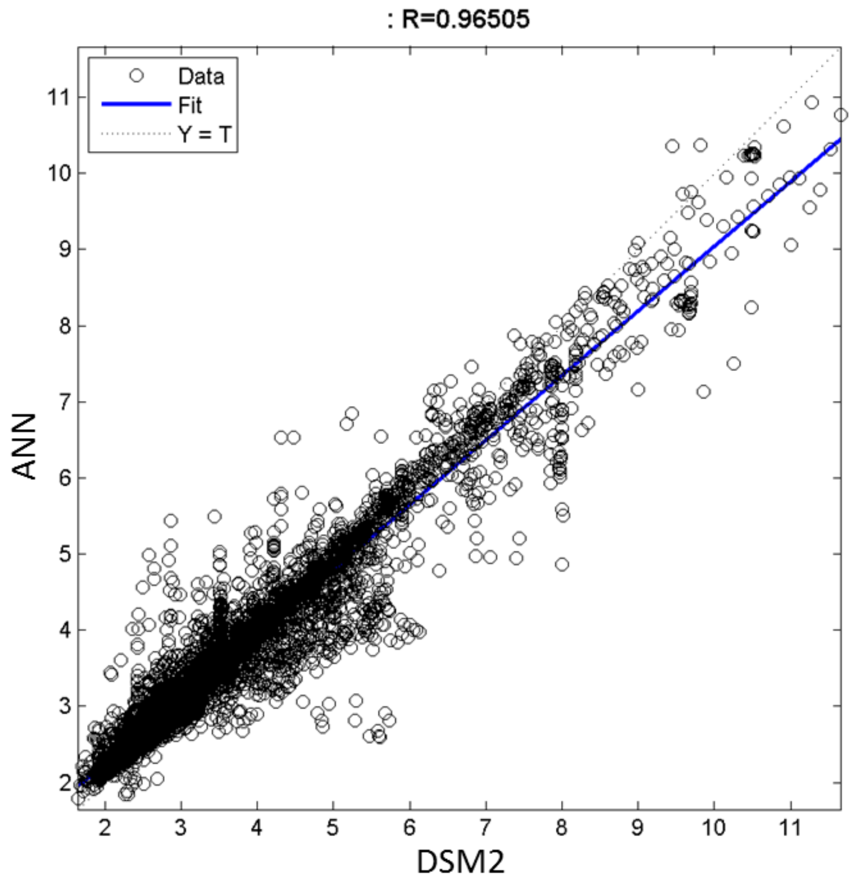

Figure D-47 ANN vs. DSM2 simulated DOC at Middle River @ Union Island (Rmid041).

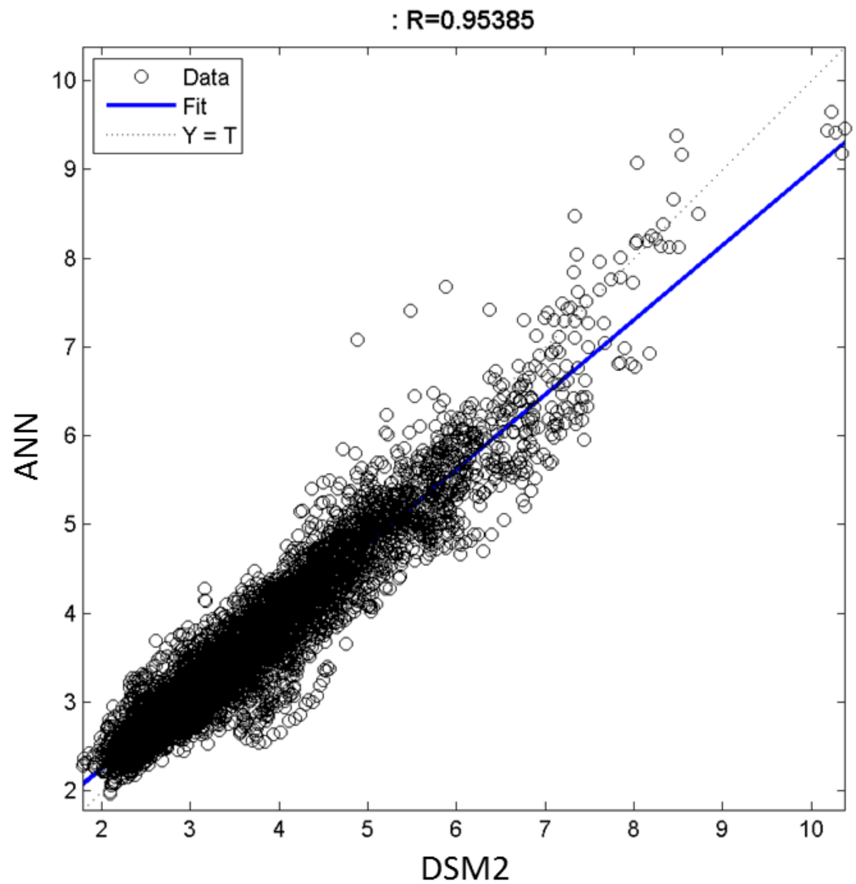

Figure D-48 ANN vs. DSM2 simulated DOC at Middle River at Victoria Canal

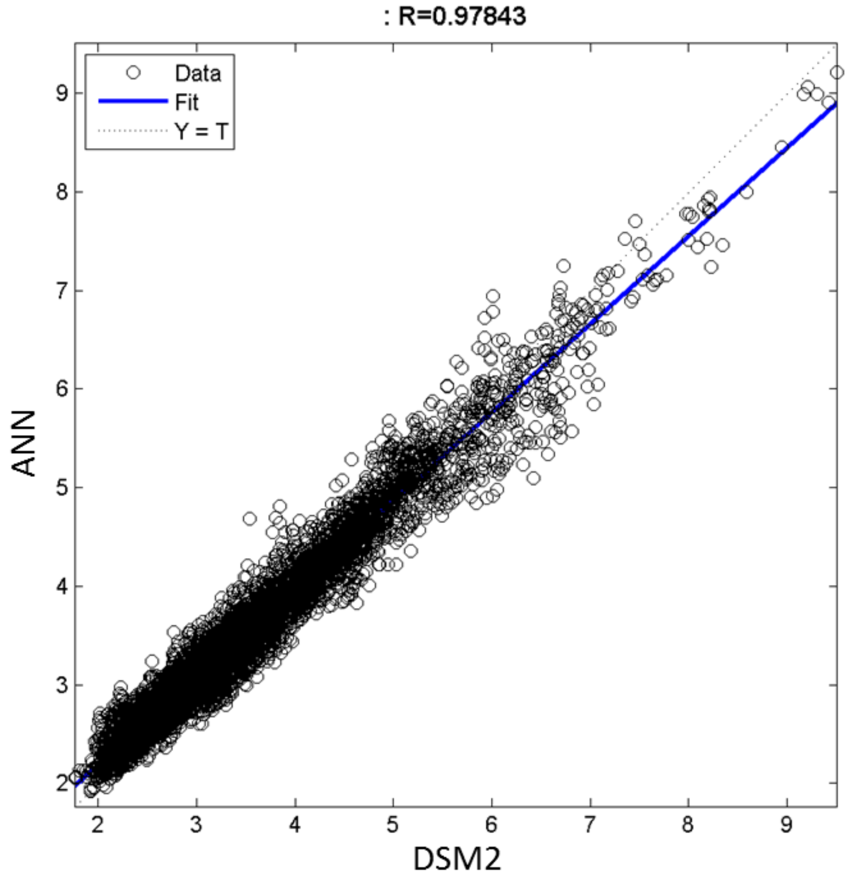

Figure D-49 ANN vs. DSM2 simulated DOC at Jones Pumping

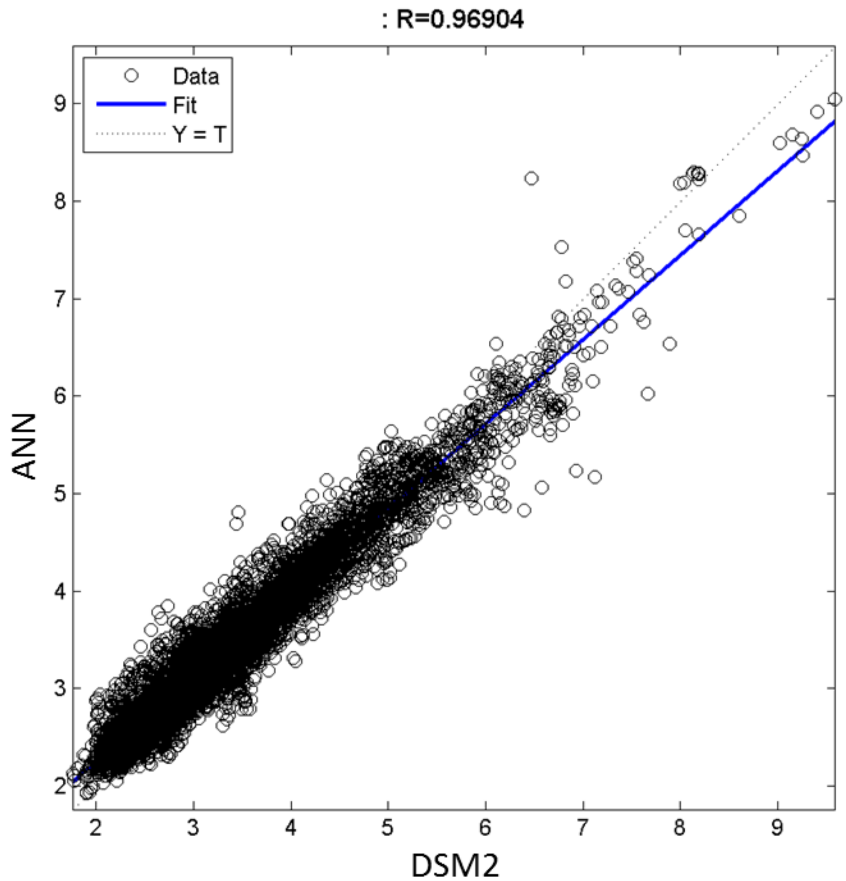

Figure D-50 ANN vs. DSM2 simulated DOC at CCF Intake (CHSWP003).

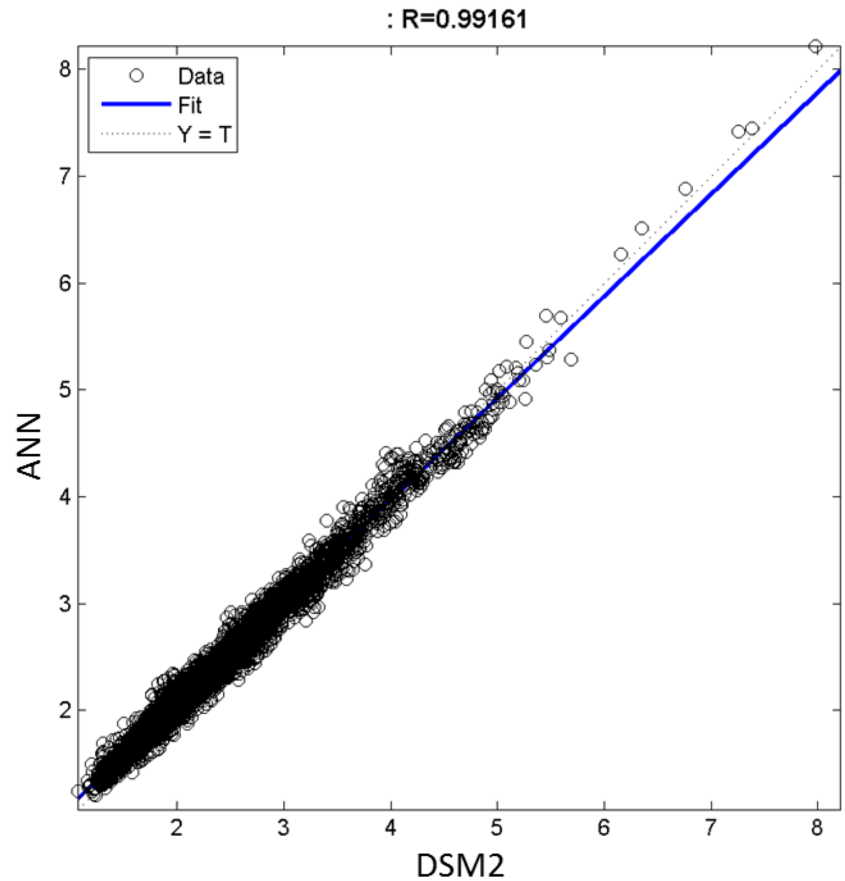

Figure D-51 ANN vs. DSM2 simulated DOC at Antioch (RSAN007).