Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 14:
DSM2 Fingerprinting Methodology

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14 DSM2 Fingerprinting Methodology

14.1 Introduction

A methodology has been developed where a single simulation using the Delta Simulation Model 2 (DSM2) can be used to estimate the concentration of any conservative constituent at any specified time and location in the Delta[1]. Transport of conservative tracer constituents is simulated to determine volume contributions from various sources. These volume contributions can then be utilized to estimate concentrations of any conservative constituent. Use of DSM2 in this mode is referred to as fingerprinting. The main methods of applying the fingerprinting technique are:

- **Volume Fingerprinting** - Determine the relative contributions of water sources to the volume at any specified location.
- **Volume 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.

Fingerprinting techniques can also be applied to a specific constituent as follows[2]:

- **Constituent Fingerprinting** - Determine the relative contributions of conservative constituent sources to the concentration at any specified location.
- **Constituent and Timing Fingerprinting** - In addition to determining the relative contributions of conservative constituent sources to the concentration at any specified location, the time period during which that constituent entered the system is also recorded.

The volume fingerprinting techniques are the most general. Volume fingerprinting can be used to estimate concentrations of any conservative constituent without rerunning DSM2. Constituent fingerprinting is a more specific method in which the results are valid for the constituent simulated. For constituent fingerprinting, the results are not easily extrapolated to other constituents.

Fingerprinting provides valuable insight into the system being modeled. Applications of fingerprinting include:

Hydrodynamics

- Determine the relative flow contribution of each source at a specified location. For example, how much of the flow at Clifton Court originated from the Sacramento River, the San Joaquin River, eastside streams[3], the ocean, and agricultural return flows? (Volume fingerprinting)

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[1] Parviz Nader-Tehrani in DWR's Delta Modeling Section developed this methodology for volume fingerprinting.
[2] Prior to the development of volume fingerprinting, the Delta Modeling Section has used the superposition principle for specific constituent fingerprinting (see Hutton and Chung, 1992).
[3] Eastside streams include the Mokelumne, Cosumnes, and Calaveras rivers.

- Determine the relative flow contribution and timing of each source at a specified location. For example, how much of the flow at Clifton Court originated from the Sacramento River, the San Joaquin River, eastside streams, the ocean, and agricultural return flows during the current month, last month, the month before that, etc.?
  (Volume and timing fingerprinting)

Water Quality

- Estimate conservative water quality constituent concentrations at specified locations using a single DSM2 simulation.
  (Volume fingerprinting)

- Estimate conservative water quality constituent concentrations and timing at specified locations using a single DSM2 simulation.
  (Volume and timing fingerprinting)

- Determine the relative importance of sources of a water quality constituent at a specified location. For example, how much of the EC at the entrance to Clifton Court Forebay was contributed by each source?
  (Constituent fingerprinting)

- Determine the relative contributions and timing of each source of a water quality constituent at a specified location. For example, how much of the EC at the entrance to Clifton Court Forebay contributed by each source entered the Delta this month, last month, the month before that, etc.?
  (Constituent and timing fingerprinting)

14.2 Conceptualization of Volume Fingerprinting

To illustrate the concept of volume fingerprinting, consider a stream with two tributaries (Figure 14.1). If a sample of water was removed from the stream at each of the three locations indicated in Figure 14.1, the volume of water in each sample would be made up of contributions from the three streams as shown in Figure 14.2. For illustration purposes, hypothetical relative volume contributions from each source have been indicated. DSM2 fingerprinting can be used to determine the relative volume of water at a given location from specified sources.

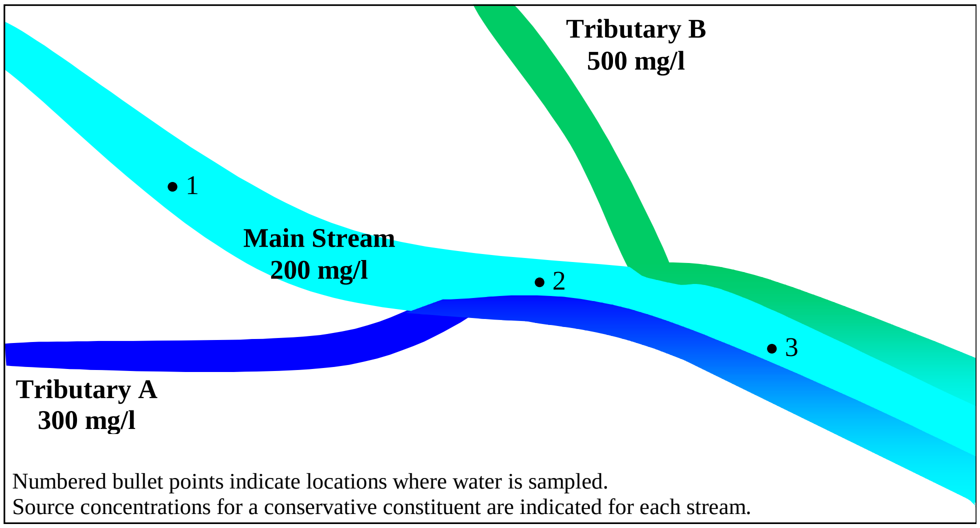


Figure 14.1: Conceptualization of a Stream with Two Tributaries.

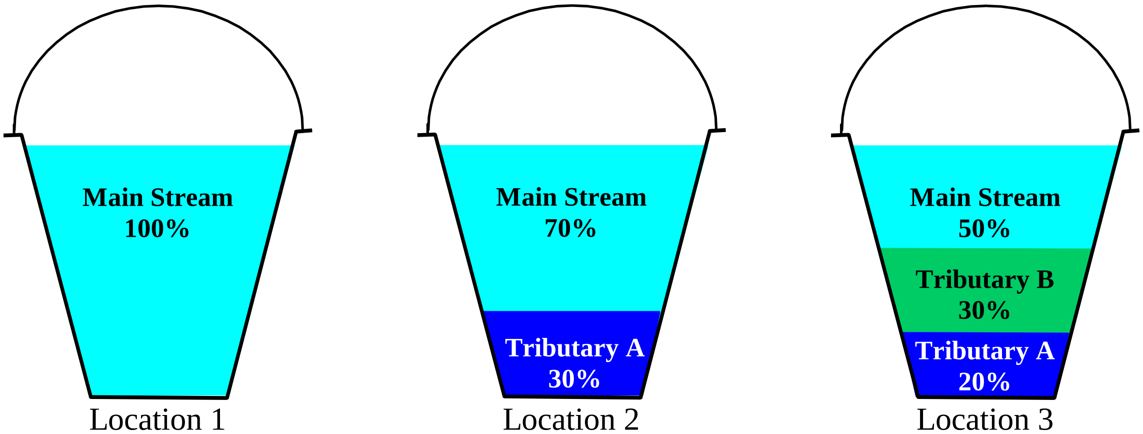


Figure 14.2: Conceptualization of Relative Volume Contributions from each Source for Water Sampled from Three Locations.

From the volume contributions and source concentrations, the concentration of a conservative constituent can be estimated by summing the volume of each source multiplied by the concentration of the constituent associated with that source (Equation 14-1).

$$C_{CC} = \sum_{i=1}^{n} \frac{V_{\%i}}{100} C_i \qquad \text{[Eqn. 14-1]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a specified location,
C_i = concentration of a conservative water quality from source i at the specified location,
n = total number of sources, and
$V_{\% i}$ = percent volume at a specified location contributed by source i.

Using the source concentrations from Figure 14.1 and the relative volume contributions from Figure 14.2, the concentration of a conservative constituent for the three sample locations can be estimated using Equation 14-1 as shown in Table 14.1 and Figure 14.3.

Using the volume fingerprinting methodology, the concentration of any conservative constituent can be estimated from the simulated volume contributions if the source concentrations are known. This methodology does not take into account any antecedent conditions. Because of the long residence time in the Delta due to tidal influences, the volume fingerprinting methodology provides a very rough estimate of conservative constituent concentrations. The timing of the sources becomes very important if the source flows or concentrations vary drastically with time. Thus for more accurate conservative constituent concentration estimates, the volume and timing fingerprinting methodology should be utilized.

Table 14.1: Estimation of Conservative Constituent Concentrations using Volume Contributions and Source Concentrations.

Source	% Volume, $V_{\%}$	Source Concentration, C (mg/l)	$V_{\%}/100 \times C$ (mg/l)
Location 1			
Main Stream	100	200	200
Tributary A	0	300	0
Tributary B	0	500	0
Total	*100*		***200***
Location 2			
Main Stream	70	200	140
Tributary A	30	300	90
Tributary B	0	500	0
Total	*100*		***230***
Location 3			
Main Stream	50	200	100
Tributary A	20	300	60
Tributary B	30	500	150
Total	*100*		***310***

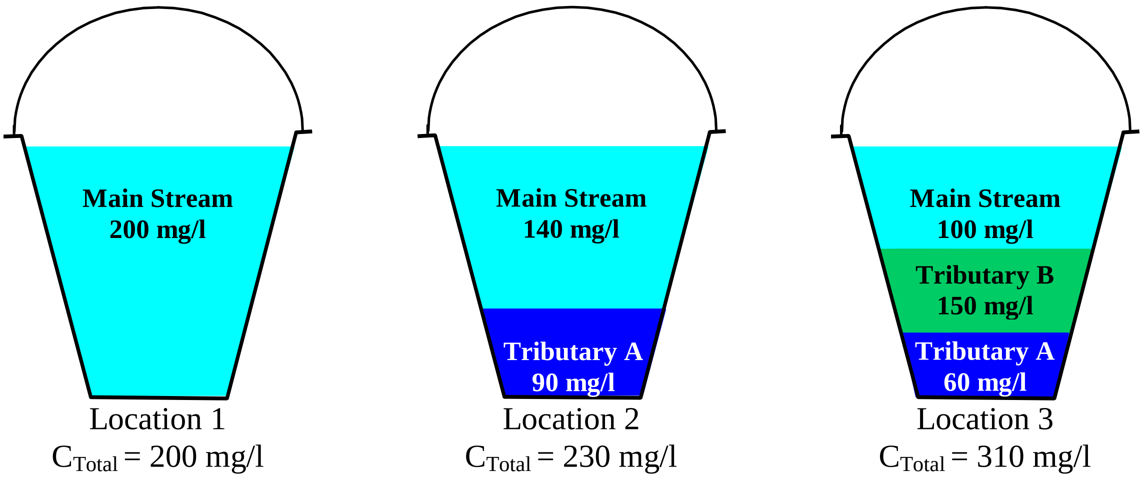


Figure 14.3: Conceptualization of Relative Concentrations Computed from Source Volumes and Source Concentrations for Water Sampled from Three Locations.

14.3 Conceptualization of Volume and Timing Fingerprinting

In some cases, it may be desirable to know not only the source of water, but also to have information of the timing when that water entered the system. In systems with long residence times, such as the Delta, the water from each source in a sample of water at a specified location may consist of water that entered the system at different times with different concentrations. Thus in addition to determining the source of the water in the sample, the timing of when that source entered the system is also useful for more accurate estimates of conservative constituent concentrations.

For illustration purposes, consider a sample of water withdrawn from a system with two sources (Figure 14.4). The sampled water could be divided both by source and by time period of entry into the system (Figure 14.5). For illustration purposes, hypothetical relative volume contributions from each source have been indicated for each time period. The number of time periods represented in the sample is referred to in this document as the system "memory". The length of the system memory will depend on the hydrologic conditions and the retention time of the system. For this example the system memory is three time periods long.

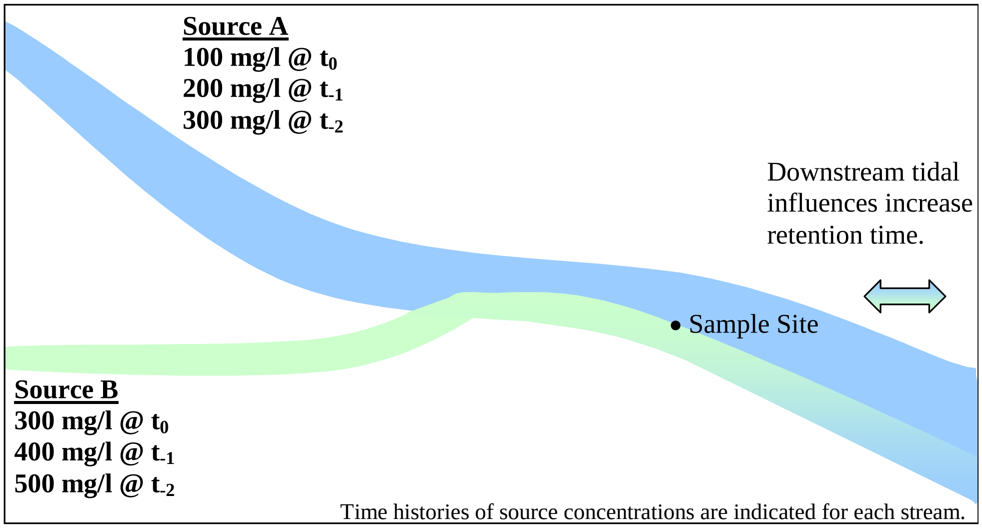


Figure 14.4: Conceptualization of Two Source Streams with a Long Retention Time after their Confluence.

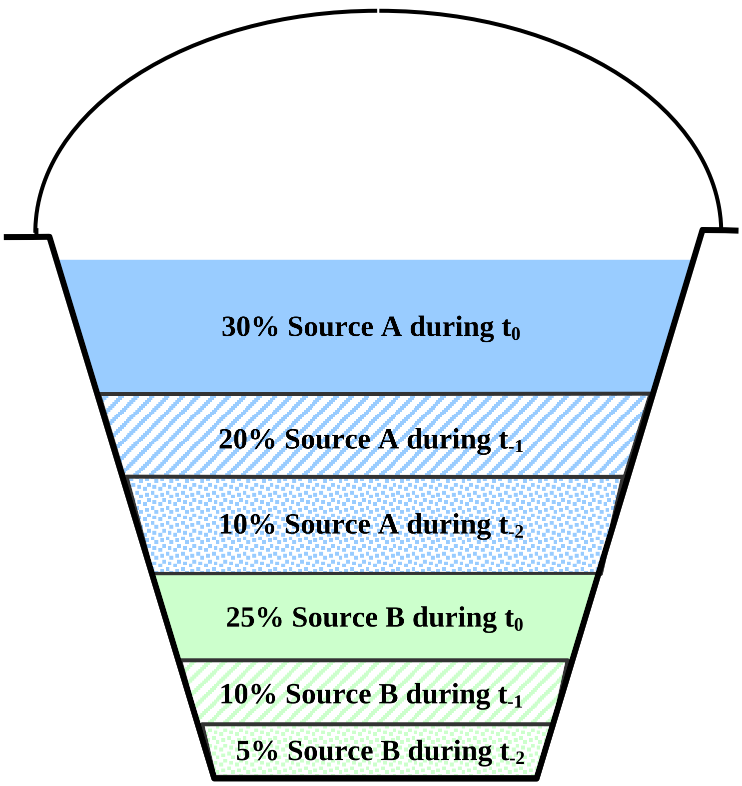


Figure 14.5: Conceptualization of Volume and Timing of Source Contributions in a Water Sample from Two Source Streams with a Long Retention Time.

From the volume contributions, source concentrations, and timing, the concentration of a conservative constituent can be estimated by summing the volume of each source for each time period multiplied by the concentration of the constituent associated with that source for that time period (Equation 14-2).

$$C_{CC}(t) = \sum_{i=1}^{n}\sum_{j=0}^{m} \frac{V_{\% i,-j}}{100} C_{i,-j} \qquad \text{[Eqn. 14-2]}$$

where,

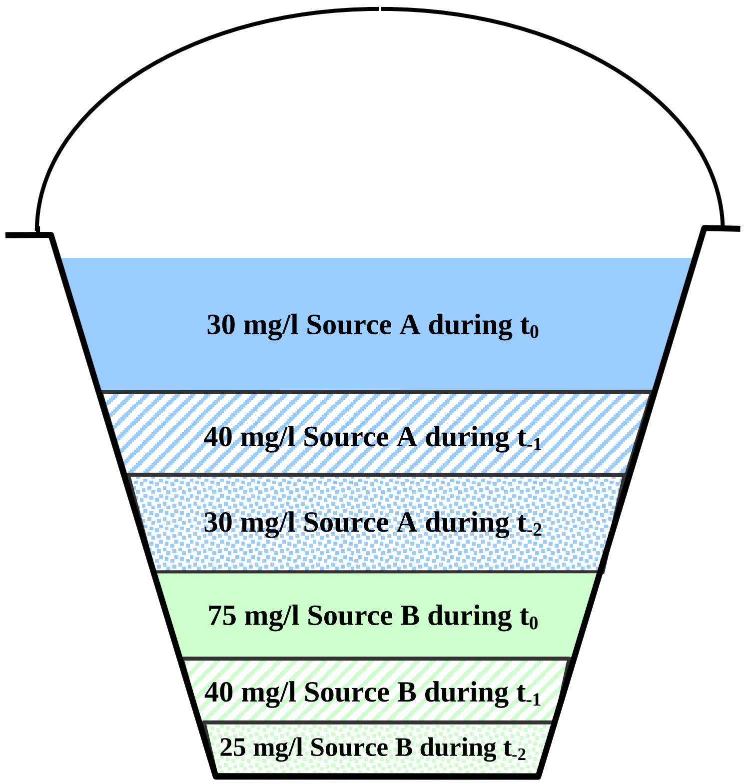
$C_{CC}(t)$ = concentration of a conservative water quality constituent at a specified location and time,
$C_{i,-j}$ = concentration of a conservative water quality constituent from source *i* at time *-j*[4],
n = total number of sources,
m = length of the system memory, and
$V_{\% i,-j}$ = percent volume at a specified location from source *i* at time *-j*.

Using the source concentrations from Figure 14.4 and the relative volume contributions from Figure 14.5, the concentration of a conservative constituent for the sample location can be estimated using Equation 14-2 as shown in Table 14.2 and Figure 14.6.

Table 14-2: Estimation of Conservative Constituent Concentrations using Volume Contributions, Source Concentrations, and Source Timing.

Source	**% Volume, $V_\%$**	**Source Concentration, C (mg/l)**	**$V_\%$/100 x C (mg/l)**
Source A for t_0	30	100	30
Source A for t_{-1}	20	200	40
Source A for t_{-2}	10	300	30
Source B for t_0	25	300	75
Source B for t_{-1}	10	400	40
Source B for t_{-2}	5	500	25
Total	*100*		***240***

4 Note that the time periods are counted backwards from the present. t_0 is the present time period, t_{-1} is one time period in the past, etc. Similarly $C_{i,0}$ is the concentration of the constituent from source *i* from the present time, $C_{i,-1}$ is the concentration of the constituent from source *i* from one time period in the past, etc.



C_{Total} = 240 mg/l

Figure 14.6: Conceptual Relative Concentrations Computed from Source Volumes, Source Concentrations, and Source Timing.

Using the volume and timing fingerprinting methodology, the concentration of any conservative constituent can be estimated from the simulated timed volume contributions if the timed source concentrations are known. The volume and timing fingerprinting method should be used when boundary flows and concentrations vary drastically with time. Because of the long residence time in the Delta due to tidal influences and the varying boundary conditions, this methodology provides a better estimate of conservative constituent concentrations than the volume fingerprinting method.

To further illustrate the two different types of fingerprinting (volume fingerprinting and volume and timing fingerprinting), hypothetical fingerprinting results were generated for the three sample locations for the system shown in Figure 14.1. Pie charts for each type of fingerprinting (Figure 14.7) could represent relative contributions of either water volumes or of conservative constituent concentration depending on the type of analysis that was conducted.

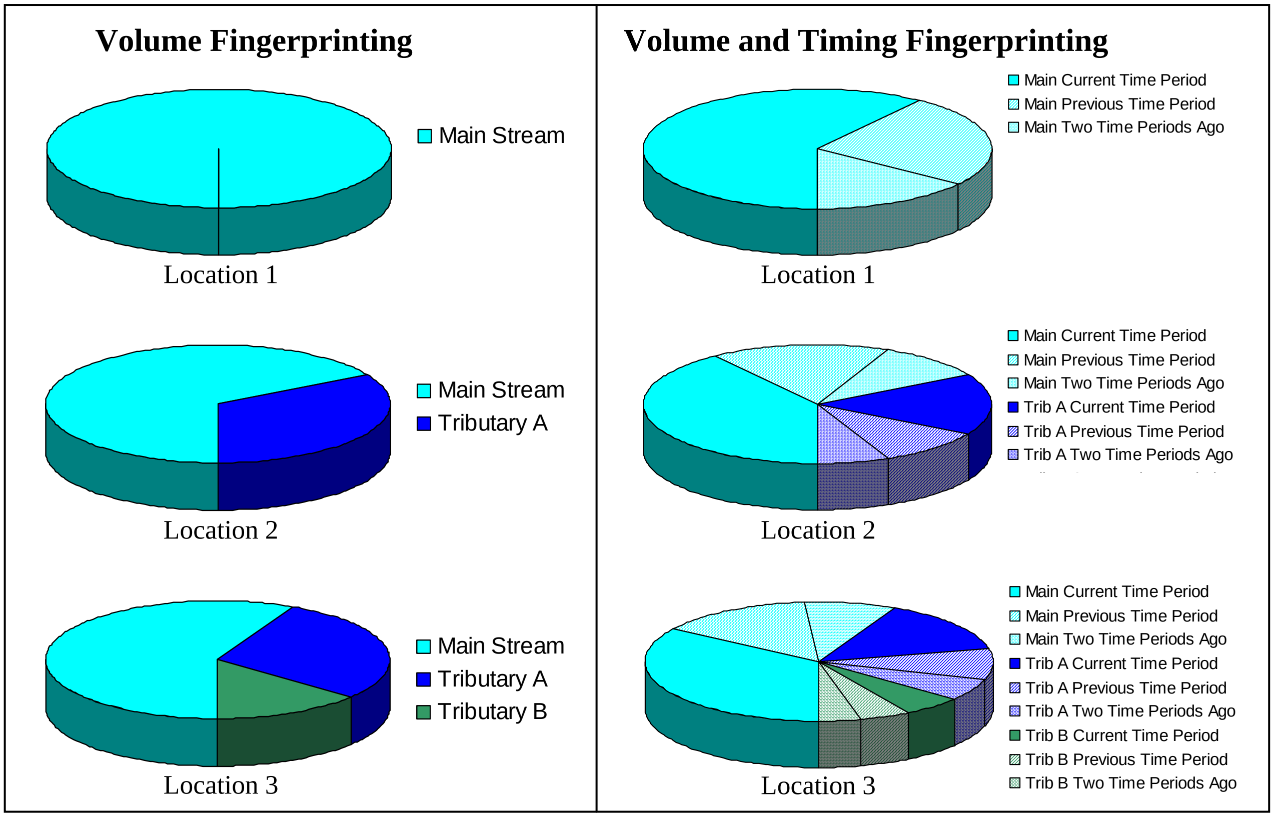


Figure 14.7: Pie Charts of Relative Contributions of Water Volume or of Conservative Constituent Concentrations using Two Fingerprinting Methods.

14.4 Constituent Fingerprinting

The volume fingerprinting methodologies described above provide a general analysis tool for water volumes and conservative constituent concentrations. Constituent fingerprinting is a specialized application of volume fingerprinting or volume and timing fingerprinting in which a specific constituent is utilized instead of a general conservative constituent. Constituent fingerprinting is discussed in more detail in section 14.6.

14.5 Application of Fingerprinting in the Delta using DSM2

Fingerprinting techniques have been utilized in DSM2 to analyze relative sources of flow and conservative constituents in the Sacramento-San Joaquin Delta. Due to the tidal flows in the Delta, the residence time or system "memory" can be up to six months depending on the hydrologic conditions. For fingerprinting studies, six main sources are typically used: the Sacramento River, the San Joaquin River, Martinez, eastside streams (all combined), agricultural drains (all combined), and the Yolo Bypass (Figure 14.9). A sample of water withdrawn from any location in the Delta contains water contributions from these sources (Figure 14.8). Similarly, the concentration of a conservative constituent at any location in the Delta is derived from contributions from these sources. The flow and conservative constituent contributions from the various sources at a given location can be determined by conducting fingerprinting simulations utilizing DSM2.

DSM2 provides various methods for running fingerprinting simulations. These methods fall into two main categories, which are described in this chapter:

- Modify DSM2-QUAL boundary condition input files to use tracer constituents for fingerprinting analysis. This method can be used for volume fingerprinting, volume and timing fingerprinting, constituent fingerprinting, and constituent and timing fingerprinting.

- Modify DSM2-QUAL OUTPUTPATHS section to request internally computed fingerprinting results. This method can only be used for constituent or constituent and timing fingerprinting (see section 14.6.3).

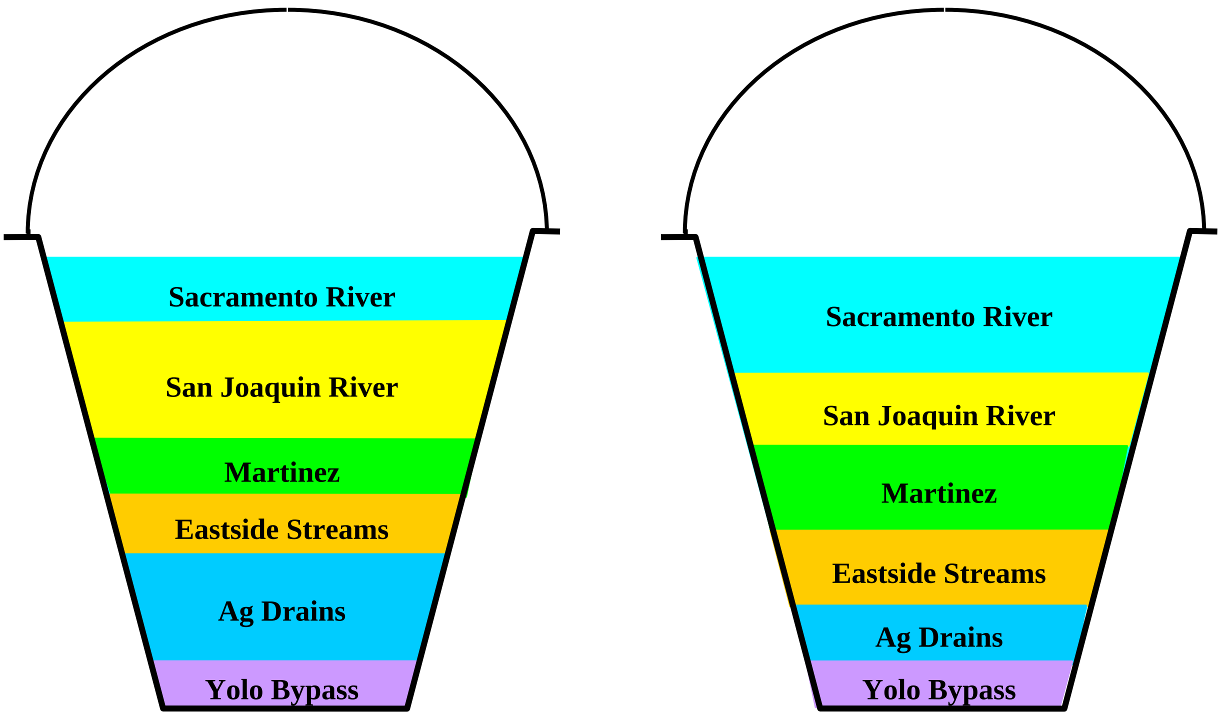


Figure 14.8: Conceptualization of Relative Contributions of Six Sources to Water Samples from Two Different Locations in the Delta.

Note: Relative contributions are for illustrative purposes only. They do not reflect actual results from the Delta.

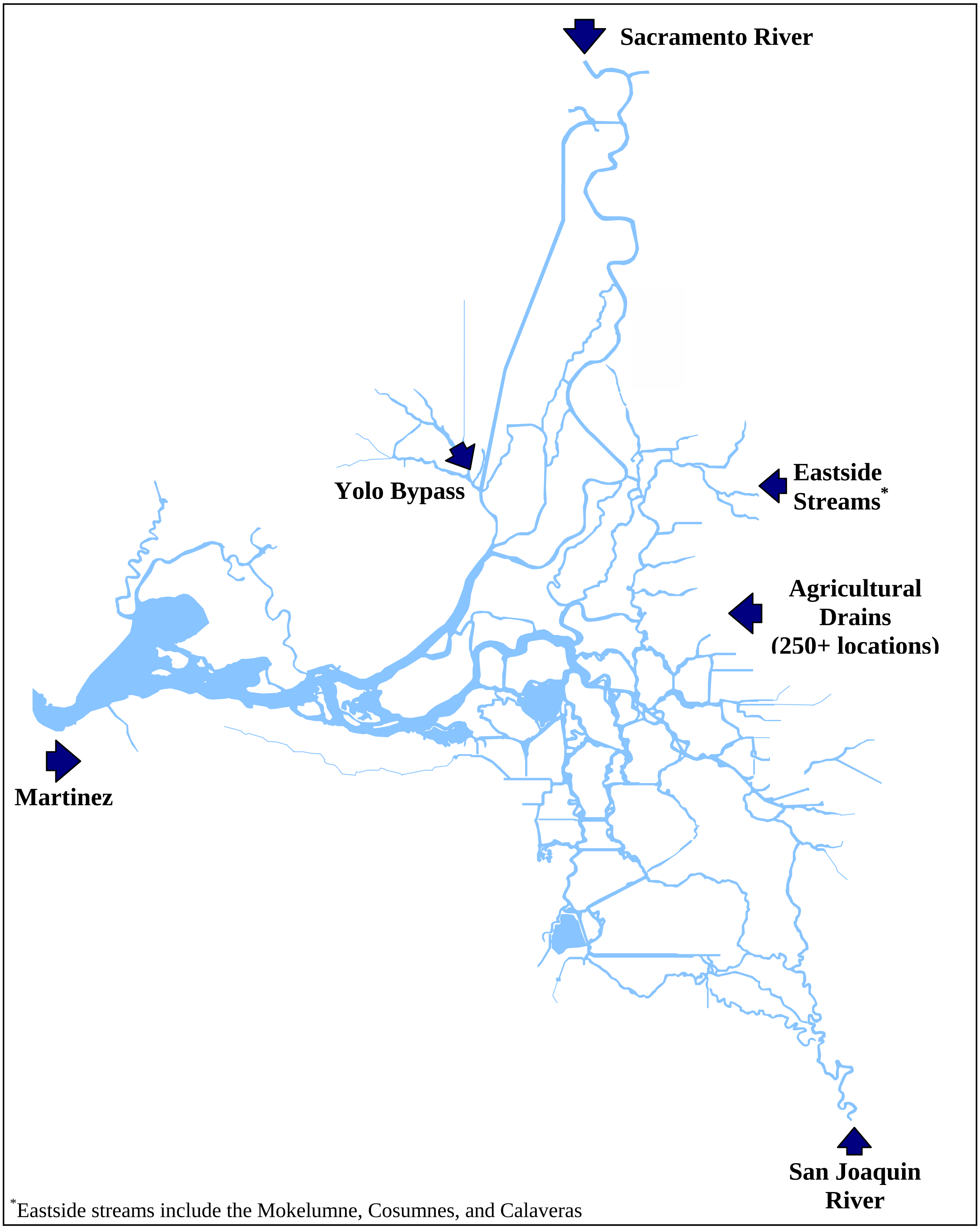


Figure 14.9: Typical Fingerprinting Source Locations for the Sacramento-San Joaquin Delta.

14.5.1 Volume Fingerprinting for Conservative Constituents by using Tracer Constituents in QUAL

Volume fingerprinting indicates the volume of water at a given location and time contributed by each source. For volume fingerprinting simulations, tracer constituents are used to represent contributions from each source. These tracers are arbitrarily defined conservative constituents in DSM2. The concentration of each tracer constituent is set to a constant value at the point of origin of each tracer. The concentration of each tracer constituent is then set equal to zero at all other locations. Thus for the six source locations typically used in DSM2 fingerprinting studies, the tracer concentrations would be set up as illustrated in Table 14.3. In this example, tracer 1 is associated with the Sacramento River, tracer 2 is associated with the San Joaquin River, etc. Additional source locations can be included by adding additional tracer constituents for each new source.

In addition, a tracer for checking mass conservation can be specified. Thus, for a six-source volume fingerprinting simulation of the Delta, seven tracer constituents would be specified: one for each source and one for mass conservation. For the mass conservation tracer, the concentration at each source is set equal to the constant value used for the individual source tracers (Table 14.3). If the same constant value is used at each source, the concentration of the mass conservation tracer will equal that constant value at all locations throughout the system. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the simulated concentration of the mass conservation tracer (Equation 14-3). Although it is not necessary to use a separate mass conservation tracer, it provides a method to check that the simulation was set up correctly.

$$C_{Tmc} = \sum_{i=1}^{n} C_{T\,i} \qquad \text{[Eqn. 14-3]}$$

where,

C_{Tmc} = concentration of the mass conservative tracer at a given location,
C_{Ti} = concentration of tracer constituent *i* at a given location,
n = total number of sources.

The value assigned for the concentration of each tracer at the source with which it is associated is arbitrary. For convenience in analysis, the same constant value is typically used for each tracer. A concentration of 10,000 is often used because percent contributions are easily determined by dividing by 100. A concentration of 10,000 is also large enough to indicate minor contributions, which can be lost in round off error if smaller values are used.

Table 14.3: Specified Tracer Concentations for Volume Fingerprinting in the Delta.

Location	Tracer 1	Tracer 2	Tracer 3	Tracer 4	Tracer 5	Tracer 6	Tracer 7 to Check Mass Conservation
Sacramento River	Constant value e.g., 10,000	0	0	0	0	0	Constant value e.g., 10,000
San Joaquin River	0	Constant value e.g., 10,000	0	0	0	0	Constant value e.g., 10,000
Martinez	0	0	Constant value e.g., 10,000	0	0	0	Constant value e.g., 10,000
Eastside Streams	0	0	0	Constant value e.g., 10,000	0	0	Constant value e.g., 10,000
Ag Drains	0	0	0	0	Constant value e.g., 10,000	0	Constant value e.g., 10,000
Yolo Bypass	0	0	0	0	0	Constant value e.g., 10,000	Constant value e.g., 10,000

Percent Volume Contributions for Volume Fingerprinting

The volume fingerprinting methodology indicates the volume of water at a given location contributed by each source represented by a tracer constituent. The percent volume contribution of a particular source, *k*, at a given location and time can be determined as shown in Equation 14-4:

$$V_{\%k} = \frac{C_{Tk}}{\sum_{i=1}^{n} C_{Ti}} \times 100\% = \frac{C_{Tk}}{C_{Tmc}} \times 100\% \qquad \text{[Eqn. 14-4]}$$

where,

C_{Ti} = concentration of the tracer constituent *i* at a given location,
C_{Tk} = concentration of the tracer constituent associated with specific source *k* at a given location,
n = total number of sources, and
$V_{\% k}$ = percent volume contribution from source *k* at a specified location.

Conservative Constituent Estimates for Volume Fingerprinting

The concentration of a conservative constituent at a specified location can be estimated from the percent volume contributions from each source if the source concentrations are known (Equation 14-5):

$$C_{CC} = \sum_{i=1}^{n} C_{Ti} \frac{V_{\%i}}{100} \qquad \text{[Eqn. 14-5]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a given location,
C_{Ti} = concentration of the tracer constituent *i* at a given location,
n = total number of sources, and
$V_{\% i}$ = percent volume contribution from source *i* at a specified location.

Examples of volume fingerprinting results for different analysis periods are given in section 14.5.4.

Once the fraction of water contributed by each source, $\frac{V_{\%i}}{100}$, has been determined, a single DSM2 simulation can be used to estimate the concentration of any conservative constituent from the source concentrations for that constituent. However, Equation 14-5 only approximates the concentration of a conservative water quality constituent for a specific location. Antecedent conditions are not considered. This method does not account for changes in source flows and concentrations. If the residence time of the system is longer than the analysis period for the volume contributions, the volume and timing fingerprinting method provides a more accurate estimate of conservative constituent concentration estimates.

14.5.2 Volume and Timing Fingerprinting for Conservative Constituents by using Tracer Constituents in QUAL

The volume fingerprinting method presented in section 14.5.1 can be expanded to include the timing of the sources. Typically in DSM2, the volume and timing analysis is conducted on a monthly basis. An arbitrarily defined conservative tracer constituent is assigned to each source location for each month out of the year. Since the system memory for the Delta is considered to be six months or less, the volume and timing fingerprinting simulations are simplified by combining tracers for months that are six months apart. In other words, the same tracer is used to represent sources in January and July, February and August, March and September, etc. At the point of origin for each tracer, the concentration of that tracer constituent is set equal to a constant value for the two months represented by that source, and it is set equal to zero for the remaining ten months out of the year. The concentrations of the tracer constituents are set equal to zero at all other locations for all times. Thus for the six source locations typically used in DSM2 fingerprinting studies, the tracer concentrations would be set up as illustrated in Table 14.4. In this example, tracers 1-6 are associated with the Sacramento River, tracers 7-12 are associated with the San Joaquin River, etc. Additional source locations can be included in a volume and timing fingerprinting simulation by adding six additional tracer constituents for each source. An example of the six tracer constituents that would be required to represent a single source in a volume and timing fingerprinting study is shown in Figure 14.10. For a six-source volume fingerprinting simulation of the Delta, thirty-six tracer constituents would be specified: six for each source.

Analysis of volume and timing fingerprinting results can be tricky, especially if the short cut of assigning two source time periods to each tracer is used. If two source time periods are assigned to each tracer, the source time represented by that tracer will depend upon the month for which the simulation results are analyzed. For example, consider a tracer that represents water from a given source entering the system in January and July. Simulated concentrations of that tracer represent the volume contribution by its source during January for simulation results in January through June. However, for simulation results for July through December, that tracer represents the volume contributed by its source during July. To further illustrate this concept, the source months represented by each tracer in Figure 14.10 for each simulation month are summarized in Table 14..

In addition, a tracer for checking mass conservation can be specified. Thus, for a six-source volume fingerprinting simulation of the Delta, forty-two tracer constituents would be specified: six for each source (6x6 = 36) and six for mass conservation (36+6 = 42). For the mass conservation tracer, the concentration at each source for each time period is set equal to the constant value used for the individual source tracers (Table 14.4). If the same constant value is used at each source, the concentration of the mass conservation tracer will equal that constant value at all locations throughout the system. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the sum of the simulated concentration of the mass conservation tracers (Equation 14-6). Although it is not necessary to use a separate mass conservation tracer, it provides a method to check that the simulation was set up correctly.

$$\sum_{j=1}^{m} C_{Tmc,j} = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{T(i,j)} \qquad \text{[Eqn. 14-6]}$$

where,

$C_{Tmc,j}$ = concentration of the mass conservative tracer at a given location for time period j,

$C_{T(i,j)}$ = Concentration of the tracer constituent i at a given location for time period j,

n = total number of sources, and

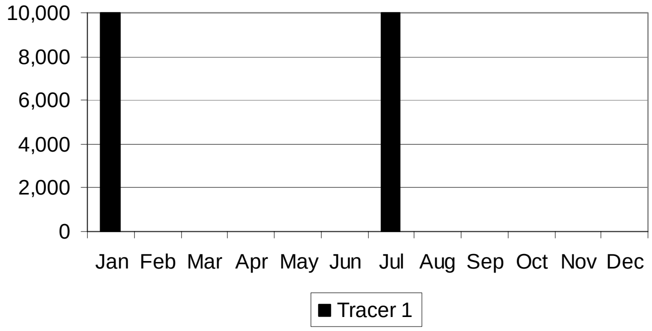
m = total number of time periods based on system memory.

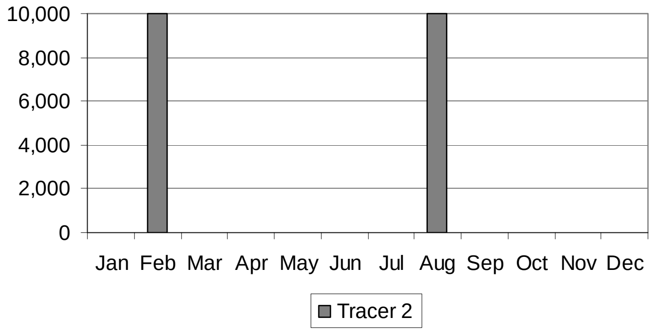
Table 14.4: Specified Tracer Concentations for Volume and Timing Fingerprinting in the Delta.

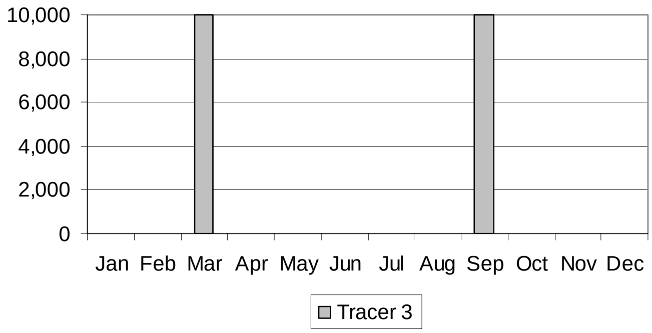
Location	Tracers 1-6	Tracers 7-12	Tracers 13-18	Tracers 19-24	Tracers 25-30	Tracers 31-36	Tracers 37-42 to Check Mass Conservation
Sacramento River	Constant value e.g.,10,000 or zero*	0	0	0	0	0	Constant value e.g.,10,000 or zero*
San Joaquin River	0	Constant value e.g.,10,000 or zero*	0	0	0	0	Constant value e.g.,10,000 or zero*
Martinez	0	0	Constant value e.g.,10,000 or zero*	0	0	0	Constant value e.g.,10,000 or zero*
Eastside Streams	0	0	0	Constant value e.g.,10,000 or zero*	0	0	Constant value e.g.,10,000 or zero*
Ag Drains	0	0	0	0	Constant value e.g.,10,000 or zero*	0	Constant value e.g.,10,000 or zero*
Yolo Bypass	0	0	0	0	0	Constant value e.g.,10,000 or zero*	Constant value e.g.,10,000 or zero*

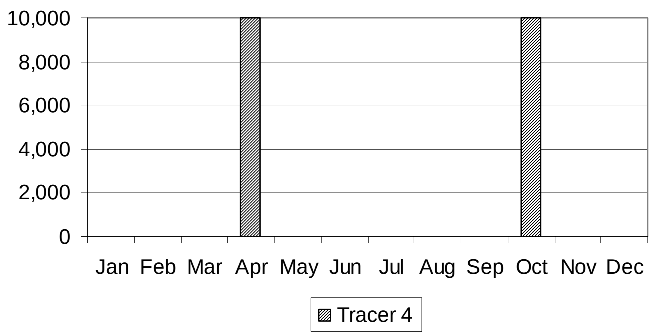
*Tracer is assigned a constant concentration for the two months represented by that tracer, and a value of zero is assigned for all other months.

Similar to the volume fingerprinting method, the value assigned for the concentration of each tracer at the source with which it is associated is arbitrary. For convenience, the same constant value is typically used for each tracer. A concentration of 10,000 is often used because percent contributions are easily determined by dividing by 100. A concentration of 10,000 is also large enough to indicate minor contributions, which can be lost in rounding error if smaller values are used.


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Tracer 1


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Tracer 2


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Tracer 3


10,000
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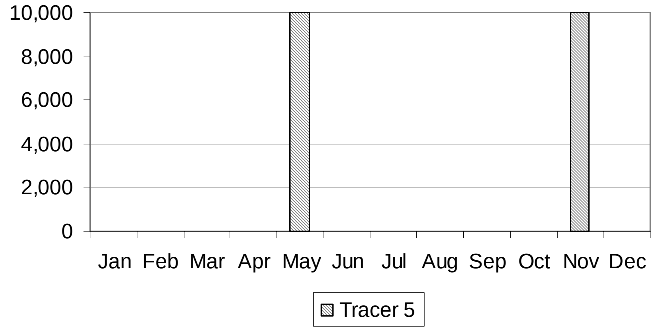
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Tracer 4



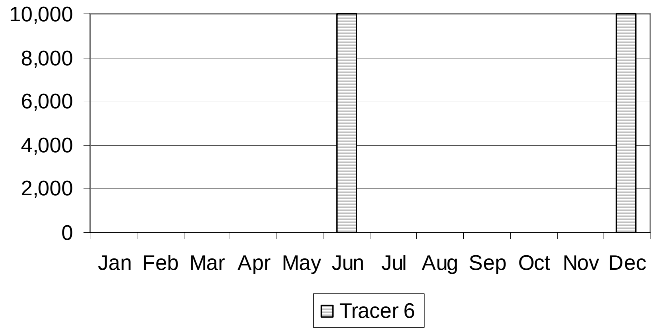


Figure 14.10: Specified Tracer Concentrations for a Single Source for Volume and Timing Fingerprinting in the Delta.

Table 14.5: Source Month Represented by each Tracer for a Specified Month in the Delta.

Simulation Results Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Tracer 1	Jan	Jan	Jan	Jan	Jan	Jan	Jul	Jul	Jul	Jul	Jul	Jul
Tracer 2	Aug	Feb	Feb	Feb	Feb	Feb	Feb	Aug	Aug	Aug	Aug	Aug
Tracer 3	Sep	Sep	Mar	Mar	Mar	Mar	Mar	Mar	Sep	Sep	Sep	Sep
Tracer 4	Oct	Oct	Oct	Apr	Apr	Apr	Apr	Apr	Apr	Oct	Oct	Oct
Tracer 5	Nov	Nov	Nov	Nov	May	May	May	May	May	May	Nov	Nov
Tracer 6	Dec	Dec	Dec	Dec	Dec	Jun	Jun	Jun	Jun	Jun	Jun	Dec

Percent Volume Contributions for Volume and Timing Fingerprinting

The volume and timing fingerprinting methodology indicates the volume of water at a given location contributed by each source from a specified month. At a given location, the percent volume contribution of a particular source, *k*, from a specified time, *t*, can be determined as shown in Equation 14-7:

$$V_{\%(k,t)} = \frac{C_{T(k,t)}}{\sum_{i=1}^{n} C_{T(i,t)}} \times 100\% = \frac{C_{T(k,t)}}{C_{Tmc,t}} \times 100\% \qquad \text{[Eqn. 14-7]}$$

where,

$C_{Tmc,t}$ = concentration of the mass conservative constituent associated with specific source *m* at a given location for a specific time *t*,
$C_{T(k,t)}$ = concentration of the tracer constituent associated with specific source *k* at a given location for a specific time *t*,
$C_{T(i,t)}$ = concentration of the tracer constituent *i* at a given location for a specific time *t*,
n = total number of sources, and
$V_{\%\,(k,t)}$ = percent volume contributed from source *k* at a specified location for a specific time *t*.

For the Delta, six time periods (n = 6) represent the six-month "system memory". Because a single tracer represents two time periods for volume and timing fingerprinting, care must be taken when conducting analyses to ensure that the correct source times are associated with each tracer (see Figure 14.10 and Table 14.).

Conservative Constituent Estimates for Volume and Timing Fingerprinting

The concentration of a conservative constituent at a specified location can be estimated from the percent volume contributions from each source if the source concentrations are known (Equation 14-8):

$$C_{CC} = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{T(i,j)} \frac{V_{\%(i,j)}}{100} \qquad \text{[Eqn. 14-8]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a specified location for a give time,
n = total number of sources,
m = total number of time periods based on the system memory, and
$V_{\%\,(i,j)}$ = percent volume contributed from source i at a specified location for a specific time *j*.

Once the fraction of water contributed by each source during each time period, $\frac{V_{\%(i,j)}}{100}$, has been determined, a single DSM2 simulation can be used to provide a good estimate of the concentration of any conservative constituent from the source concentrations for that constituent. Because of the long residence times in the Delta and fluctuations in boundary flows and constituent concentrations, using the volume and timing fingerprinting method provides a more accurate estimate of conservative constituent concentration estimates than using the volume fingerprinting method.

14.5.3 Accuracy of Conservative Constituent Concentration Estimates

The accuracy of conservative constituent concentration estimates using fingerprinting depends on various factors. Variations in the source flows and/or concentrations over the analysis period (hourly, daily, monthly) affect the accuracy of constituent concentration estimates using fingerprinting. For example, EC concentrations for the Sacramento River, eastside streams, and Yolo Bypass are relatively constant with time. However, EC concentrations for Martinez, the San Joaquin River, and agricultural drains vary with time. Using fingerprinting methods that include timing of the sources increases the accuracy of the constituent concentration estimates.

The relative importance of errors in a fingerprinting analysis may depend on the application. To illustrate this point, consider volume fingerprinting results for Martinez that are going to be used to estimate constituent concentrations for both EC and DOC at Rock Slough. Typical source concentrations at Martinez for these two constituents are 25,000 umhos/cm for EC and between 1.6 and 7.0 mg/l for DOC. [5] Assume that the fingerprinting analysis found the volume of water from Martinez at Rock Slough to be 2% of the total volume of water at Rock Slough.

To illustrate the impacts of errors in boundary constituent concentrations on estimates of constituent concentrations at other locations in the Delta, consider a 10% error in the Martinez source concentration. For the EC concentration estimate, a 10% error in the Martinez source concentration estimate results in a 2,500 umhos/cm error at the Martinez boundary. Based on the fingerprinting concentration volume contribution at Rock Slough, the original Martinez contribution at Rock Slough would be 500 umhos/cm, while the same contribution with a 10% increase in the Martinez concentration would be 550 umhos/cm. The 50 umhos/cm difference at Rock Slough between these two scenarios is considerably smaller than the 2,500 umhos/cm error at Martinez.

For the DOC concentration estimate, a 10% error in the Martinez source concentration estimate results in a 0.02 to 0.07 mg/l increase in the DOC concentration at Martinez. Based on the fingerprinting volume contribution, the high-end (7 mg/l) contribution at Rock Slough would be 0.14 mg/l, while the same contribution of DOC from Martinez with a 10% increase would be 0.15 mg/l. The 0.01 mg/l difference at Rock Slough is on the same order of magnitude as the difference in DOC at Martinez (0.02 and 0.07 mg/l for the low- and high-end errors).

The significance of an error in a source concentration estimate at a location of interest depends not only upon the magnitude of the error at the boundary, but also depends on the relative concentrations from the other sources and the volume contribution from the source in question. Errors related to a major source of a constituent will have more of an impact on the concentration estimate than errors related to minor sources.

14.5.4 Sample Volume Fingerprinting Results

Results from fingerprinting simulations can be analyzed in several different ways. Results can be examined on different time scales (hourly, daily, monthly, etc). Analyses can be conducted based on hydrologic conditions, such as dividing the simulation results by water year type. To illustrate the wide range of applications of fingerprinting, examples from a volume fingerprinting

[5] The DOC water quality at Martinez is based on data collected at Mallard Island (Pandey, 2001).

study of historical conditions for water years 1992-1998 are presented below. All results shown are for the entrance to Clifton Court Forebay. In Figure 14.11, monthly percent volume contributions from two sources, the Sacramento and San Joaquin rivers, are shown as a time series plot. Other sources contributed less than 20% and were omitted for illustration purposes. The time series plot indicates that it depends on the time period whether the Sacramento River or the San Joaquin River provides the majority of the volume at the entrance to Clifton Court Forebay.

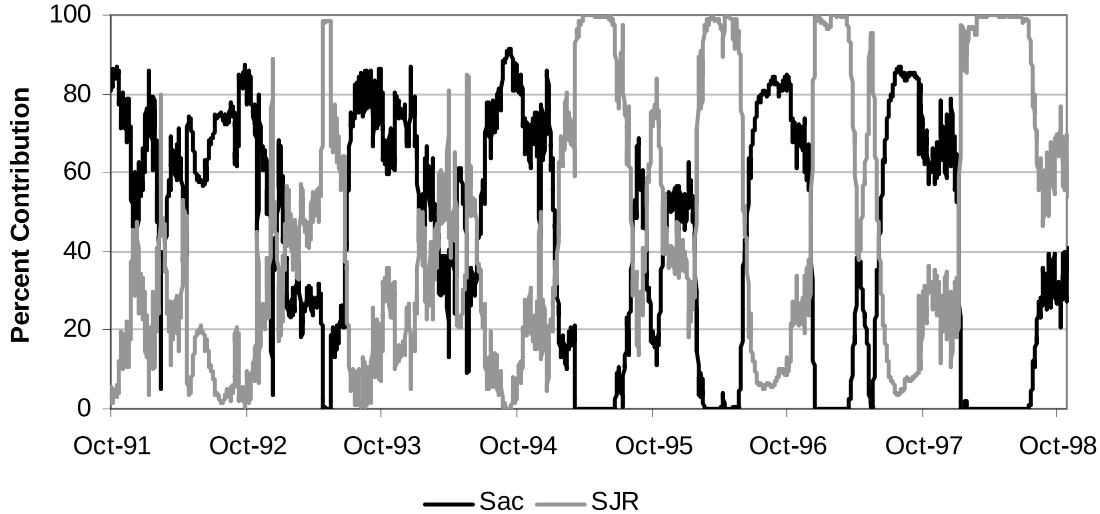


Figure 14.11: Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay.

As an additional analysis, the volume fingerprinting results were examined based on water year types. Pie charts illustrate the relative volume contributions from six sources by water year type (Figure 14.12). These results indicate that at the entrance to Clifton Court Forebay the Sacramento River provide the majority of the water volume during critical years, whereas the San Joaquin River provides the majority of the water volume during wet years.

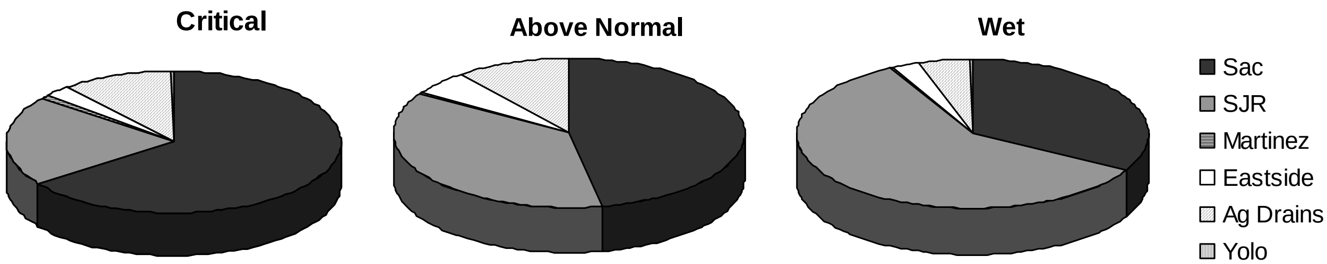


Figure 14.12: Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay based on Water Year Types.

Monthly average volume contributions over the seven-year period were also analyzed. The monthly average results in Figure 14.13 indicate that at the entrance to Clifton Court Forebay the Sacramento River provides the majority of the water volume during dry months, whereas the San Joaquin River provides the majority of the water volume during wet months.

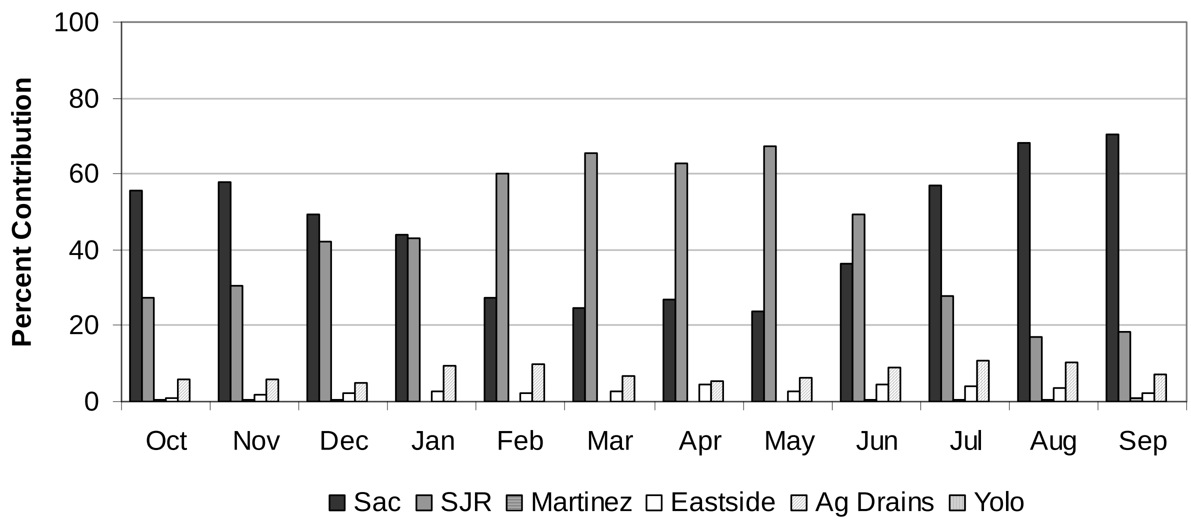


Figure 14.13: Monthly Average Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay.

14.6 Special Applications of Fingerprinting using DSM2

The volume-based fingerprinting methods described in section 14.5 provide a general analysis methodology that can be used to estimate the concentration of any conservative constituent. This section describes adaptations of those techniques when analysis is desired for a specific conservative constituent.

14.6.1 Constituent Fingerprinting

For the volume fingerprinting method, tracer constituents represent any conservative constituent. For the case when fingerprinting analysis is only desired for a specific constituent (e.g., EC), the arbitrary concentration of the tracer constituent (Table 14.3) can be replaced with the source concentrations of the desired constituent (Table 14.). In addition to specifying a tracer constituent for each source, the conservative constituent being investigated (e.g., EC) is simulated as its own constituent in the traditional manner. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the simulated constituent concentration (Equation 14-9). This provides a method to check that the simulation was set up correctly.

$$C_{CC} = \sum_{i=1}^{n} C_{Ti} \qquad \text{[Eqn. 14-9]}$$

where,

C_{CC} = concentration of the conservative constituent to be simulated,
C_{Ti} = concentration of tracer constituent i, and
n = total number of sources.

Table 14.6: Specified Tracer Concentations for Constituent Fingerprinting in the Delta.

Location	Tracer 1	Tracer 2	Tracer 3	Tracer 4	Tracer 5	Tracer 6	Constituent (e.g., EC)
Sacramento River	Observed Values	0	0	0	0	0	Observed Values
San Joaquin River	0	Observed Values	0	0	0	0	Observed Values
Martinez	0	0	Observed Values	0	0	0	Observed Values
Eastside Streams	0	0	0	Observed Values	0	0	Observed Values
Ag Drains	0	0	0	0	Observed Values	0	Observed Values
Yolo Bypass	0	0	0	0	0	Observed Values	Observed Values

Percent Contributions for Constituent Fingerprinting

The constituent fingerprinting methodology indicates the relative contributions of a specified source to the constituent concentration at a given location. The percent contribution of a particular source, k, at a given location and time can be determined as shown in Equation 14-10:

$$C_{\%k} = \frac{C_{Tk}}{\sum_{i=1}^{n} C_{Ti}} \times 100\% = \frac{C_{Tk}}{C_{CC}} \times 100\% \qquad \text{[Eqn. 14-10]}$$

where,

$C_{\%k}$ = percent contribution of the conservative constituent from source *k* at a specified location,
C_{Tk} = concentration of tracer constituent *k*, and
n = total number of sources.

14.6.2 Constituent and Timing Fingerprinting

The constituent fingerprinting method described in section 14.6.1 can be extended to constituent and timing fingerprinting also by adding tracer constituents for each desired source location and time. For the case when fingerprinting analysis is only desired for a specific constituent (e.g., EC), the arbitrary concentration of the tracer constituent (Table 14.4) can be replaced with the source concentrations of the desired constituent (Table 14.7).

Table 14.7: Specified Tracer Concentations for Constituent and Timing Fingerprinting in the Delta.

Location	Tracers 1-6	Tracers 7-12	Tracers 13-18	Tracers 19-24	Tracers 25-30	Tracers 31-36	Constituent (e.g., EC)
Sacramento River	Observed values or zero*	0	0	0	0	0	Observed values
San Joaquin River	0	Observed values or zero*	0	0	0	0	Observed values
Martinez	0	0	Observed values or zero*	0	0	0	Observed values
Eastside Streams	0	0	0	Observed values or zero*	0	0	Observed values
Ag Drains	0	0	0	0	Observed values or zero*	0	Observed values
Yolo Bypass	0	0	0	0	0	Observed values or zero*	Observed values

*Tracer is assigned the observed concentration for the two months represented by that tracer, and a value of zero is assigned for all other months.

Percent Contributions for Constituent and Timing Fingerprinting

The constituent and timing fingerprinting methodology indicates the relative contributions of a specified source during a specified month to the constituent concentration at a given location.

Based on Equation 14-10, the percent contribution of a particular source, *k*, from a specified month, *t*, at a given location can be determined as shown in Equation 14-11:

$$C_{\%(k,t)} = \frac{C_{T(k,t)}}{\sum_{i=1}^{n}\sum_{j=1}^{m} C_{T(i,j)}} \times 100\% = \frac{C_{T(k,t)}}{C_{CC}} \times 100\% \qquad \text{[Eqn. 14-11]}$$

where,

$C_{\%(k,t)}$ = percent contribution of the conservative constituent *k* during time *t* at a specified location,
$C_{T(i,j)}$ = concentration of tracer constituent from source *i* at time *j* at a specified location,
$C_{T(k,t)}$ = concentration of tracer constituent *k* at time *t*,
n = total number of sources, and
m = length of the system memory.

14.6.3 Constituent or Constituent and Timing Fingerprinting for Conservative Constituents by using an OUTPUTPATHS Section in the QUAL Input

In addition to the fingerprinting methods described above, DSM2 will internally set up and run fingerprinting simulations by specifying an appropriate OUTPUTPATHS section in the QUAL input. The OUTPUTPATHS section requests fingerprinting results at specified locations. The amount of the constituent contributed by the specified source is then computed internally when QUAL is run in a process that is transparent to the user. Results are only provided for the constituents and sources specified in a QUAL OUTPUTPATHS section.

For constituent fingerprinting, an OUTPUTPATHS section is added to the QUAL input that includes one of the following key words:

- FROM_NAME tracks conservative constituents from a location name
- FROM_TYPE tracks conservative constituents from an accounting type
- FROM_NODE tracks conservative constituents from a node number
- FROM_ALL tracks conservative constituents from all sources[6]

Additional details on OUTPUTPATHS sections in the DSM2 input files can be found in the 1998 annual report (Nader-Tehrani et al., 1998).

Sample Scenario

How much of the EC at various locations in the Delta originated from the ocean (Martinez)?

[6] The FROM_ALL computation occurs automatically for any fingerprinting simulation specified by one of the above FROM_XXX keywords. However the results are only provided in the output if the FROM_ALL keyword is specified.

Sample OUTPUTPATHS Section

```
OUTPUTPATHS
NAME FROM_NAME  TYPE  INTERVAL PERIOD  FILENAME
antioch         mtz   ec       1day    ave      output-files/qual.dss
jerseypt        mtz   ec       1day    ave      output-files/qual.dss
victoria        mtz   ec       1day    ave      output-files/qual.dss
cvp             mtz   ec       1day    ave      output-files/qual.dss
END
```

Using the above OUTPUTPATHS section, DSM2 would compute the one-day average contributions of EC from Martinez at the four specified locations (Antioch, Jersey Point, Victoria, and the CVP). The results would be stored in a file called qual.dss located in the output-files directory.

14.7 Summary

Fingerprinting techniques have been used to analyze source contributions of Delta flows and conservative constituent concentrations using DSM2. Fingerprinting studies are conducted by simulating the transport of conservative tracer constituents associated with each source. The two main applications of fingerprinting are volume fingerprinting and volume and timing fingerprinting. Results from fingerprinting analyses provide:

- A method for using a single DSM2 simulation to estimate the concentration of any conservative constituent at specified locations in the Delta if the source concentrations are known. The volume and timing fingerprinting method provides the best estimate of conservative constituent concentrations.
- The relative importance of each source.
- Improved understanding of the Delta.

Use of fingerprinting techniques with DSM2 provides a powerful analysis tool for understanding both hydrodynamics and water quality dynamics in the Delta.

14.8 References

Hutton, P. and F. Chung. (1992). "Simulating THM Formation Potential in Sacramento Delta. Part II." *Journal of Water Resources Planning and Management.* American Society of Civil Engineers. 118 (5).

Nader-Tehrani, P. and R. Finch. (1998). "Chapter 5: DSM2 Input and Output." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Pandey, G. (2001). "Chapter 3: Simulation of Historical DOC and UVA Conditions in the Delta." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.