CONTROLLABILITY OF FIRST FLUSH TURBIDITY IN THE DELTA: ANALYSIS USING DSM2 AND ARTIFICIAL NEURAL NETWORK EMULATION

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EXECUTIVE SUMMARY

A 2008 Biological Opinion by the U.S. Fish and Wildlife Service (FWS) has recommended changes in the manner in which flows and freshwater exports through the Delta are managed to address the decline in population of the Delta smelt (*Hypomesus transpacificus*). Delta smelt abundance is related to various water quality parameters, including temperature, conductivity, and turbidity, possibly due to linkages between Delta smelt migration and turbidity levels. To support implementation of the 2008 Biological Opinion, there is a need to understand and predict fate and movement of turbidity in the Delta. The analysis presented here built on an existing modeling study that developed an artificial neural network (ANN) model for turbidity in the Delta, created as an emulator for DSM2 model of turbidity. The ANN emulation has the advantage of providing relatively rapid results given boundary flows and turbidity. Because of this rapid response, the ANN modeled turbidity was used for estimating the degree of controllability at a specific station in the Delta (the Old River at Bacon station). The Old and Middle River (OMR) flow was used to evaluate the impact on turbidity. The OMR flow depends on the natural flows in the system as well as the volume of exports through the State Water Project and Central Valley Project.

Two different ANNs were used (labeled Phase 3 and Phase 3A) that differed in the flow and turbidity data sets used for training. In the Phase 3 ANN, the training was performed using DSM2 values, where the inputs to DSM2 were a range of synthetic flows and turbidity values. In the Phase 3A ANN, the training data set differed in that the inputs to DSM2 were historical flows and estimated turbidity values. Given the challenge of forecasting turbidity in the Delta, both trained ANNs have relative advantages. Thus, the Phase 3 ANN benefits from a broader training data range, whereas the Phase 3A ANN follows the historical data more closely, and matches it better. For the purpose of the controllability analysis presented here, both ANNs may be considered to provide useful information.

Key results from both ANNs, given a turbidity compliance threshold of 12 NTU at the Old River at Bacon Station, are as follows:

- Phase 3 ANN: 84 high turbidity events, 13 events controlled. There were a total of 1,631 days with high turbidity over 1975-2011, of which 854 days were not controlled (52.4%). Adding the export cost over the controlled events, the water cost was 1,695 TAF over this period.

- Phase 3A ANN: 81 high turbidity events, 38 events controlled. There were a total of 1,471 days with high turbidity over 1975-2011, of which 520 days were not controlled (35.4%). Adding the export cost over the controlled events, the water cost was 3,950 TAF over this period. The water cost was larger because the number controlled days was larger than for the Phase 3 ANN.

The two ANNs differ in the predictions of controllability, and suggest that somewhere between a half to one-third of the events cannot be controlled. The individual controlled and uncontrolled events may be related to the corresponding flows and turbidities in the major inflows from Vernalis in the south and from the North Delta (Yolo Bypass and Sacramento River flows). Controlled events were associated with relatively lower flows and turbidities from the south and north. High flows and/or high turbidities resulted in turbidity conditions that were usually not controllable. When flows from the north were high but from the south were low, the events were partially controllable.

Other modifications that can be made to the calculation are the use a different turbidity threshold instead of 12 NTU or the use of different starting and stopping criteria for defining an event. Two scenarios were evaluated:

- Using the Phase 3 ANN model and 12 NTU as the definition for the start of an event, the total number of events defined (84 events) was the same. However, by considering a controlled turbidity threshold of 15 NTU, the number of controlled events increased from 13 to 33.

- By increasing the threshold of 12 NTU to 15 NTU for the event definition, a total of 81 events were defined. Among the 81 events defined, a total of 23 events were controlled, considering a compliance (considered as controlled) threshold of 15 NTU.

The results suggested a higher threshold (15 NTU) for compliance (considered as controlled) increased the number of controlled events markedly. This is because a large number of days have turbidity levels between 12-15 NTU after OMR change. The 15 NTU number used in this analysis is illustrative, and other ranges may be considered, as determined by the biological response of the Delta smelt.

Supporting analyses were also considered using the synthetic turbidity data and observed smelt salvage data from 1981 to 2012. The analysis focused on the role of turbidity and not of other water quality parameters such as salinity or temperature that may also be important. The direct relationship between salvage and antecedent turbidity was noisy, although a threshold-based statistical formulation showed that instances of higher salvage were more likely to be associated with higher turbidity conditions.

Overall, the analyses presented in this report provide insight into the significance of turbidity for smelt salvage the potential controllability of this parameter through OMR flow adjustment. Although the exact amount of control (number of days and volume of water cost) is dependent on the ANN assumptions and the thresholds considered, the calculations suggest that turbidity at the Old River at Bacon station is somewhat controllable, under a specific subset of flow and turbidity conditions at the Delta boundaries. Similarly, the turbidity is uncontrollable under certain flow conditions, no matter what level of OMR flow control is attempted. These results can serve as a guide for additional refined modeling to further elucidate mechanisms and determine the best strategies for responding to high turbidity events in the Delta.

1. INTRODUCTION

The Delta smelt (*Hypomesus transpacificus*) is an endangered species endemic to the Sacramento-San Joaquin estuary of California, with low recorded abundance in the last decade by the Interagency Ecological Program (IEP). A 2008 Biological Opinion by the U.S. Fish and Wildlife Service (FWS) recommended changes in the manner in which flows and freshwater exports through the Delta are managed to address the decline in population of this species (http://www.fws.gov/sfbaydelta/ocap/). Delta smelt abundance is related to various water quality parameters, including temperature, conductivity, and turbidity, possibly due to linkages between Delta smelt migration and turbidity levels (Moyle et al., 1992; Sommer et al. 2011; Nobriga et al., 2008).

To support implementation of the 2008 Biological Opinion, there is a need to understand and predict fate and movement of turbidity in the Delta. Besides greater collection of turbidity data that has been initiated since 2009, turbidity modeling is also needed. Toward this end, mechanistic modeling has been performed by calibrating the Delta Simulation Model (DSM2) model with a first-order decay term for turbidity (Liu and Sandhu, 2011; RMA, 2013). The DSM2 model is a one-dimensional hydrodynamic and water quality model that dynamically simulates hydrodynamics, water quality and particle tracking in a network of riverine or estuarine channels with Delta (DWR, 2002). DSM2 calculates flow, stage, velocity, and mass transport processes for conservative and non-conservative constituents, including salinity, water temperature, dissolved organic carbon, nutrients, dissolved oxygen, and transport of individual neutrally-buoyant particles. DSM2 is a powerful tool for the analysis of complex hydrodynamic, water quality, and ecological conditions, and has a long history of use to address various flow and water quality problems in the Delta. To allow easier access to mechanistic modeling for operational purposes and for long term planning models, an emulation of the DSM2 turbidity model using artificial neural networks (ANNs) has also been developed over three phases from 2012-2014 (Tetra Tech, 2014). The different phases of ANN development corresponded to improvements in the underlying DSM2 calibration. The training basis and fits achieved for turbidity for the final phase at different stations are presented in Tetra Tech (2014), and referred to in this document as Phase 3 training.

Using the Phase 3 ANN model, the sensitivity of turbidity at various Delta locations to flows and boundary turbidities was evaluated. The model was used to hindcast high turbidity events (i.e., first flush events) in December, January, and February over a 35-year period from 1975-2011 (Tetra Tech, 2014). Using this approach, and by defining an event to be the 3-day minimum turbidity exceeding 12 NTU over three compliance stations—Holland Cut, Prisoners Point, and Victoria Canal—we identified 37 events, of which 9 were controlled by modifying the Old and Middle River (OMR) flow (Hutton, 2008). Control was defined as minimum turbidity being decreased to below 12 NTU across all three compliance stations.

This memorandum builds on the Phase 3 ANN and initial controllability study with additional analyses related to the occurrence of turbidity, the controllability of first flush turbidity at an additional station, the consideration of a range of turbidity values as the threshold for compliance, and the relationship between turbidity hindcast through models and observed Delta smelt salvage data. These analyses are described further below.

Based on input from the Delta Conditions Team (DCT)[1], an additional turbidity station was considered on Old River at Bacon Island (CDEC code ORB). Thus, a turbidity event was described in terms of a threshold being exceeded at this single station. Given this selection, the characterization of first flush frequency differed from that based on turbidity exceedance at the three turbidity compliance locations: Holland Cut, Prisoners Point, and Victoria Canal.

Instead of using a specific 12 NTU value for defining the exceedance threshold, this work considered a range of values such as 12-15 NTU to define compliance. Given this approach, if a station is at elevated turbidity and OMR flow modification brings the turbidity down to the 12-15 NTU range, the event would be considered to be controlled. The ANN model was run using the historical boundary used in the DSM2 simulation for the period of 1975-2011. When a turbidity event was identified (based on the station/threshold selection), the OMR flow was changed by 500 cfs increments until the turbidity was below the threshold or the limit of potential OMR change was reached (defined by OMR flow under the zero Delta export condition). In the event that the turbidity could not be lowered below the desired threshold, an event was characterized as uncontrollable. Using the outcomes of this analysis we identified the flow and turbidity conditions that led to some types of events being generally controllable or uncontrollable.

In addition to the Phase 3 ANN, we chose to apply another training approach to bound the uncertainty for the purpose of this work. In the Phase 3 ANN development, we ran the DSM2 model using a set of synthetic flow and turbidity values at the boundaries to present a wide range of conditions to the ANN. This is considered valid because ANNs are better at interpolating within a range of input variables that extrapolating outside of the training range. For the present work, however, we chose to supplement the Phase 3 ANN, with another trained ANN, termed Phase 3A, where we used the historical turbidity and flow values. Over the full period of record, the Phase 3A ANN provided greater fidelity to the DSM2 turbidity values that we were seeking to emulate. Given the uncertainties inherent in the general methodology applied here, both approaches have utility and results from both are presented here.

We used the synthetic turbidity data for 1975-2012 to evaluate the relationship between turbidity, OMR flow and observed Delta smelt salvage from the available record. The salvage data needs to be compared to the synthetic turbidity data because no daily observed turbidity data are available for the South Delta region prior to 1999.

These analyses are further described in the following chapters. Chapter 2 of this report describes the updated ANN controllability analysis and interpretation by using the Old River at Bacon Island station for compliance, in comparison with the original approach of using three stations. Chapter 3 evaluates the use of a range of turbidity values for compliance. Chapter 4 presents the evaluation of the observed salvage data in the context of flow and

[1] Meeting on May 5, 2014

synthetic turbidity values. Chapter 5 presents the key conclusions of this analysis. Supporting information is presented in Appendices A through C.

2. EVALUATION OF FIRST FLUSH CONTROLLABILITY BASED ON TURBIDITY AT THE OLD RIVER AT BACON ISLAND STATION

In a previous effort at assessing the controllability of turbidity we defined an event to be the 3-day minimum turbidity exceeding 12 NTU over three compliance stations—Holland Cut, Prisoners Point, and Victoria Canal—as computed by running the ANN model using the historical inflows and estimated turbidity. Once an event was identified, the OMR flow was changed in increments of 500 cfs to decrease the turbidity at compliance stations such that they were all below the 12 NTU threshold. Over the modeled period, 37 events were identified of which 9 were controlled, with the majority being uncontrolled (Tetra Tech, 2014).

In the current analysis, the above approach was applied only at the Old River at Bacon Island (ORB) station, i.e., compliance was based on turbidity exceedance at a single station. The ANN developed in Phase 3 of this work (Tetra Tech, 2014) was applied in the analysis. In comparison to the 37 events obtained by considering the three-station minimum turbidity, use of the ORB station resulted in 84 events in total (Table 2-1). Among the 84 events, 13 events were controlled. In terms of the number of days, a total of 1,631 days during December – February were part of a turbidity event. Of these days, 854 days (52.4%) were not controlled. For events that were controlled, a total OMR export cost of 1,695 TAF was estimated. The OMR export cost is the reduced water export that was modeled to achieve turbidity compliance.

The flow and turbidity data can be used to characterize the nature of controllable events. For events that were controlled, the seasonal average of Vernalis flow was generally below 4,000 cfs and turbidity at Vernalis was generally below 20 NTU (Figure 2-1 and Figure 2-2). For events that are not fully controlled, the seasonal average of Vernalis flow was above 4,000 cfs and the turbidity at Vernalis was greater than 20 NTU (Figure 2-3 and Figure 2-4). This pattern is similar to the previous approach of using the minimum turbidity across three stations. In that case, the seasonal average of Vernalis flow was generally below 2,500 cfs and the seasonal average of turbidity was generally below 20 NTU for the controlled events (Figure 2-5 and Figure 2-6). For uncontrolled events, Vernalis flow is usually above 2,500 cfs and turbidity is greater than 20 NTU (Figure 2-7 and Figure 2-8).

An alternative ANN model (Phase 3A ANN model) was developed based on DSM2 simulations using the historical flow and turbidity boundary for the period of 1975-2011, considering the scenarios with and without export. The simulated turbidity calculated by Phase 3A ANN showed very good agreement with the DSM2 results, using the historical boundaries with and without the export scenarios (Figure A-1 in Appendix A), and showed better agreement than the Phase 3 model (Figure A-2). The Phase 3A ANN estimated a similar number of events at ORB (81 events) as the Phase 3 ANN. Among the 81 events, 38 events were controlled. In terms of number of days, a total of 1,471 days during December – February constituted the events (Table 2-2). Among these, 520 days (35.4%) were not controlled. For events that were controlled, a total OMR export cost of 3,949 TAF was estimated.

For events that could be controlled, based on the Phase 3A ANN, the seasonal average of Vernalis flow is usually below 5,000 cfs and turbidity at Vernalis is generally below 20 NTU (Figure 2-9 and Figure 2-10). For events that are not fully controlled, the seasonal average of Vernalis flow was above 5,000 cfs and turbidity at Vernalis was generally greater than 20 NTU (Figure 2-11 and Figure 2-12).

Based on results from Phase 3A model, a more generalized classification of the events is summarized in Table 2-3. The events based on their flow and turbidity characteristics can be divided into several categories with different controllability. The events may be classified as follows:

1) **Low flow and turbidity:** where flow and turbidity from Vernalis (< 6000 cfs, < 40 NTU) and North Delta (< 50,000 cfs and < 50 NTU) are both relatively low, these events can be fully controlled;

2) **High North Delta turbidity:** when the flow and turbidity from Vernalis is low, but when North Delta turbidity is high (> 50 NTU), the events can only be partially controlled;

3) **High North Delta flow:** when flow and turbidity from Vernalis is low, but when North Delta flows are high (> 50,000 cfs), the events cannot be controlled;

4) **High Vernalis turbidity:** while flow from Vernalis is low when the turbidity is high (> 40 NTU), the events cannot be controlled;

5) **High Vernalis flow:** regardless of turbidity level, when Vernalis flow is high (> 6,000 cfs), the events cannot be controlled.

Further characterization of these events helped elucidate the mechanisms associated with controllability. For this purpose, DSM2-simulated flow and turbidity were plotted for each controlled event to identify possible explanations for controllability. For each event controlled, turbidity at ORB before and after the OMR change, the Vernalis flow and turbidity from the North Delta and Vernalis were plotted (Appendix B). The plots for each individual controlled event suggest that for events that are controlled (at ORB), Vernalis flow is generally below 6,000 cfs, with most events below 2,500 cfs.

The box plots of the controlled and non-controlled events suggested that, for controlled events, 75th percentile of the Vernalis flow is below 3,000cfs (Figure 2-13). For controlled events, 75th percentile of the North Delta flow is below 30,000 cfs. For controlled events, the 75th percentile of turbidity from San Joaquin River is below 20 NTU, and 75th percentile of the turbidity from North Delta is below 70 NTU (Figure 2-14). The scatter plots of flow and turbidity for the controlled and non-controlled events showed the controlled events (in red) generally have lower SJR flow (< 6,000 cfs) and turbidity (<100 NTU; Figure 2-15). North Delta turbidity for the controlled events is generally below 400 NTU (Figure 2-15). For controlled events, North Delta flow is generally below 1.6 x 10^5 cfs (Figure 2-16).

Table 2-1
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
1	12/1/75	12/22/75	12	-69	-5506	7041	3504	7911	43	5	13	27467	401	22	0	237
2	1/12/77	1/16/77	1	-983	-4426	4894	1114	5588	16	3	14	8931	42	5	0	6
3	12/20/77	2/28/77	12		-7423	9510	3906	9911	214	39	39	51854	1513	71	50	
4	1/14/79	1/28/79	1		-276	3376	6761	3857	109	45	28	30867	1550	15	14	
5	2/24/79	2/28/79	2		3624	2323	12140	2587	133	25	28	66652	5512	5	5	
6	12/28/79	1/16/80	12		-3435	5761	4932	6521	116	25	33	68477	4373	20	4	
7	1/20/80	2/10/80	2		4562	6103	20095	6618	111	16	30	67800	5538	22	22	
8	2/16/80	2/21/80	2		-406	6667	12700	7246	190	64	41	125626	8940	6	5	
9	2/23/80	2/29/80	2		13082	2955	27600	3138	116	30	19	193277	8879	7	7	
10	12/13/80	12/19/80	12	-43	-5114	6331	2710	7154	21	8	12	15100	273	7	0	126
11	1/30/81	2/28/81	2		-5024	6520	3102	7246	177	9	20	26991	324	30	11	
12	12/1/82	1/8/82	12		-3321	4443	2315	5100	105	33	23	98620	4473	39	5	
13	1/10/82	2/28/82	2		-4217	6844	5192	7406	72	18	26	76105	4864	50	20	
14	12/1/82	12/7/82	12		-1778	7997	12574	8701	116	40	16	67405	7774	7	7	
15	12/9/82	12/13/82	12		42	8540	16860	9238	63	13	14	40415	2532	5	5	
16	12/30/82	1/7/83	12		2463	8233	20256	8908	55	11	11	55098	3431	9	9	
17	1/27/83	2/28/83	2		9517	9279	31618	9638	81	32	18	148951	8590	33	33	
18	12/1/83	12/22/83	12		6544	3525	19318	3955	76	22	18	94691	5554	22	21	
19	12/24/83	12/27/83	12		4231	3191	15325	3575	120	70	27	170563	15463	4	4	
20	12/31/83	2/4/84	12		9766	4124	24633	4380	52	11	12	72902	3884	36	36	
21	12/1/84	12/29/84	12		-5748	7870	4652	8755	66	6	25	34572	1014	29	5	
22	2/14/85	2/23/85	2		-5599	7103	3069	7868	18	14	22	16771	415	10	2	
23	12/4/85	12/18/85	12		-7321	8392	2345	9395	58	33	16	19042	516	15	5	
24	1/18/86	2/20/86	2		-4878	6407	3098	7157	146	51	45	91953	5938	34	20	
25	2/23/86	2/28/86	2		6699	4435	20533	4737	80	18	28	246846	12295	6	6	
26	1/14/87	1/16/87	1		-4642	5514	1990	6274	12	9	8	11758	479	3	1	
27	2/9/87	2/28/87	2		-5129	6211	2243	7028	101	14	20	17731	417	20	8	
28	12/12/87	12/25/87	12		-8717	9200	1217	10403	86	9	8	16568	140	14	8	
29	1/9/88	2/4/88	2		-8493	9212	1532	10339	83	24	20	25868	300	27	12	
30	2/6/88	2/11/88	2		-8581	9311	1463	10274	28	9	15	13183	178	6	2	
31	12/1/88	12/7/88	12		-6613	7230	1346	8098	11	3	11	10265	76	7	5	
32	12/31/88	1/5/89	12		-8576	9207	1372	10271	14	3	9	13242	118	6	2	
33	1/17/90	1/28/90	1		-8786	9360	1288	10541	37	8	15	18542	221	12	3	
34	2/19/90	2/28/90	2		-8702	9486	1521	10573	15	28	32	13836	317	10	7	

Table 2-1 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
35	2/18/92	2/28/92	2		-7884	9144	2823	10397	139	50	49	38581	1001	12	11	
36	12/17/92	12/26/92	12		-4686	5092	994	5882	17	8	5	10067	221	10	7	
37	1/6/93	2/28/93	2		-7576	9540	3780	10350	133	53	60	59036	2084	54	35	
38	12/23/93	12/27/93	12		-9390	10200	1662	11474	27	12	6	19725	383	5	5	
39	1/28/94	1/30/94	1	590	-6161	6992	1860	7991	64	8	18	19458	293	3	0	95
40	2/2/94	2/28/94	2		-4302	5300	1988	5941	58	17	28	20650	457	27	7	
41	12/8/94	12/17/94	12		-6601	7197	1297	8140	28	8	10	17265	392	10	3	
42	12/26/94	2/28/95	12		-6837	9378	5087	10217	116	34	52	82287	2394	65	30	
43	12/21/95	1/12/96	12	468	-5383	6374	2143	7156	49	17	13	23430	494	23	0	298
44	1/21/96	2/28/96	2		-2593	7121	8870	7394	214	36	44	96693	4491	40	37	
45	12/7/96	1/3/97	12		435	6672	14310	7097	98	45	44	115999	10101	28	23	
46	1/6/97	1/12/97	1		22502	3252	43901	4612	98	45	19	225110	15012	7	7	
47	1/14/97	1/25/97	1		15237	1655	29126	1760	124	34	17	126591	11076	12	12	
48	1/28/97	2/28/97	2		17684	1742	32436	1582	77	15	14	91779	8235	32	32	
49	12/2/97	12/29/97	12		-8921	9839	2049	11056	54	9	12	22733	736	28	4	
50	1/13/98	2/5/98	2		-464	4583	8570	4704	150	53	55	128170	4485	24	13	
51	2/8/98	2/16/98	2		14819	3563	31226	3154	132	36	31	229246	11484	9	9	
52	2/20/98	2/28/98	2		16167	2337	31446	2309	112	30	16	181788	7659	9	9	
53	12/30/98	1/1/99	12		-180	1753	3456	2188	19	10	8	22577	789	3	1	
54	1/25/99	2/6/99	2		-1360	4530	6841	5058	52	20	28	49664	2137	13	11	
55	2/12/99	2/25/99	2		1944	4841	13759	5062	52	29	27	113209	6816	14	14	
56	1/25/00	2/28/00	2		-7713	10489	5934	11461	97	43	40	83722	3850	35	22	
57	1/22/01	1/26/01	1		-6371	7531	2423	8471	18	6	11	13963	524	5	2	
58	2/4/01	2/10/01	2	375	-6223	7424	2398	8285	27	6	12	13362	456	7	0	155
59	2/22/01	2/28/01	2	1272	-6733	8729	3949	9316	117	41	30	33381	1107	7	0	165
60	12/3/01	2/1/02	12		-8220	9311	2409	10417	108	17	19	35871	643	61	33	
61	12/19/02	2/28/02	12		-8246	9159	2036	10342	124	10	21	47720	569	72	34	
62	12/15/03	2/28/04	12		-8832	9602	1755	10818	112	17	19	48276	803	77	22	
63	12/19/04	12/24/04	12	503	-8619	9312	1567	10443	15	8	11	13308	360	6	0	179
64	1/2/05	1/29/05	1		-8647	11011	4991	12068	96	34	53	33424	1475	28	20	
65	1/31/05	2/28/05	2		-5919	8431	5187	9125	61	18	34	24457	1405	29	12	
66	12/10/05	12/14/05	12		-8900	9889	2086	11058	44	7	11	15704	443	5	4	
67	12/16/05	12/22/05	12		-8132	9090	2111	10193	71	7	12	19474	665	7	3	
68	12/24/05	1/17/06	12		-2705	8859	12574	9646	109	42	41	168574	6558	25	20	
69	1/26/06	2/28/06	2		-4747	7933	6890	8785	65	9	18	53822	2727	34	6	

Table 2-1 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
70	1/1/00	12/27/06	12		-8509	9538	2275	10674	43	14	6	16256	590	27	9	
71	1/4/07	1/12/07	1		-6906	7992	2490	8909	16	9	5	16565	692	9	7	
72	1/24/07	2/23/07	2		-5020	6155	2447	6920	66	8	9	19576	761	31	2	
73	12/1/07	12/8/07	12	78	-5579	6119	1375	7002	45	4	12	10791	277	8	0	90
74	12/11/07	12/22/07	12	-349	-6247	6765	1471	7767	40	5	13	12536	325	12	0	154
75	1/9/08	1/12/08	1		-3395	4261	2149	5071	31	21	54	28437	564	4	1	
76	1/14/08	1/17/08	1		-4030	4587	1707	5360	32	15	24	21887	427	4	3	
77	1/24/08	1/30/08	1		-4389	5681	3031	6307	43	38	79	26821	803	7	2	
78	2/1/08	2/3/08	2	-1919	-5414	7064	3716	8089	34	42	48	51534	721	3	0	21
79	2/5/08	2/8/08	2		-4993	6355	2910	7050	13	45	31	37629	817	4	4	
80	2/24/09	2/28/09	2	700	-4363	5110	1723	5860	150	38	19	37940	1512	5	0	91
81	1/21/10	2/28/10	2		-4816	6106	2688	6879	76	29	27	35735	835	39	9	
82	12/6/10	12/16/10	12		-7480	9441	4752	10566	34	16	21	27753	1493	11	3	
83	12/19/10	1/11/11	12		-5374	10915	11802	11898	29	34	33	60152	5128	24	22	
84	2/23/11	2/25/11	2	742	-2425	7870	11768	8712	32	34	23	31624	1411	3	0	78
Total														**1631**	**854**	**1695**

Table 2-2
Phase 3A ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final	OMR Original	Allowed OMR change	Vernalis flow	South Delta diversions	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
1	12/1/75	12/23/75	12	-2588	-5501	7045	3523	7915	42	5	13	27274	401	23	0	133
2	1/10/77	1/14/77	1	-2401	-4601	5021	1122	5711	17	3	13	8625	42	5	0	49
3	12/21/77	2/28/77	12		-7415	9528	3954	9927	212	39	40	52306	1532	70	43	
4	1/22/79	1/26/79	1		-400	3299	6332	3782	49	17	22	21734	750	5	3	
5	12/26/79	12/28/79	12	963	-3587	4938	3103	5633	322	6	26	46997	1025	3	0	60
6	1/1/80	2/10/80	2		1291	5946	13979	6574	113	25	34	83563	5927	41	27	
7	2/15/80	2/28/80	2		5705	4867	19243	5267	152	47	29	164115	8957	14	10	
8	12/11/80	12/16/80	12	-2249	-5165	6313	2742	7130	30	8	12	16381	289	6	0	72
9	1/29/81	2/28/81	2		-5031	6532	3110	7263	180	9	22	27723	398	31	4	
10	12/1/82	1/7/82	12		-3423	4470	2166	5133	106	32	23	97821	4360	38	13	
11	1/9/82	2/28/82	2		-4144	6777	5222	7336	72	19	26	76779	4908	51	21	
12	12/8/82	12/13/82	12		-62	8532	16700	9227	66	13	14	42139	2639	6	2	
13	12/28/82	1/1/83	12		4957	6085	20620	6670	68	18	13	83260	4584	5	3	
14	1/3/83	1/6/83	1	5528	1153	9039	19550	9713	46	10	11	46193	3018	4	0	35
15	1/29/83	2/7/83	2		10024	9496	32790	9892	94	35	21	161643	8067	10	10	
16	12/1/83	12/11/83	12		5330	3638	17655	4117	74	26	22	74033	6385	11	11	
17	12/27/83	1/1/84	12		8042	3067	20467	3370	81	61	21	259842	13225	6	6	
18	1/3/84	1/5/84	1		15376	3667	32200	3860	51	19	13	121914	6557	3	3	
19	12/1/84	12/30/84	12	-524	-5607	7747	4689	8618	65	6	24	34124	1011	30	0	302
20	2/15/85	2/20/85	2	-556	-5806	7294	3083	8084	15	14	22	16114	413	6	0	84
21	12/3/85	12/16/85	12	-1014	-7352	8471	2434	9490	67	41	18	20372	604	14	0	198
22	1/17/86	1/20/86	1	-541	-7241	8241	2173	9203	152	53	30	28440	1728	4	0	113
23	1/24/86	2/28/86	2		-2036	5579	6802	6187	135	48	47	148434	8520	36	18	
24	2/7/87	2/27/87	2	-827	-5103	6154	2177	6967	101	13	19	17812	411	21	0	204
25	12/11/87	12/26/87	12		-8751	9238	1221	10431	85	9	8	16694	141	16	1	
26	1/6/88	2/3/88	2		-8539	9237	1505	10376	105	25	19	27650	304	29	3	
27	2/6/88	2/12/88	2	-2335	-8621	9358	1463	10336	26	9	16	12973	176	7	0	101
28	12/1/88	12/4/88	12	-607	-7515	8079	1358	8995	12	3	11	10590	77	4	0	55
29	12/31/88	1/3/89	12	-3254	-8629	9253	1415	10260	16	3	8	13550	120	4	0	114
30	1/16/90	1/27/90	1		-8762	9342	1299	10524	51	8	17	20642	239	12	1	
31	2/15/90	2/20/90	2	-3594	-8594	9260	1368	10341	35	50	27	15519	415	6	0	113
32	2/23/90	2/25/90	2	-5103	-8769	9522	1543	10579	12	17	31	13183	315	3	0	26
33	1/14/92	1/16/92	1	-1593	-6260	6649	980	7625	5	7	9	9632	199	3	0	81
34	2/19/92	2/28/92	2		-7980	9132	2615	10392	136	49	46	37882	1009	11	10	

Table 2-2 (continued)
Phase 3A ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final	OMR Original	Allowed OMR change	Vernalis flow	South Delta diversions	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
35	12/18/92	12/22/92	12	-1922	-4522	4981	1011	5807	19	8	5	10555	228	5	0	59
36	1/3/93	2/28/93	2		-7582	9472	3639	10294	138	51	57	57728	1997	57	33	
37	12/16/93	12/27/93	12	-4265	-9348	10107	1682	11331	31	12	9	21908	403	12	0	179
38	12/29/93	1/1/94	12	-6271	-7021	7709	1553	8680	22	12	10	16625	379	4	0	6
39	1/31/94	2/5/94	2	-814	-3647	4409	1622	4973	43	8	11	13318	266	6	0	67
40	2/7/94	2/22/94	2		-5067	6080	2013	6801	62	23	34	22465	510	16	2	
41	2/26/94	2/28/94	2	668	-3894	4951	2143	5588	43	9	24	19349	462	3	0	42
42	12/10/94	12/15/94	12	-1265	-5645	6244	1293	7123	24	7	10	15192	390	6	0	91
43	12/23/94	2/28/95	12		-6907	9360	4919	10209	115	33	50	79232	2310	68	28	
44	12/20/95	1/12/96	12	-1932	-5266	6268	2156	7043	51	17	13	24180	493	24	0	179
45	1/20/96	2/28/96	2		-2753	7199	8711	7491	212	36	44	95450	4407	41	30	
46	12/1/96	12/3/96	12	-4887	-7553	8797	3033	9696	19	10	17	15367	765	3	0	16
47	12/12/96	12/17/96	12		-3386	9061	11810	9534	140	44	57	93817	6956	6	6	
48	12/19/96	1/10/97	12		9183	4756	25297	4833	85	56	35	192988	14512	23	23	
49	1/14/97	2/11/97	2		17277	1636	32026	1496	104	34	18	139805	11944	29	28	
50	2/13/97	2/15/97	2		17621	1222	31676	1627	72	8	15	65993	6825	3	2	
51	1/1/00	12/28/97	12		-8896	9820	2063	11035	56	9	13	23047	731	28	2	
52	1/10/98	1/28/98	1		-2075	5254	6809	5767	144	48	43	97483	3357	19	11	
53	1/31/98	2/15/98	2		8524	4123	22183	3557	147	54	55	215373	10438	16	12	
54	1/27/99	2/6/99	2		-1082	4221	6764	4733	46	17	26	46522	1770	11	10	
55	2/16/99	2/22/99	2		2586	4302	14182	4568	49	32	22	119605	6896	7	7	
56	2/24/99	2/26/99	2		2035	5248	14801	6101	43	18	20	102083	5594	3	3	
57	1/23/00	2/28/00	2		-7625	10301	5730	11267	98	42	39	80728	3811	37	18	
58	2/2/01	2/8/01	2	-2395	-5895	7110	2473	7912	30	6	12	14676	455	7	0	88
59	2/19/01	2/22/01	2	-1191	-4566	6192	3194	6870	34	12	17	17721	839	4	0	60
60	2/25/01	2/28/01	2	506	-8094	10367	4531	10989	148	51	36	36987	1058	4	0	78
61	12/2/01	12/5/01	12	757	-1166	2065	2022	2480	151	7	13	27741	571	4	0	19
62	12/9/01	2/1/02	12		-8692	9802	2447	10957	98	18	20	36486	653	55	18	
63	12/22/02	2/28/03	12		-8240	9148	2022	10325	113	11	18	47524	561	69	20	
64	12/14/03	2/28/04	12		-8781	9550	1751	10761	111	17	19	47991	799	78	9	
65	12/17/04	12/22/04	12	-4510	-8427	9087	1619	10165	21	8	15	14469	367	6	0	96
66	1/4/05	2/26/05	2		-7250	9654	5036	10537	74	25	42	27922	1410	54	19	
67	12/8/05	12/26/05	12	-1807	-8860	9971	2417	11044	72	8	17	25734	850	19	0	310
68	12/28/05	1/17/06	12		-1355	8319	14185	9074	104	47	41	187140	7322	21	20	
69	1/23/06	2/28/06	2		-4530	7802	7105	8672	67	9	18	54595	2879	37	12	

Table 2-2 (continued)
Phase 3A ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR.

Event	Start Date	End Date	Month	OMR final	OMR Original	Allowed OMR change	Vernalis flow	South Delta diversions	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
70	12/1/06	12/25/06	12	-3010	-8430	9453	2255	10589	46	14	6	16301	591	25	0	269
71	1/4/07	1/8/07	1	-942	-6742	7860	2502	8781	16	9	5	17113	747	5	0	136
72	2/2/07	2/4/07	2	-889	-4555	5672	2387	6403	51	8	7	13558	517	3	0	27
73	2/7/07	2/28/07	2	-1941	-5168	6294	2460	7079	69	10	12	25596	1141	22	0	151
74	12/8/07	12/21/07	12	-3874	-6589	7107	1469	8144	42	5	13	12810	319	14	0	81
75	1/21/08	2/3/08	2		-4618	5880	2957	6648	50	33	58	30265	694	14	7	
76	2/24/09	2/28/09	2	140	-4363	5110	1723	5860	150	38	19	37940	1512	5	0	82
77	1/19/10	2/28/10	2		-4810	6067	2629	6842	79	29	27	34916	826	41	6	
78	12/6/10	12/10/10	12	-4391	-7491	9625	5041	10731	35	18	26	24119	1198	5	0	65
79	12/15/10	12/20/10	12	-1152	-7736	9759	4769	10800	33	30	26	47087	4283	6	0	108
80	12/22/10	12/25/10	12		-5836	10388	9781	11242	54	40	36	69899	4774	4	2	
81	12/29/10	1/1/11	12		-6639	11883	11126	12836	38	37	33	63174	6114	4	3	
Total														**1471**	**520**	**3949**

Table 2-3
Categories of Delta Events and Controllability based on Phase 3A model

Category	Vernalis Flow (cfs)	Vernalis Turbidity (NTU)	North Delta flow (cfs)	North Delta turbidity (NTU)	Controllability
1 (low flow, low turbidity)	< 6000	< 40	<50,000	<50	25/25 controlled
2 (high North Delta turbidity)	< 6000	< 40	<50,000	>50	10/22 controlled
3 (high North Delta flow)	< 6000	<40	>50,000		0/4 controlled
4 (high Vernalis turbidity)	< 6000	>40			0/5 controlled
5 (high Vernalis flow)	>6000				1/25 controlled

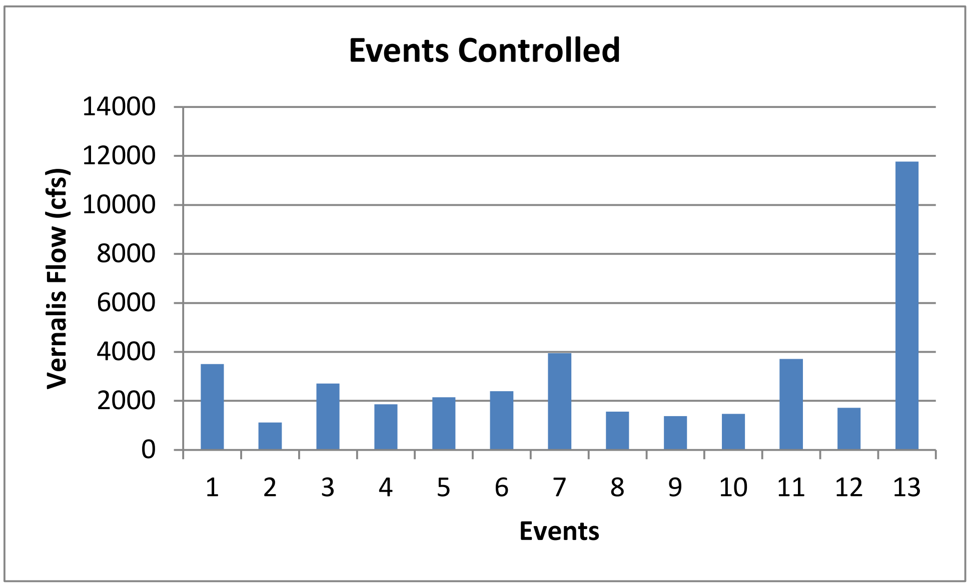

Figure 2-1 **Season mean of Vernalis flow for the controlled events at ORB estimated using the Phase 3 ANN.**

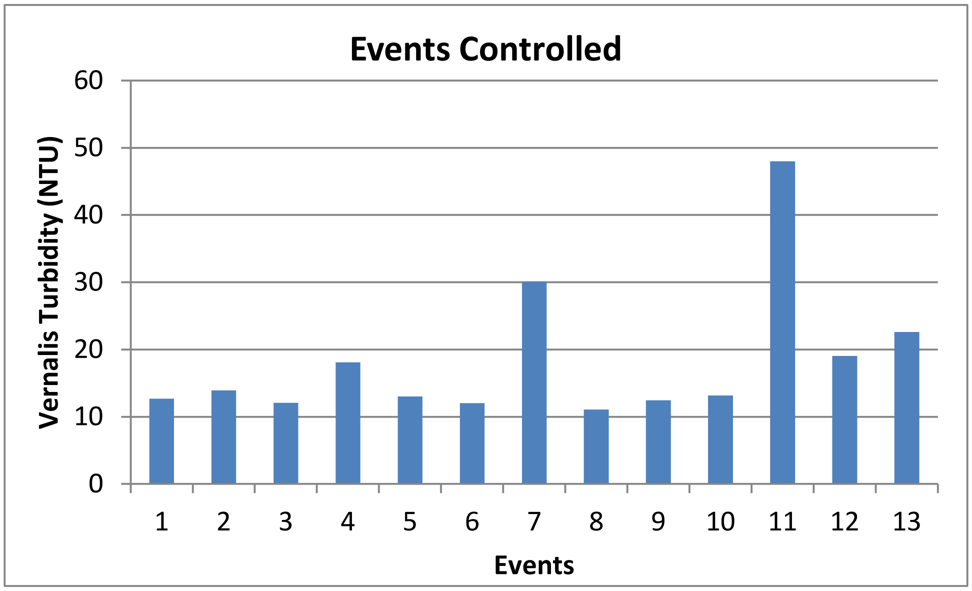

Figure 2-2 **Season mean of Vernalis turbidity for the controlled events at ORB estimated using the Phase 3 ANN.**

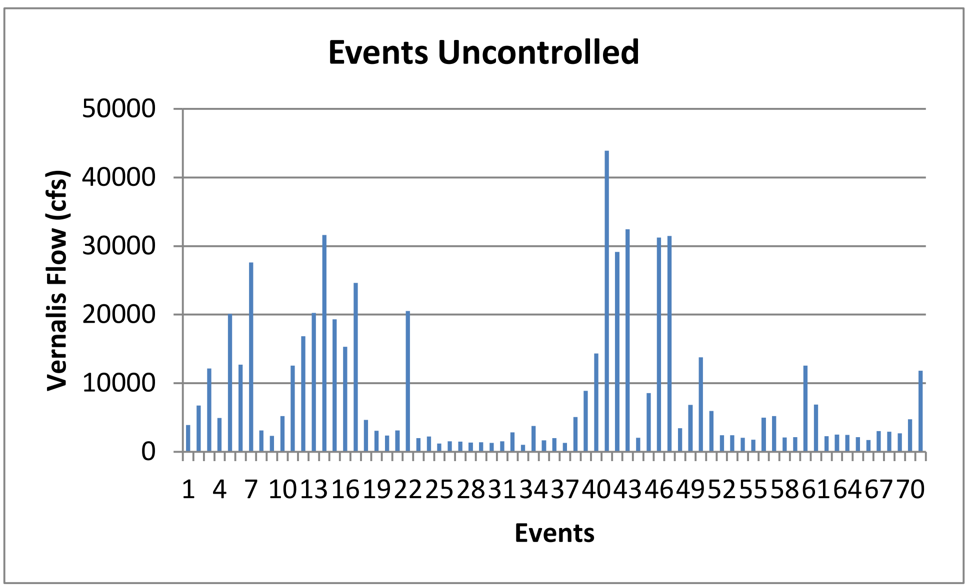

Figure 2-3 **Season mean of Vernalis flow for the uncontrolled events at ORB estimated using the Phase 3 ANN.**

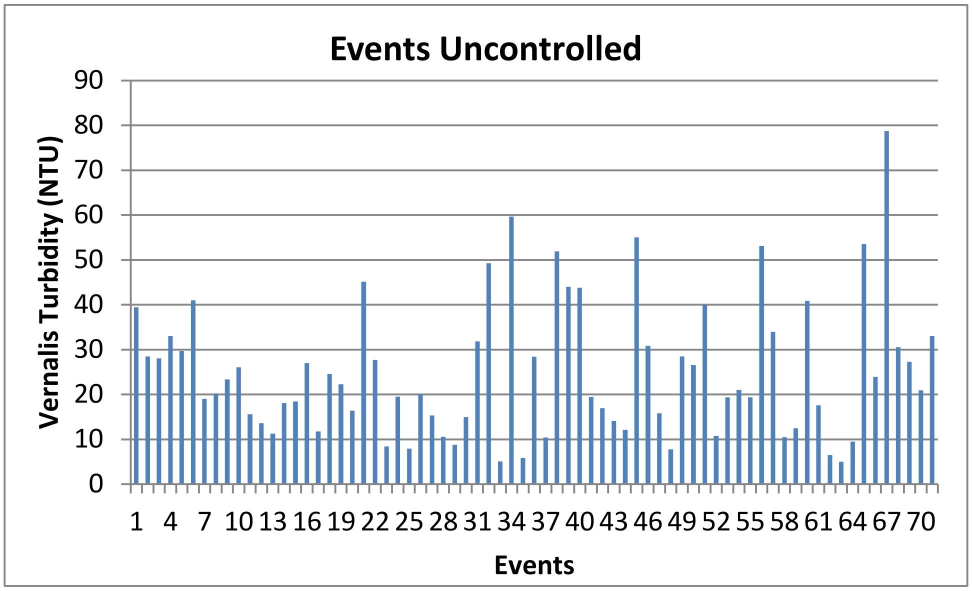

Figure 2-4 **Season mean of Vernalis turbidity for the uncontrolled events at ORB estimated using the Phase 3 ANN.**

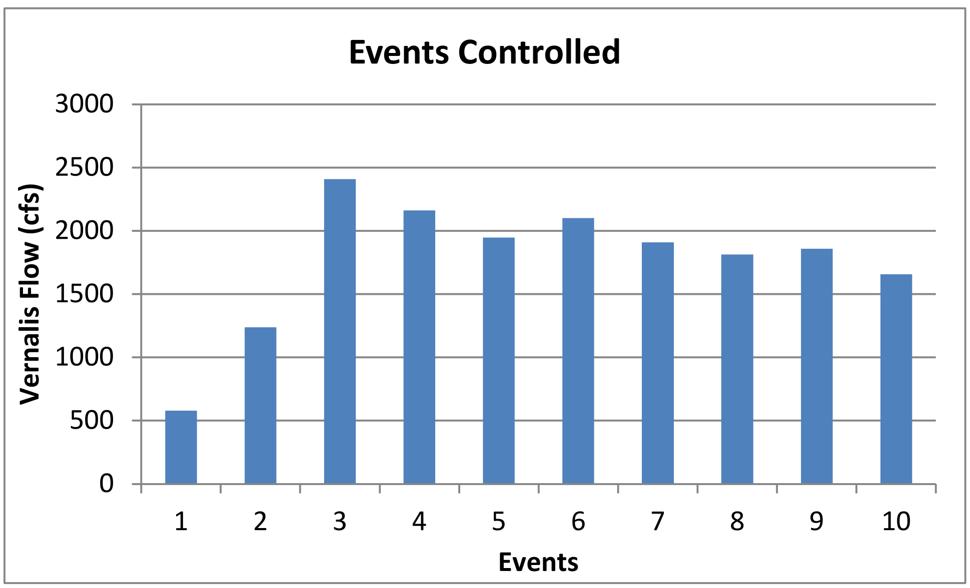

Figure 2-5 **Season mean of Vernalis flow for the controlled events estimated using 3 stations minimum by the phase 3 ANN**

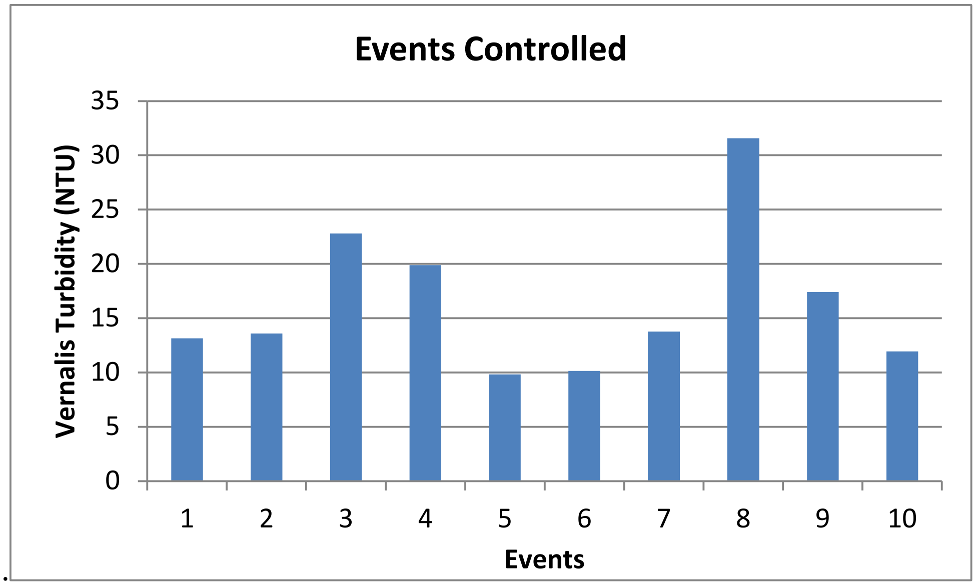

Figure 2-6 **Season mean of Vernalis turbidity for the controlled events estimated using 3 stations minimum by the phase 3 ANN**

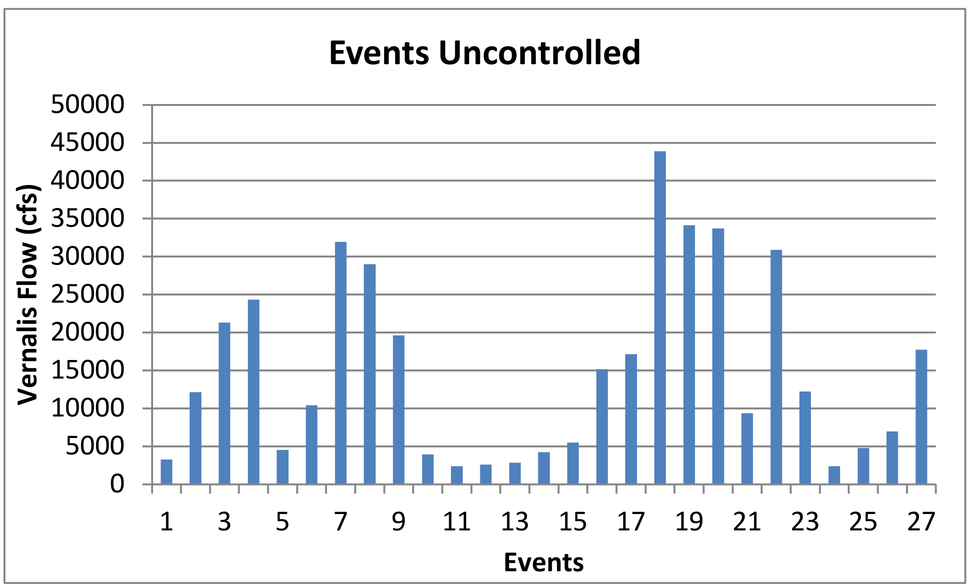

Figure 2-7 **Season mean of Vernalis flow for the uncontrolled events estimated using the 3 stations minimum by the phase 3 ANN**

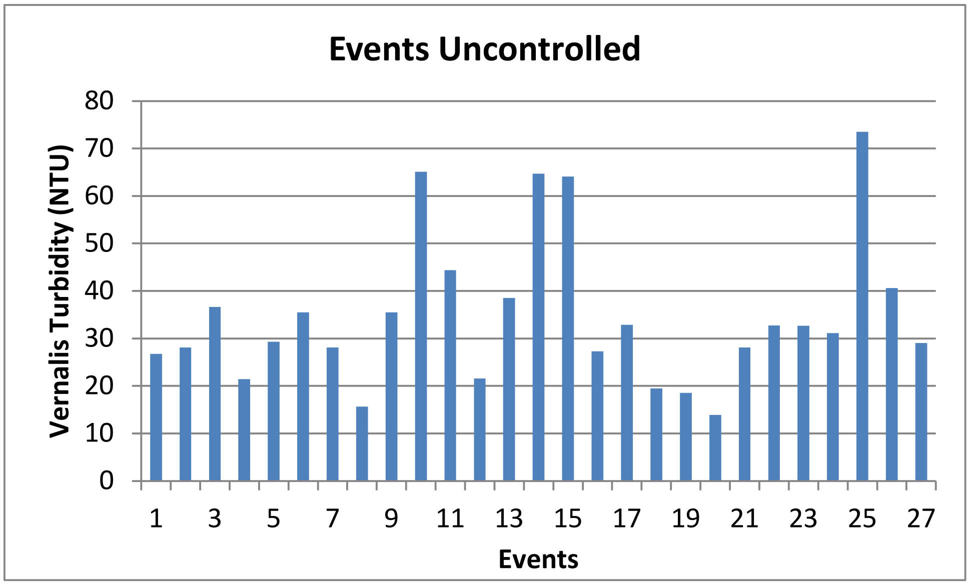

Figure 2-8 **Season mean of Vernalis turbidity for the uncontrolled events estimated using the 3 stations minimum by the phase 3 ANN**

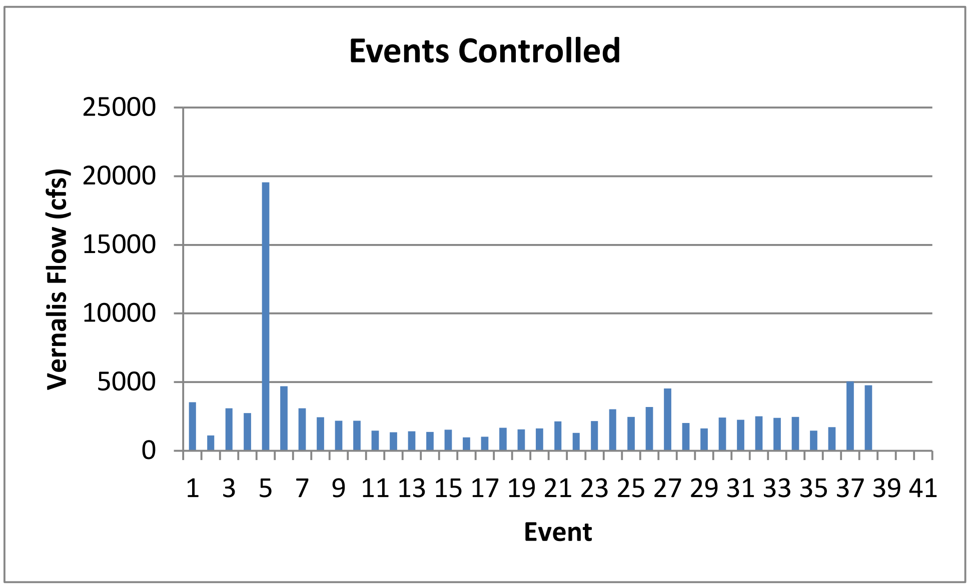

Figure 2-9 **Season mean of Vernalis flow for the controlled events at ORB estimated using the phase 3A ANN**

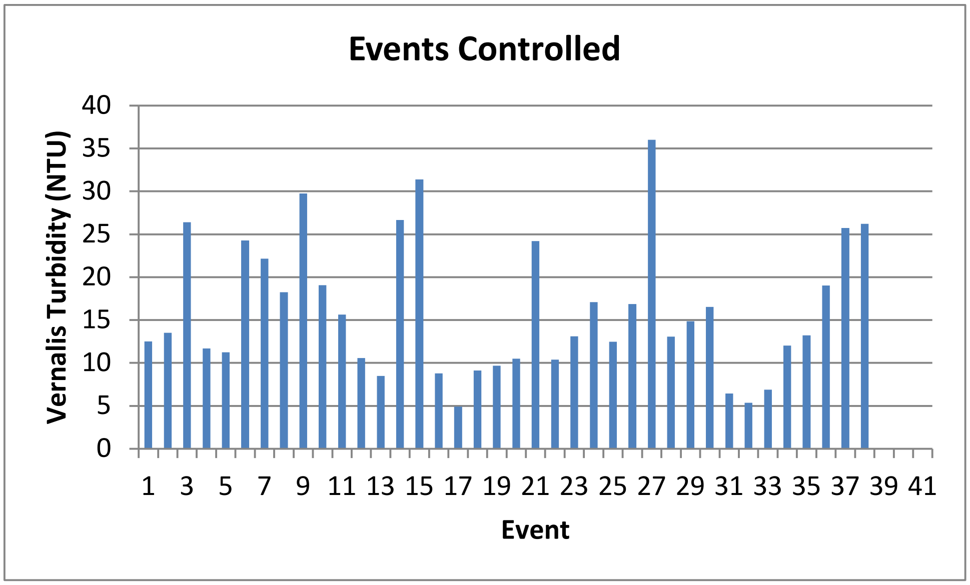

Figure 2-10 **Season mean of Vernalis turbidity for the controlled events at ORB estimated using the phase 3A ANN**

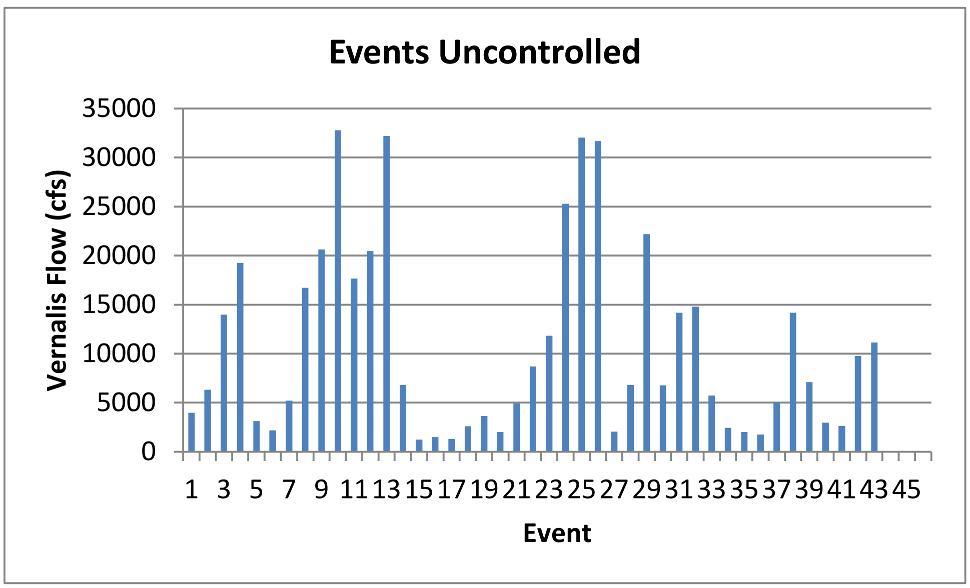

Figure 2-11 **Season mean of Vernalis flow for the uncontrolled events at ORB estimated using the phase 3A ANN**

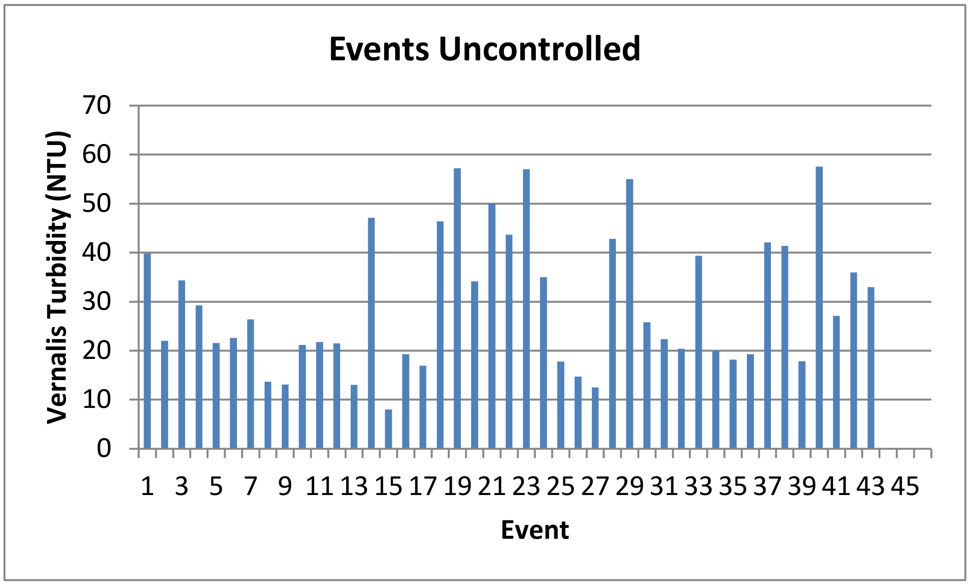

Figure 2-12 **Season mean of Vernalis turbidity for the uncontrolled events at ORB estimated using the phase 3A ANN**

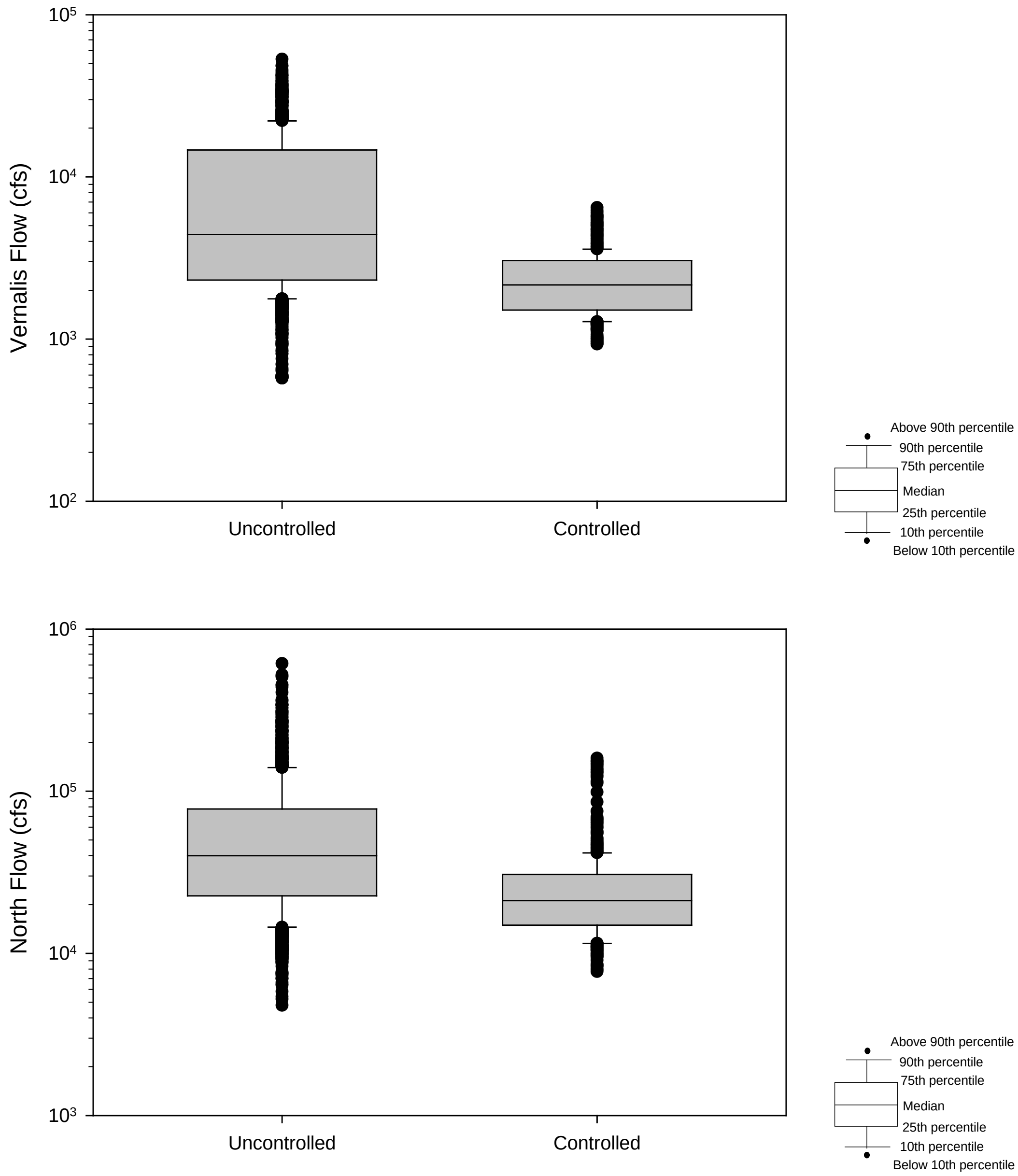

Figure 2-13 Vernalis and North Delta flow for controlled and un-controlled events.

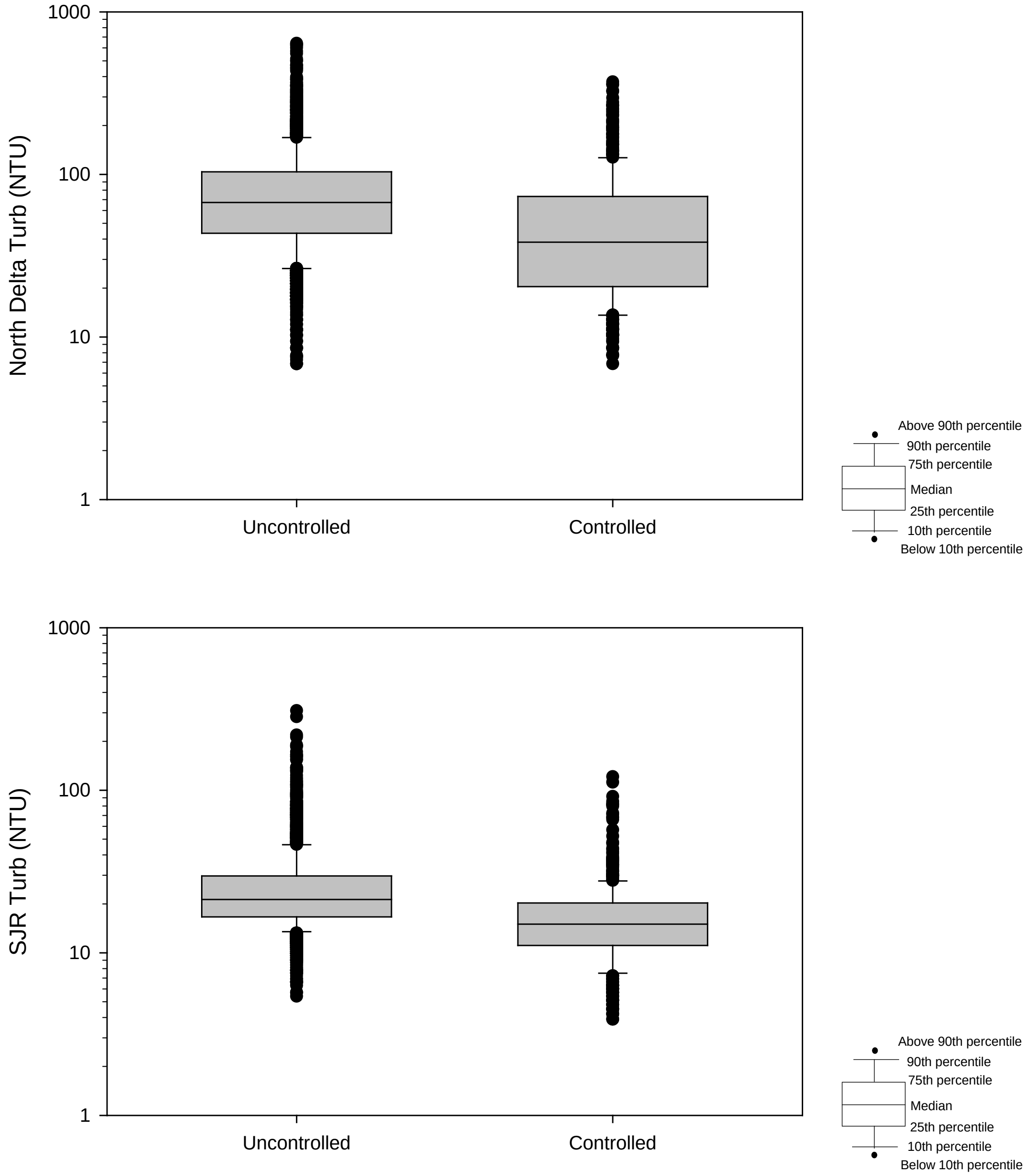

Figure 2-14 Box plots for North Delta and SJR turbidity for controlled and un-controlled events.

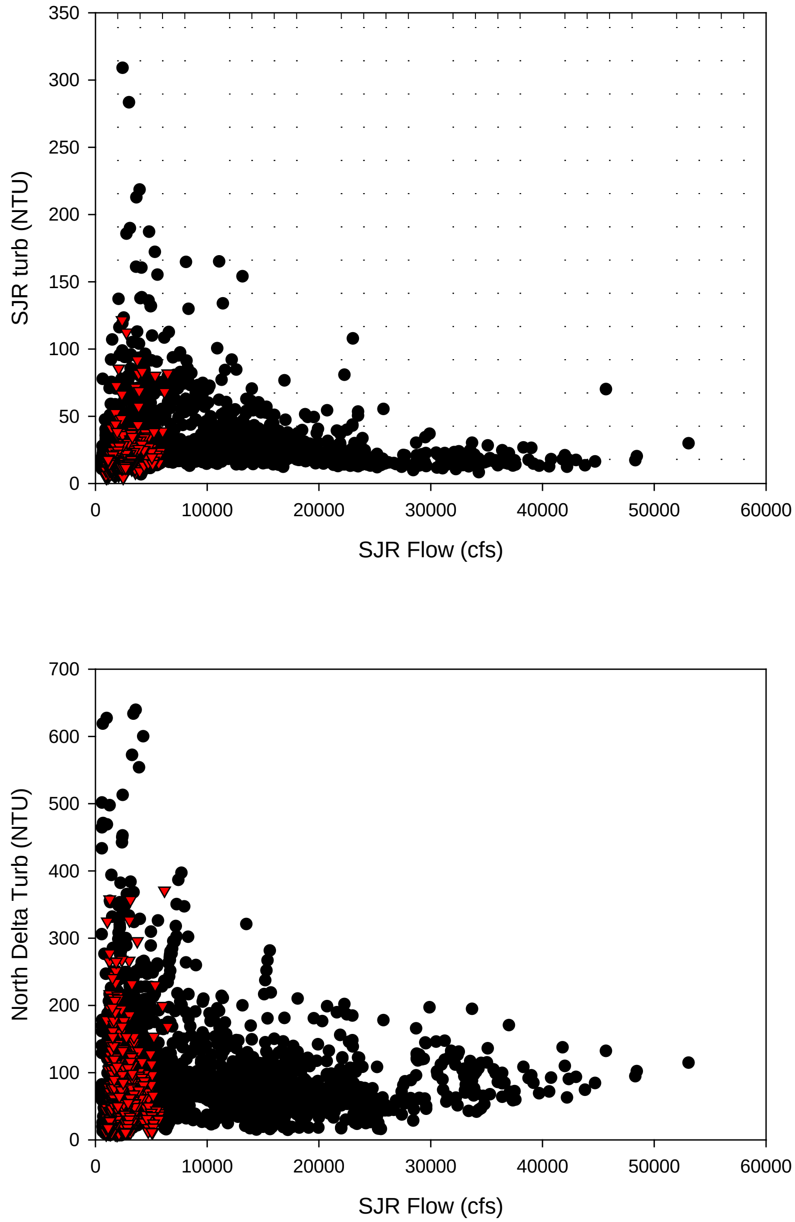

Figure 2-15 **Scatter plots of SJR flow and North Delta and SJR turbidity for controlled (red symbols) and non-controlled events (black symbols).**

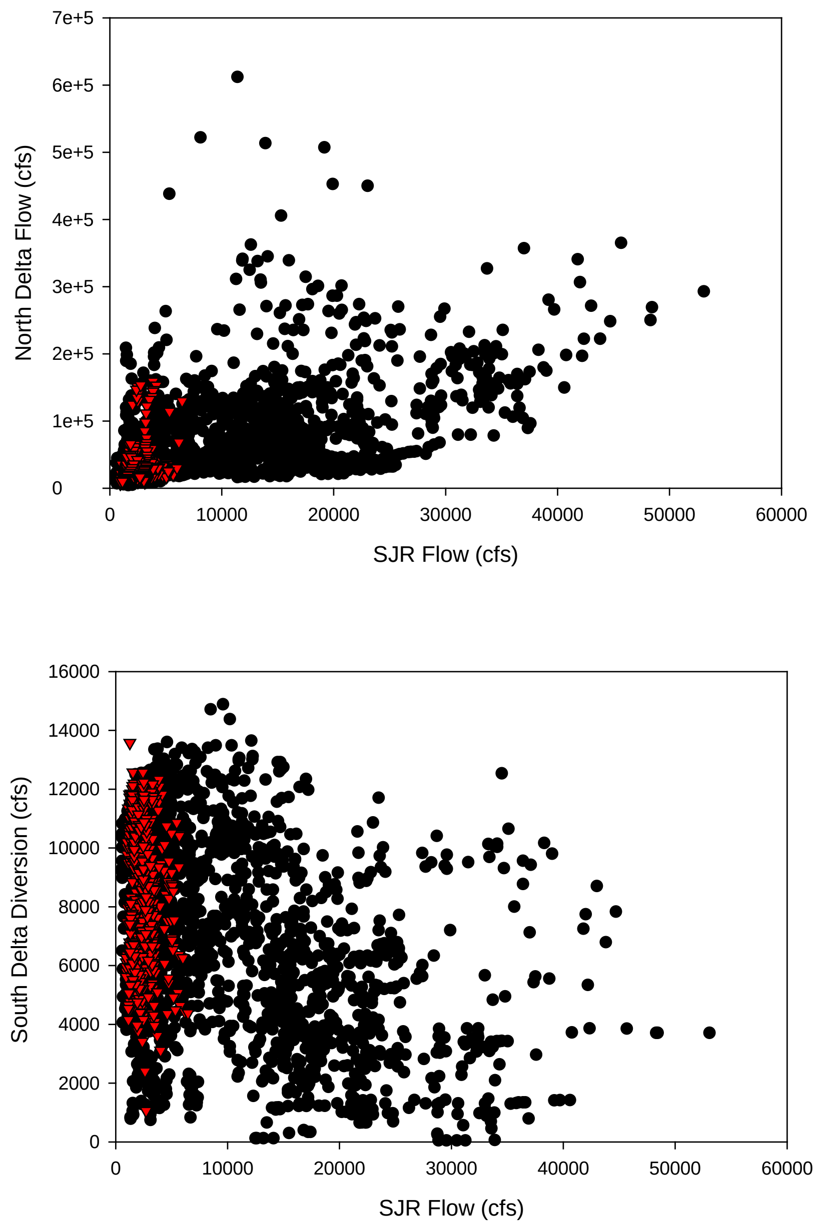

Figure 2-16 **Scatter plots of SJR flow and North Delta flow and South Delta diversions for controlled (red symbols) and non-controlled events (black symbols).**

3. TURBIDITY THRESHOLD RANGE DEFINITION

In the previous analysis of controllability of turbidity (Tetra Tech, 2014), and in Chapter 2, a specific turbidity threshold of 12 NTU was used in defining the exceedance threshold and compliance. An event was considered as non-controlled if the turbidity level exceeded 12.1 NTU. However, the turbidity levels to protect fish from salvage may be a range, rather than a specific value. Also, no model of the Delta has been shown to represent turbidity to this level of accuracy. In this part of the analysis, we broadened the definition of events and controllability by considering a range of turbidity of 12-15 NTU. Specifically two scenarios were evaluated: 1) the definition of an event considers a threshold of 12 NTU, but the compliance (the point where the event is considered as controlled) uses a threshold of 15 NTU; 2) the definition and compliance of an event both use a threshold of 15 NTU. In the first scenario, therefore, the starting and stopping conditions for an event are different (12 and 15 NTU), while in the second scenario, the starting and stopping conditions for an event are the same (15 NTU) but higher than shown in Chapter 2. The results from this updated analysis are presented in Table 3-1 and Table 3-2.

Using the Phase 3 model and 12 NTU as the definition for the start of an event, the total number of events defined (84 events, Table 3-2) was the same as in Table 4-1. However, by considering a controlled turbidity threshold of 15 NTU, the number of *controlled* events increased from 13 to 33. Because the OMR export cost is only counted when events are controlled, the total OMR export cost also increased from 1,695 TAF to 4,627 TAF.

By increasing the threshold of 12 NTU to 15 NTU for the event definition (Table 3-2), a total of 81 events were defined. Among the 81 events defined, a total of 23 events were controlled, considering a compliance (considered as controlled) threshold of 15 NTU. Total OMR export cost for the controlled events is 2,141 TAF. By considering a higher threshold of 15 NTU as the event definition, the total number of days with events also decreased from 1,631 days to 1,276 days.

The results suggested a higher threshold (15 NTU) for compliance (considered as controlled) increased the number of controlled events markedly. This is because a large number of days have turbidity levels between 12-15 NTU after OMR change.

Table 3-1
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for a compliance threshold of 15NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days (using threshold of 15 NTU)	Export Cost (TAF)
1	1/1/00	12/22/75	12	-69	-5506	7041	3504	7911	43	5	13	27467	401	22	0	237
2	1/12/77	1/16/77	1	-983	-4426	4894	1114	5588	16	3	14	8931	42	5	0	93
3	12/20/77	1/1/00	12	1836	-7423	9510	3906	9911	214	39	39	51854	1513	71	46	
4	1/14/79	1/28/79	1	3100	-276	3376	6761	3857	109	45	28	30867	1550	15	11	
5	2/24/79	1/1/00	2	5947	3624	2323	12140	2587	133	25	28	66652	5512	5	5	
6	12/28/79	1/16/80	12	1959	-3435	5761	4932	6521	116	25	33	68477	4373	20	3	
7	1/20/80	2/10/80	2	10630	4562	6103	20095	6618	111	16	30	67800	5538	22	13	
8	2/16/80	2/21/80	2	5336	-406	6667	12700	7246	190	64	41	125626	8940	6	2	
9	2/23/80	2/29/80	2	16037	13082	2955	27600	3138	116	30	19	193277	8879	7	1	
10	12/13/80	12/19/80	12	-43	-5114	6331	2710	7154	21	8	12	15100	273	7	0	126
11	1/30/81	1/1/00	2	1431	-5024	6520	3102	7246	177	9	20	26991	324	30	9	
12	1/1/00	1/8/82	12	656	-3321	4443	2315	5100	105	33	23	98620	4473	39	1	
13	1/10/82	1/1/00	2	1450	-4217	6844	5192	7406	72	18	26	76105	4864	50	15	
14	1/1/00	12/7/82	12	5766	-1778	7997	12574	8701	116	40	16	67405	7774	7	2	
15	12/9/82	12/13/82	12	8126	42	8540	16860	9238	63	13	14	40415	2532	5	0	91
16	12/30/82	1/7/83	12	10696	2463	8233	20256	8908	55	11	11	55098	3431	9	0	199
17	1/27/83	1/1/00	2	18730	9517	9279	31618	9638	81	32	18	148951	8590	33	5	
18	1/1/00	12/22/83	12	10069	6544	3525	19318	3955	76	22	18	94691	5554	22	0	154
19	12/24/83	12/27/83	12	7421	4231	3191	15325	3575	120	70	27	170563	15463	4	0	25
20	12/31/83	2/4/84	12	13891	9766	4124	24633	4380	52	11	12	72902	3884	36	0	93
21	1/1/00	12/29/84	12	737	-5748	7870	4652	8755	66	6	25	34572	1014	29	3	
22	2/14/85	2/23/85	2	143	-5599	7103	3069	7868	18	14	22	16771	415	10	0	169
23	12/4/85	12/18/85	12	784	-7321	8392	2345	9395	58	33	16	19042	516	15	1	
24	1/18/86	2/20/86	2	1096	-4878	6407	3098	7157	146	51	45	91953	5938	34	16	
25	2/23/86	1/1/00	2	11134	6699	4435	20533	4737	80	18	28	246846	12295	6	6	
26	1/14/87	1/16/87	1	388	-4642	5514	1990	6274	12	9	8	11758	479	3	0	102
27	2/9/87	1/1/00	2	678	-5129	6211	2243	7028	101	14	20	17731	417	20	3	
28	12/12/87	12/25/87	12	162	-8717	9200	1217	10403	86	9	8	16568	140	14	5	
29	1/9/88	2/4/88	2	330	-8493	9212	1532	10339	83	24	20	25868	300	27	6	
30	2/6/88	2/11/88	2	-839	-8581	9311	1463	10274	28	9	15	13183	178	6	0	96
31	1/1/00	12/7/88	12	-420	-6613	7230	1346	8098	11	3	11	10265	76	7	3	
32	12/31/88	1/5/89	12	499	-8576	9207	1372	10271	14	3	9	13242	118	6	0	190
33	1/17/90	1/28/90	1	198	-8786	9360	1288	10541	37	8	15	18542	221	12	1	
34	2/19/90	1/1/00	2	543	-8702	9486	1521	10573	15	28	32	13836	317	10	3	

Table 3-1 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for a compliance threshold of 15NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days (using threshold of 15 NTU)	Export Cost (TAF)
35	2/18/92	1/1/00	2	1261	-7884	9144	2823	10397	139	50	49	38581	1001	12	10	
36	12/17/92	12/26/92	12	355	-4686	5092	994	5882	17	8	5	10067	221	10	3	
37	1/6/93	1/1/00	2	952	-7576	9540	3780	10350	133	53	60	59036	2084	54	28	
38	12/23/93	12/27/93	12	538	-9390	10200	1662	11474	27	12	6	19725	383	5	0	111
39	1/28/94	1/30/94	1	590	-6161	6992	1860	7991	64	8	18	19458	293	3	0	95
40	2/2/94	1/1/00	2	349	-4302	5300	1988	5941	58	17	28	20650	457	27	3	
41	12/8/94	12/17/94	12	-99	-6601	7197	1297	8140	28	8	10	17265	392	10	0	151
42	12/26/94	1/1/00	12	811	-6837	9378	5087	10217	116	34	52	82287	2394	65	25	
43	12/21/95	1/12/96	12	468	-5383	6374	2143	7156	49	17	13	23430	494	23	0	298
44	1/21/96	1/1/00	2	4410	-2593	7121	8870	7394	214	36	44	96693	4491	40	30	
45	12/7/96	1/3/97	12	6421	435	6672	14310	7097	98	45	44	115999	10101	28	15	
46	1/6/97	1/12/97	1	25754	22502	3252	43901	4612	98	45	19	225110	15012	7	3	
47	1/14/97	1/25/97	1	16892	15237	1655	29126	1760	124	34	17	126591	11076	12	0	39
48	1/28/97	1/1/00	2	19426	17684	1742	32436	1582	77	15	14	91779	8235	32	0	111
49	12/2/97	12/29/97	12	255	-8921	9839	2049	11056	54	9	12	22733	736	28	1	
50	1/13/98	2/5/98	2	3280	-464	4583	8570	4704	150	53	55	128170	4485	24	10	
51	2/8/98	2/16/98	2	18382	14819	3563	31226	3154	132	36	31	229246	11484	9	5	
52	2/20/98	1/1/00	2	18504	16167	2337	31446	2309	112	30	16	181788	7659	9	0	42
53	12/30/98	1/1/99	12	1077	-180	1753	3456	2188	19	10	8	22577	789	3	0	25
54	1/25/99	2/6/99	2	3170	-1360	4530	6841	5058	52	20	28	49664	2137	13	8	
55	2/12/99	2/25/99	2	6785	1944	4841	13759	5062	52	29	27	113209	6816	14	8	
56	1/25/00	1/1/00	2	1654	-7713	10489	5934	11461	97	43	40	83722	3850	35	18	
57	1/22/01	1/26/01	1	-1064	-6371	7531	2423	8471	18	6	11	13963	524	5	0	112
58	2/4/01	2/10/01	2	375	-6223	7424	2398	8285	27	6	12	13362	456	7	0	155
59	2/22/01	1/1/00	2	1272	-6733	8729	3949	9316	117	41	30	33381	1107	7	0	165
60	12/3/01	2/1/02	12	514	-8220	9311	2409	10417	108	17	19	35871	643	61	17	
61	12/19/02	1/1/00	12	168	-8246	9159	2036	10342	124	10	21	47720	569	72	21	
62	12/15/03	1/1/00	12	340	-8832	9602	1755	10818	112	17	19	48276	803	77	4	
63	12/19/04	12/24/04	12	503	-8619	9312	1567	10443	15	8	11	13308	360	6	0	179
64	1/2/05	1/29/05	1	1032	-8647	11011	4991	12068	96	34	53	33424	1475	28	17	
65	1/31/05	1/1/00	2	1162	-5919	8431	5187	9125	61	18	34	24457	1405	29	8	
66	12/10/05	12/14/05	12	861	-8900	9889	2086	11058	44	7	11	15704	443	5	2	
67	12/16/05	12/22/05	12	150	-8132	9090	2111	10193	71	7	12	19474	665	7	2	
68	12/24/05	1/17/06	12	5030	-2705	8859	12574	9646	109	42	41	168574	6558	25	14	
69	1/26/06	1/1/00	2	415	-4747	7933	6890	8785	65	9	18	53822	2727	34	0	418

Table 3-1 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for a compliance threshold of 15NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days (using threshold of 15 NTU)	Export Cost (TAF)
70	1/1/00	12/27/06	12	541	-8509	9538	2275	10674	43	14	6	16256	590	27	1	
71	1/4/07	1/12/07	1	969	-6906	7992	2490	8909	16	9	5	16565	692	9	3	
72	1/24/07	2/23/07	2	370	-5020	6155	2447	6920	66	8	9	19576	761	31	0	419
73	1/1/00	12/8/07	12	78	-5579	6119	1375	7002	45	4	12	10791	277	8	0	90
74	12/11/07	12/22/07	12	-349	-6247	6765	1471	7767	40	5	13	12536	325	12	0	154
75	1/9/08	1/12/08	1	-1079	-3395	4261	2149	5071	31	21	54	28437	564	4	0	57
76	1/14/08	1/17/08	1	-180	-4030	4587	1707	5360	32	15	24	21887	427	4	1	
77	1/24/08	1/30/08	1	928	-4389	5681	3031	6307	43	38	79	26821	803	7	1	
78	2/1/08	2/3/08	2	-1919	-5414	7064	3716	8089	34	42	48	51534	721	3	0	21
79	2/5/08	2/8/08	2	1362	-4993	6355	2910	7050	13	45	31	37629	817	4	4	
80	2/24/09	1/1/00	2	700	-4363	5110	1723	5860	150	38	19	37940	1512	5	0	91
81	1/21/10	1/1/00	2	596	-4816	6106	2688	6879	76	29	27	35735	835	39	6	
82	12/6/10	12/16/10	12	-739	-7480	9441	4752	10566	34	16	21	27753	1493	11	0	241
83	12/19/10	1/11/11	12	4033	-5374	10915	11802	11898	29	34	33	60152	5128	24	21	
84	2/23/11	2/25/11	2	742	-2425	7870	11768	8712	32	34	23	31624	1411	3	0	78
85	1/1/00	12/22/75	12	-69	-5506	7041	3504	7911	43	5	13	27467	401	22	0	237
Total														**1631**	**449**	**4627**

Table 3-2
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for an event definition threshold of 15 NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
1	12/2/75	12/5/75	12	219	-5406	6881	3355	7767	42	5	17	27955	420	4	0	46
2	12/11/75	12/20/75	12	-173	-5773	7352	3563	8236	34	5	11	26757	395	10	0	129
3	12/20/77	1/1/00	12	1731	-7423	9510	3906	9911	214	39	39	51854	1513	71	46	
4	1/15/79	1/19/79	1	3127	-787	3914	6886	4450	207	83	38	44263	2681	5	3	
5	1/21/79	1/28/79	1	2018	-1	2973	6550	3418	49	19	21	21514	790	8	5	
6	2/24/79	1/1/00	2	5947	3624	2323	12140	2587	133	25	28	66652	5512	5	5	
7	12/30/79	1/16/80	12	1938	-3373	5798	5143	6559	112	27	35	70706	4790	18	2	
8	1/20/80	2/2/80	2	11066	5635	5862	21321	6414	124	21	35	88139	7014	14	13	
9	2/17/80	2/21/80	2	6508	-55	6563	13140	7133	217	70	46	144391	10058	5	2	
10	2/23/80	2/25/80	2	12129	9828	2958	22733	3169	143	43	21	250430	11207	3	1	
11	12/14/80	12/18/80	12	-838	-5338	6522	2714	7355	19	8	12	14934	271	5	0	100
12	1/30/81	1/1/00	2	1274	-5024	6520	3102	7246	177	9	20	26991	324	30	9	
13	1/1/00	1/5/82	12	521	-3545	4466	1963	5129	106	30	17	94762	3777	36	0	290
14	1/10/82	1/12/82	1	2177	-2406	4590	5067	5177	65	22	32	92483	5183	3	3	
15	1/14/82	1/1/00	2	885	-4380	7059	5234	7620	72	18	26	75005	4853	46	12	
16	1/1/00	12/7/82	12	579	-1778	7997	12574	8701	116	40	16	67405	7774	7	0	33
17	12/10/82	12/12/82	12	948	-219	8870	16867	9587	61	14	13	40201	2432	3	0	7
18	12/30/82	1/5/83	12	6116	3105	8086	20971	8769	58	12	11	58962	3878	7	0	4
19	1/29/83	2/3/83	2	17541	11415	9636	35233	10111	114	46	26	190394	9790	6	3	
20	1/1/00	12/28/84	12	305	-5887	7989	4619	8887	67	6	25	35023	1017	28	3	
21	2/18/85	2/22/85	2	-153	-5355	6660	2732	7390	15	11	22	16270	406	5	1	
22	12/4/85	12/17/85	12	484	-7325	8416	2381	9423	61	35	17	19529	529	14	1	
23	1/18/86	1/22/86	1	28	-7476	8515	2160	9510	160	48	22	31181	1153	5	2	
24	1/24/86	2/20/86	2	1196	-4309	5944	3303	6638	146	53	50	105106	6976	28	13	
25	2/23/86	1/1/00	2	11134	6699	4435	20533	4737	80	18	28	246846	12295	6	6	
26	2/10/87	2/12/87	2	720	-5439	6159	1427	7032	33	7	14	12349	272	3	0	10
27	2/14/87	1/1/00	2	1132	-4945	6142	2499	6935	122	15	20	19236	404	15	3	
28	12/13/87	12/25/87	12	76	-8795	9276	1211	10492	87	9	8	15725	138	13	5	
29	1/9/88	2/3/88	2	-161	-8491	9207	1532	10338	85	25	20	26232	304	26	7	
30	1/1/00	12/7/88	12	-349	-6613	7230	1346	8098	11	3	11	10265	76	7	3	
31	1/17/90	1/27/90	1	1	-8795	9375	1295	10562	39	8	15	19161	226	11	1	
32	2/19/90	1/1/00	2	4	-8702	9486	1521	10573	15	28	32	13836	317	10	2	
33	2/19/92	1/1/00	2	1152	-7980	9132	2615	10392	136	49	46	37882	1009	11	10	
34	12/17/92	12/25/92	12	249	-4686	5101	999	5892	18	8	5	10295	222	9	3	
35	1/6/93	1/1/00	2	887	-7576	9540	3780	10350	133	53	60	59036	2084	54	31	

Table 3-2 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for an event definition threshold of 15 NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
36	2/3/94	2/8/94	2	482	-4009	4807	1555	5492	44	14	14	13720	350	6	0	81
37	2/11/94	2/26/94	2	508	-4330	5408	2182	6062	62	19	34	22640	513	16	3	
38	12/9/94	12/16/94	12	-494	-6279	6881	1296	7797	25	7	10	16238	389	8	0	127
39	12/27/94	1/1/00	12	345	-6809	9382	5146	10217	117	35	53	83365	2424	64	25	
40	12/22/95	1/9/96	12	-508	-5055	6062	2177	6834	51	17	13	23619	506	19	0	200
41	1/21/96	2/26/96	2	3833	-3103	7349	8319	7630	225	38	46	94779	4296	37	28	
42	12/7/96	1/2/97	12	6130	260	6724	14103	7168	97	44	44	103512	9416	27	15	
43	1/6/97	1/9/97	1	27950	25903	2437	48042	3749	100	50	21	259068	15406	4	3	
44	12/3/97	12/28/97	12	-271	-8906	9828	2056	11039	54	9	12	22762	745	26	3	
45	1/14/98	1/26/98	1	3719	-81	3931	8184	4229	157	51	50	115807	3561	13	8	
46	2/3/98	2/5/98	2	7113	3047	4066	13714	3004	191	100	132	222803	12026	3	2	
47	2/8/98	2/13/98	2	16984	13682	3739	29571	3016	143	37	38	241134	12211	6	5	
48	1/25/99	2/2/99	2	3371	-1285	4657	7261	5241	57	24	32	55948	2300	9	8	
49	2/13/99	2/20/99	2	6489	2014	4662	13565	4817	54	31	27	105834	7052	8	7	
50	1/25/00	1/1/00	2	1383	-7713	10489	5934	11461	97	43	40	83722	3850	35	19	
51	2/5/01	2/9/01	2	-832	-6232	7445	2388	8303	26	6	13	13184	456	5	0	115
52	2/26/01	1/1/00	2	597	-7403	9804	4814	10373	148	52	36	37237	1020	3	0	77
53	12/6/01	1/24/02	12	442	-8430	9579	2534	10698	116	19	22	38693	664	50	17	
54	1/27/02	1/31/02	1	-447	-9541	10331	1758	11630	22	7	7	20222	573	5	3	
55	12/19/02	1/1/00	12	-78	-8246	9159	2036	10342	124	10	21	47720	569	72	22	
56	12/16/03	2/2/04	12	-69	-9147	9817	1636	11125	105	10	15	37065	642	49	5	
57	2/8/04	1/1/00	2	164	-8630	9648	2078	10704	126	33	31	78030	1179	22	4	
58	12/19/04	12/23/04	12	-1307	-8707	9379	1578	10506	15	8	12	13555	361	5	0	135
59	1/2/05	1/28/05	1	821	-8605	11013	5071	12064	96	34	54	33762	1462	27	16	
60	1/31/05	2/13/05	2	643	-5957	7865	4078	8655	84	15	27	24959	976	14	5	
61	2/19/05	2/24/05	2	1315	-5080	8756	7091	9077	37	28	56	24814	2176	6	2	
62	2/26/05	1/1/00	2	2024	-5620	9570	8199	10432	58	20	32	28638	1765	3	2	
63	12/11/05	12/14/05	12	-230	-8855	9877	2081	11061	45	7	11	15498	440	4	0	160
64	12/24/05	1/16/06	12	4530	-2874	8978	12446	9751	111	43	42	170788	6626	24	15	
65	1/28/06	1/1/00	2	-770	-4942	8073	6781	8927	64	9	18	53782	2636	32	0	2
66	12/2/06	12/18/06	12	-586	-8039	9027	2174	10113	53	12	7	15721	563	17	0	2
67	12/20/06	12/22/06	12	265	-9735	10837	2433	12186	13	23	5	18185	653	3	0	2
68	1/5/07	1/11/07	1	901	-6742	7828	2486	8727	15	9	5	16751	724	7	0	2
69	1/26/07	1/30/07	1	761	-4789	5932	2468	6724	55	9	5	11117	525	5	0	93
70	2/1/07	2/21/07	2	-213	-4909	6049	2449	6794	68	7	11	22658	853	21	0	199

Table 3-2 (continued)
Phase 3 ANN simulated non-compliance events at the ORB for the period of 1975- 2011 and the required changes in OMR, for an event definition threshold of 15 NTU

Event	Start Date	End Date	Month	OMR final (cfs)	OMR original (cfs)	Allowed OMR change (cfs)	Vernalis flow (cfs)	South Delta diversions (cfs)	North Delta turbidity (NTU)	East side turbidity (NTU)	Vernalis Turbidity (NTU)	North Delta inflow (cfs)	East side stream flow (cfs)	Duration of event	Non achievable days	Export Cost (TAF)
71	1/1/00	12/4/07	12	-1646	-5146	5580	1395	6474	42	4	9	10004	263	4	0	28
72	12/12/07	12/14/07	12	-3356	-6189	6694	1480	7701	46	5	13	13148	289	3	0	43
73	1/14/08	1/16/08	1	-112	-4036	4633	1749	5385	33	16	25	22851	433	3	1	
74	1/27/08	1/30/08	1	1752	-3369	5121	4003	5758	43	43	103	34049	925	4	1	
75	2/1/08	2/3/08	2	-3247	-5414	7064	3716	8089	34	42	48	51534	721	3	0	13
76	2/5/08	2/8/08	2	1362	-4993	6355	2910	7050	13	45	31	37629	817	4	4	
77	2/25/09	1/1/00	2	423	-4412	5144	1707	5889	142	41	19	40224	1558	4	0	81
78	1/21/10	1/25/10	1	916	-4178	5649	3085	6100	102	66	79	46690	1245	5	1	
79	1/27/10	1/1/00	2	-84	-4999	6239	2573	7062	73	23	19	33438	773	33	5	
80	12/6/10	12/10/10	12	9	-7491	9625	5041	10731	35	18	26	24119	1198	5	0	164
81	12/21/10	1/11/11	12	4192	-5183	11003	12347	11983	29	31	32	60485	4851	22	19	
Total														**1276**	**443**	**2141**

4. SYNTHETIC TURBIDITY/SMELT SALVAGE DATA EVALUATION

The development of a synthetic turbidity data set in the Delta over more than three decades, as presented here, allows exploration of the relationship between synthetic turbidity at any station (Holland Cut, Prisoners Point, Victoria Canal, and Old River at Bacon in particular) and the observed salvage of Delta smelt for which data were available from 1981-2012.[2] Note that longer term tow-net surveys for Delta smelt have been reported, with data reaching back to 1959 (Moyle et al., 2008; Nobriga et al., 2008), but these data were not available for the present analysis. Also, the synthetic turbidity in this study reached back to 1975, and not to the early part of the smelt abundance observations.

This chapter relates the two variables (turbidity and smelt salvage) as a complement to the overall turbidity analysis. It does not address other variables, such as salinity or temperature, that may also have an effect of smelt salvage. Finally, the evaluation of controllability of turbidity, as presented in Chapter 2 and 3, is not addressed in the context of the salvage data.

The direct use the simulated turbidity series to predict combined SWP and CVP salvage yields imprecise estimates. A log-linear model of the turbidity data against a 10-day moving total only gives an r^2 value of about 0.19. A tabular evaluation of the event based data shows the substantial variability in the relationship between the turbidity input and the smelt salvage output. However, there does appear to be some association with high simulated turbidity and high salvage counts, and one way to quantify this is by converting the data into binary outcomes: are the turbidity values high in the sense of being above some specified threshold? Similarly, is the salvage over the following 10 days high? We used logistic regression, a generalized linear model for binary outcomes described by the equation

$$E[Y|X] = \text{logit}^{-1}(\beta \cdot X) = \frac{1}{1 + \exp(-\beta \cdot X)}$$

to estimate the probability of high salvage associated with high turbidity. Y is the binary outcome of cumulative smelt salvage over the following k days exceeding some predefined threshold. The explanatory variables X are the binary (besides the intercept for the linear predictor) indicators of whether each of the turbidity series exceeds a predefined threshold. Only data from December, January, and February (DJF) were used, similar to that used to characterize turbidity events in Chapter 2.

Figure 4-1 shows the distribution of the k-day salvage sums and the selection of 300 as the threshold for constructing Y. The selection of k and the salvage threshold was arbitrary, but repeating the analysis with other reasonable values didn't substantially change the results.

[2] Data provided by Metropolitan Water District of Southern California to authors.

Figures Figure 4-2 to Figure 4-4 illustrate the binary inputs (partitioned by the vertical line) and outcomes (partitioned by the horizontal line) for three different turbidity thresholds given in Table 4-1. Table 4-1 also shows the regression estimates for each of these models and a comparison between the high and low turbidity cases of the estimated probability for a large *k*-day salvage count. P_{over} is the estimated probability for affirmative outcome (cumulative salvage over threshold) given affirmative inputs (all turbidity over threshold). P_{under} is the estimated probability for affirmative outcome given negative (all turbidity under threshold) inputs. Thus, according to the estimates in Table 4-1, for a 10-day period, with turbidity exceeding 12 NTU at the four stations, there is a 76% probability that the smelt salvage will exceed the 300 count. This decreases to 51% for a 5 NTU threshold and increases to 78% for a 15 NTU threshold.

The behavior of the DJF data over time is illustrated in Figure 4-5. Monthly values (averages for turbidity and totals for salvage) were calculated when at least 50% of the data were not specified as “NaN.” NaNs accounting for less than 50% of the days in a month were replaced by zeroes. The maximum values for each quantity occurred in the early part of the dataset, but the next several order statistics occur both before and after 2000.

In addition to the overall analysis, an event-by-event summary of the compliance station turbidity, major inflows, and smelt salvage, showing the complexity of the relationships, is presented in Appendix C.

Taken together, this analysis provides some support the relationship between smelt salvage and turbidity at the selected compliance stations for a roughly three-decade period. For all three thresholds, the probability of a high salvage count increases with high turbidity. However, there are other factors at play in high salvage events because there are non-negligible probabilities of low salvage under high turbidity and high salvage under low turbidity. Future work may consider the simultaneous effects of additional variables besides turbidity to more fully characterize smelt salvage.

Table 4-1
Logistic Regression Summary, showing width of the window for salvage accumulation, *k*, the thresholds for logistic regression, and the estimated coefficients (standard errors in parentheses). P_{over} is the estimated probability for affirmative (cumulative salvage over threshold) outcome given affirmative (all turbidity over threshold) inputs. P_{under} is the estimated probability for affirmative outcome given negative (all turbidity under threshold) inputs.

Model	k	NTU Threshold	Salvage Threshold	Intercept	Prisoner's Point	Victoria	Bacon Island	Holland	P_{over}	P_{under}
1	10	12	300	-1.88 (0.08)	+0.13 (0.17)	+1.67 (0.15)	+1.40 (0.39)	-0.17 (0.40)	0.76	0.13
2	10	5	300	-2.91 (0.18)	0.84 (0.22)	1.29 (0.11)	0.21 (0.48)	0.61 (0.53)	0.51	0.05
3	10	15	300	-1.76 (0.07)	+0.86 (0.16)	+1.19 (0.17)	+1.15 (0.40)	-0.15 (0.40)	0.78	0.15

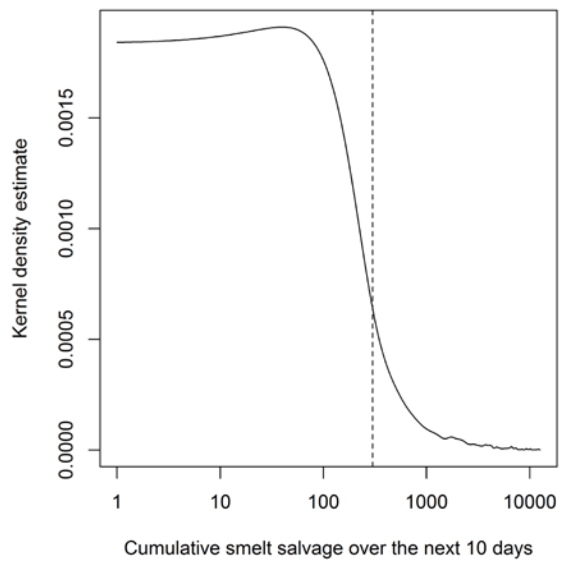

Figure 4-1 Density estimate of 10-day moving window sum of smelt salvage (CVP + SWP)

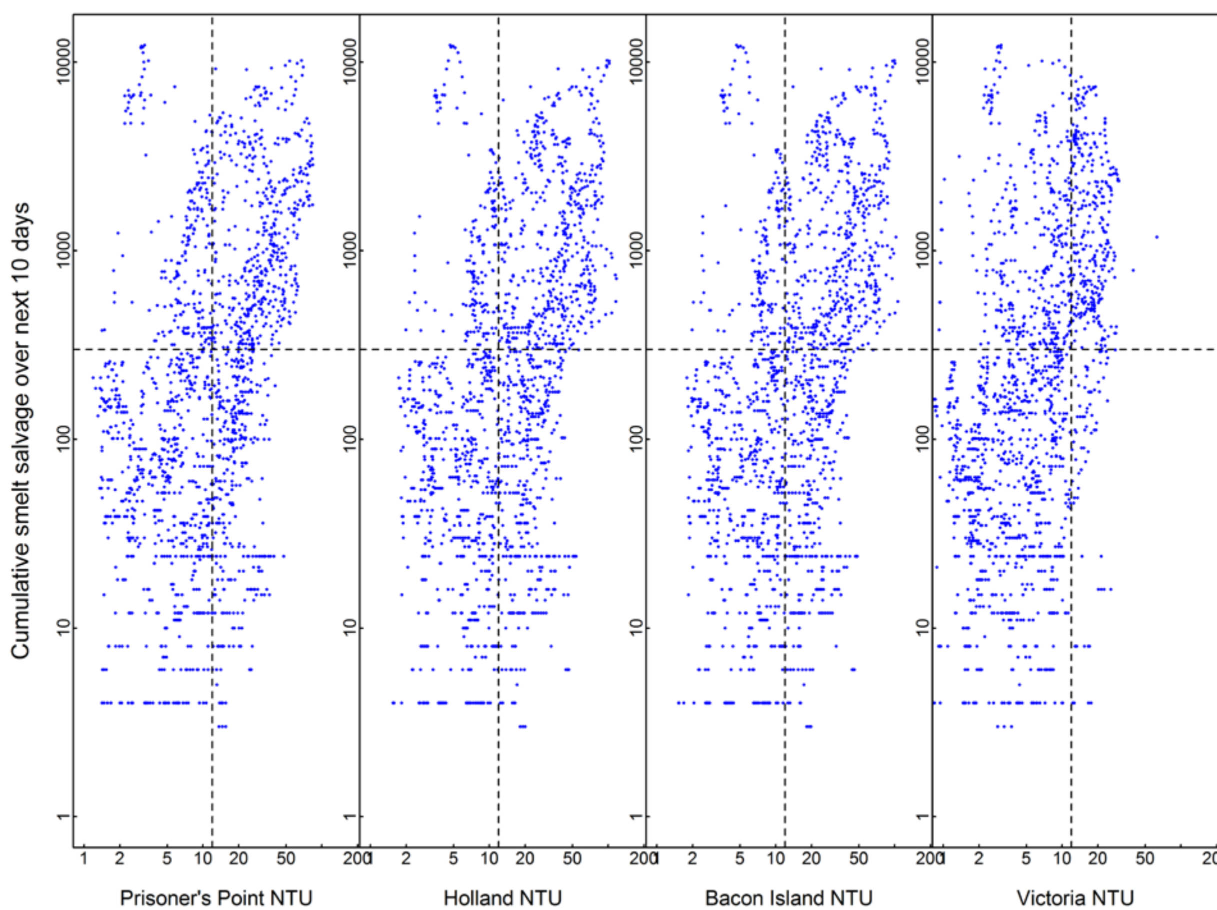

Figure 4-2 Categories for Logistic Model 1

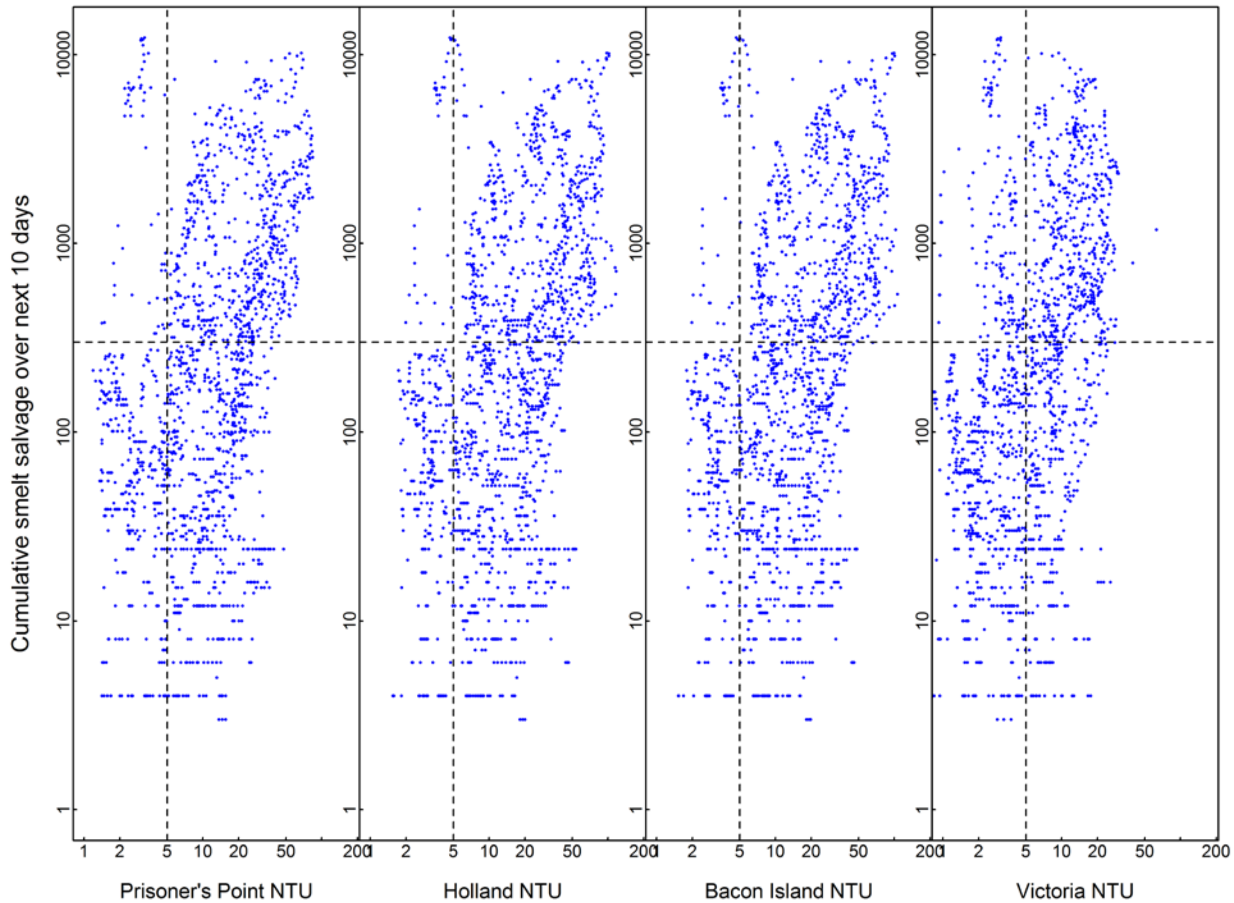

Figure 4-3 **Categories for Logistic Model 2**

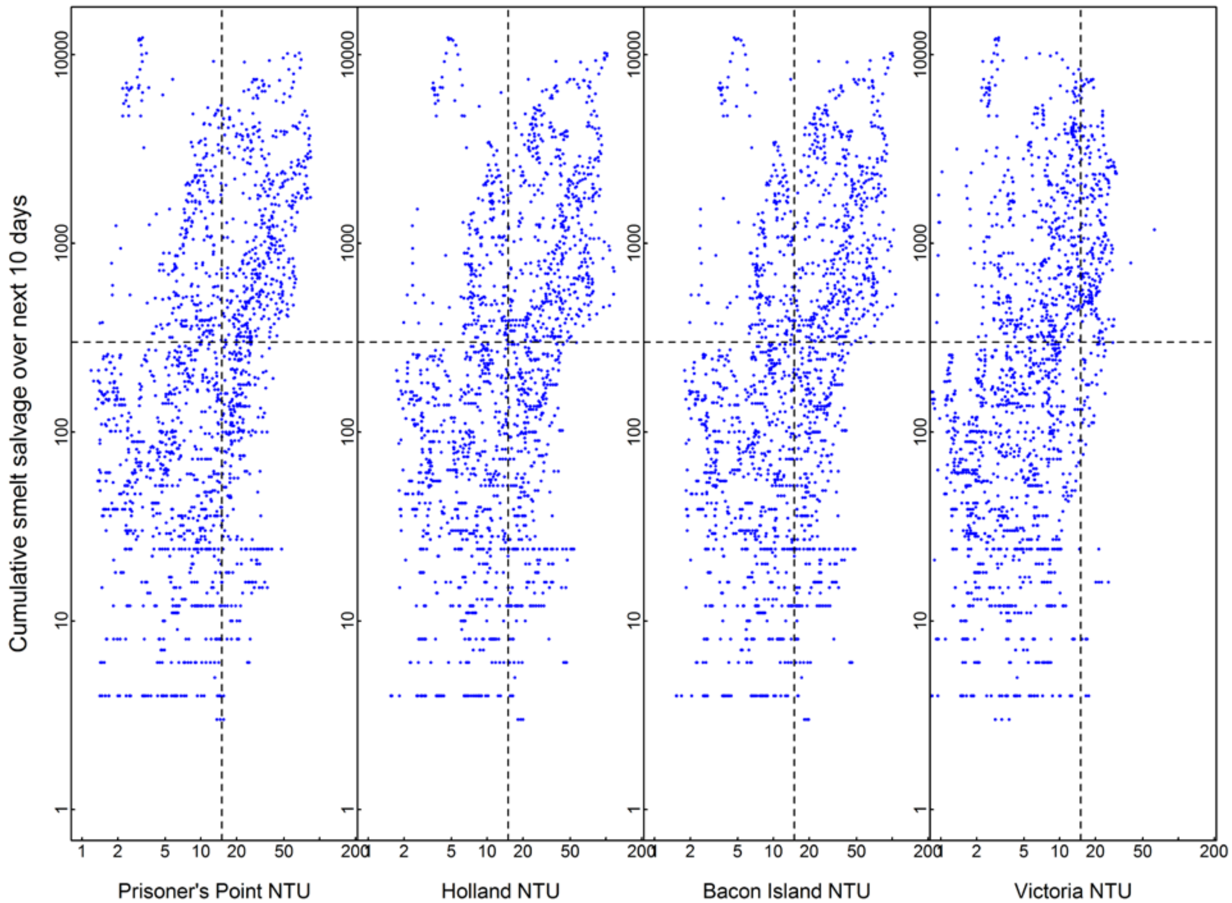

Figure 4-4 Categories for Logistic Model 3

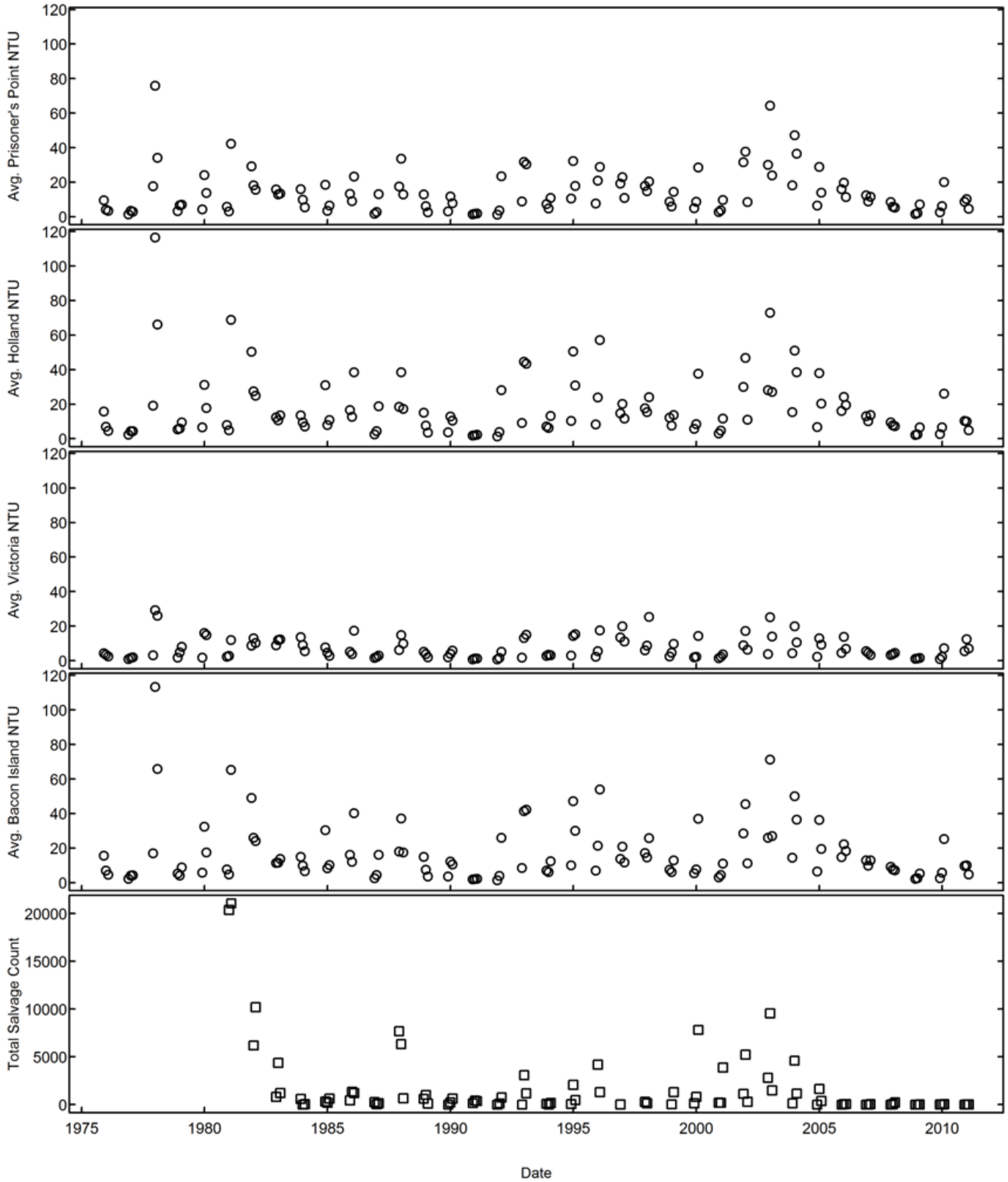

Figure 4-5 **December, January, and February monthly average turbidities and monthly total CVP + SWP salvage counts**

5. CONCLUSIONS

This study built on the ANN emulation of a first order turbidity decay model within DSM2 to estimate the controllability of turbidity by manipulation of the OMR flows. Two different ANNs were used (labeled Phase 3 and Phase 3A) that differed in the flow and turbidity data sets used for training. In the Phase 3 ANN, the training was performed using DSM2 values, where the inputs to DSM2 were a range of synthetic flows and turbidity values. In the Phase 3A ANN, the training data set differed in that the inputs to DSM2 were historical flows and estimated turbidity values. Given the challenge of forecasting turbidity in the Delta, both trained ANNs have relative advantages. Thus, the Phase 3 ANN benefits from a broader training data range, whereas the Phase 3A ANN follows the historical data more closely, and matches it better. For the purpose of the controllability analysis presented here, both ANNs may be considered to provide useful information.

Key results from both ANNs, given a turbidity compliance threshold of 12 NTU at the Old River at Bacon Station, are as follows:

- Phase 3 ANN: 84 high turbidity events, 13 events controlled. There were a total of 1,631 days with high turbidity over 1975-2011, of which 854 days were not controlled (52.4%). Adding the export cost over the controlled events, the water cost was 1,695 TAF over this period.

- Phase 3A ANN: 81 high turbidity events, 38 events controlled. There were a total of 1,471 days with high turbidity over 1975-2011, of which 520 days were not controlled (35.4%). Adding the export cost over the controlled events, the water cost was 3,950 TAF over this period. The water cost was larger because the number controlled days was larger than for the Phase 3 ANN.

The two ANNs differ in the predictions of controllability, and suggest that somewhere between a half to one-third of the events cannot be controlled. The individual controlled and uncontrolled events may be related to the corresponding flows and turbidities in the major inflows from Vernalis in the south and from the North Delta (Yolo Bypass and Sacramento River flows). Controlled events were associated with relatively lower flows and turbidities from the south and north. High flows and/or high turbidities resulted in turbidity conditions that were usually not controllable. When flows from the north were high but from the south were low, the events were partially controllable.

Other modifications that can be made to the calculation are the use a different turbidity threshold instead of 12 NTU or the use of different starting and stopping criteria for defining an event. Two scenarios were evaluated:

- Using the Phase 3 ANN model and 12 NTU as the definition for the start of an event, the total number of events defined (84 events) was the same. However, by considering a controlled turbidity threshold of 15 NTU, the number of controlled events increased from 13 to 33.

- By increasing the threshold of 12 NTU to 15 NTU for the event definition, a total of 81 events were defined. Among the 81 events defined, a total of 23 events were controlled, considering a compliance (considered as controlled) threshold of 15 NTU.

The results suggested a higher threshold (15 NTU) for compliance (considered as controlled) increased the number of controlled events markedly. This is because a large number of days have turbidity levels between 12-15 NTU after OMR change. The 15 NTU number used in this analysis is illustrative, and other ranges may be considered, as determined by the biological response of the Delta smelt.

Supporting analyses were also considered using the synthetic turbidity data and observed smelt salvage data from 1981 to 2012. The analysis focused on the role of turbidity and not of other water quality parameters such as salinity or temperature that may also be important. The direct relationship between salvage and antecedent turbidity was noisy, although a threshold-based statistical formulation showed that instances of higher salvage were more likely to be associated with higher turbidity conditions. Importantly, other long term data for smelt show that the highest abundances occurred before the time period of the present dataset (Nobriga et al., 2008) and may need to be considered in future analysis.

Overall, the analyses presented in this report provide insight into the significance of turbidity for smelt salvage the potential controllability of this parameter through OMR flow adjustment. Although the exact amount of control (number of days and volume of water cost) is dependent on the ANN assumptions and the thresholds considered, the calculations suggest that turbidity at the Old River at Bacon station is somewhat controllable, under a specific subset of flow and turbidity conditions at the Delta boundaries. Similarly, the turbidity is uncontrollable under certain flow conditions, no matter what level of OMR flow control is attempted. These results can serve as a guide for additional refined modeling to further elucidate mechanisms and determine the best strategies for responding to high turbidity events in the Delta.

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Sommer, T., Mejia, F. H., Nobriga, M. L., Feyrer, F., & Grimaldo, L. 2011. The spawning migration of delta smelt in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science, 9(2).

Appendix A. Comparison of DSM2 and ANN-simulated turbidity at ORB by Phase 3 ANN model and Phase 3A model

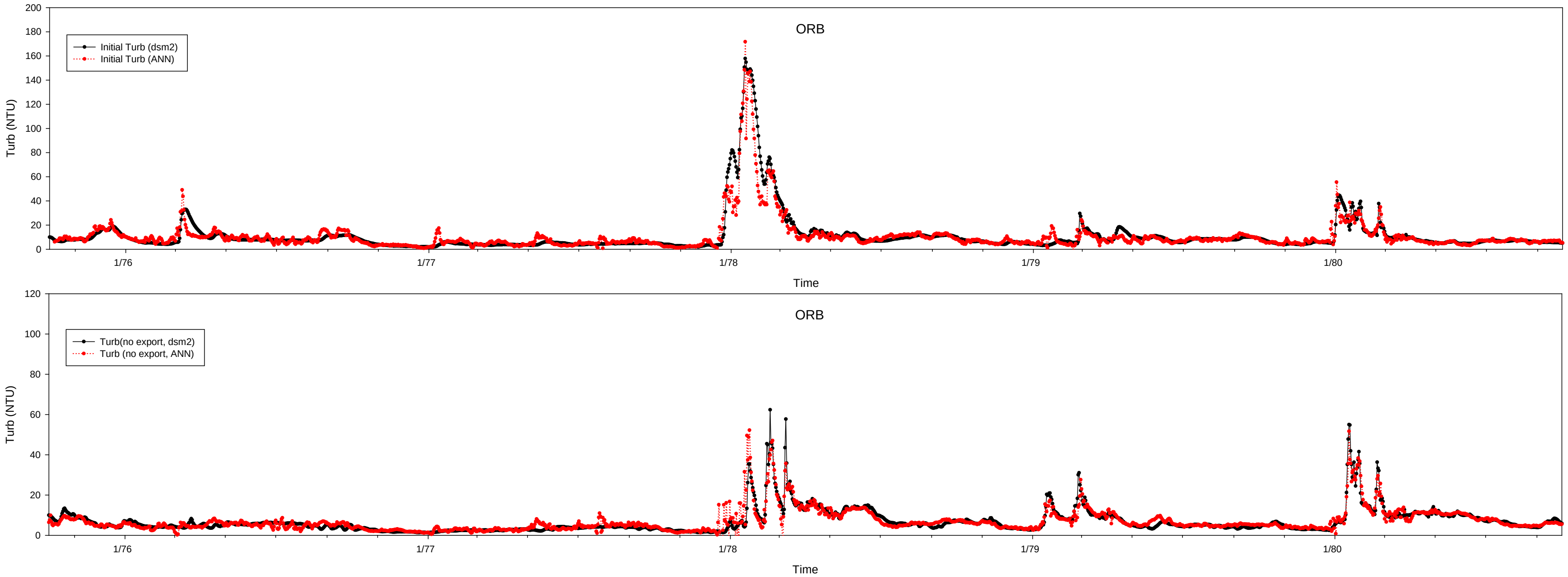
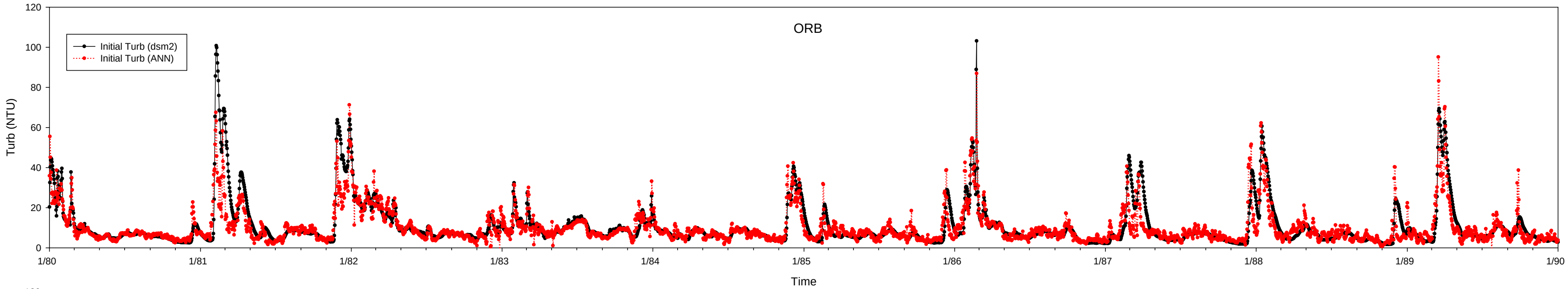


Figure A-1 Comparison of ANN (Phase3A) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.



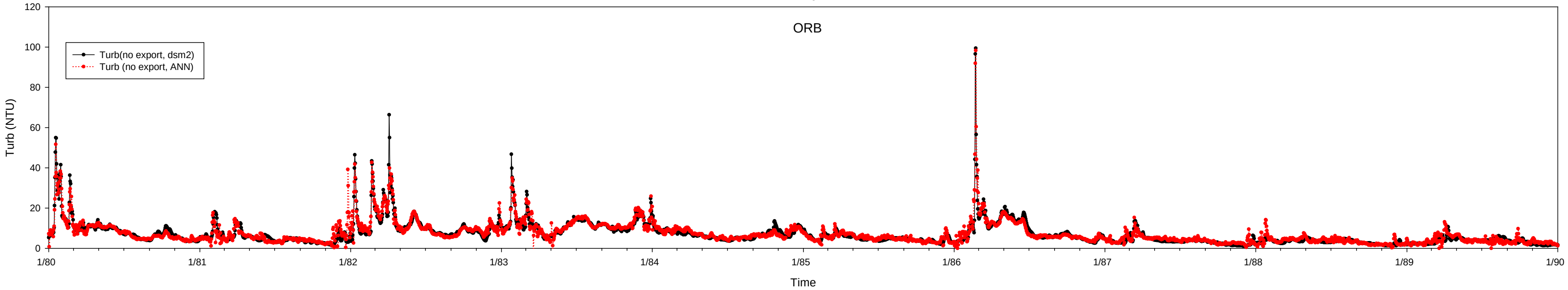


Figure A-1 (cont.) Comparison of ANN (Phase3A) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.

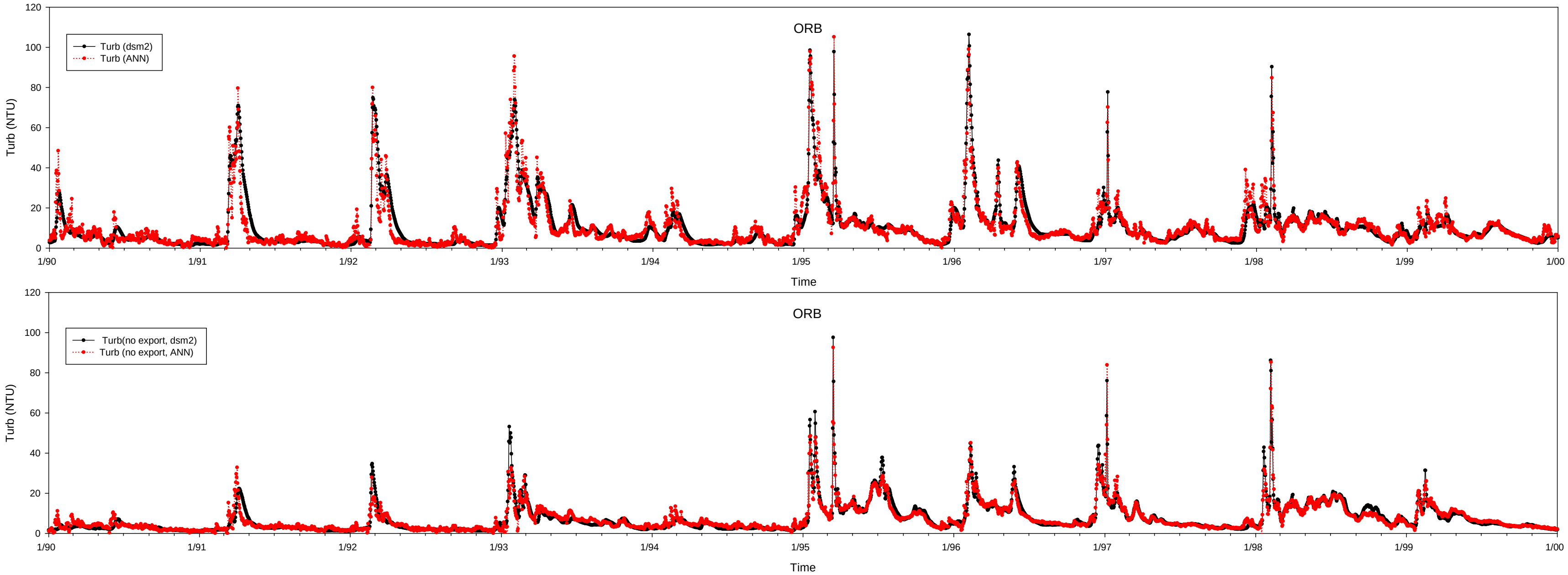
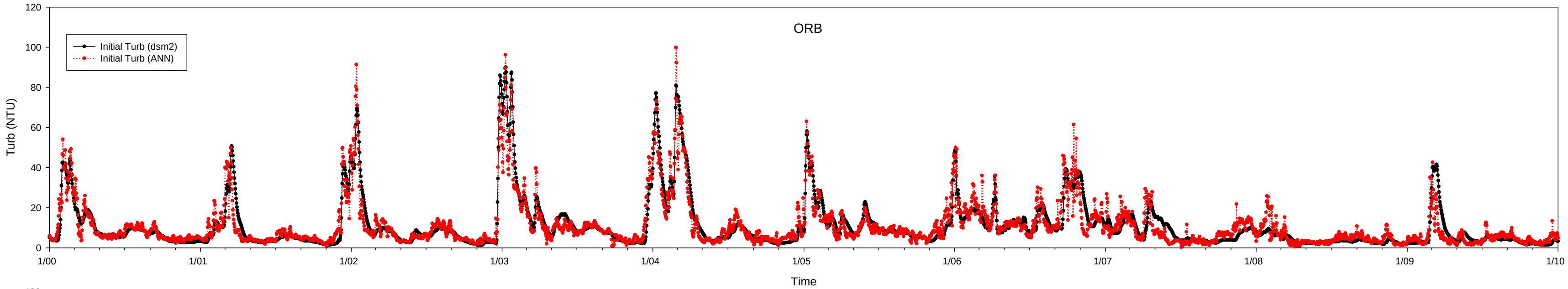


Figure A-1 (cont.) Comparison of ANN (Phase3A) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.



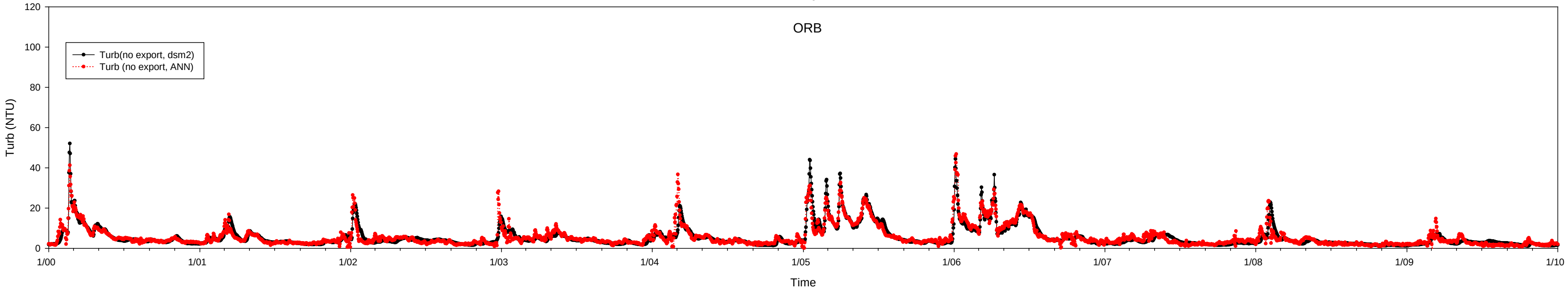


Figure A-1 (cont.) Comparison of ANN (Phase3A) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.

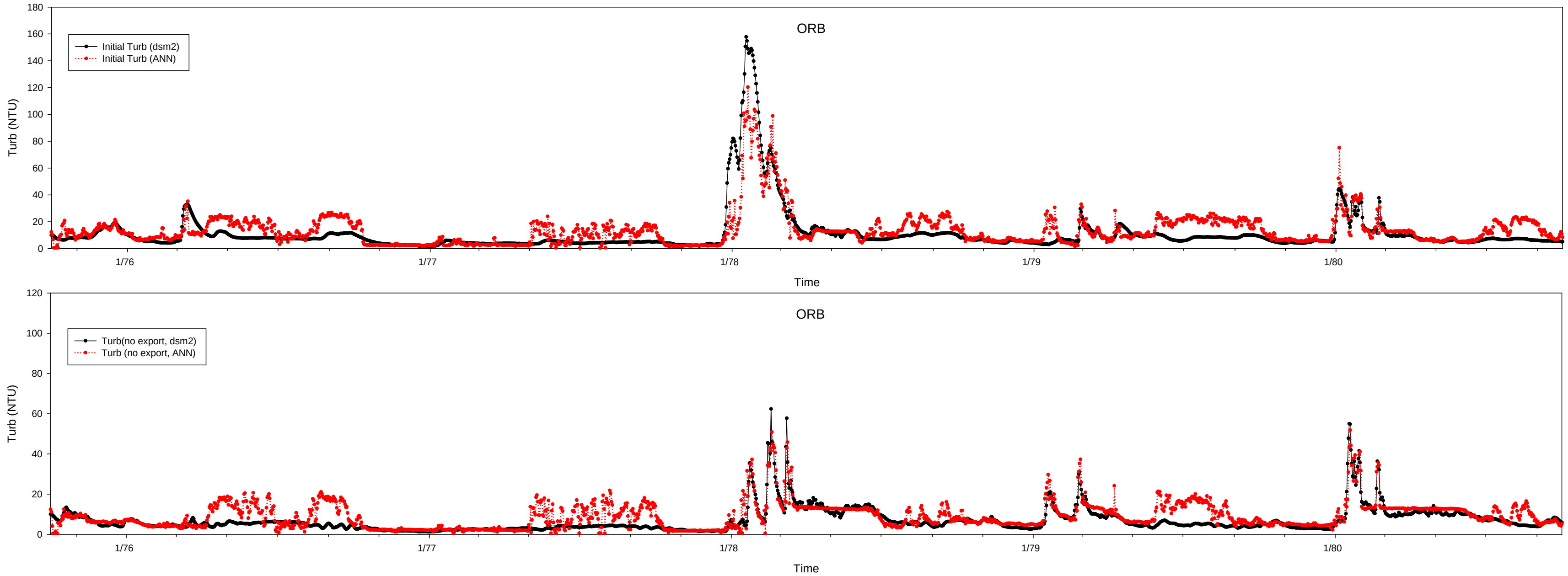


Figure A-2 Comparison of ANN (Phase3) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.

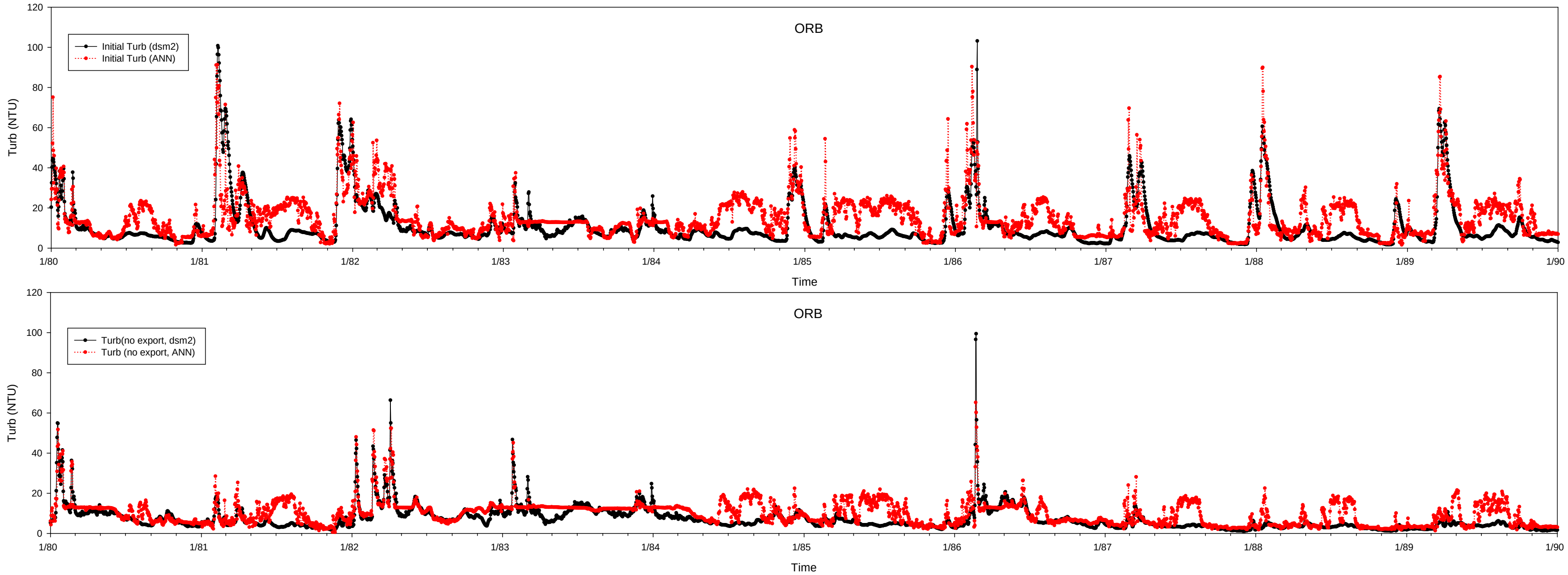
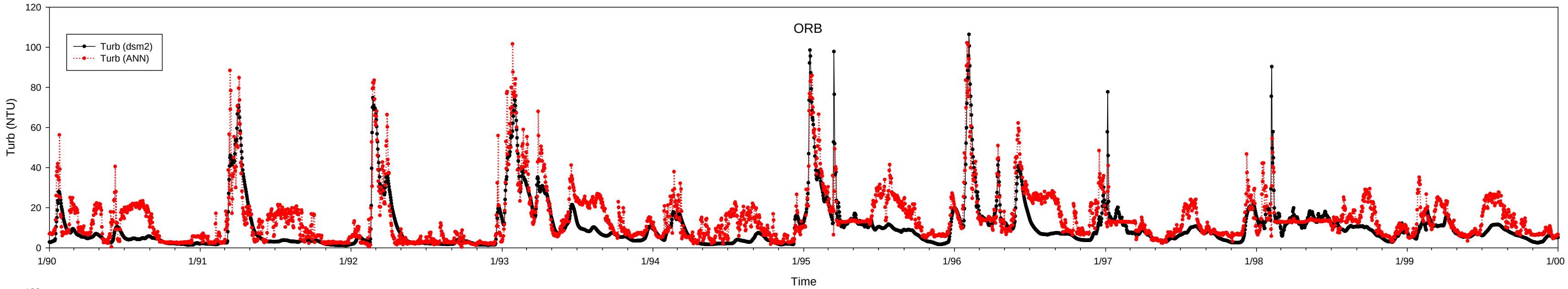


Figure A-2 (cont.) Comparison of ANN (Phase3) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.



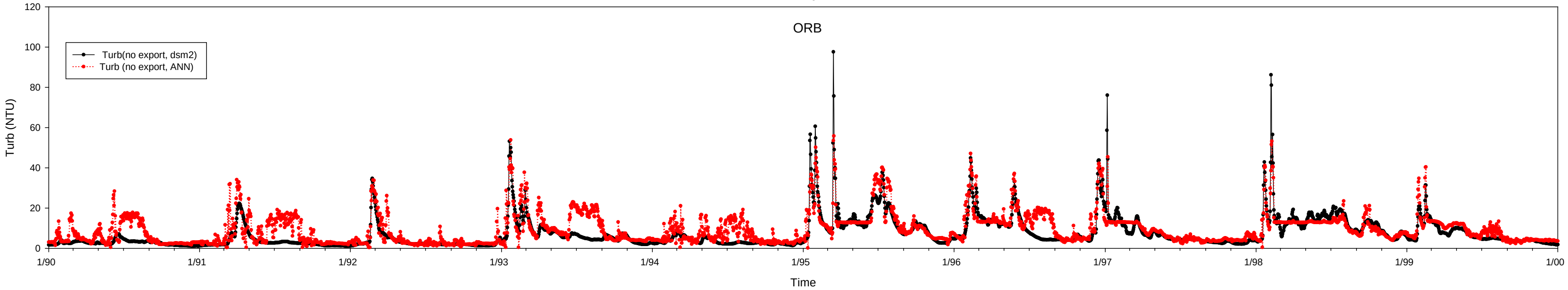


Figure A-2 (cont.) Comparison of ANN (Phase3) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011

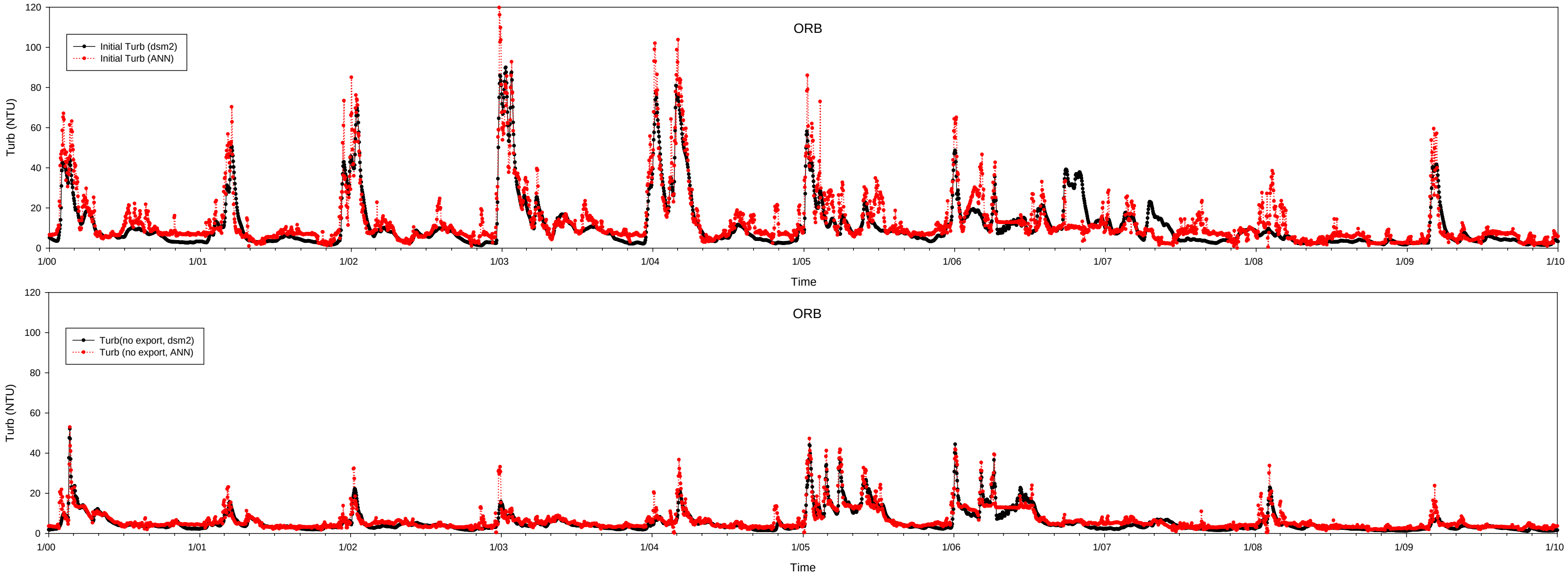


Figure A-2 (cont.) Comparison of ANN (Phase3) and DSM2 simulated turbidity at ORB using historical boundary for the period of 1975-2011.

Appendix B. Relationship between controllability at ORB and Vernalis River flow and turbidity from Sacramento and San Joaquin River

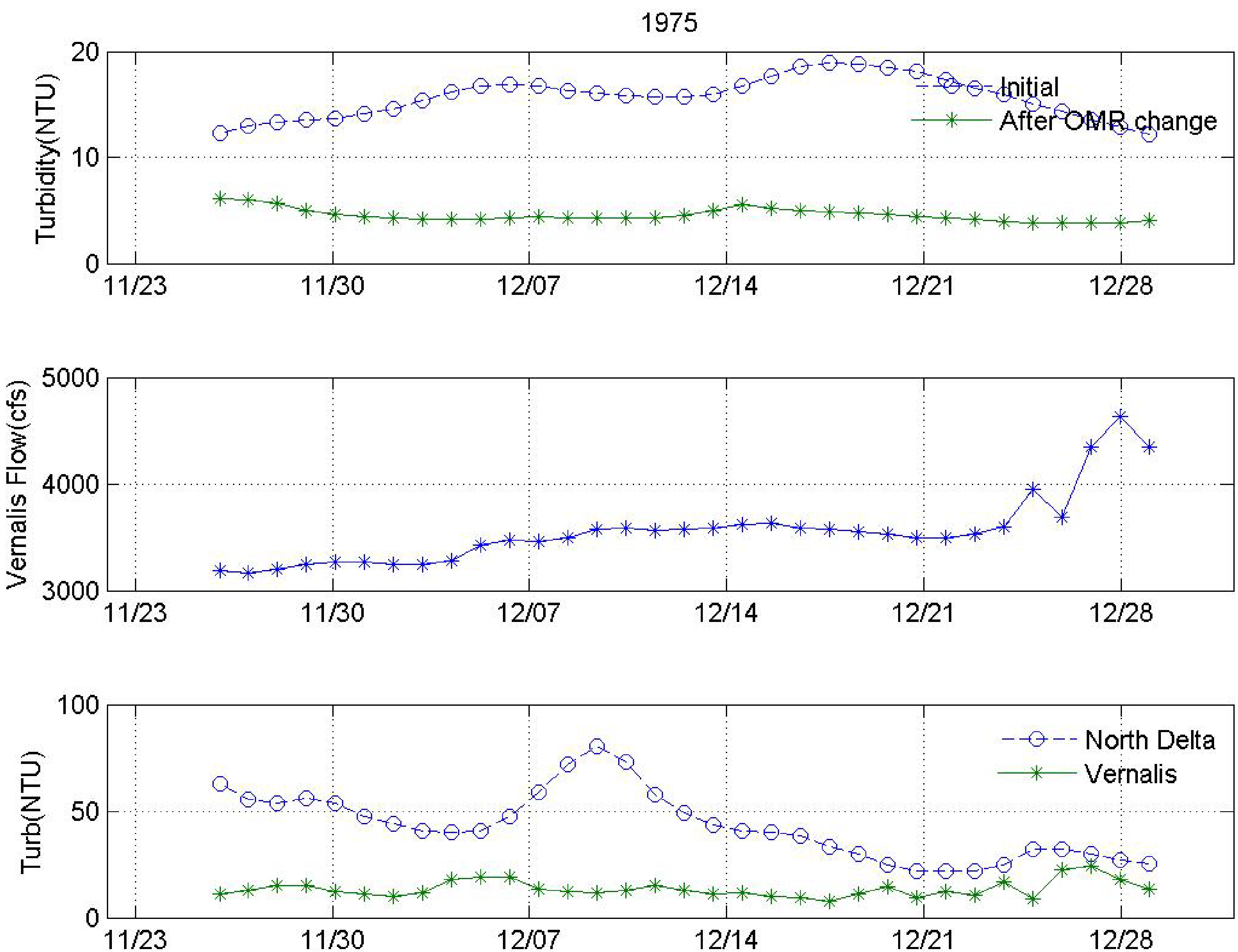


Figure B-1 **November-December 1975**

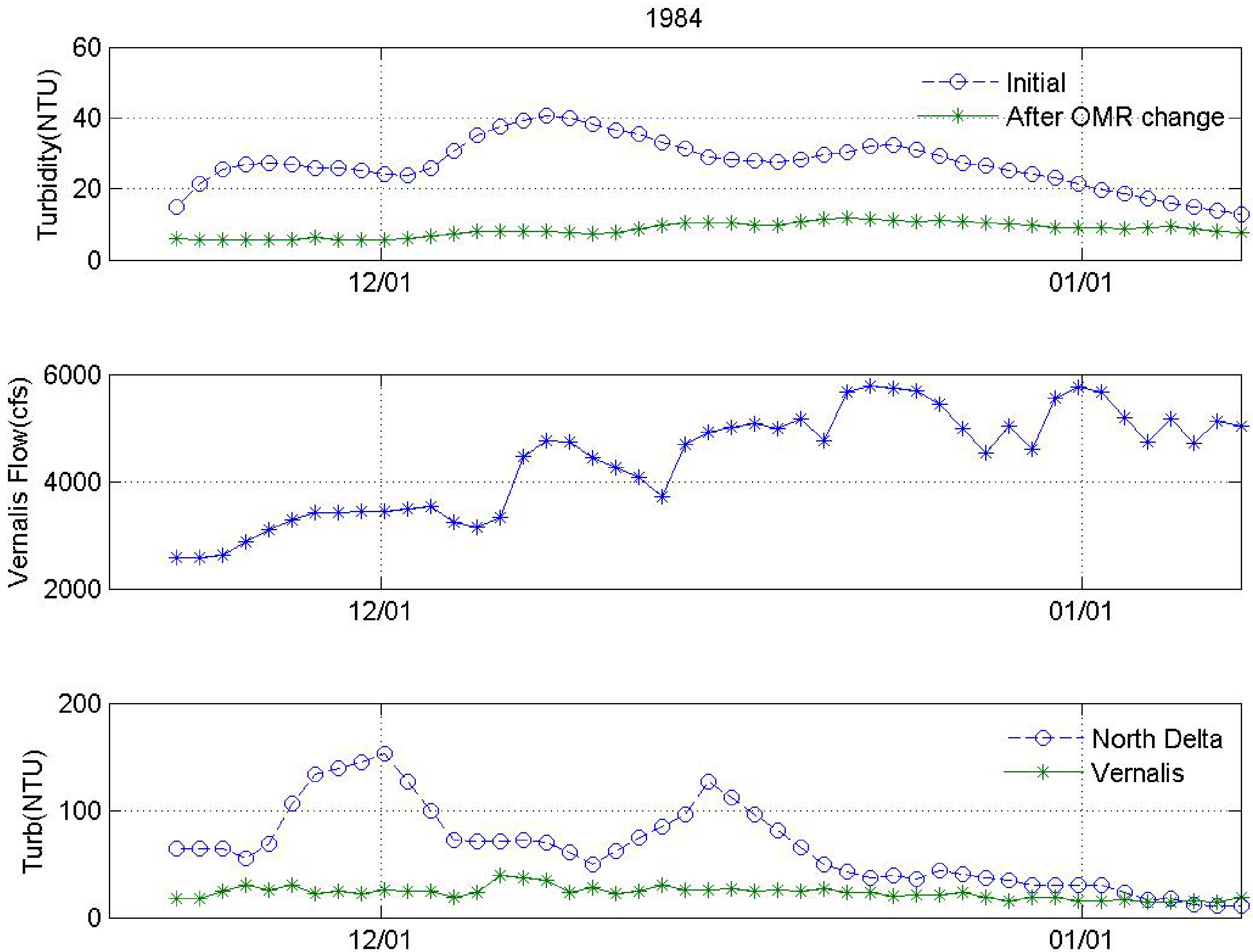


Figure B-2 **December-January 1984**

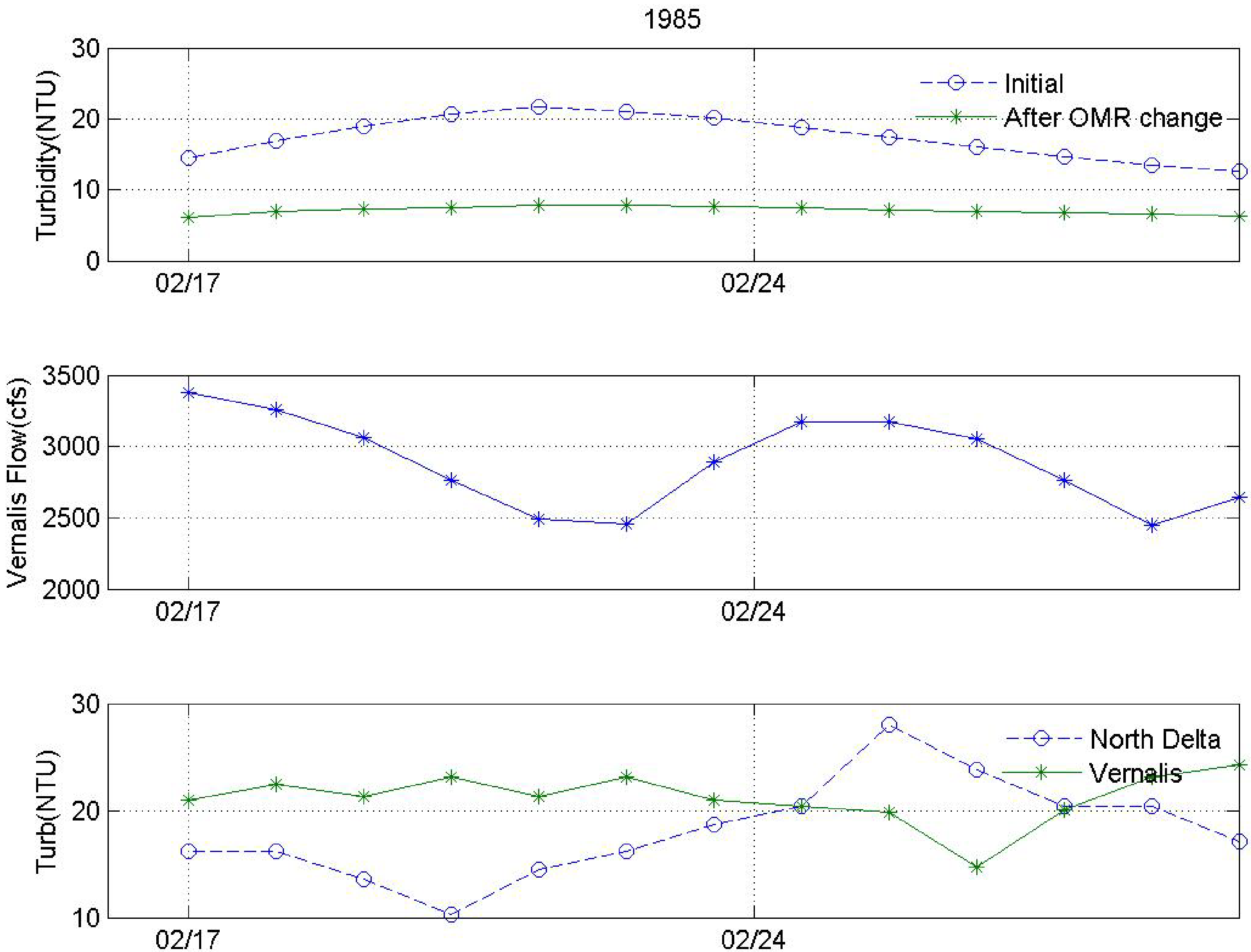


Figure B-3 **February 1985**

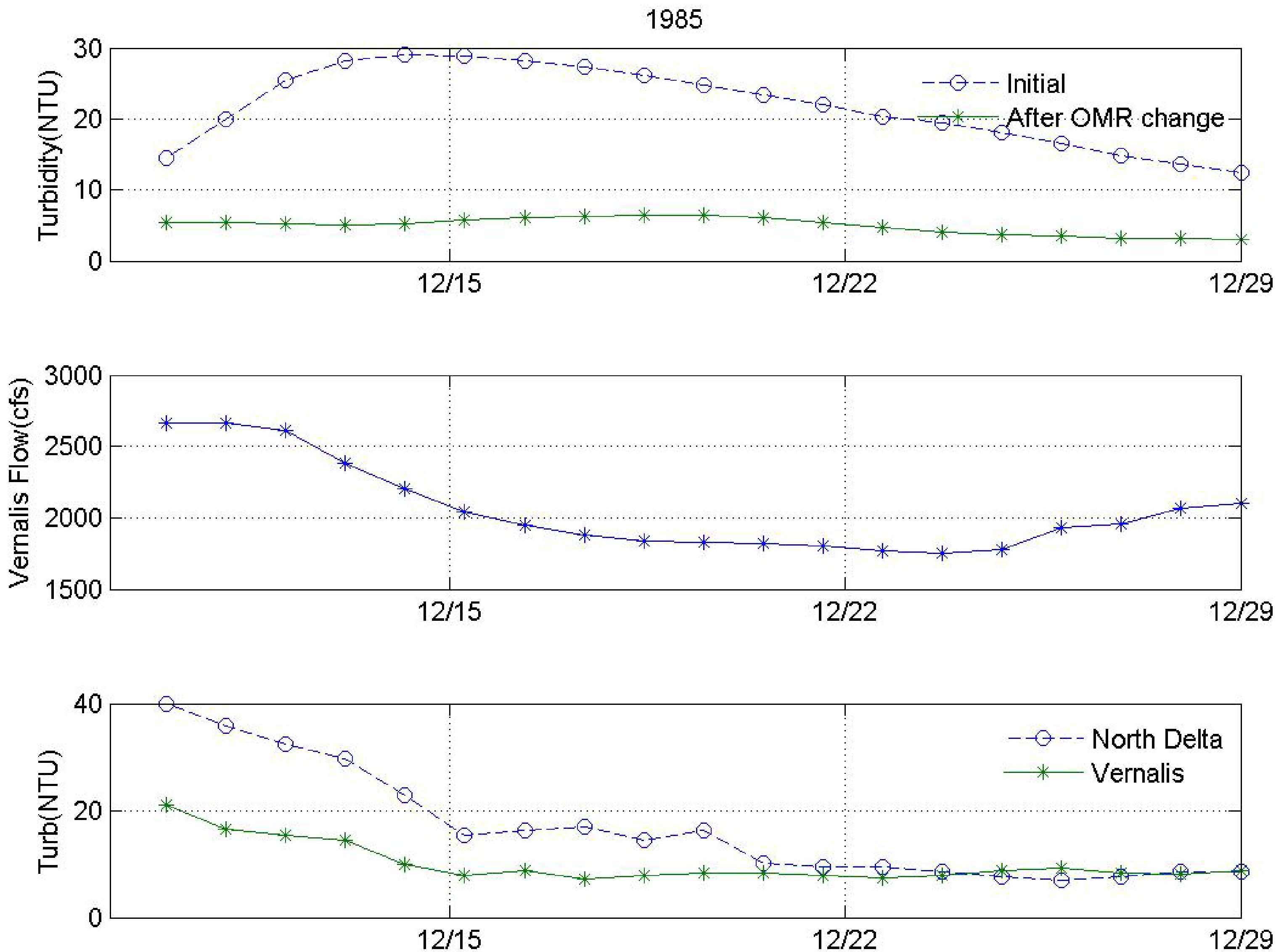


Figure B-4 **December 1985**

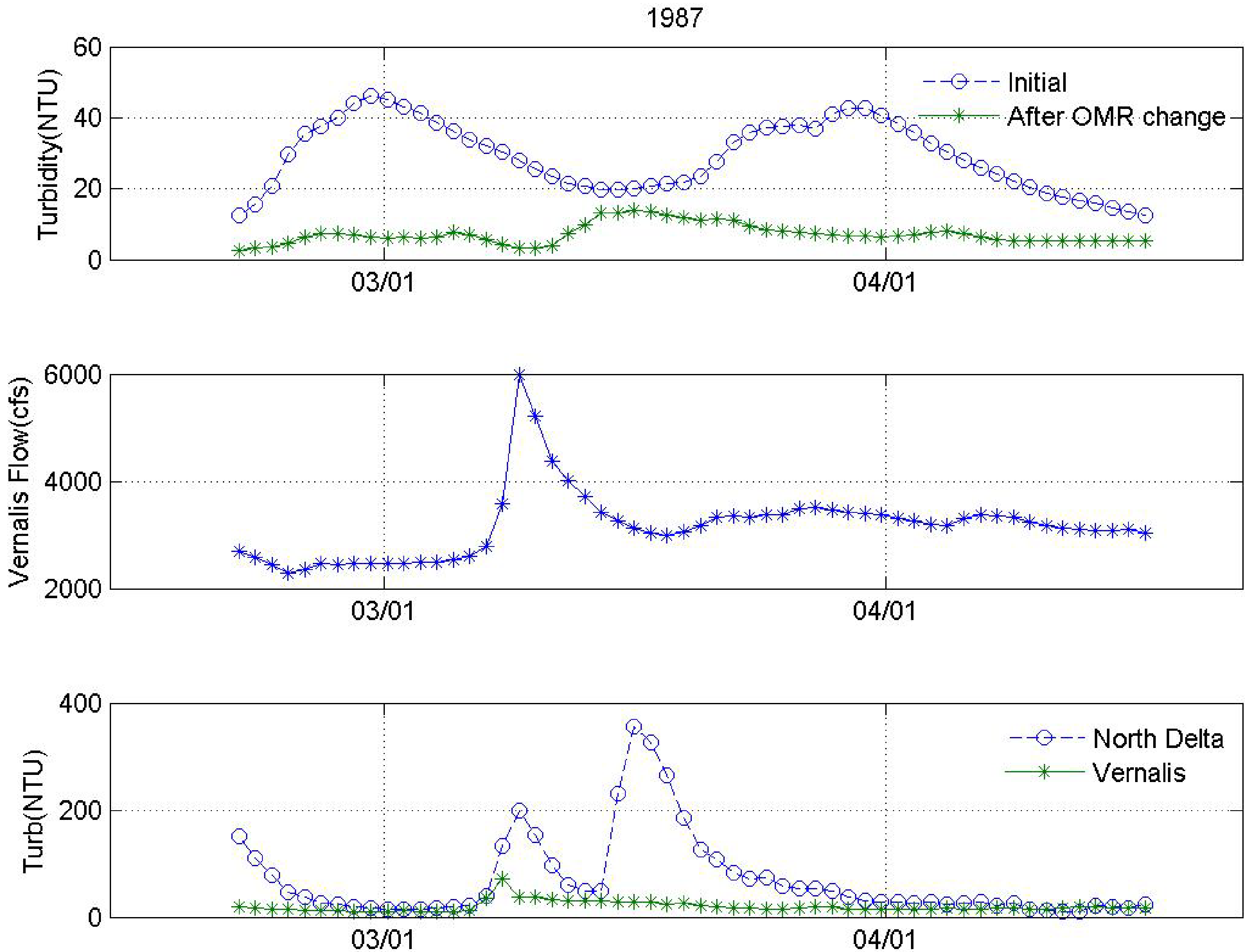


Figure B-5 **March-April 1987**

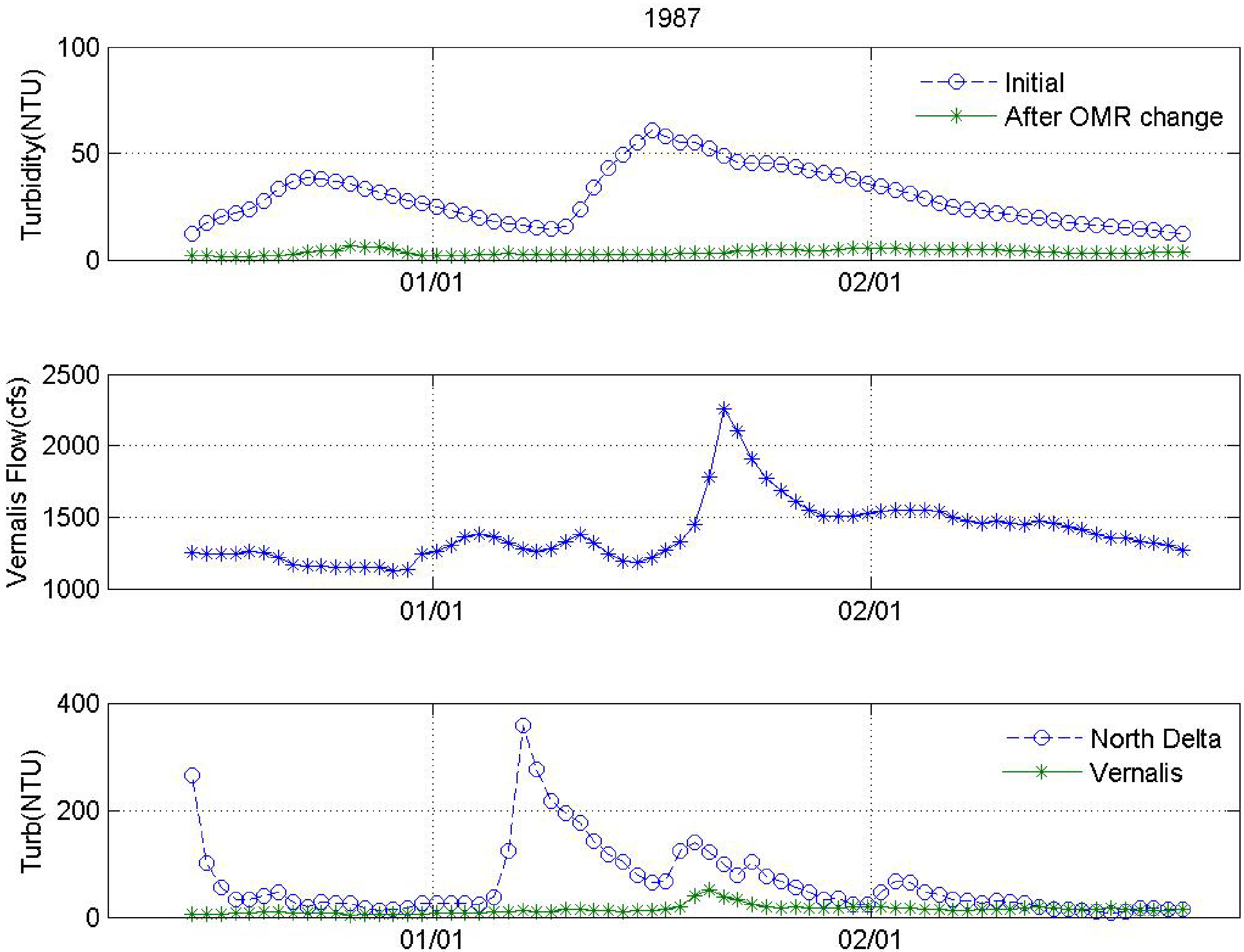


Figure B-6 **January-February 1987**

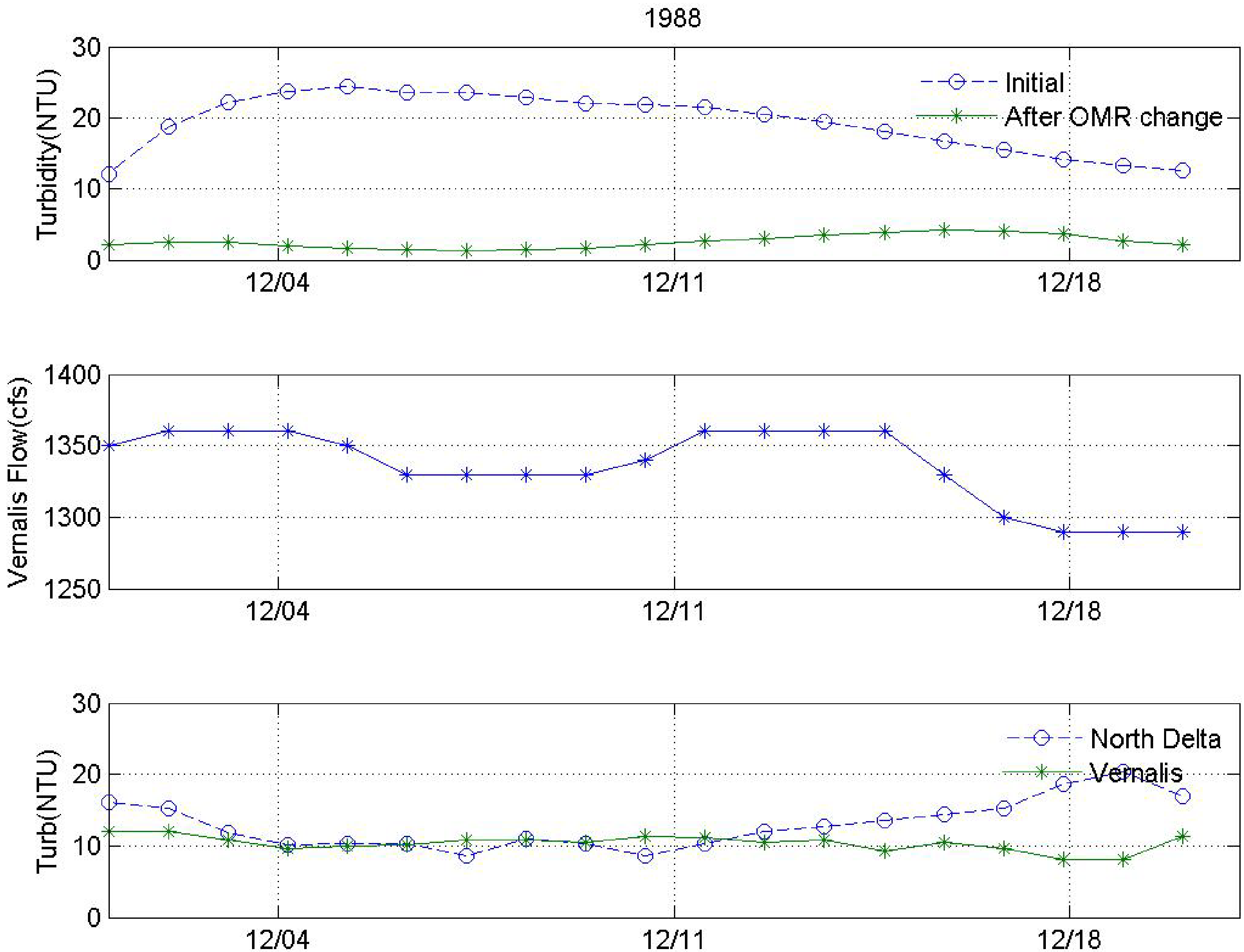


Figure B-7 **December 1988**

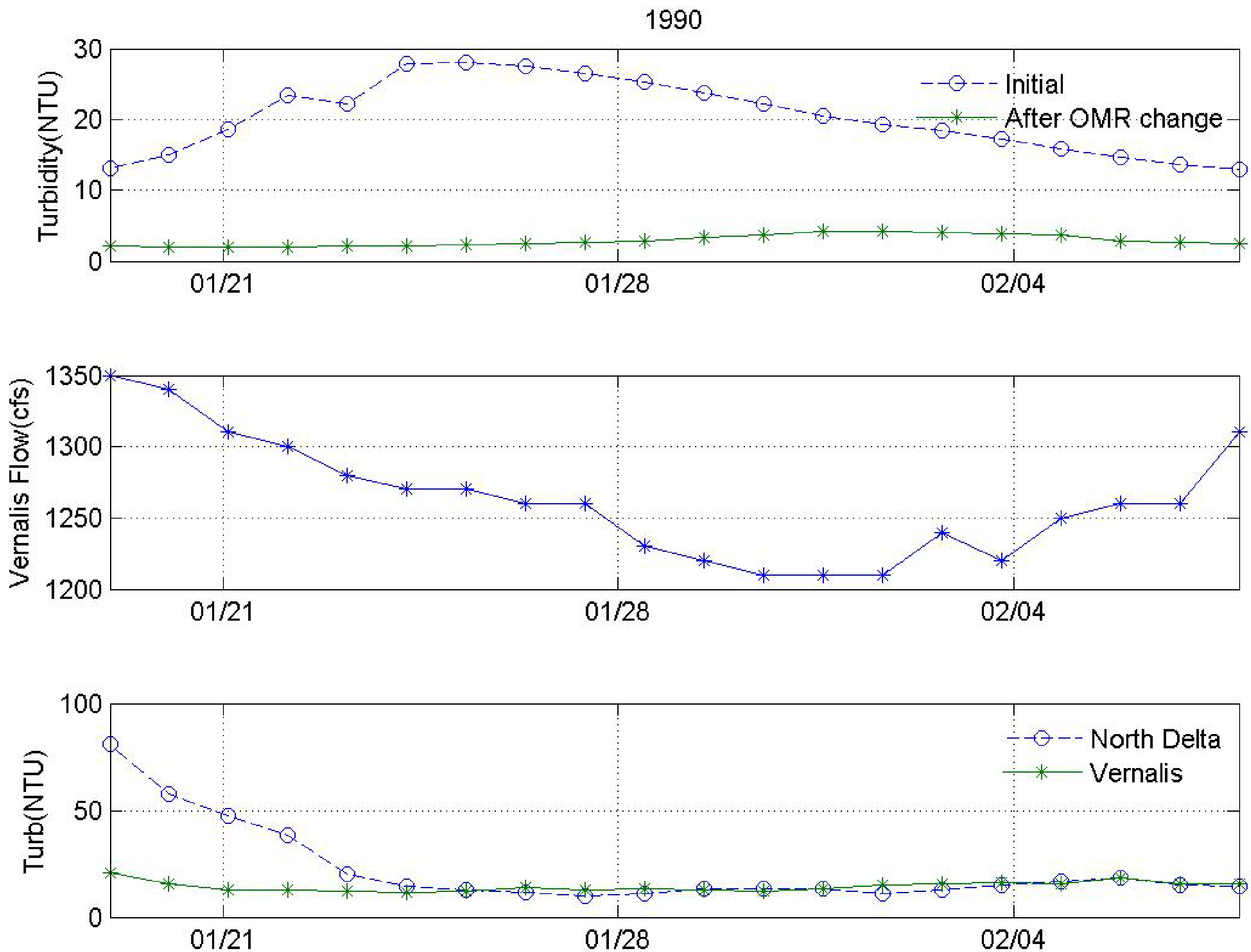


Figure B-8 January-February 1990

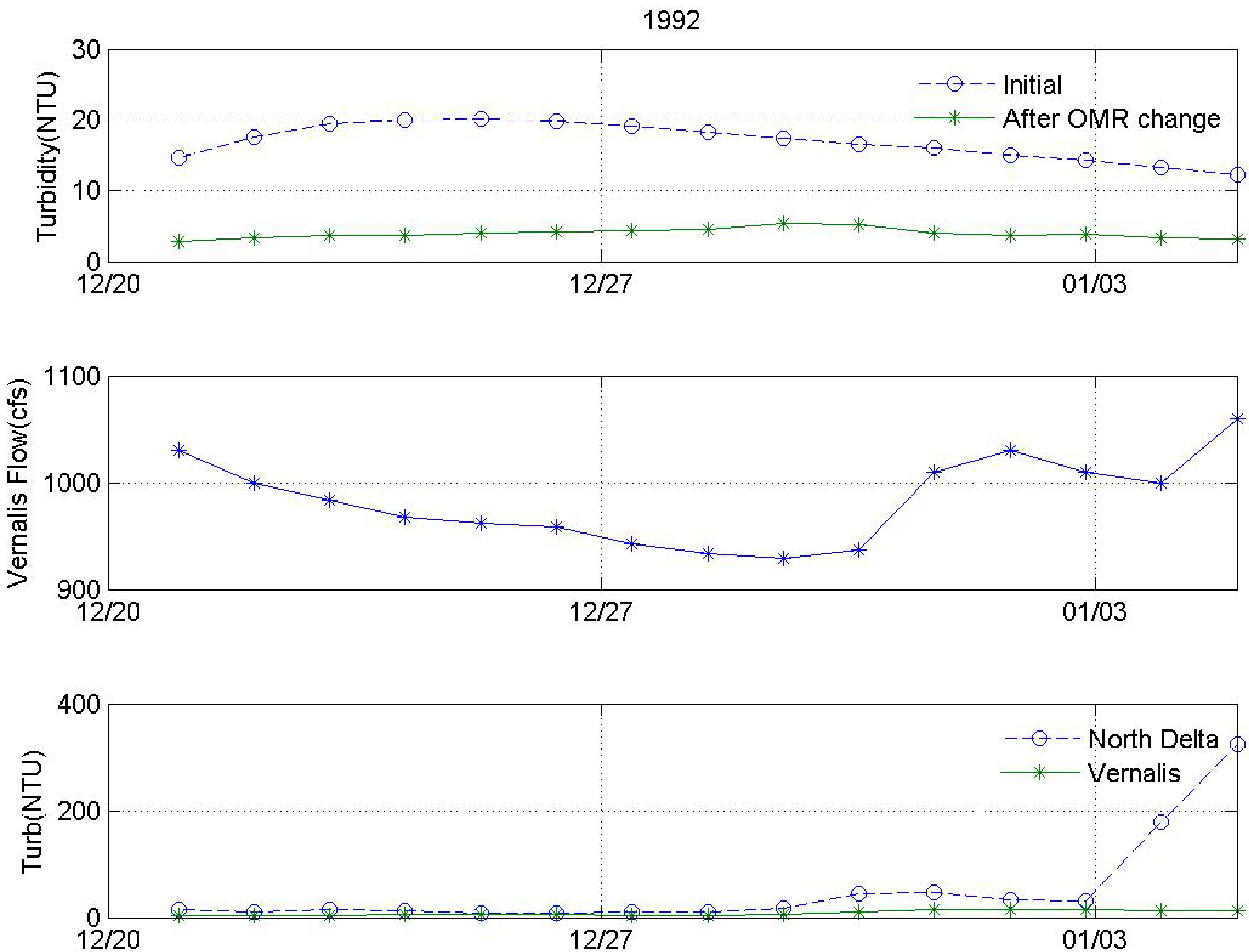


Figure B-9 **December 1992-January 1993**

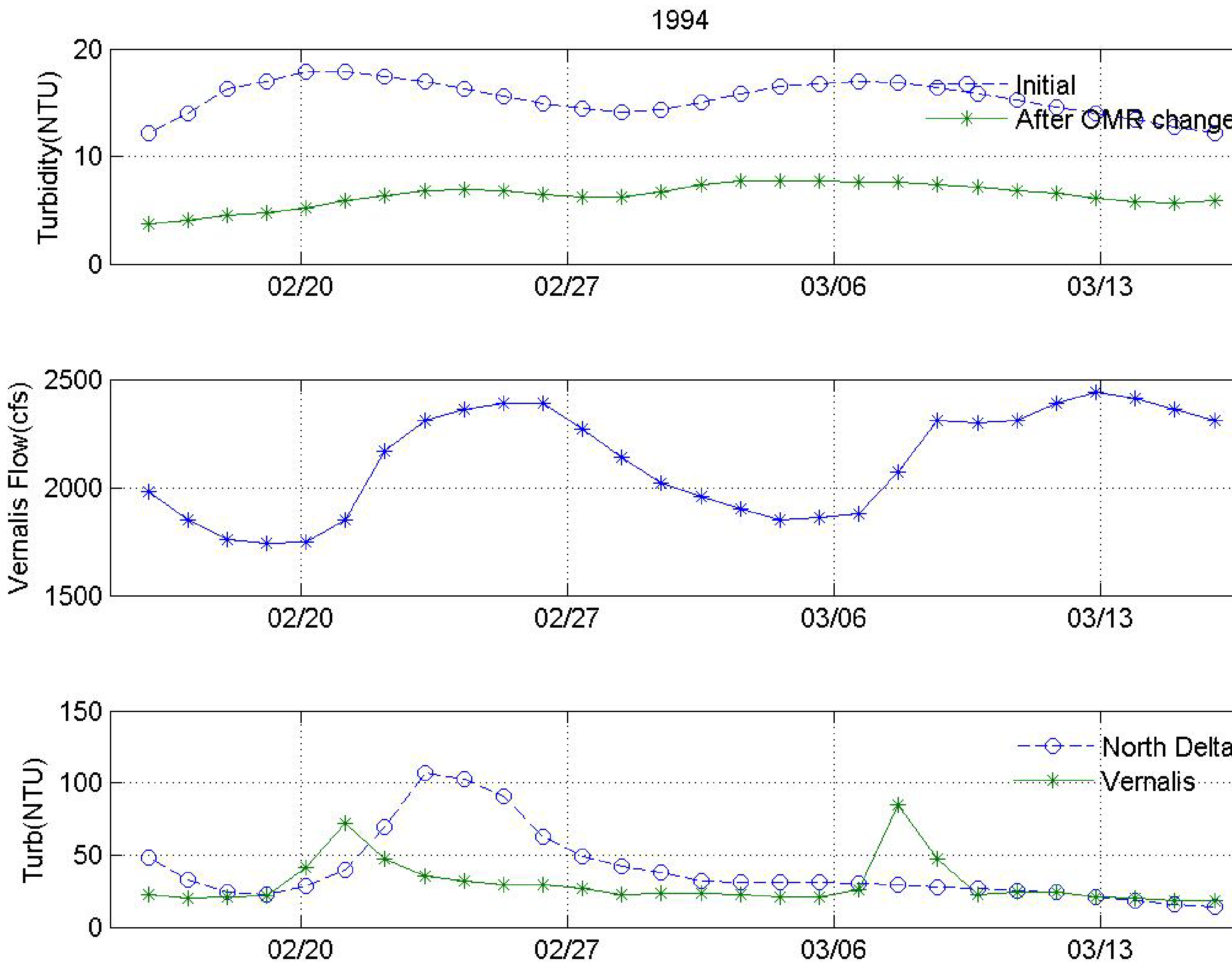


Figure B-10 **February-March 1994**

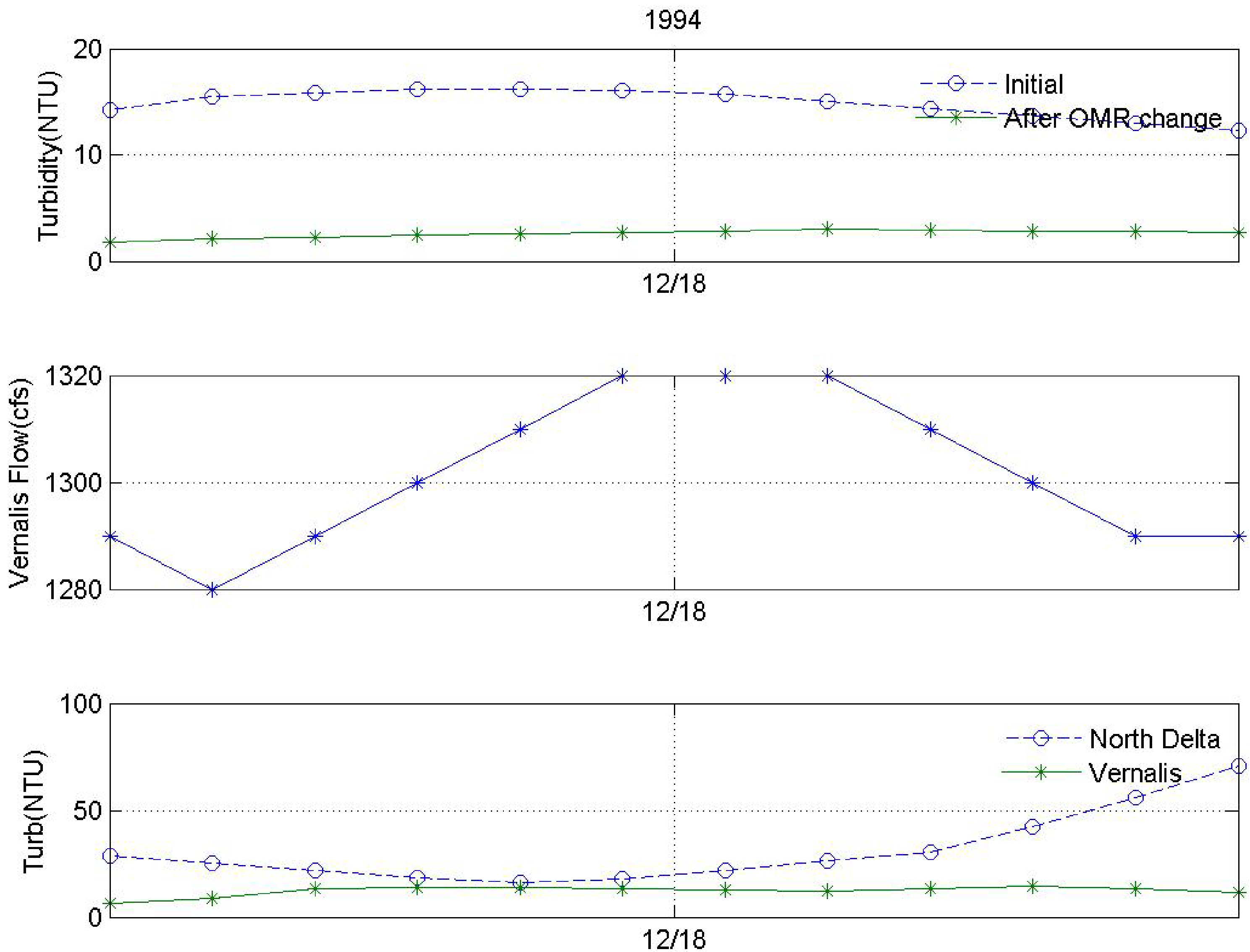


Figure B-11 **December 1994**

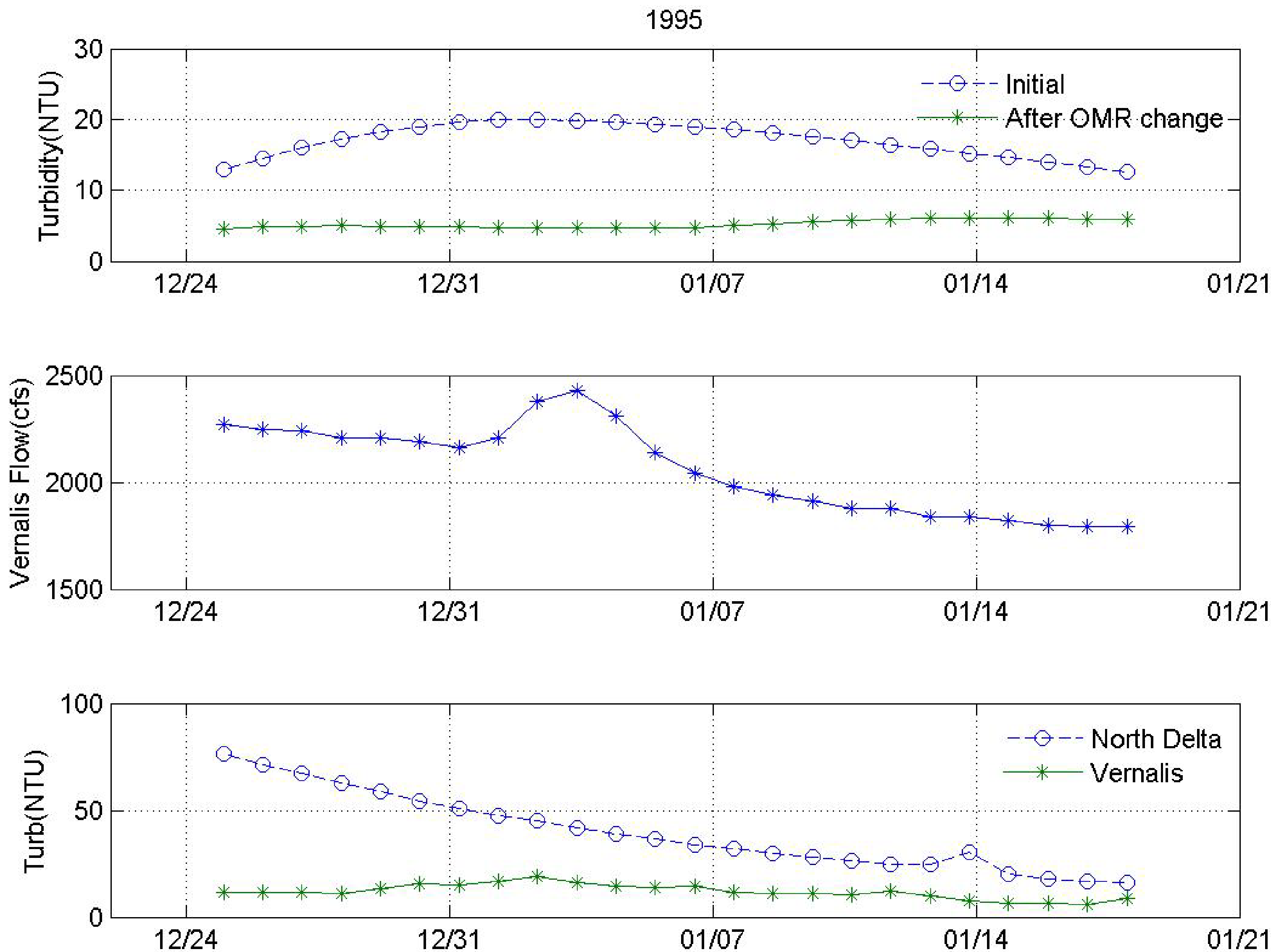


Figure B-12 **December 1994-January 1995**

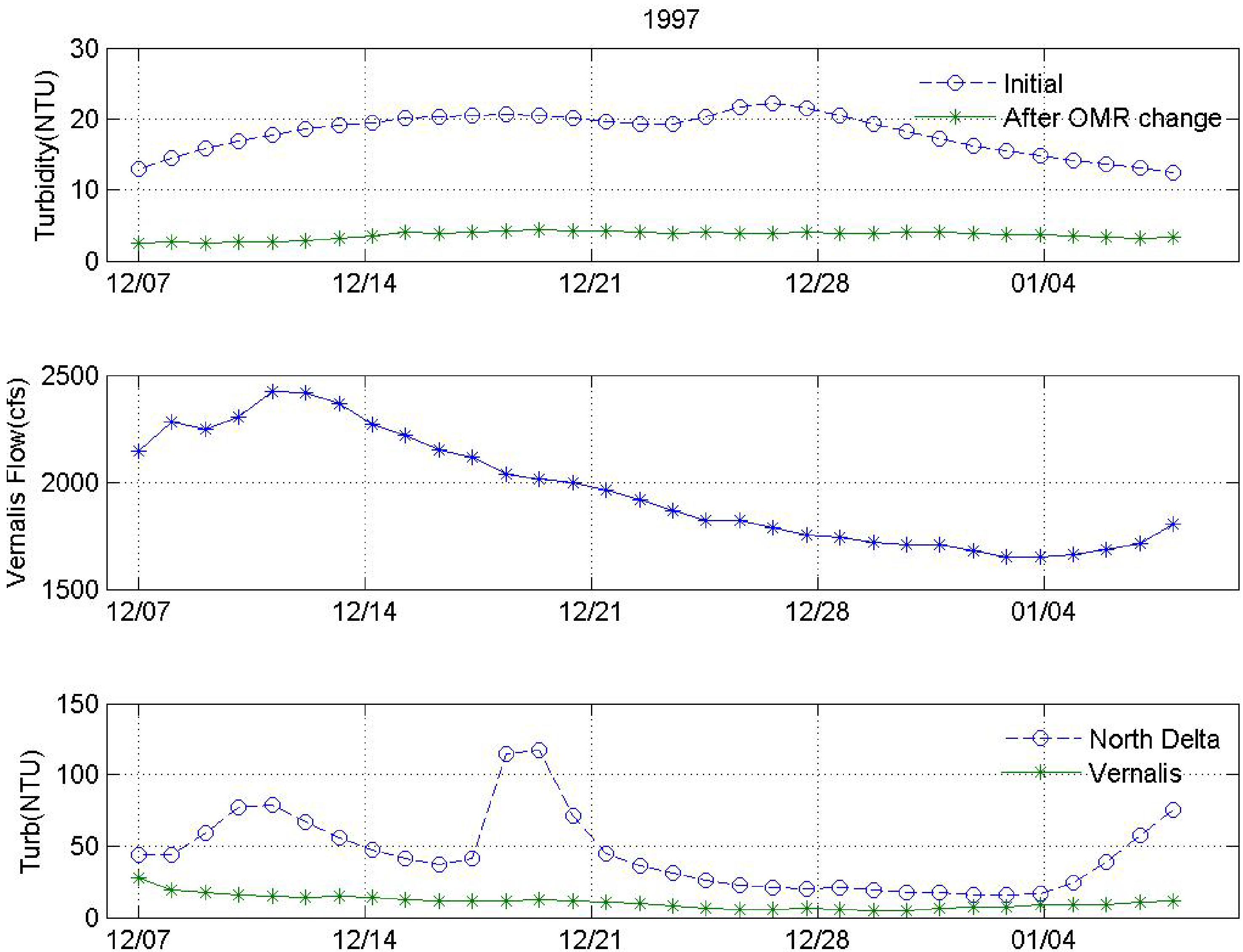


Figure B-13 **December 1997-January 1998**

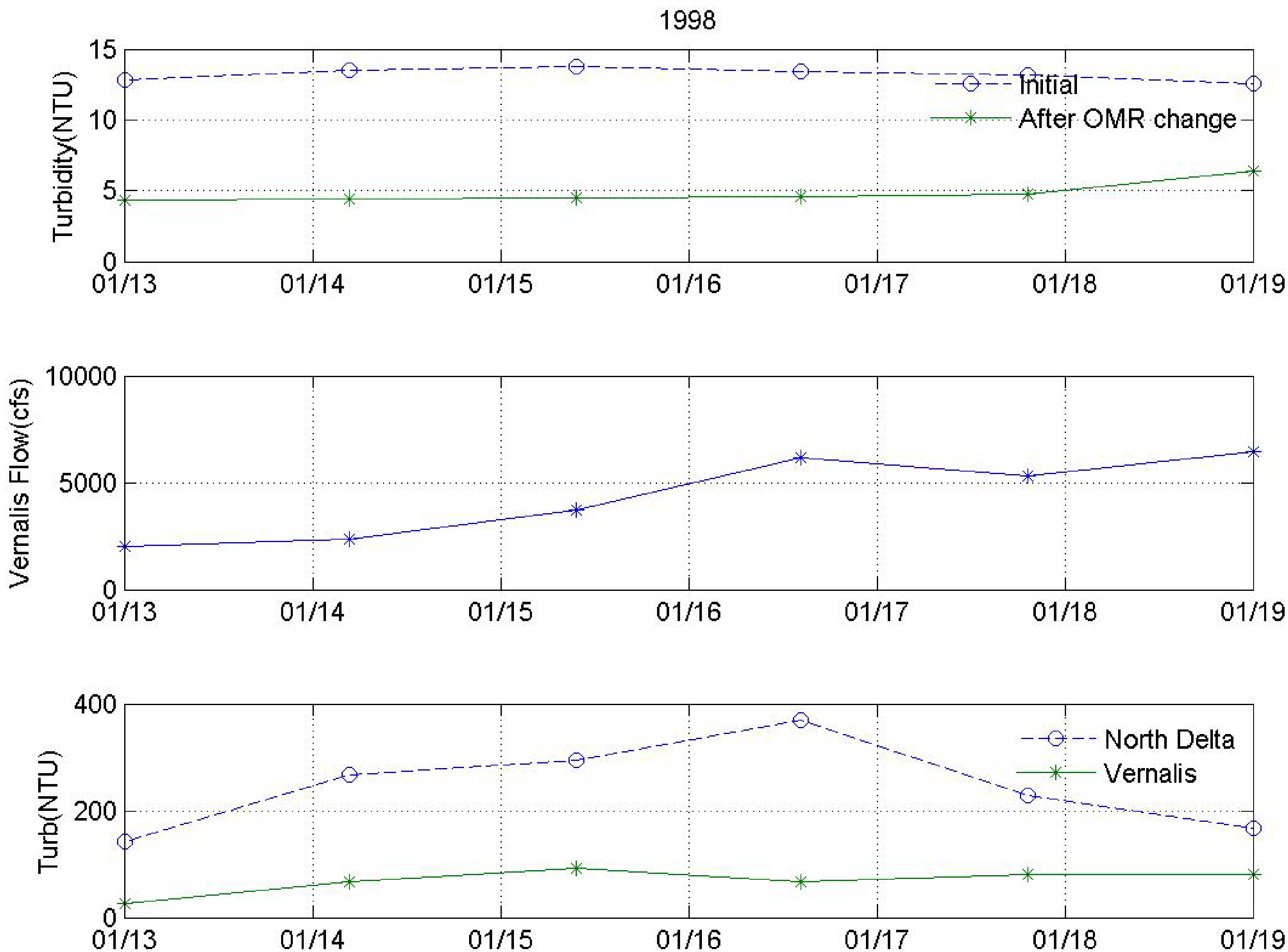


Figure B-14 **January 1998**

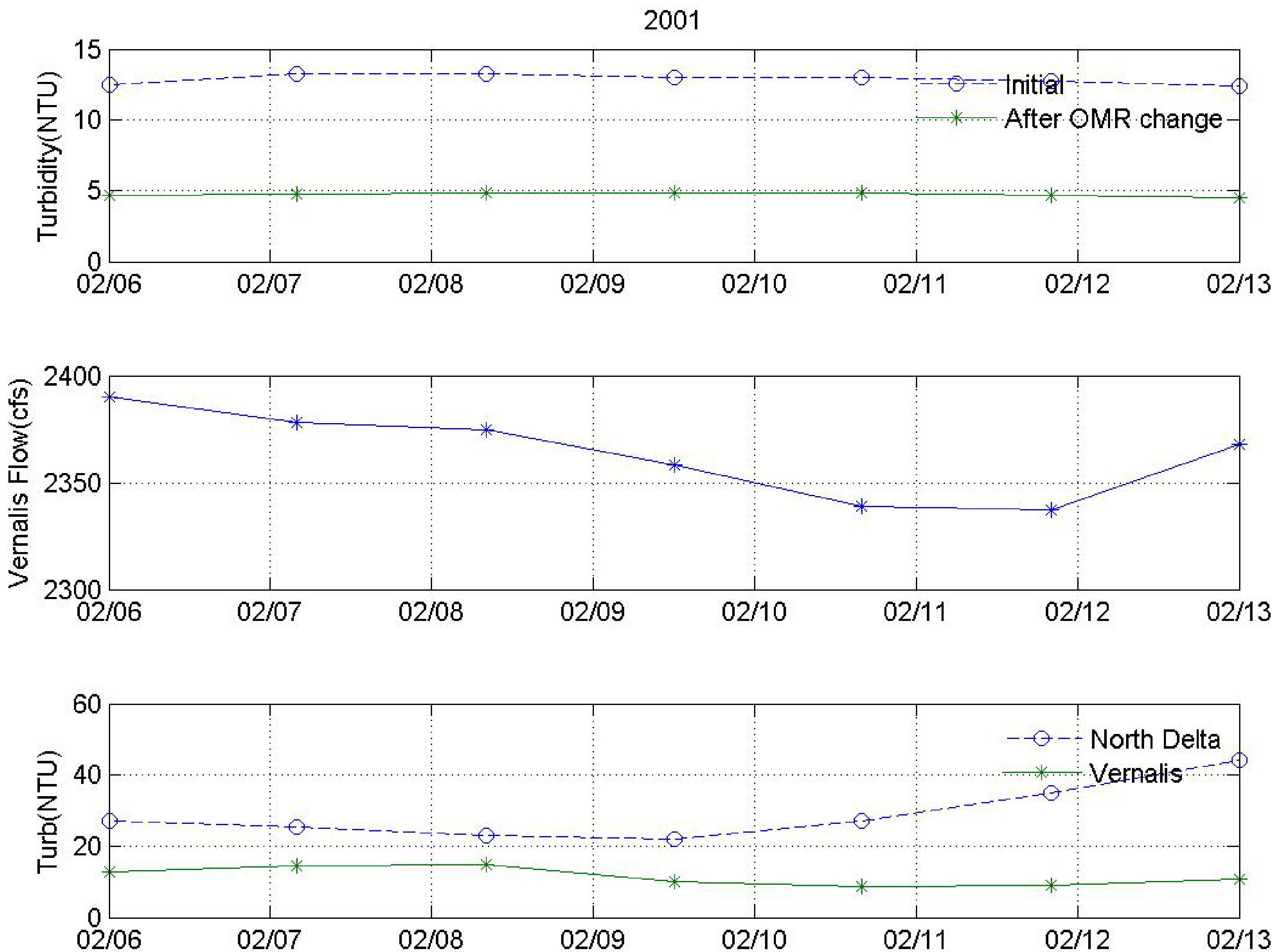


Figure B-15 **February 2001**

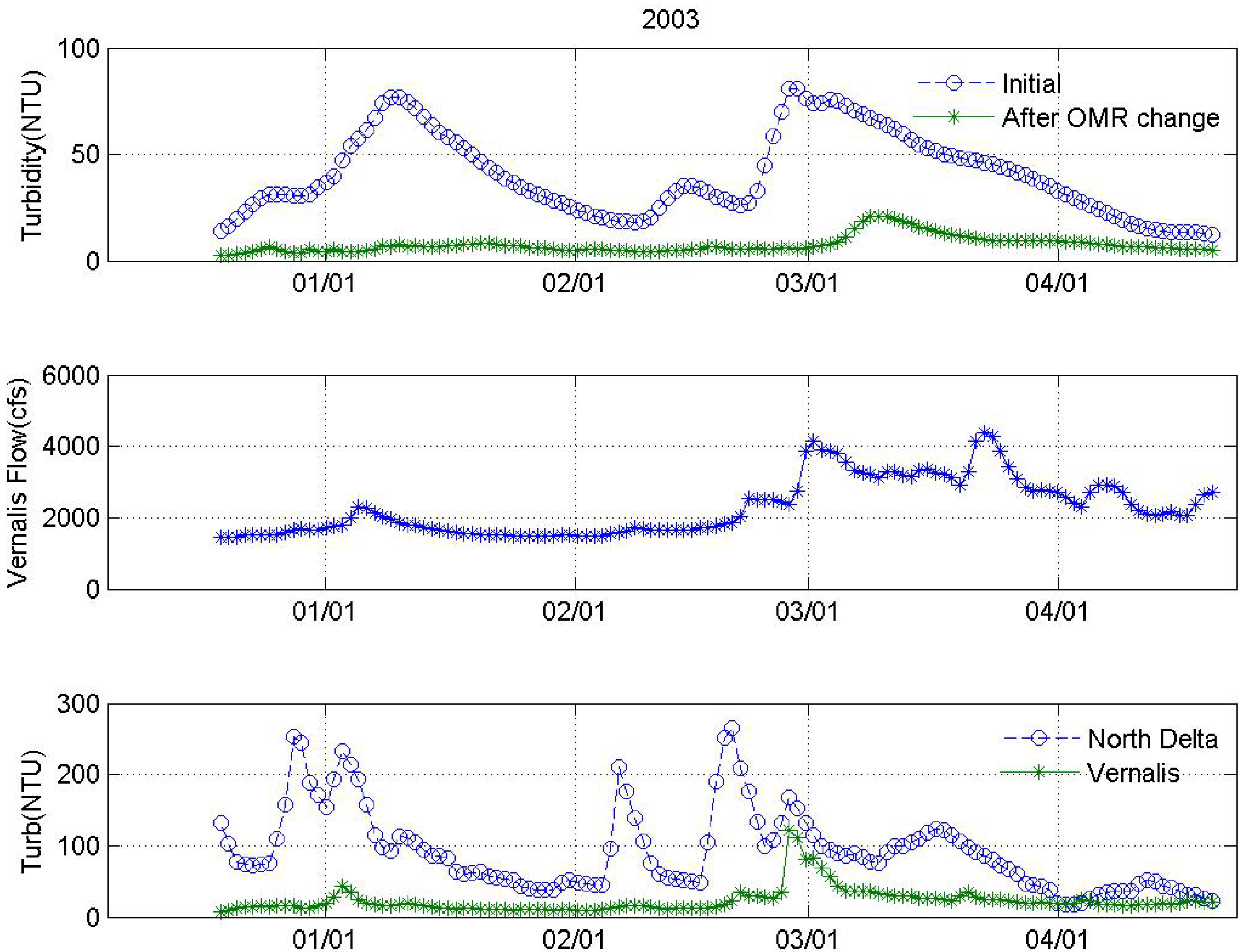


Figure B-16 **January-April 2003**

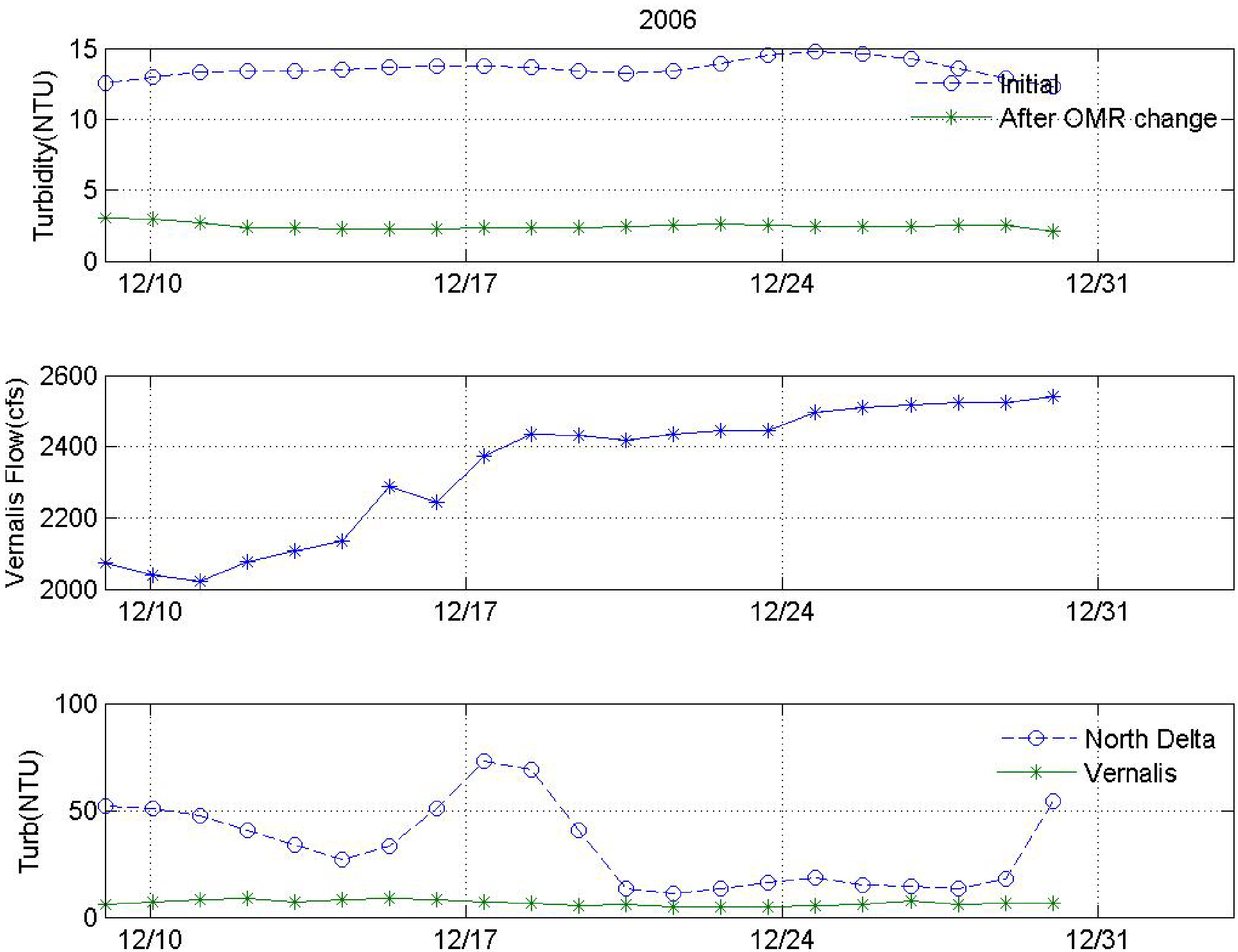


Figure B-17 **December 2006**

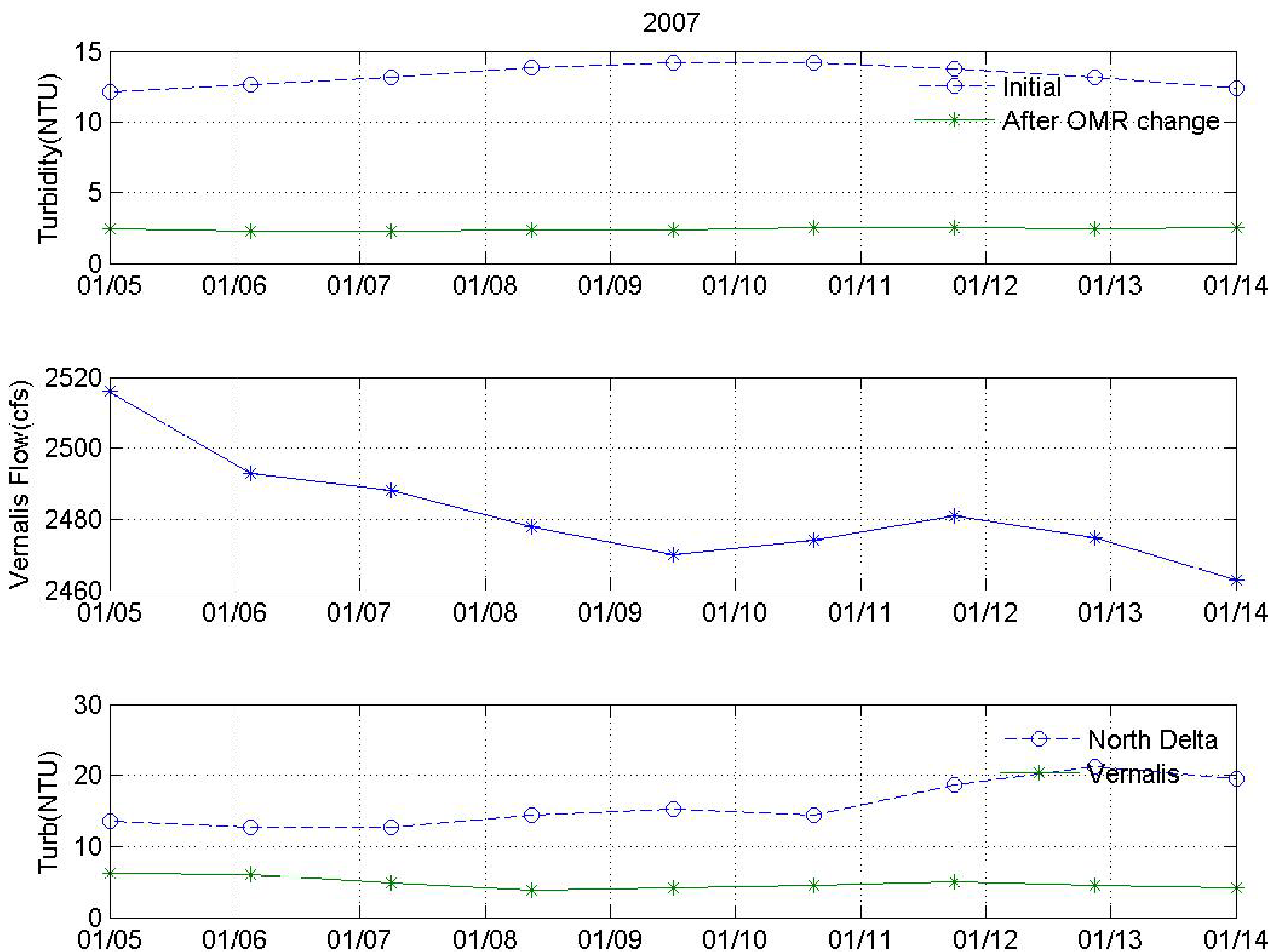


Figure B-18 **January 2007**

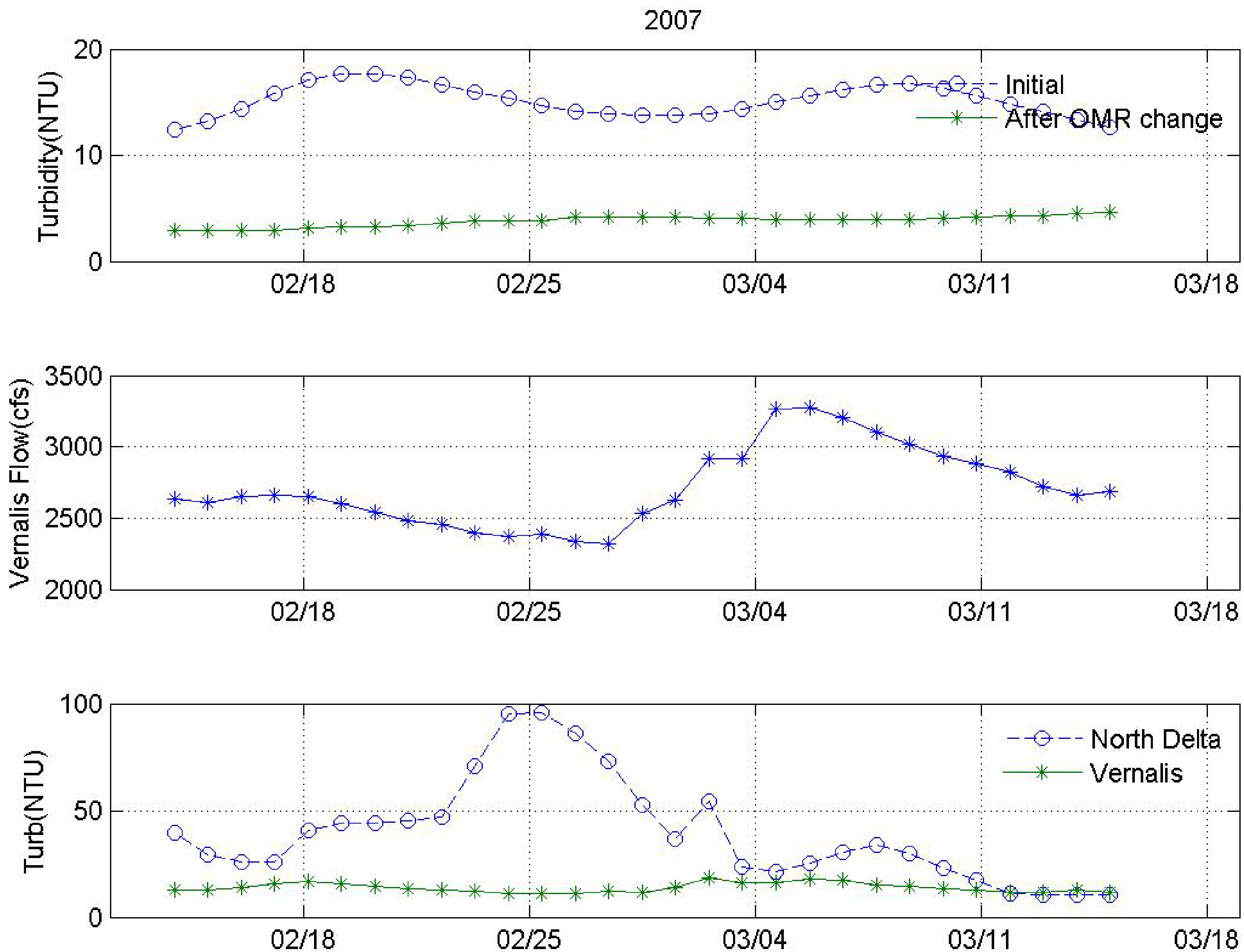


Figure B-19 **February-March 2007**

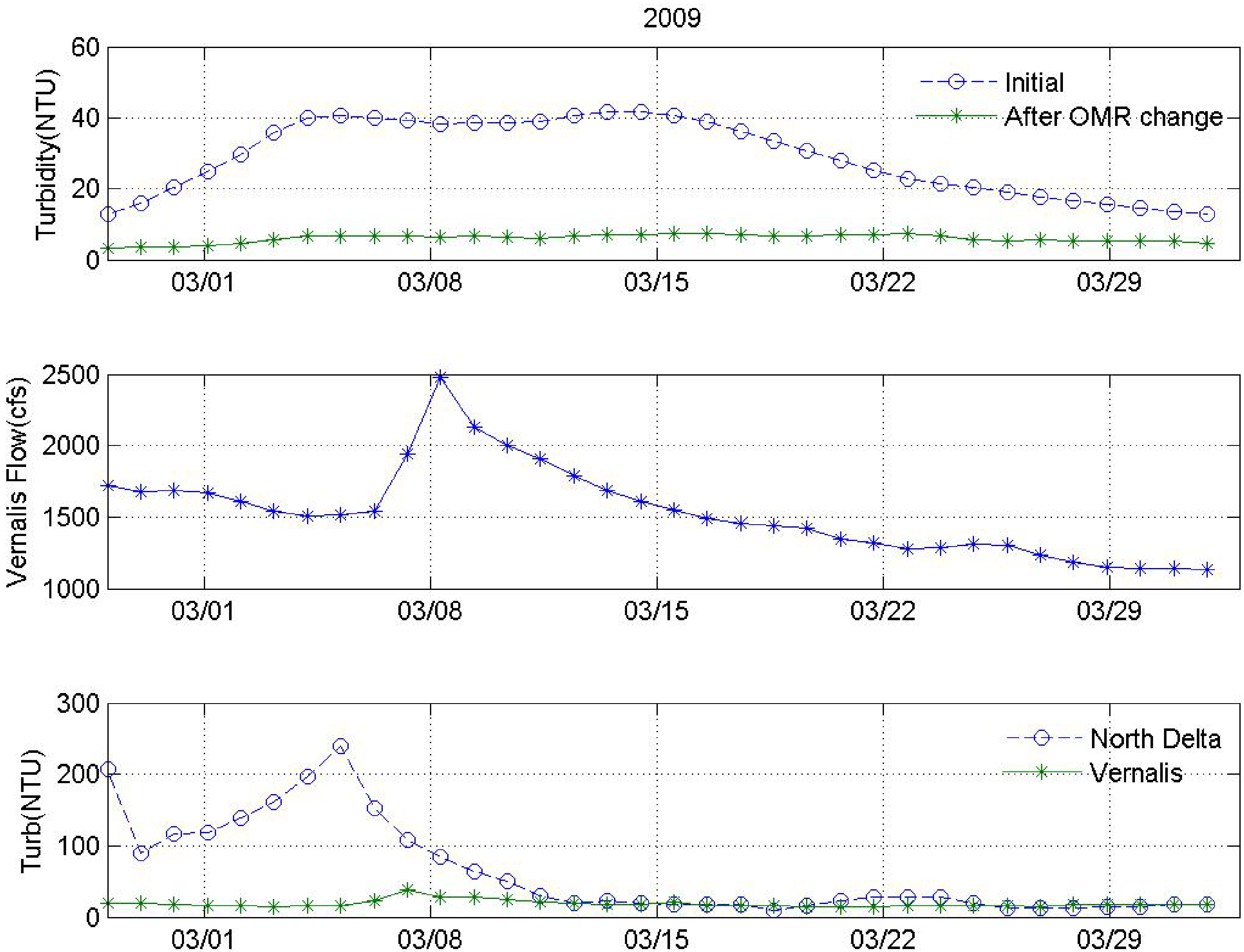


Figure B-20 **March 2009**

Appendix C. Flows and Simulated Turbidity During Exceedance Events

The following plots show simulated turbidity values at Prisoner's Point (red), Holland (blue), Victoria (green), and Bacon Island (orange) for the identified events with the contemporaneous SWP + CVP smelt salvage counts. An event is only plotted when there is at least one observed (possibly 0) smelt salvage observation over the period.

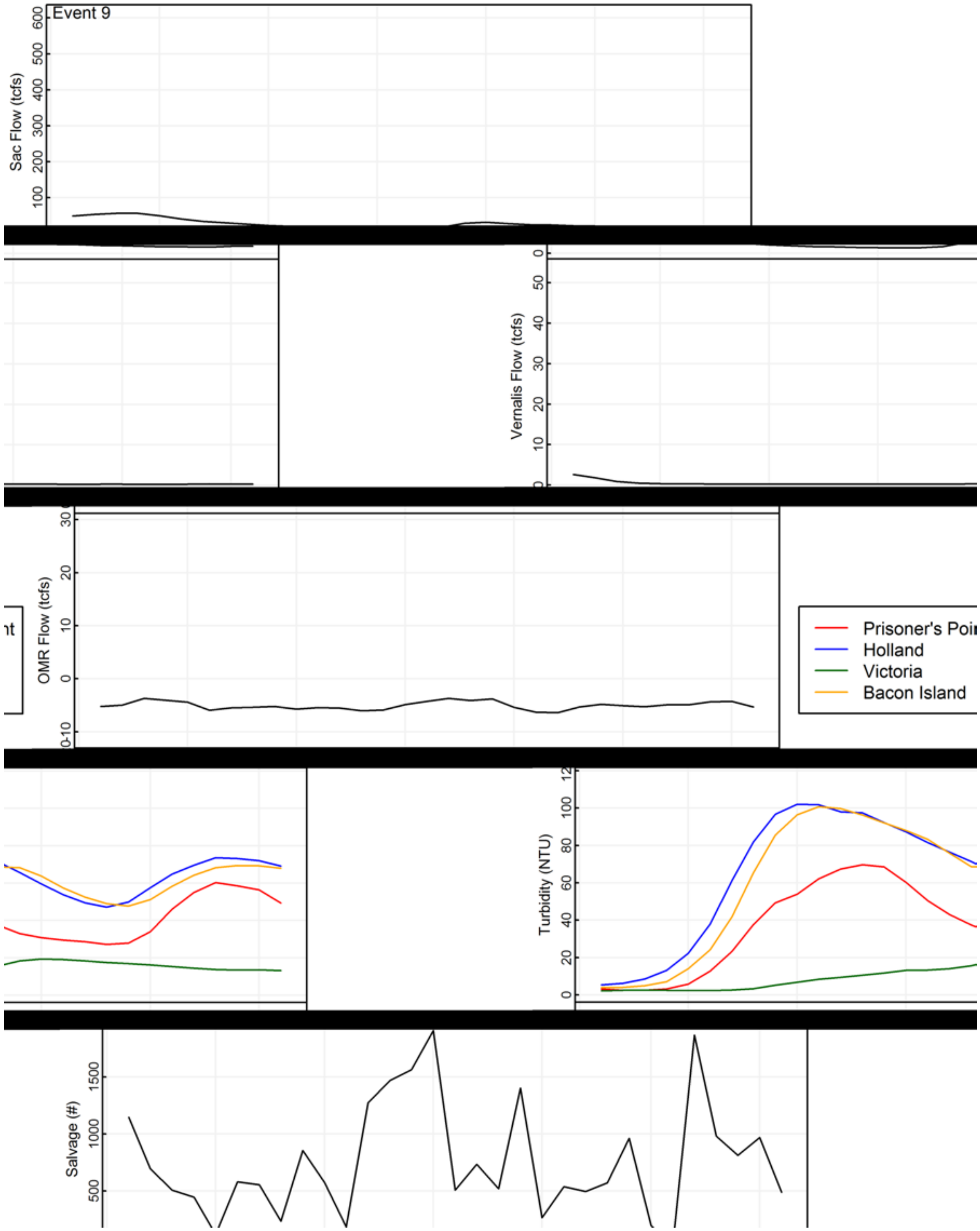


Figure C-1 **Event 9**

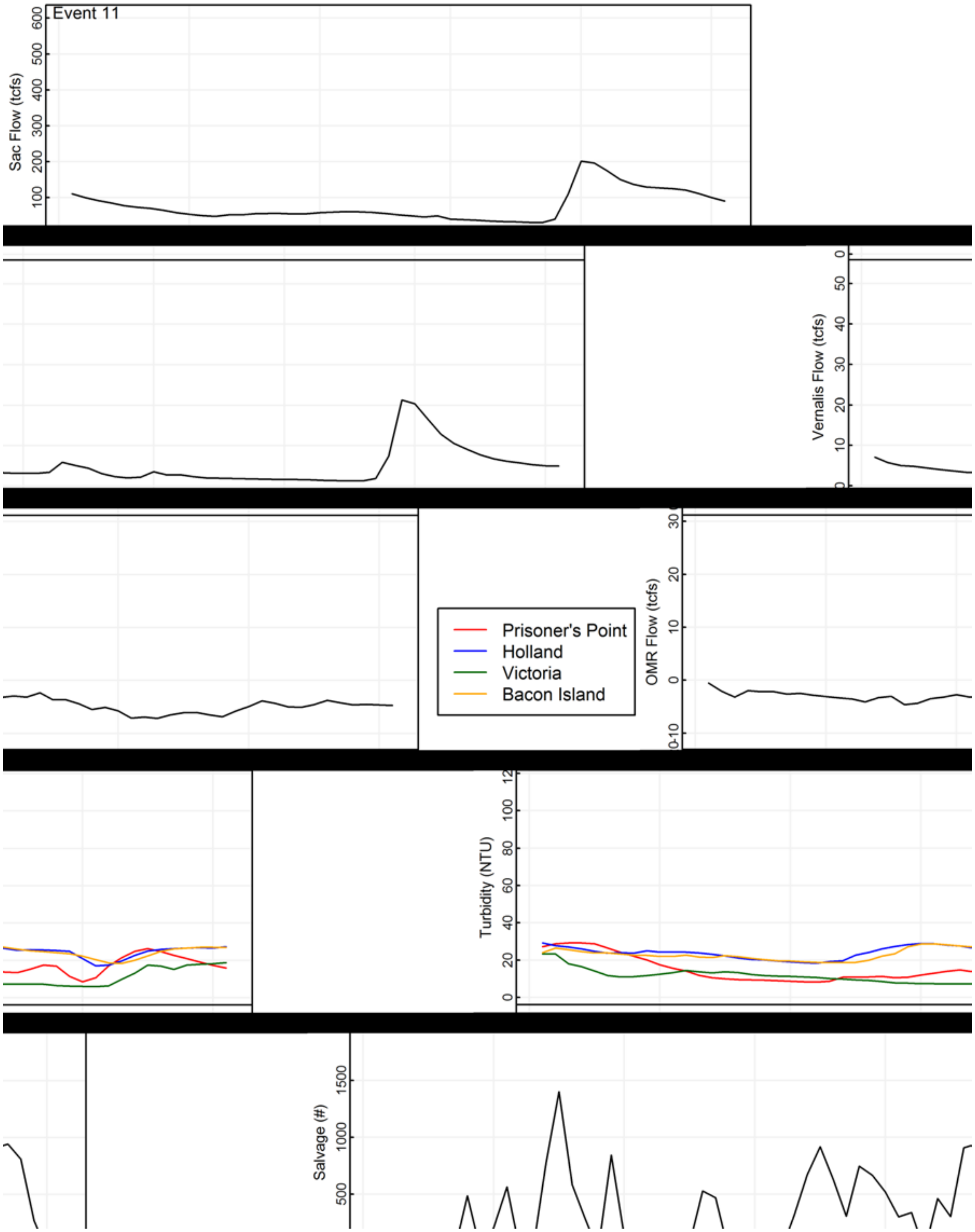


Figure C-2 **Event 11**

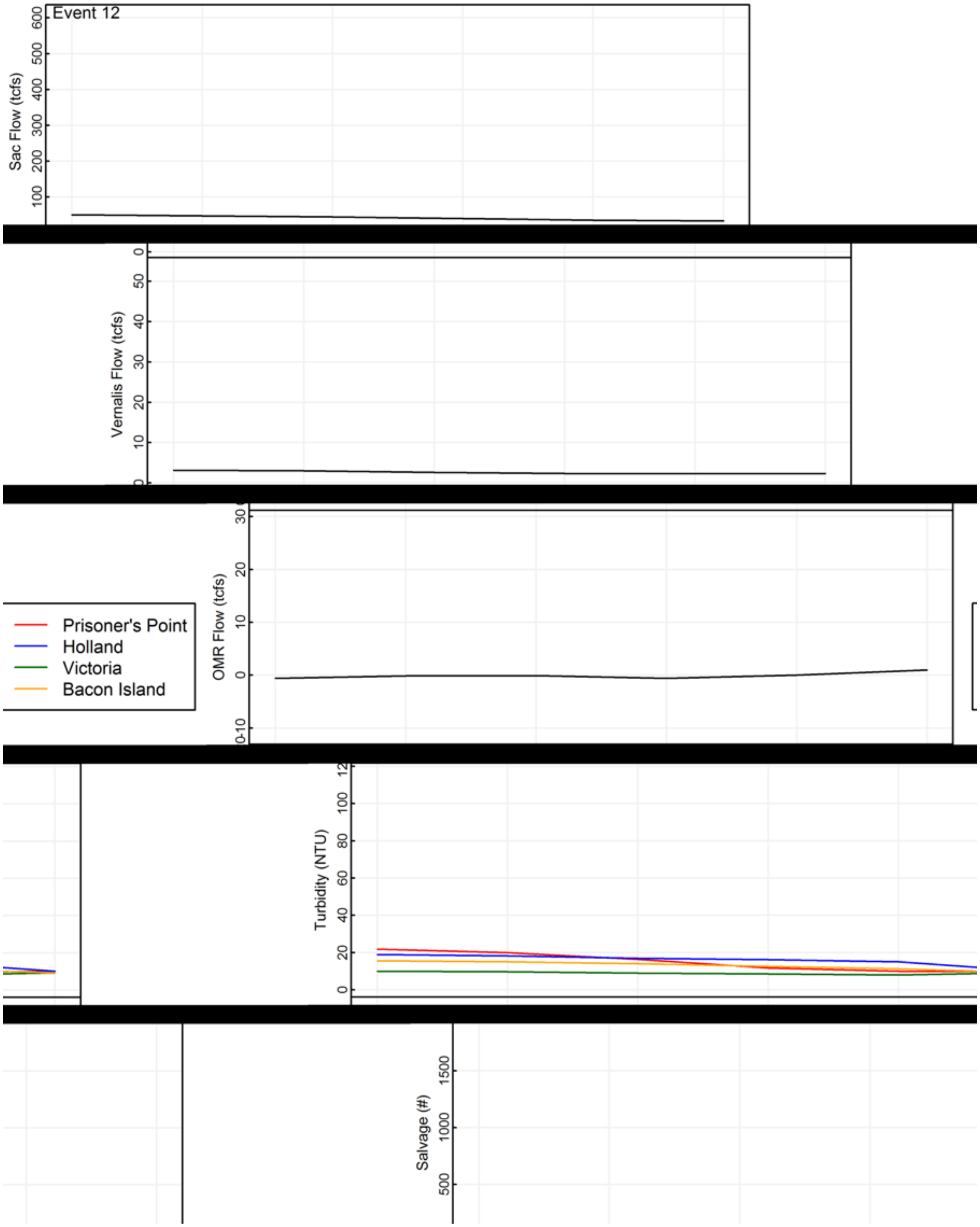


Figure C-3 **Event 12**

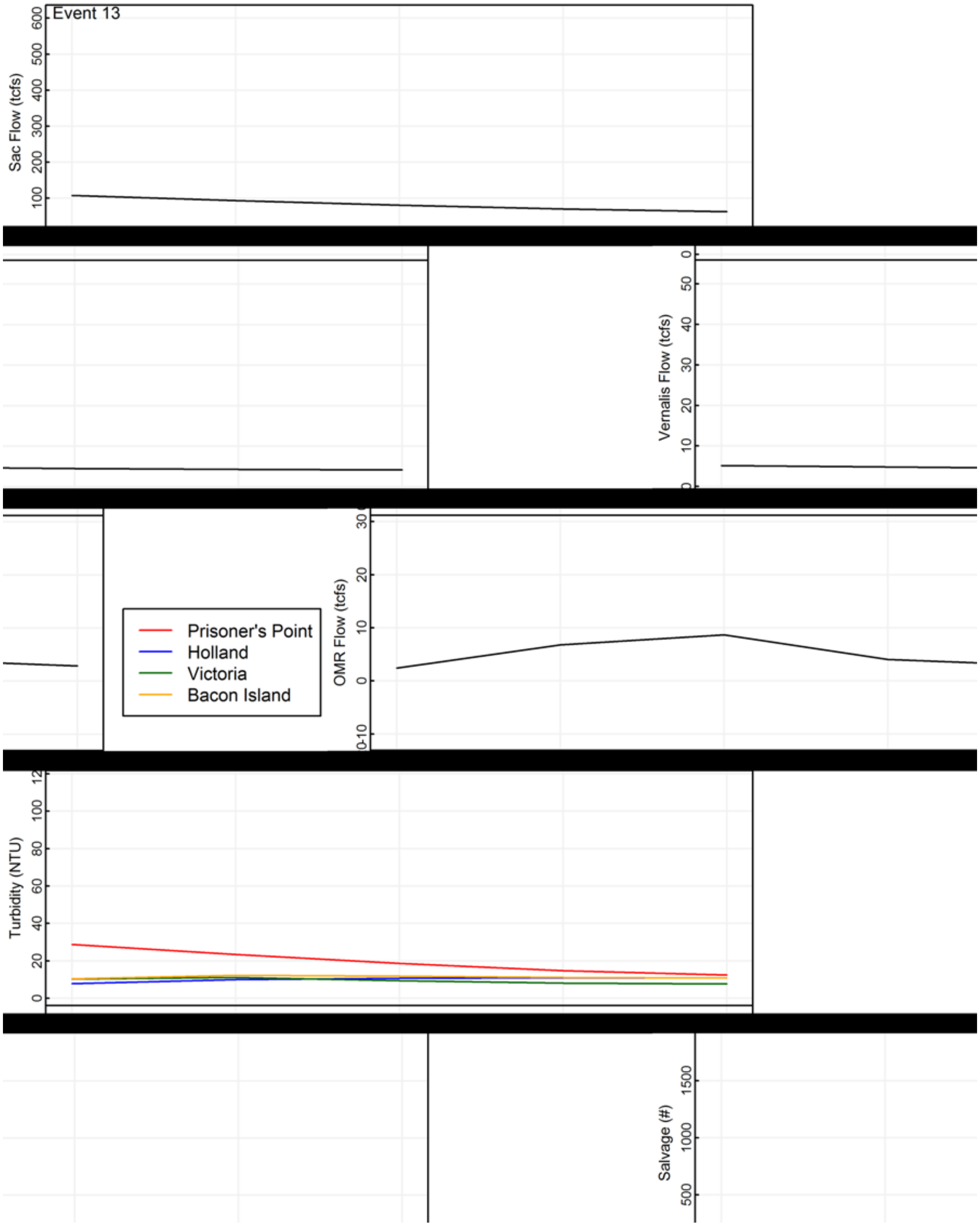


Figure C-4 **Event 13**

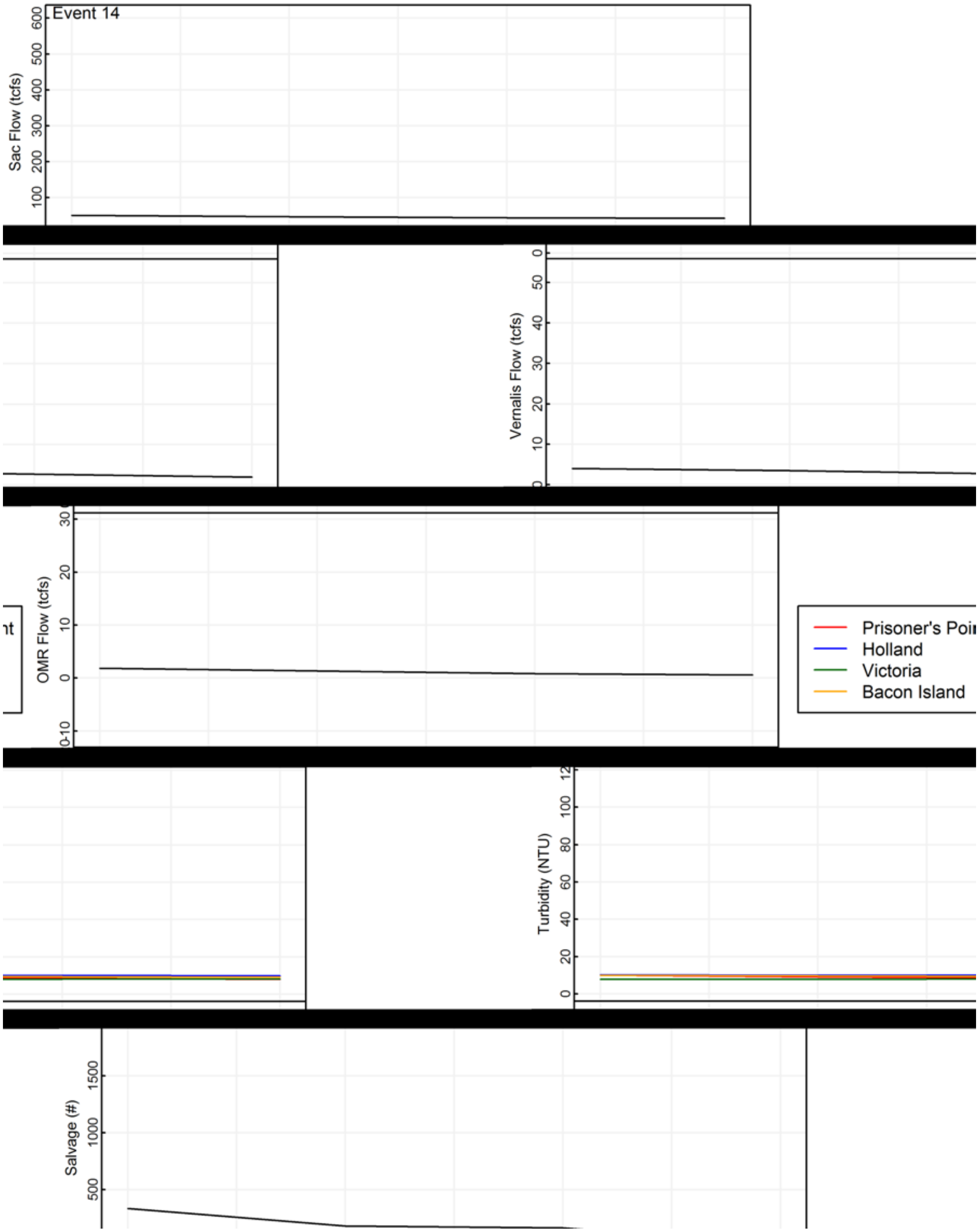


Figure C-5 **Event 14**

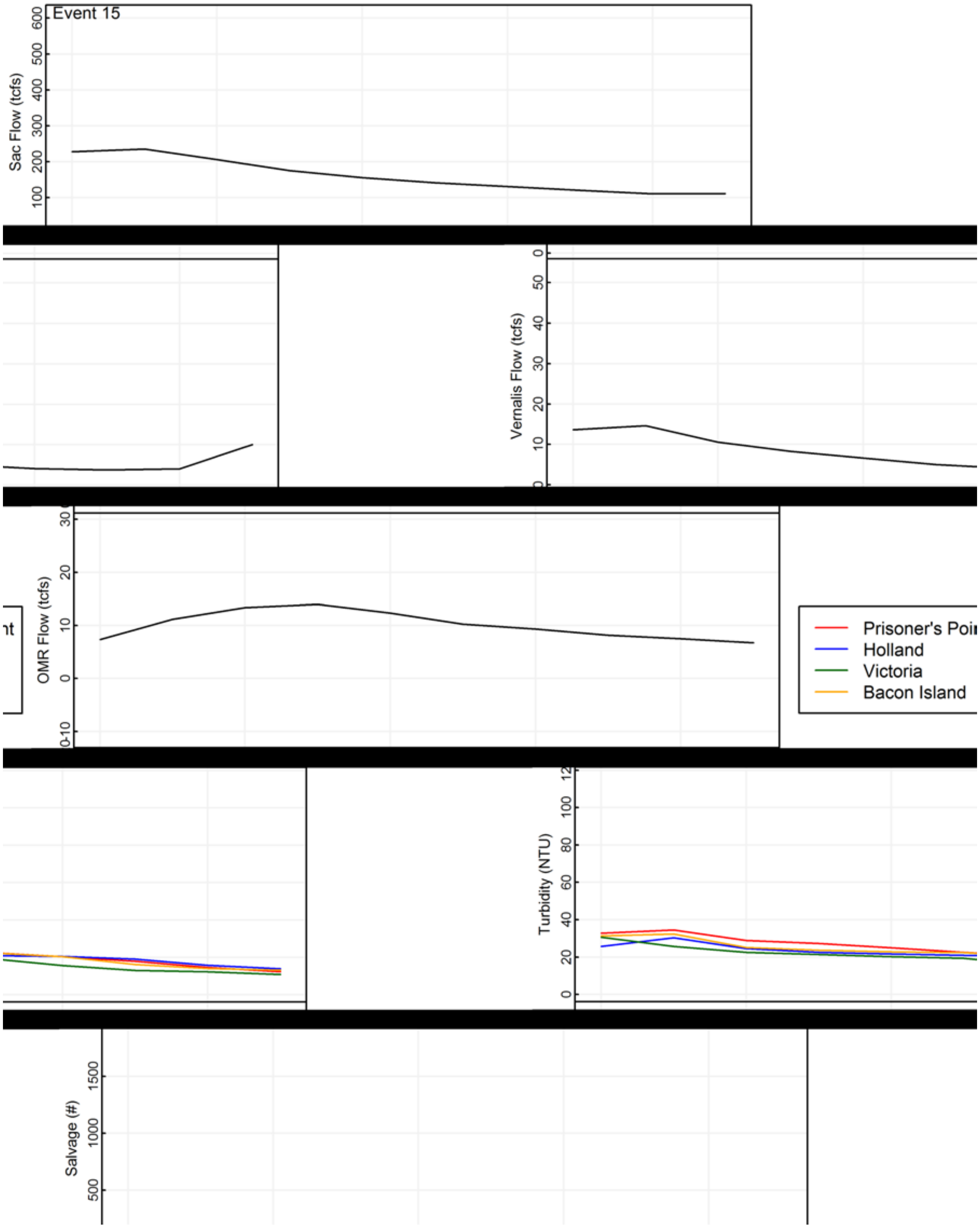


Figure C-6 **Event 15**

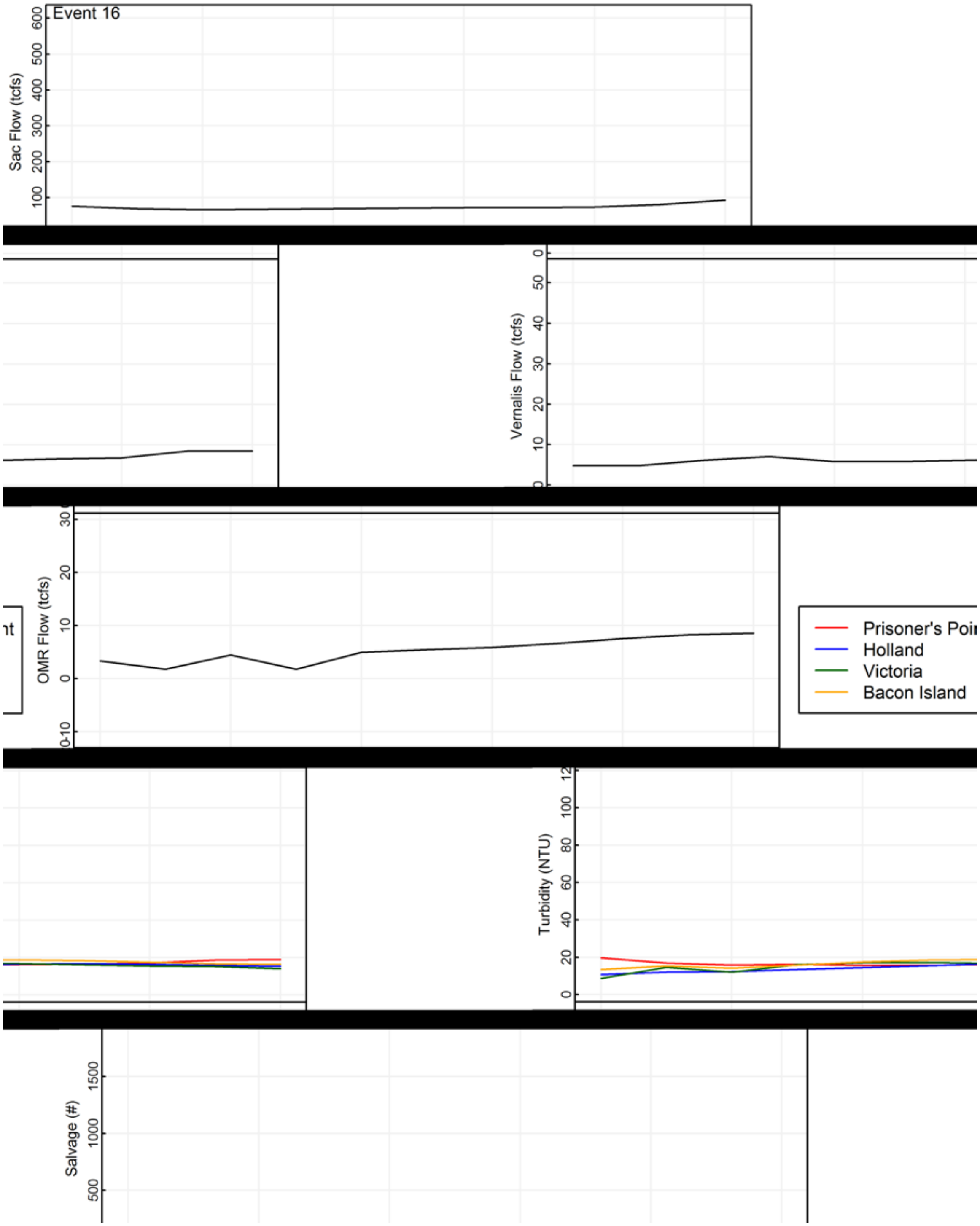


Figure C-7 **Event 16**

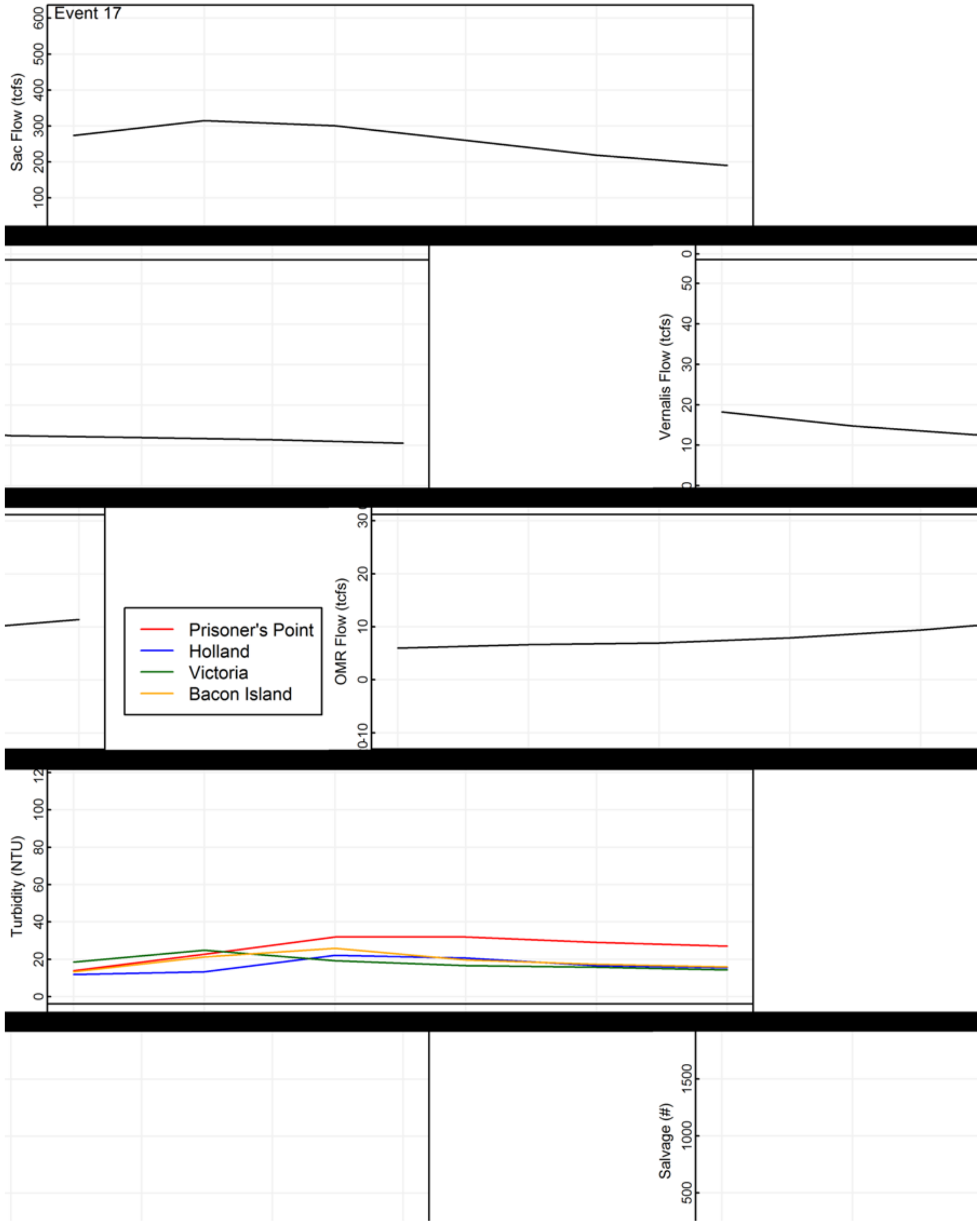


Figure C-8 **Event 17**

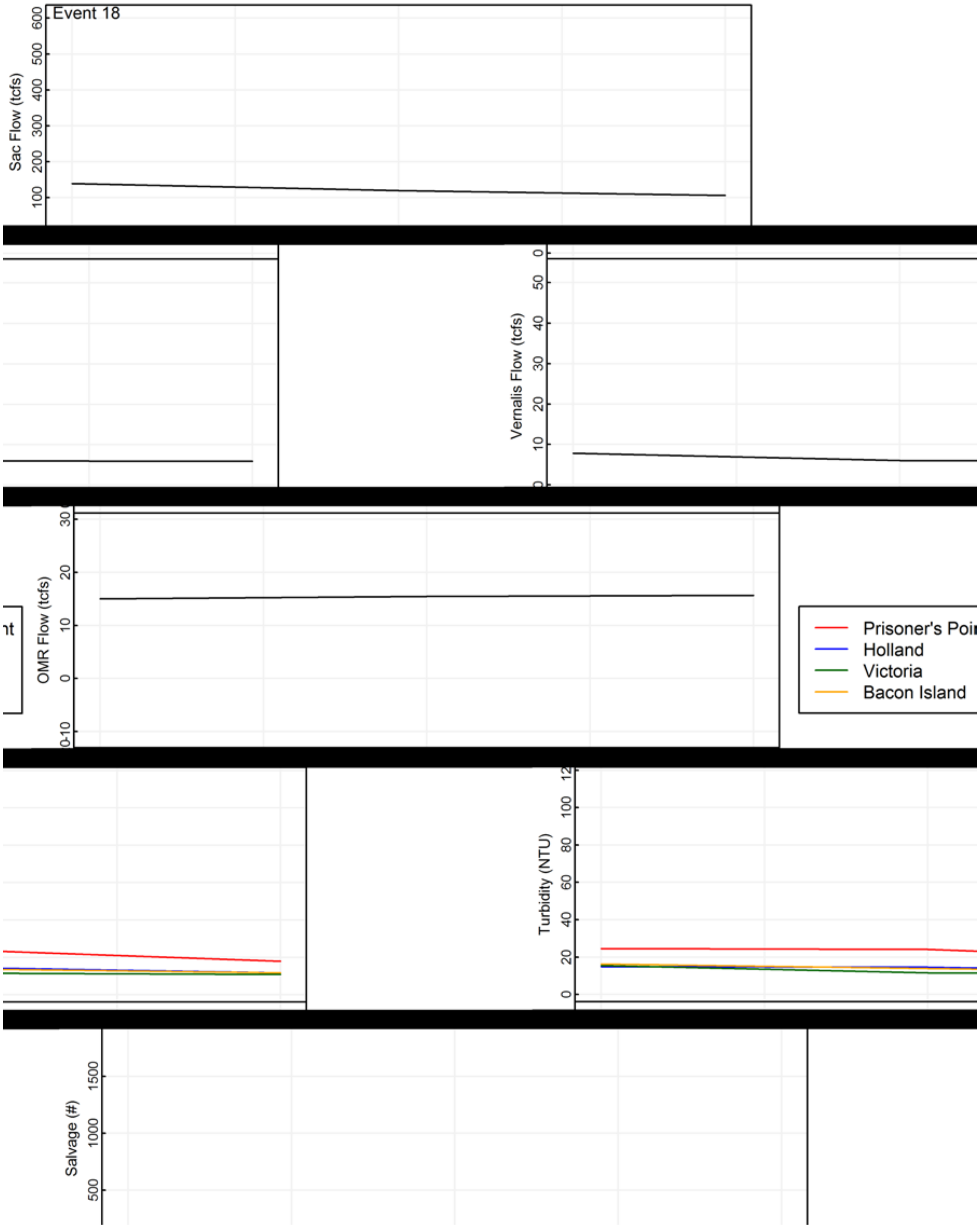


Figure C-9 **Event 18**

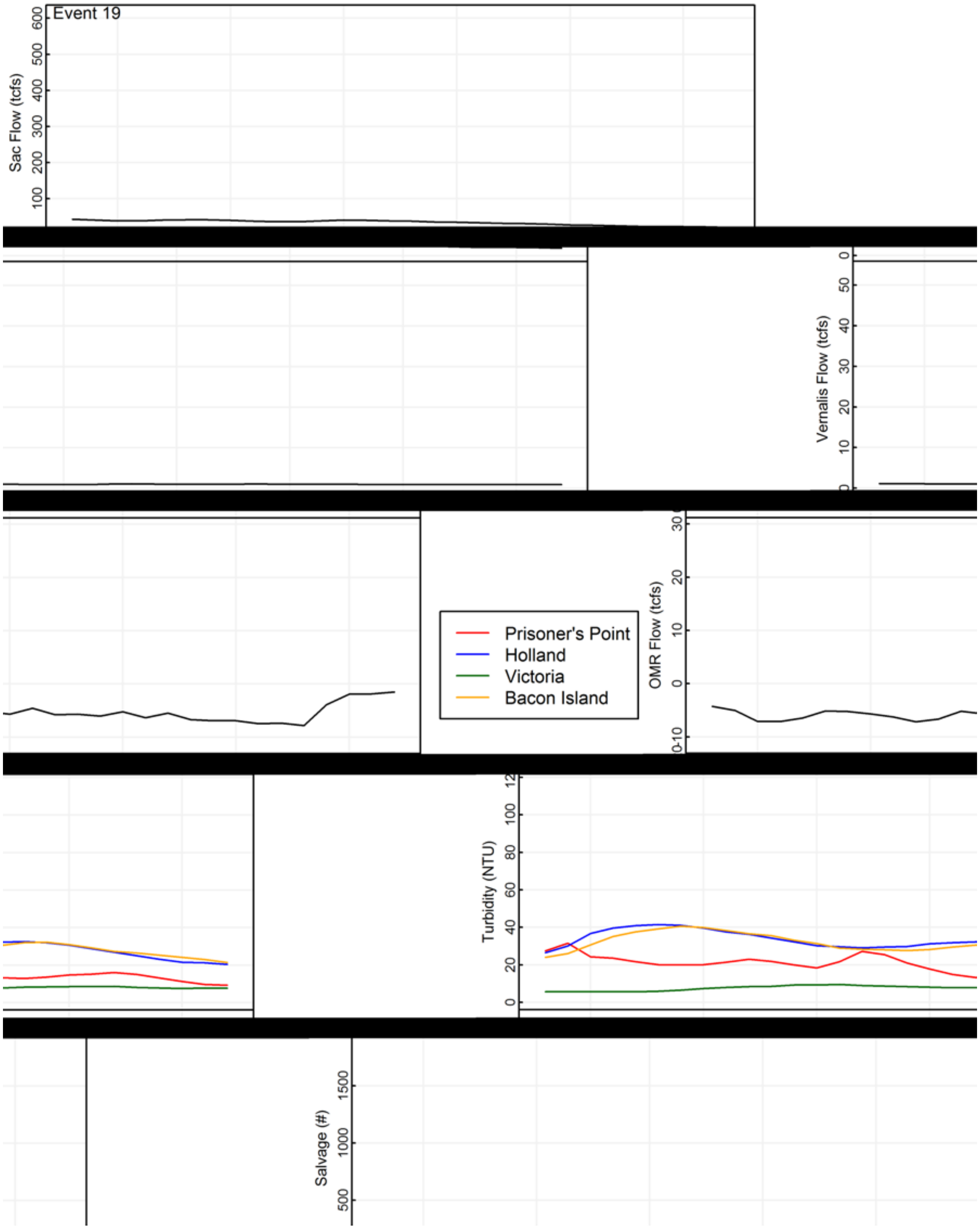


Figure C-10 **Event 19**

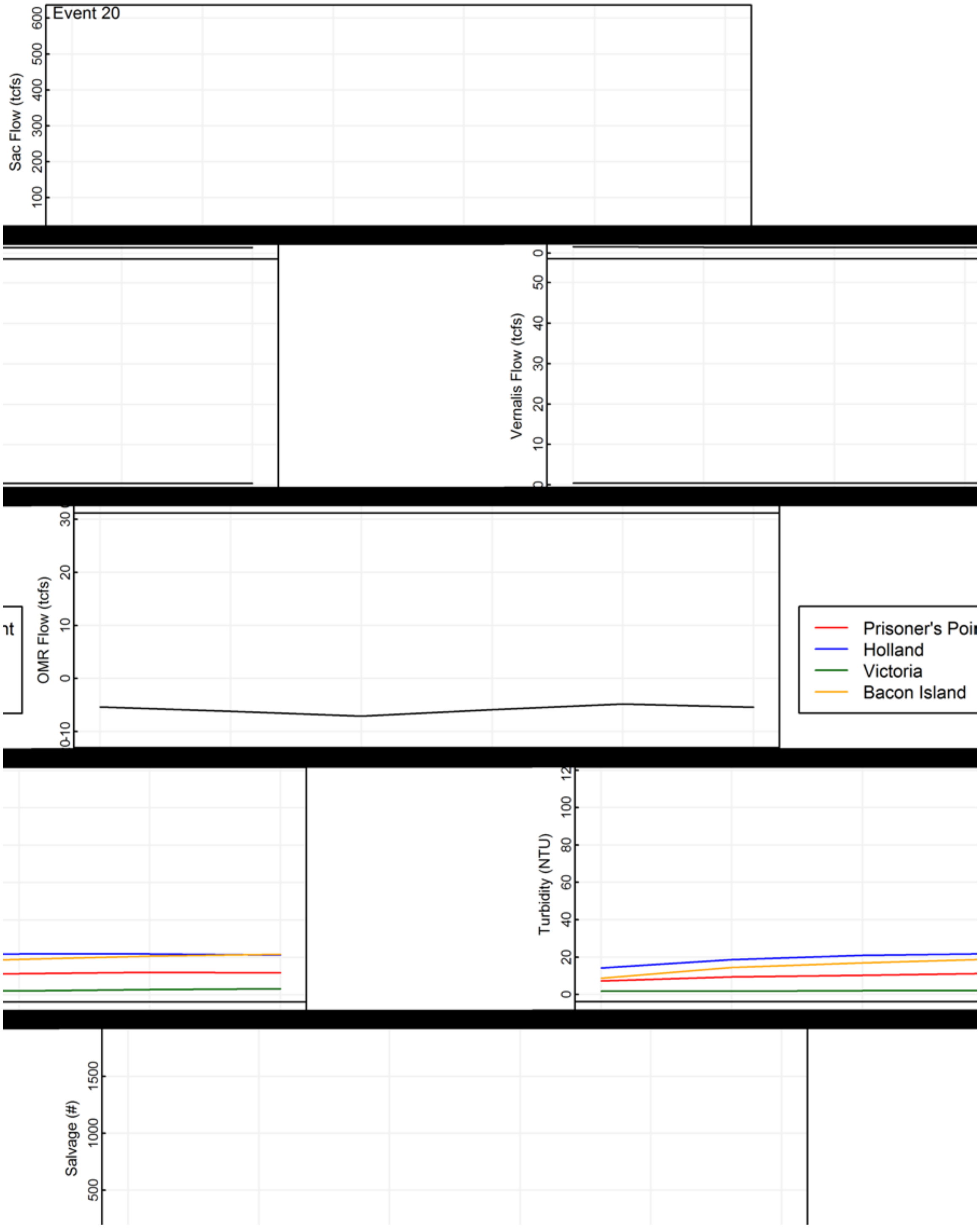


Figure C-11 **Event 20**

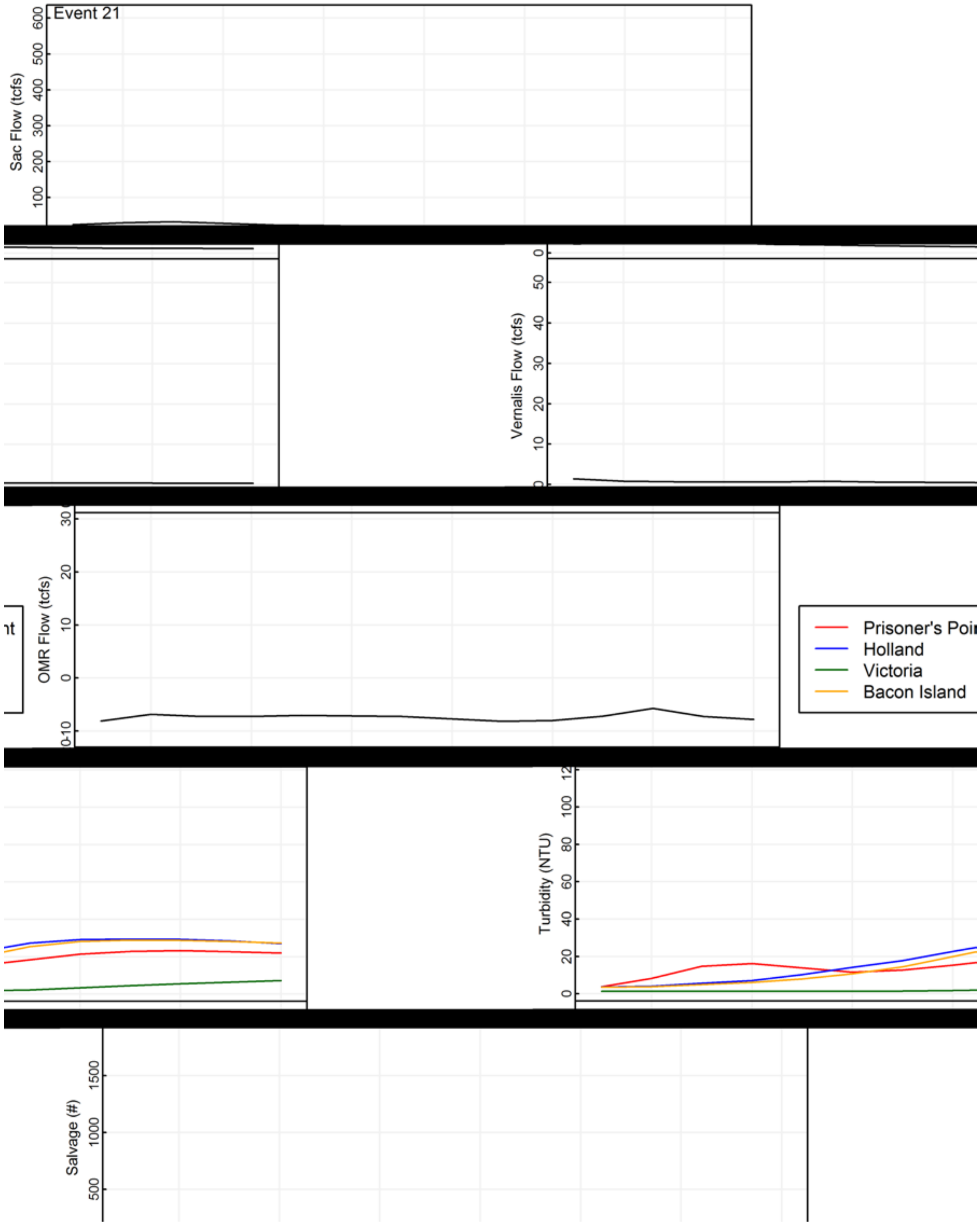


Figure C-12 **Event 21**

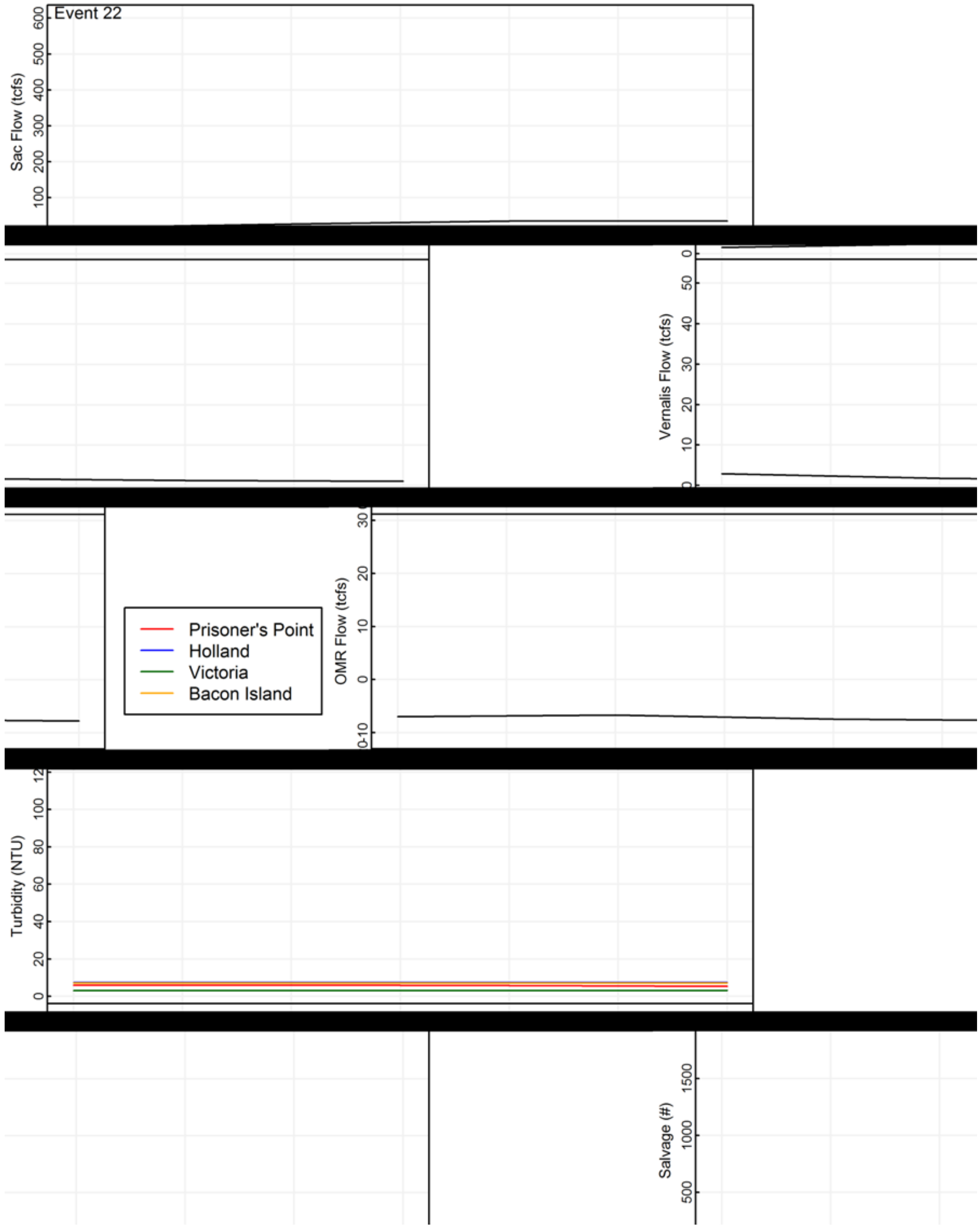


Figure C-13 **Event 22**

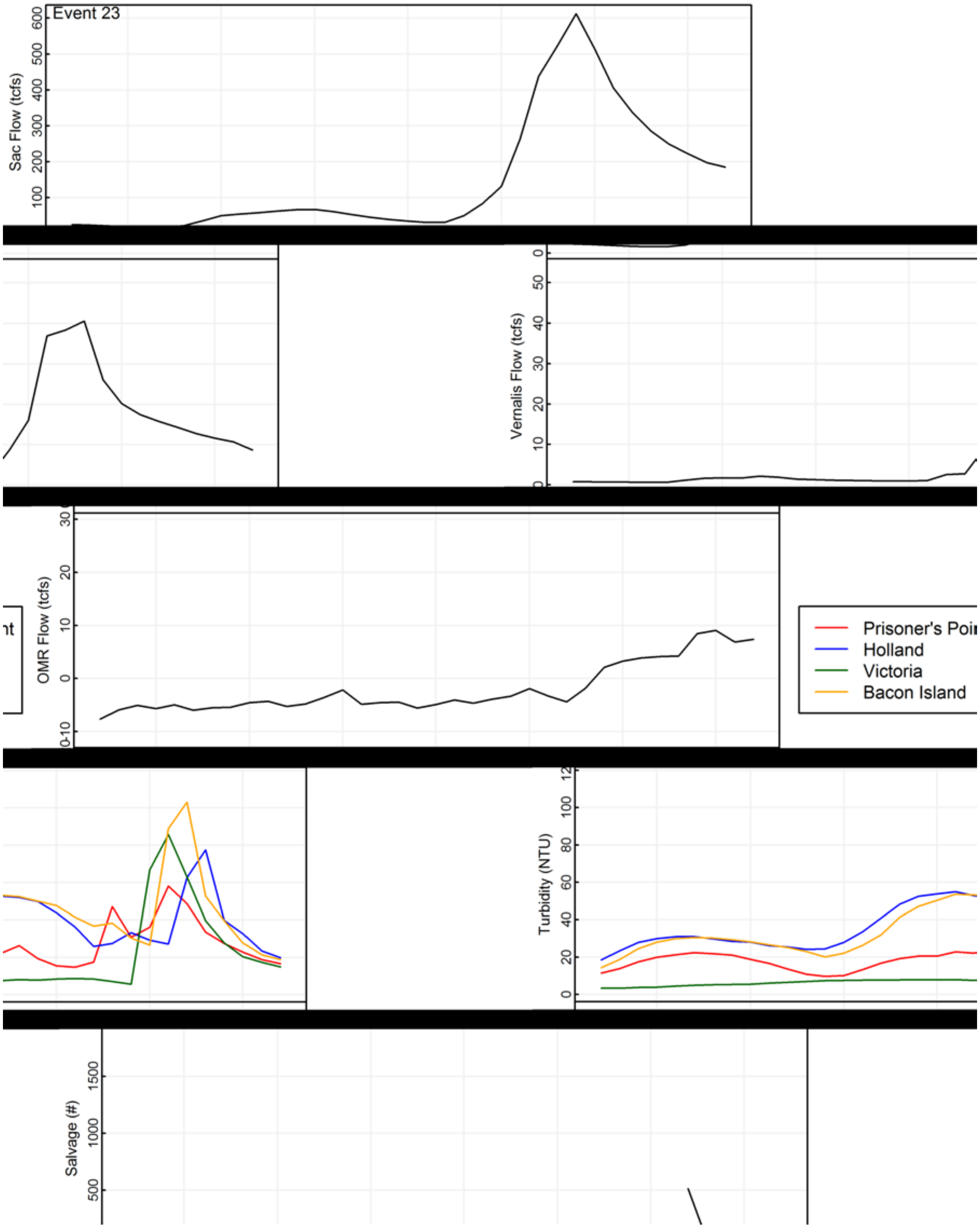


Figure C-14 **Event 23**

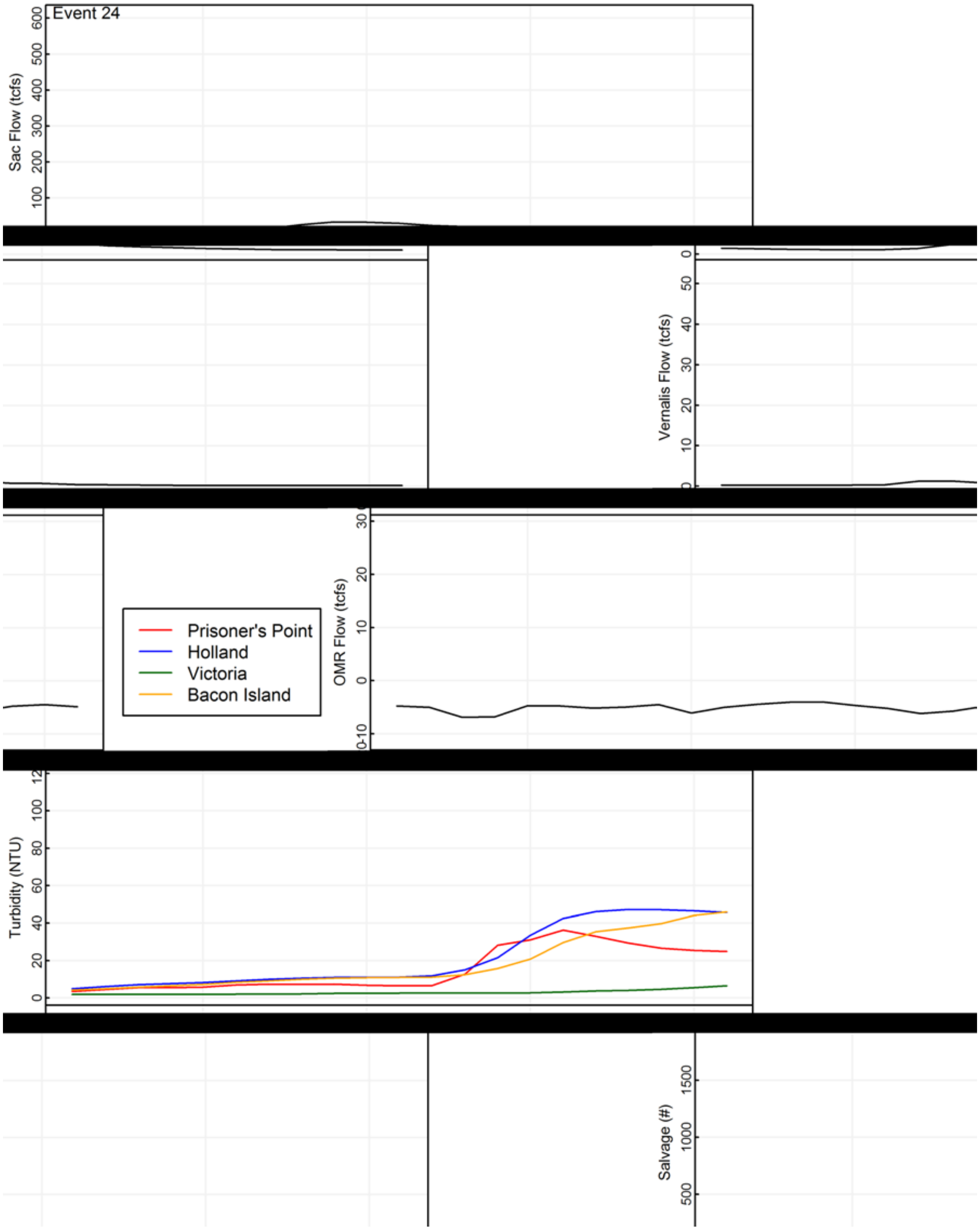


Figure C-15 **Event 24**

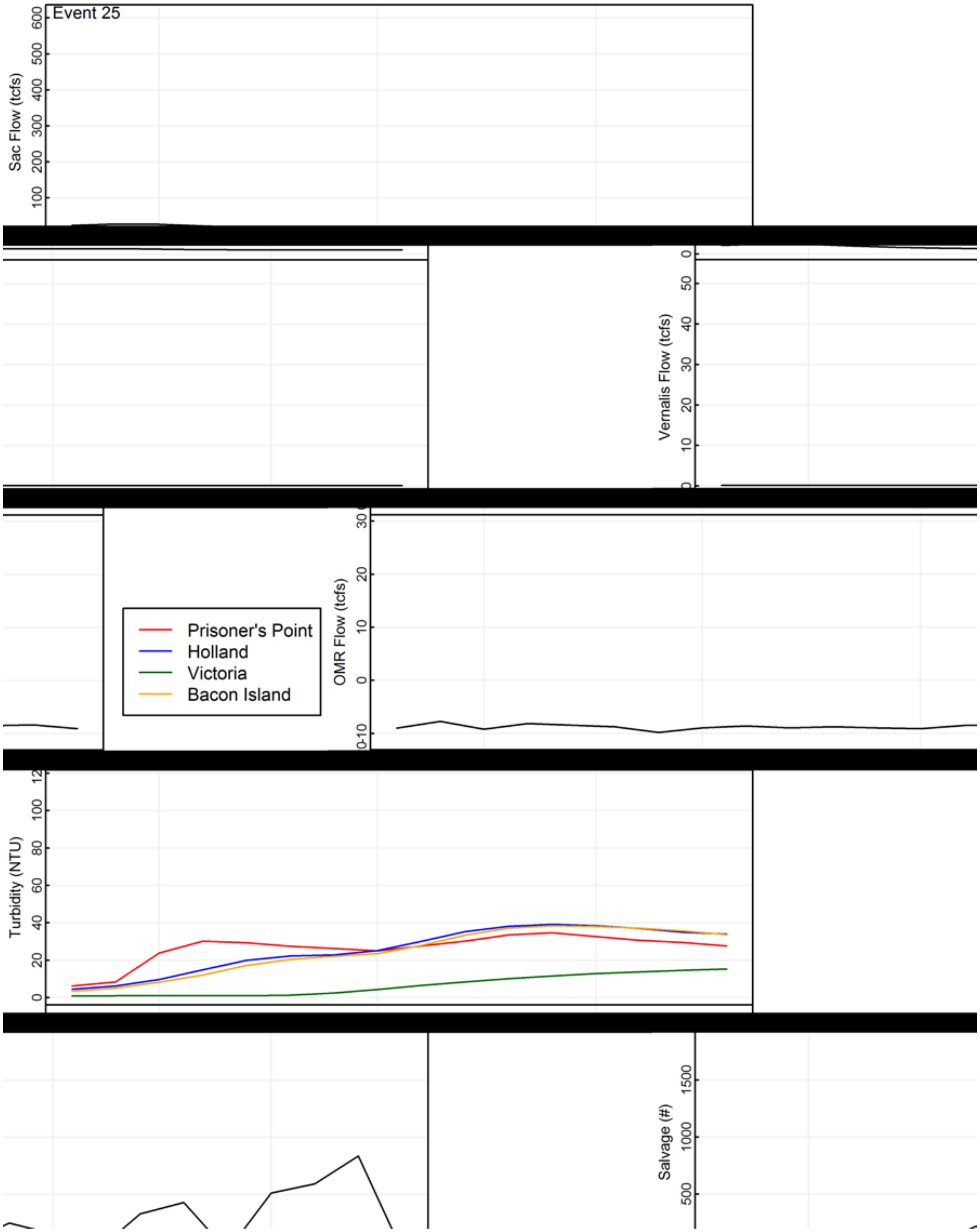


Figure C-16 **Event 25**

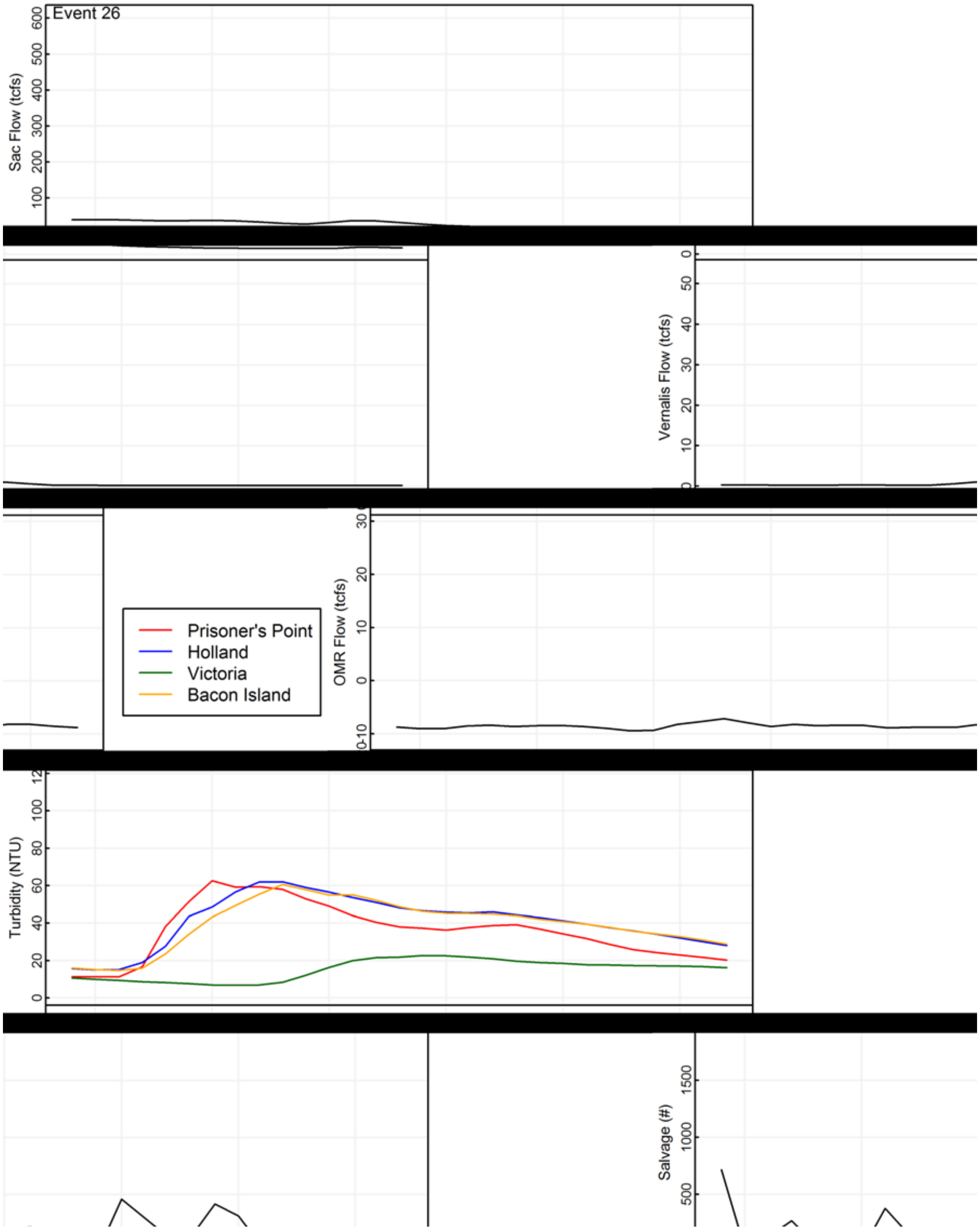


Figure C-17 **Event 26**

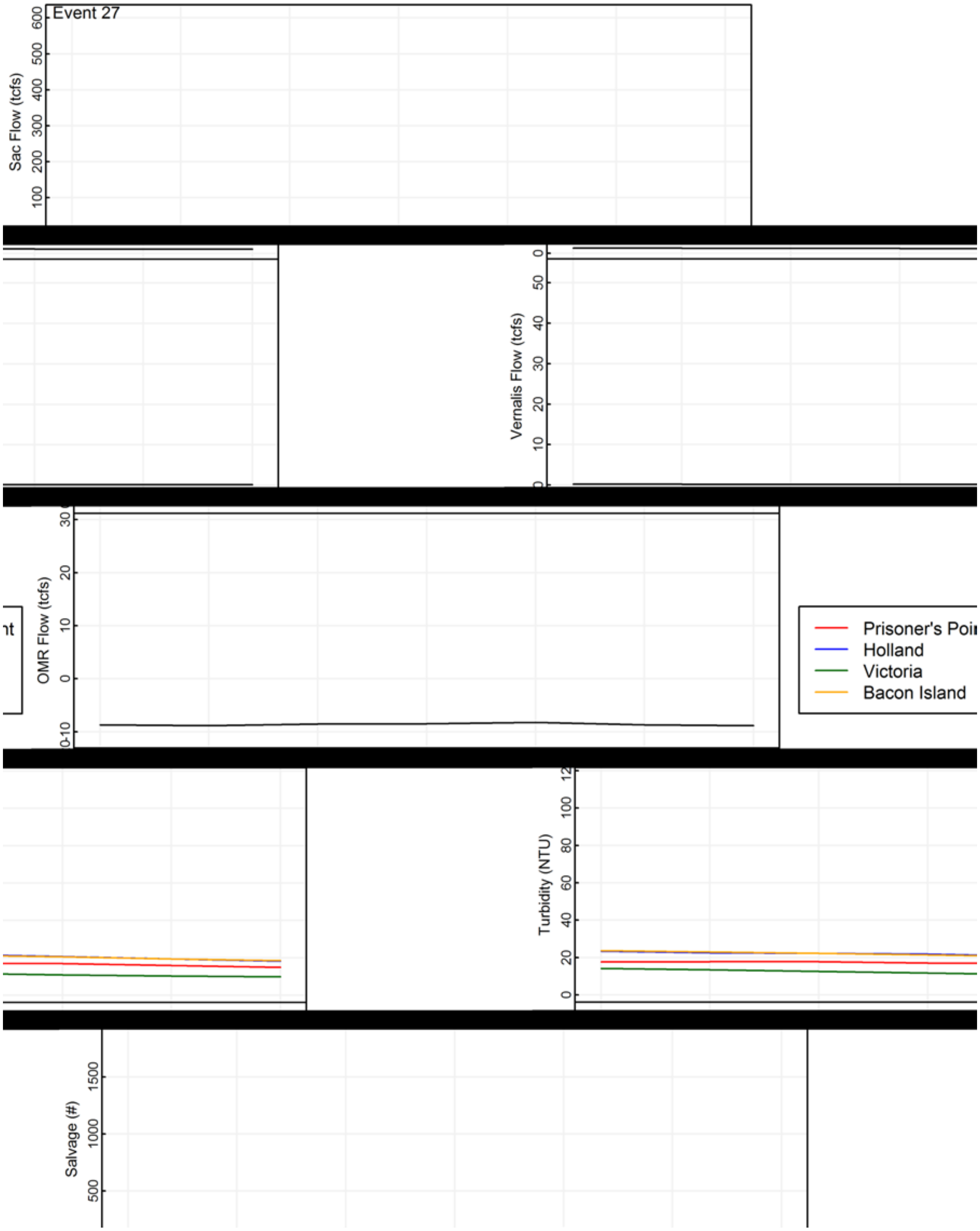


Figure C-18 **Event 27**

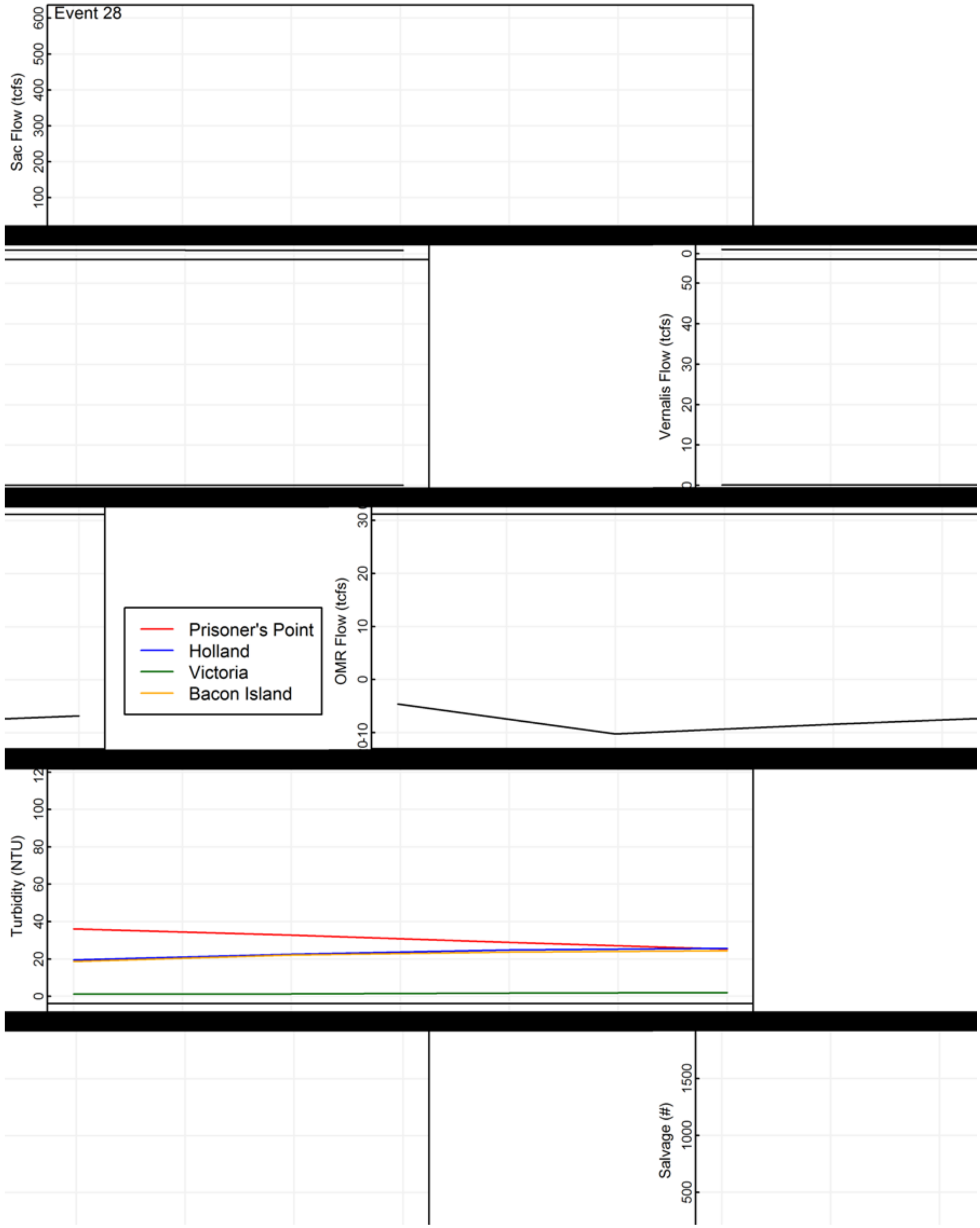


Figure C-19 **Event 28**

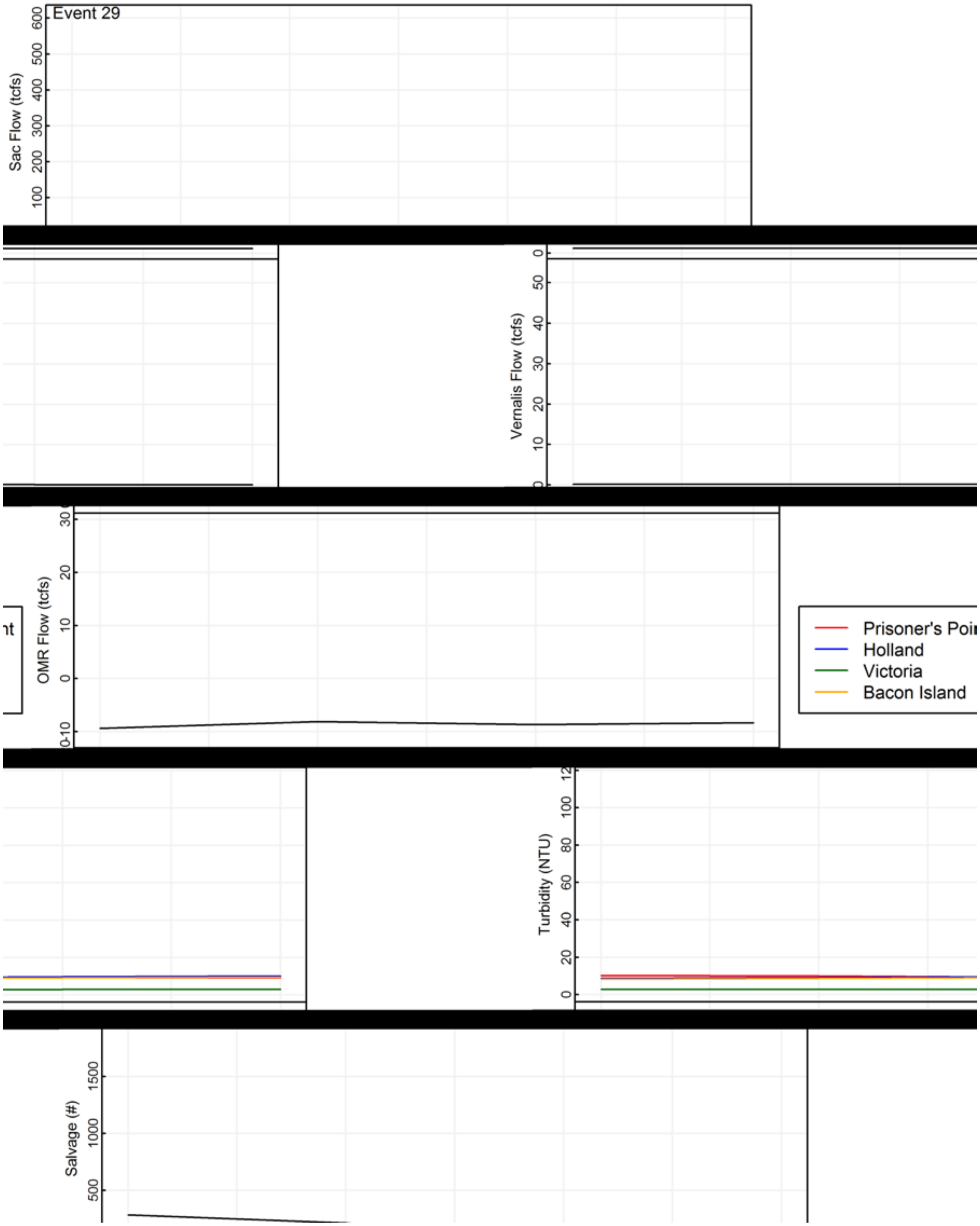


Figure C-20 Event 29

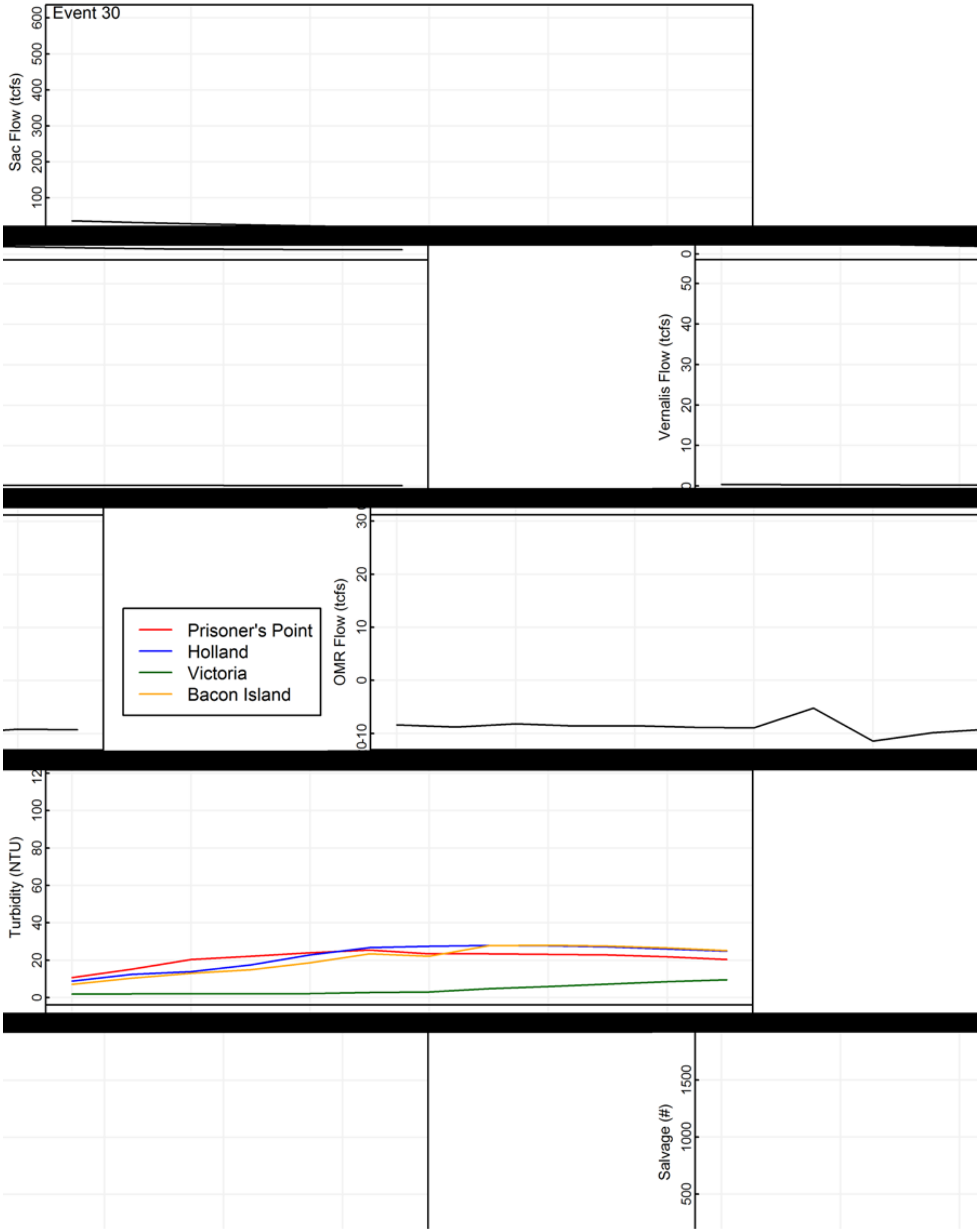


Figure C-21 **Event 30**

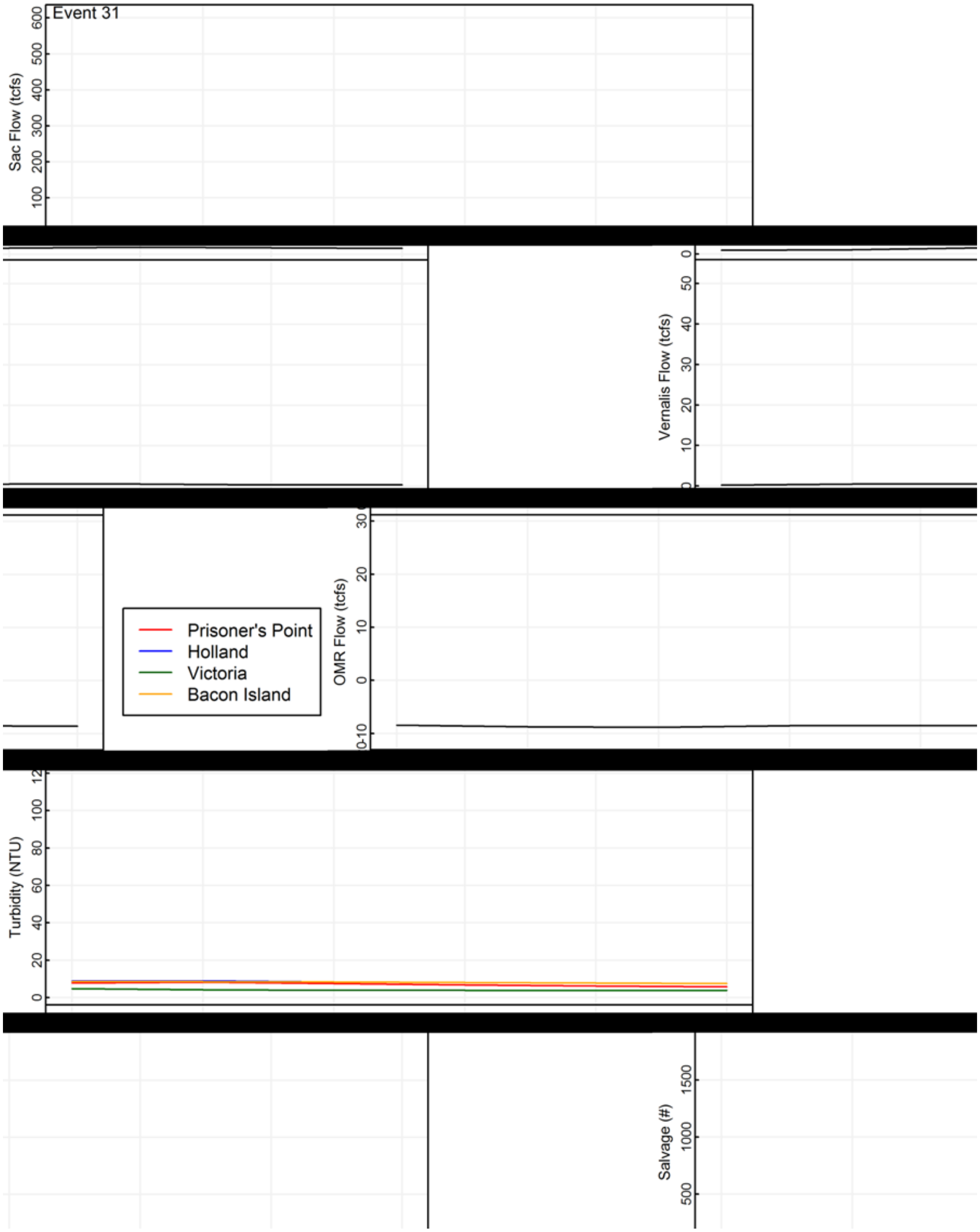


Figure C-22 **Event 31**

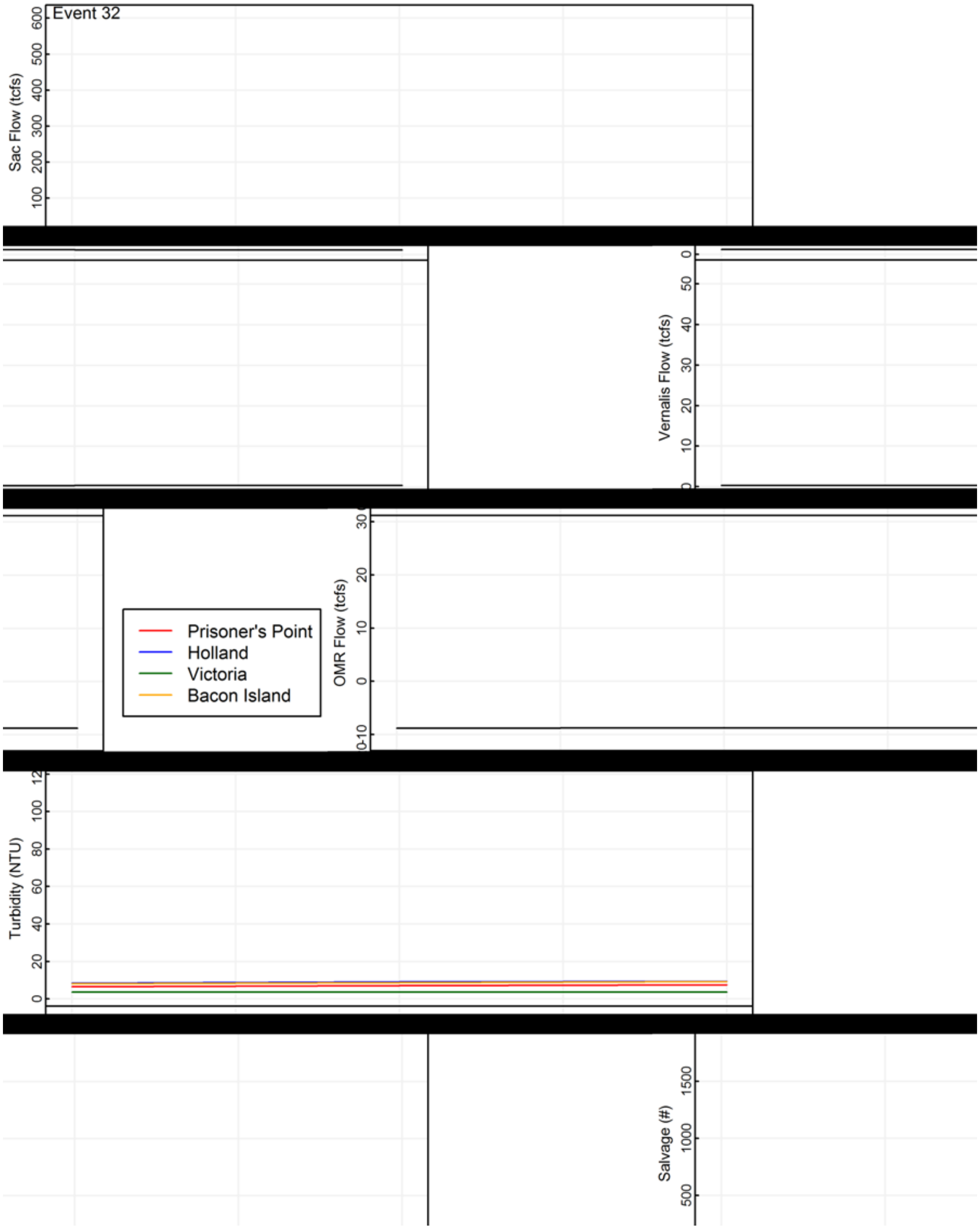


Figure C-23 Event 32

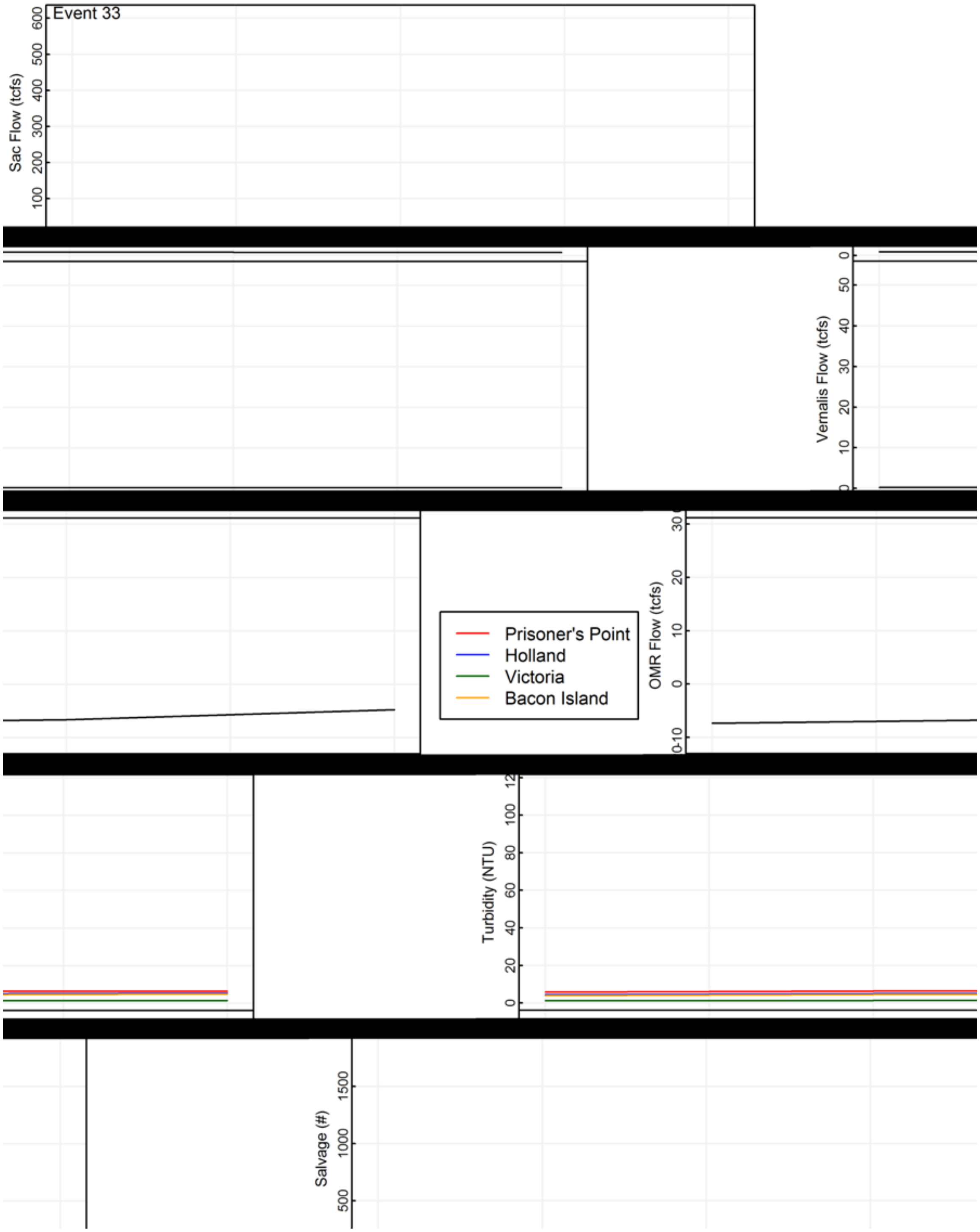


Figure C-24 **Event 33**

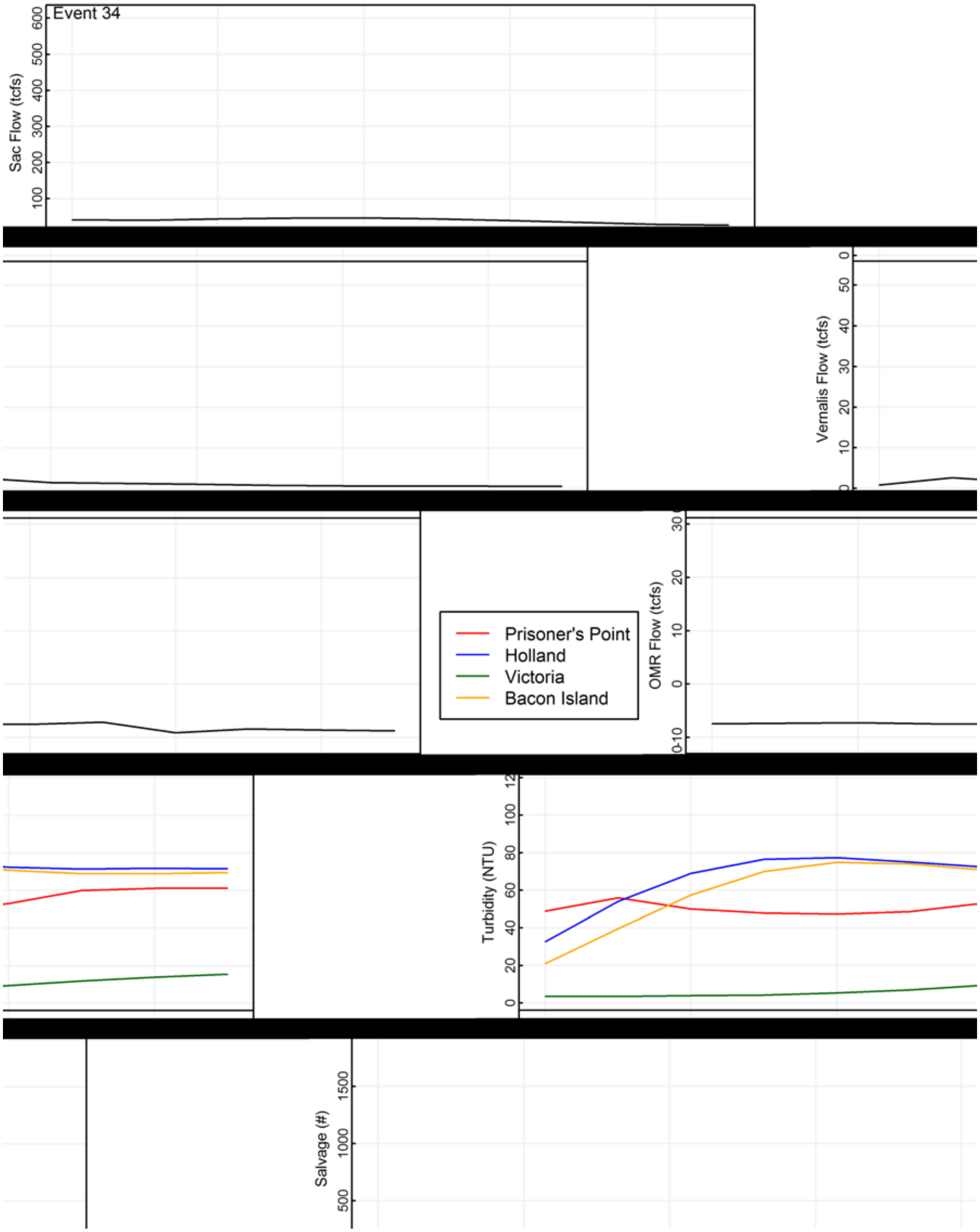


Figure C-25 **Event 34**

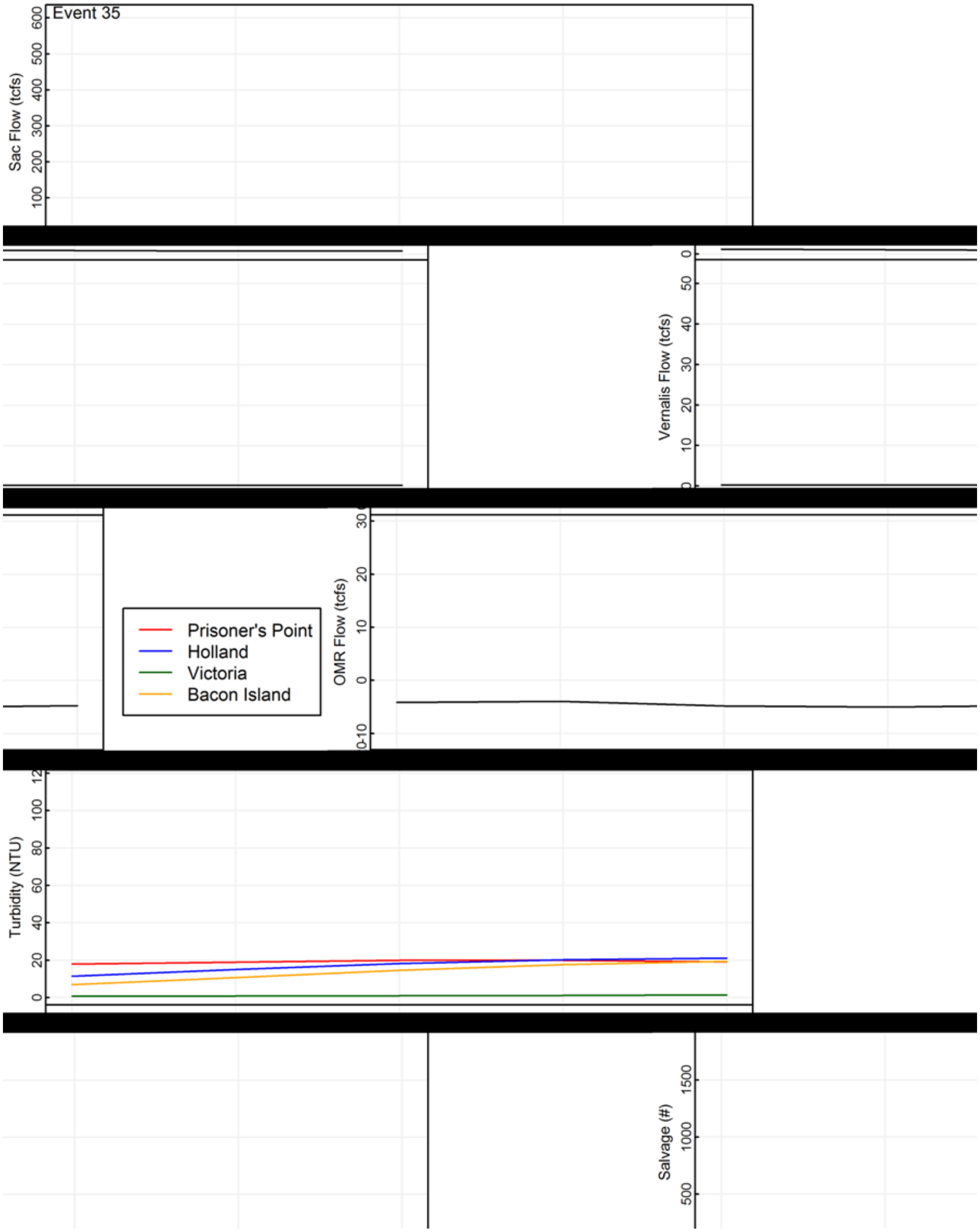


Figure C-26 **Event 35**

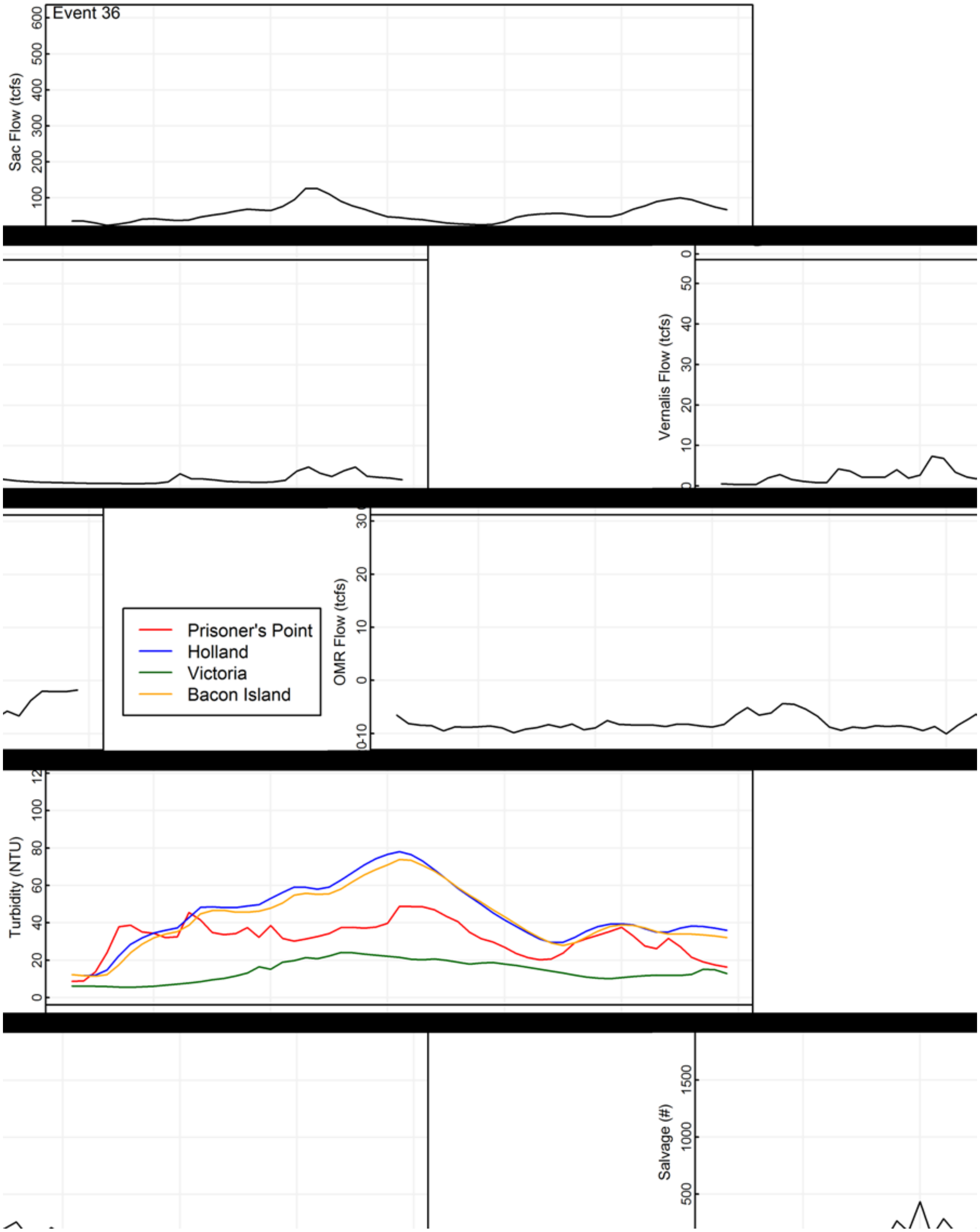


Figure C-27 **Event 36**

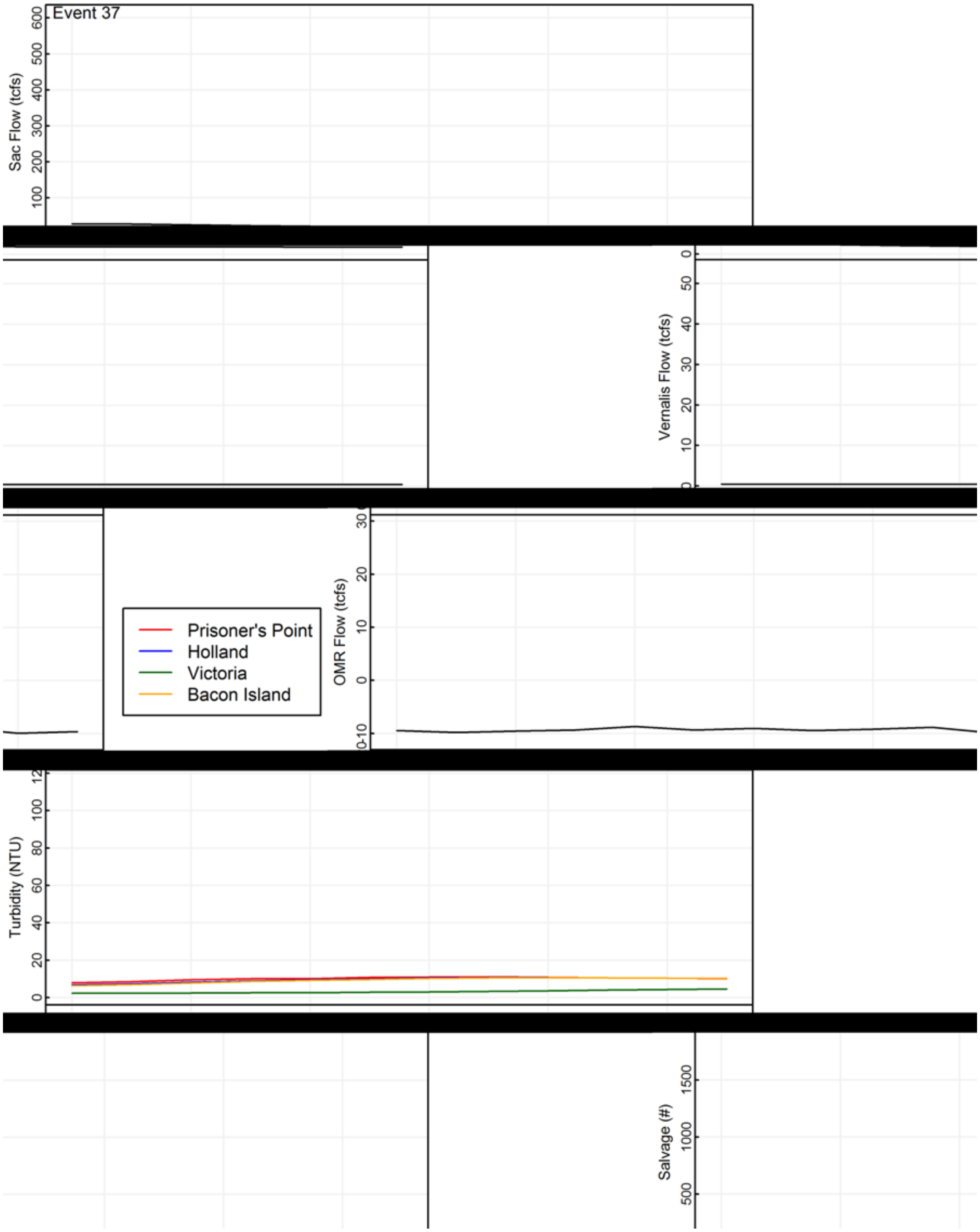


Figure C-28 **Event 37**

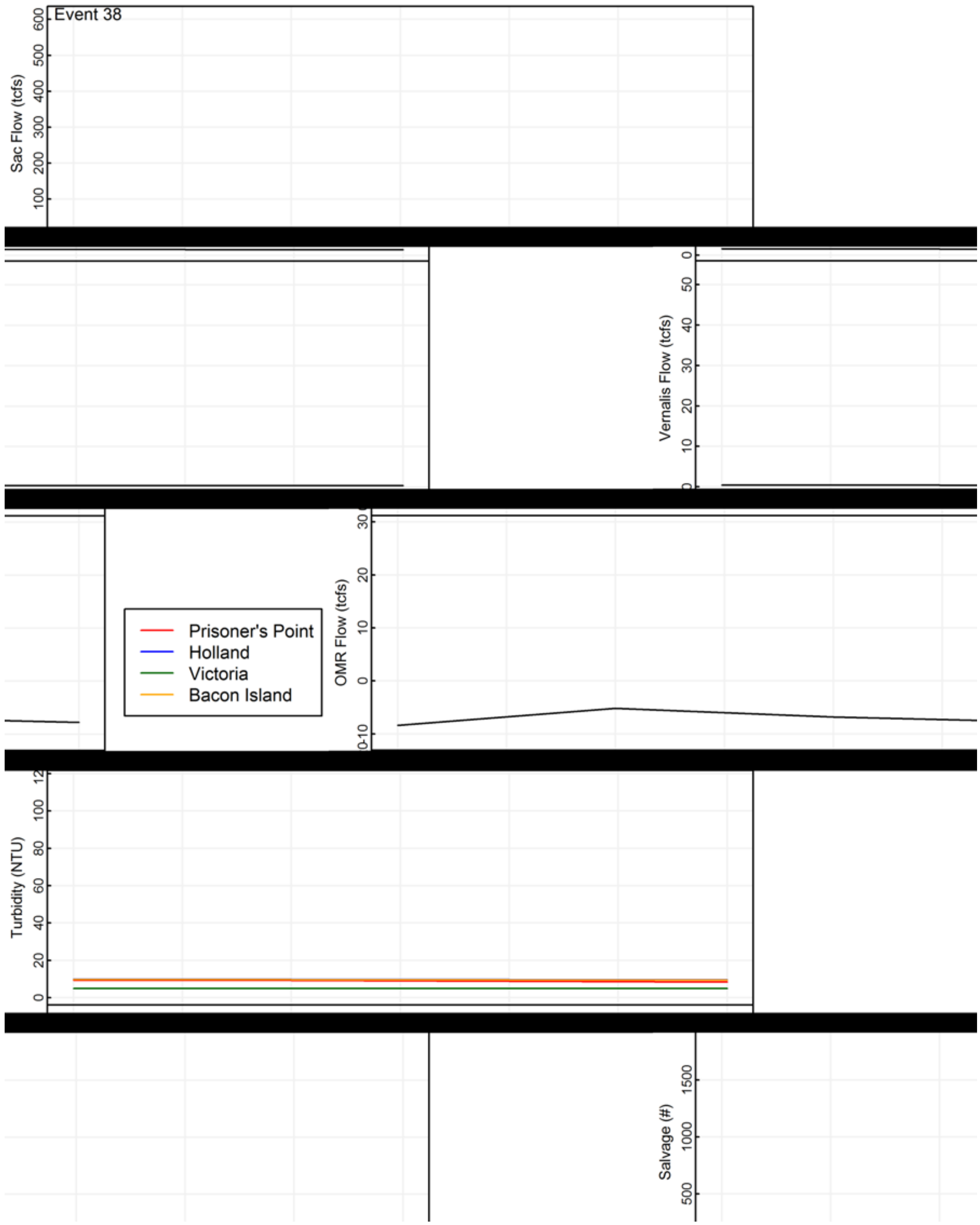


Figure C-29 **Event 38**

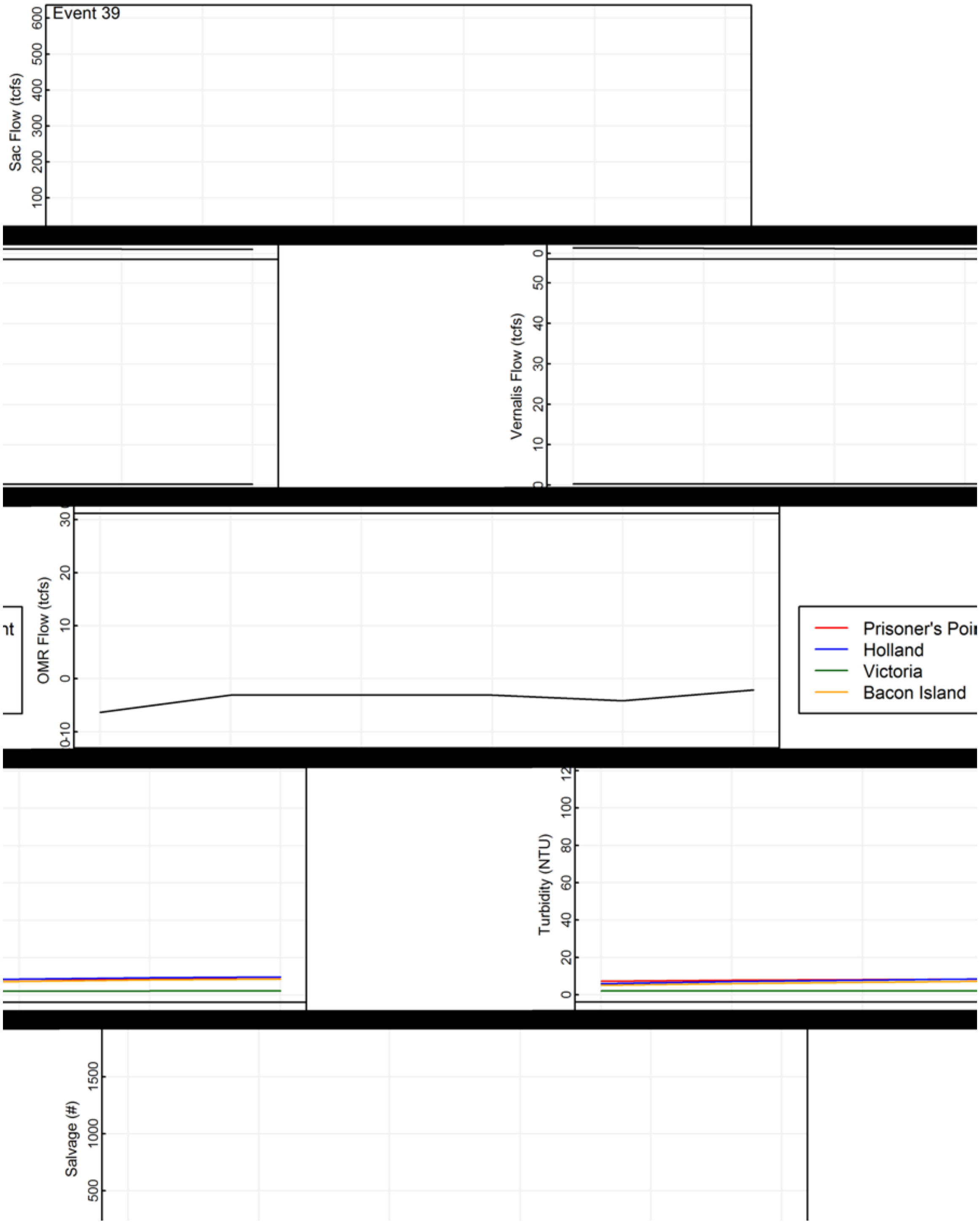


Figure C-30 **Event 39**

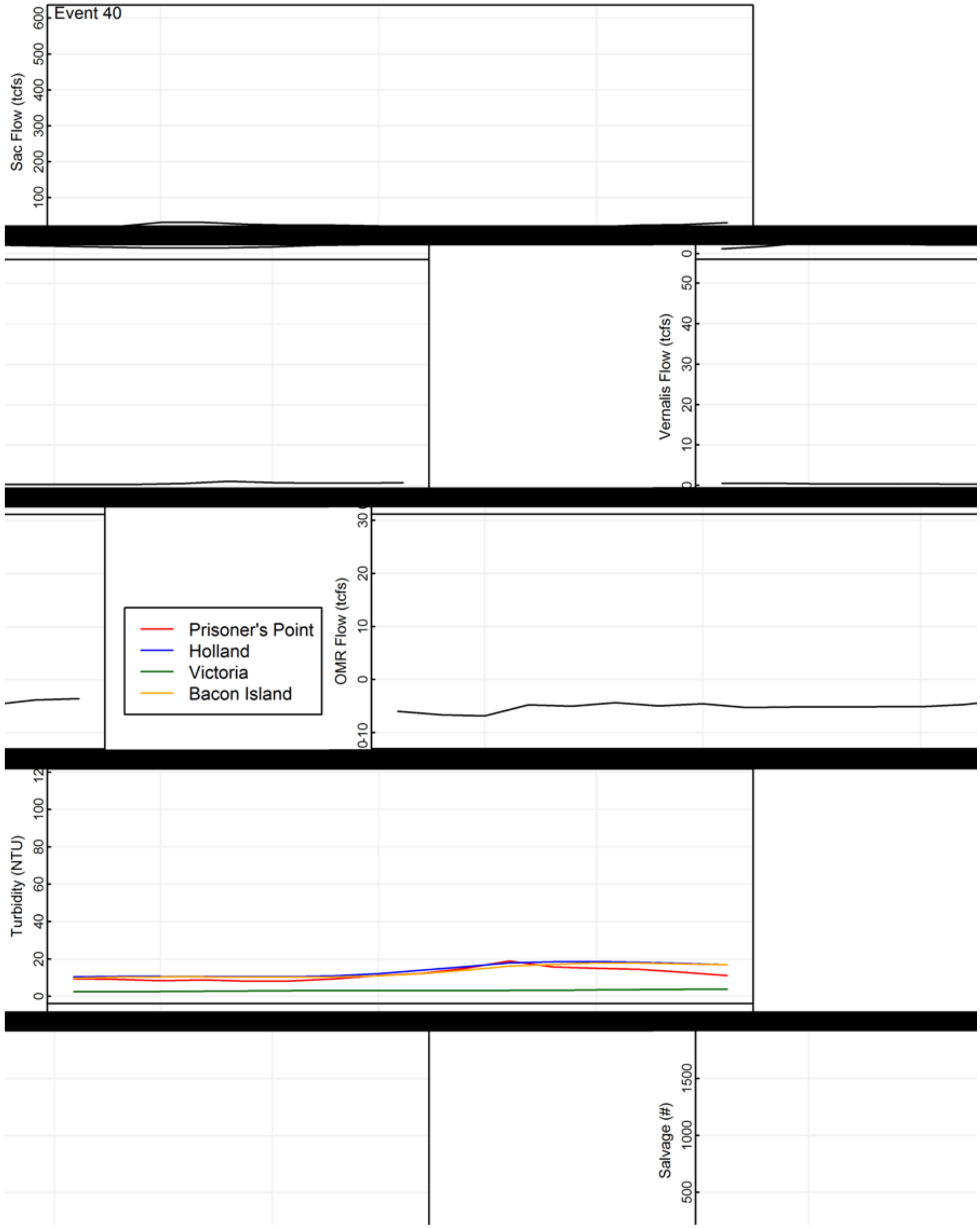


Figure C-31 **Event 40**

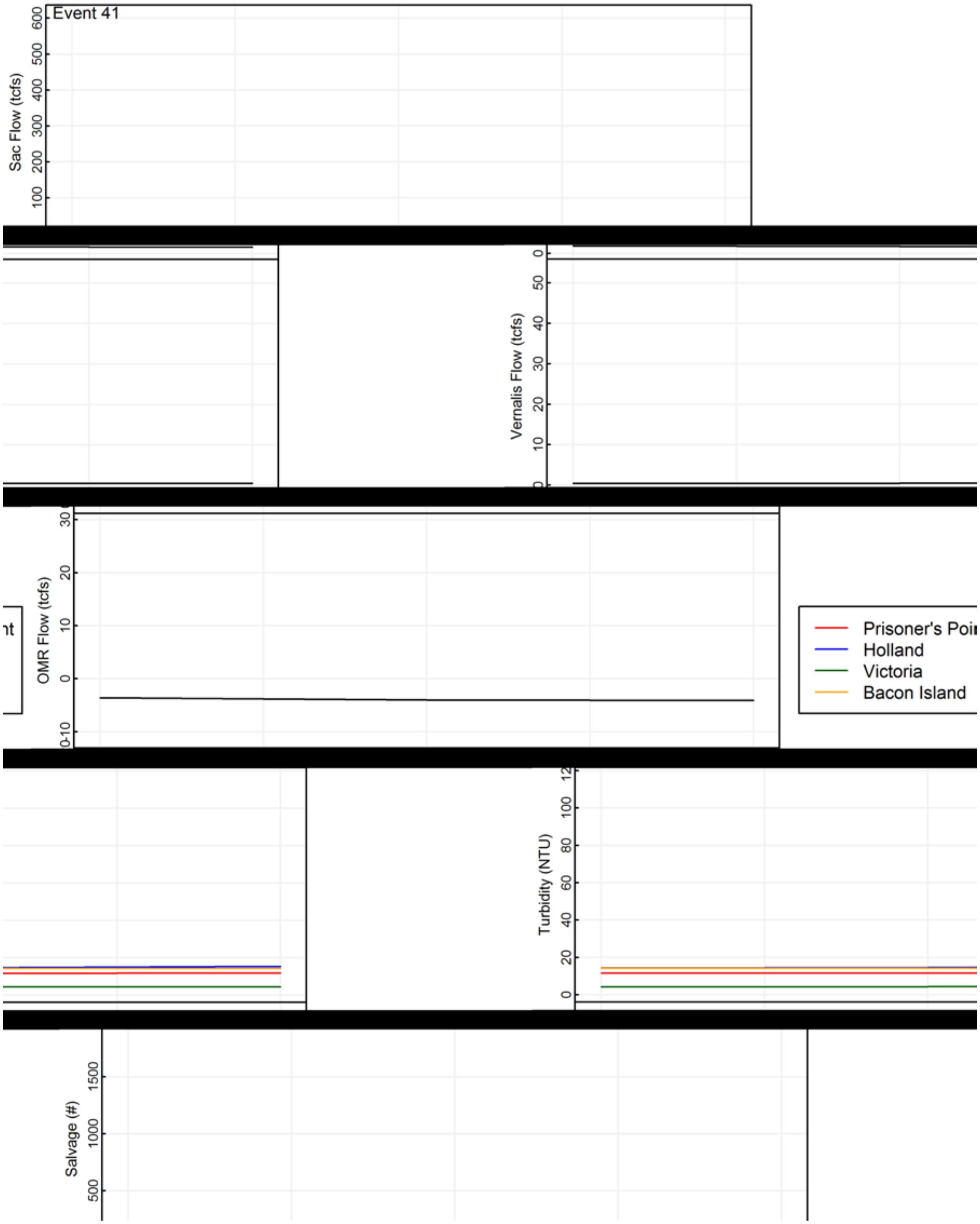


Figure C-32 **Event 41**

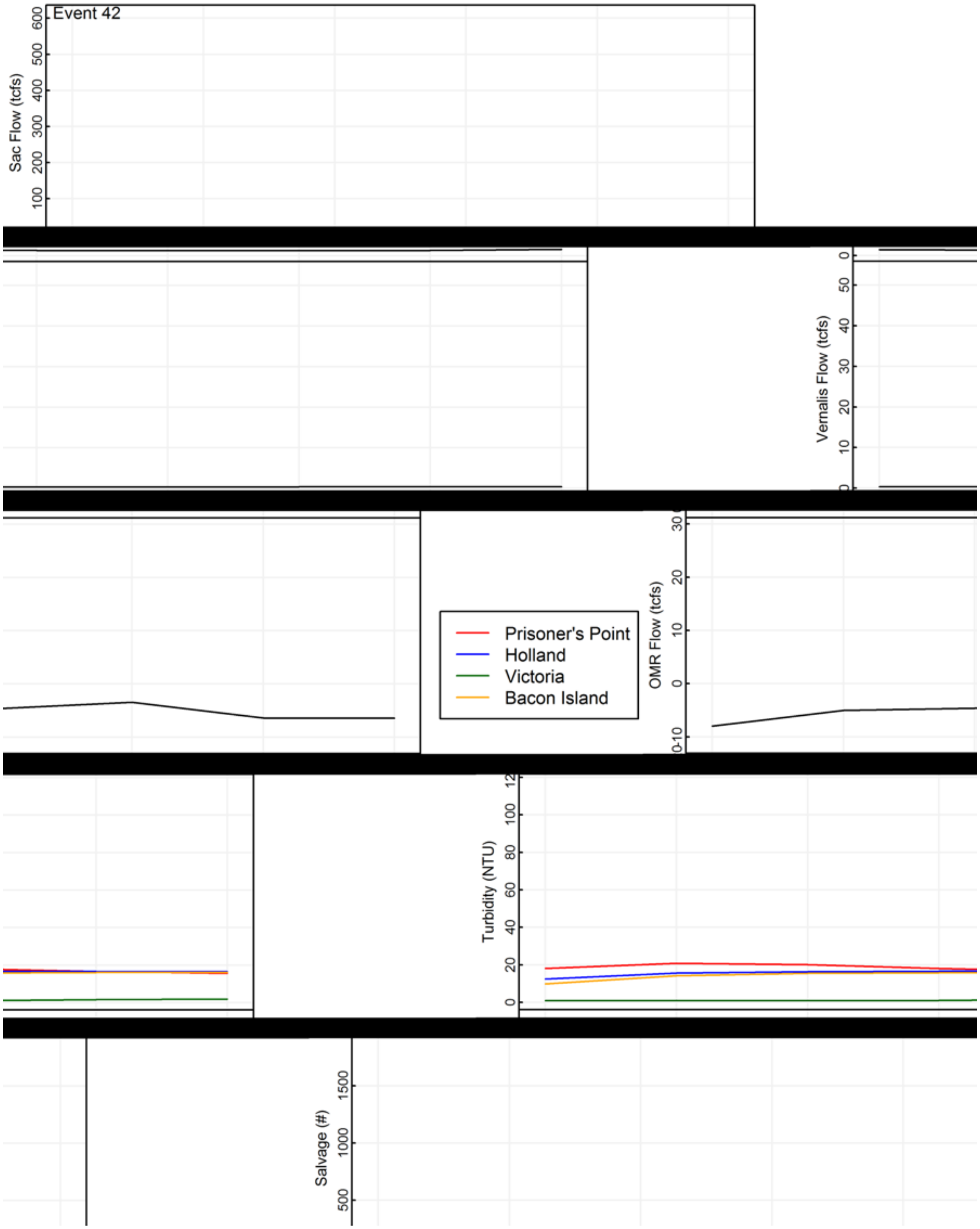


Figure C-33 **Event 42**

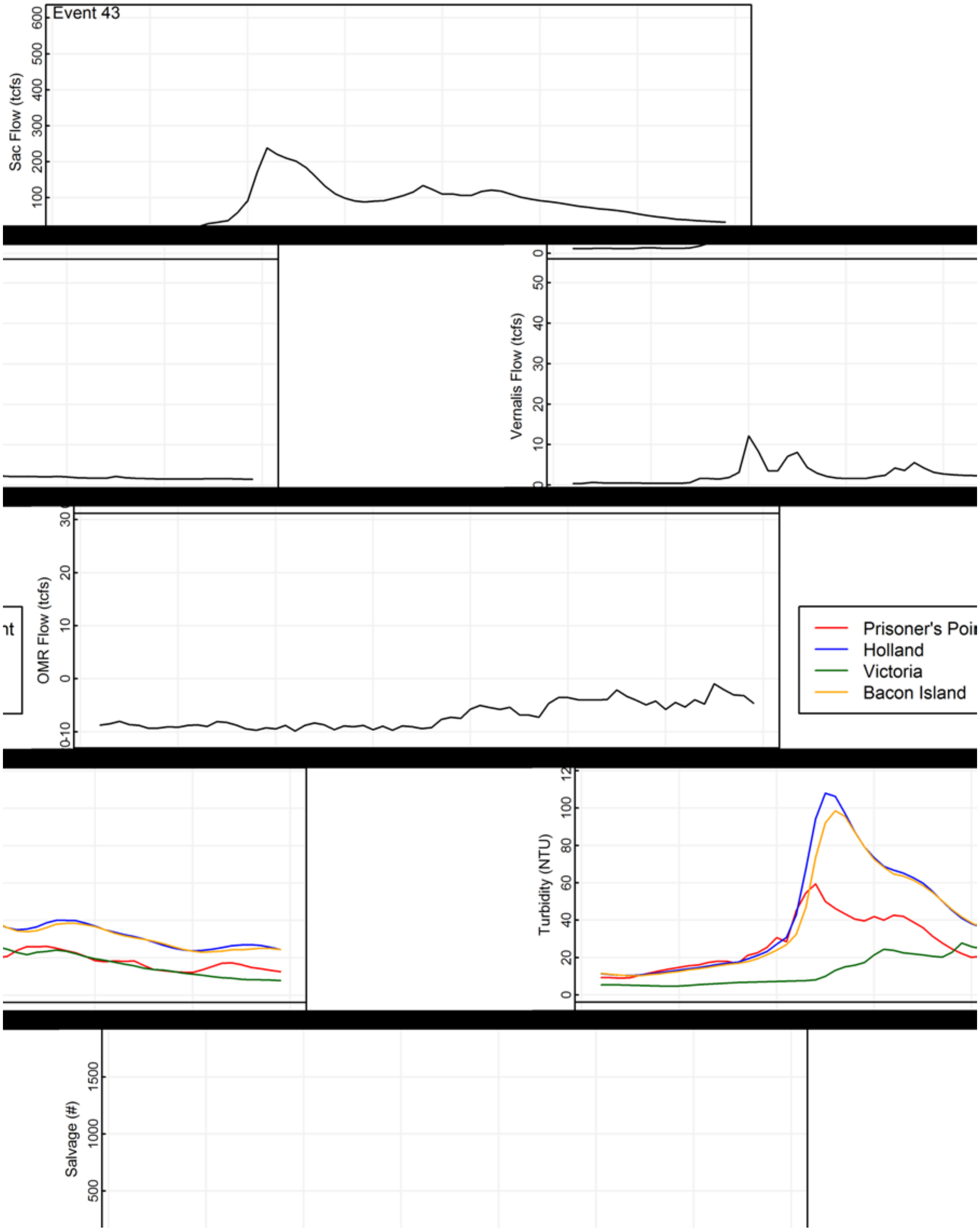


Figure C-34 **Event 43**

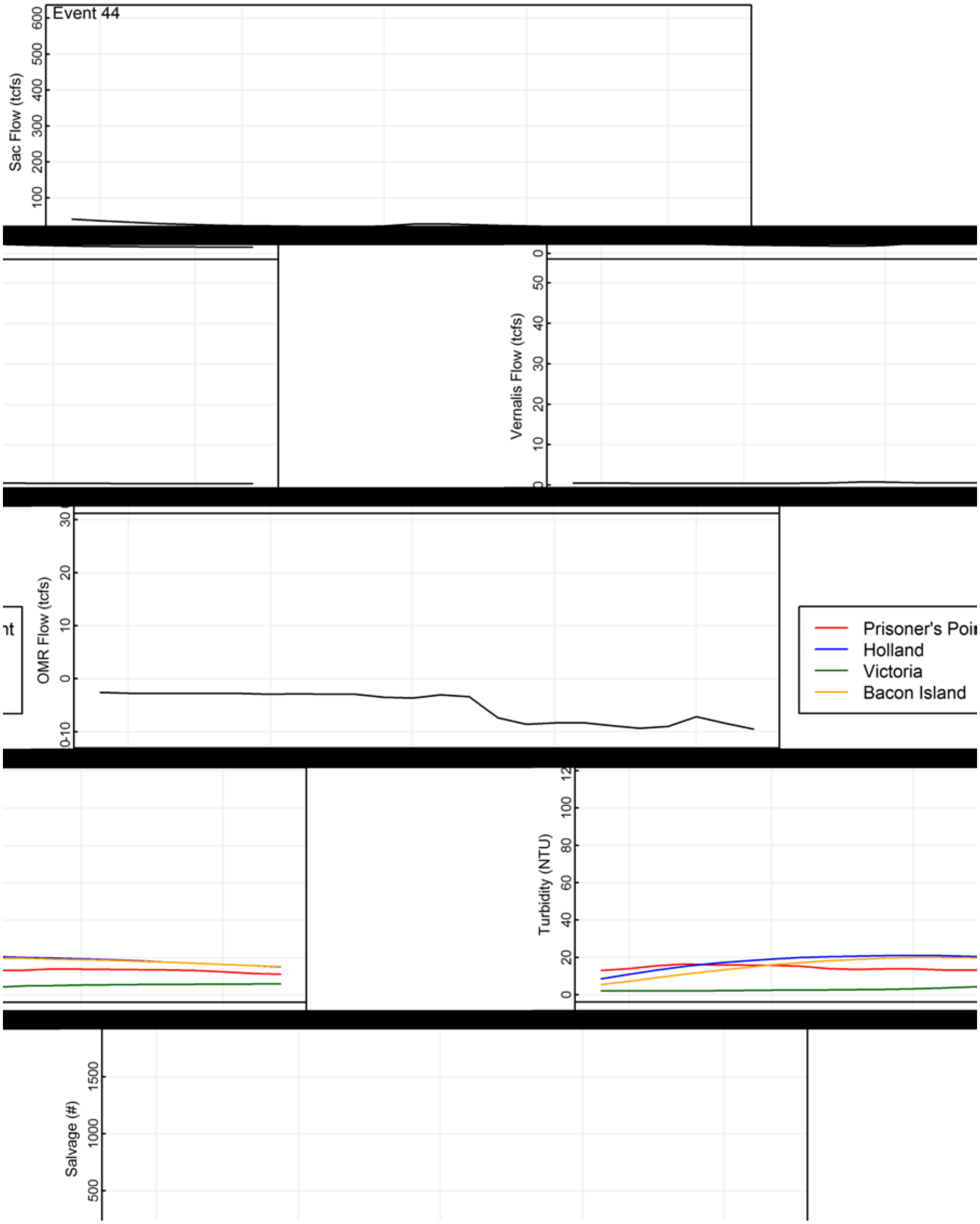


Figure C-35 **Event 44**

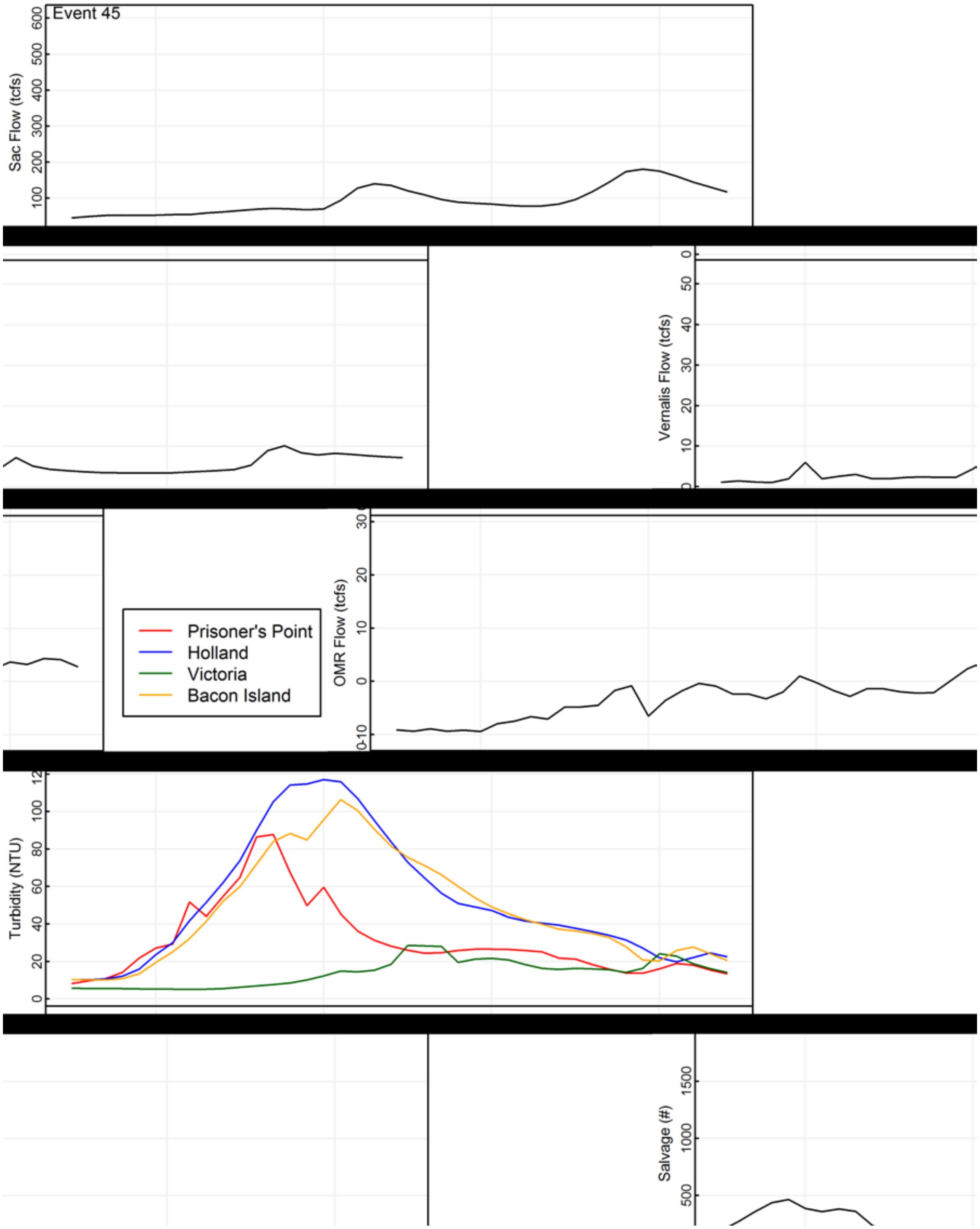


Figure C-36 **Event 45**

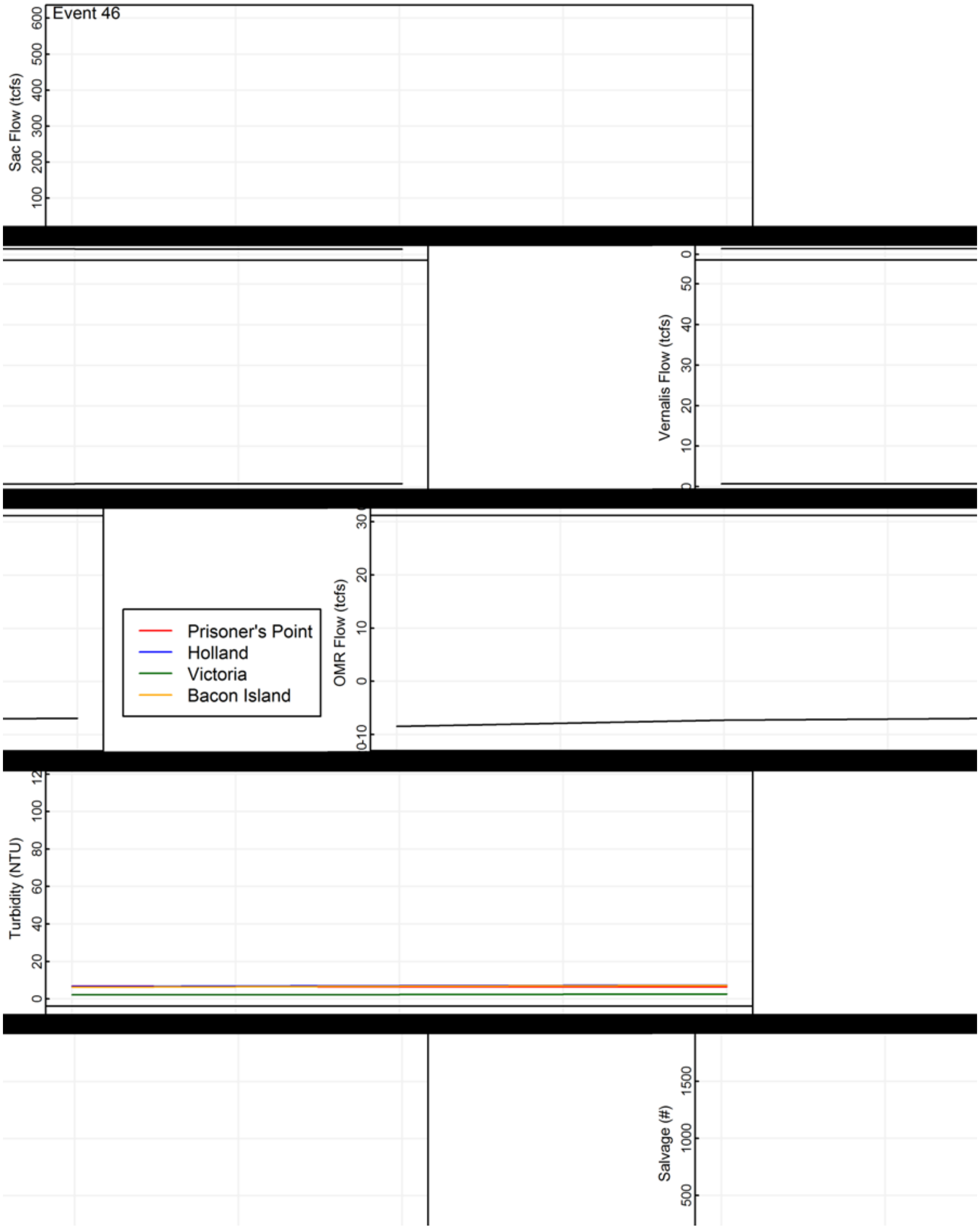


Figure C-37 Event 46

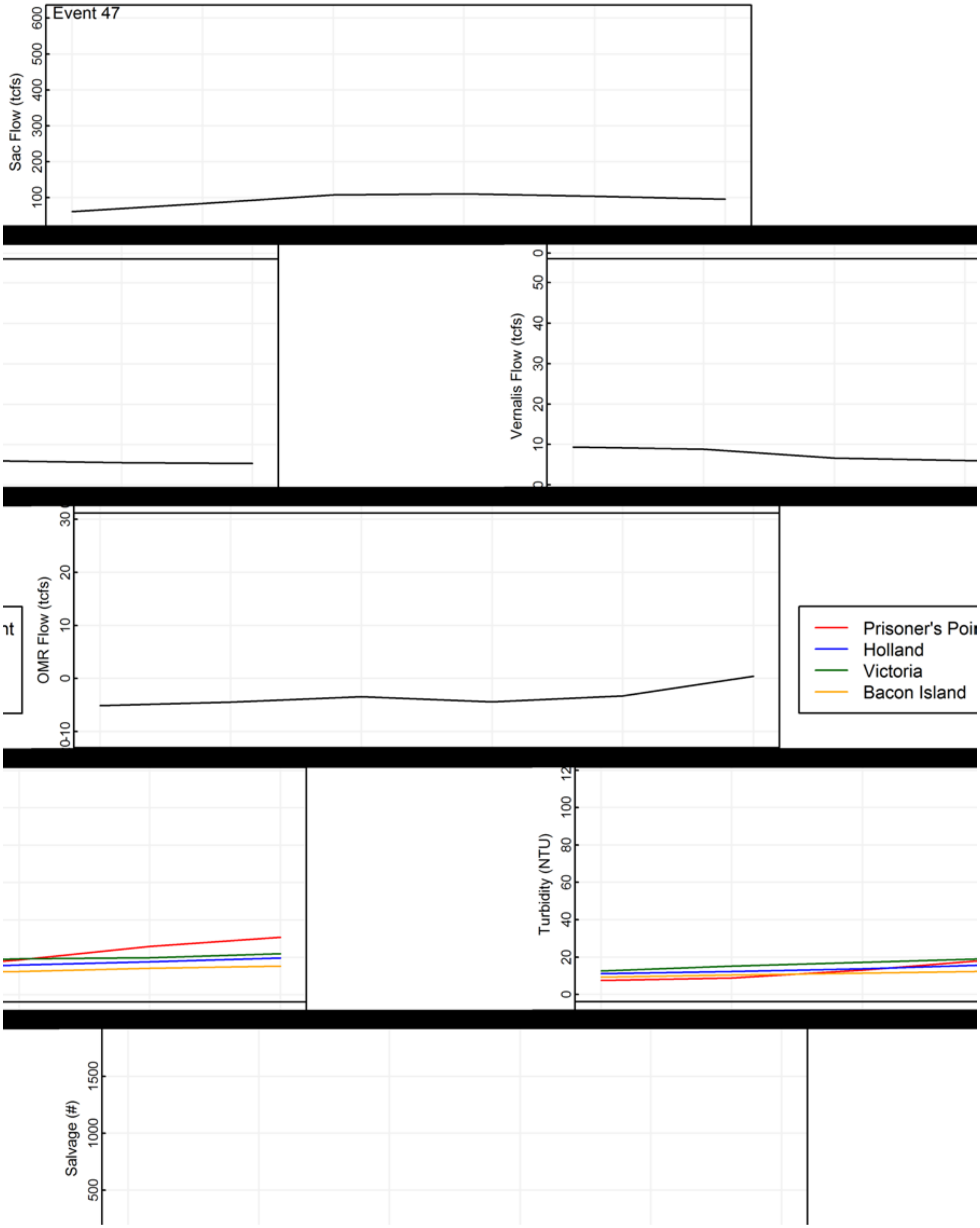


Figure C-38 **Event 47**

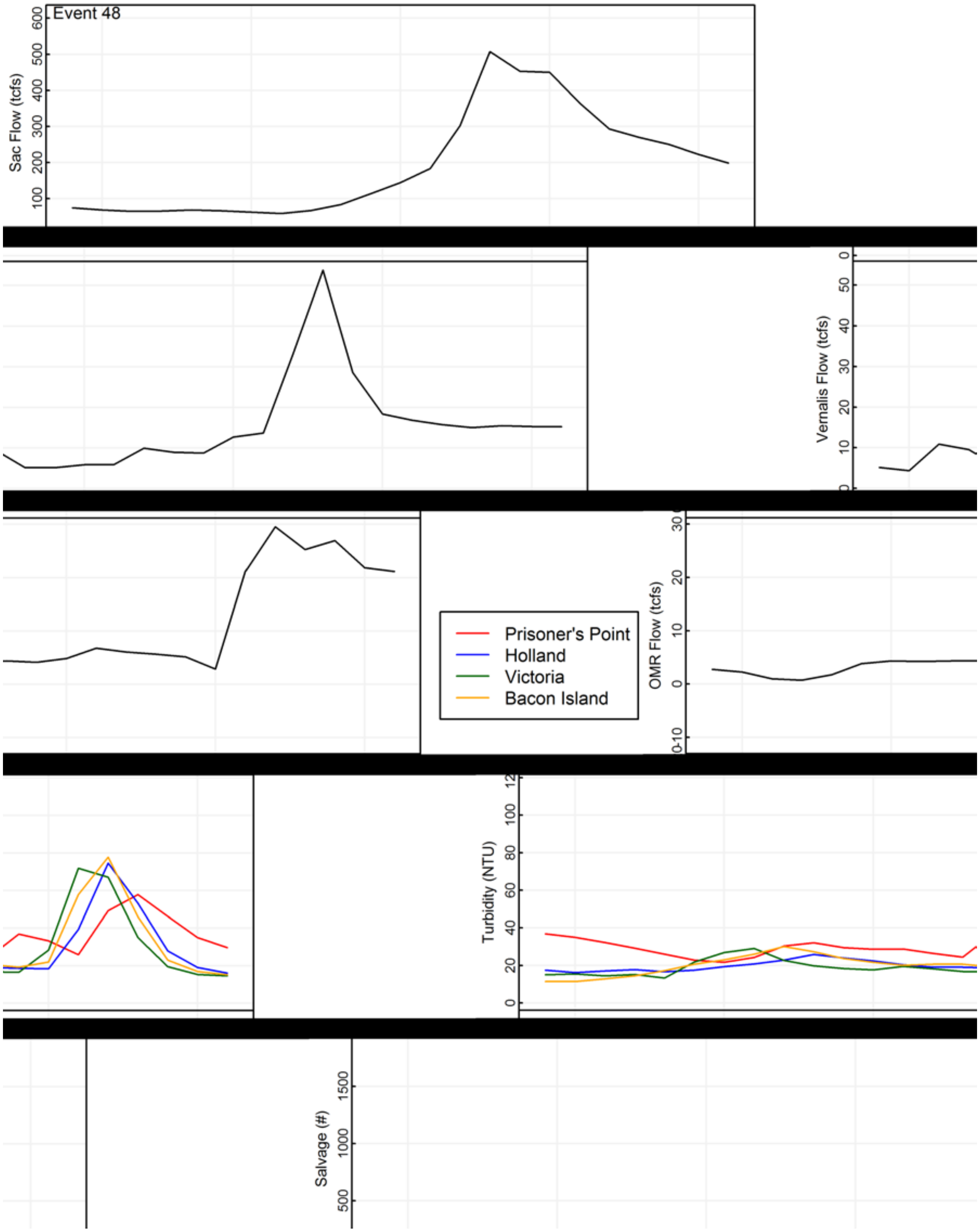


Figure C-39 **Event 48**

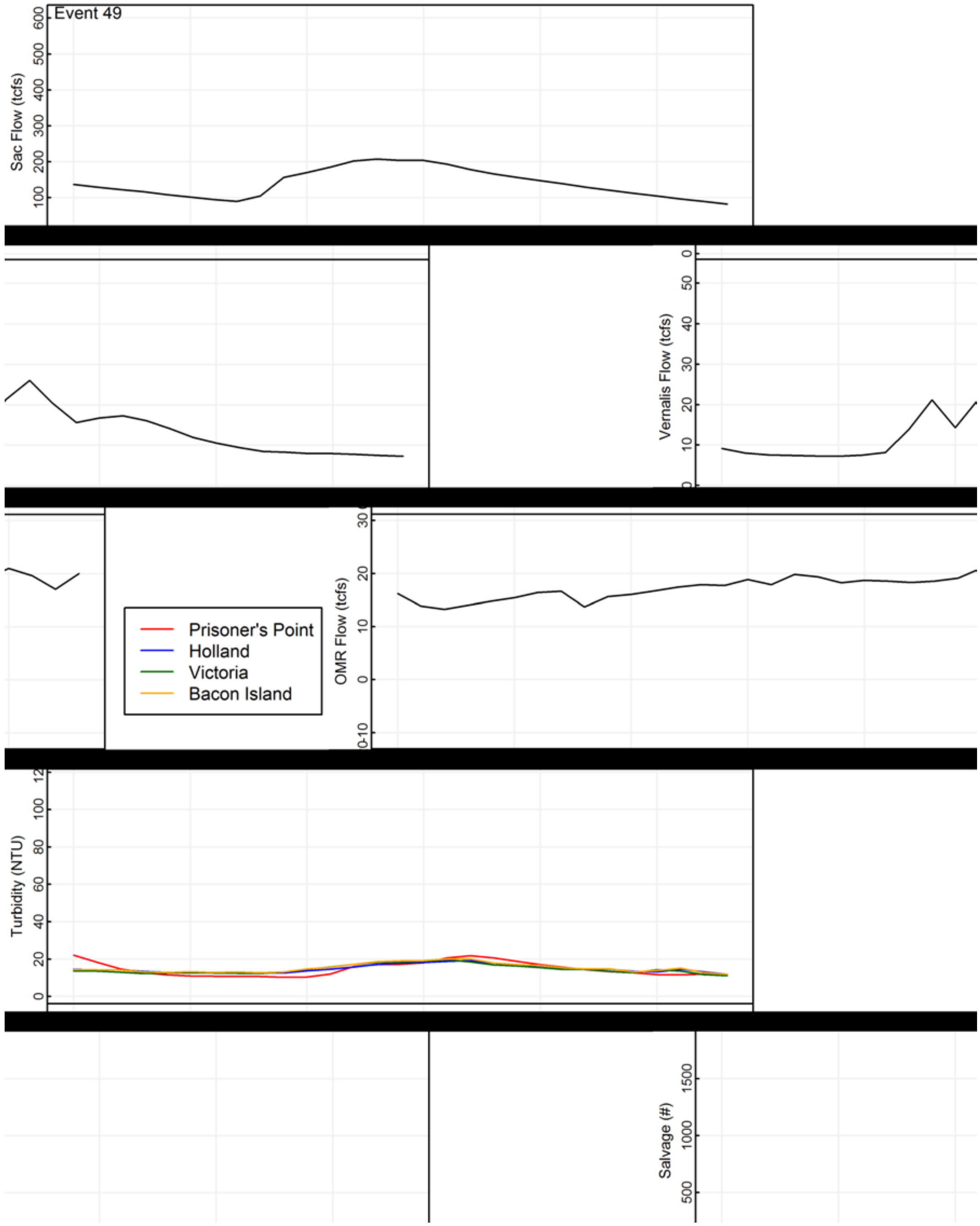


Figure C-40 **Event 49**

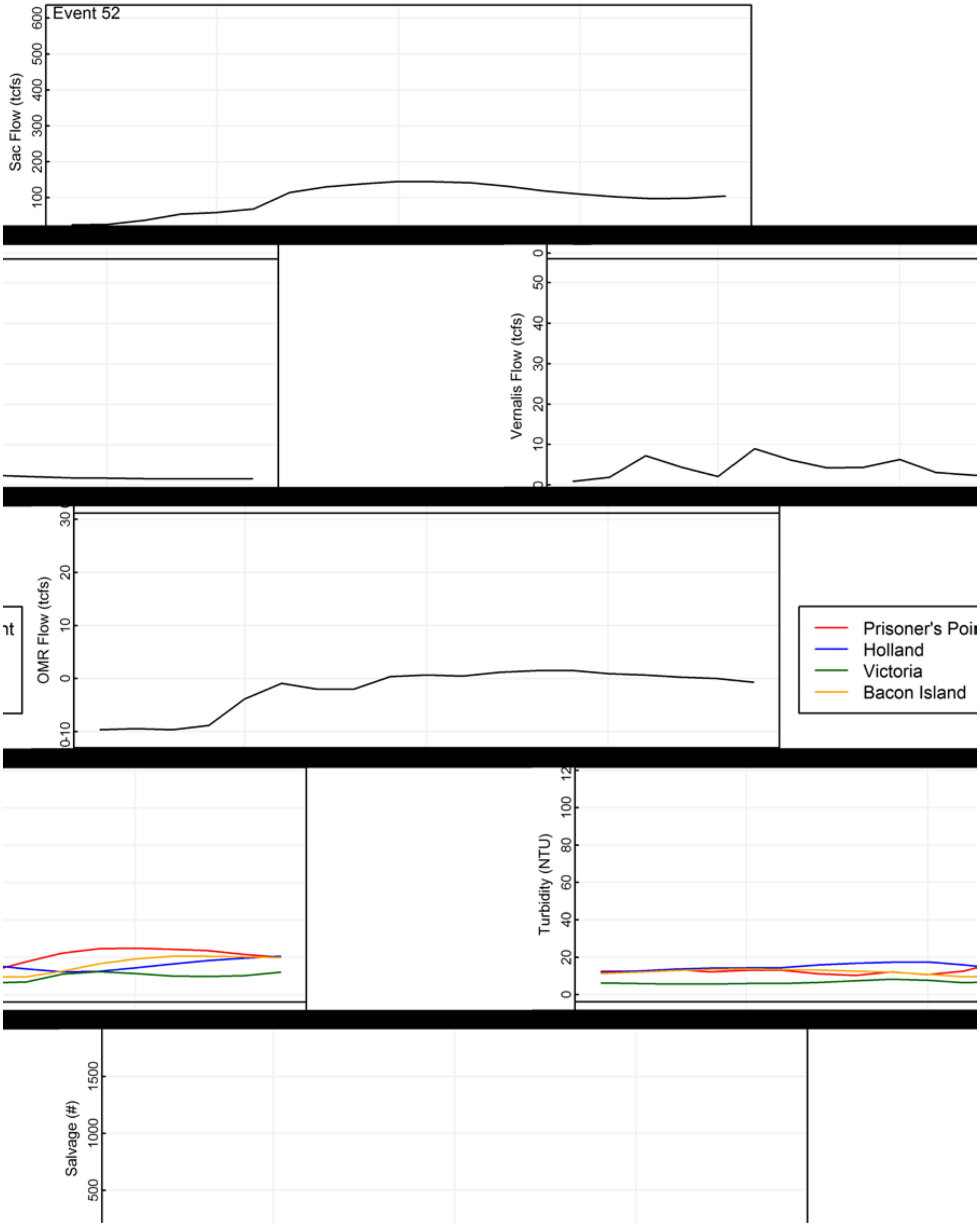


Figure C-41 **Event 52**

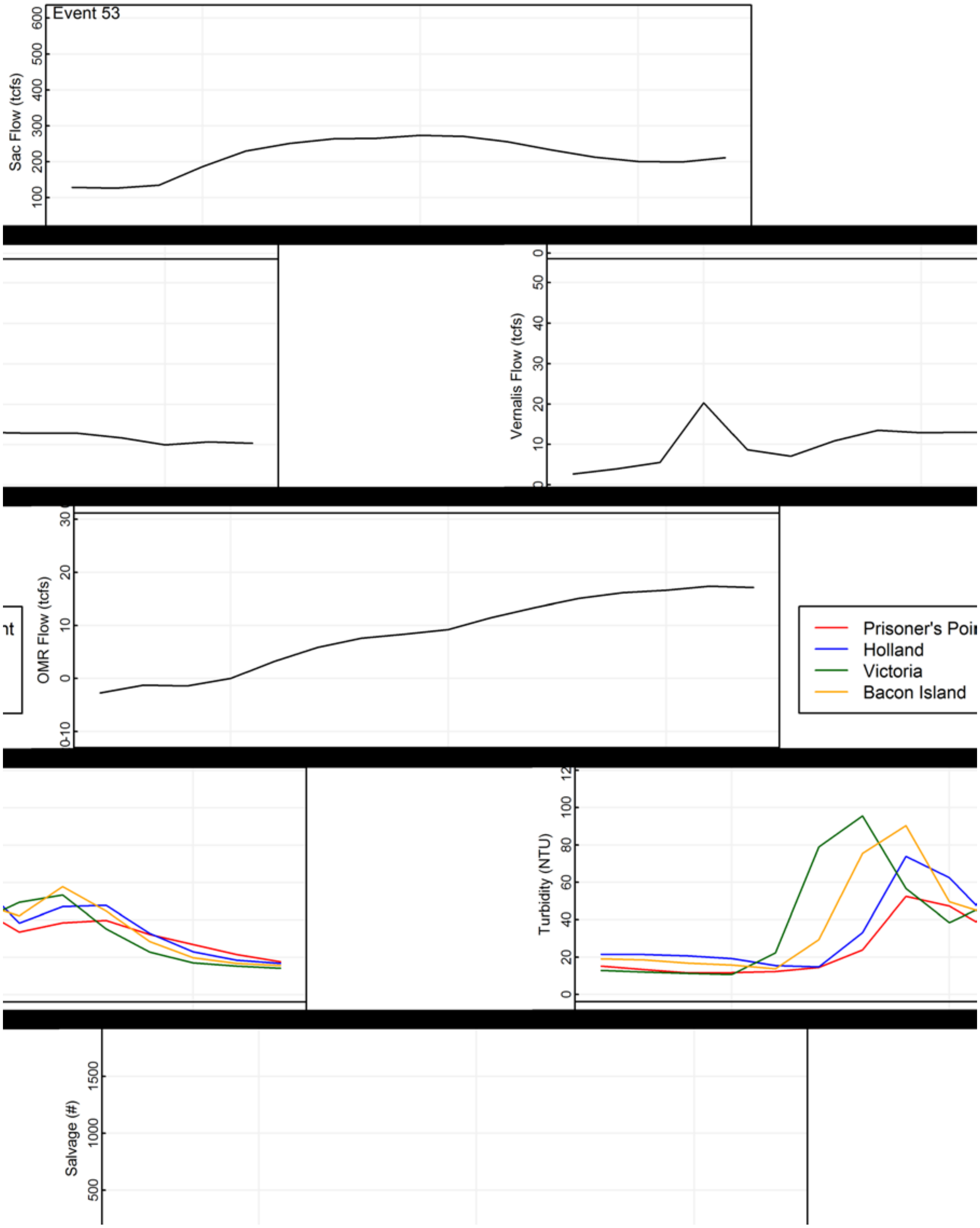


Figure C-42 **Event 53**

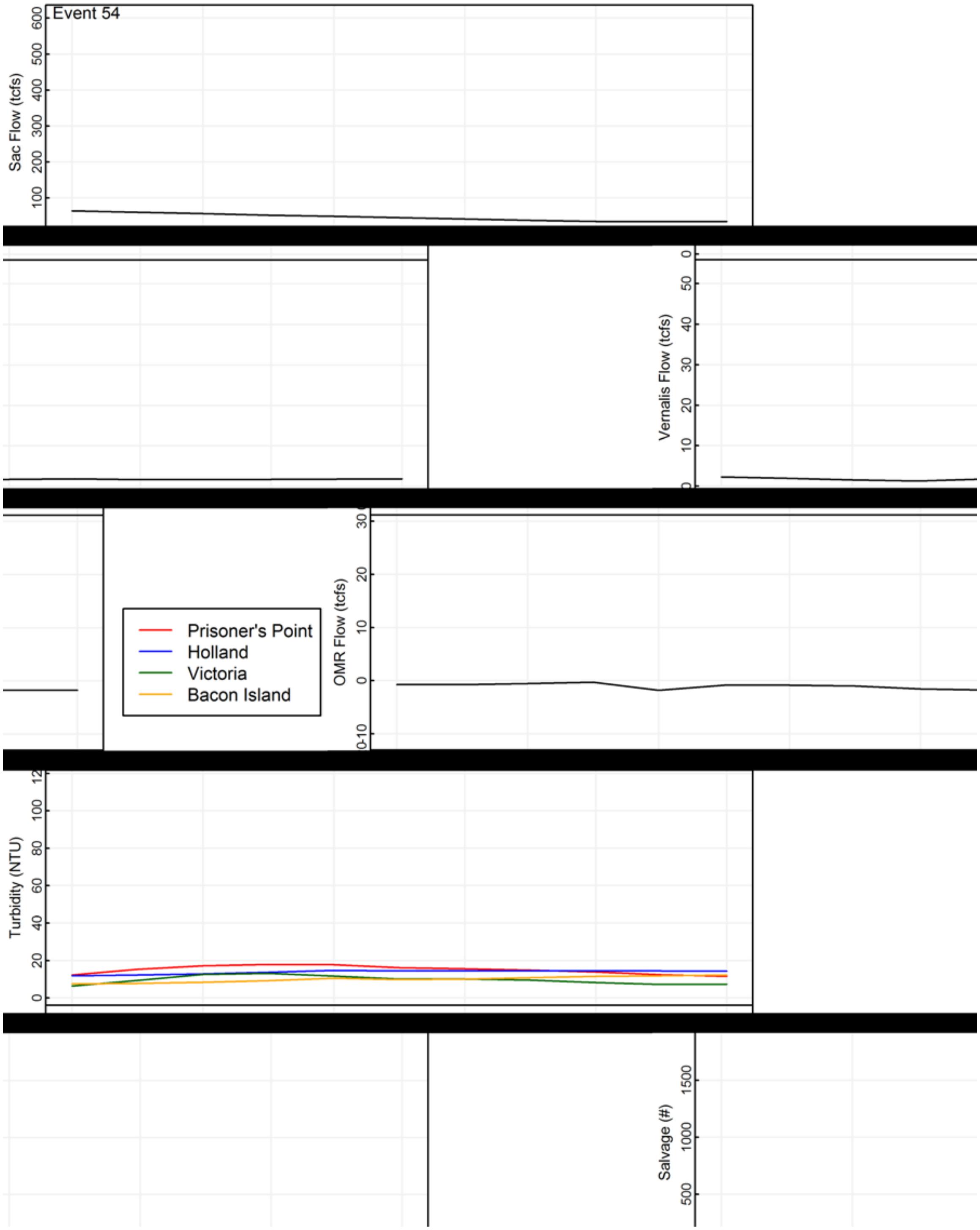


Figure C-43 **Event 54**

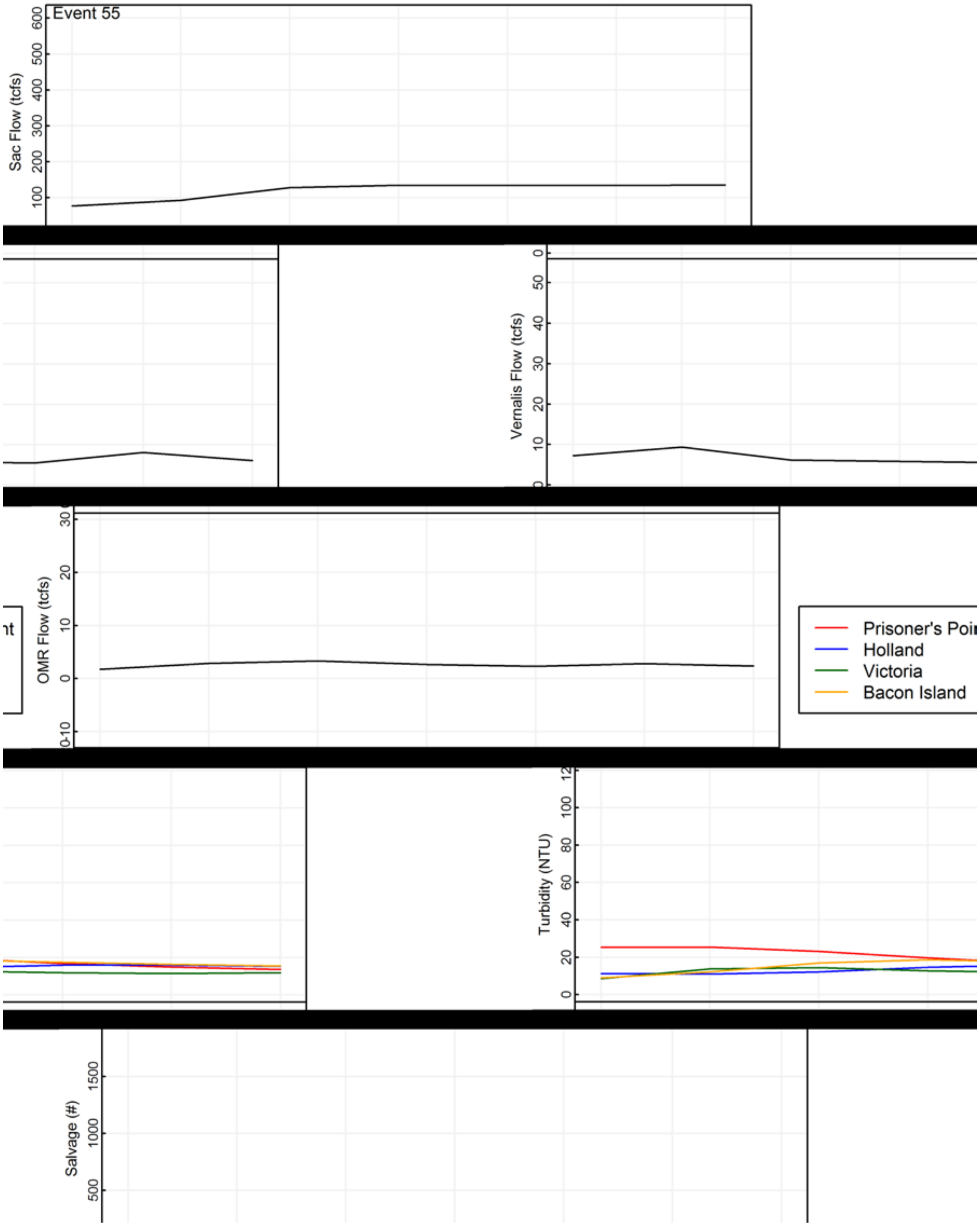


Figure C-44 **Event 55**

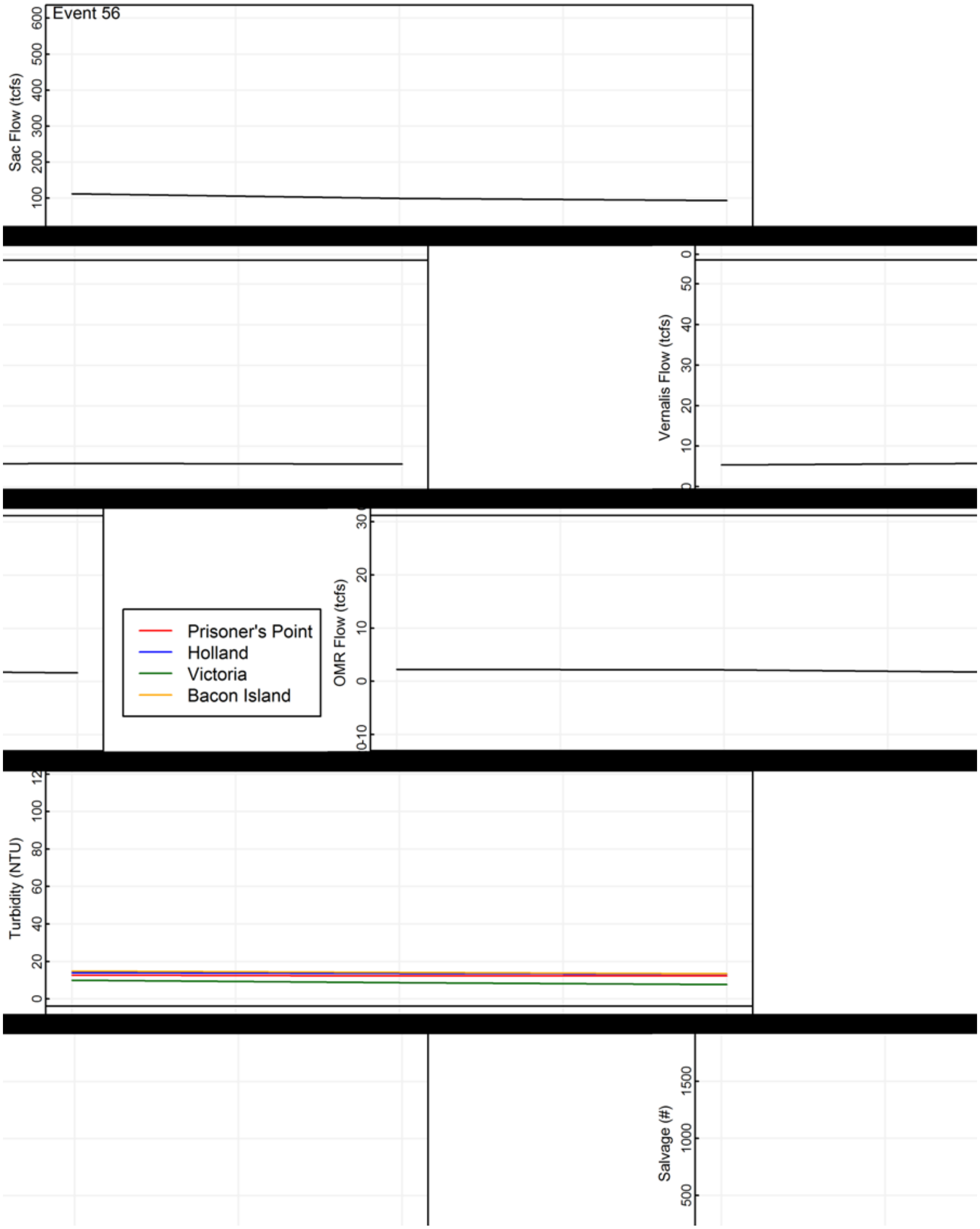


Figure C-45 **Event 56**

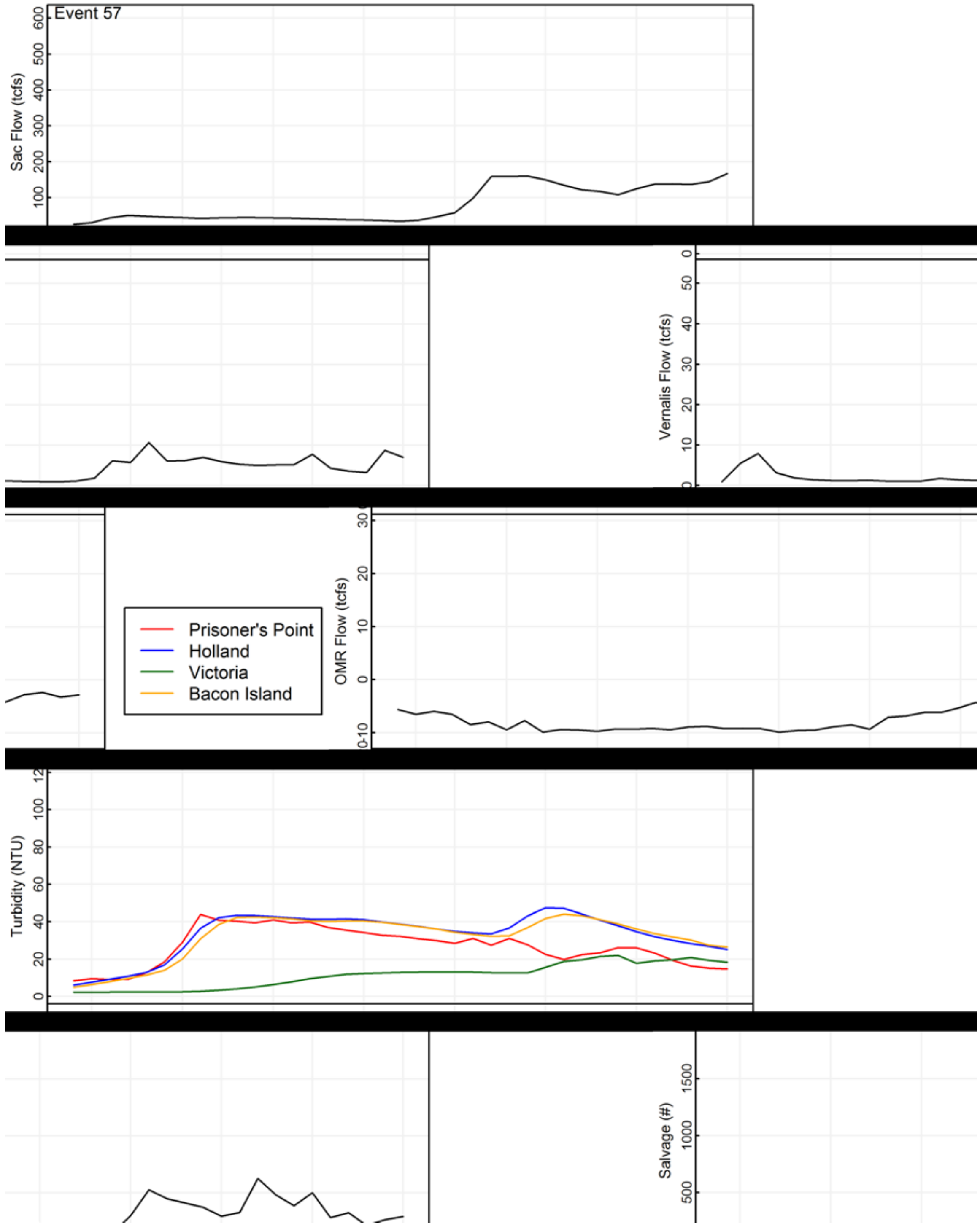


Figure C-46 **Event 57**

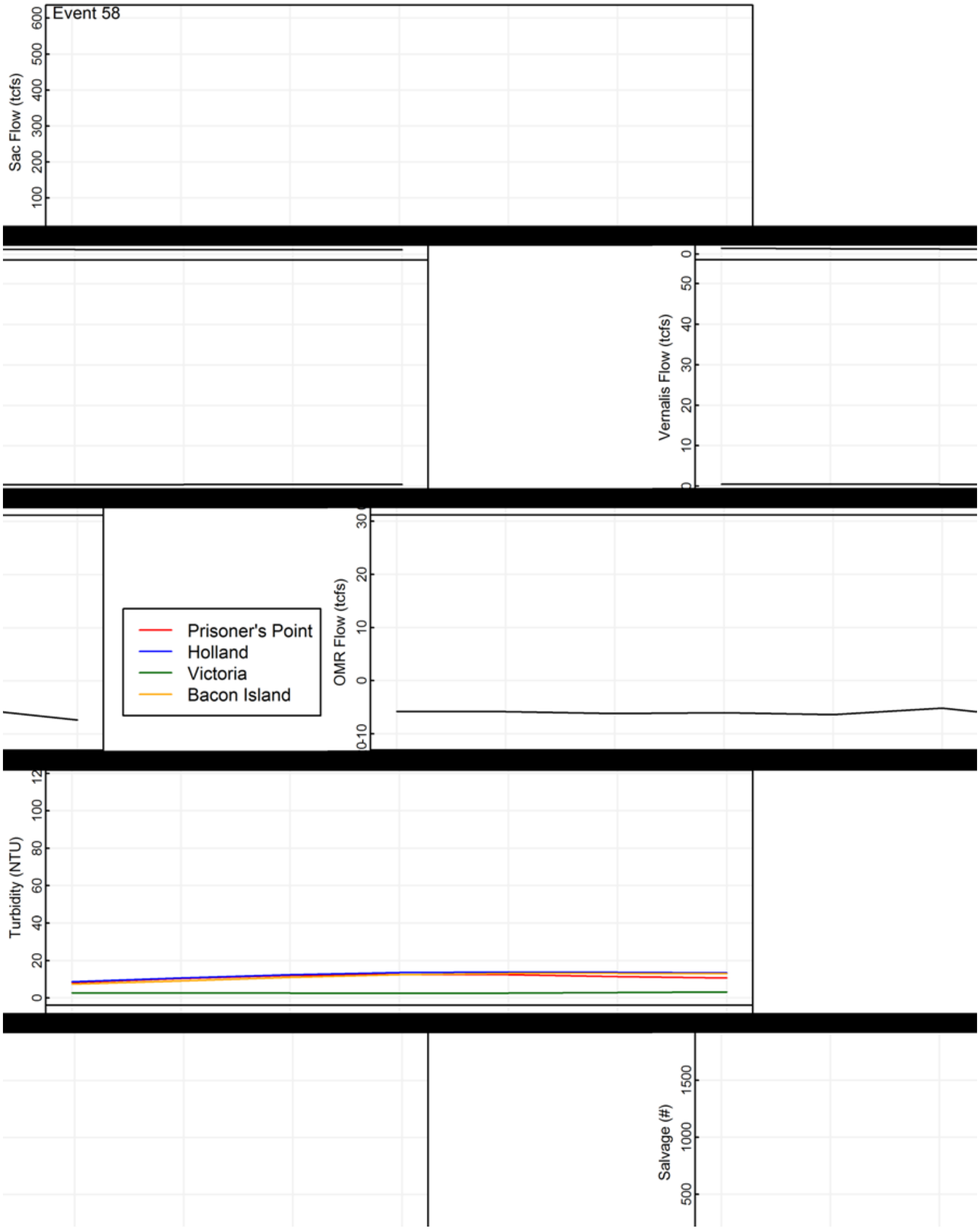


Figure C-47 **Event 58**

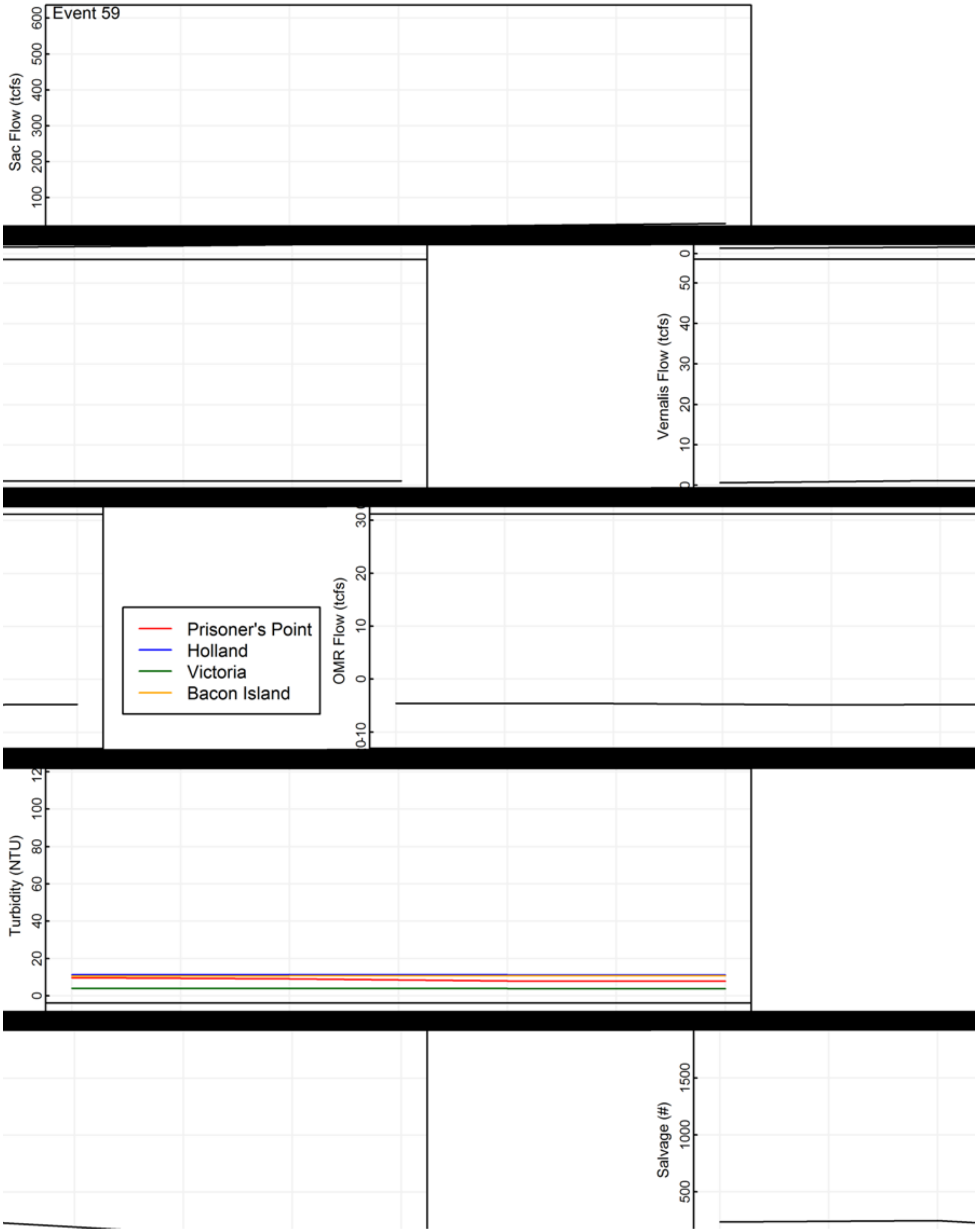


Figure C-48 **Event 59**

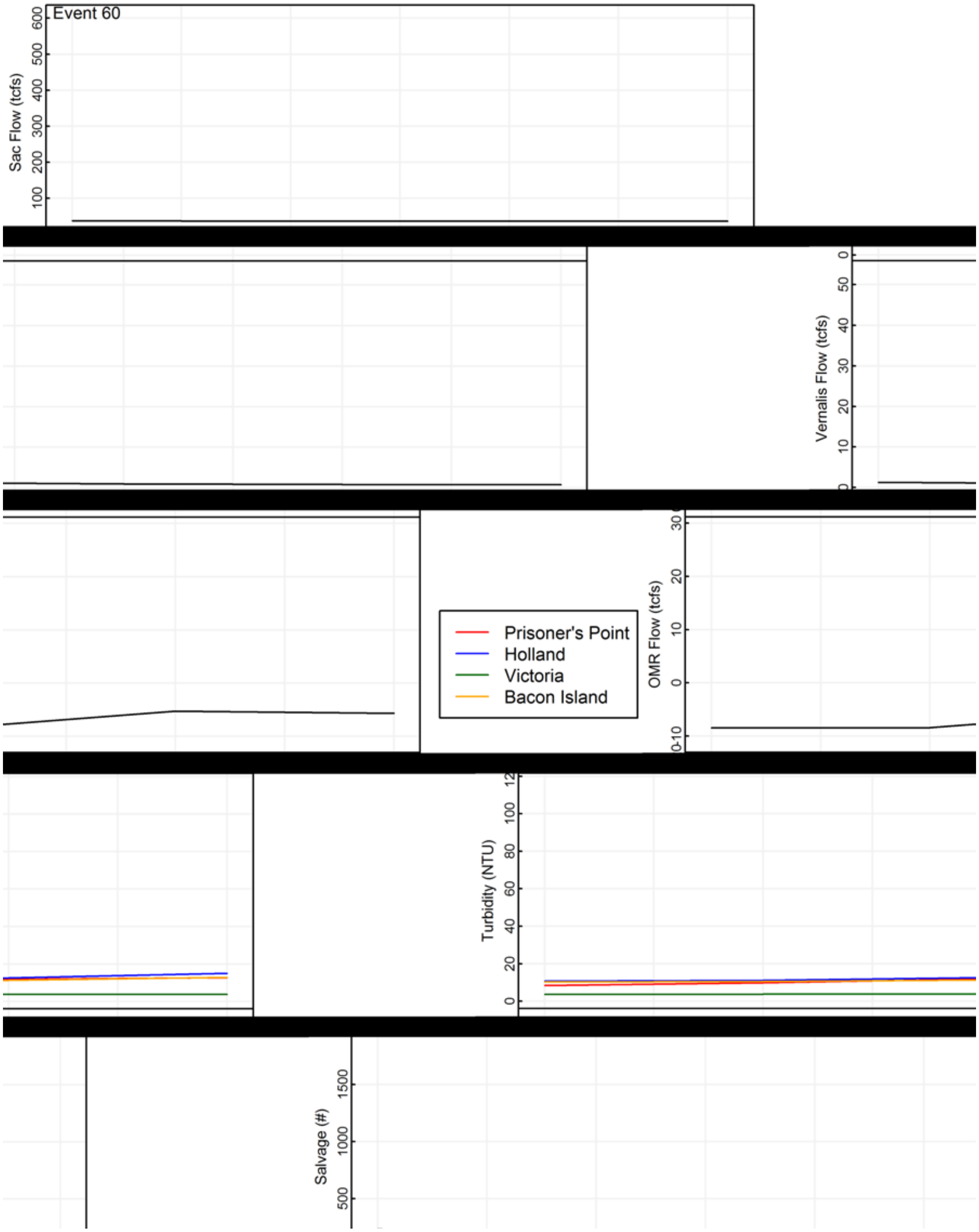


Figure C-49 **Event 60**

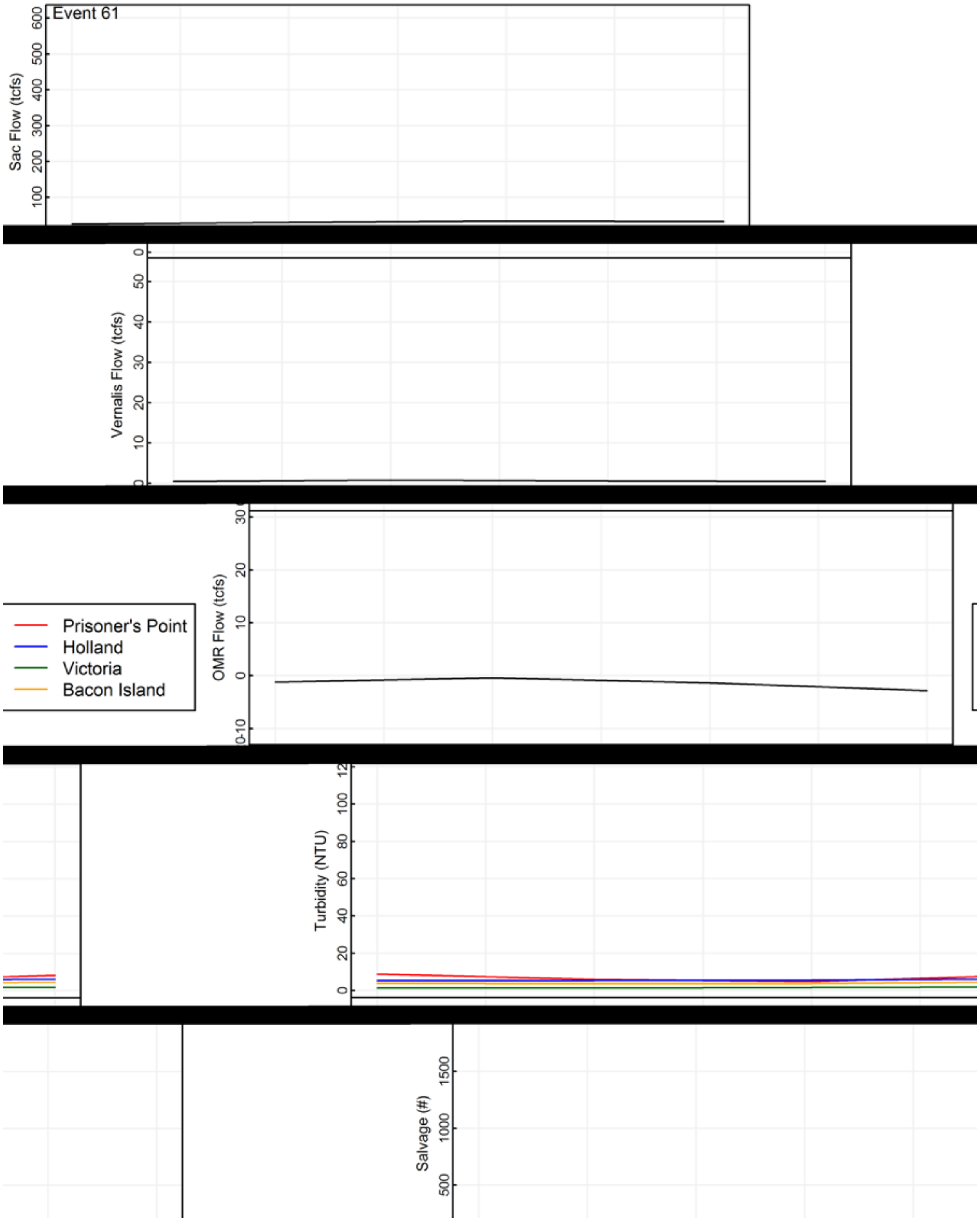


Figure C-50 **Event 61**

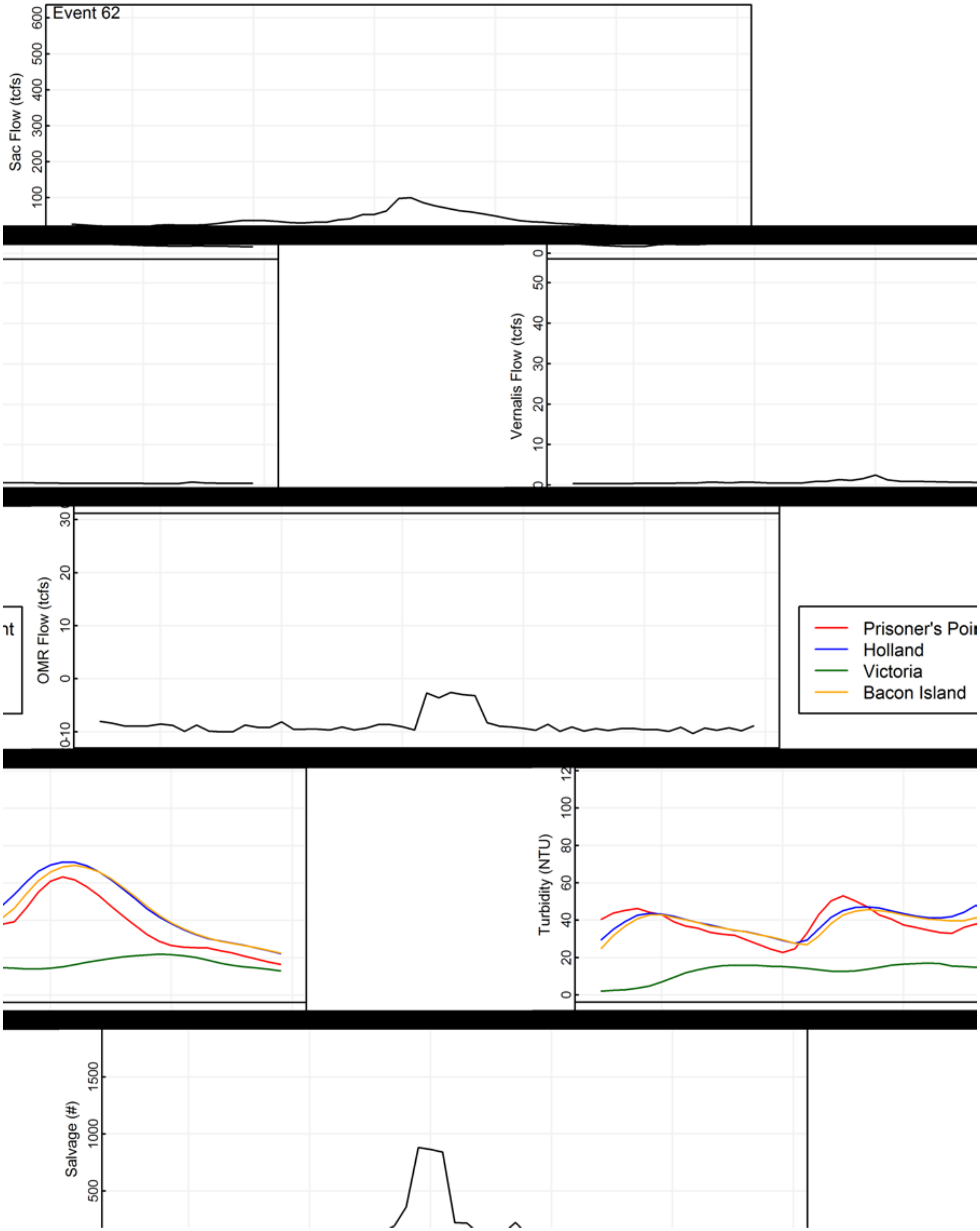


Figure C-51 Event 62

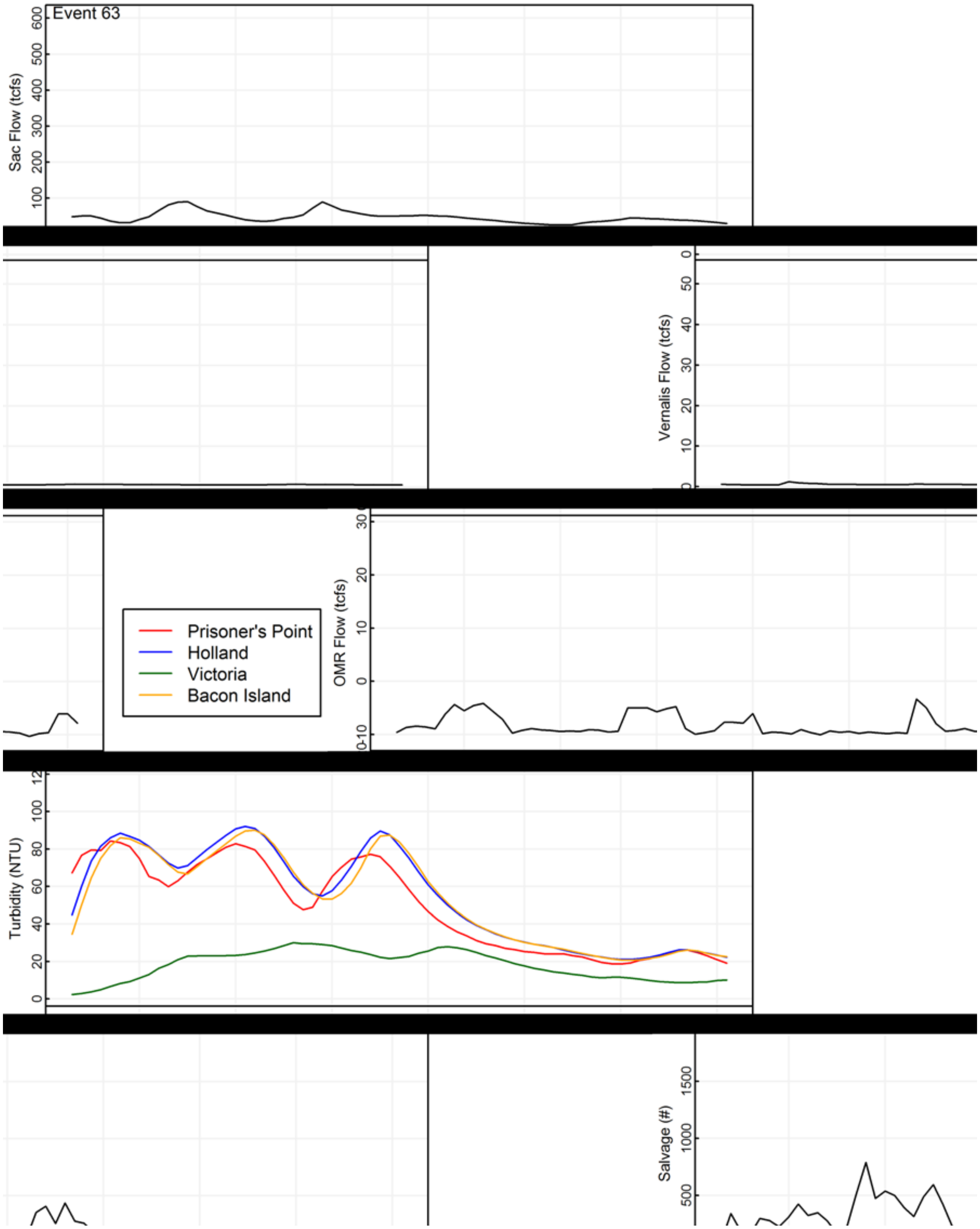


Figure C-52 **Event 63**

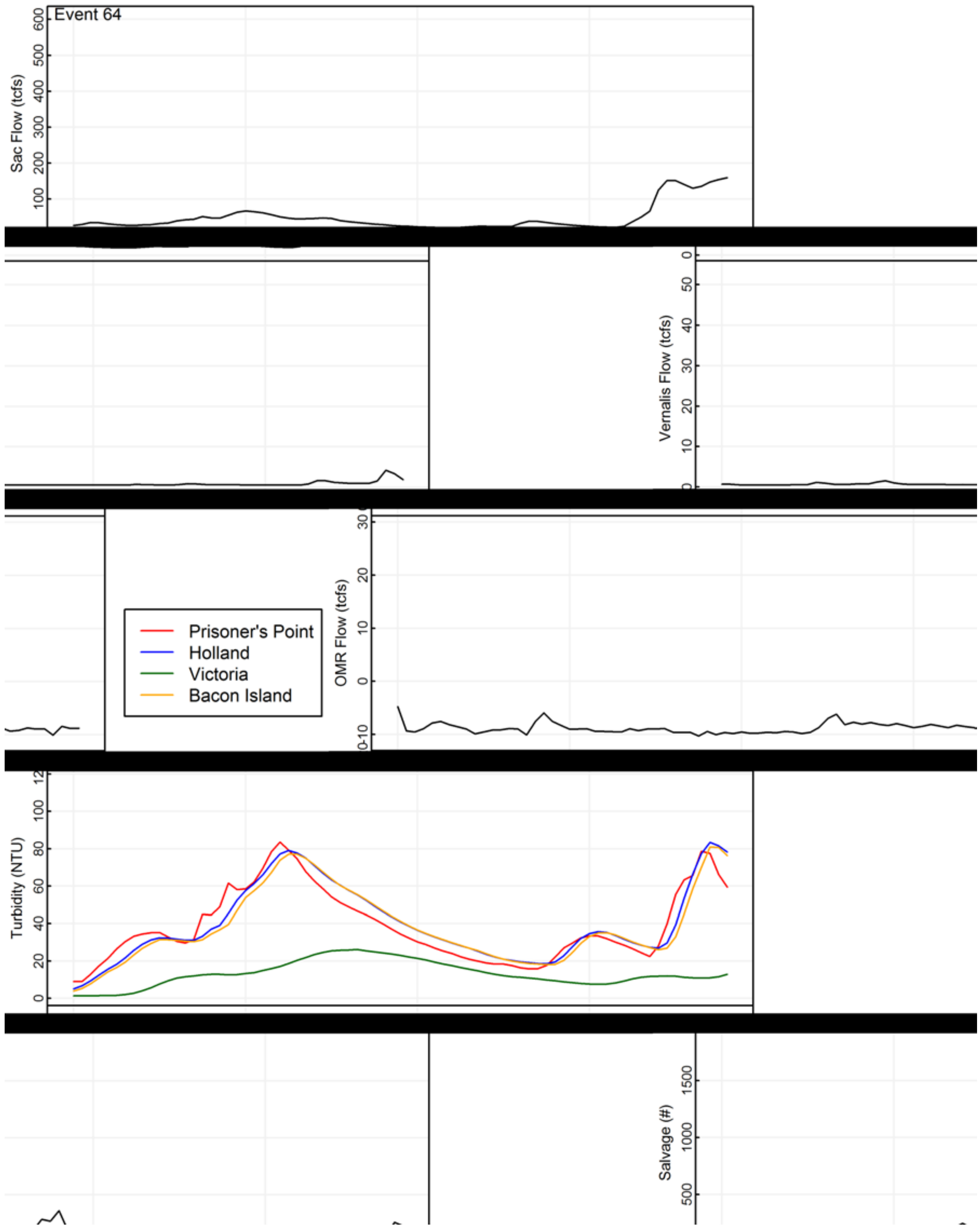


Figure C-53 **Event 64**

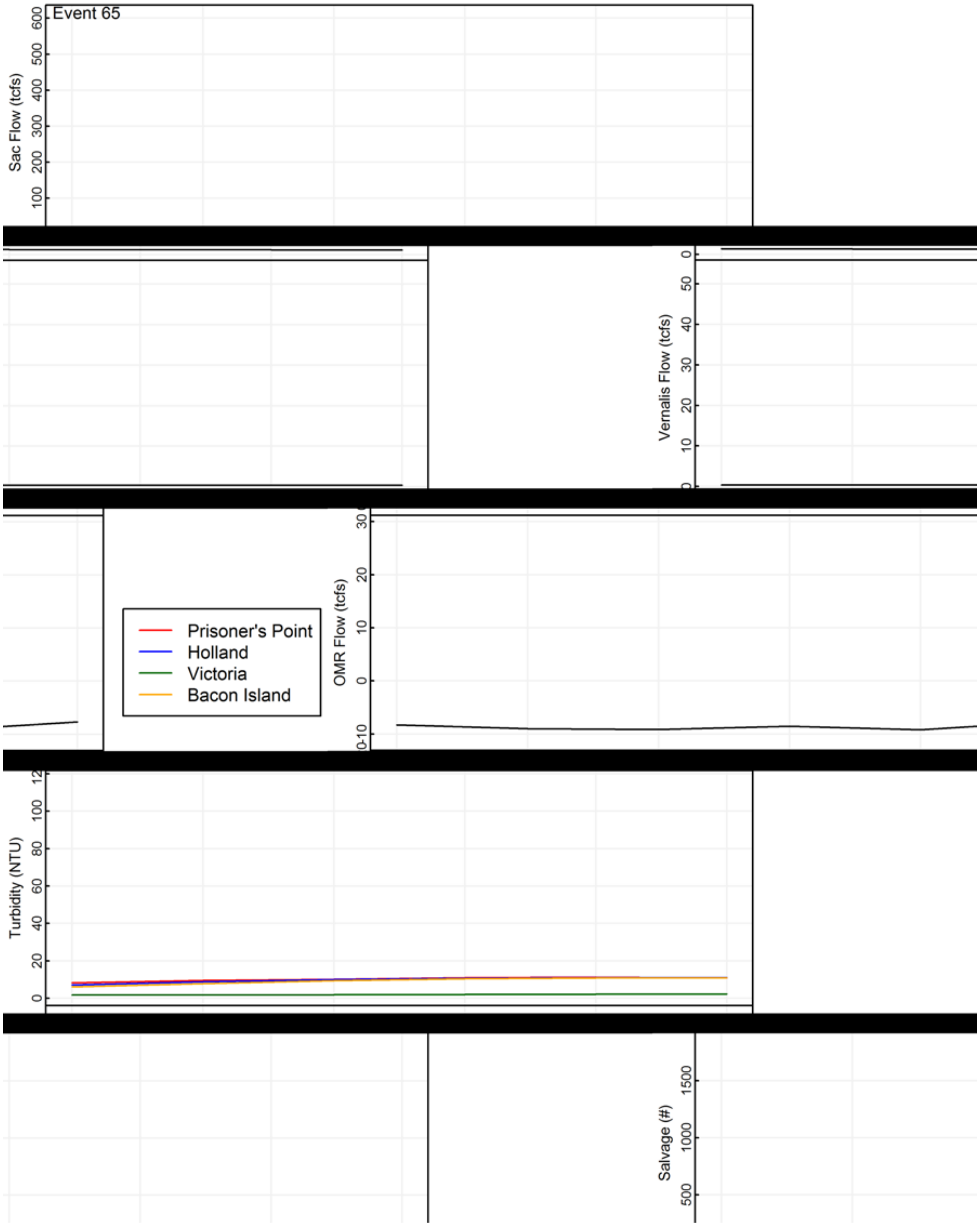


Figure C-54 **Event 65**

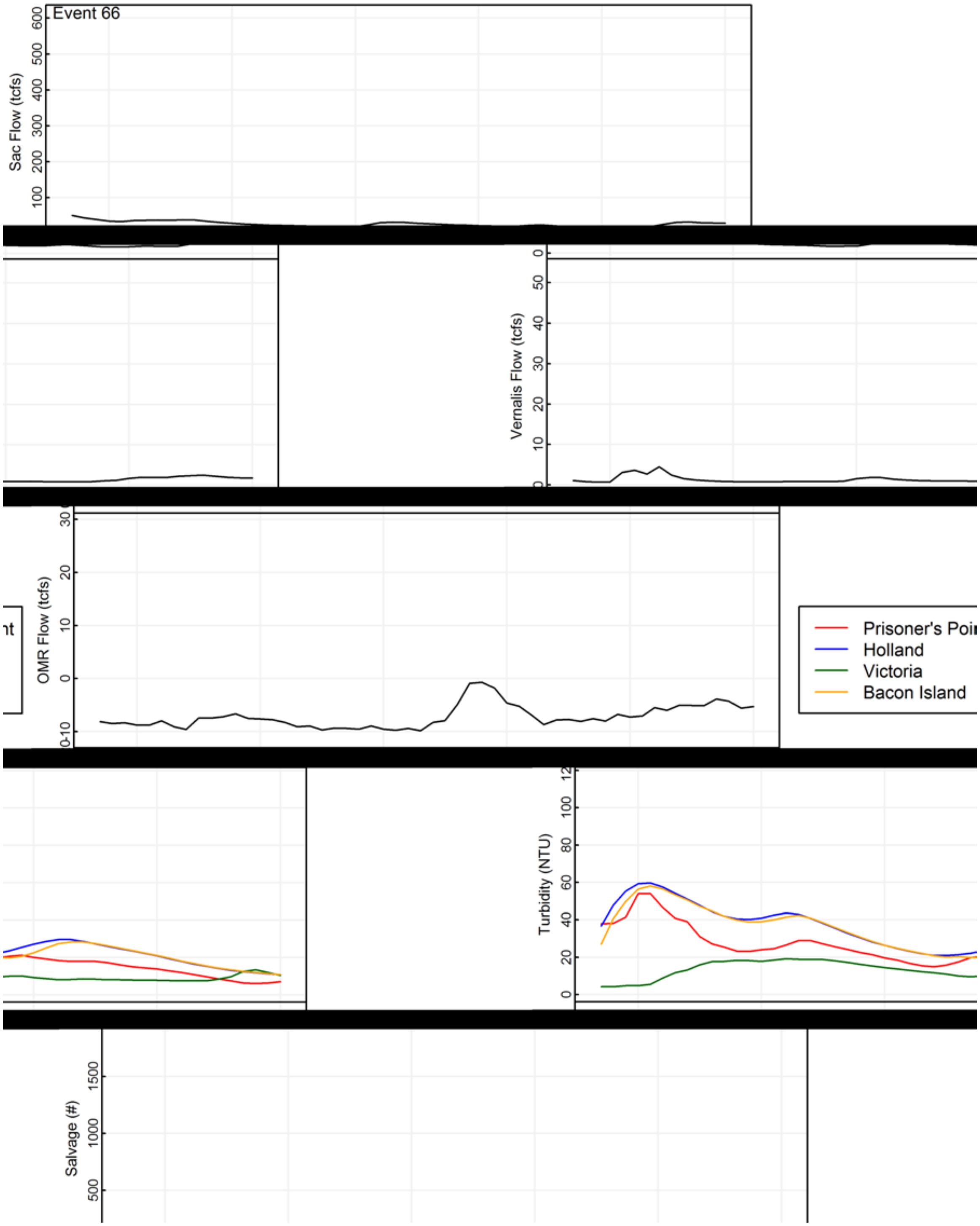


Figure C-55 **Event 66**

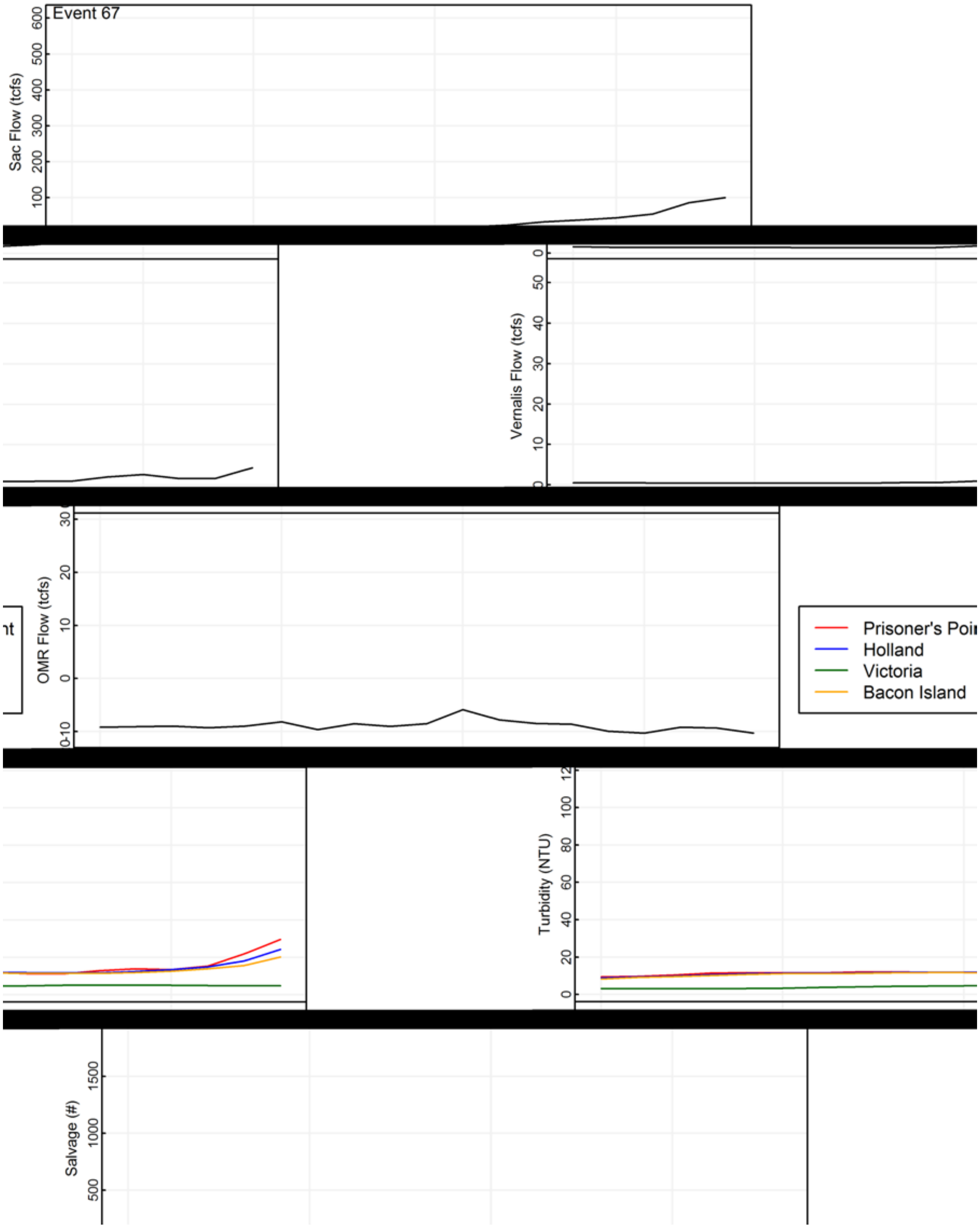


Figure C-56 **Event 67**

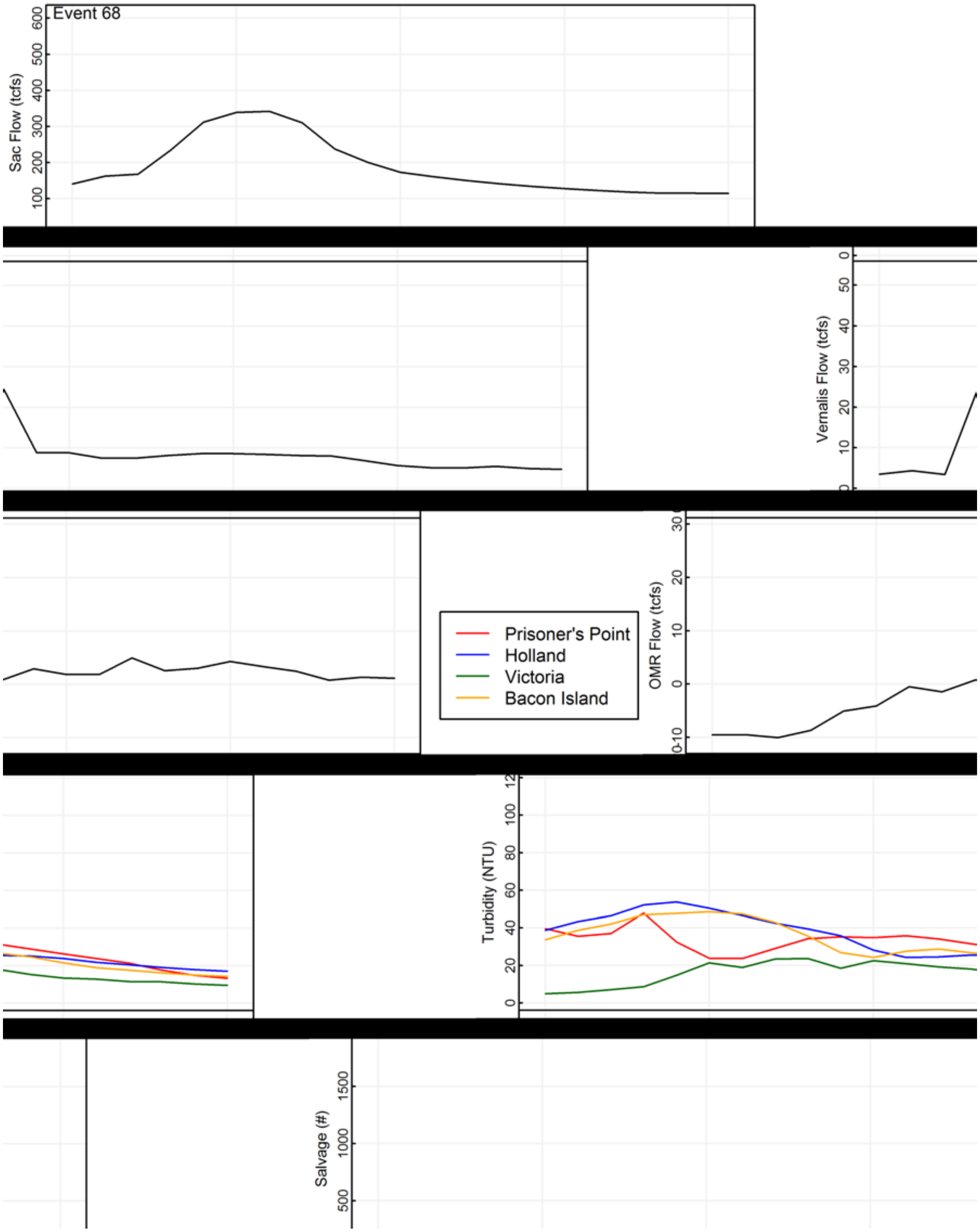


Figure C-57 Event 68

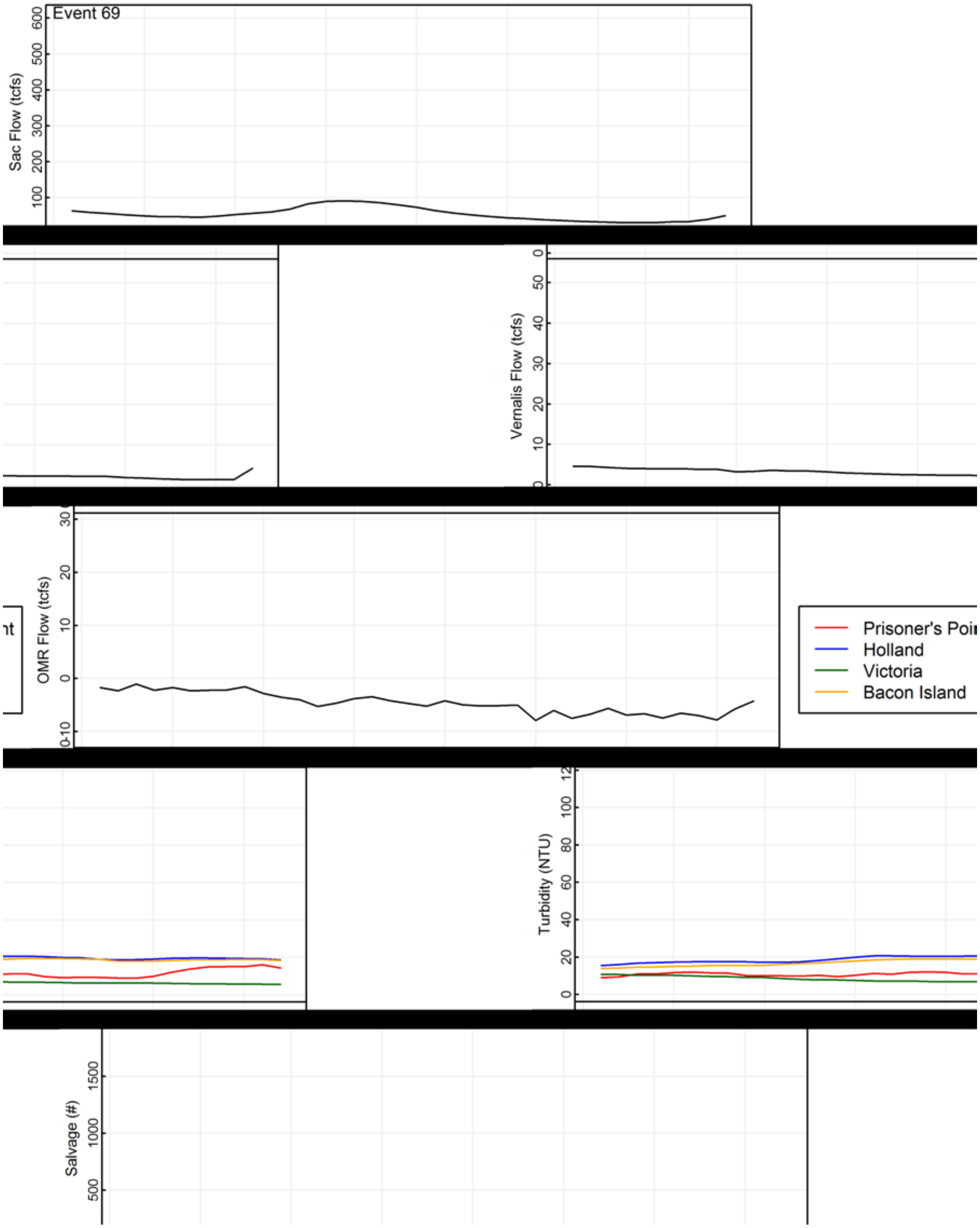


Figure C-58 **Event 69**

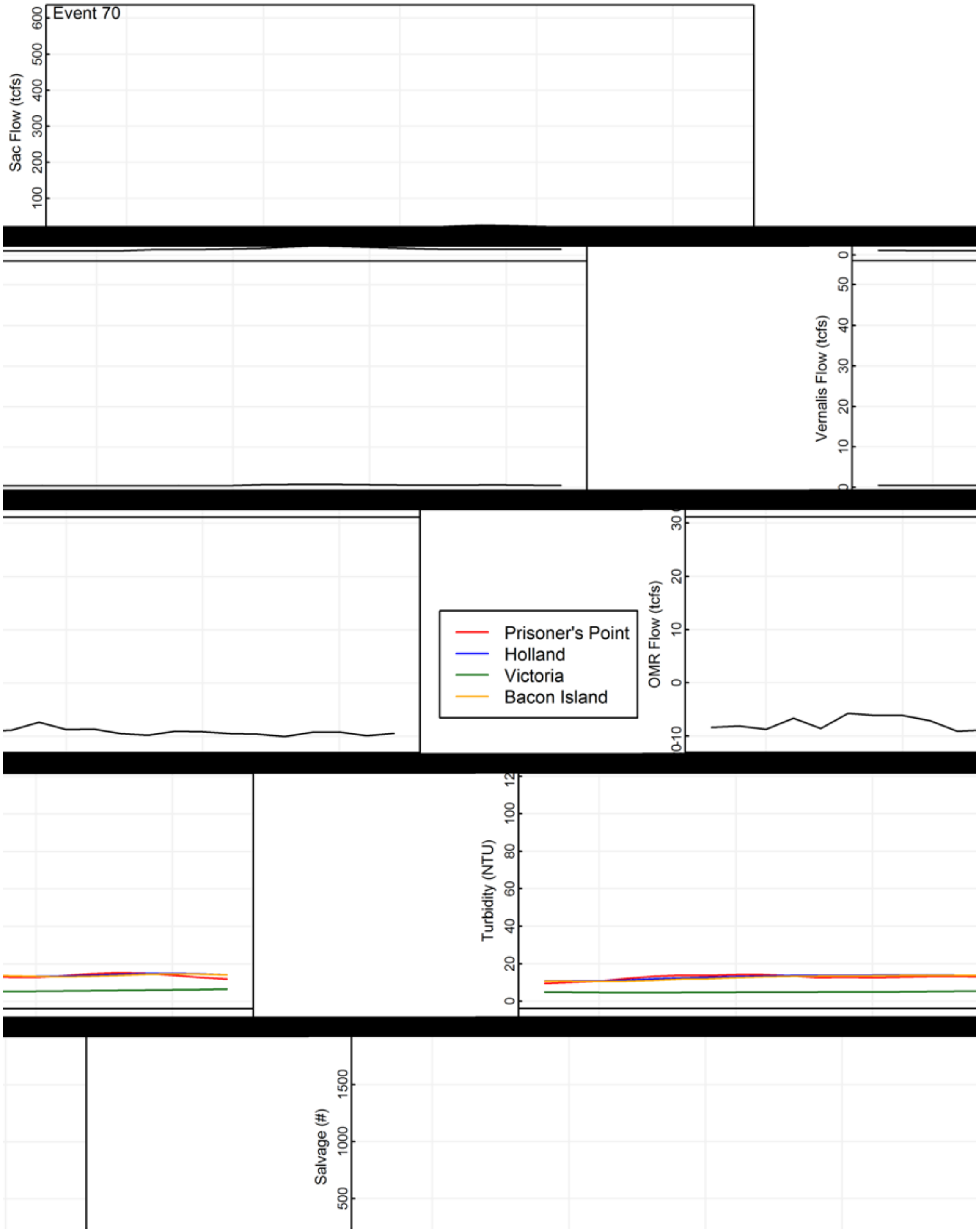


Figure C-59 **Event 70**

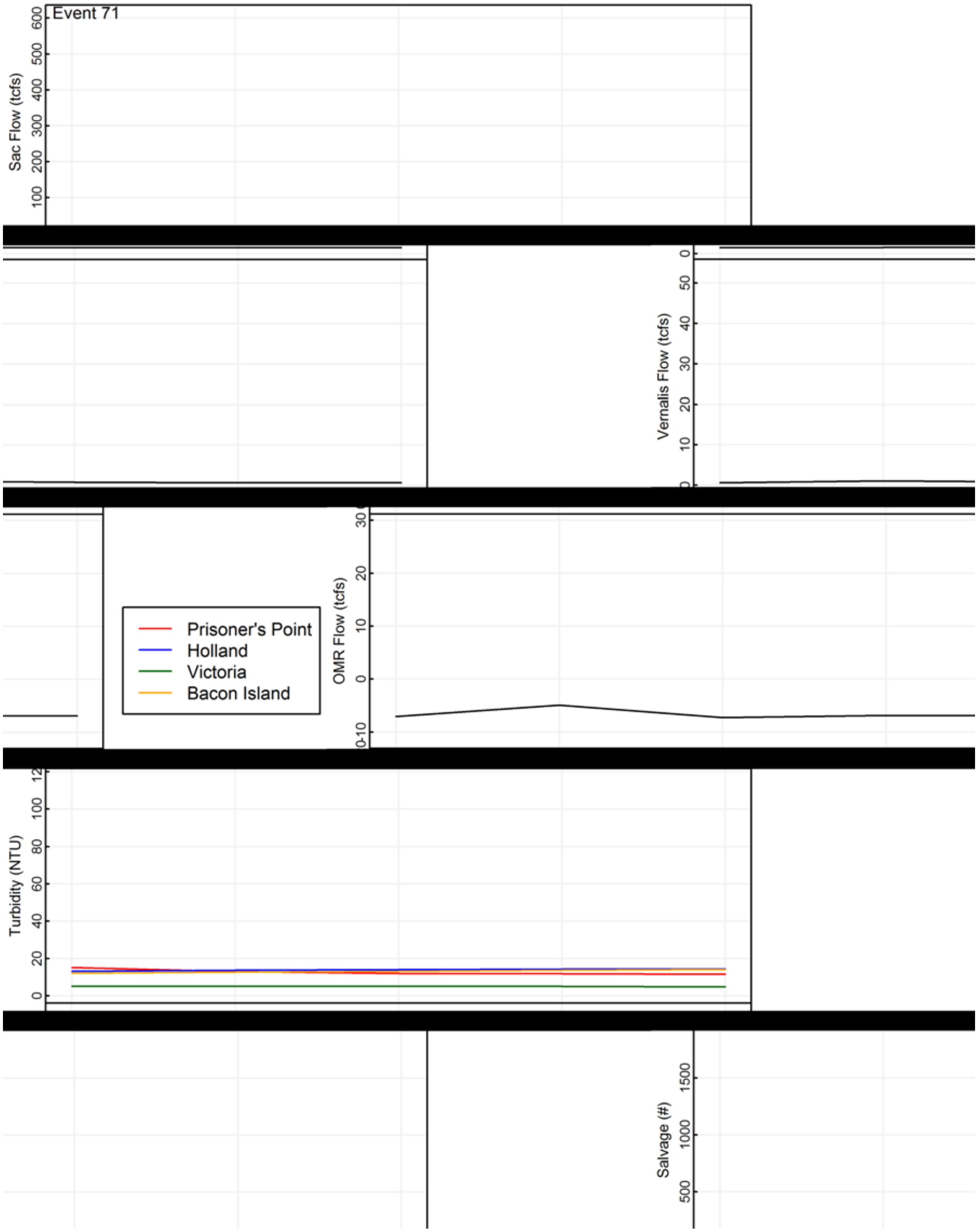


Figure C-60 **Event 71**

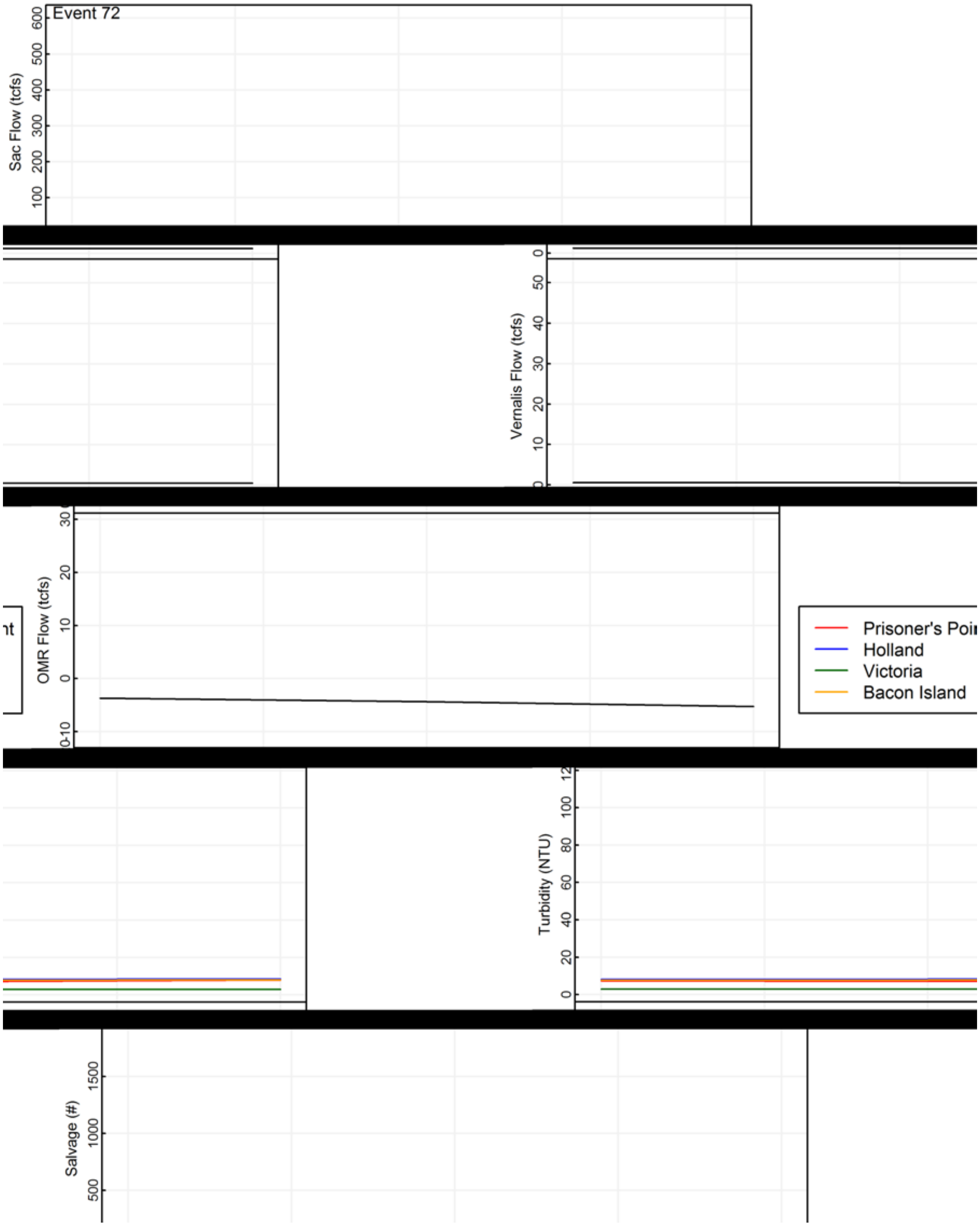


Figure C-61 Event 72

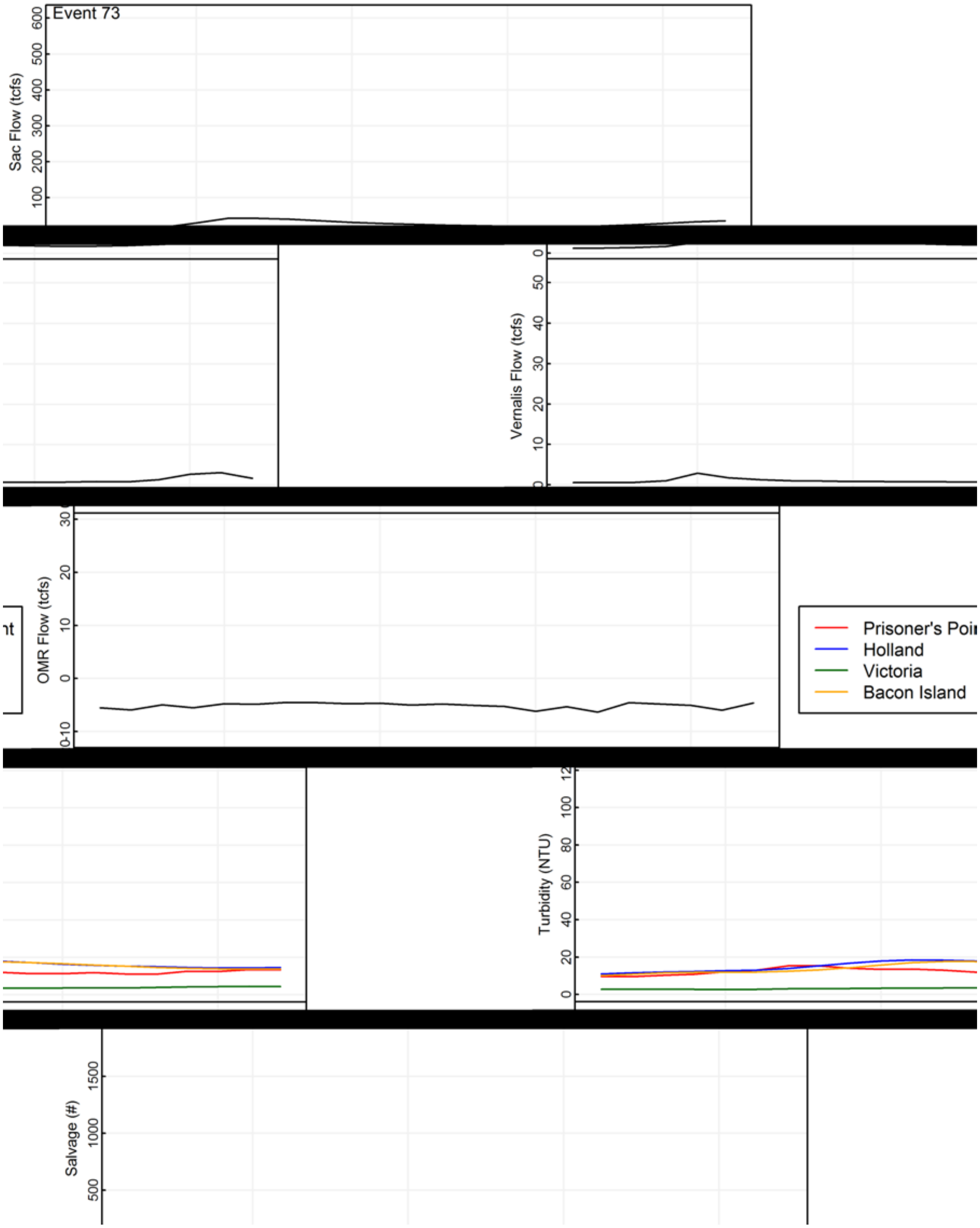


Figure C-62 **Event 73**

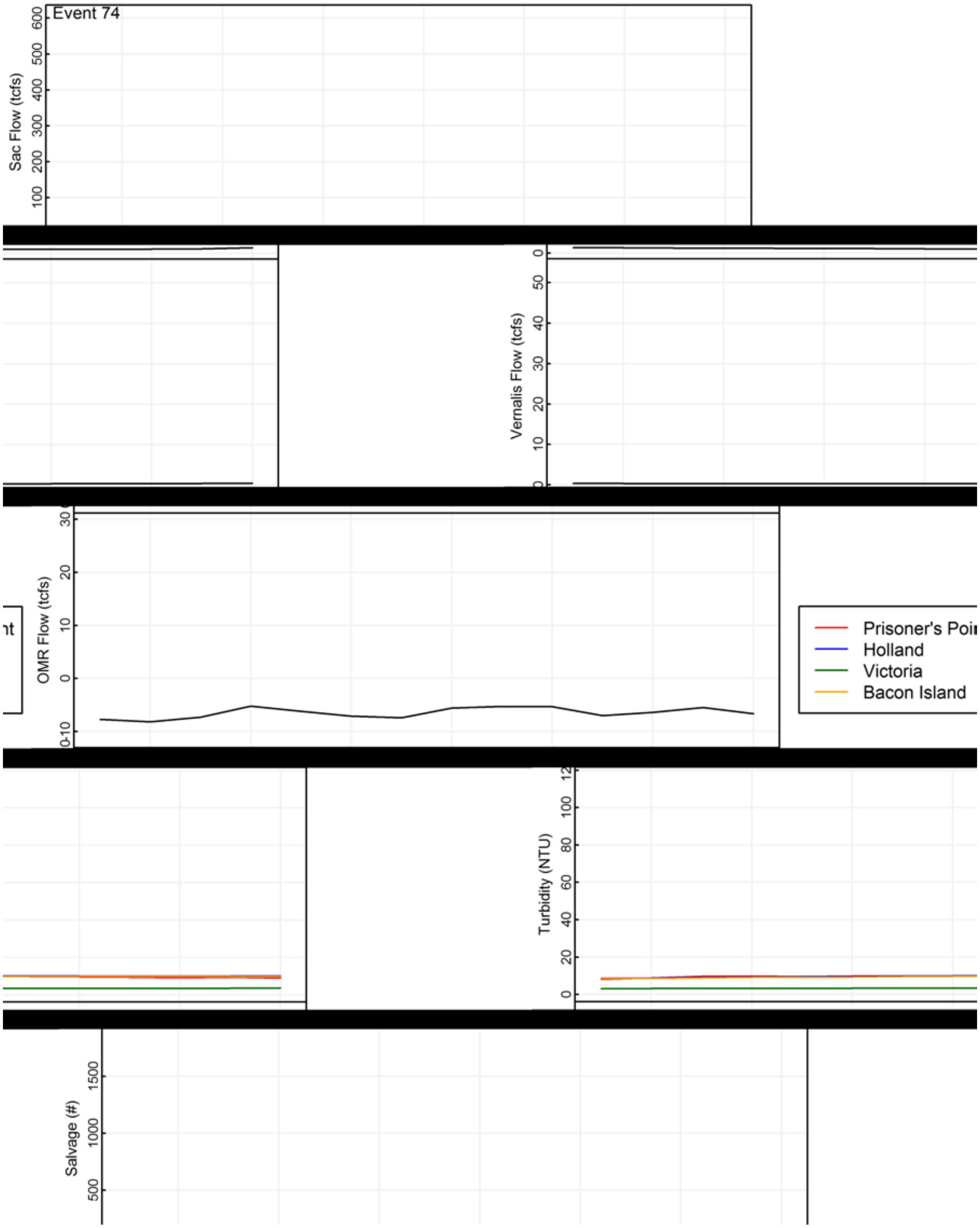


Figure C-63 **Event 74**

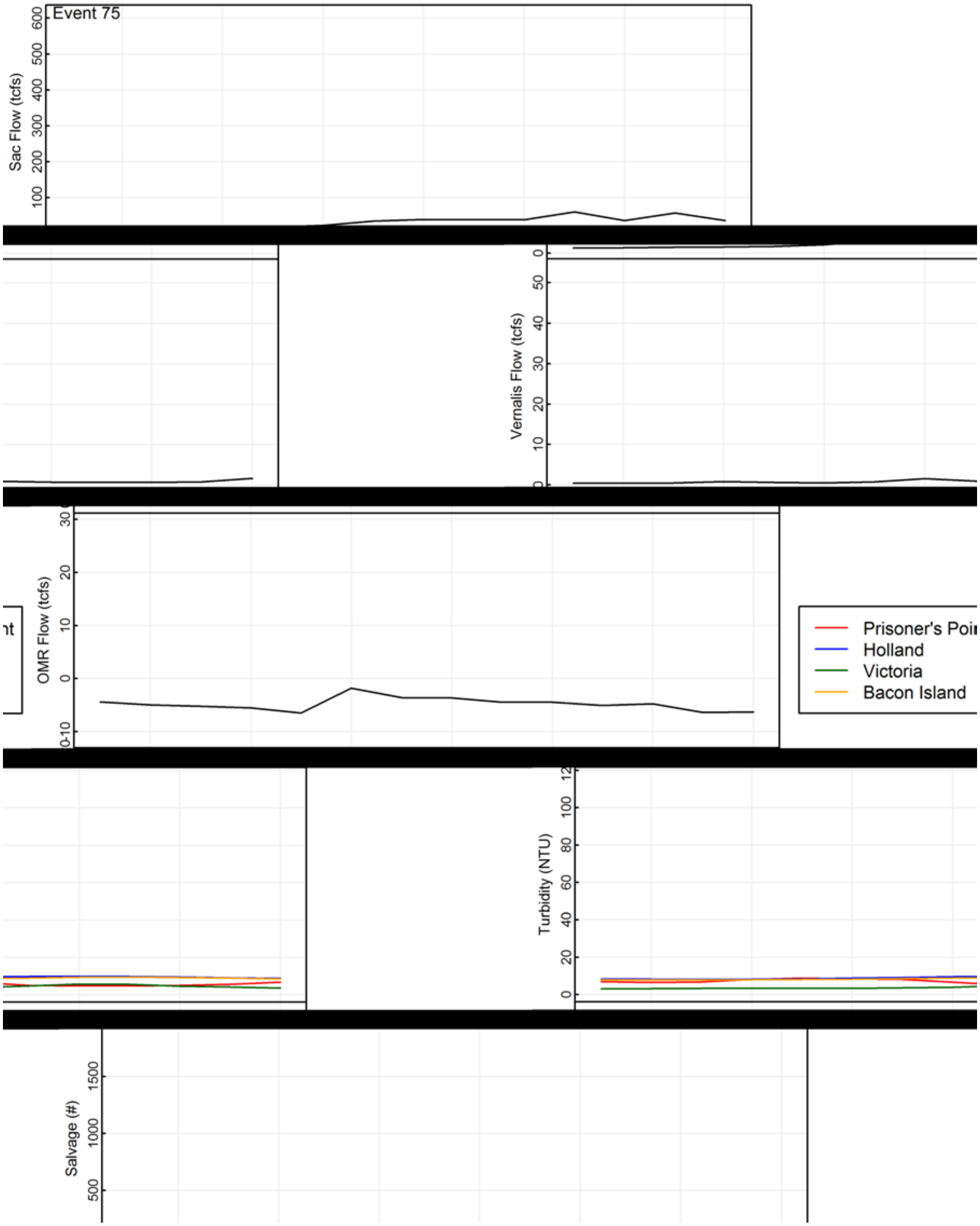


Figure C-64 **Event 75**

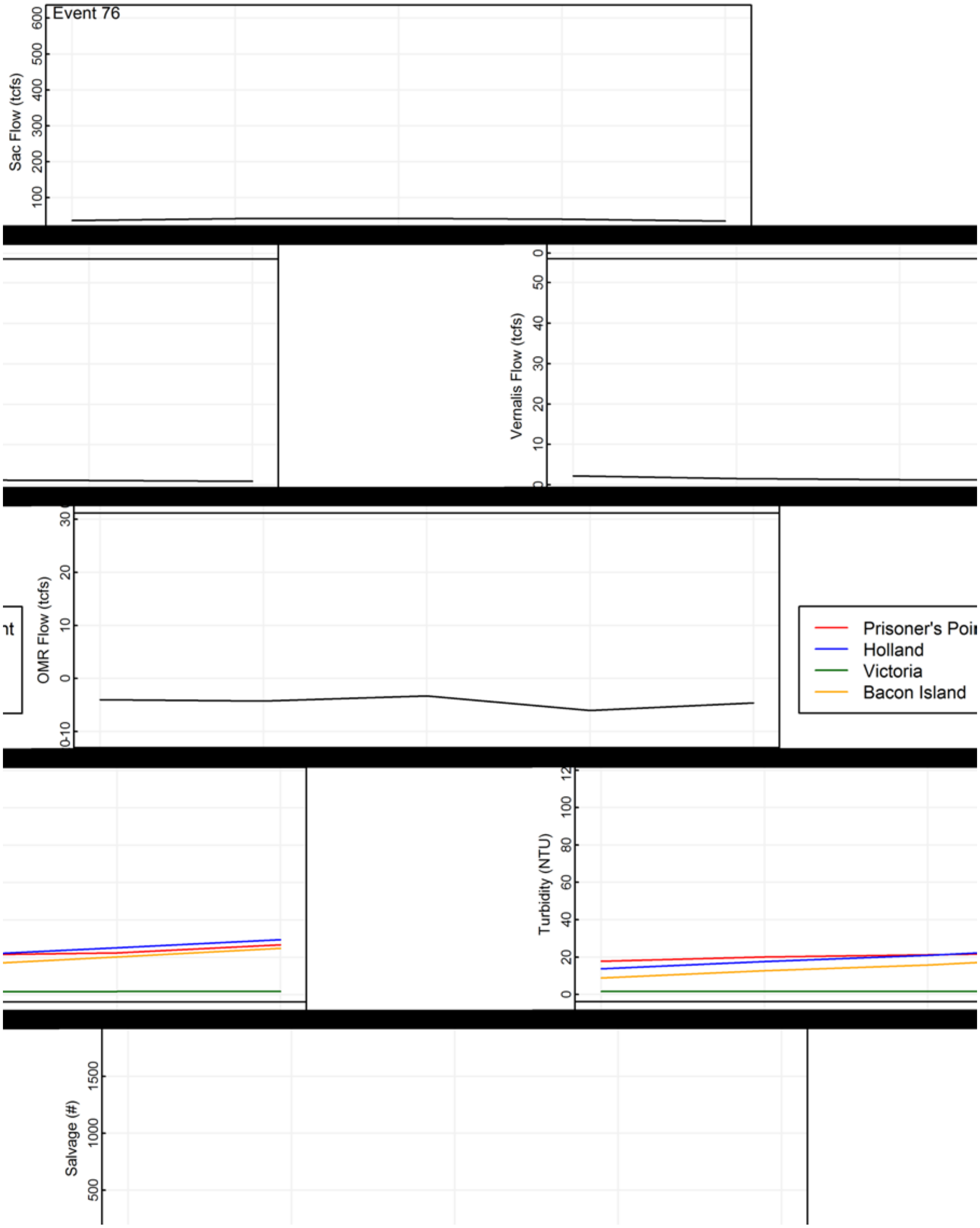


Figure C-65 **Event 76**

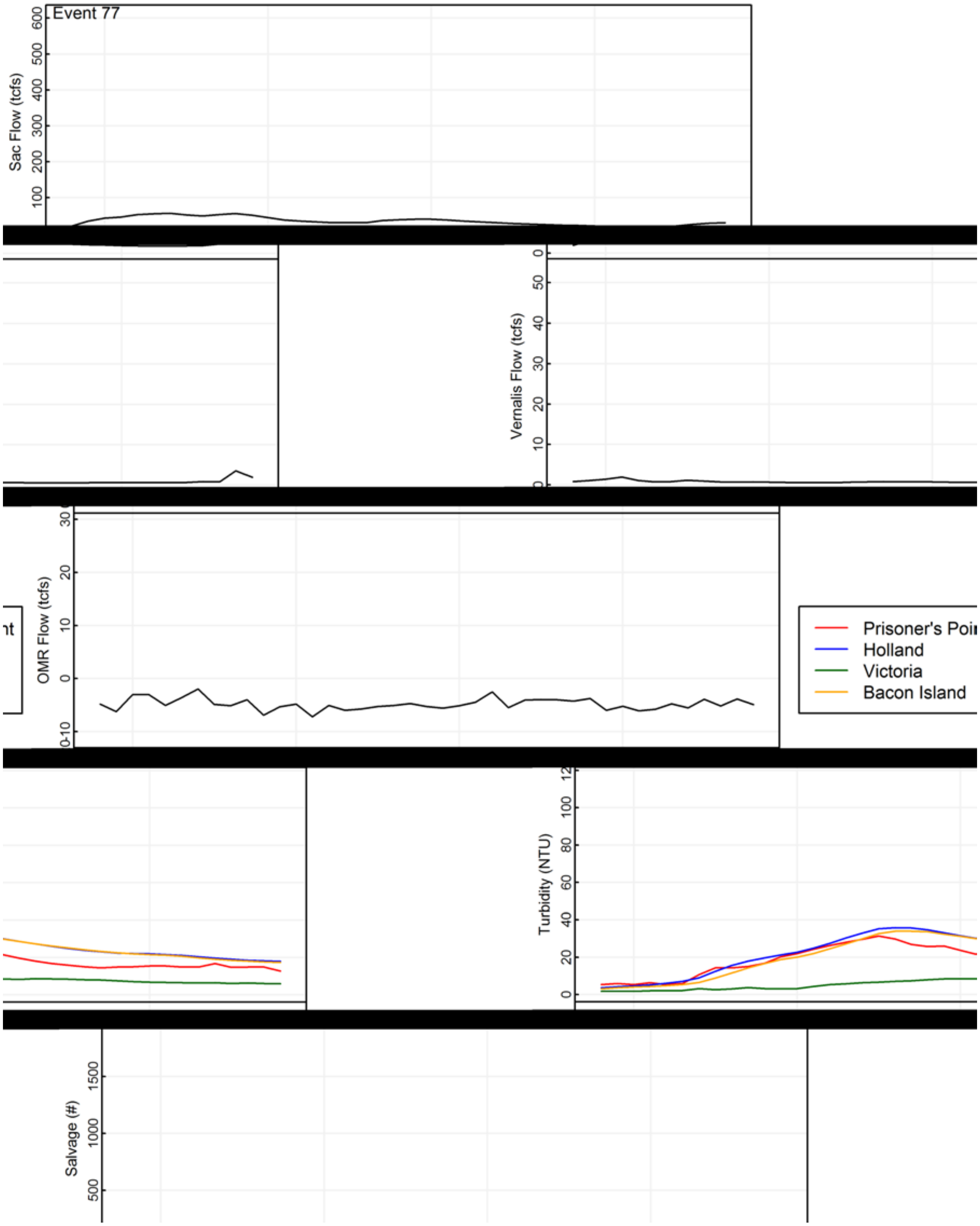


Figure C-66 **Event 77**

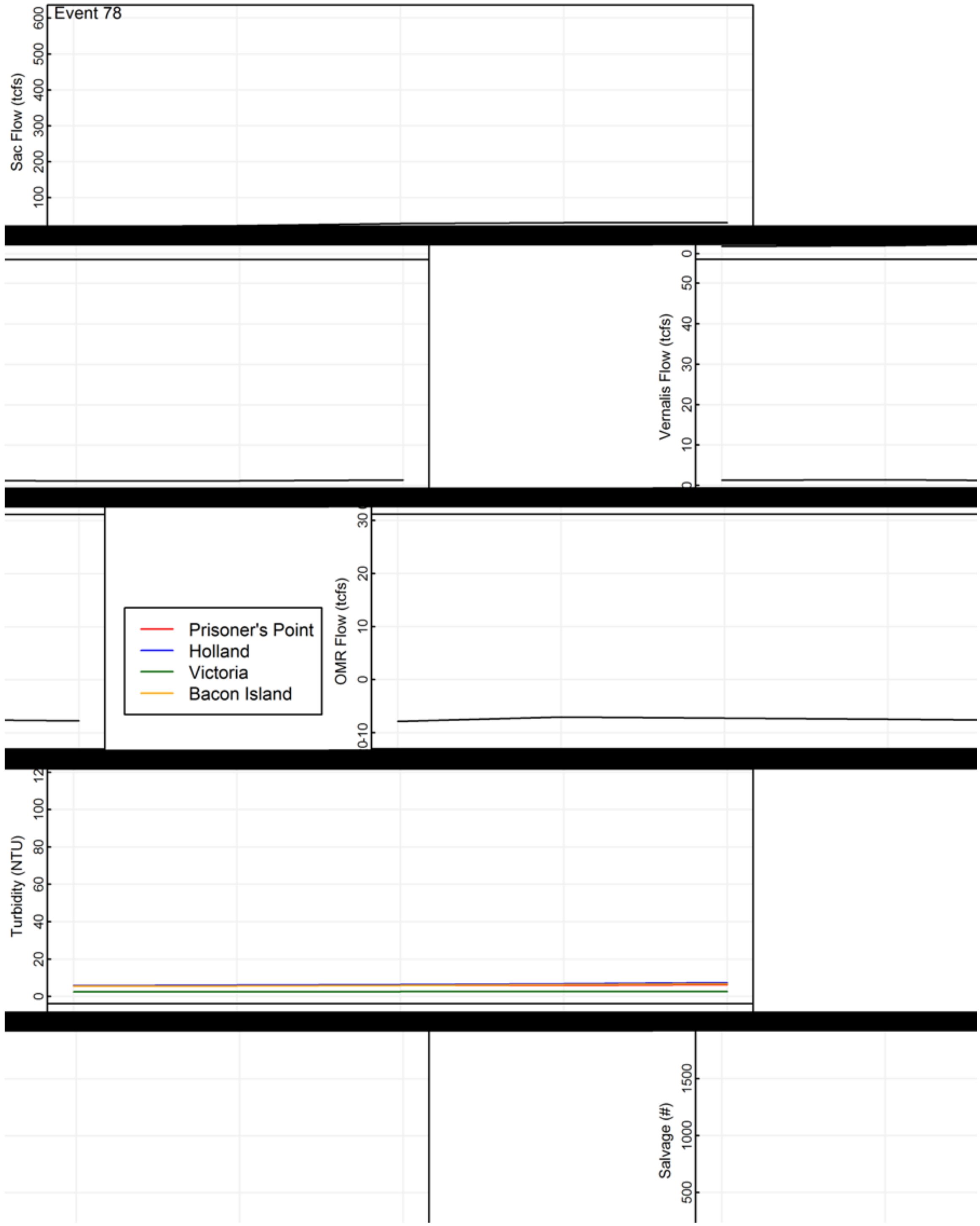


Figure C-67 Event 78

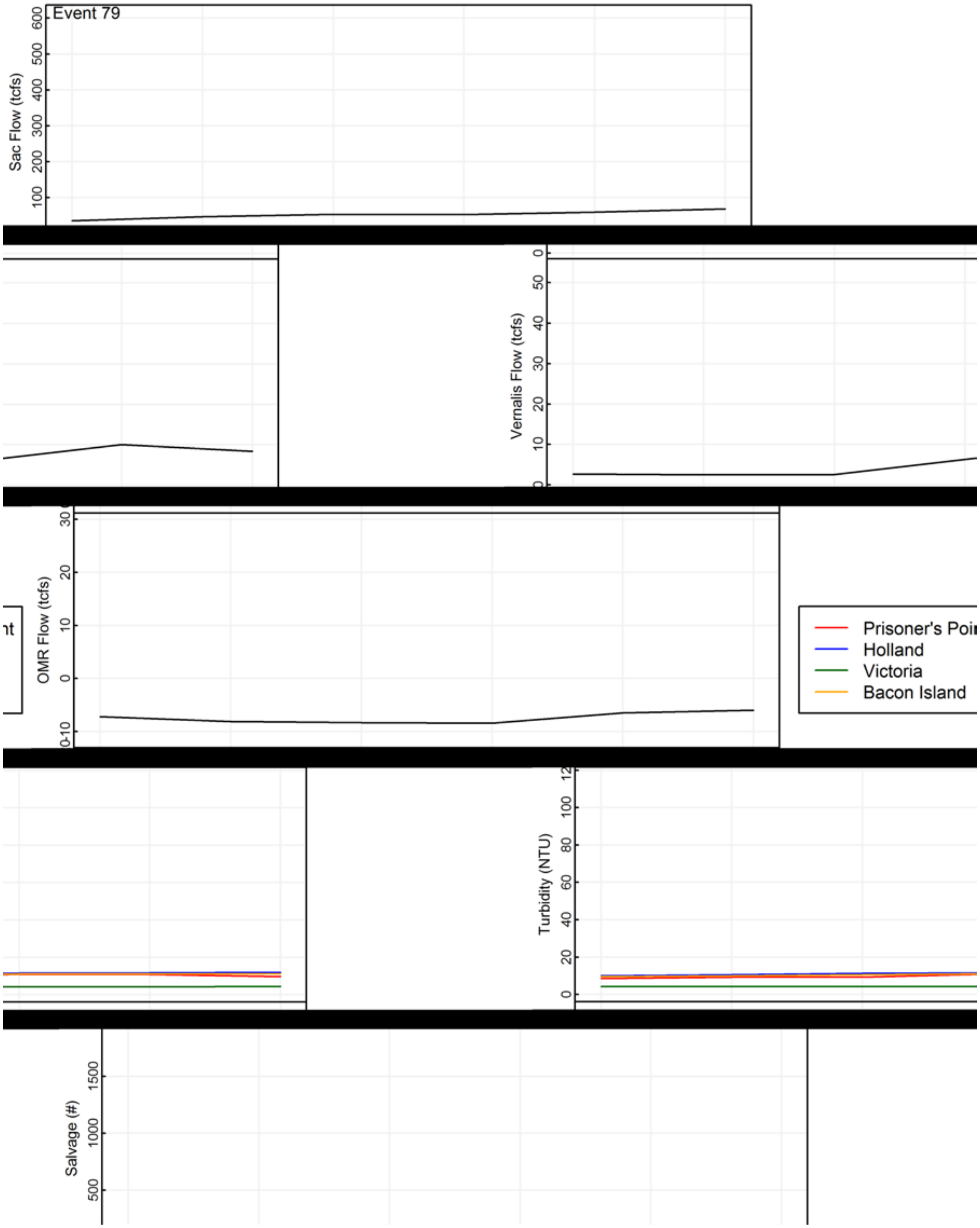


Figure C-68 **Event 79**

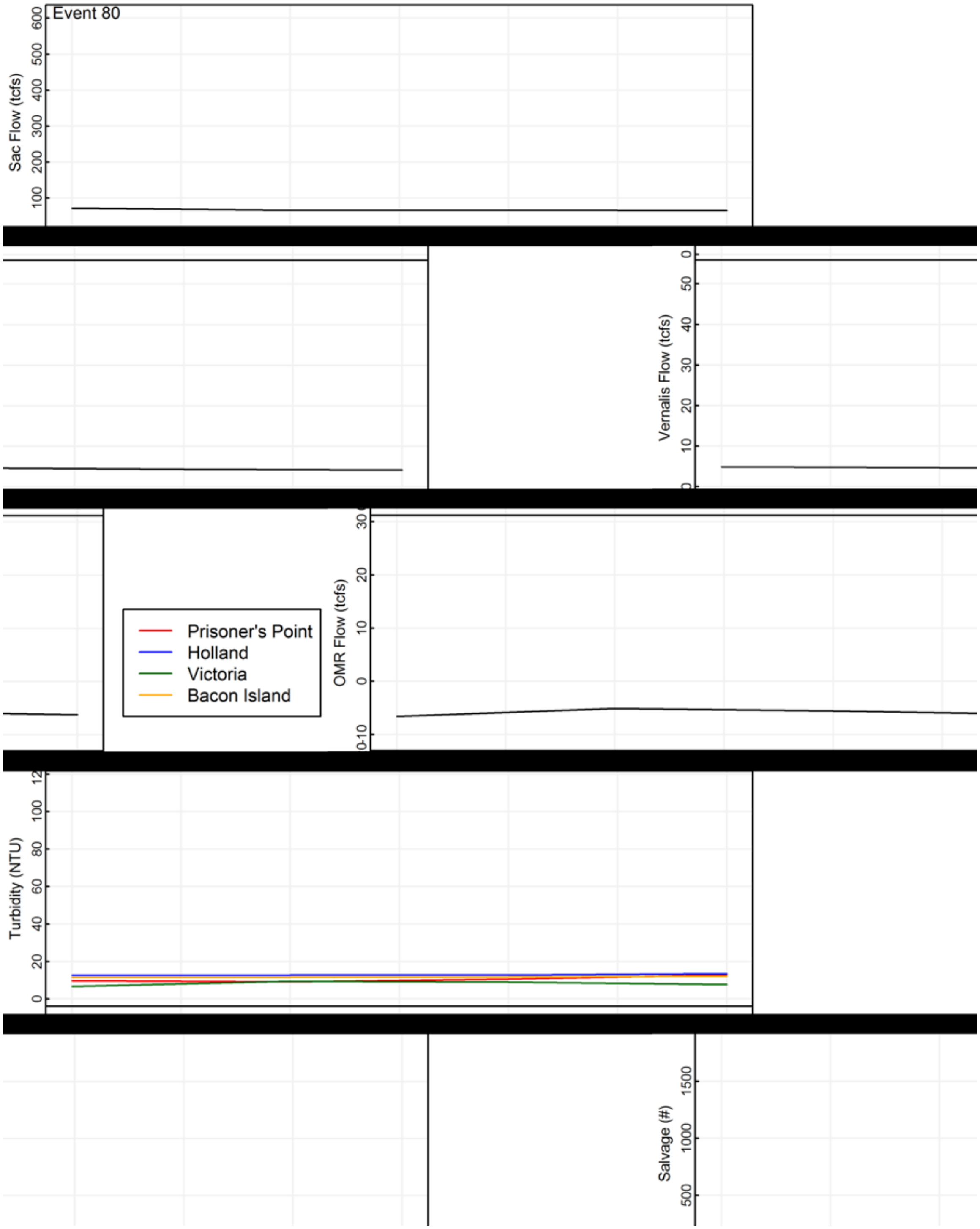


Figure C-69 Event 80

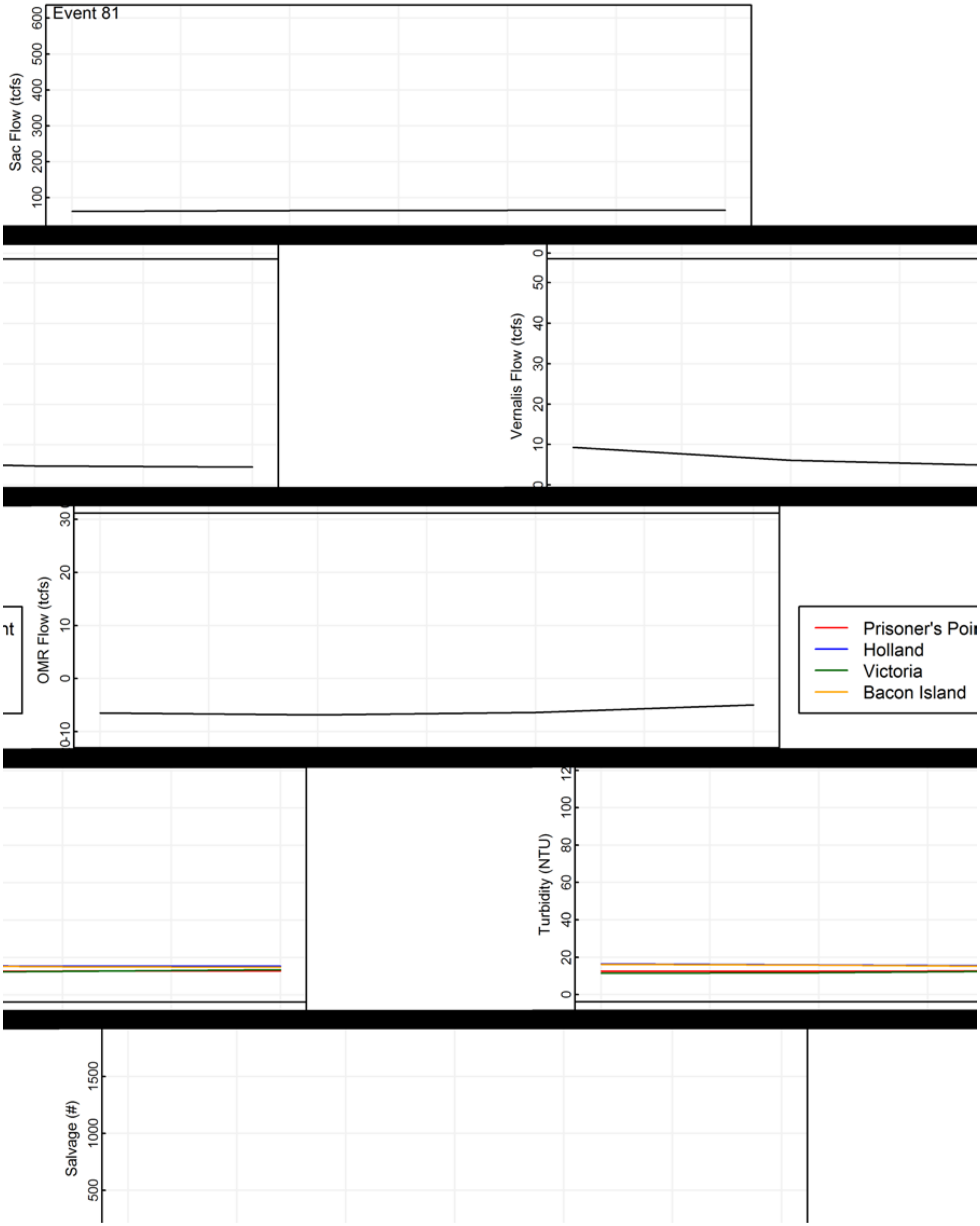


Figure C-70 **Event 81**