



Ministry of Water, Land & Air Protection LOWER MAINLAND REGION

Preliminary Assessment of Millionaire Creek Automated Water Quality Monitoring Data.

June 2004

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Prepared for:

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BC Ministry of Water, Land
& Air Protection

ENVIRONMENTAL QUALITY

Overview

The purpose of this report is to review and validate data collected to the end of 2003 by the Millionaire Creek automated water quality monitoring station. Data errors are repaired and preliminary assessment completed by **Aquatic Informatics Inc.**

Millionaire Creek, located in Maple Ridge, British Columbia, is a tributary to the North Alouette River and is important for fisheries as well as for recreational and irrigation use. Sub-urban residential development is planned in the watershed. As such, the British Columbia Ministry of Water, Land, and Air Protection (MWLAP) have initiated an automated water quality pilot study in the watershed to assess non-point source impacts from land-use development on small, event-driven streams. This information may be useful to the District of Maple Ridge and to local developers in understanding if, or how, development may be affecting the aquatic habitat. It could also help other communities to evaluate the effectiveness of the land-use plan and corresponding stormwater Best Management Practices (BMPs) in protecting aquatic habitat.

In July 2000, the Environmental Impact Section of the MWLAP conducted a reconnaissance survey in Millionaire Creek. The survey included a limited collection of water quality and benthic invertebrate samples (Quilty, 2001¹). In October 2001, the MWLAP installed an automated water quality monitoring station near the mouth of Millionaire Creek, and augmented the automated monitoring with an ongoing grab-sampling program.



In general, the Millionaire Creek automated station has performed quite well, logging relatively accurate data.

There were, however, corruptions in the dataset, which is normal for this type of monitoring. Outliers and noise were removed using highly sensitive analog filters, and drift and gaps were reconstructed with Artificial Neural Networks (ANNs).

Preliminary data assessment focused on risk assessment for salmonids, based on exposure to elevated water temperature and turbidity. Results suggest that high summer water temperatures may be causing chronic impacts (reduced growth) to salmonids, and high turbidity events during fall and winter may be causing severe impacts (mortality). Future data analysis should compare before/after impacts related to development.

¹ Quilty, EJ. 2001. Water Quality Reconnaissance Survey: Millionaire Creek, North Millionaire Creek, Hennipen Creek, and Anderson Creek. Prepared by QA Environmental Consulting for the B.C. Ministry of Water, Land, and Air Protection, Surrey. April 2001.

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Part I. Data Correction and Validation

Automated water quality data typically has sections of data errors such as outliers, drift, noise, and gaps. Before data analysis is attempted, data must be validated and corruptions eliminated. This section summarizes results from data validation and correction work completed on Millionaire Creek automated water quality data. Details of the methodology are described in publications provided in **Appendix I** and **Appendix II**. In general, the signals were statistically filtered to remove outliers and noise, and data gaps were then reconstructed using Artificial Neural Networks (ANNs). The corrected/validated signals are approved by AI Inc. for further analysis.

Temperature

Figure 1.1, **Figure 1.2**, and **Figure 1.3** show raw and corrected stream temperature readings for 2001, 2002, and 2003, respectively. 2001 data is incomplete (starts in October). Field measurements for temperature were available for 2003 only, and are included in **Figure 1.3**. Water level data is also included in each plot to help illustrate changing stream conditions. The raw data figures show obvious data corruptions, including outliers and gaps. Many of the outliers are associated with calibration visits, and most gaps are the result of sensor removal for maintenance or repair. The corrected stream temperature signals are free from data errors and gaps.

pH

Figure 2.1, **Figure 2.2**, and **Figure 2.3** show raw and corrected pH readings for 2001, 2002, and 2003, respectively. Field measurements and laboratory results from grab samples are included. The raw data is quite complete, although grab sampling results do not correspond well with automated readings. The corrected pH signals have higher correlation with grab sample results. It should be noted that grab samples might not be more accurate than corrected continuous data due to potential for sample contamination and drift during sampling and transport.

Conductivity

Figure 3.1, **Figure 3.2**, and **Figure 3.3** show raw and corrected conductivity readings for 2001, 2002, and 2003, respectively. Field measurements and laboratory results from grab samples are included. The raw data is relatively good, although grab sample results are slightly offset from automated readings and there are outliers associated with calibration visits. Also, for much of the summer of 2003 the sensor appears to frequently be exposed to the air, with readings repeatedly dropping to zero. The corrected conductivity signals are free from data errors and gaps.

Dissolved Oxygen

Figure 4.1, **Figure 4.2**, and **Figure 4.3** show raw and corrected conductivity readings for 2001, 2002, and 2003, respectively. Field measurements and laboratory results from grab samples are

included. Most of the raw data is quite good, although there are some outliers and gaps. The corrected dissolved oxygen signals are free from data errors and gaps.

Turbidity

Figure 5.1, Figure 5.2, and Figure 5.3 show raw and corrected conductivity readings for 2001, 2002, and 2003, respectively. Raw Millionaire Creek turbidity readings were noisy, which is typical of data from these types of sensors. Gaps were not filled because turbidity is difficult to model well from the available input variables.

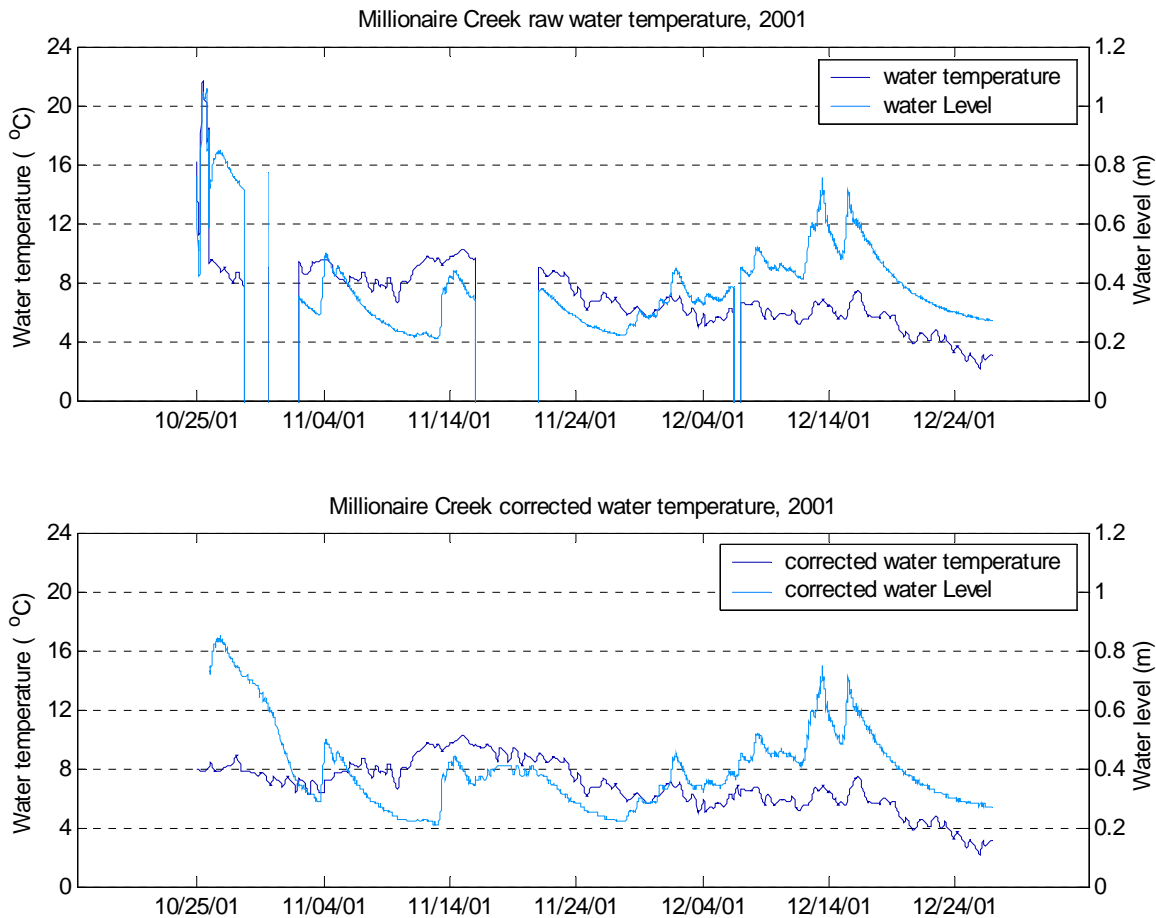


Figure 1.1. Millionaire Creek raw (top) and corrected (bottom) water temperature and level data for 2001. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

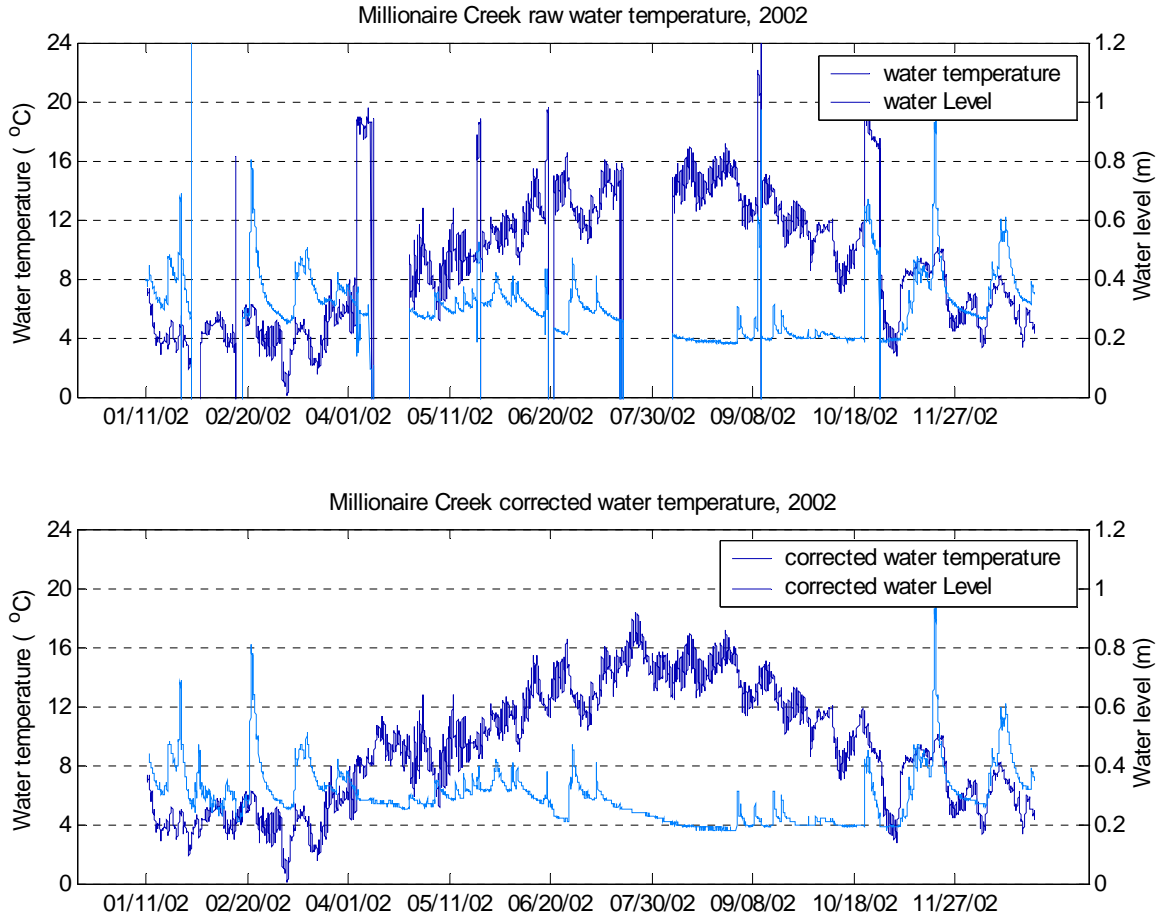


Figure 1.2. Millionaire Creek raw (top) and corrected (bottom) water temperature and level data for 2002. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

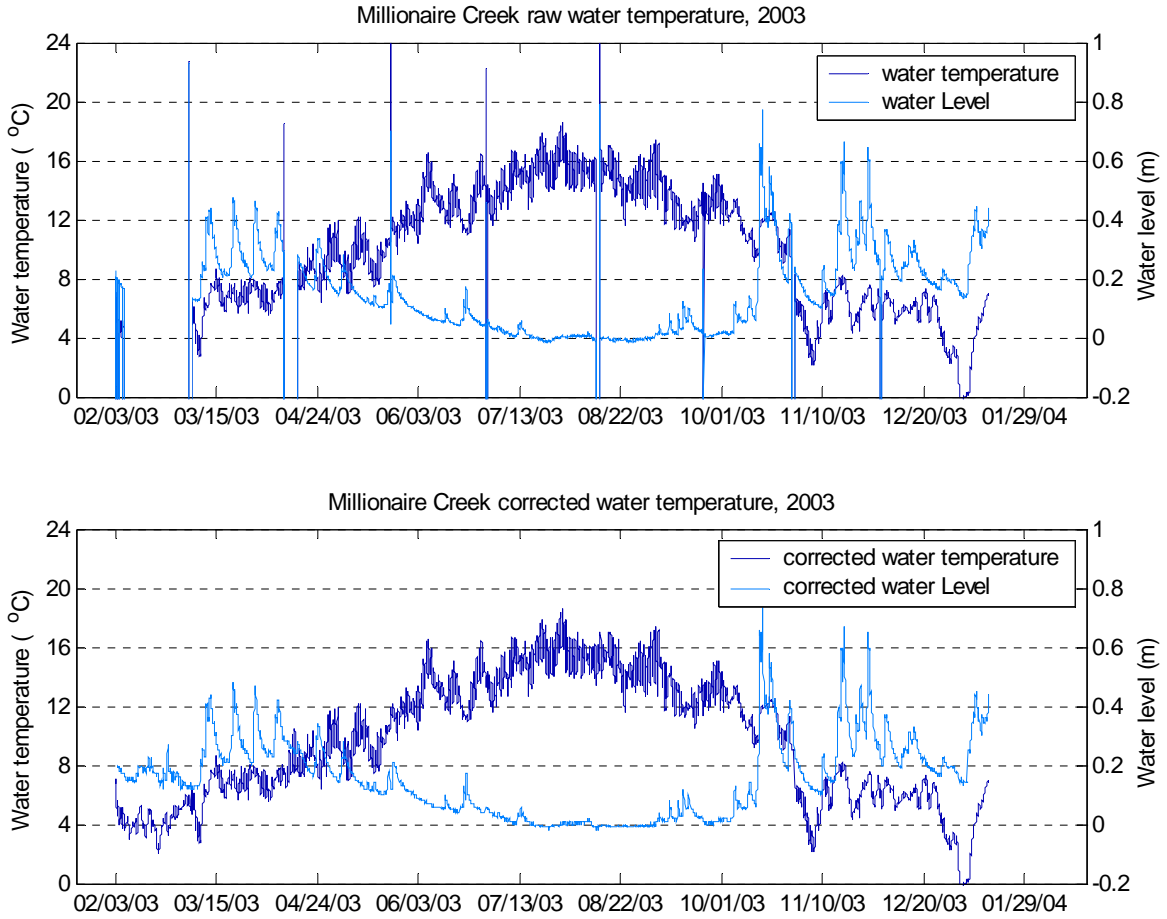


Figure 1.3. Millionaire Creek raw (top) and corrected (bottom) water temperature and level data for 2003. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

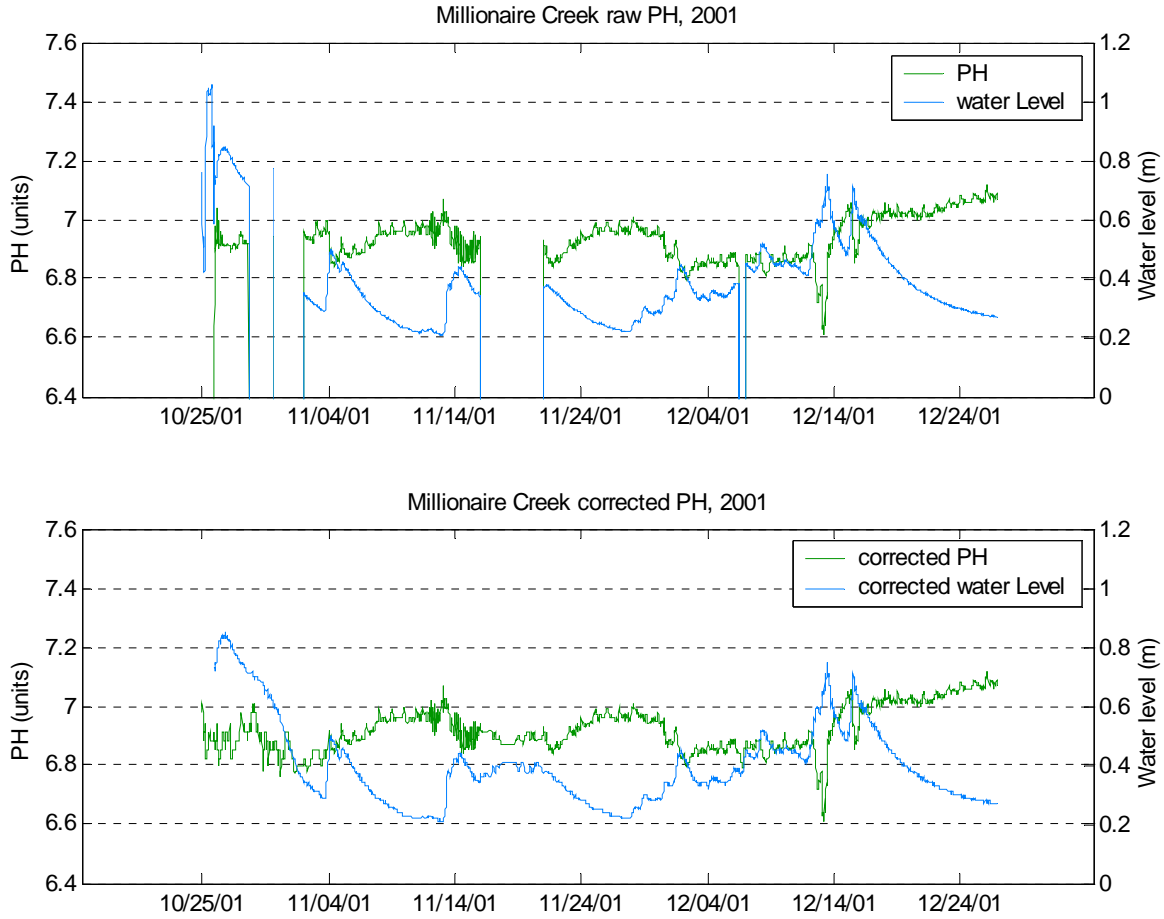


Figure 2.1. Millionaire Creek raw (top) and corrected (bottom) pH and level data for 2001. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

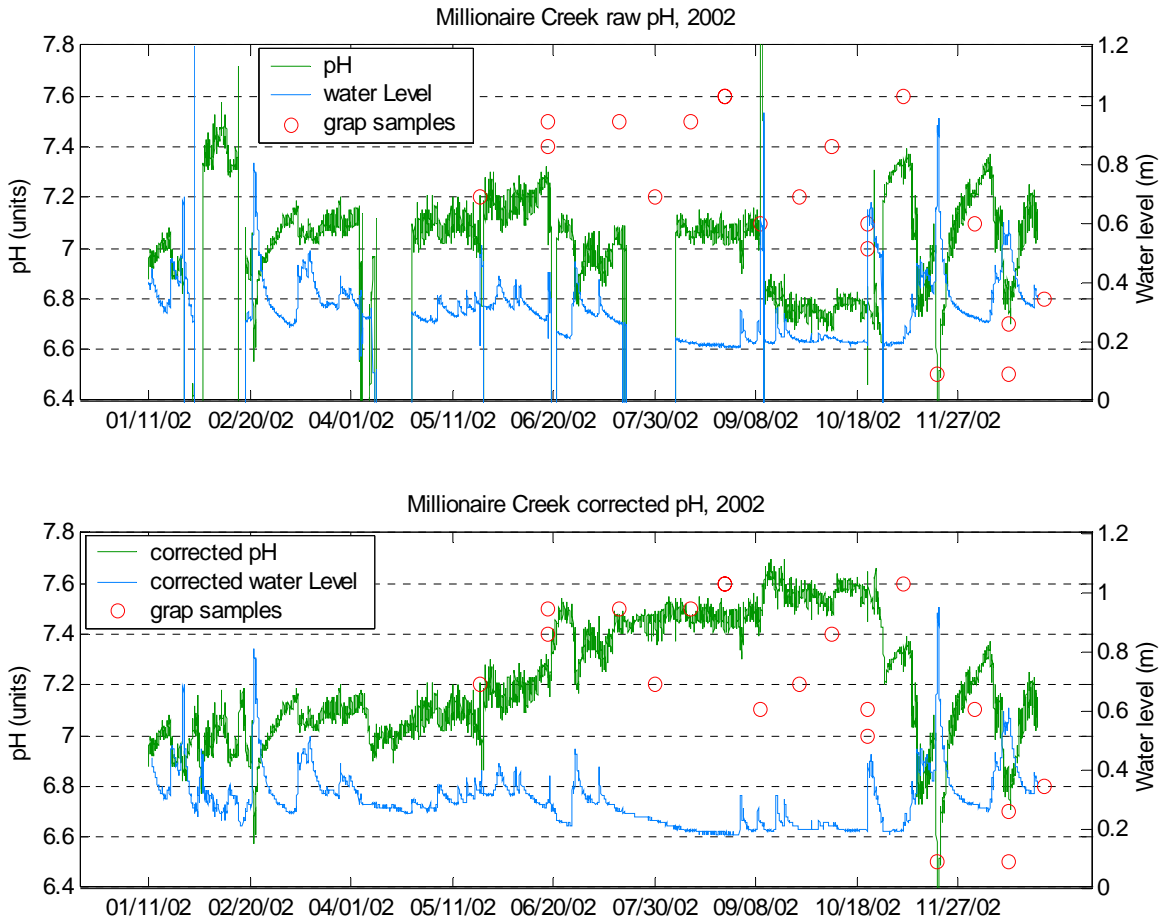


Figure 2.2. Millionaire Creek raw (top) and corrected (bottom) pH and level data for 2002. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

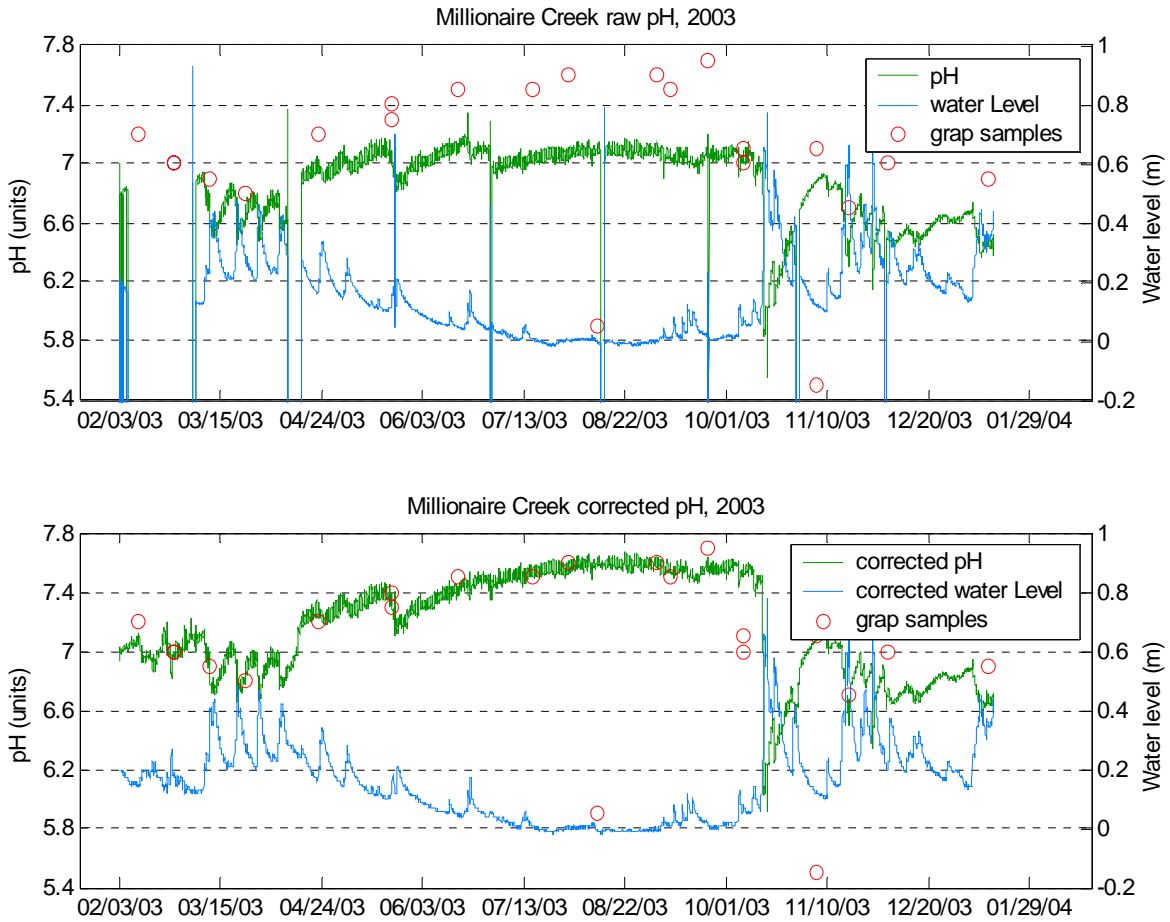


Figure 2.3. Millionaire Creek raw (top) and corrected (bottom) pH and level data for 2003. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

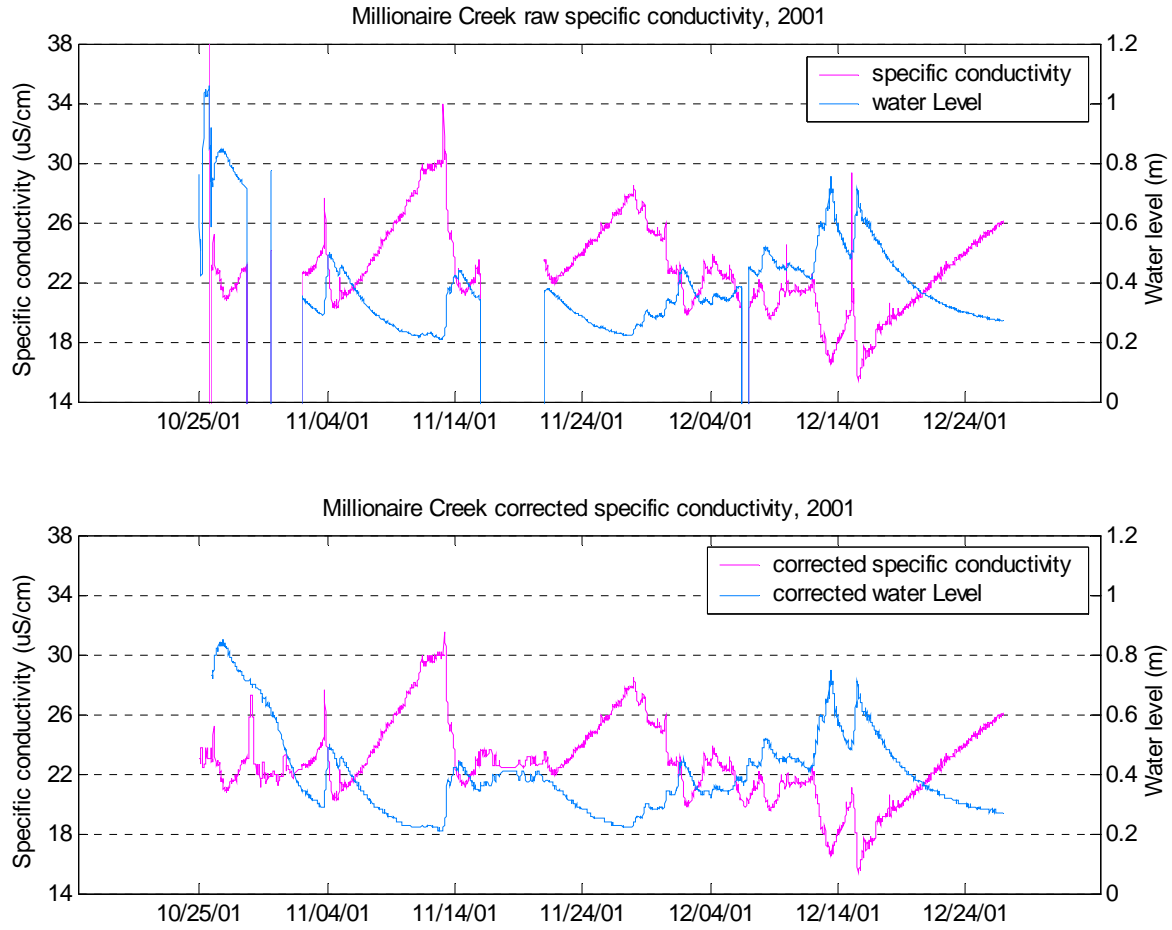


Figure 3.1. Millionaire Creek raw (top) and corrected (bottom) conductivity and level data for 2001. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

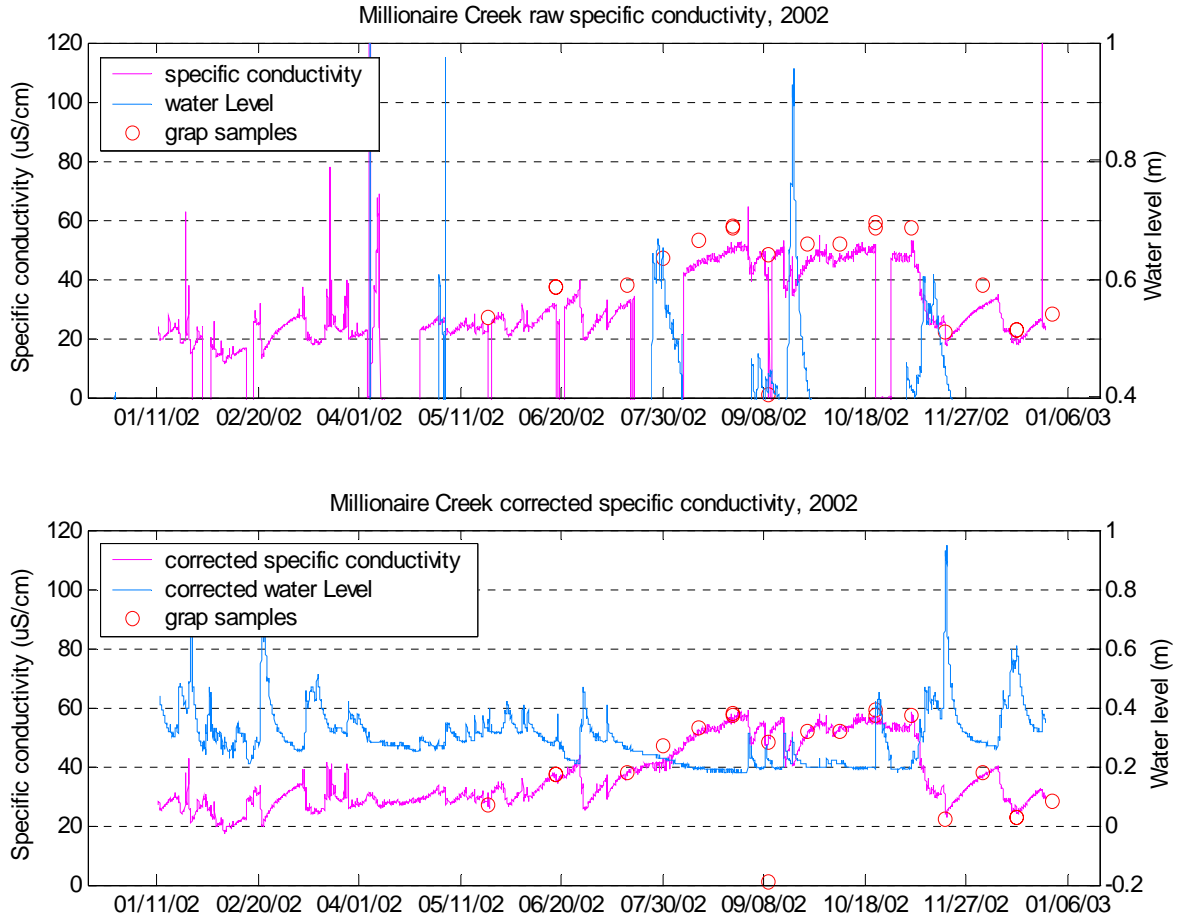


Figure 3.2. Millionaire Creek raw (top) and corrected (bottom) conductivity and level data for 2002. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

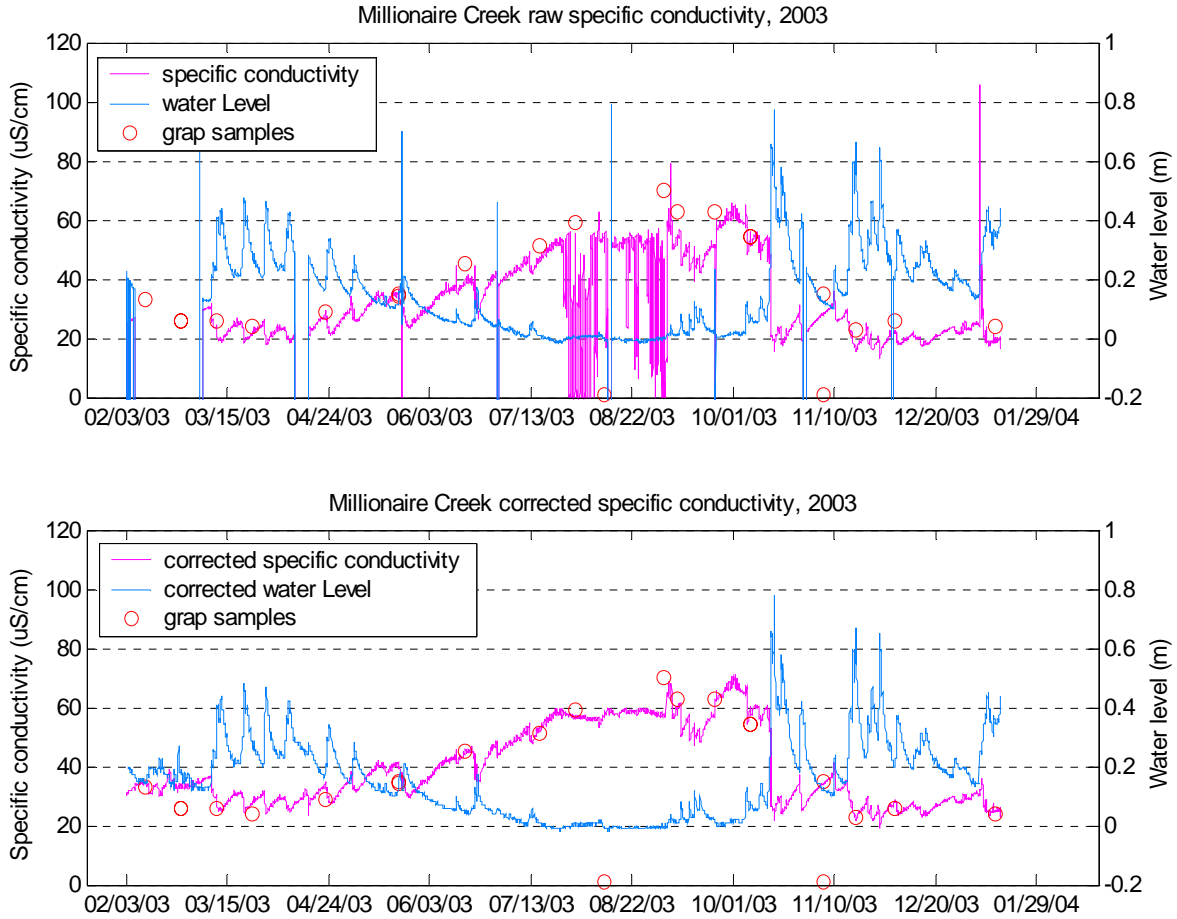


Figure 3.3. Millionaire Creek raw (top) and corrected (bottom) conductivity and level data for 2003. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

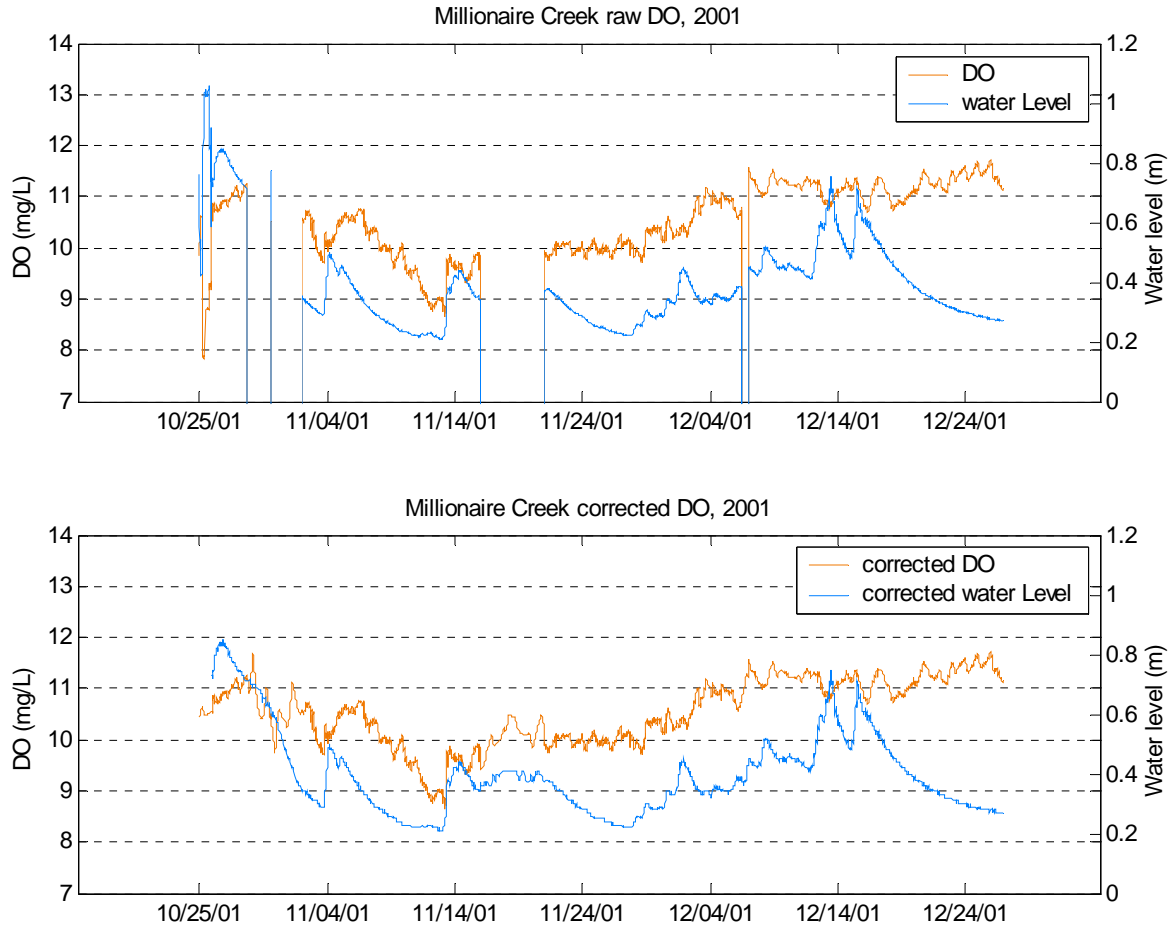


Figure 4.1. Millionaire Creek raw (top) and corrected (bottom) dissolved oxygen and level data for 2001. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

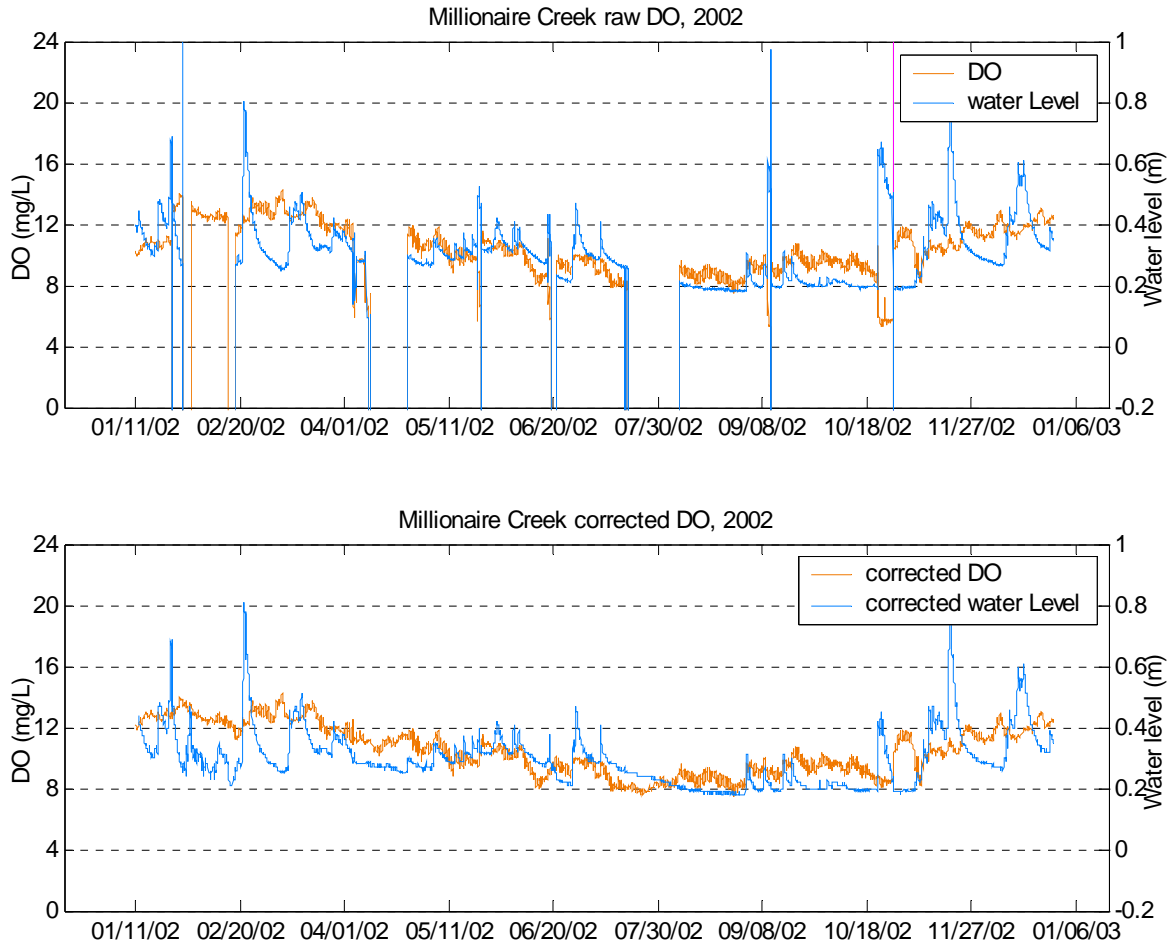


Figure 4.2. Millionaire Creek raw (top) and corrected (bottom) dissolved oxygen and level data for 2002. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

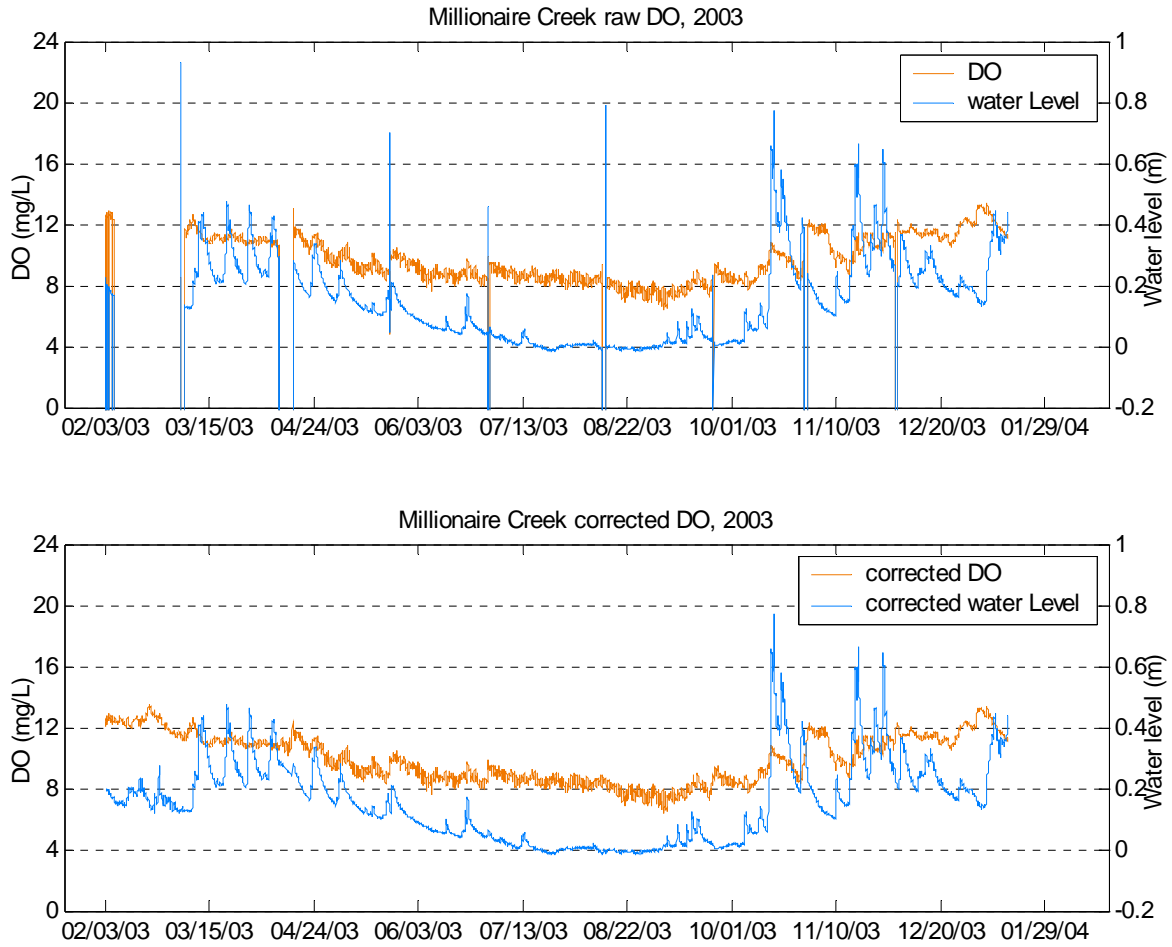


Figure 4.3. Millionaire Creek raw (top) and corrected (bottom) dissolved oxygen and level data for 2003. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

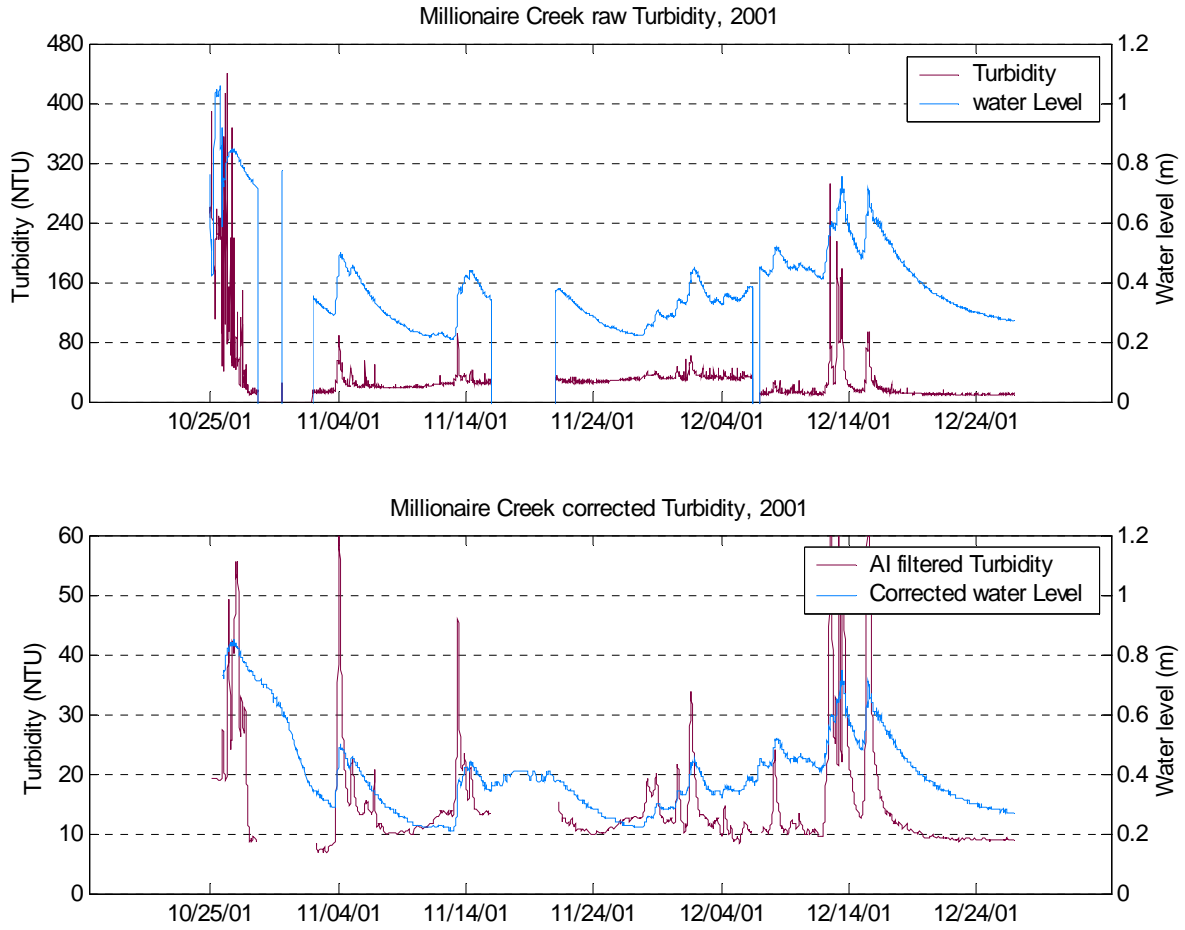


Figure 5.1. Millionaire Creek raw (top) and corrected (bottom) turbidity and level data for 2001. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

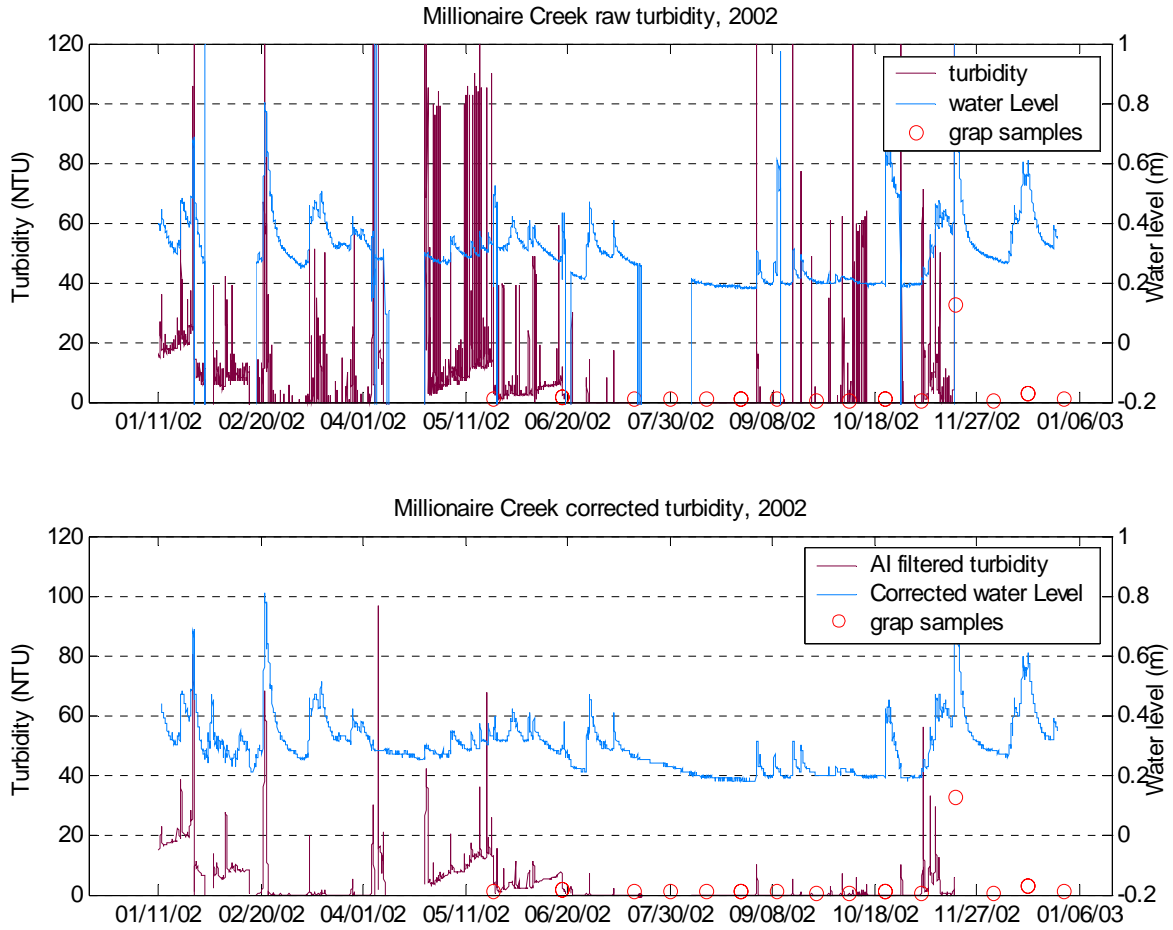


Figure 5.2. Millionaire Creek raw (top) and corrected (bottom) turbidity and level data for 2002. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

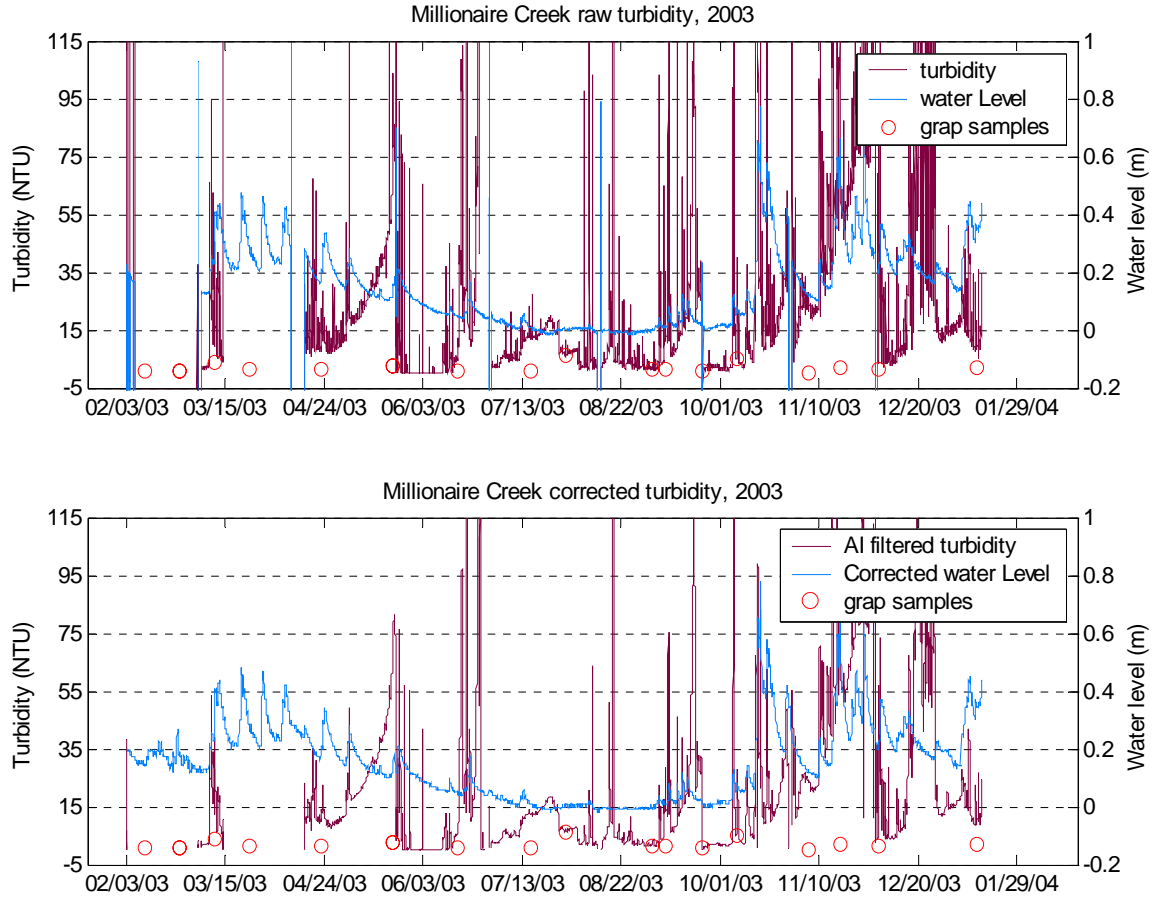


Figure 5.3. Millionaire Creek raw (top) and corrected (bottom) turbidity and level data for 2003. Gaps in raw data are marked with drop lines and were filled using ANN models trained on data near the gaps.

Part II. Preliminary Data Assessment

Preliminary data assessment includes exposure-based risk assessment for stream temperature and turbidity. Risk assessment is designed to combine the information from biological studies with an analysis of each population's exposure to quantified effects. Risk occurs when the stress' magnitude, frequency, and duration exceed the species ability to deal with that stress¹.

Exposure estimates are calculated using AI Inc. algorithms that measure the magnitude and duration of water quality events and compare the results to exposure guidelines^{2,3}.

Temperature

Water temperature in Millionaire Creek was typical of Pacific Northwest streams, ranging from near 0 °C in winter to as high as 19 °C in summer. Magnitude and duration of temperatures events greater than the optimal temperature range for salmonids, 12 – 16 °C, were compared to exposure curves for the most sensitive species of salmon in Millionaire Creek: chum and coho.

Stream temperatures in Millionaire Creek during 2002 and 2003 were not sufficiently high to cause **acute impacts** to salmonids, which occurs when stream temperatures reach near 25 °C².

Chronic impacts (reduced growth) may occur when stream temperatures exceed roughly 16 °C, depending on the duration of exposure. The effect of temperature on growth varies significantly with the ration of available food². Our analysis suggests that during **2002** there were 20 events in which exposure was high enough to potentially cause chronic impacts (**Appendix III, Table 1**). These events accounted for 210 hours (8.7 days) in total duration during July and August. Most events lasted for 1 – 10 hours, though one lasted for nearly 3 days. The highest observed temperature was 18.34 °C, on July 22.

2003 was warmer, with 48 chronic events totalling 390 hours or 16.3 days duration (**Appendix III, Table 2**). Chronic events lasted from 1 – 21 hours. The maximum temperature observed in 2003 was 18.61 °C, on July 30.

It should be noted that elevated temperatures causing reduced growth to salmonids are normal during the summer months in Pacific Northwest streams².

² Sullivan, K., D.J. Martin, R.D. Cardwell, J.E. Toll, and S. Duke. 2000. *An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria*. Sustainable Ecosystems Institute, Portland, Oregon.

³ Newcombe, C.P. 2003. *Impact assessment model for clear water fishes exposed to excessively cloudy water*. JAWRA. 39(3): 529-544.

These streams rarely remain in the optimal temperature range year-round. Optimal growth generally occurs at a midpoint of annual temperatures, and it declines when waters are warmer or cooler². In addition, salmon are highly mobile and adaptive, and are likely to avoid high temperatures by seeking refuge (cooler tributaries, groundwater up-welling, etc.).

Turbidity

Once statistically filtered to reduce noise, turbidity data was automatically risk assessed according to severity of effects (SOE) guidelines³. These guidelines assign impacts according to a colour scheme, depending on the duration of the event:

Colour	Severity of Effect
green	Ideal
yellow	slightly impaired
orange	significantly impaired
red	severely impaired
grey	values with least supporting data or least likelihood of problems or both

Magnitude and duration of events above set thresholds of 1, 5, 8, and 20 NTU were estimated. Measurements start as soon as an event exceeds a threshold, and end when levels drop below the threshold. *Therefore, multiple upper threshold events may occur within a lower threshold event. For example, there may be 3 events greater than 8 NTU during a single 1 NTU event. Hence it is possible to have fewer low magnitude events, though they will have longer duration.*

2002 turbidity events are summarized in **Appendix III, Table 3**. During 2002 there were 20 events greater than 1 NTU, 20 greater than 5 NTU, 25 greater than 8 NTU, and 12 greater than 20 NTU. Most events were in the winter or fall. Events greater than 20 NTU were relatively short in duration, ranging from less than 1 hour to about 40 hours. No events were higher than yellow (slightly impaired).

2003 events are summarized in **Appendix III, Table 4**. During 2003 there were 34 events greater than 1 NTU, 37 greater than 5 NTU, 48 events greater than 8 NTU, and 49 events greater than 20 NTU. Most events were in the winter or fall. Events greater than 20 NTU were highly variable in duration, ranging from less than 1 hour to above 330 hours (14 days). There were 8 events above the 20 NTU threshold that were rated higher than orange (significantly impaired).

APPENDIX I. Methods Paper for Data Correction.

Quilty, E., P. Hudson, and T. Farahmand. 2004. *Data Validation and Correction of High Frequency Water Quality Data using Artificial Neural Networks*. 11th Canadian National Conference and 2nd Policy Forum on Drinking Water: Promoting Public Health through Safe Drinking Water, April 3-6, 2004. Calgary, AB.

APPENDIX II. Methods Paper for Statistical Filtering.

Quilty, E., T. Farahmand, and P. Hudson. 2004. *Validation and Correction of High Frequency Water Quality Data*. 57th Annual Conference of the Canadian Water Resources Association: Knowledge for Better Adaptation. June 16-18, 2004. Montreal, QB.

APPENDIX III. Risk Assessment Tables.

Table 1. Millionaire Creek 2002 temperature events rated as having chronic impacts on salmonids.

Event No.	Start Date	End Date	Duration (days)	Duration (hours)	Magnitude Duration	Max Reached	Rating
1	26/06/2002 13:57	26/06/2002 19:25	0.227	5.46	3.9044	16.5	chronic
2	11/07/2002 15:29	11/07/2002 16:50	0.056	1.35	1.1671	16.02	chronic
3	19/07/2002 18:27	19/07/2002 21:00	0.106	2.55	2.0072	16.11	chronic
4	20/07/2002 17:33	20/07/2002 22:26	0.203	4.88	3.3793	16.41	chronic
5	21/07/2002 15:37	22/07/2002 3:04	0.477	11.45	8.0976	17.02	chronic
6	22/07/2002 13:44	25/07/2002 9:15	2.813	67.51	48.4182	18.34	chronic
7	25/07/2002 11:44	26/07/2002 9:08	0.891	21.39	15.2298	17.81	chronic
8	26/07/2002 14:34	27/07/2002 0:22	0.408	9.80	6.8772	16.93	chronic
9	27/07/2002 17:04	27/07/2002 23:12	0.255	6.13	4.2361	16.44	chronic
10	12/08/2002 15:28	12/08/2002 19:11	0.155	3.728	2.6801	16.13	chronic
11	13/08/2002 12:48	13/08/2002 22:24	0.400	9.59	6.7224	16.84	chronic
12	14/08/2002 11:49	14/08/2002 22:20	0.438	10.50	7.4488	16.96	chronic
13	15/08/2002 13:13	15/08/2002 20:22	0.298	7.16	5.1135	16.54	chronic
14	23/08/2002 16:13	23/08/2002 18:15	0.085	2.04	1.6679	16.03	chronic
15	24/08/2002 13:59	24/08/2002 20:04	0.253	6.07	4.3801	16.28	chronic
16	26/08/2002 13:42	26/08/2002 20:26	0.280	6.73	4.7294	16.32	chronic
17	27/08/2002 13:27	27/08/2002 21:48	0.347	8.34	5.955	16.53	chronic
18	28/08/2002 12:01	28/08/2002 23:33	0.480	11.53	8.1693	17.1	chronic
19	29/08/2002 12:37	29/08/2002 21:35	0.374	8.97	6.3156	16.65	chronic
20	31/08/2002 13:59	31/08/2002 18:30	0.188	4.52	3.3427	16.08	chronic
TOTAL			8.74	209.7			

Table 2. Millionaire Creek 2003 temperature events rated as having chronic impacts on salmonids.

Event No.	Start Date	End Date	Duration (days)	Duration (hours)	Magnitude Duration	Max Reached	Rating
1	06/06/2003 14:09	06/06/2003 19:03	(days)	(hours)	Duration	16.42	chronic
2	07/06/2003 13:29	07/06/2003 19:40	0.204	4.90	3.56	16.56	chronic
3	28/06/2003 14:14	28/06/2003 19:34	0.258	6.19	4.43	16.42	chronic
4	10/07/2003 13:38	10/07/2003 21:32	0.222	5.33	3.89	16.68	chronic
5	11/07/2003 12:56	11/07/2003 21:08	0.329	7.90	5.66	16.64	chronic
6	12/07/2003 12:25	12/07/2003 18:48	0.342	8.20	5.81	16.53	chronic
7	15/07/2003 13:14	15/07/2003 19:57	0.266	6.37	4.56	16.37	chronic
8	18/07/2003 14:53	18/07/2003 19:42	0.280	6.71	4.74	16.21	chronic
9	19/07/2003 13:59	19/07/2003 21:00	0.201	4.82	3.36	16.47	chronic
10	20/07/2003 12:29	20/07/2003 22:30	0.292	7.01	5.09	16.76	chronic
11	21/07/2003 10:53	22/07/2003 0:45	0.417	10.01	7.21	17.65	chronic
12	22/07/2003 10:28	23/07/2003 1:30	0.578	13.86	10.06	17.84	chronic
13	23/07/2003 10:23	23/07/2003 22:20	0.626	15.03	11.03	17.41	chronic
14	24/07/2003 13:09	24/07/2003 20:45	0.498	11.95	8.59	16.54	chronic
15	25/07/2003 13:46	25/07/2003 21:15	0.316	7.59	5.43	16.64	chronic
16	26/07/2003 13:01	26/07/2003 21:20	0.312	7.48	5.30	16.63	chronic
17	27/07/2003 12:39	27/07/2003 23:17	0.346	8.31	5.79	17.02	chronic
18	28/07/2003 11:04	29/07/2003 2:39	0.443	10.63	7.63	17.63	chronic

Event No.	Start Date	End Date	Duration	Duration	Magnitude	Max Reached	Rating
19	29/07/2003 9:27	30/07/2003 5:35	0.649	15.58	11.14	18.4	chronic
20	30/07/2003 7:34	31/07/2003 5:03	0.839	20.13	14.81	18.61	chronic
21	31/07/2003 8:38	01/08/2003 0:05	0.895	21.48	15.79	17.83	chronic
22	01/08/2003 13:09	01/08/2003 22:07	0.643	15.44	11.20	16.66	chronic
23	02/08/2003 13:16	02/08/2003 22:02	0.374	8.97	6.33	16.72	chronic
24	03/08/2003 12:59	03/08/2003 21:20	0.365	8.76	6.17	16.57	chronic
25	04/08/2003 13:37	04/08/2003 21:10	0.348	8.34	5.96	16.57	chronic
26	05/08/2003 12:28	05/08/2003 23:39	0.315	7.55	5.28	17.02	chronic
27	06/08/2003 14:59	06/08/2003 18:00	0.466	11.18	7.96	16.05	chronic
28	07/08/2003 13:53	07/08/2003 21:09	0.126	3.02	2.34	16.49	chronic
29	08/08/2003 14:06	08/08/2003 20:15	0.303	7.27	5.10	16.23	chronic
30	10/08/2003 14:59	10/08/2003 18:38	0.256	6.15	4.37	16.06	chronic
31	11/08/2003 16:13	11/08/2003 17:15	0.152	3.64	2.67	16.01	chronic
32	12/08/2003 14:44	12/08/2003 18:35	0.043	1.04	1.00	16.14	chronic
33	13/08/2003 14:55	13/08/2003 18:30	0.160	3.85	2.85	16.22	chronic
34	14/08/2003 12:23	14/08/2003 21:06	0.149	3.58	2.69	17.04	chronic
35	15/08/2003 14:46	15/08/2003 19:26	0.364	8.73	6.21	16.21	chronic
36	17/08/2003 11:11	17/08/2003 22:50	0.194	4.67	3.19	17.03	chronic
37	18/08/2003 11:31	18/08/2003 23:00	0.485	11.64	8.31	17.02	chronic
38	19/08/2003 12:36	19/08/2003 20:08	0.478	11.48	8.14	16.62	chronic
39	20/08/2003 15:12	20/08/2003 19:12	0.314	7.53	5.30	16.22	chronic
40	21/08/2003 14:11	21/08/2003 21:05	0.167	4.01	2.86	16.5	chronic
41	29/08/2003 14:58	29/08/2003 19:06	0.287	6.89	4.93	16.31	chronic
42	30/08/2003 14:41	30/08/2003 20:04	0.172	4.13	3.03	16.47	chronic
43	31/08/2003 15:40	31/08/2003 18:52	0.224	5.38	3.90	16.06	chronic
44	02/09/2003 16:29	02/09/2003 19:47	0.133	3.18	2.34	16.06	chronic
45	03/09/2003 14:07	03/09/2003 21:36	0.138	3.30	2.51	17	chronic
46	04/09/2003 13:02	04/09/2003 21:24	0.312	7.48	5.34	17.2	chronic
47	05/09/2003 11:38	05/09/2003 20:06	0.349	8.37	5.93	17.32	chronic
48	06/09/2003 11:43	06/09/2003 18:48	0.353	8.46	6.13	17.16	chronic
TOTAL			0.296	7.09	5.22		

Table 3. Severity of effects ratings for Millionaire Creek 2002 turbidity events.

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Dur-Mag (NTU hrs)	Max (NTU)	Rating
1 NTU	11/01/2002 16:59	25/01/2002 6:57	13.625	327.00	267.10	78	data gap
	25/01/2002 17:44	29/01/2002 13:55	3.885	93.25	27.17	10	data gap
	01/02/2002 14:46	15/02/2002 21:39	14.583	350.00	102.76	26	data gap
	21/02/2002 3:18	22/02/2002 23:42	1.896	45.50	45.08	55	grey
	11/03/2002 4:37	11/03/2002 9:54	0.271	6.50	1.97	15	green
	27/03/2002 22:30	27/03/2002 23:07	0.031	0.75	0.05	2	green
	04/04/2002 16:22	05/04/2002 11:57	0.865	20.75	16.51	30	data gap
	07/04/2002 1:30	09/04/2002 4:58	2.208	53.00	44.19	96	grey
	09/04/2002 11:22	09/04/2002 11:57	0.052	1.25	0.20	6	green
	26/04/2002 0:45	23/05/2002 7:39	27.458	659.00	216.42	23	data gap
	26/05/2002 9:30	27/05/2002 5:59	0.854	20.50	1.70	2	grey
	27/05/2002 17:00	07/06/2002 6:41	10.573	253.75	24.24	5	grey
	07/06/2002 12:48	07/06/2002 18:29	0.240	5.75	0.93	4	green
	08/06/2002 0:30	18/06/2002 16:14	10.677	256.25	52.34	7	grey
	28/06/2002 20:50	28/06/2002 21:59	0.052	1.25	0.15	4	green
	06/11/2002 11:30	07/11/2002 2:14	0.656	15.75	3.82	65	grey
	08/11/2002 3:15	08/11/2002 7:29	0.177	4.25	0.38	3	green
	08/11/2002 16:30	12/11/2002 17:44	4.177	100.25	24.63	27	grey
	18/11/2002 6:00	18/11/2002 7:56	0.083	2.00	0.30	4	data gap
	5 NTU	11/01/2002 17:03	25/01/2002 6:55	13.604	326.50	267.04	78
25/01/2002 17:50		29/01/2002 13:45	3.865	92.75	27.10	10	green
01/02/2002 14:52		03/02/2002 23:14	2.396	57.50	16.31	10	green
05/02/2002 14:30		05/02/2002 14:59	0.021	0.50	0.11	6	green
06/02/2002 7:45		15/02/2002 21:19	9.760	234.25	74.93	26	yellow
21/02/2002 4:50		22/02/2002 23:34	1.813	43.50	44.77	55	green
11/03/2002 4:56		11/03/2002 8:09	0.167	4.00	1.61	15	green
04/04/2002 17:00		05/04/2002 11:47	0.813	19.50	16.34	30	green
07/04/2002 1:30		09/04/2002 4:53	2.188	52.50	44.12	96	green
09/04/2002 11:41		09/04/2002 11:47	0.021	0.50	0.11	6	green
26/04/2002 0:49		26/04/2002 15:29	0.635	15.25	8.41	21	green
02/05/2002 11:30		02/05/2002 20:29	0.375	9.00	2.24	6	green
03/05/2002 17:00		04/05/2002 0:44	0.323	7.75	1.93	6	green
04/05/2002 6:45		22/05/2002 10:56	18.240	437.75	175.76	23	yellow
14/06/2002 23:00		17/06/2002 22:29	2.979	71.50	18.45	7	green
06/11/2002 11:30		06/11/2002 12:15	0.052	1.25	1.57	65	green
08/11/2002 17:52		09/11/2002 2:29	0.385	9.25	4.59	27	green
09/11/2002 8:30		09/11/2002 11:44	0.135	3.25	0.80	6	green
10/11/2002 18:30		11/11/2002 16:59	0.958	23.00	8.73	19	green
12/11/2002 11:00		12/11/2002 15:22	0.188	4.50	1.11	6	green
8 NTU	11/01/2002 17:06	25/01/2002 6:54	13.583	326.00	266.91	78	data gap
	25/01/2002 17:55	26/01/2002 22:28	1.208	29.00	10.23	10	yellow
	01/02/2002 14:56	02/02/2002 1:15	0.448	10.75	4.06	10	yellow

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Dur-Mag (NTU hrs)	Max (NTU)	Rating
8 NTU	03/02/2002 8:37	03/02/2002 9:15	0.042	1.00	0.35	9	green
	06/02/2002 9:29	07/02/2002 19:15	1.427	34.25	15.39	26	yellow
	08/02/2002 19:59	09/02/2002 0:45	0.219	5.25	1.75	8	green
	09/02/2002 13:14	09/02/2002 23:00	0.427	10.25	3.42	8	yellow
	10/02/2002 15:14	10/02/2002 21:30	0.281	6.75	2.28	9	green
	11/02/2002 7:29	11/02/2002 10:15	0.135	3.25	1.08	8	green
	12/02/2002 3:14	12/02/2002 6:45	0.167	4.00	1.33	8	green
	13/02/2002 4:29	13/02/2002 10:15	0.260	6.25	2.08	8	green
	14/02/2002 5:44	14/02/2002 12:30	0.302	7.25	2.42	8	yellow
	15/02/2002 6:59	15/02/2002 11:00	0.188	4.50	1.50	8	green
	21/02/2002 5:14	22/02/2002 20:00	1.635	39.25	43.54	55	yellow
	11/03/2002 5:19	11/03/2002 7:45	0.115	2.75	1.27	15	green
	04/04/2002 17:29	05/04/2002 11:13	0.750	18.00	15.96	30	yellow
	07/04/2002 1:31	08/04/2002 10:15	1.375	33.00	36.67	96	yellow
	08/04/2002 18:59	09/04/2002 4:50	0.427	10.25	5.05	13	yellow
	26/04/2002 0:52	26/04/2002 15:07	0.604	14.50	8.20	21	yellow
	05/05/2002 14:14	06/05/2002 15:45	1.083	26.00	9.32	15	yellow
	10/05/2002 16:14	10/05/2002 17:45	0.083	2.00	0.67	8	green
	11/05/2002 13:44	22/05/2002 10:48	10.896	261.50	124.45	23	yellow
	06/11/2002 11:31	06/11/2002 12:14	0.031	0.75	1.44	65	green
08/11/2002 18:09	09/11/2002 1:07	0.302	7.25	4.04	27	yellow	
10/11/2002 19:14	11/11/2002 12:30	0.740	17.75	7.39	19	yellow	
20 NTU	18/01/2002 20:43	19/01/2002 2:28	0.240	5.75	5.10	22	yellow
	20/01/2002 1:43	20/01/2002 20:28	0.781	18.75	18.97	34	yellow
	23/01/2002 15:13	25/01/2002 6:47	1.656	39.75	51.44	78	yellow
	06/02/2002 16:45	06/02/2002 18:59	0.094	2.25	2.26	26	green
	21/02/2002 6:38	21/02/2002 15:24	0.375	9.00	10.74	37	yellow
	21/02/2002 21:33	22/02/2002 12:52	0.646	15.50	25.93	55	yellow
	05/04/2002 0:45	05/04/2002 11:06	0.438	10.50	11.60	30	yellow
	07/04/2002 1:33	07/04/2002 8:01	0.281	6.75	22.27	96	yellow
	26/04/2002 7:11	26/04/2002 8:16	0.063	1.50	1.30	21	green
	17/05/2002 0:53	17/05/2002 1:44	0.042	1.00	0.91	23	green
	06/11/2002 11:34	06/11/2002 12:11	0.031	0.75	1.56	65	green
	08/11/2002 20:45	08/11/2002 21:26	0.031	0.75	0.73	27	green

Table 4. Severity of effects ratings for Millionaire Creek 2003 turbidity events.

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Mag-Dur (NTU hrs)	Max (NTU)	Rating	
1 NTU	05/03/2003 20:55	14/03/2003 19:55	9.094	218.25	62.67	28.2	data gap	
	16/04/2003 12:46	23/05/2003 10:43	37.208	893.00	779.40	78.5	data gap	
	23/05/2003 19:50	24/05/2003 7:32	0.500	12.00	1.02	4.1	grey	
	24/05/2003 15:02	25/05/2003 10:31	0.906	21.75	7.21	21.9	grey	
	11/06/2003 18:18	12/06/2003 17:27	0.990	23.75	4.01	7.3	grey	
	14/06/2003 7:11	15/06/2003 1:59	0.792	19.00	2.58	4.4	grey	
	15/06/2003 14:41	20/06/2003 19:59	5.313	127.50	101.43	86.5	data gap	
	21/06/2003 4:15	21/06/2003 9:14	0.271	6.50	20.34	103.2	data gap	
	21/06/2003 15:15	21/06/2003 15:59	0.094	2.25	1.37	32.2	data gap	
	21/06/2003 23:16	26/06/2003 21:29	5.010	120.25	171.85	145.2	data gap	
	30/06/2003 20:23	08/08/2003 18:44	39.042	937.00	313.77	18.7	grey	
	09/08/2003 4:08	09/08/2003 7:49	0.167	4.00	0.22	1.4	green	
	09/08/2003 14:33	13/08/2003 3:51	3.563	85.50	8.48	4.1	grey	
	14/08/2003 20:20	29/08/2003 0:25	14.260	342.25	88.86	92	grey	
	29/08/2003 6:35	04/09/2003 21:44	6.635	159.25	11.46	3.5	grey	
	05/09/2003 5:31	05/09/2003 6:44	0.052	1.25	0.06	1.2	green	
	05/09/2003 23:16	10/09/2003 13:43	4.708	113.00	27.85	26.5	data gap	
	10/09/2003 23:16	14/09/2003 4:28	3.281	78.75	29.60	21.6	data gap	
	14/09/2003 10:30	24/09/2003 8:41	10.073	241.75	295.80	141.1	data gap	
	26/09/2003 18:30	27/09/2003 1:29	0.292	7.00	0.57	2	green	
	27/09/2003 9:45	27/09/2003 11:59	0.094	2.25	0.18	2	green	
	27/09/2003 20:30	01/10/2003 1:14	3.198	76.75	6.39	2	grey	
	02/10/2003 18:15	03/10/2003 6:14	0.500	12.00	0.99	2	grey	
	03/10/2003 12:15	03/10/2003 22:59	0.448	10.75	0.89	2	grey	
	05/10/2003 4:45	07/10/2003 1:14	1.917	46.00	12.51	63	data gap	
	07/10/2003 7:31	16/10/2003 2:43	9.031	216.75	53.12	21	data gap	
	16/10/2003 22:30	17/10/2003 14:29	0.729	17.50	24.90	68	data gap	
	17/10/2003 22:30	29/10/2003 7:14	11.490	275.75	196.90	41	data gap	
	30/10/2003 14:46	16/11/2003 9:14	17.000	408.00	445.96	105	data gap	
	16/11/2003 16:00	28/11/2003 3:59	11.563	277.50	730.02	109	data gap	
	28/11/2003 20:30	02/12/2003 16:44	3.906	93.75	296.20	93.3	data gap	
	03/12/2003 1:30	03/12/2003 7:59	0.333	8.00	31.10	119.7	data gap	
	03/12/2003 19:46	19/12/2003 6:59	15.802	379.25	145.42	47.9	data gap	
	19/12/2003 14:30	26/12/2003 18:14	7.260	174.25	254.25	76.2	data gap	
	5 NTU	09/03/2003 7:57	13/03/2003 22:36	4.729	113.50	52.81	28.2	green
		16/04/2003 12:54	23/05/2003 10:39	37.188	892.50	779.33	78.5	data gap
		24/05/2003 15:11	25/05/2003 7:08	0.740	17.75	6.77	21.9	green
		12/06/2003 10:10	12/06/2003 17:19	0.313	7.50	1.92	7.3	green
		17/06/2003 18:00	20/06/2003 19:57	3.146	75.50	93.80	86.5	data gap
		21/06/2003 4:15	21/06/2003 9:14	0.250	6.00	20.28	103.2	data gap
21/06/2003 15:17		21/06/2003 15:57	0.073	1.75	1.31	32.2	data gap	
21/06/2003 23:20		26/06/2003 21:29	4.990	119.75	171.79	145.2	data gap	
05/07/2003 20:15		07/07/2003 23:22	2.135	51.25	11.98	6.7	green	
10/07/2003 1:46		11/07/2003 2:11	1.021	24.50	6.08	6.6	green	

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Mag-Dur (NTU hrs)	Max (NTU)	Rating
5 NTU	11/07/2003 15:53	11/07/2003 19:28	0.156	3.75	0.80	5.2	green
	12/07/2003 13:01	04/08/2003 16:46	23.188	556.50	257.78	18.7	yellow
	17/08/2003 0:16	19/08/2003 16:42	2.729	65.50	53.45	92	green
	21/08/2003 7:25	21/08/2003 20:10	0.542	13.00	3.34	7	green
	07/09/2003 4:00	07/09/2003 10:09	0.281	6.75	2.02	8.8	green
	09/09/2003 3:51	10/09/2003 13:39	1.458	35.00	17.41	26.5	data gap
	10/09/2003 23:21	14/09/2003 4:20	3.260	78.25	29.54	21.6	green
	14/09/2003 10:34	24/09/2003 8:29	10.042	241.00	295.69	141.1	yellow
	06/10/2003 20:30	07/10/2003 1:13	0.240	5.75	9.06	63	data gap
	07/10/2003 7:35	07/10/2003 21:14	0.594	14.25	5.38	15	green
	08/10/2003 10:00	08/10/2003 21:14	0.510	12.25	6.73	21	green
	11/10/2003 19:03	11/10/2003 21:29	0.104	2.50	0.76	8	green
	12/10/2003 5:15	13/10/2003 17:29	1.552	37.25	13.02	15	green
	15/10/2003 15:15	16/10/2003 2:38	0.500	12.00	5.88	19	data gap
	16/10/2003 22:31	17/10/2003 14:27	0.708	17.00	24.83	68	data gap
	17/10/2003 22:31	29/10/2003 7:12	11.469	275.25	196.83	41	data gap
	30/10/2003 14:51	31/10/2003 8:57	0.802	19.25	17.25	38.6	green
	31/10/2003 15:16	16/11/2003 9:13	15.896	381.50	427.62	105	data gap
	16/11/2003 16:01	28/11/2003 3:59	11.542	277.00	729.96	109	data gap
	28/11/2003 20:30	02/12/2003 16:44	3.885	93.25	296.14	93.3	data gap
	03/12/2003 1:30	03/12/2003 7:59	0.313	7.50	31.03	119.7	data gap
	03/12/2003 19:54	03/12/2003 20:58	0.052	1.25	0.38	7.8	green
	04/12/2003 20:02	05/12/2003 17:23	0.958	23.00	14.96	23.2	green
	06/12/2003 2:45	06/12/2003 7:31	0.208	5.00	1.10	5.3	green
	08/12/2003 12:28	08/12/2003 14:24	0.094	2.25	0.52	5.8	green
	12/12/2003 0:17	19/12/2003 6:58	7.448	178.75	105.54	47.9	data gap
	19/12/2003 14:31	26/12/2003 18:12	7.240	173.75	254.19	76.2	data gap
8 NTU	09/03/2003 9:37	11/03/2003 19:58	2.500	60.00	36.86	28.2	yellow
	12/03/2003 16:27	13/03/2003 12:21	0.844	20.25	7.80	13	yellow
	16/04/2003 13:02	17/04/2003 0:06	0.469	11.25	4.51	12.6	yellow
	17/04/2003 20:05	18/04/2003 1:26	0.229	5.50	1.96	8.6	green
	18/04/2003 7:31	18/04/2003 13:24	0.250	6.00	2.65	11.7	green
	19/04/2003 12:12	20/04/2003 18:28	1.271	30.50	15.39	17.6	yellow
	21/04/2003 1:00	22/04/2003 5:29	1.208	29.00	12.50	20.4	yellow
	23/04/2003 8:18	25/04/2003 6:04	1.917	46.00	21.63	19.3	yellow
	28/04/2003 6:50	28/04/2003 9:13	0.104	2.50	0.84	8.2	green
	28/04/2003 16:20	28/04/2003 17:44	0.063	1.50	0.51	8.2	green
	29/04/2003 1:00	23/05/2003 10:36	24.469	587.25	666.75	78.5	orange
	24/05/2003 15:22	24/05/2003 20:13	0.229	5.50	3.22	21.9	green
	25/05/2003 6:24	25/05/2003 6:35	0.021	0.50	0.18	9	green
	17/06/2003 22:49	20/06/2003 19:55	2.927	70.25	92.32	86.5	data gap
	21/06/2003 4:16	21/06/2003 9:13	0.229	5.50	20.15	103.2	data gap
	21/06/2003 15:18	21/06/2003 15:56	0.052	1.25	1.17	32.2	data gap
	21/06/2003 23:23	26/06/2003 21:29	4.969	119.25	171.65	145.2	data gap
	13/07/2003 1:27	28/07/2003 4:14	15.125	363.00	203.05	18.7	orange
	17/08/2003 13:22	19/08/2003 16:29	2.156	51.75	49.70	92	yellow
	07/09/2003 4:12	07/09/2003 5:18	0.063	1.50	0.53	8.8	green

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Mag-Dur (NTU hrs)	Max (NTU)	Rating
8 NTU	09/09/2003 6:22	10/09/2003 13:36	1.333	32.00	16.67	26.5	yellow
	10/09/2003 23:25	11/09/2003 17:04	0.771	18.50	12.70	21.6	yellow
	14/09/2003 10:37	24/09/2003 8:26	10.021	240.50	295.56	141.1	yellow
	06/10/2003 20:41	07/10/2003 1:13	0.219	5.25	8.93	63	data gap
	07/10/2003 7:38	07/10/2003 13:14	0.240	5.75	2.83	15	green
	08/10/2003 12:50	08/10/2003 21:03	0.375	9.00	5.90	21	yellow
	12/10/2003 6:30	12/10/2003 10:29	0.167	4.00	1.72	11	green
	12/10/2003 16:30	12/10/2003 22:56	0.271	6.50	3.33	15	green
	15/10/2003 16:15	16/10/2003 2:34	0.438	10.50	5.43	19	yellow
	16/10/2003 22:31	17/10/2003 14:25	0.688	16.50	24.70	68	data gap
	17/10/2003 22:32	19/10/2003 9:59	1.500	36.00	23.06	41	yellow
	20/10/2003 6:45	29/10/2003 7:10	9.063	217.50	166.55	41	data gap
	30/10/2003 14:54	31/10/2003 8:52	0.781	18.75	17.11	38.6	yellow
	31/10/2003 15:18	16/11/2003 9:13	15.875	381.00	427.48	105	data gap
	16/11/2003 16:02	28/11/2003 3:58	11.521	276.50	729.83	109	data gap
	28/11/2003 20:31	02/12/2003 16:43	3.865	92.75	296.01	93.3	data gap
	03/12/2003 1:31	03/12/2003 7:58	0.292	7.00	30.90	119.7	data gap
	04/12/2003 21:09	05/12/2003 17:11	0.885	21.25	14.50	23.2	yellow
	12/12/2003 2:25	12/12/2003 6:09	0.167	4.00	1.64	10.9	green
	12/12/2003 13:35	12/12/2003 14:34	0.052	1.25	0.44	8.7	green
	14/12/2003 13:38	14/12/2003 19:55	0.271	6.50	2.38	9.1	green
	15/12/2003 12:35	15/12/2003 22:11	0.406	9.75	3.83	11	yellow
	16/12/2003 4:17	19/12/2003 6:57	3.177	76.25	75.29	47.9	data gap
	19/12/2003 14:32	26/12/2003 18:11	7.219	173.25	254.05	76.2	data gap
	27/12/2003 0:20	12/01/2004 5:28	16.281	390.75	239.68	49	orange
	12/01/2004 17:56	13/01/2004 7:37	0.583	14.00	5.71	14	yellow
	13/01/2004 13:48	14/01/2004 0:04	0.438	10.50	3.97	19.9	yellow
	14/01/2004 8:19	15/01/2004 1:15	0.719	17.25	6.25	10.4	yellow
20 NTU	09/03/2003 11:41	09/03/2003 16:18	0.208	5.00	4.37	23.1	yellow
	09/03/2003 22:35	10/03/2003 4:33	0.260	6.25	6.00	28.2	yellow
	11/03/2003 13:39	11/03/2003 14:38	0.052	1.25	1.17	24.2	green
	21/04/2003 5:07	21/04/2003 6:32	0.073	1.75	1.48	20.4	green
	04/05/2003 0:27	04/05/2003 10:46	0.448	10.75	9.48	24.6	yellow
	04/05/2003 20:46	04/05/2003 22:43	0.083	2.00	1.79	22.6	green
	09/05/2003 14:21	23/05/2003 8:13	13.750	330.00	511.05	78.5	orange
	24/05/2003 15:42	24/05/2003 15:50	0.021	0.50	0.44	21.9	green
	18/06/2003 7:51	19/06/2003 18:42	1.458	35.00	67.95	86.5	yellow
	20/06/2003 16:19	20/06/2003 19:49	0.156	3.75	4.18	28.8	yellow
	21/06/2003 4:17	21/06/2003 9:11	0.208	5.00	19.85	103.2	data gap
	21/06/2003 15:24	21/06/2003 15:50	0.031	0.75	0.88	32.2	green
	22/06/2003 12:20	22/06/2003 14:49	0.115	2.75	2.62	26.7	green
	24/06/2003 4:22	26/06/2003 21:27	2.719	65.25	141.99	145.2	data gap
	19/08/2003 5:02	19/08/2003 16:24	0.479	11.50	31.82	92	yellow
	09/09/2003 14:38	09/09/2003 16:12	0.073	1.75	1.80	26.5	green
	11/09/2003 6:28	11/09/2003 14:32	0.354	8.50	7.46	21.6	yellow
	16/09/2003 11:03	16/09/2003 14:55	0.167	4.00	3.53	24.4	yellow
	18/09/2003 5:21	18/09/2003 8:44	0.146	3.50	3.02	22.2	yellow

Threshold	Start Date	End Date	Duration (days)	Duration (hours)	Mag-Dur (NTU hrs)	Max (NTU)	Rating
20 NTU	18/09/2003 16:57	18/09/2003 17:17	0.031	0.75	0.63	20.1	green
	19/09/2003 7:05	21/09/2003 18:09	2.469	59.25	152.04	141.1	orange
	22/09/2003 2:49	24/09/2003 5:29	2.115	50.75	56.21	33.9	orange
	06/10/2003 21:42	07/10/2003 1:10	0.156	3.75	8.23	63	data gap
	08/10/2003 14:28	08/10/2003 15:14	0.042	1.00	0.86	21	green
	16/10/2003 22:34	17/10/2003 14:19	0.667	16.00	24.41	68	yellow
	17/10/2003 22:37	18/10/2003 6:11	0.323	7.75	9.64	41	yellow
	20/10/2003 16:07	20/10/2003 20:59	0.208	5.00	4.84	27	yellow
	26/10/2003 4:15	29/10/2003 7:03	3.125	75.00	86.39	41	orange
	30/10/2003 18:18	31/10/2003 6:28	0.510	12.25	13.22	38.6	yellow
	31/10/2003 15:27	31/10/2003 16:42	0.063	1.50	1.46	24	green
	31/10/2003 22:48	01/11/2003 1:18	0.115	2.75	2.58	22.8	green
	03/11/2003 4:31	06/11/2003 23:14	3.781	90.75	83.55	24.1	orange
	07/11/2003 15:51	08/11/2003 3:13	0.479	11.50	9.69	20.5	yellow
	08/11/2003 9:57	10/11/2003 20:55	2.469	59.25	53.79	40.7	orange
	11/11/2003 3:00	16/11/2003 9:10	5.260	126.25	217.66	105	data gap
	16/11/2003 16:06	28/11/2003 3:57	11.500	276.00	729.53	109	data gap
	28/11/2003 20:33	02/12/2003 16:41	3.844	92.25	295.71	93.3	data gap
	03/12/2003 1:32	03/12/2003 7:57	0.271	6.50	30.61	119.7	data gap
	04/12/2003 21:40	04/12/2003 22:16	0.042	1.00	0.90	23.2	green
	05/12/2003 5:50	05/12/2003 6:10	0.021	0.50	0.44	22.6	green
	16/12/2003 13:01	17/12/2003 6:56	0.750	18.00	27.21	47.9	yellow
	17/12/2003 13:07	17/12/2003 13:22	0.021	0.50	0.45	23.3	green
	18/12/2003 16:03	19/12/2003 6:52	0.625	15.00	23.29	47.6	data gap
	19/12/2003 14:36	22/12/2003 12:14	2.906	69.75	127.17	76.2	orange
	22/12/2003 22:51	24/12/2003 23:59	2.052	49.25	66.05	52.3	orange
	25/12/2003 6:00	26/12/2003 18:06	1.510	36.25	46.89	46.2	yellow
	27/12/2003 0:27	27/12/2003 12:59	0.531	12.75	15.83	49	yellow
	07/01/2004 4:30	07/01/2004 19:50	0.646	15.50	14.89	26.3	yellow
	10/01/2004 4:16	10/01/2004 8:27	0.177	4.25	4.75	32.3	yellow