GVSU Storm Water Monitoring Data Summary, Progress Report, and Recommendations

Photo taken below Little Mac Bridge in the 1970's

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Introduction and Background

This report summarizes storm water runoff data collected between 2006 and 2007 at the Allendale Campus of Grand Valley State University (GVSU). Data collection also took place during the summer of 2008; however, 2008 data is not included in this report. This report is intended as a summary of the data collected in 2006 and 2007, an archive of that data, and a preliminary analysis of a small amount of the runoff data. Additional analysis will be completed using the data to answer specific research questions about discrete areas as they arise.

Since construction of the GVSU Allendale Campus began in 1960 the infrastructure has steadily increased to accommodate a growing student population. This growth has resulted in roughly 170 acres of impermeable surfaces as of 2004 (Womble and Wampler, 2006). When precipitation falls onto these impermeable surfaces the runoff is rapid and abundant. Historically much of the runoff has been directed toward the ravines east of campus resulting in severe erosion, water quality degradation, and slope stability problems.

A hydrograph (graph of water flow or height versus discharge) for a watershed with little or no urbanization, or few permeable, surfaces has broad peaks which occur with a significant time lag between the rain event and the peak flow. The time between the precipitation event and the peak flow is referred to as the lag time (Figure 1). Urbanized watersheds, such as those that have been directed toward the ravines, have very short lag times and high peak flows.

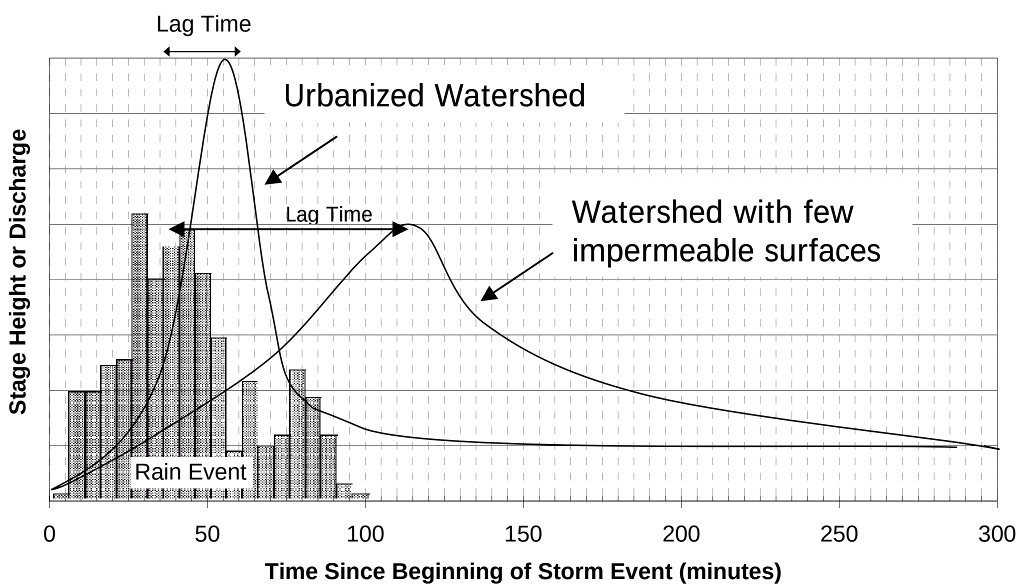


Figure 1. Example hydrograph showing lag time and the affect of urbanization on a typical runoff hydrograph.

Lag times from ravines with storm water runoff pipes near GVSU range from a few minutes to several 10's of minutes. Lag times for Sand Creek, a non-urbanized stream located northwest of GVSU, typically range from 100's to 1,000's of minutes. An example of the difference in hydrographs can be seen in the response to an intense rainfall (~ 2.25 inches in about an hour) event that occurred on July 17th, 2006 (Figure 2). The lag time for lower Little Mac ravine was approximately 50 minutes, while that for Sand Creek was between 250 and 1,400 minutes.

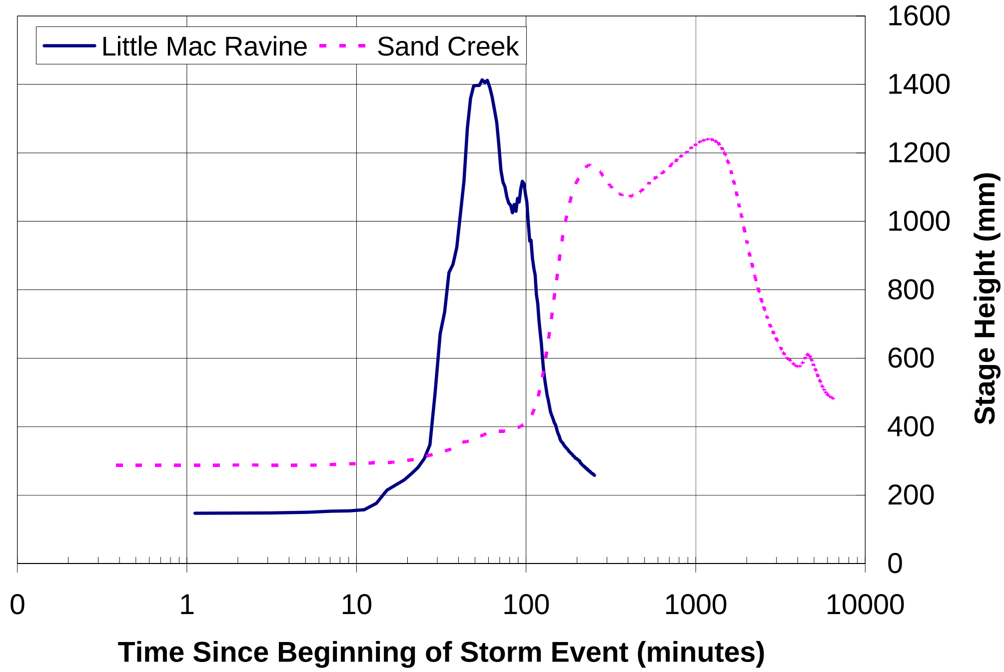


Figure 2. Hydrographs for stream gages located at Sand Creek and Little Mac ravine during a rain event that occurred July 17th, 2006.

In order to reduce lag times and runoff volumes at GVSU, it will be necessary to mimic the non-urbanized conditions of the Sand Creek Watershed by increasing opportunities for infiltration and water detention. GVSU facilities have already made great strides toward this goal by incorporating rain gardens and detention ponds into new construction, increasing detention, infiltration, and lag times. The large rain garden, located near the Turf Building on the west side of campus has been equipped with monitors to evaluate the amount of water that is being absorbed by the rain garden during rain events (Figure 3). Preliminary data suggests this structure is capable of reducing peak runoff rates by over 600 percent (Figure 4). In addition to large water retention structures, many opportunities exist to increase infiltration through the modifications of existing detention structures.

Figure 3. Photo of the Rain Garden and monitoring sites located near the Turf Building. Inset is the construction plan for the Rain Garden.

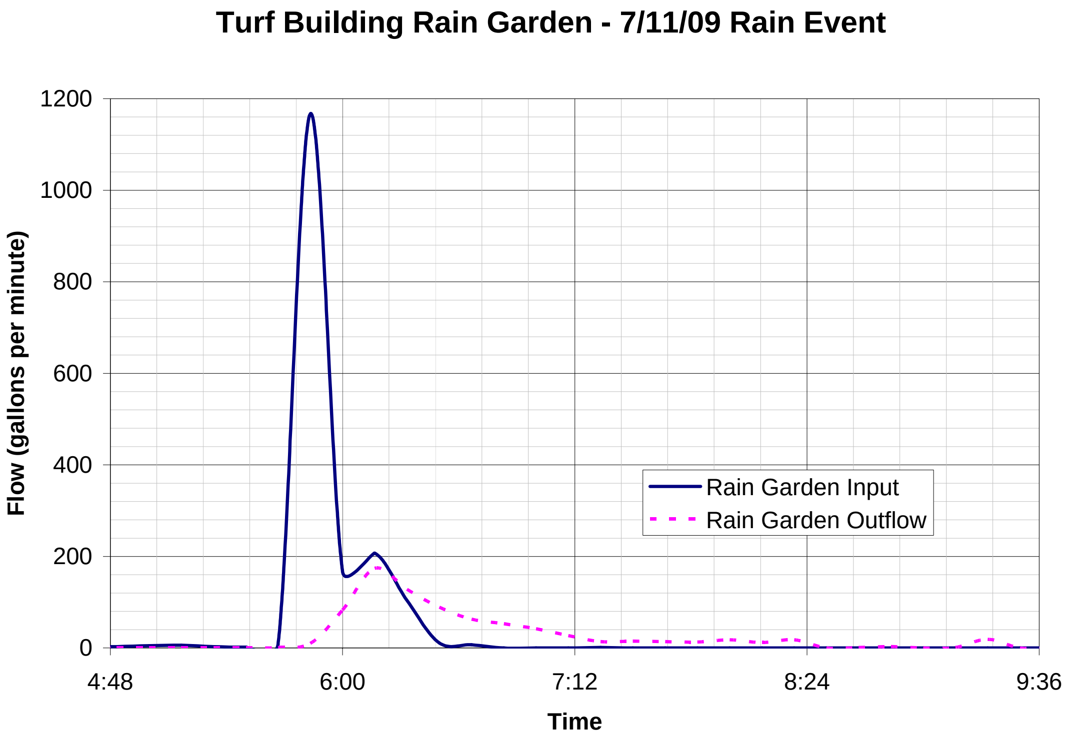


Figure 4. Example of reduction flow as a result of the installation a large rain garden near the Turf Building, GVSU.

Hydrographs and Storm Water Runoff Data

In 2006, four stream gages were installed to monitor runoff from the GVSU Campus, and one gage was installed at Sand Creek, northeast of campus. This system of gages was expanded to include 10 additional gages in 2007 with the help of a grant from Facilities (Figure 5). Continuous monitoring was done through the summer of 2008 with intermittent interruption in data due to equipment malfunctions and weather. Most gages were removed during the winter to prevent damage. A summary of the data available for each gage can be found in Table A1. Complete hydrographs and thermographs can be found in Appendix A. This data can also be found on the accompanying compact disk. Numerous storms occurred in 2006, while 2007 had few runoff events.

The response to storm events is clearly different for ravines and watershed into which abundant storm water runoff has been directed. The Shire ravine was used as a “control ravine”. The watershed for the Shire ravine is largely un-impacted by campus runoff and has a hydrograph more similar to an un-urbanized stream like Sand Creek (Figure 6).

Figure 5. Monitoring site locations for water quality and runoff at GVSU.

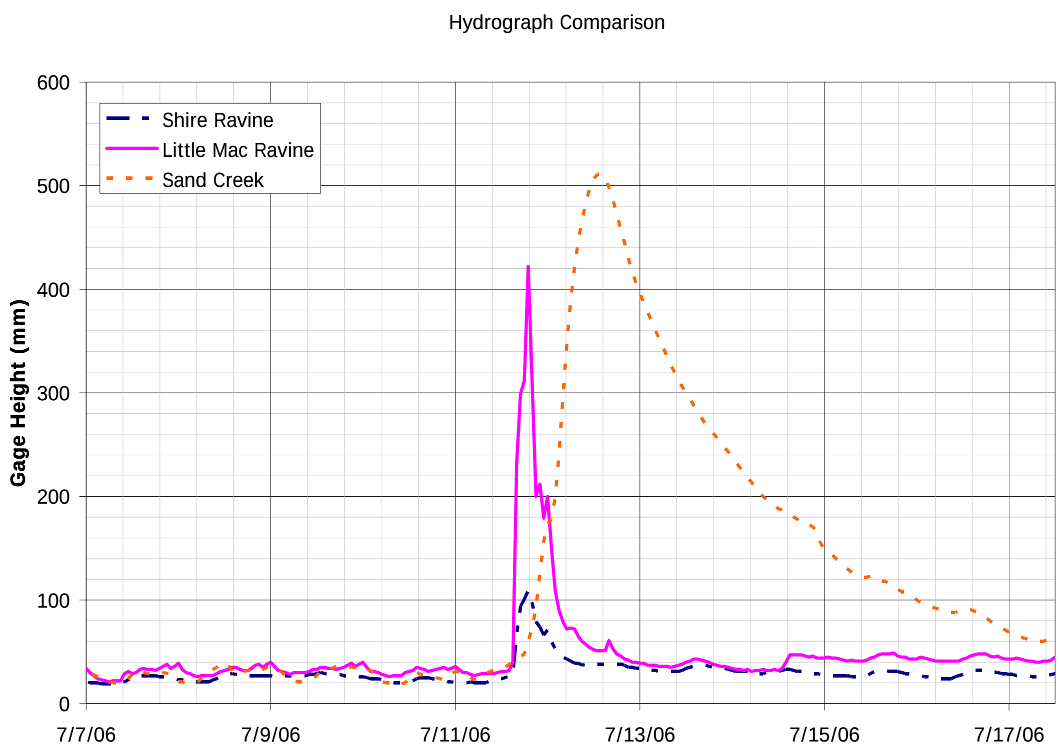


Figure 6. Comparison of Little Mac ravine, Shire ravine, and Sand Creek in response to a rain event that occurred 7/11/06

In order to determine the discharge associated with a given water level at each gage it is necessary to make numerous field measurements of discharge at different flows. A graph relating the stage (recorded in mm for gages) versus flow volume is termed a "rating curve". Developing rating curves to convert stage height to discharge has been problematic for many gages due to the difficulty of reaching gages during high flow events.

Water Quality Data

Numerous water quality samples were collected at several sites surrounding GVSU during the summer of 2007 (Figure 7). Samples were analyzed by GVSU student Katie Conroy. This data was used extensively in a baseline study of the biological activity in the ravines written by GVSU biology professor, Dr. Eric Snyder (Snyder et al., 2008).

Figure 7. Water Quality Sample locations.

Samples were collected in plastic bottles that had been rinsed with deionized water. At the sample location, the bottle was rinsed three times with sample water. The bottle was loosely capped then submerged about halfway down or at least 10 cm beneath the water surface, then uncapped and allowed to fill. The bottle was then labeled with the date, sample location, and time sample was taken. Two methods were used to filter the samples: 1) gravity filtration, and 2) vacuum filtering. Vacuum filtering was accomplished using a filter-funnel (a funnel with a upper portion that has small holes), a rubber stopper with holes for funnels, the appropriate size filter paper, and an Erlenmyer vacuum flask. Samples were stored in a refrigerator at 4°C or lower. Testing of samples was done as soon as possible after collection.

Water samples were analyzed for six parameters: ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, phosphate, sulfate, and iron. The procedures used came from the Smart 2 Colorimeter operations manual. The Smart 2 Colorimeter was used the conduct the tests, along with glass vials specifically made for the Smart 2 Colorimeter. The ammonia-nitrogen high range test, code 3642-SC, was used to test for ammonia. This is a Nesslerization method. The nitrate-nitrogen low range test, code 3649-SC, was used to test for nitrate. This is a cadmium reduction method. The nitrite-nitrogen low range test, code 3650-SC, was used to test for nitrite. This is a Diazotization method. The phosphate low range test, code 3653-SC, was used to test for phosphate. This is an ascorbic acid reduction method. The sulfate high range test, code 3665-SC, was used to test for sulfate. This is a barium chloride method. The iron test, code 3648-SC, was used to test for iron, by the Bipyridyl method.

All samples were tested in triplicate or quadruplicate. Results were an average of individual results. Data were transferred to an Excel spreadsheet to calculate the average and standard deviation for each sample. Potential sources of error include water sample collection. Due to surface tension, solids and chemicals may sit on the surface which could interfere with the true concentrations. In order to eliminate this problem, water samples were collected beneath the surface of the water. Water near the bottom, where in contact with the ground or cement (drain culverts, etc), were also avoided. Ions and solids can gather on the bottom or be attracted to the bottom which would interfere with the true concentrations. Results of the chemical analyses are summarized in Appendix B.

Erosion and Evaluation of Erosion Control Measures

Photos of several erosion control structures were taken by Dr. Patty Videtich and her students in 2002 and 2003. Several of these structures have failed or are in the process of failure. Photos taken in 2008, and the original photos taken in 2002 and 2003, are compiled with brief descriptions and a location map in Appendix C.

Several common themes were observed during the evaluation of the erosion control structures: 1) the rip/rap grain-size distribution is resulting in inadequate compaction and instability of the structures; 2) check dams are almost universally failing through erosion at the downstream side and lateral erosion due to sedimentation; 3) headward erosion near pipe outlets is common and often results in failure of the piping systems; 4) many detention pond structures are not functioning at capacity during storm events.

The only reliable method of reducing and preventing erosion in the long term is to reduce runoff volumes and increase the lag time for storm events. Therefore, it is important that GVSU Facilities adopt a proactive approach for the design of new buildings and parking lots as well as an aggressive program of retrofitting structures that can be enhanced to be more effective.

Conclusions and Recommendations

Although great strides have been made, and excellent leadership is being shown by GVSU Facilities in returning GVSU to a pre-settlement conditions in relation to storm water runoff, significant areas remain which could be improved to reduce storm water impacts. They are summarized below.

1. GVSU policy should include installation of permeable surfaces (asphalt and concrete) in all new parking lots and walkways. This should be the default construction method. Impermeable surfaces should only be installed in locations where permeable alternatives are not practical. This includes areas of brick pavers which are being placed on a concrete base to prevent settling. The concrete base should be permeable.

2. The practice of centralizing flow into larger and larger pipes should be discontinued in favor of distributing discharge points with small detention structures to attenuate flows.

3. The installation of erosion control structures in the ravines should be phased out and removed as soon as possible as an alternative for dealing with high flow volumes. These structures are ineffective in the long term and are creating long term damage to the ravine systems.

4. Monitoring of major storm water discharge points should be expanded and all new storm water structures should be monitored. Data collected will continue to serve as a basis for evaluating changes to runoff as best management practices are implemented at GVSU.

5. The Turf building rain garden has demonstrated that rain gardens are an effective and aesthetically pleasing way to treat storm water. Additional rain garden features are needed throughout campus.

6. There is a tendency to view storm water structures as merely functional. If carefully and thoughtfully designed, there is abundant opportunity on the GVSU Allendale Campus to add additional water features which both beautify the campus and solve runoff problems. Many opportunities for small detention pond structures, rain gardens, bioswales, permeable asphalt, and permeable concrete are needed throughout campus. Some of these opportunities are summarized in Figure 8 and Table 1.

Table 1. List of sites for possible storm water reduction features

Letter	Name	Description	Type	Category
A	Calder Pond Denention Pond	Needs 1) Move outlet); 2) more volume; 3) larger surface area; 4) complex shape.	Detention Pond	Retrofit
B	Zumberge Pond	Needs: 1) increase surface area; 2) allow natural vegetaion along edge; modify outlet	Detention Pond	Retrofit
C	Lot F Detention	Remove non-native pine trees and create a functional water feature	Detention Pond	New
D	Armstrong Pond	New Detention Structure	Detention Pond	New
E	Calder Campus NW	Modify existing detention pond	Detention Pond	Retrofit
F	Lake Michigan Hall Savannah	New Detention Structure	Detention Pond	New
G	Arboretum Pond	New Detention Structure	Detention Pond	New
H	Lot C Detention	New Detention Structure	Detention Pond	New
I	Vollyball Rain Garden	New Rain Garden	Rain Garden	New
J	Arboretum Detention Pond	New Detention Pond	Detention Pond	New

4/18/08 Aerial Photo

Figure 8. Potential storm water ponds and rain gardens.

References

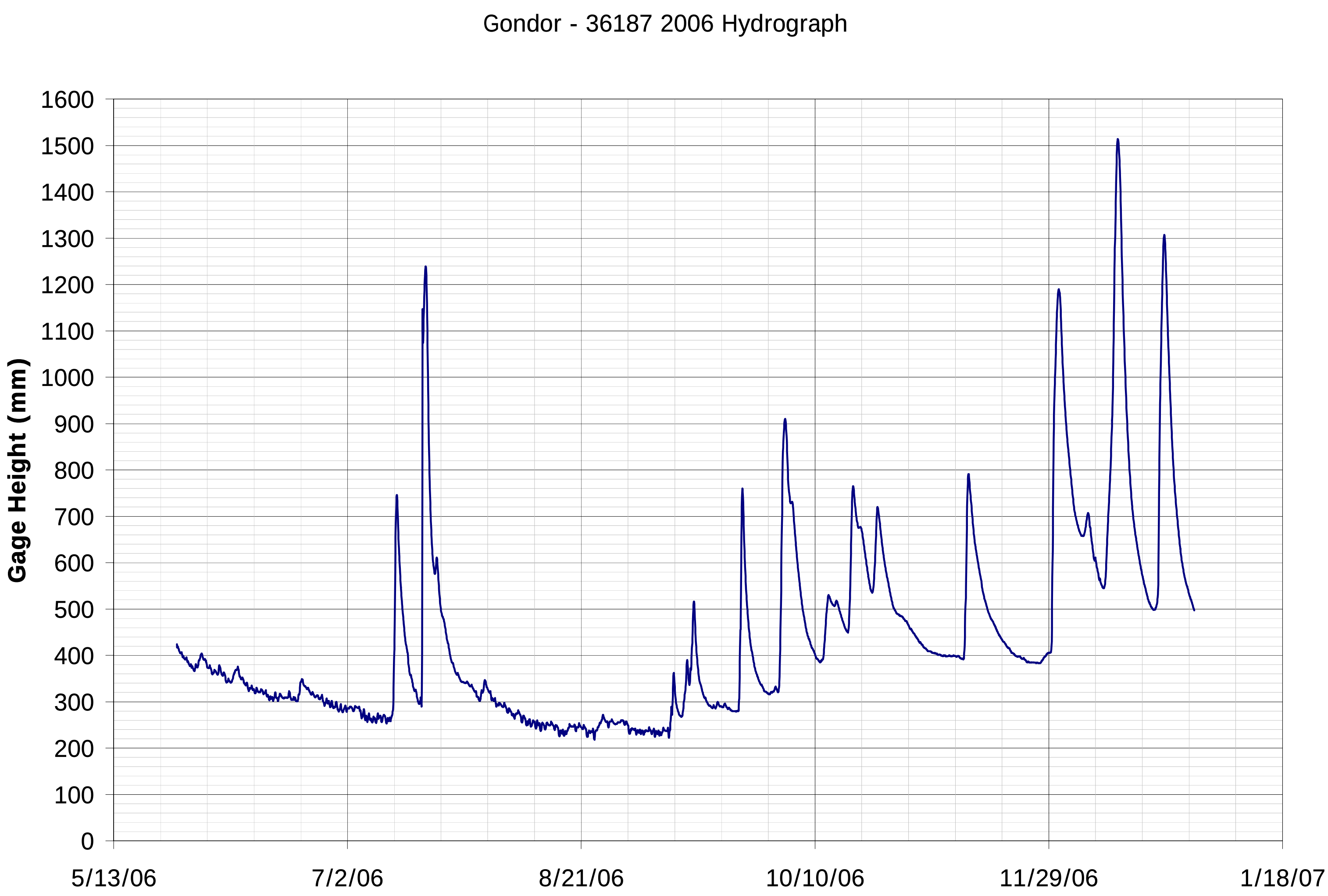
Womble, P.J., and Wampler P. J., 2006. Urbanization induced changes to a ravine system and evaluation of land use and infrastructure sustainability at Grand Valley State University, Allendale, MI. Student Summer Scholars final report.

Snyder, Eric, Nelson, Jason, Drogowski, Jason, and Harju, Michelle, 2008. Aquatic ecosystem response to storm water abatement measures in the ravines of the GVSU Allendale campus: establishment of base-line biological condition. Unpublished report submitted to GVSU facilities September 15, 2008. 27 p.

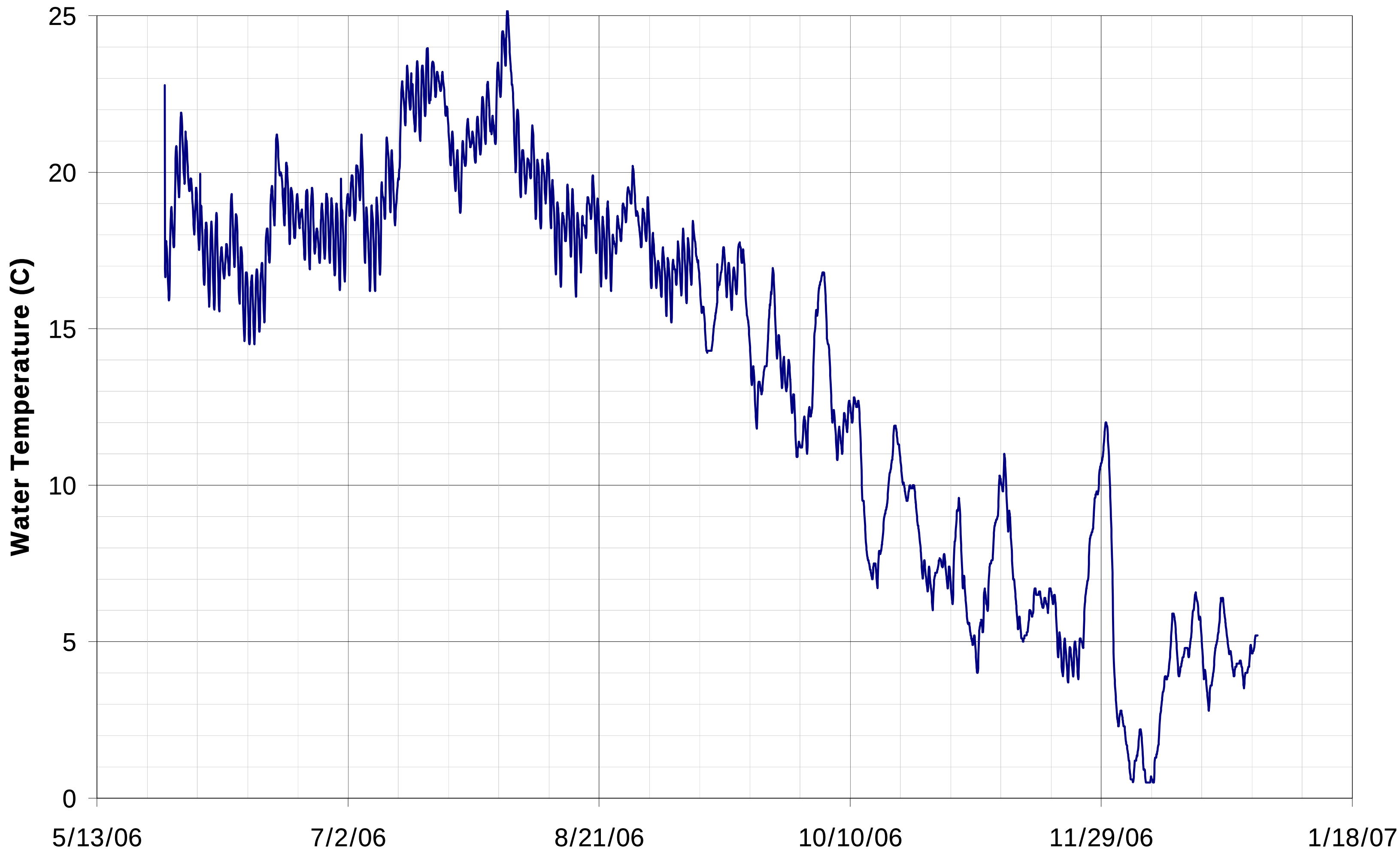
Table A1. Summary of available gage data collected between 2006 and 2008 at the GVSU campus and Sand Creek.

Gage Name	Easting (ft)	Northing (ft)	Serial#	1/06	2/06	3/06	4/06	5/06	6/06	7/06	8/06	9/06	10/06	11/06	12/06	1/07	2/07	3/07	4/07	5/07	6/07	7/07	8/07	9/07	10/07	11/07	12/07	1/08	2/08	3/08	4/08	5/08	6/08	7/08
Gondor	N/A	N/A	36187					5/26-12/30								1/10-3/9				5/4-11/17 Note: 3/9-5/4 data is corrupt								1/10-7/23						
Isengard	12718931.4	536388.7	36186					5/16-11/30 Note: 9/10-9/12 data missing							winter-no data					5/4-11/4							winter-no data				4/29-7/10 Note: 7/10-7/31 no data, gage maintanence			
Fangorn	12718239.1	537939.7	36185					5/10-12/29								winter-no dat				5/22-12/14 Note: 9/14-9/21 data missing								winter-no data			4/17-7/10 Note: 7/10-7/31 no data, gage maintanence			
Shire	12718304.4	533483.6	36188					5/12-9/20 Note: 8/22-9/13 data missing						data missing		winter-no dat				5/22-12/14								winter-no data			4/17-6/14			
Mordor	12716351.7	537104.2	36184					5/9-12/30 Note: date/depth discrepency 9/11 due to checking gage, Oddessy files Mordor_007-009 hydrographs are strange.								winter-no dat				5/3-12/14 Note: 5/77-5/22 data missing								winter-no data			4/29-7/10 Note: 7/10-7/31 no data, gage maintanence			
Edoras	12718529.5	539522.6	36402																	5/11-6/12	36405.06.12.07 file empty		7/13-8/17	PDA	9/22-12/14			winter-no data			4/17-5/18		gage washed away	
Buckland	12718413.0	534855.4	36405																	5/11-8/17 note: 8/17-9/22 on yellow PDA				PDA	9/22-12/14			winter-no data			4/29-7/10			
Bree	12715534.0	539279.4	36403																	5/8-9/21 note: 9/21-10/30 on yellow PDA						10/30-12/14		winter-no data			4/29-7/9			
Lothlorian	12712322.9	540020.2	36399																	5/10-9/4				9/22-12/14				winter-no data			4/19-6/14			
Dunland	12714503.6	537470.7	36397																	5/10-10/12						gage was moved								
Lorian	12717542.9	537580.0	36401																	5/11-12/14 Note: 5/18-5/22 no data (36401.06.12.07 file empty)								winter-no data			4/16-7/18			
Moria	12718867.8	534777.0	36400, 36404																	5/11-12/14 Note: 9/4-9/22 data will not calibrate								winter-no data			4/29-7/10			
Dead Marshes	12715981.6	536013.0	36404 (discontinued)																	5/9-12/14								data logger 36404 moved to Moria						
Anduin	12717130.9	542638.1	36398																	. 5/9-12/26 5 min interval								1/10-5/03 Note: due to cold temps data is innacurate. 10 min interval				5/15-7/9 5 min interval		
Saruman	12717396.8	535784.1	YSI-Ethernet Probe																		6/22/07 to 7/10/08 5-minute interval, temperature, conductivity, level													

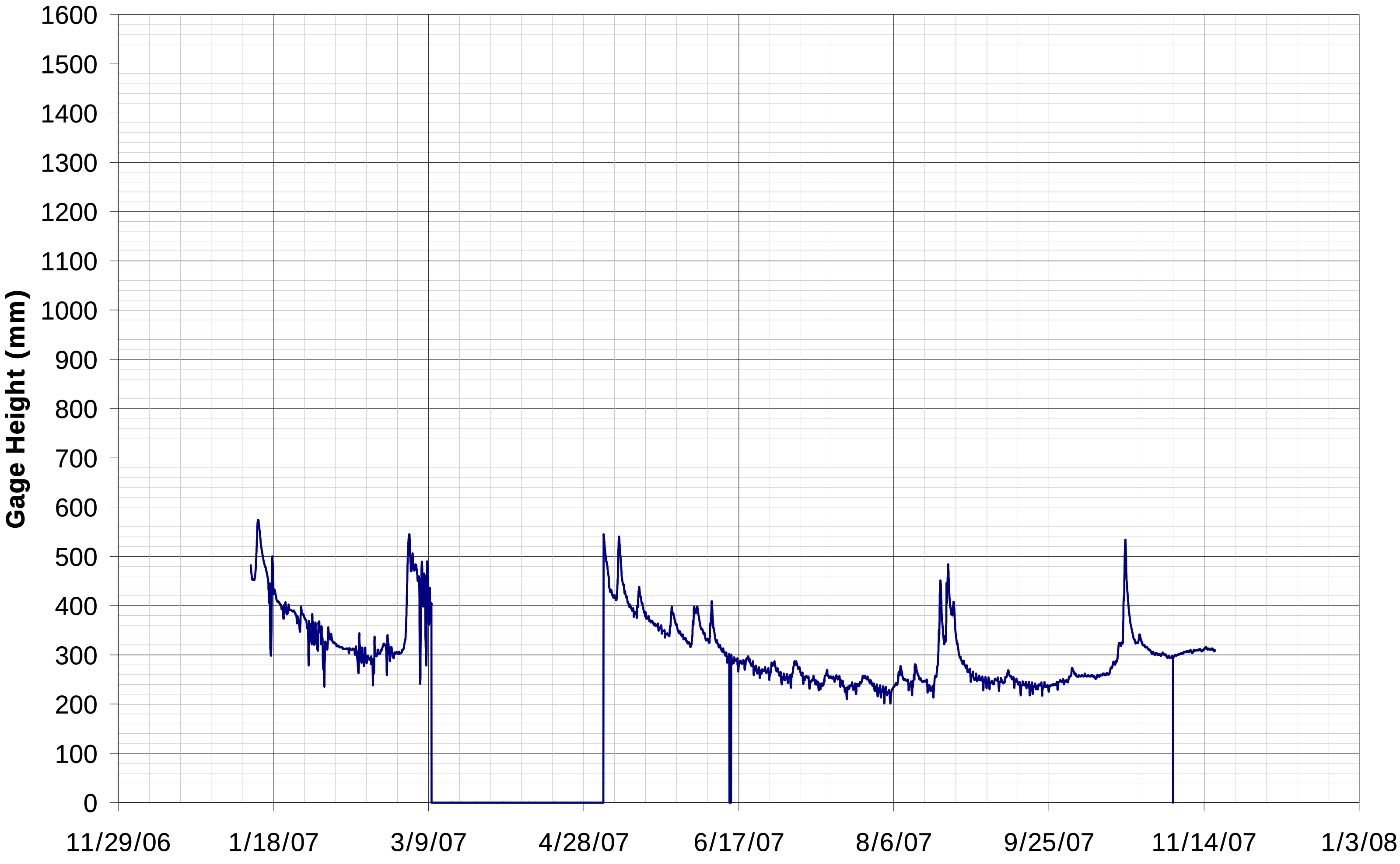
Appendix A. Hydrograph and Thermograph Data 2006 and 2007



Gondor - 36187 2006 Thermograph



Gondor - 36187 2007 Hydrograph



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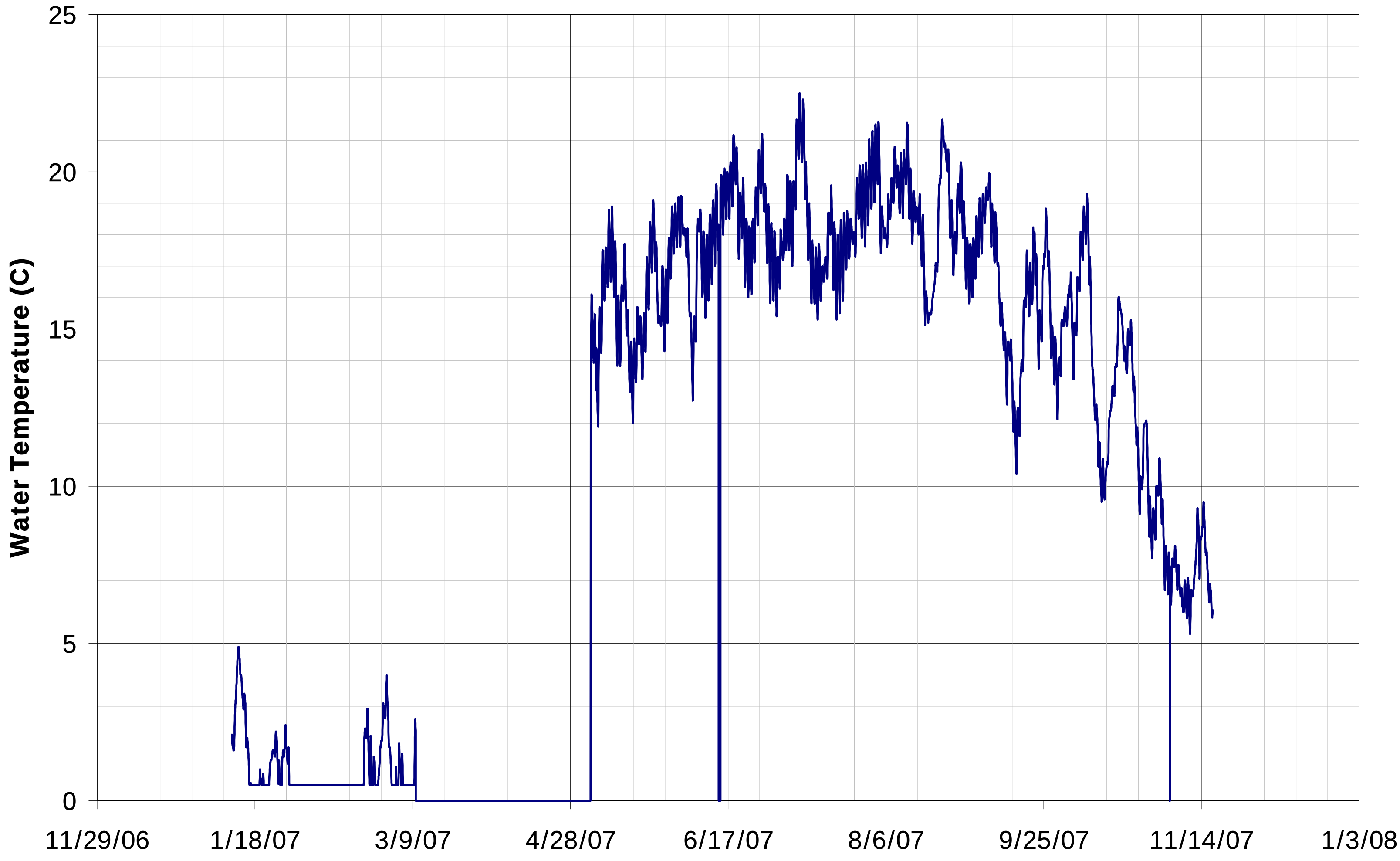
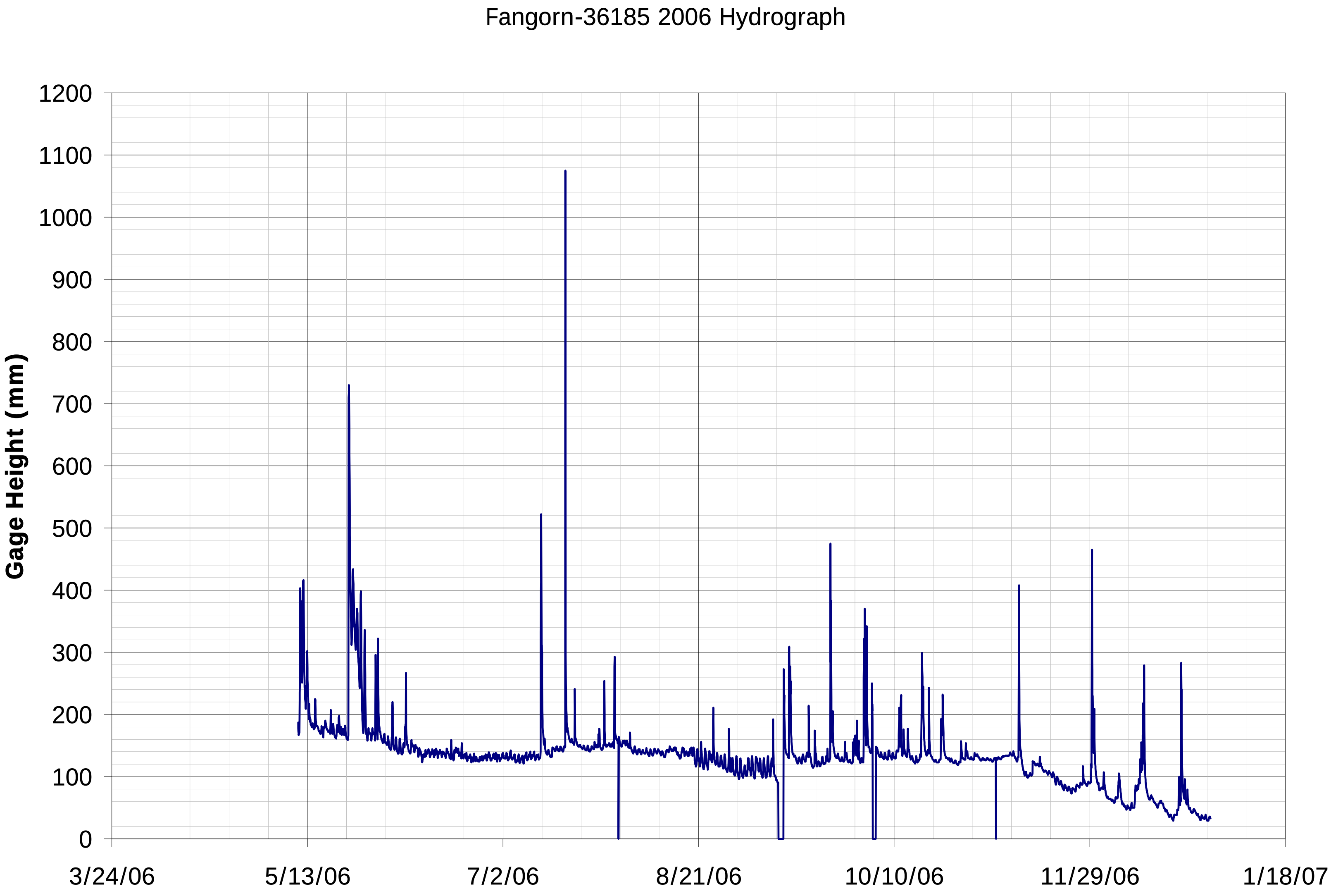
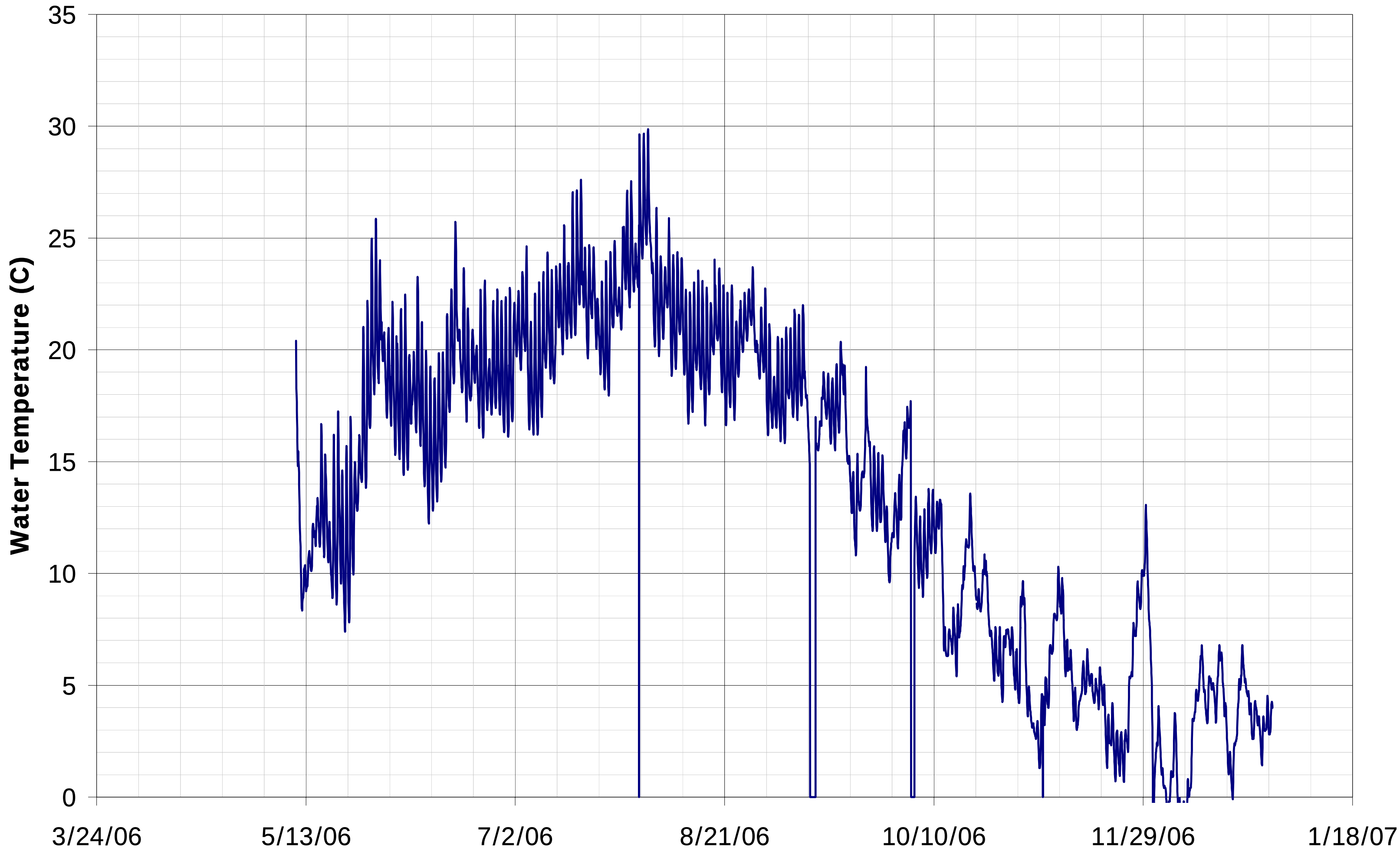


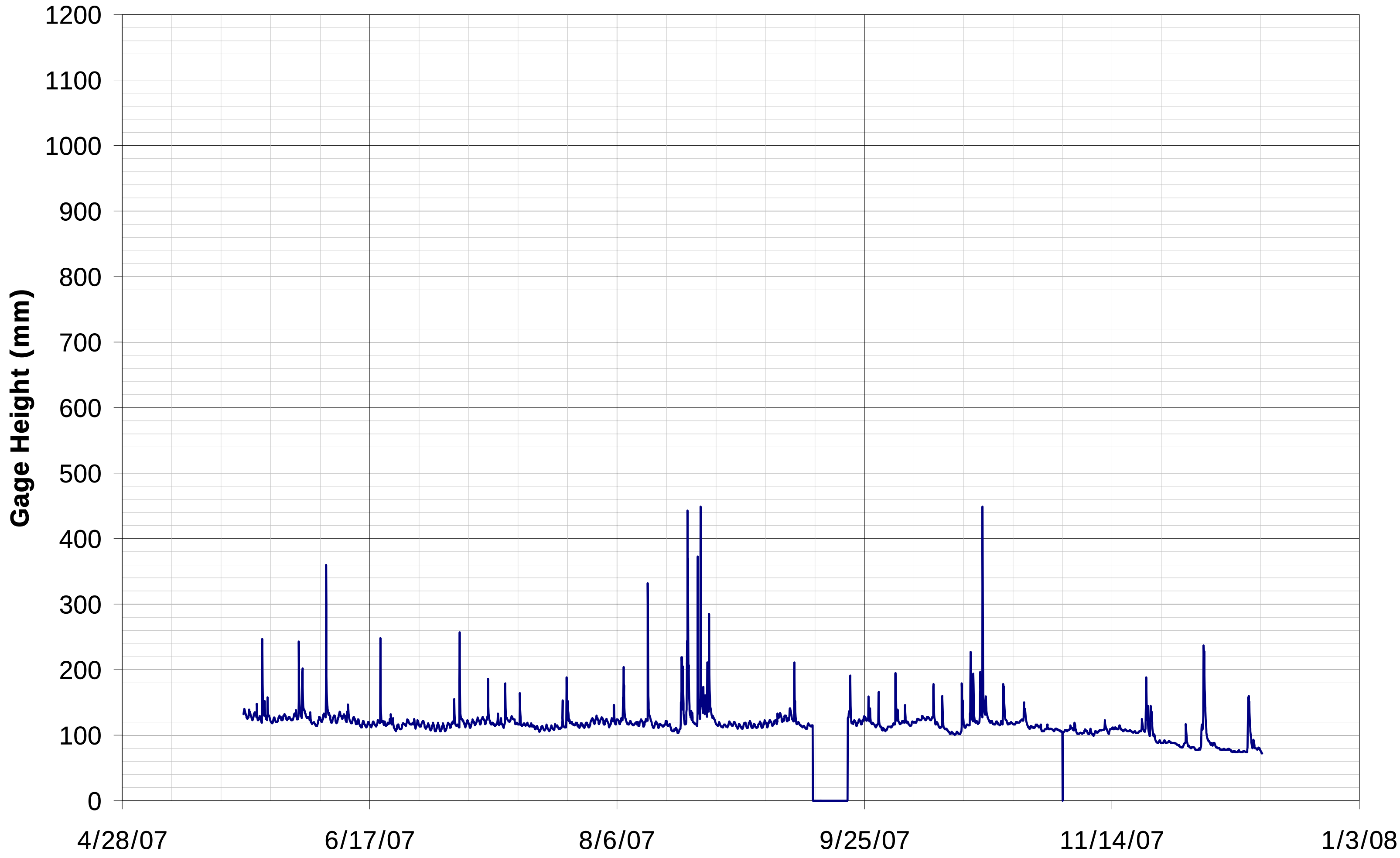


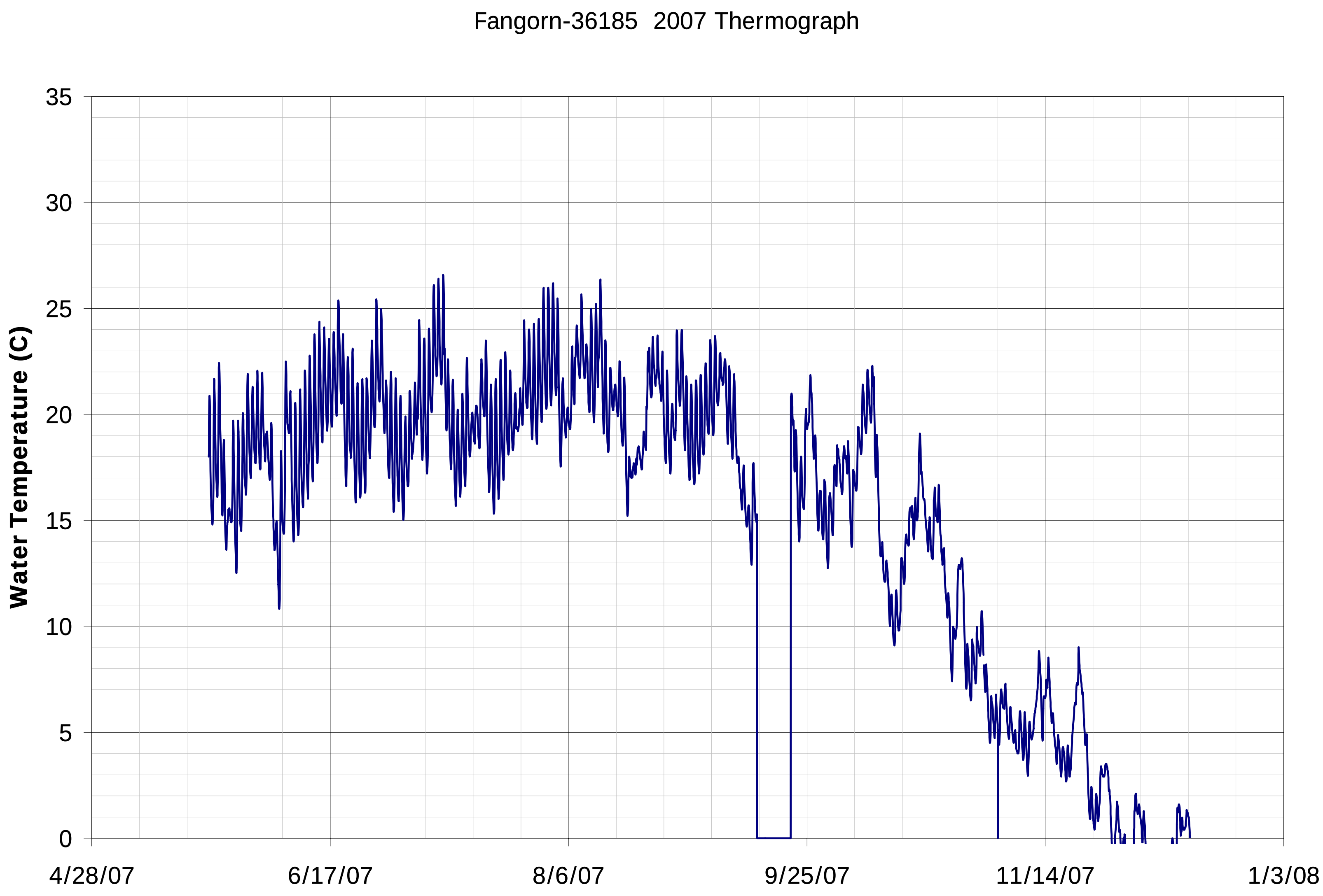
Fangorn-36185 2006 Hydrograph
Gage Height (mm)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
3/24/06
5/13/06
7/2/06
8/21/06
10/10/06
11/29/06
1/18/07

Fangorn-36185 2006 Thermograph



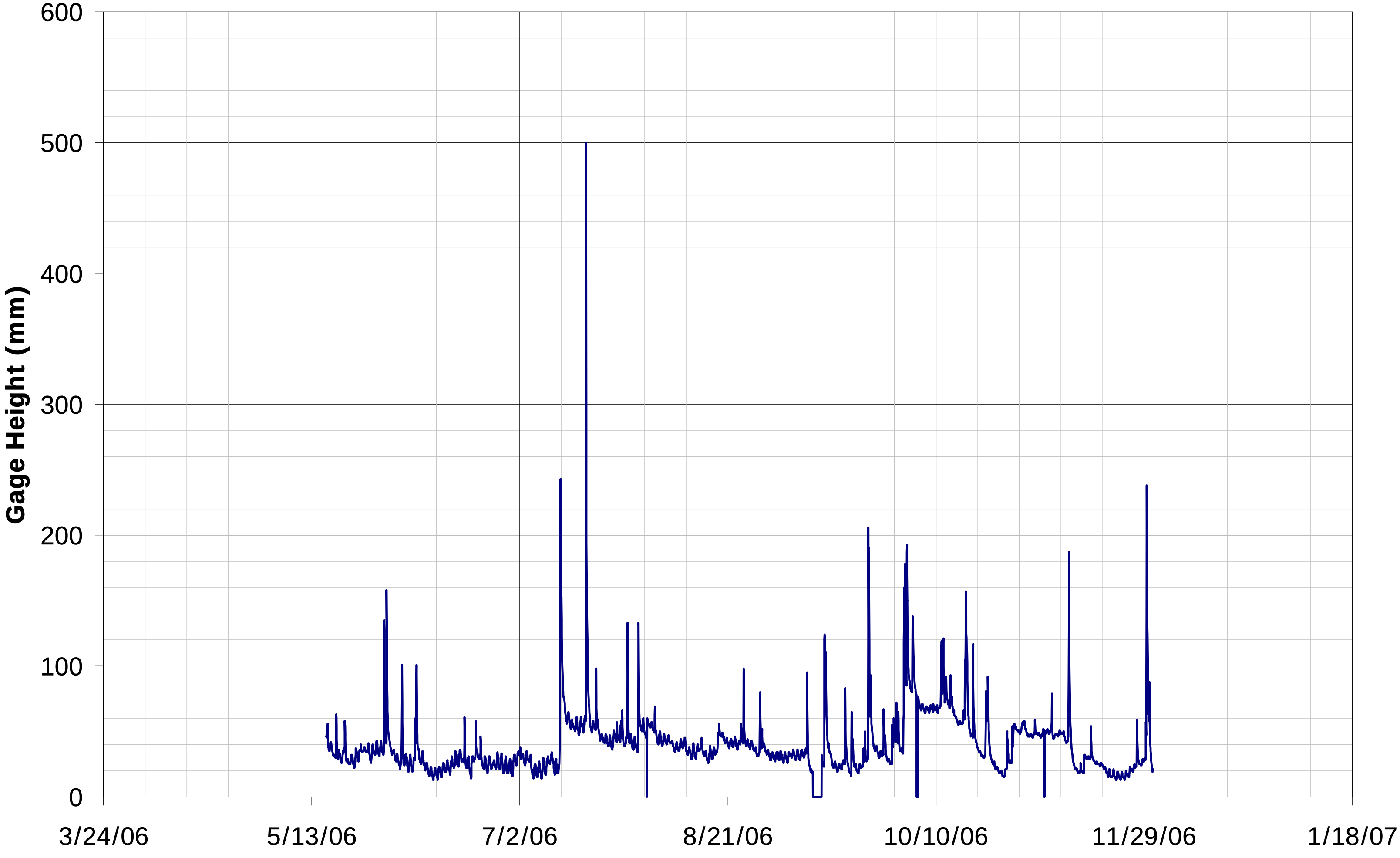
Fangorn-36185 2007 Hydrograph



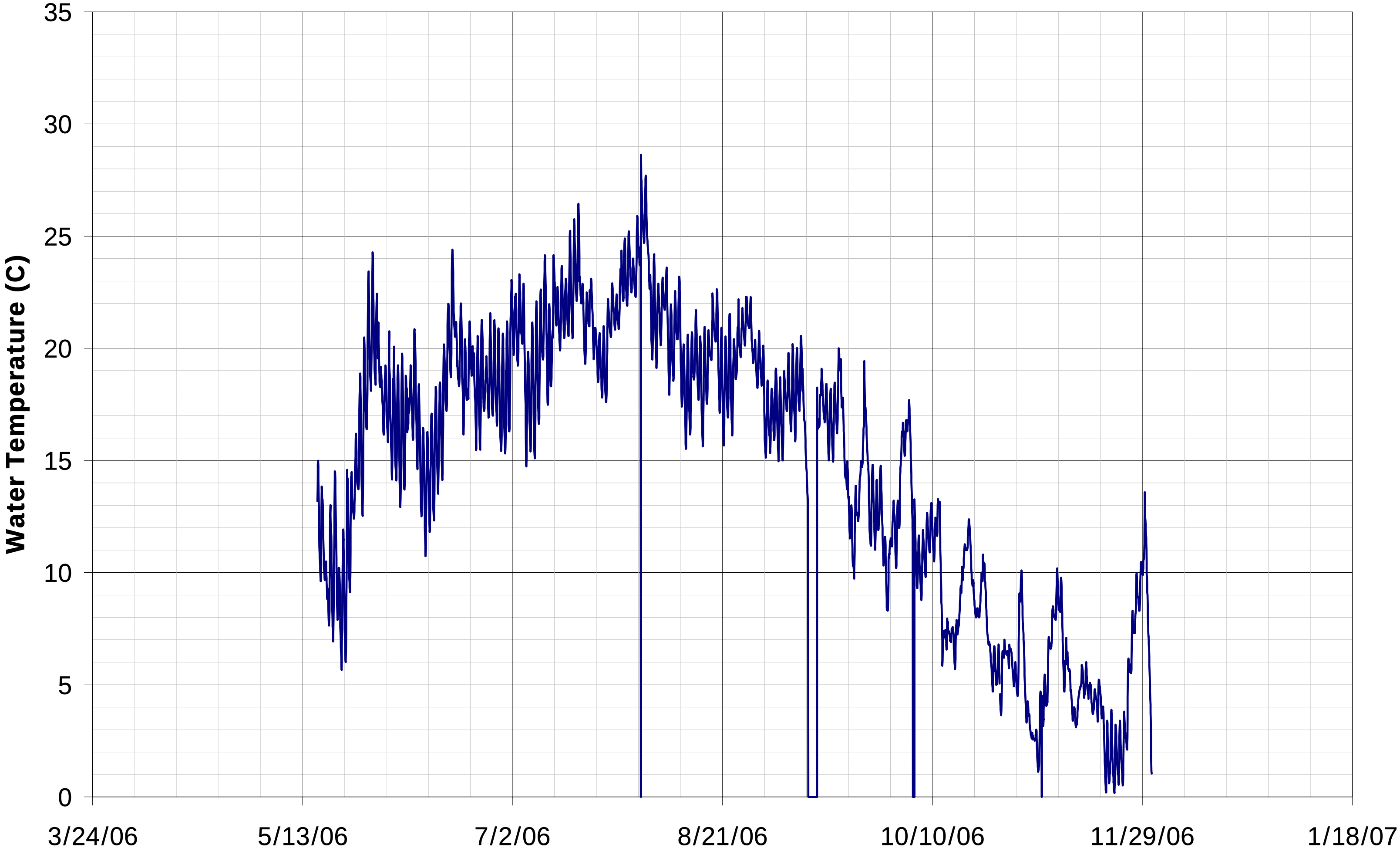


Fangorn-36185 2007 Thermograph
Water Temperature (C)
35
30
25
20
15
10
5
0
4/28/07
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08

Isengard-36186 - 2006 Hydrograph



Isengard-36186 - 2006 Thermograph



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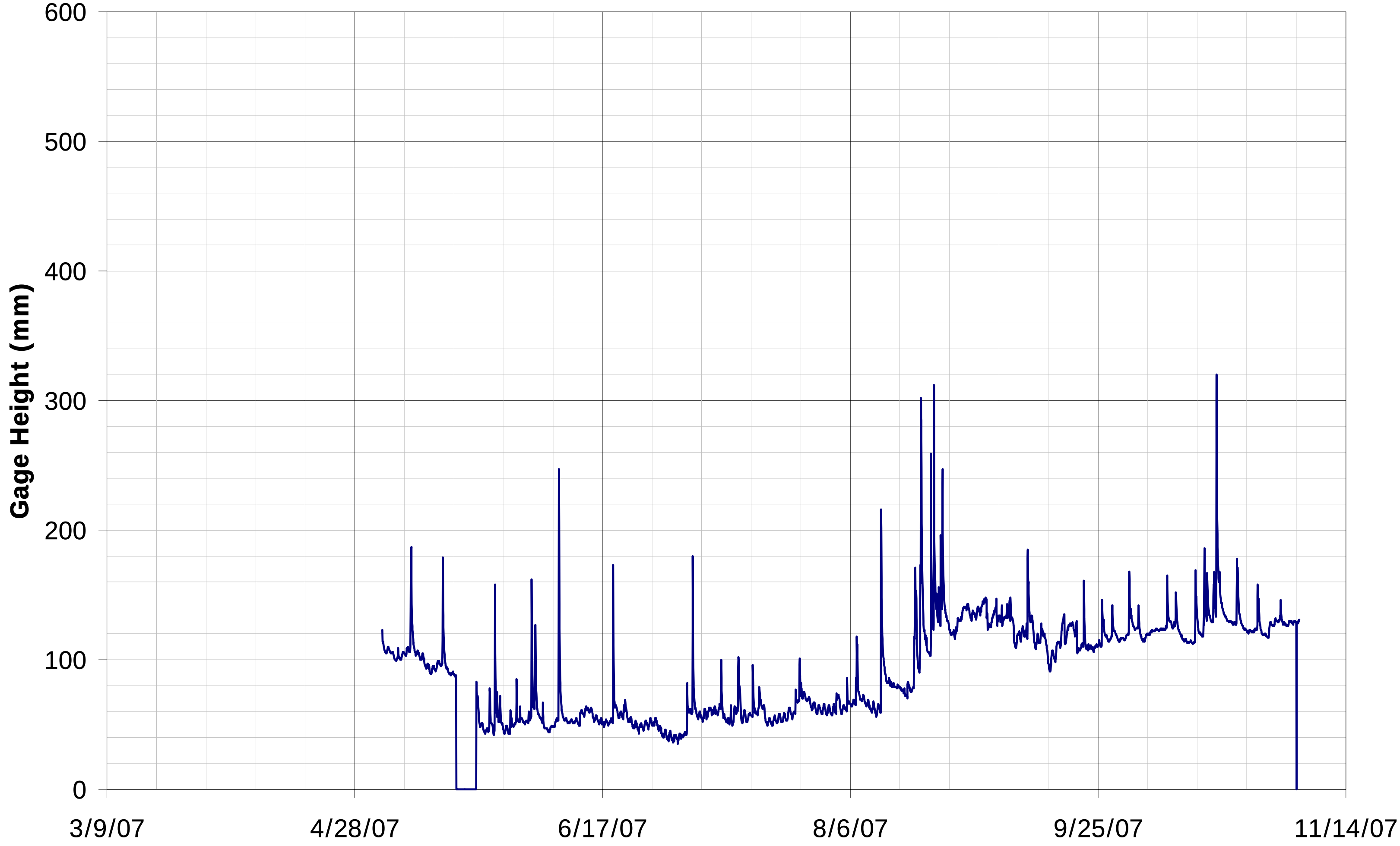
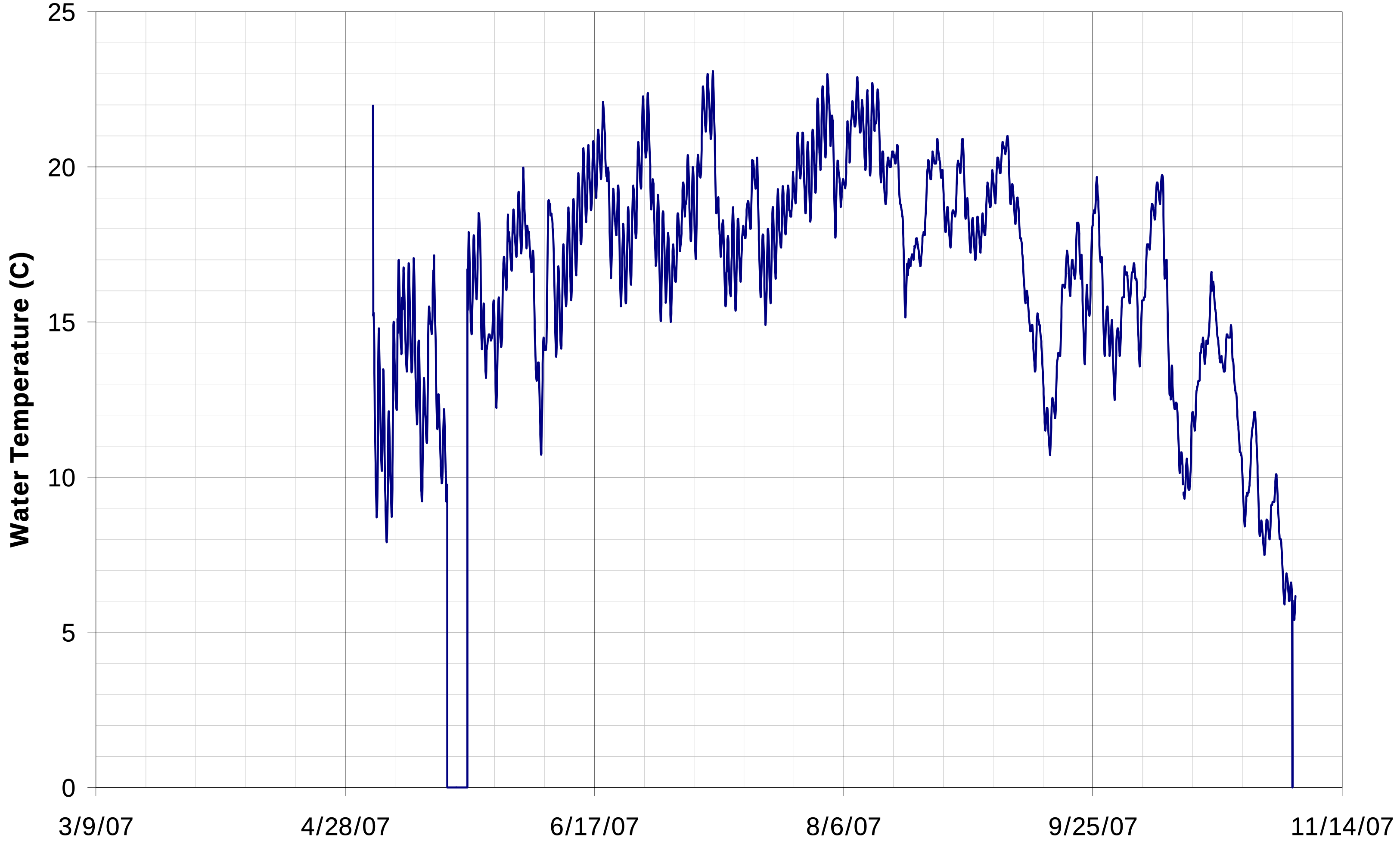
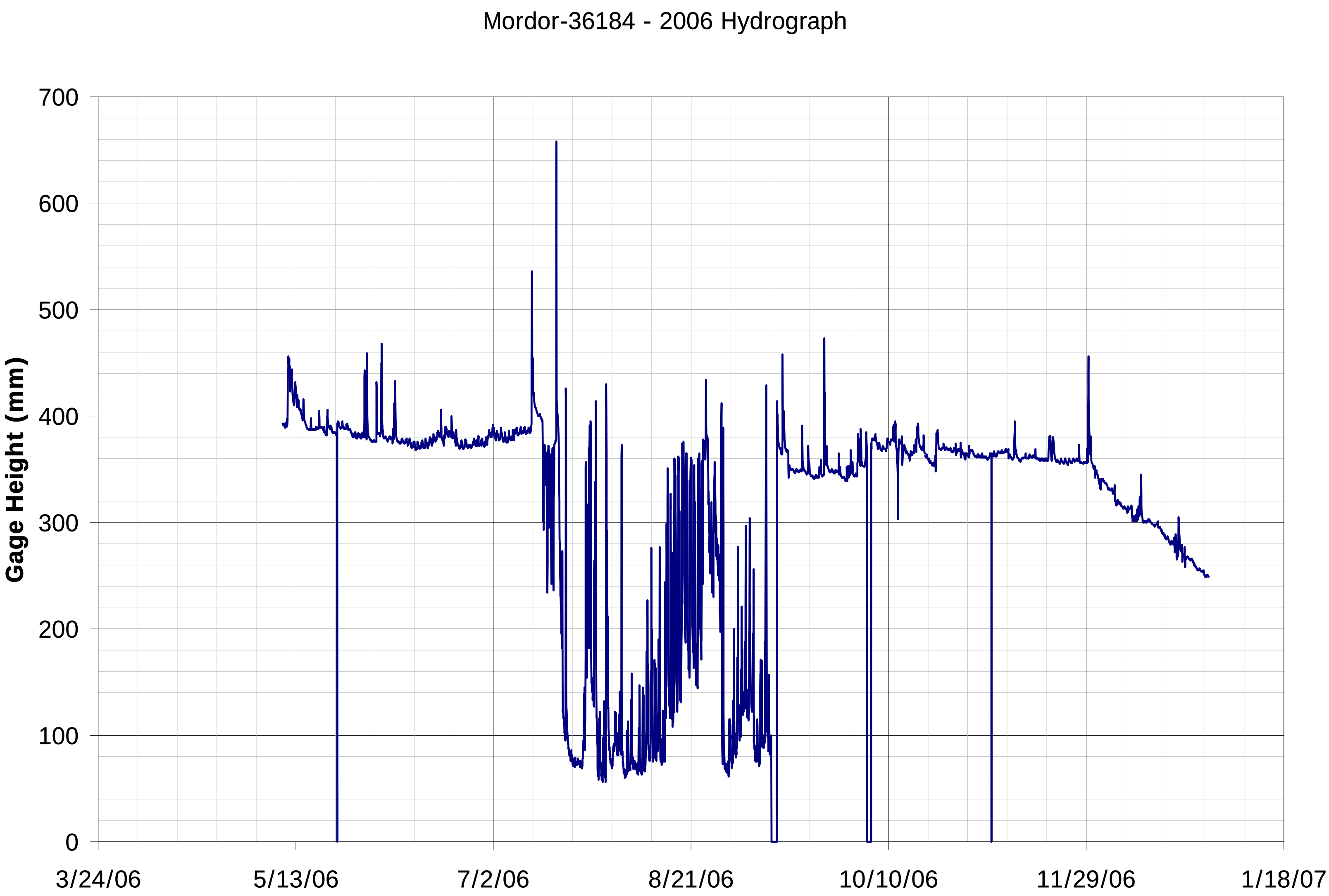


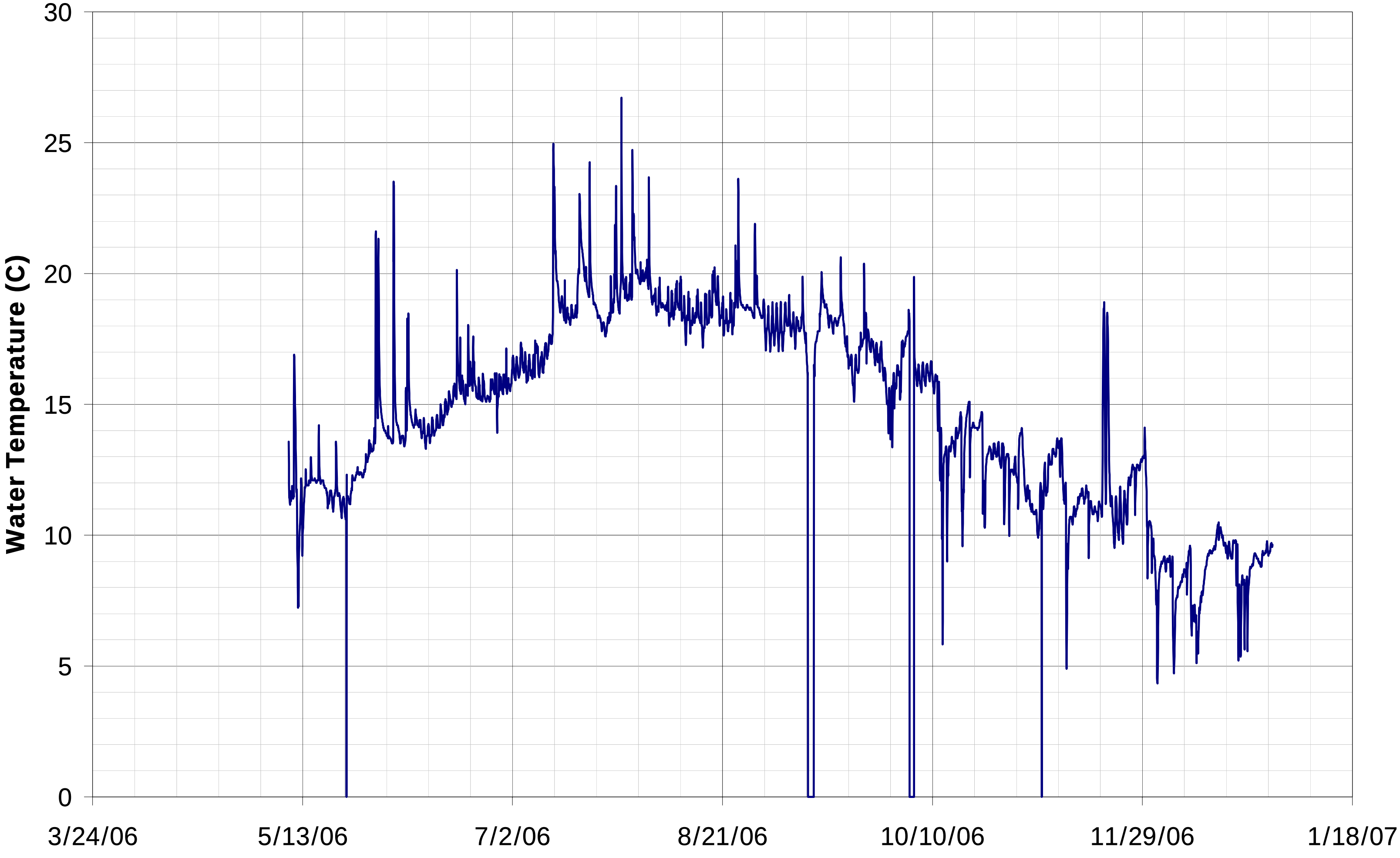
Isengard-36186 - 2007 Thermograph





Mordor-36184 - 2006 Hydrograph
Gage Height (mm)
700
600
500
400
300
200
100
0
3/24/06
5/13/06
7/2/06
8/21/06
10/10/06
11/29/06
1/18/07

Mordor-36184 - 2006 Thermograph



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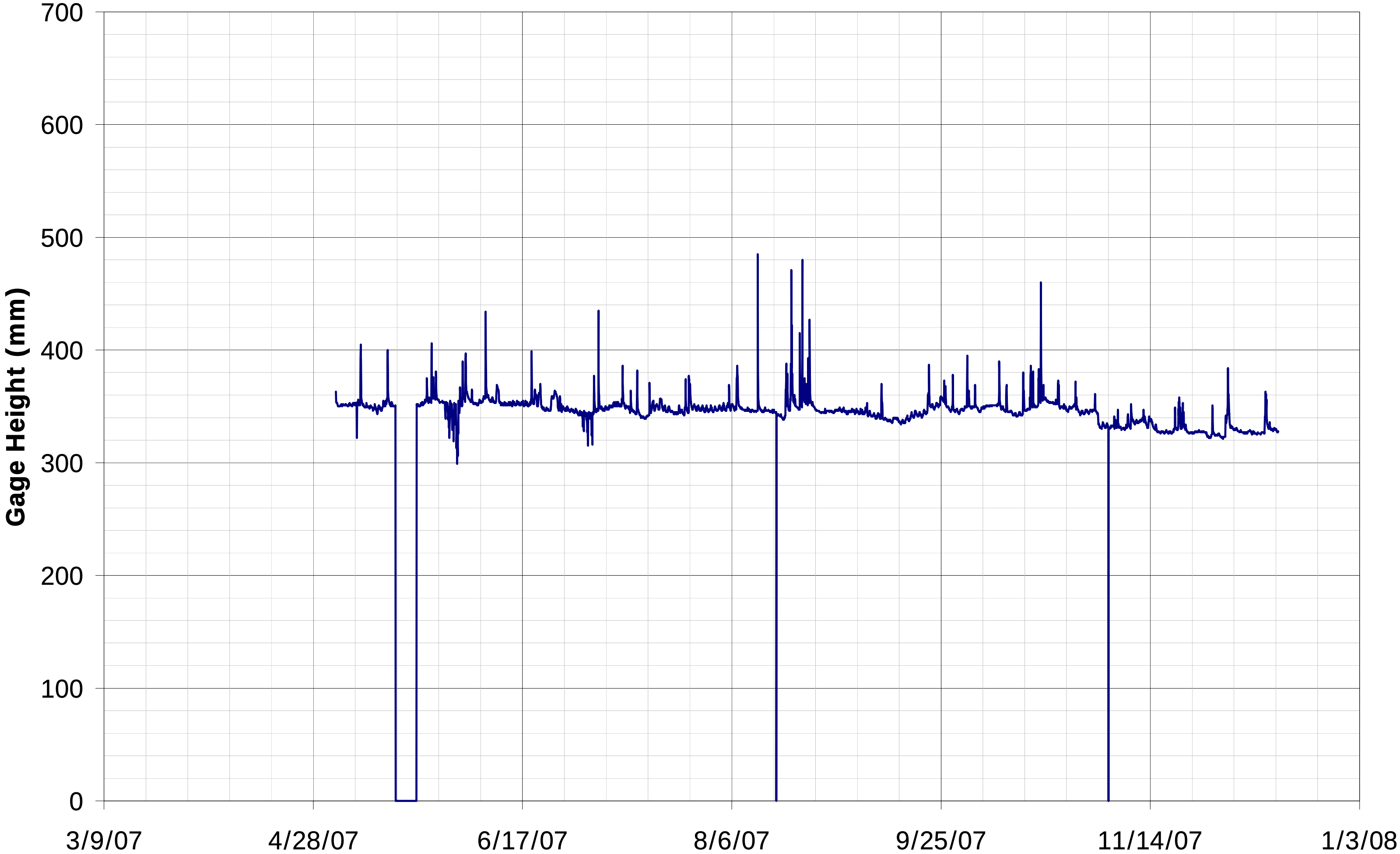
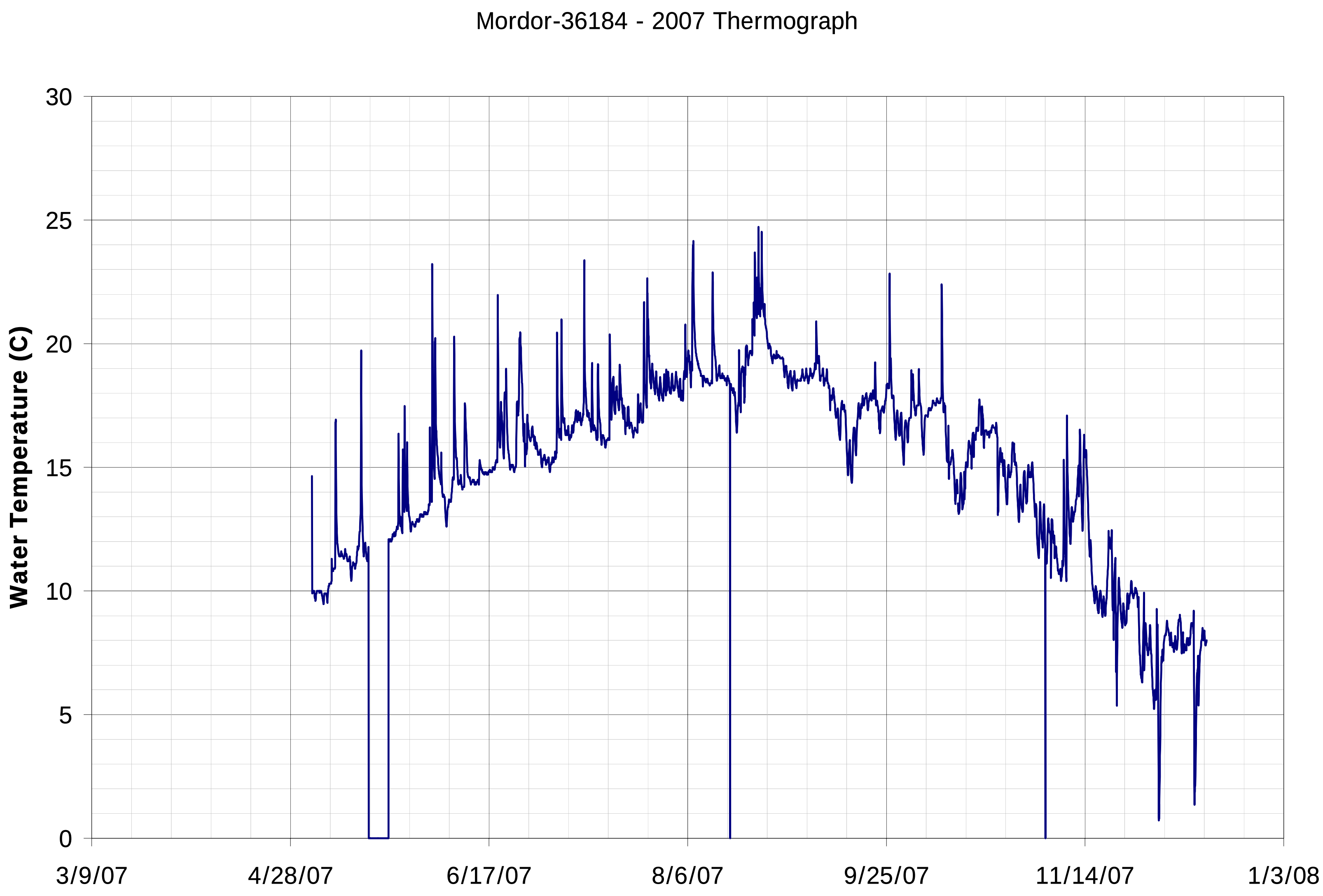
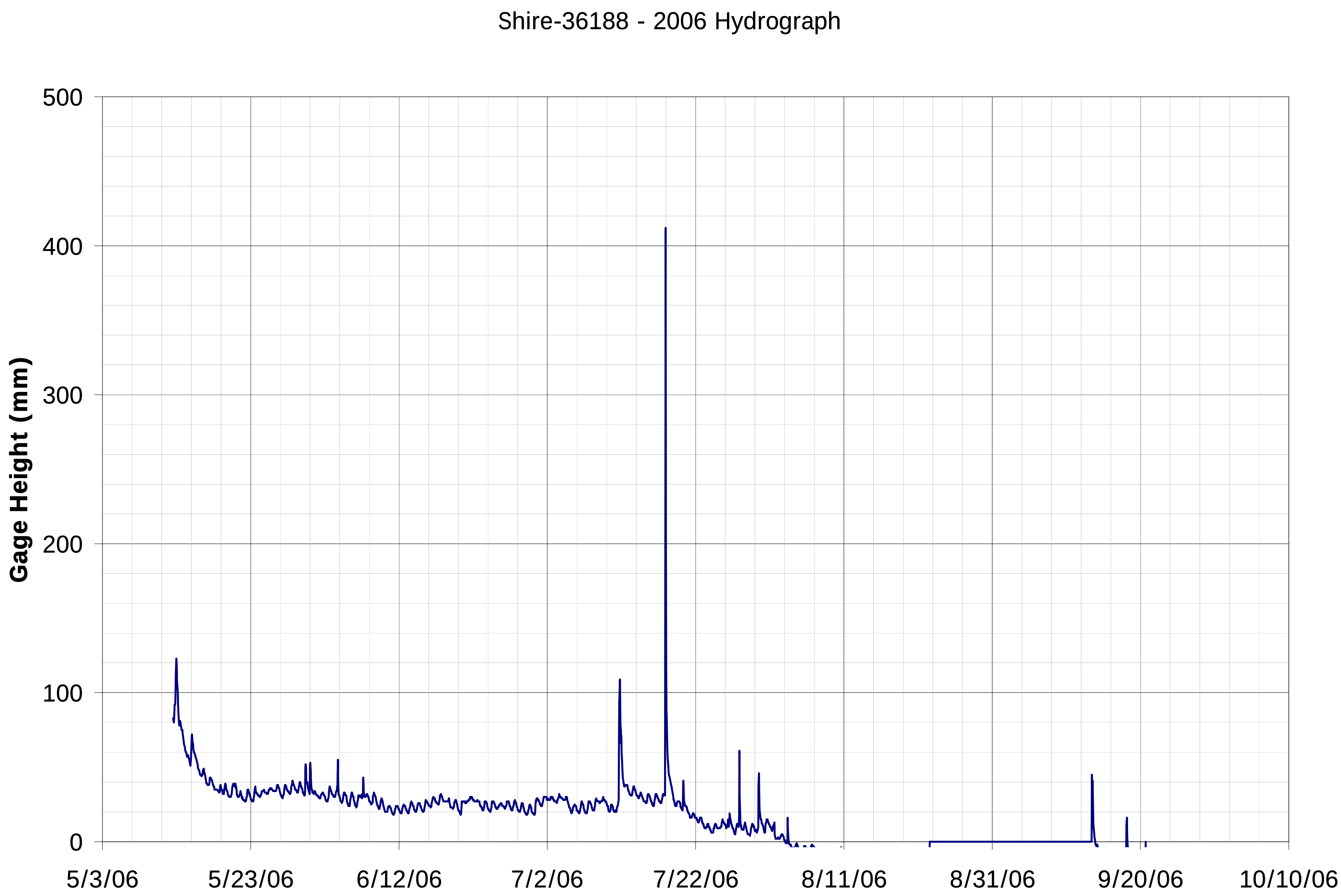




Mordor-36184 - 2007 Thermograph
Water Temperature (C)
30
25
20
15
10
5
0
3/9/07
4/28/07
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08


Shire-36188 - 2006 Hydrograph
Gage Height (mm)
500
400
300
200
100
0
5/3/06
5/23/06
6/12/06
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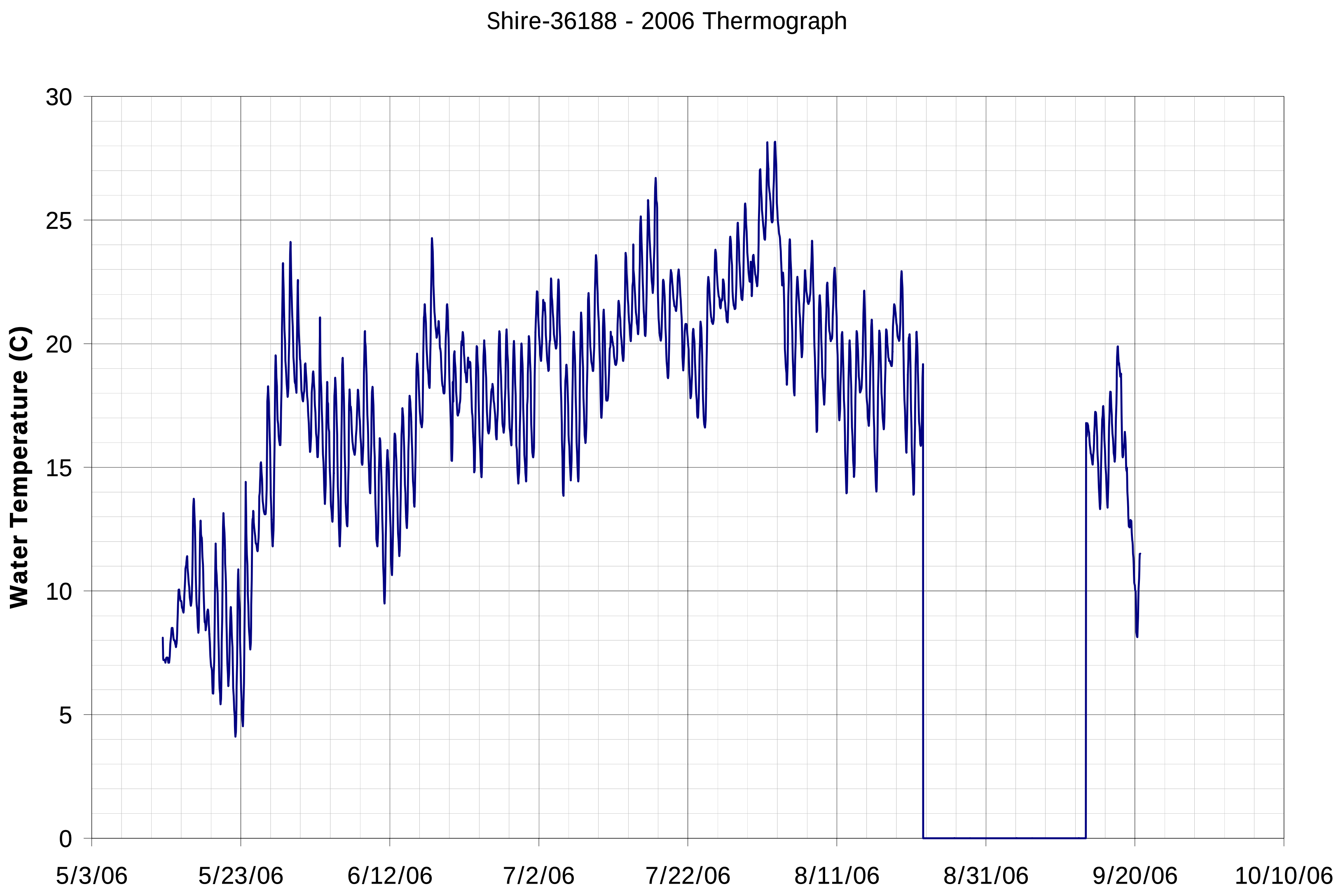
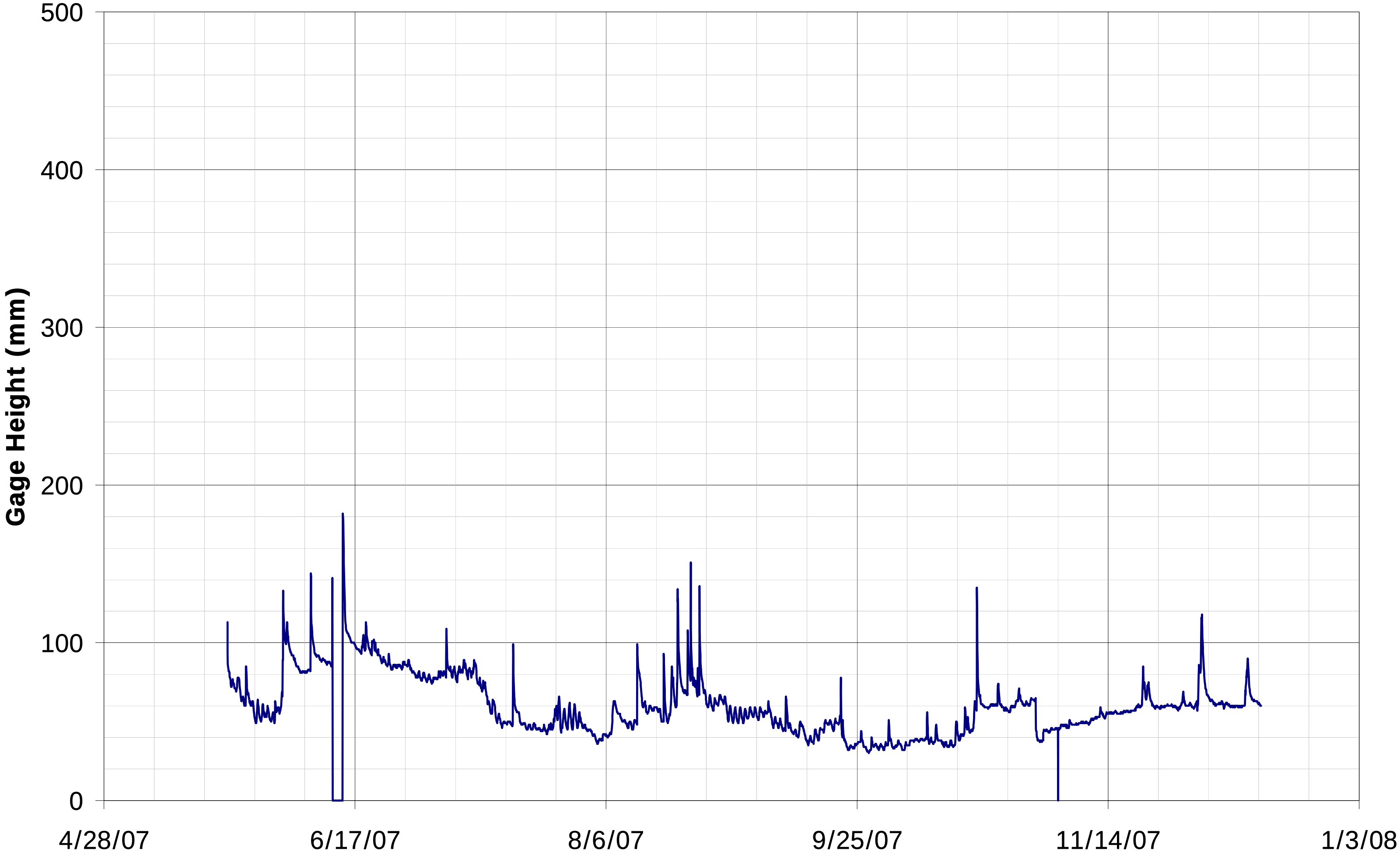
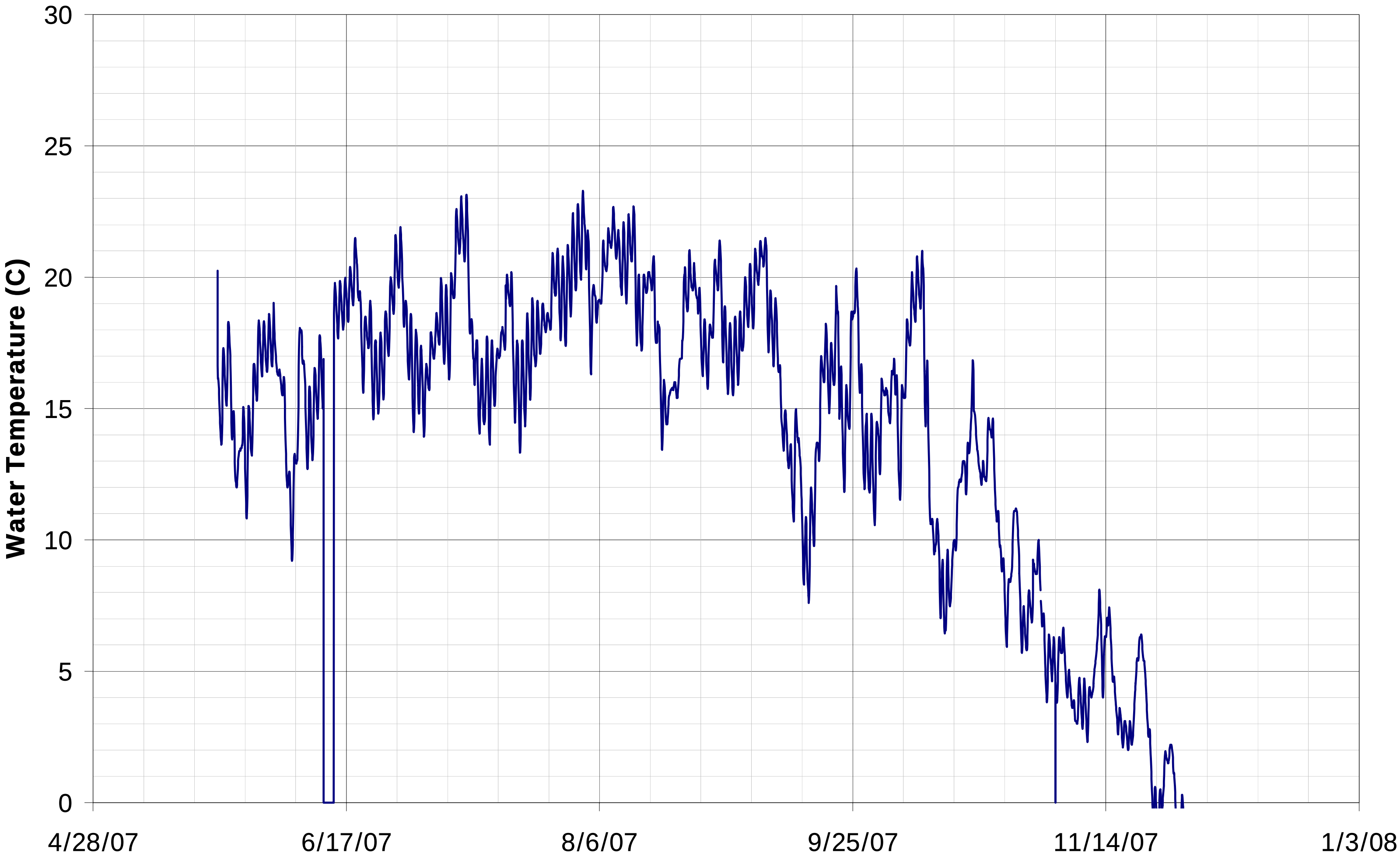
9/20/06
10/10/06


Shire-36188 - 2006 Thermograph
Water Temperature (C)
30
25
20
15
10
5
0
5/3/06
5/23/06
6/12/06
7/2/06
7/22/06
8/11/06
8/31/06
9/20/06
10/10/06

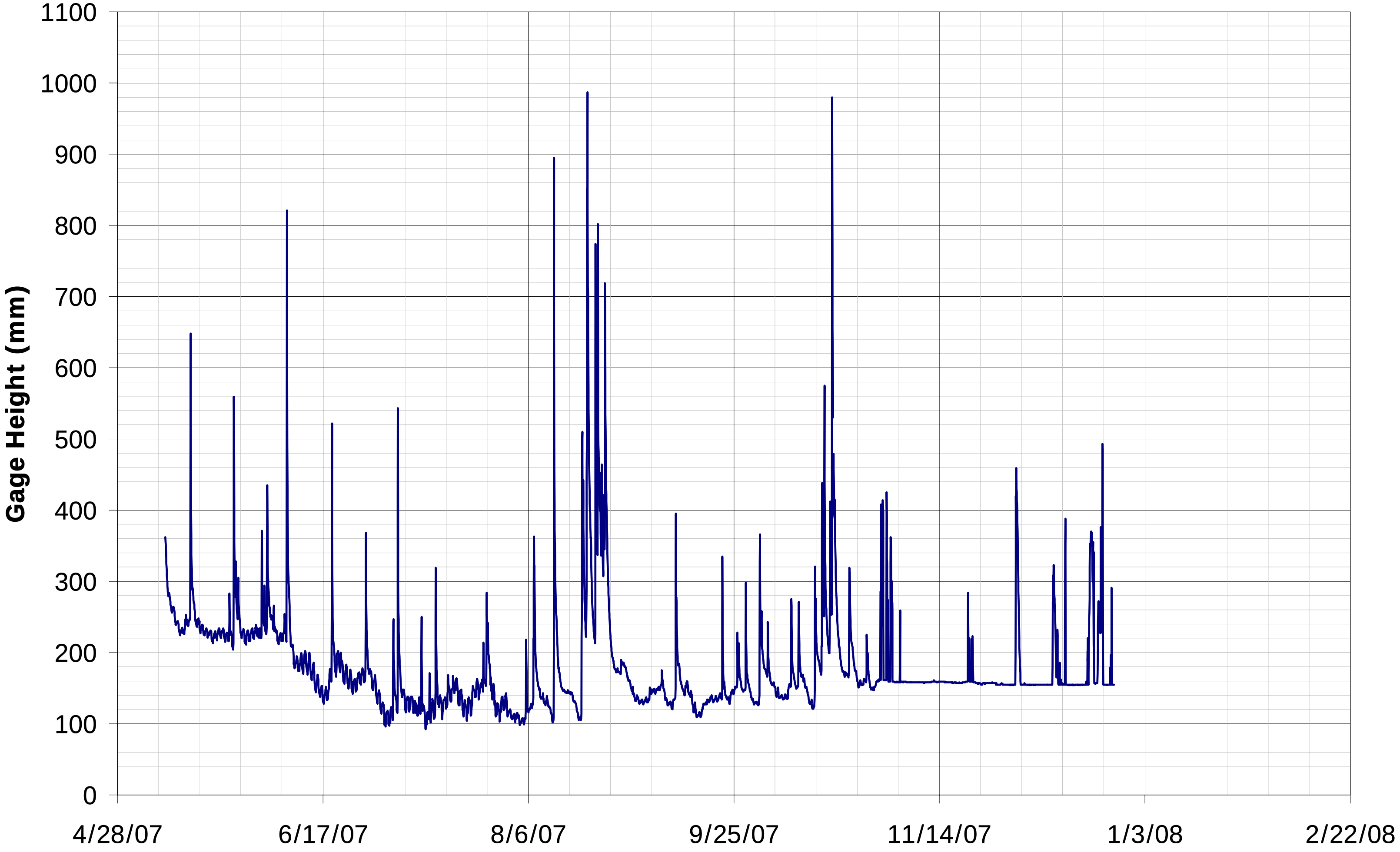
Shire-36188 - 2007 Hydrograph

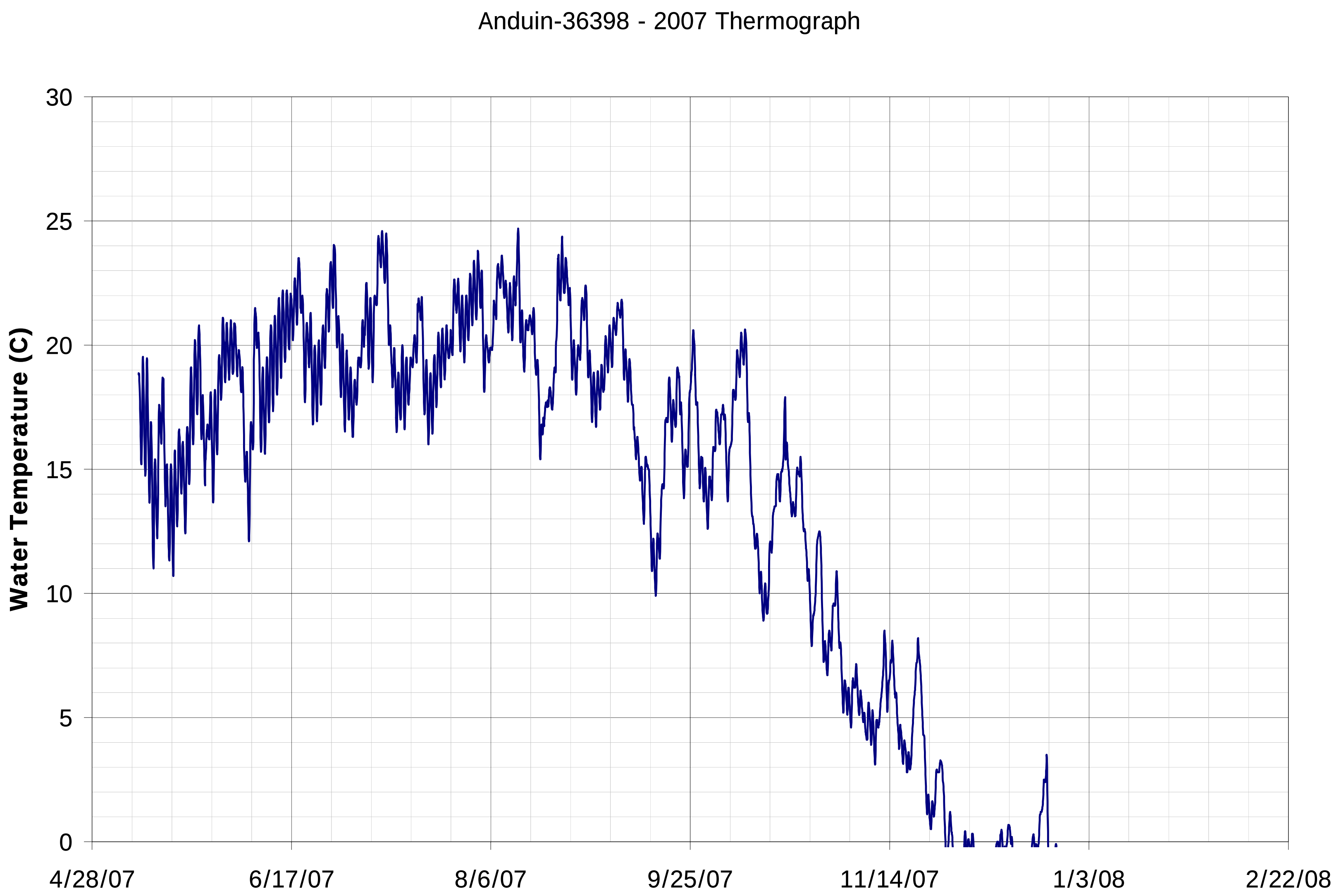


Shire-36188 - 2007 Thermograph



Anduin-36398 - 2007 Hydrograph





Anduin-36398 - 2007 Thermograph
Water Temperature (C)
30
25
20
15
10
5
0
4/28/07
6/17/07
8/6/07
9/25/07
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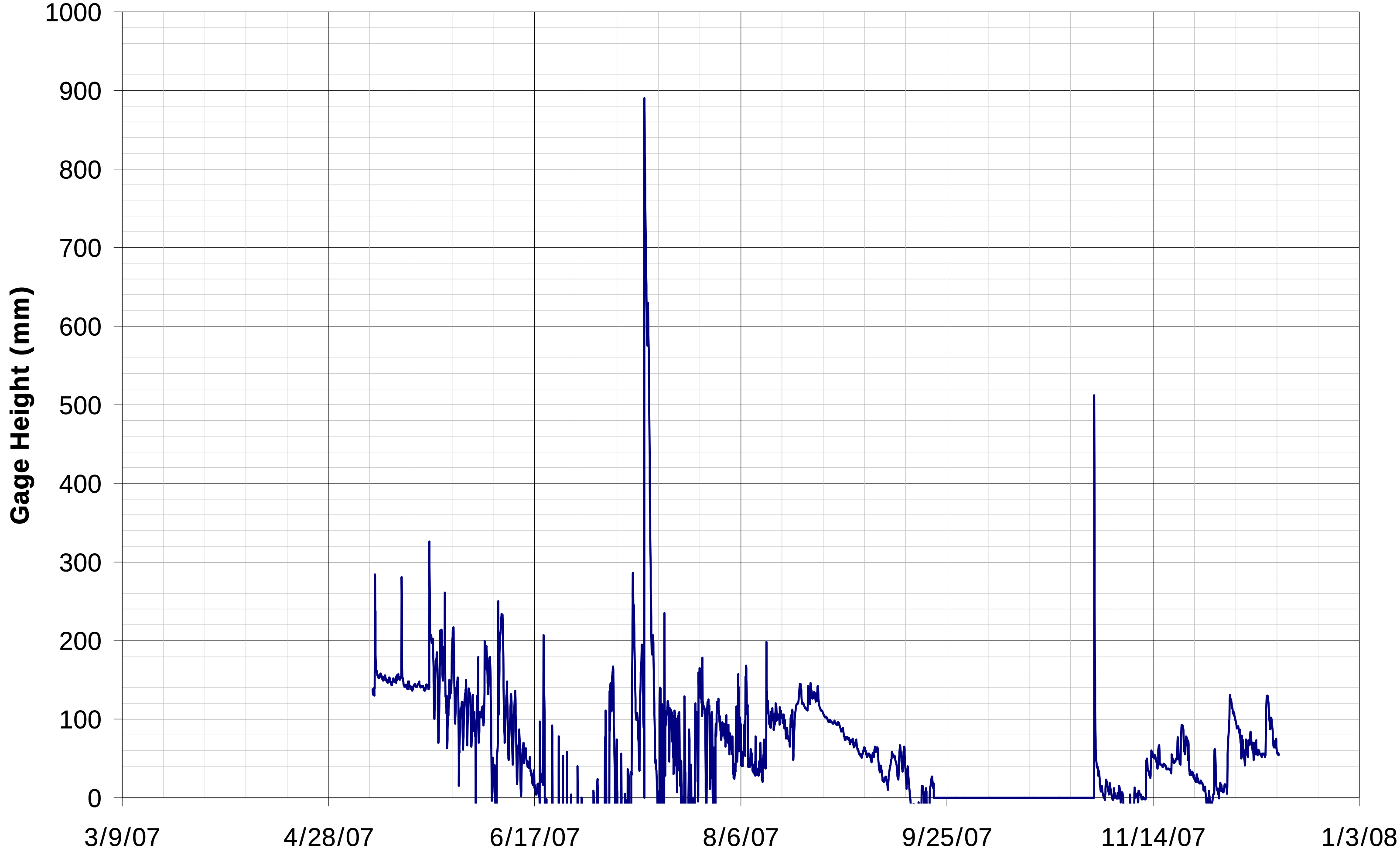
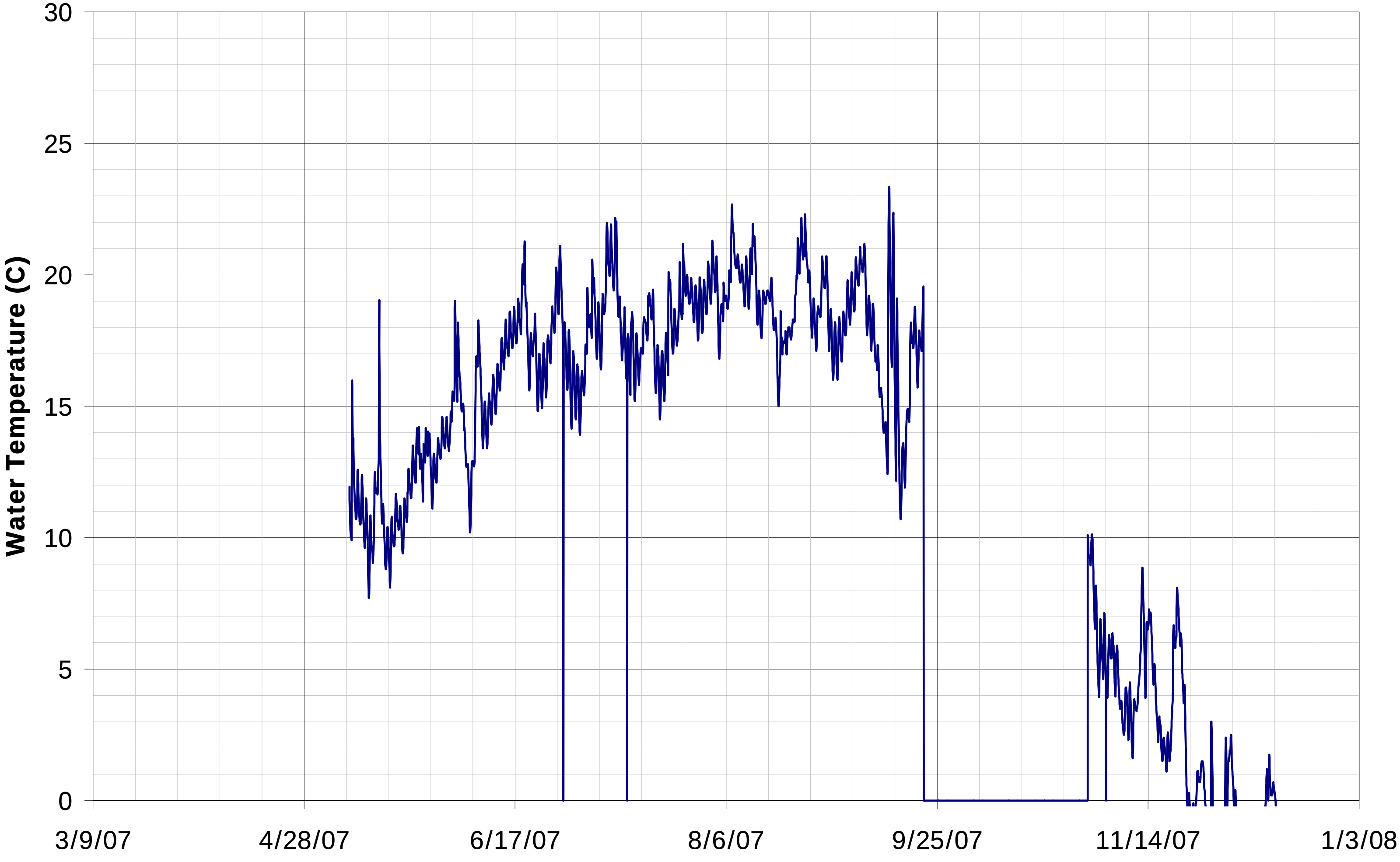
1/3/08
2/22/08

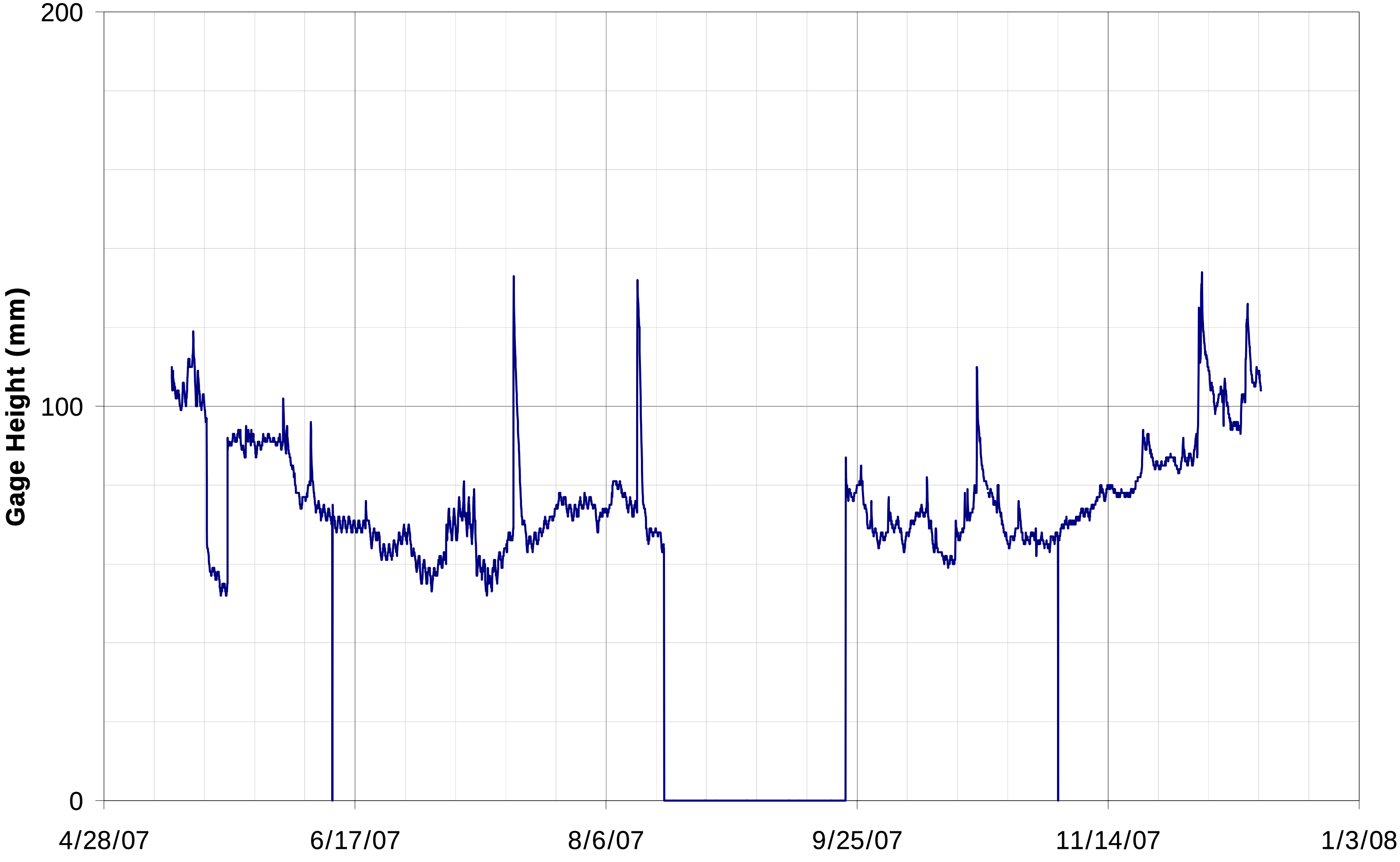
Bree-36403 - 2007 Hydrograph

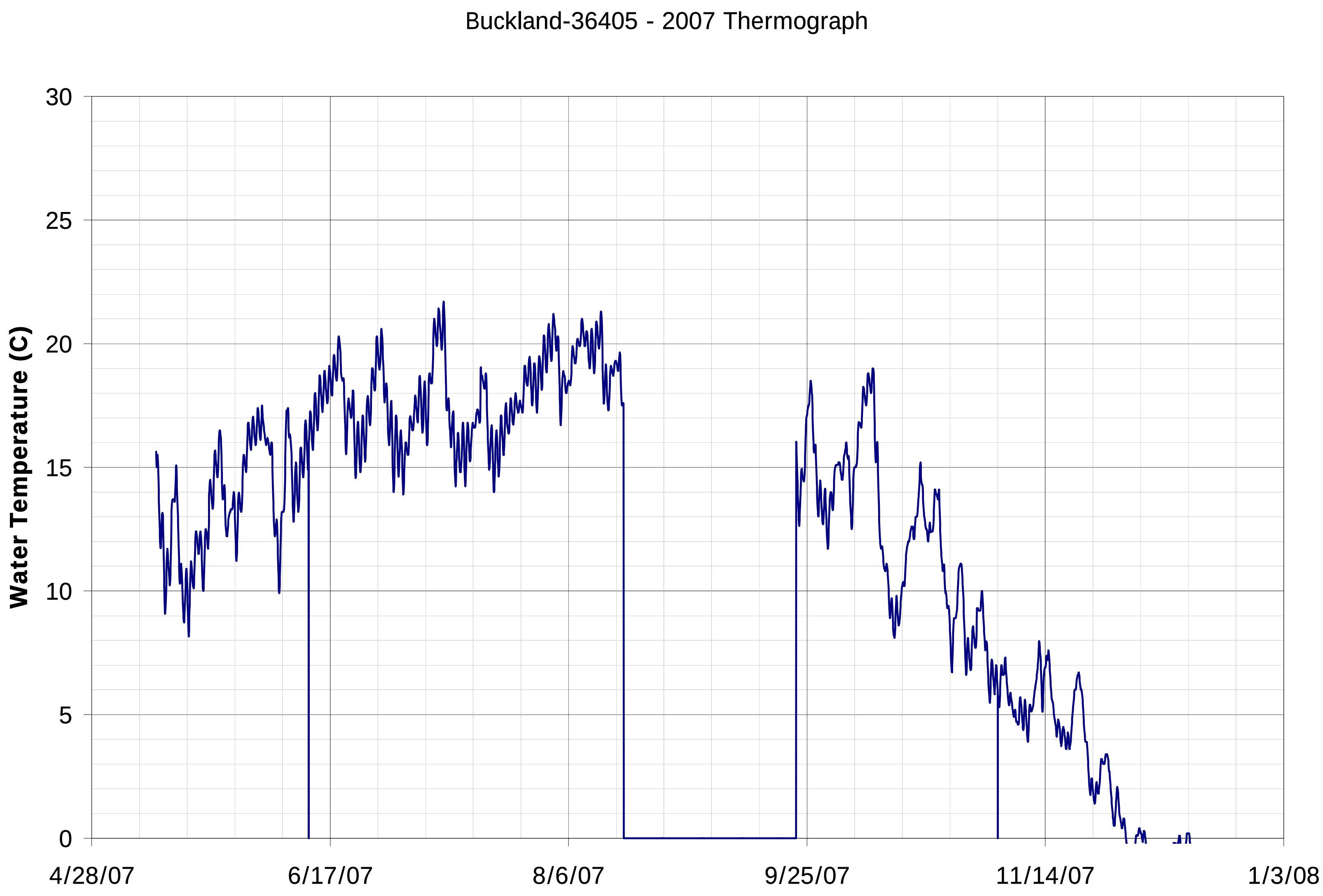


Bree-36403 - 2007 Thermograph



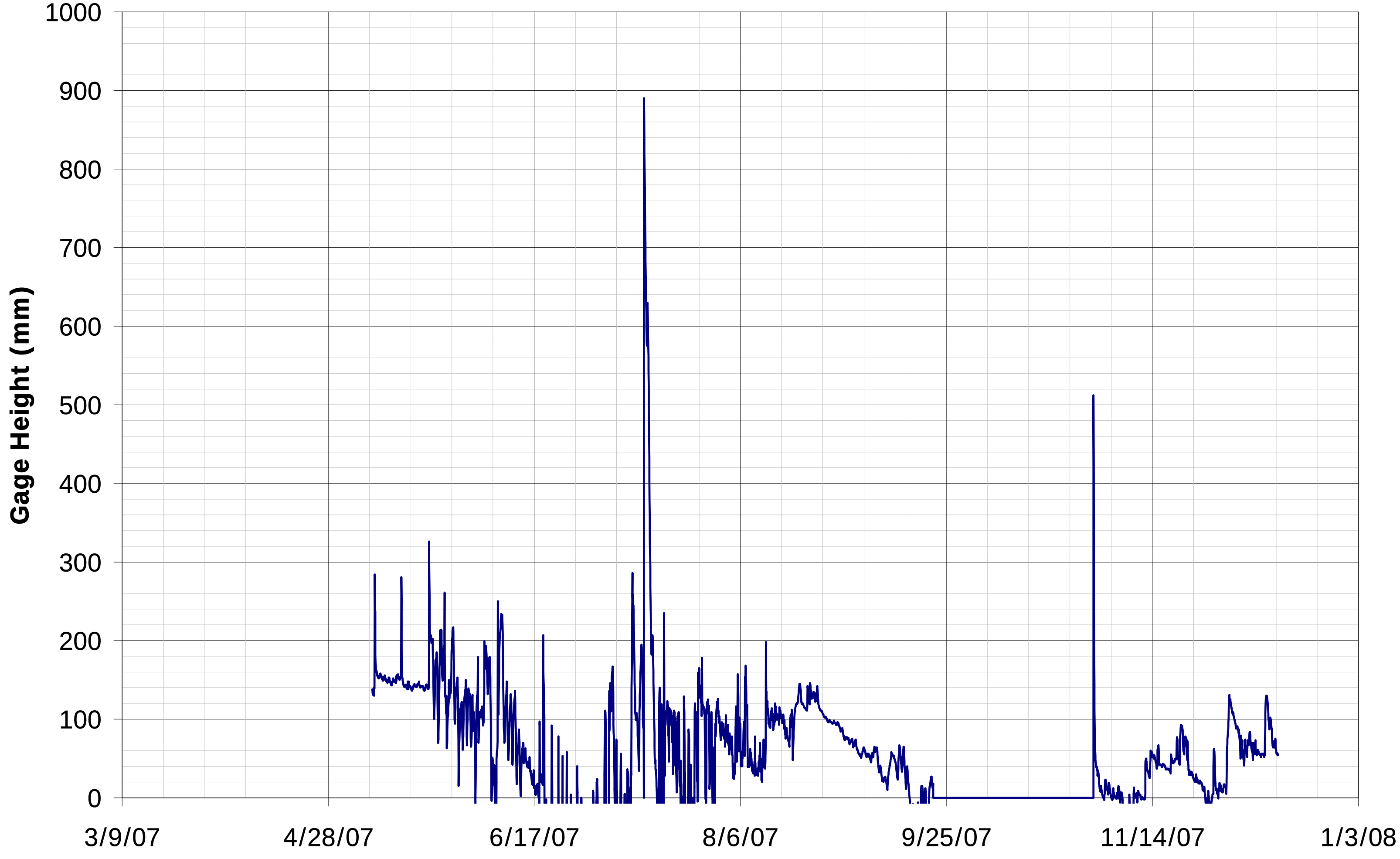
Buckland-36405 - 2007 Hydrograph



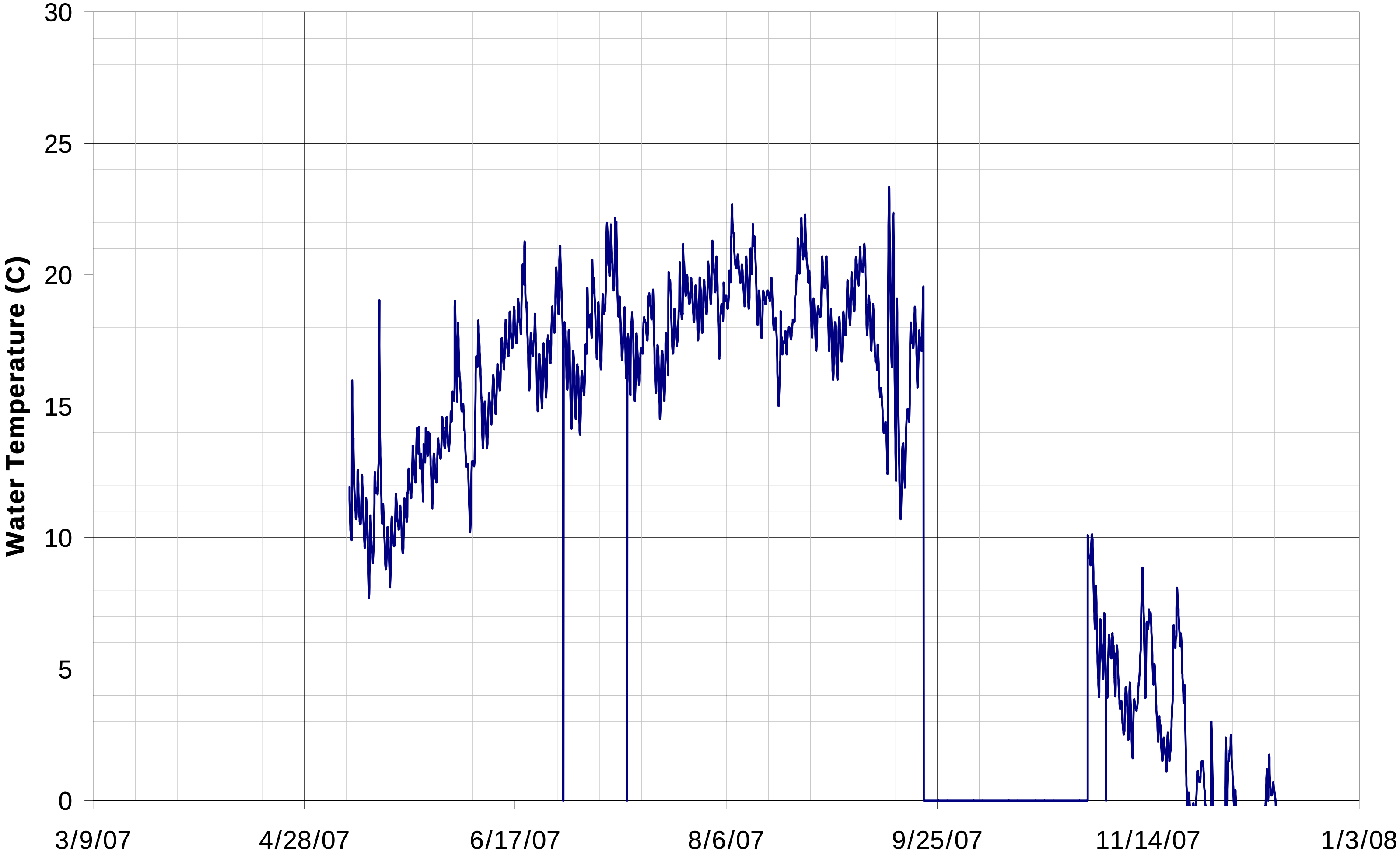


Buckland-36405 - 2007 Thermograph
Water Temperature (C)
30
25
20
15
10
5
0
4/28/07
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08

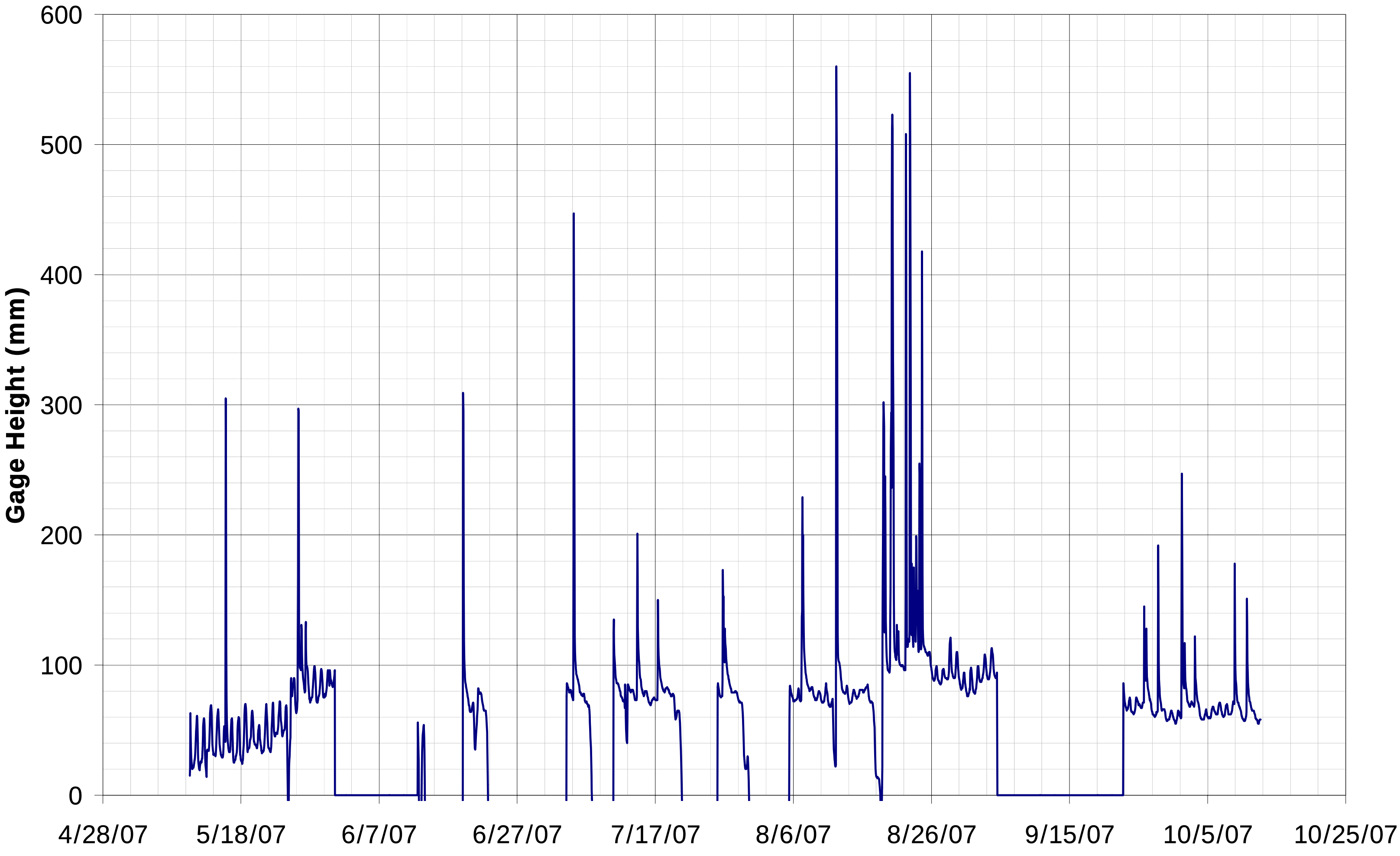
Dead Marshes-36404 - 2007 Hydrograph



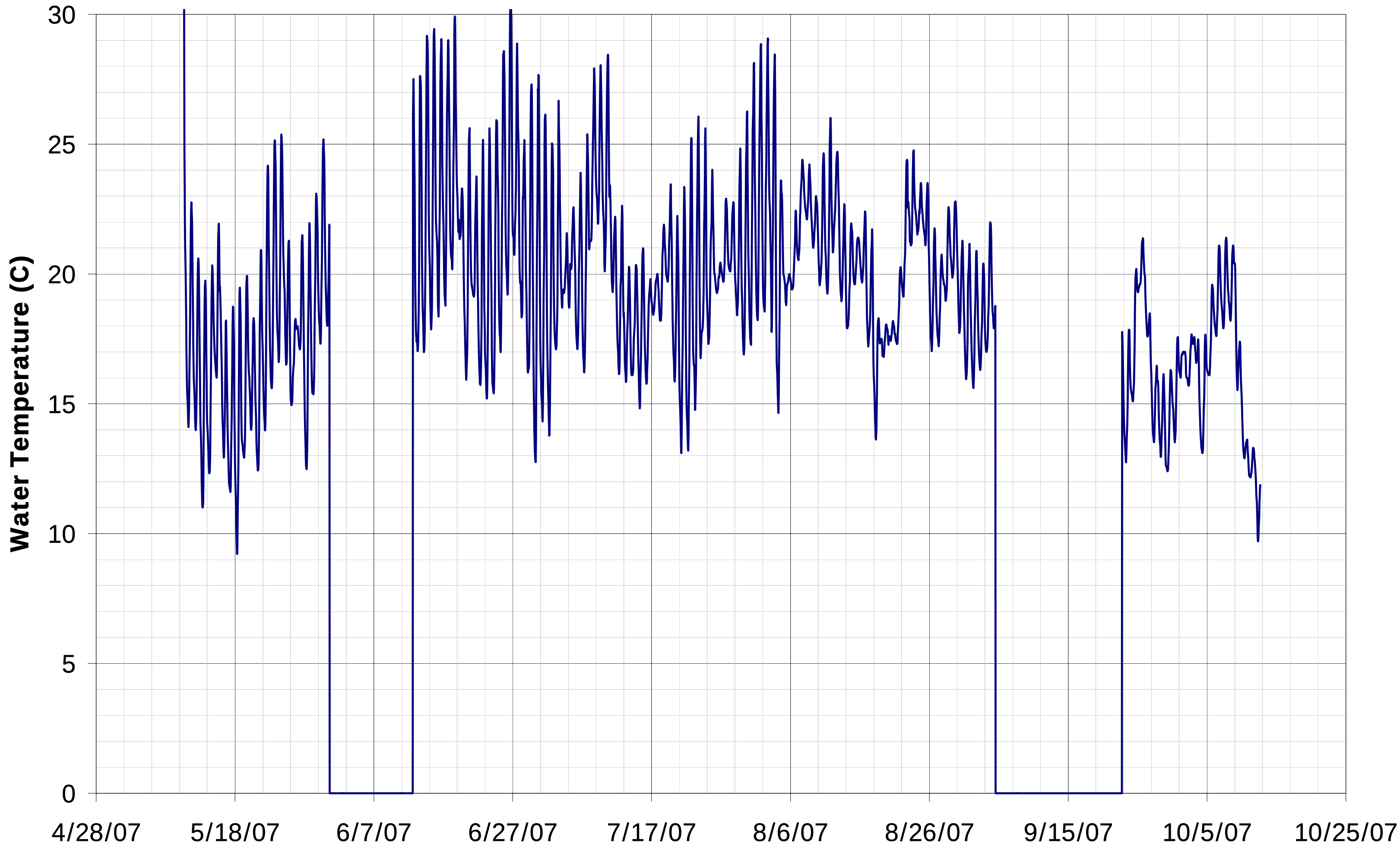
Dead Marshes-36404 - 2007 Thermograph



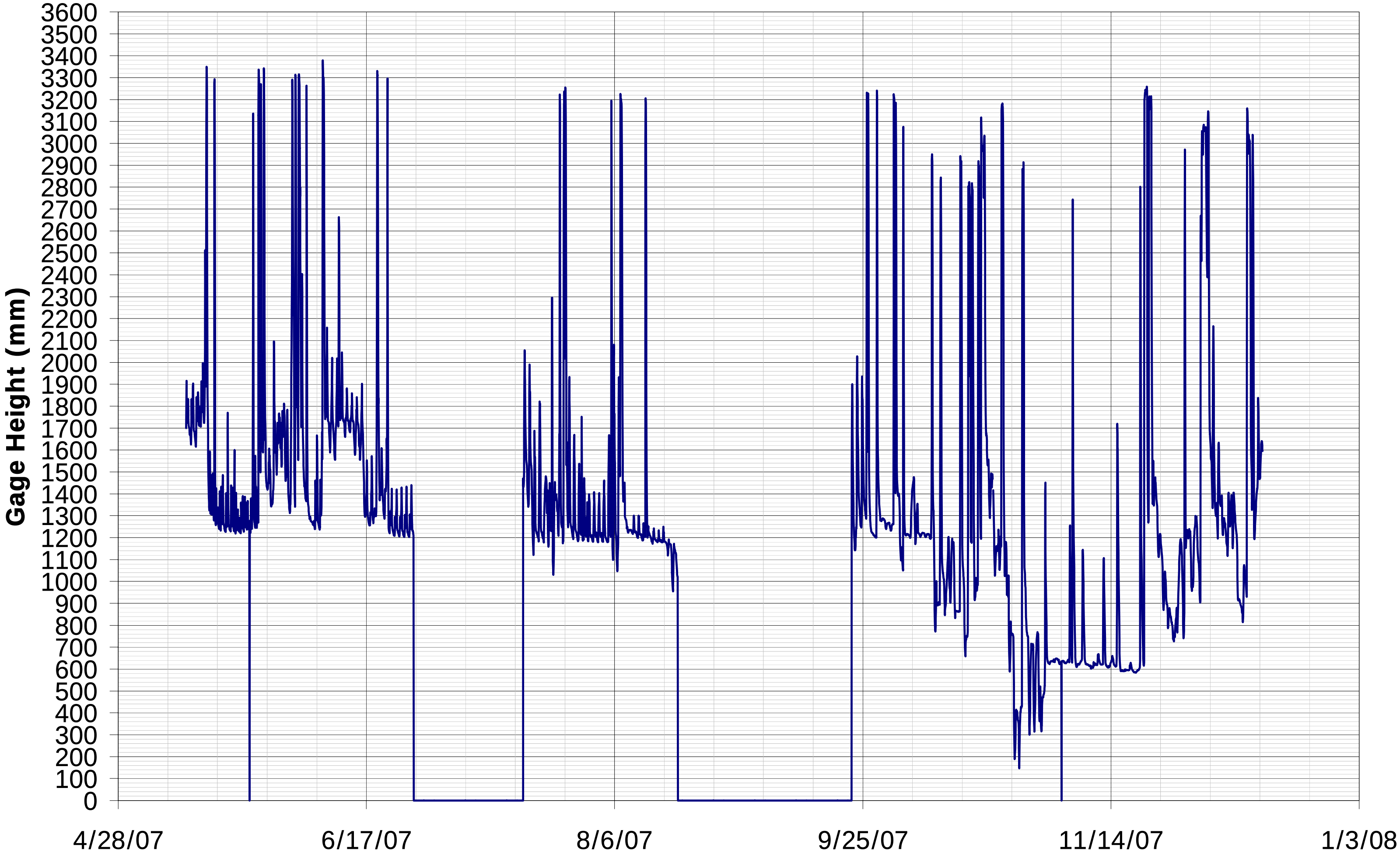
Dunland-36397 - 2007 Hydrograph

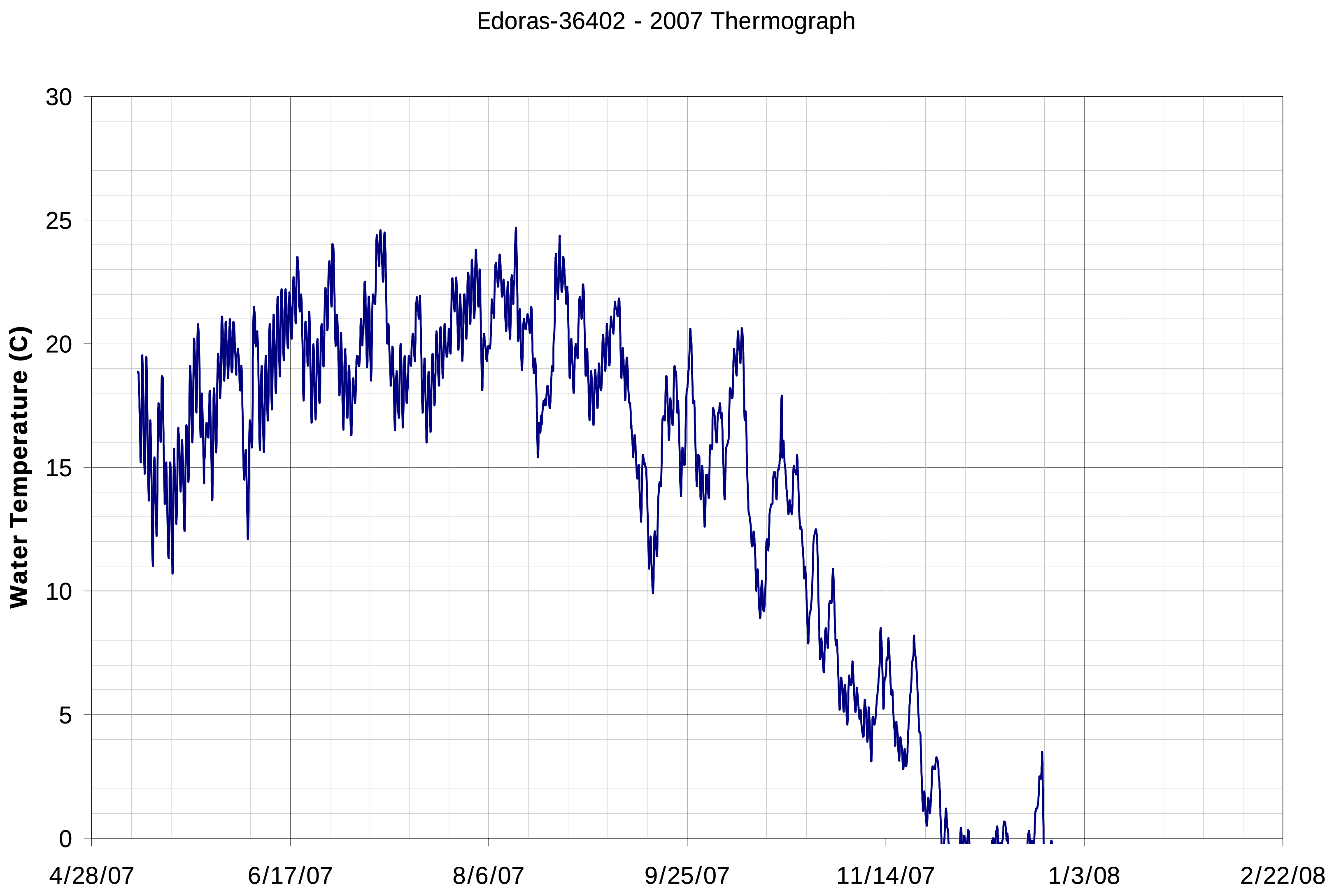


Dunland-36397 - 2007 Thermograph

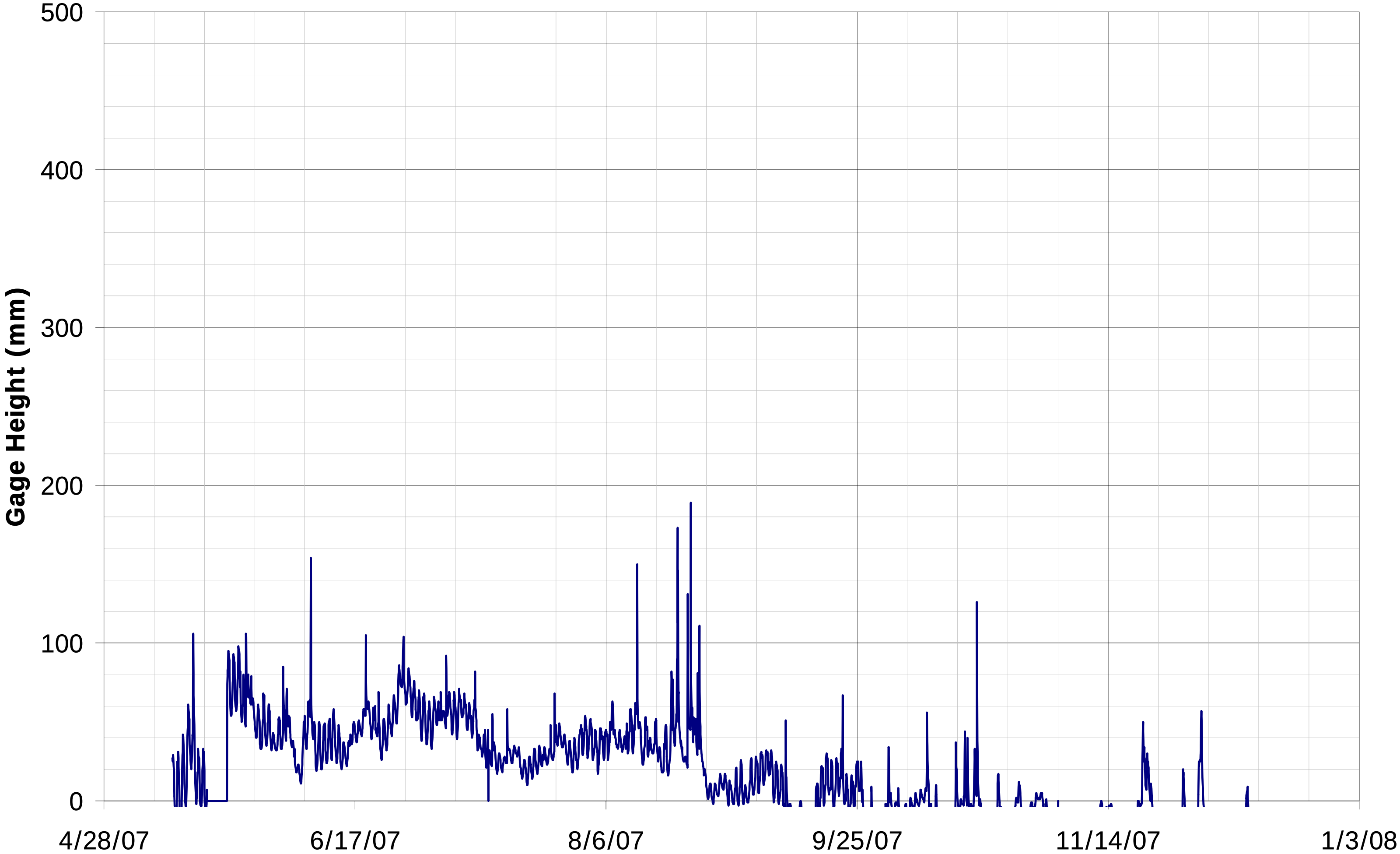


Edoras-36402 - 2007 Hydrograph

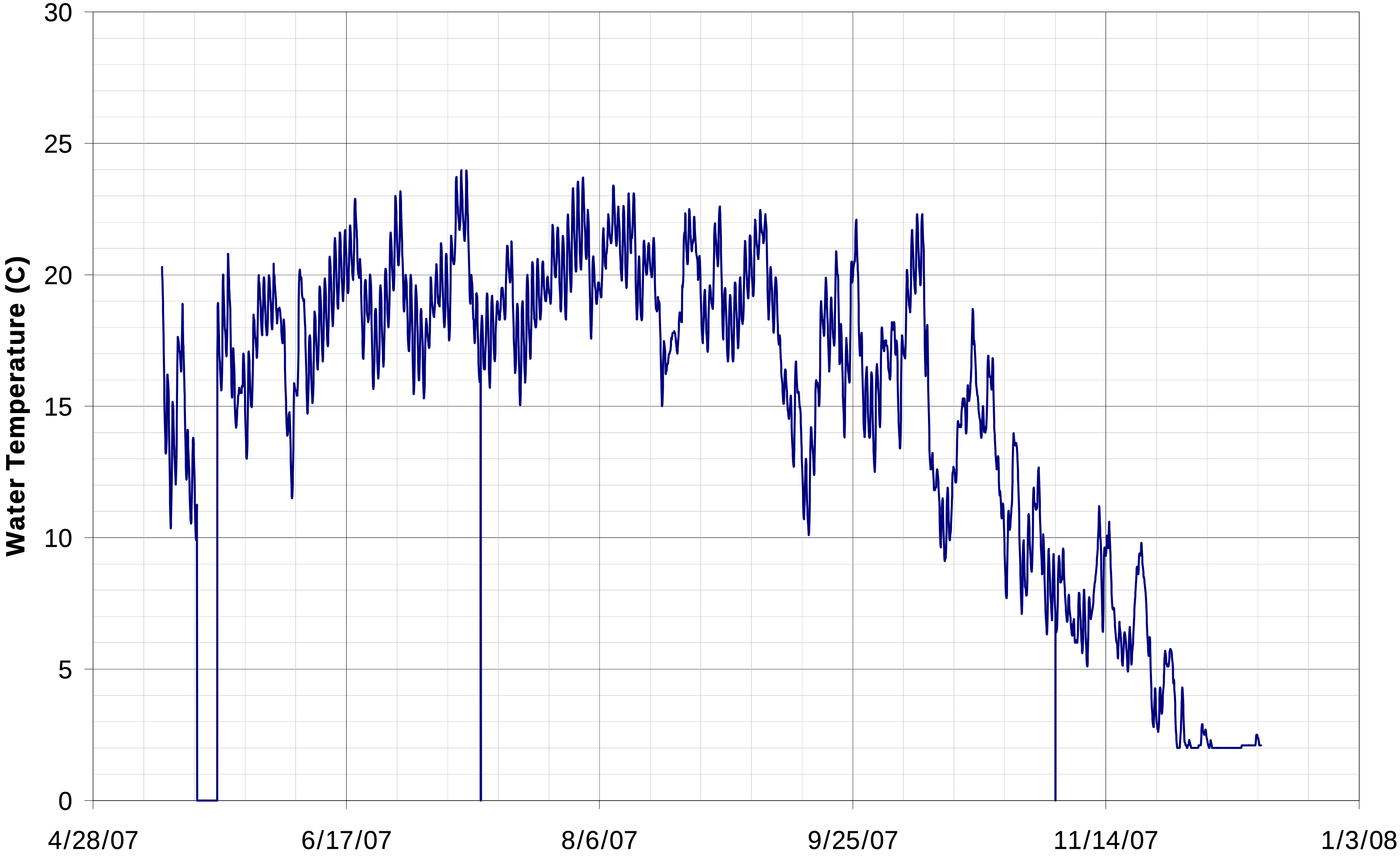



Edoras-36402 - 2007 Thermograph
Water Temperature (C)
30
25
20
15
10
5
0
4/28/07
6/17/07
8/6/07
9/25/07
11/14/07
1/3/08
2/22/08

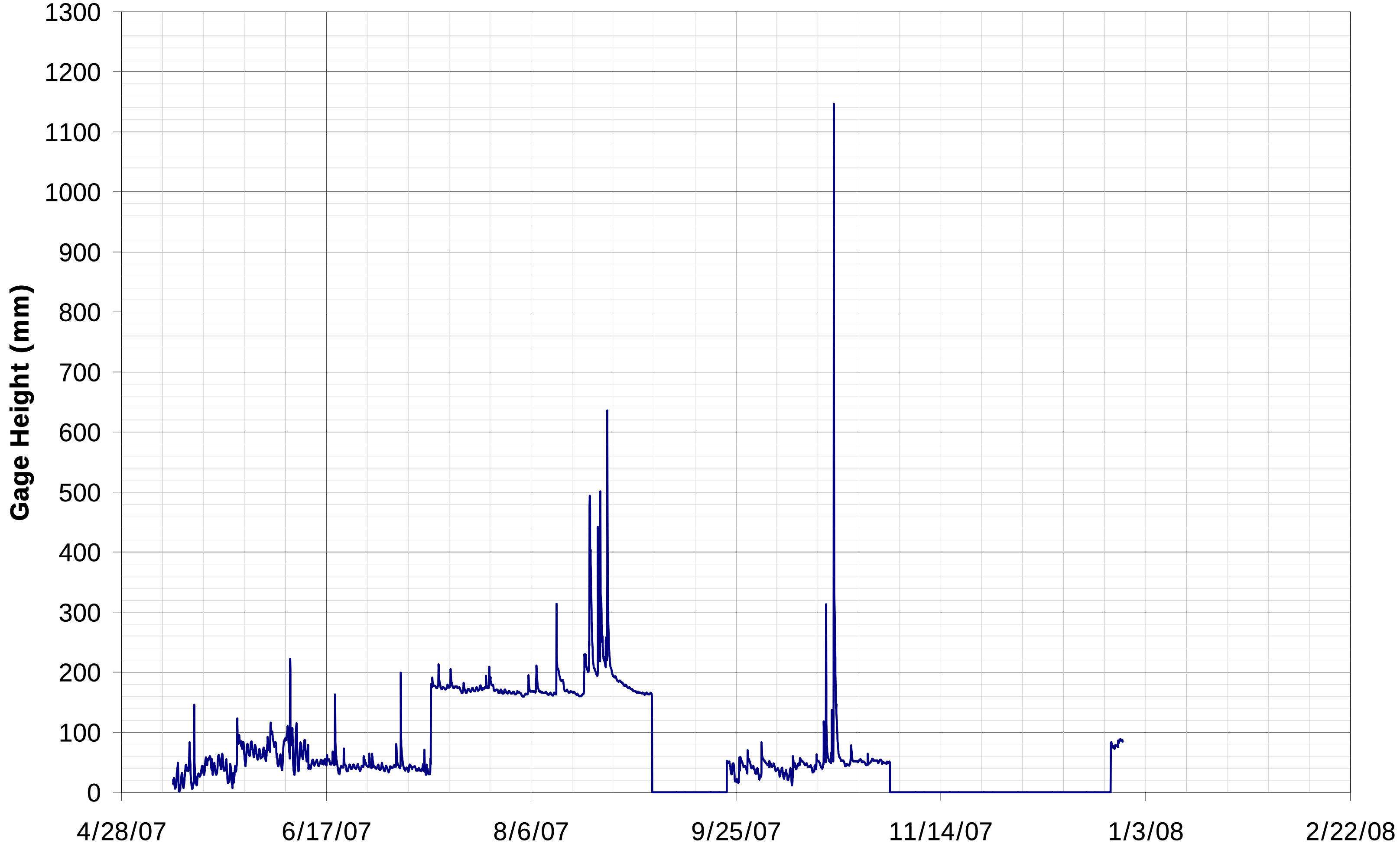
Lorian-36401 - 2007 Hydrograph



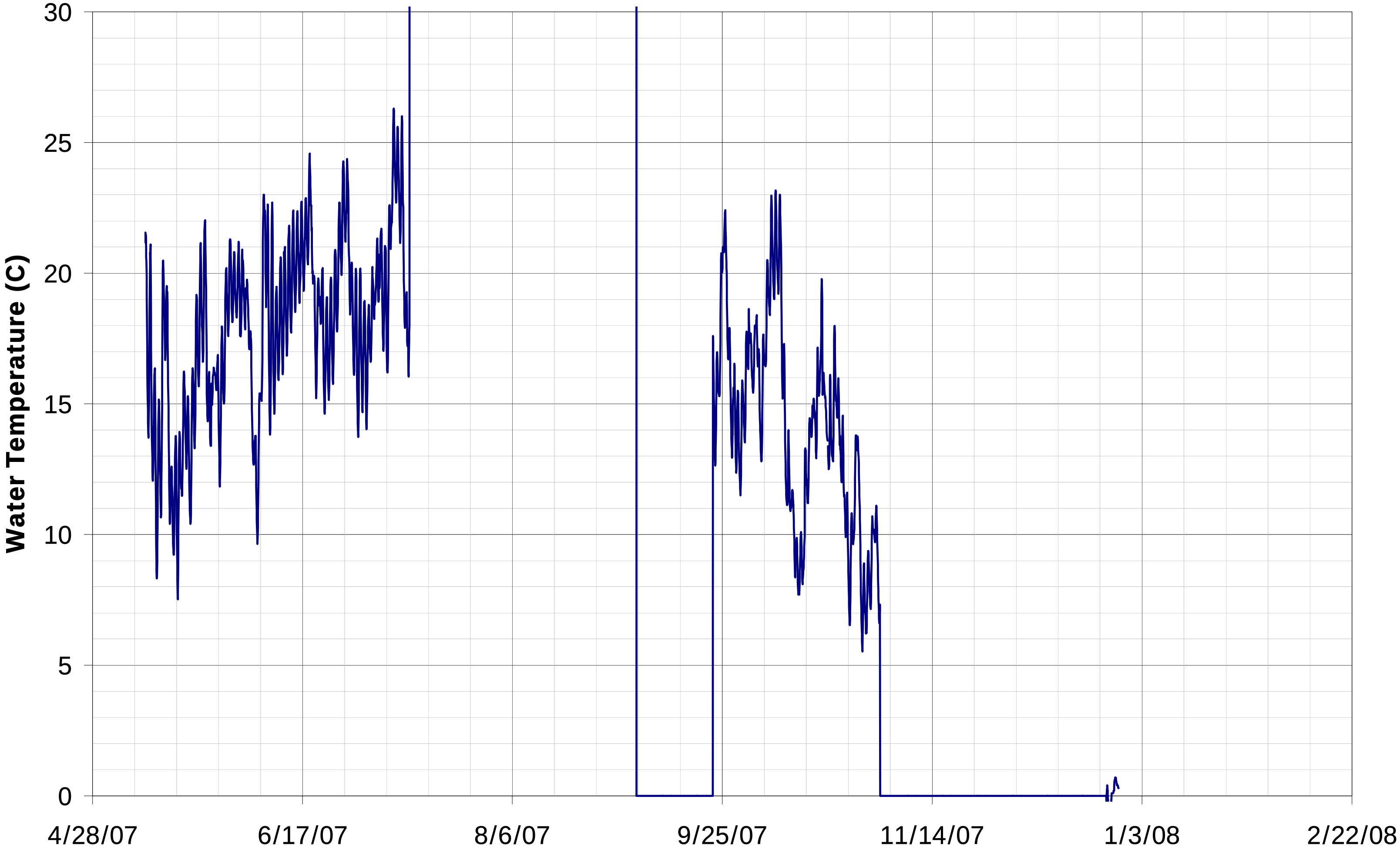
Lorian-36401 - 2007 Thermograph



Lothlorian-36399 - 2007 Hydrograph



Lothlorian-36399 - 2007 Thermograph



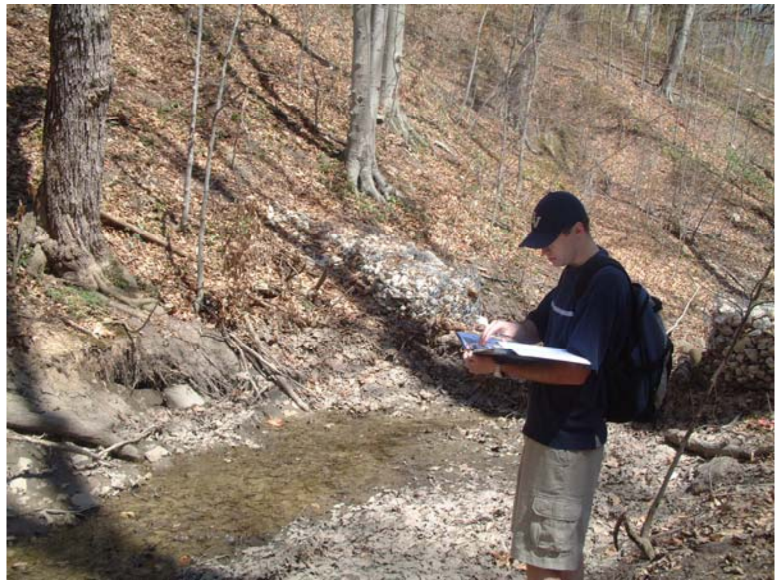
Appendix B. Water Quality Data

Sample#	Date/time	Description	NH3_N (ppm)	NH3_STD	NO3(ppm)	NO3_STD	NO2 (ppm)	NO2_STD	PO4(ppm)	PO4_STD	SO4 (ppm)	SO4_STD	Iron	Iron_STD	TEMP C	DO (mg/l)	O (% Sat)	Turb. (NTU)	Cond. (µs)	Spec Cond. (µs)	Sal (ppt)	pH	Comments
061407_1	6/14/07	Dunland Bridge	0.36	0.008	0.06	0.031	0.005	0.0071	0.07	0.005	3	0.5	--	--	20.4	4.02	56.4	14.35	1422.0	1570.0	0.8	--	
061407_2	6/14/07	Pond near #11	0.20	0.010	0.27	0.050	0.013	0.0060	0.00	0.005	19	0.5	--	--	27.0	8.69	109.0	28.40	259.5	250.0	0.1	--	
061407_3	6/14/07	Pond near #11 outlet	--	--	--	--	--	--	--	--	--	--	--	--	24.8	1.16	14.0	--	395.7	397.9	0.2	--	
061407_4	6/14/07	Lothorien	0.24	0.010	0.67	0.040	0.045	0.0074	0.08	0.006	60	4.1	--	--	18.5	6.46	69.2	9.61	1097.0	1251.0	0.6	--	
061407_5	6/14/07	Bridge near #5	0.08	0.010	0.63	0.037	0.005	0.0038	0.04	0.005	54	1.5	--	--	21.8	12.20	139.7	2.37	1335.0	1420.0	0.7	--	
061407_6	6/14/07	Hole#8 Sign N side of path	--	--	--	--	--	--	--	--	--	--	--	--	18.0	0.98	10.4	--	546.0	630.0	0.3	--	
061407_7	6/14/07	Well#2	0.51	0.015	0.10	0.012	0.004	0.0048	0.07	0.013	149	1.9	--	--	15.3	1.46	14.7	0.00	700.0	858.0	0.4	--	
061407_8	6/14/07	East of W#2	0.08	0.008	0.03	0.010	0.000	0.0000	0.02	0.010	72	2.8	--	--	26.1	7.07	87.5	35.30	732.0	716.0	0.3	--	
061407_9	6/14/07	Eastern Pond	2.85	0.017	0.04	0.013	0.000	0.0000	0.01	0.010	89	3.0	--	--	27.9	5.67	72.3	37.60	498.0	472.0	0.2	--	
061407_10	6/14/07	Sand Creek	0.16	0.008	1.83	0.024	0.028	0.0022	0.21	0.016	45	1.7	--	--	18.2	5.63	59.8	5.09	627.0	720.0	0.4	--	
061407_11	6/14/07	Grand River	0.19	0.010	2.55	0.061	0.013	0.0091	0.02	0.014	47	0.6	--	--	25.5	7.62	93.2	13.80	625.0	620.0	0.3	--	
060707_1	6/7/07	Lot D Big Pipe	0.14	0.030	2.28	0.024	0.013	0.0068	0.26	0.010	46	0.6	--	--	--	--	--	--	--	--	--	--	
052407_1	5/24/07	Bree	0.04	0.024	2.01	0.033	0.032	0.0057	0.42	0.008	75	1.0	--	--	--	--	--	--	--	--	--	--	
052407_2	5/24/07	Dead Marsh	1.02	0.029	0.41	0.041	0.016	0.0049	0.34	0.005	28	0.5	--	--	--	--	--	--	--	--	--	--	
052407_3	5/24/07	Weathertop	0.40	0.013	0.15	0.085	0.016	0.0086	0.09	0.017	4	0.8	--	--	--	--	--	--	--	--	--	--	
052407_4	5/24/07	Shire	0.14	0.010	0.33	0.052	0.017	0.0050	0.13	0.010	29	0.6	--	--	--	--	--	--	--	--	--	--	
052407_5	5/24/07	Moria	0.19	0.008	0.39	0.022	0.032	0.0039	0.09	0.026	51	1.0	--	--	--	--	--	--	--	--	--	--	
052407_6	5/24/07	Isengard	0.21	0.006	0.55	0.037	0.023	0.0038	0.13	0.010	35	0.5	--	--	--	--	--	--	--	--	--	--	
052407_7	5/24/07	Fangorn	0.14	0.008	0.79	0.034	0.018	0.0026	0.56	0.015	71	0.5	--	--	--	--	--	--	--	--	--	--	
052407_8	5/24/07	Lorien	0.17	0.013	0.24	0.031	0.017	0.0026	0.07	0.010	162	0.0	--	--	--	--	--	--	--	--	--	--	
052407_9	5/24/07	Mordor	0.19	0.013	2.94	0.085	0.029	0.0049	0.25	0.005	70	1.7	--	--	--	--	--	--	--	--	--	--	
051407_1	5/14/07	Mordor	--	--	3.00	0.067	--	--	0.22	0.013	51	0.6	--	--	11.40	10.14	92.80	--	3.04	--	--	8.30	
051407_2	5/14/07	#422 ~200m from mordor	--	--	1.94	0.060	--	--	0.15	0.010	38	22.7	--	--	12.00	11.56	107.60	--	2.78	--	--	8.30	
051407_3	5/14/07	#423 ~200m from #422	--	--	0.98	0.090	--	--	0.05	0.010	47	0.5	--	--	13.40	12.84	123.10	--	2.27	--	--	8.40	
051407_4	5/14/07	Lorien	--	--	0.16	0.064	--	--	0.39	0.025	59	0.8	--	--	--	--	--	--	--	--	--	--	
051407_5	5/14/07	Fangorn	--	--	0.90	0.087	--	--	0.04	0.014	41	0.6	--	--	13.70	10.59	103.70	--	1.99	--	--	8.20	
051407_6	5/14/07	Isengard	--	--	0.44	0.021	--	--	0.06	0.025	23	0.5	--	--	12.70	10.90	103.00	--	1.56	--	--	8.10	
051407_7	5/14/07	Moria	--	--	0.42	0.061	--	--	0.06	0.018	47	0.0	--	--	14.70	10.07	99.40	--	1.08	--	--	8.40	
051407_8	5/14/07	#427 downstream from shire	--	--	0.25	0.073	--	--	0.08	0.015	17	0.6	--	--	14.90	10.11	100.30	--	0.87	--	--	8.40	
051407_9	5/14/07	Shire	--	--	0.41	0.067	--	--	0.07	0.014	18	0.6	--	--	15.00	9.51	94.60	--	0.84	--	--	8.40	
051407_10	5/14/07	#429 upstream from shire	--	--	0.29	0.095	--	--	0.08	0.016	13	7.7	--	--	14.50	9.85	96.20	--	0.86	--	--	8.40	
051407_11	5/14/07	#430 upstream from #429	--	--	0.47	0.026	--	--	0.06	0.026	27	0.0	--	--	14.20	10.26	104.00	--	0.90	--	--	8.40	
051407_12	5/17/07	Golf Course	--	--	0.42	0.017	--	--	0.13	0.016	39	0.6	--	--	--	--	--	--	--	--	--	--	
051407_13	5/17/07	Ottawa Creek	--	--	3.33	0.041	--	--	0.17	0.027	74	1.2	--	--	--	--	--	--	--	--	--	--	
050807_1	5/8/07	Bree	--	--	2.36	0.024	--	--	0.25	0.005	56	2.4	0.16	0.060	--	--	--	--	--	--	--	--	
050207_1	5/2/07	Fangorn	--	--	0.48	0.073	--	--	0.05	0.006	42	1.3	0.62	0.118	--	--	--	--	--	--	--	--	
050207_2	5/2/07	Sam	--	--	0.86	0.029	--	--	0.10	0.000	12	0.8	0.22	0.022	--	--	--	--	--	--	--	--	
050207_3	5/2/07	Frodo	--	--	2.21	0.083	--	--	0.13	0.016	36	0.6	0.14	0.030	--	--	--	--	--	--	--	--	
050207_4	5/2/07	Mordor	--	--	1.48	0.050	--	--	0.34	0.005	36	0.5	0.16	0.087	--	--	--	--	--	--	--	--	
070107_1	7/1/07	Mordor	0.20	0.017	2.84	0.078	0.026	0.0026	0.21	0.010	42	0.5	0.01	0.010	--	--	--	1.26	--	--	--	--	
070107_2	7/1/07	Lorien	0.22	0.017	0.34	0.019	0.018	0.0079	0.04	0.005	77	0.8	0.13	0.021	--	--	--	15.31	--	--	--	--	
070107_3	7/1/07	Fangorn	0.29	0.019	1.06	0.048	0.037	0.0053	0.02	0.010	63	0.5	0.26	0.033	--	--	--	10.07	--	--	--	--	
070107_4	7/1/07	Isengard	0.22	0.010	1.07	0.017	0.013	0.0014	0.03	0.008	40	0.5	0.08	0.040	--	--	--	3.01	--	--	--	--	
070107_5	7/1/07	Moria	0.67	0.013	0.49	0.054	0.024	0.0048	0.03	0.010	28	0.5	0.10	0.053	--	--	--	31.90	--	--	--	--	
070107_6	7/1/07	Shire	0.57	0.021	0.61	0.030	0.013	0.0045	0.05	0.008	33	0.5	0.15	0.057	--	--	--	5.55	--	--	--	--	
070107_7	7/1/07	Dead Marshes	0.91	0.014	0.05	0.024	0.000	0.0000	0.04	0.010	19	0.0	0.29	0.015	--	--	--	162.00	--	--	--	--	
070107_8	7/1/07	Sauromon	0.34	0.006	1.97	0.045	0.018	0.0016	0.12	0.010	81	1.0	0.16	0.057	--	--	--	2.74	--	--	--	--	
070107_9	7/1/07	Bree	0.21	0.013	1.79	0.088	0.024	0.0018	0.99	0.017	43	0.5	0.08	0.061	--	--	--	32.10	--	--	--	--	
070107_10	7/1/07	Edoras	0.25	0.013	1.51	0.057	0.022	0.0074	0.19	0.013	30	0.0	0.09	0.086	--	--	--	17.27	--	--	--	--	
071207_1	7/12/07	Dunland Bridge	1.12	0.005	0.10	0.038	0.010	0.0060	0.04	0.014	80	0.0	0.07	0.045	20.0	6.62	73.0	5.34	764.0	844.0	0.4	--	
071207_2	7/12/07	Sand Lens Pond	0.16	0.006	0.10	0.053	0.008	0.0030	0.17	0.010	20	0.0	0.25	0.087	24.4	4.71	56.3	26.90	--	--	--	--	multiprobe did not read correct values for Co--. a-- sal. b/c it was not fully submerged in the water
071207_3	7/12/07	Pond near #11	0.91	0.017	0.24	0.067	0.011	0.0075	0.03	0.008	10	0.5	0.15	0.135	24.9	9.96	120.4	77.50	--	--	--	--	multiprobe did not read correct values for Co--. a-- sal. b/c it was not fully submerged in the water
071207_4	7/12/07	Bridge near #5	0.15	0.005	0.72	0.049	0.017	0.0067	0.17	0.010	26	0.0	0.13	0.015	22.6	6.20	71.8	20.20	--	--	--	--	multiprobe did not read correct values for Co--. a-- sal. b/c it was not fully submerged in the water
071207_5	7/12/07	WQ7	0.32	0.005	0.66	0.043	0.046	0.0073	2.00	0.008	122	0.0	0.13	0.013	19.3	2.19	23.7	10.48	--	--	--	--	multiprobe did not read correct values for Co--. a-- sal. b/c it was not fully submerged in the water
071207_6	7/12/07	W#2	0.53	0.000	0.06	0.028	0.002	0.0022	0.03	0.000	95	0.0	0.12	0.040	13.6	1.61	15.5	0.14	296.3	378.8	0.2	--	
071207_7	7/12/07	East side W#2	1.78	0.039	0.03	0.017	0.004	0.0008	0.06	0.021	86	0.6	0.03	0.038	25.2	8.43	102.3	16.11	60.5	60.3	0.0	--	
071207_8	7/12/07	Eastern Pond	2.37	0.010	0.06	0.041	0.006	0.0046	0.04	0.013	91	0.5	0.10	0.037	24.8	7.60	91.6	61.30	--	--	--	--	multiprobe did not read correct values for Co--. a-- sal. b/c it was not fully submerged in the water
071207_9	7/12/07	Lothorien	1.27	0.022	0.51	0.036	0.022	0.0075	0.23	0.010	21	0.0	0.06	0.059									
071607_1	7/16/07	#430, shire upstream 2	0.16	0.010	0.29	0.056	0.025	0.0059	0.03	0.010	34	0.6	--	--	15.5	10.03	101.3	18.60	719.0	--	--	8.01	
071607_2	7/16/07	#429, shire upstream 1	0.13	0.008	0.26	0.083	0.022	0.0167	0.04	0.010	22	0.6	--	--	16.1	9.86	100.4	8.13	655.0	--	--	8.15	
071607_3	7/16/07	#428, Shire	0.16	0.025	0.41	0.055	0.027	0.0133	0.04	0.010	20	0.5	--	--	16.3	9.88	101.0	11.20	641.0	--	--	8.16	
071607_4	7/16/07	#427, shire downstream	0.07	0.015	0.34	0.024	0.016	0.0046	0.07	0.005	19	0.6	--	--	16.5	9.51	97.6	35.60	416.0	--	--	8.2	
071607_5	7/16/07	Isengard	0.16	0.022	1.17	0.022	0.021	0.0033	0.06	0.005	36	0.5	--	--	17.0	9.31	96.9	2.67	1182.0	--	--	7.95	
071607_6	7/16/07	#423, mordor downstream 2	0.11	0.010	1.51	0.050	0.008	0.0061	0.28	0.005	25	0.5	--	--	19.0	10.17	110.1	4.03	1182.0	--	--	8.1	
071607_7	7/16/07	#422, mordor downstream 1	0.24	0.006	2.07	0.017	0.024	0.0088	0.13	0.010	27	0.8	--	--	17.0	9.62	100.1	0.66	1113.0	--	--	8.05	
071607_8	7/16/07	#421, Mordor	0.12	0.010	2.97	0.047	0.030	0.0169	0.14	0.014	30	0.6	--	--	16.0	10.03	102.1	1.05	1224.0	--	--	8.14	
081607_1	8/16/07	Fangorn	0.12	0.008	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
081607_2	8/16/07	Mordor	0.24	0.015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
082107_1	8/21/07	Dunland Bridge, WQ1	--	--	--	--	--	--	--	--	--	--	--	--	18.3	5.61	59.7	2.01	849.0	975.0	0.5	--	
082107_2	8/21/07	Sand Lens Pond, WQ3	--	--	--	--	--	--	--	--	--	--	--	--	19.2	3.49	37.8	80.70	428.6	481.6	0.2	--	
082107_3	8/21/07	Pond #11 outlet, WQ4	--	--	--	--	--	--	--	--	--	--	--	--	19.5	2.19	23.9	6.63	832.0	930.0	0.5	--	
082107_4	8/21/07	Pond #11, WQ2	--	--	--	--	--	--	--	--	--	--	--	--	19.7	1.82	19.9	73.80	300.1	333.9	0.2	--	
082107_5	8/21/07	Lothlorien, WQ5	--	--	--	--	--	--	--	--	--	--	--	--	18.8	7.10	76.4	23.70	561.0	636.0	0.3	--	
082107_6	8/21/07	Bridge #5, WQ6	--	--	--	--	--	--	--	--	--	--	--	--	19.2	7.47	81.0	18.31	622.0	700.0	0.3	--	
082107_7	8/21/07	WQ 7	--	--	--	--	--	--	--	--	--	--	--	--	18.6	5.40	57.8	29.90	531.0	606.0	0.3	--	Took water sample from other side of pipe
082107_8	8/21/07	W#2, WQ8	--	--	--	--	--	--	--	--	--	--	--	--	19.0	3.98	43.0	32.90	557.0	630.0	0.3	--	Pump was off, took sample from area where pumped water would be
082107_9	8/21/07	East of W#2, WQ9	--	--	--	--	--	--	--	--	--	--	--	--	19.0	3.75	40.5	22.40	563.0	636.0	0.3	--	
082107_10	8/21/07	Eastern Pond, WQ10	--	--	--	--	--	--	--	--	--	--	--	--	19.0	3.76	40.6	18.31	738.0	833.0	0.4	--	

Location	Before (date)	After (date)	Comments
Little Mac Ravine at Energy Dissipation structure	 4/29/03	 7/31/08	The energy dissipation structure seems to be functioning to dissipate energy. The rip rap channel protection install below the structure us slowly being eroded away and is also mechanically breaking down due to the friability of the limestone chosen for the fill. The mechnical breakdown of the rock has been beneficial in the short term because it has created a wider range of grain size and allowed the materials to key into the channel and prevent future erosion.
Downstream of the Little Mac Ravine Energy Dissipation structure	 4/29/03	 7/31/08	As demonstrated by the photos, the rip rap is not preventing continued erosion of side slopes and slumping of materials down the slope. The tree which was leaning over in 2003 has fallen and is currently spanning the ravine. At this location and others it is clear that during storm events the rip rap is overtopped by water levels.

Location	Before (date)	After (date)	Comments
Little Mac Ravine at Energy Dissipation structure	 4/29/03	 7/31/08	This set of photos highlights the channel development due to the settling and mechanical breakdown of the rip/rap materials added to protect the channel from erosion. Algae is also prominent suggesting excess nutrients in the storm water.
Downstream of the Little Mac Ravine Energy Dissipation structure	 9/3/03	 7/31/08	The downstream terminus of the rip/rap structure continues to erode away. Rocks are slowly being eroded and removed from the geotextile liner. Smaller rocks and cobbles are being eroded downstream below the channel protection creating a small pool.

Location	Before (date)	After (date)	Comments
Tributary ravine downstream of the Little Mac Ravine Energy Dissipation structure.	 4/29/03	 7/31/08	Side ravine exhibiting continued down cutting in response to base level lowering in the main ravine. This adjustment will likely continue unless material is added which allows the base of the ravine to increase rather than decrease in elevation.
The first Check dame downstream of the Little Mac Ravine Energy Dissipation structure	 4/29/03	 7/31/08	Check dams are capturing some sediment and probably slowing the water somewhat. As these structures fill with sediment the drop across the structures will increase and they will be undermined from below. Additionally these structures often are the location of log and debris dams which result in water overtopping the sides of the check dam result in eventual failure and increased bank erosion.

Location	Before (date)	After (date)	Comments
The first Check dame downstream of the Little Mac Ravine Energy Dissipation structure. Looking downstream	 4/29/03	 7/31/08	The accumulation of sediment appears to be contributing to lateral migration of the channel and eventual diversion of water around the check dam structures. Note the deep channel on the left side of the photo and the erosion of the bed along the base of the slope.
The first Check dame downstream of the Little Mac Ravine Energy Dissipation structure. Looking upstream	 4/29/03	 7/31/08	This view of the downstream portion of the check dam shows the erosion at the base. This erosion is removing large rocks placed at this location to prevent erosion and will eventually result in undermining and failure of the structure.

Location	Before (date)	After (date)	Comments
The first Check dame downstream of the Little Mac Ravine Energy Dissipation structure. Looking upstream	 4/29/03	 7/31/08	This view of the downstream portion of the check dam shows the erosion at the base. This erosion is removing large rocks placed at this location to prevent erosion and will eventually result in undermining and failure of the structure.
Looking downstream from the second check dam	 4/29/03	 7/31/08	Note the dramatic increase in lateral erosion

Location	Before (date)	After (date)	Comments
Last check dam in Little Mac Ravine. Looking downstream	 4/29/03	 7/31/08	Abundant wood debris combined with sedimentation is causing flow to divert around the check dam creating a large waterfall over easily eroded floodplain alluvium on the left. This has resulted in a plunge pool several meters deep and continued lateral erosion.
Last check dam in Little Mac Ravine. Looking upstream	 4/29/03	 7/31/08	Abundant wood debris combined with sedimentation is causing flow to divert around the check dam creating a large waterfall over easily eroded floodplain alluvium on the left. This has resulted in a plunge pool several meters deep and continued lateral erosion.

Location	Before (date)	After (date)	Comments
Calder Main Drain below Calder Arts Building. Looking up from the ravine bottom.	 9/6/02	 7/31/08	The rip rap channel protection installed below the storm water outlet structure continues to be eroded away, especially near the bottom where the flow expands into the ravine floodplain. This has resulted in a 1-2 meter deep gully on the right side of these photos (see below). This process will likely continue to cause lateral erosion.
Calder Main Drain below Calder Arts Building. Looking down on the downstream side of the rip/rap.	 4/29/03	 7/11/08	The rip rap channel protection installed below the storm water outlet structure continues to be eroded away, especially near the bottom where the flow expands into the ravine floodplain. This has resulted in a 1-2 meter deep gully on the left side of these photos. This process will likely continue to cause lateral erosion and will eventually undermine all of the rip/rap protection.