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Effect of Increased Flow Rate on the Microbial Population in the Waterloo Biofilter®

Craig Jowett, Heather Millar, Kris Pataky
Waterloo Biofilter Systems Inc.
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Background

All organisms require a source of carbon and energy to continue to grow properly. The two sources of carbon for the biosynthesis of cell tissue are carbon dioxide and carbon found in organic matter. If an organism derives its cell carbon from CO_2, it is called autotrophic; if it uses organic carbon, it is called heterotrophic (Tchobanoglous & Schroeder, 1985, pg.126). The BOD removers in fixed film Biological Nutrient Removal systems, such as the Waterloo Biofilter®, are heterotrophic (Farmingdale, 1997, pg.8). The heterotrophic aerobic bacteria in the Biofilter utilize oxygen, organic material, ammonium-N and ortho-P to produce CO_2, H_2O and more bacterial cells (Farmingdale, 1997, pg.2).

Most bacteria reproduce by binary fission, which means during active bacterial growth the size of the microbial population is continuously doubling. The time required for the population size to double is called the doubling time. Based on the growth rates (under optimal conditions) for a sample of representative bacteria the median doubling time was found to be 60 minutes (Atlas, 1988, pg. 107).

Figure 1 shows the typical bacterial growth pattern showing an initial period of little or no growth called the *lag phase*, a period of rapid growth called the *exponential or log phase*, a period of stabilization called the stationary phase, and a period where the number of cells dying outnumber those being reproduced (when wastes accumulate and nutrients are exhausted) called the *death phase* (Burks & Minnis, 1994, pg. 44). This pattern represents a single bacterial colony or an entire population such as in a Waterloo Biofilter.

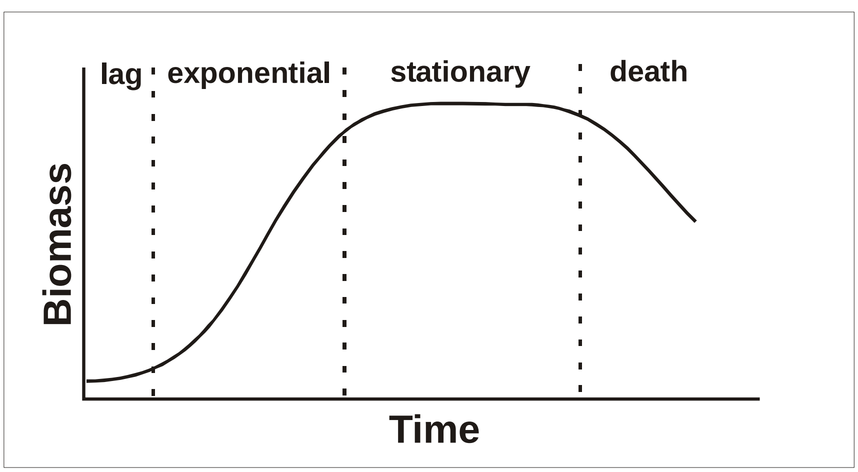

Figure 1. Typical Bacterial Growth Pattern

Effect of Increased Flow

When a flow rate of 50 m^3/day is applied to the Biofilter there is an initial start-up period where treatment is delayed (Figure 2 - **lag I**). This corresponds to the lag period in which the bacteria are adjusting to their new environment, preparing for reproduction by synthesizing the needed macromolecules for cell division (Burks & Minnis, 1994, pg.45). Once the bacteria have adjusted they will enter the exponential phase (**exponential I**) and begin to multiply rapidly. If the flow rate of 50 m^3/day is sustained the bacterial population will reach a stationary phase (**stationary I**). This steady state will be maintained as long as the Biofilter is continually fed. If the organic loading is stopped the bacterial population will enter the death phase because the nutrients will be exhausted. In this phase the bacteria will use cannibalism to obtain their food source thus the Biomass will decrease. When the flow rate is increased from 50 m^3/day to 400 m^3/day the loading rate of BOD increases as well. This increase in BOD provides the bacteria with the needed nutrients to rapidly enter a new exponential phase of growth (**exponential II**). The initial lag period or delay in treatment will not occur because the **stationary I** period represents the **lag II** period for the new 400 m^3/day flow. The population will then reach a higher stationary phase (**stationary II**).

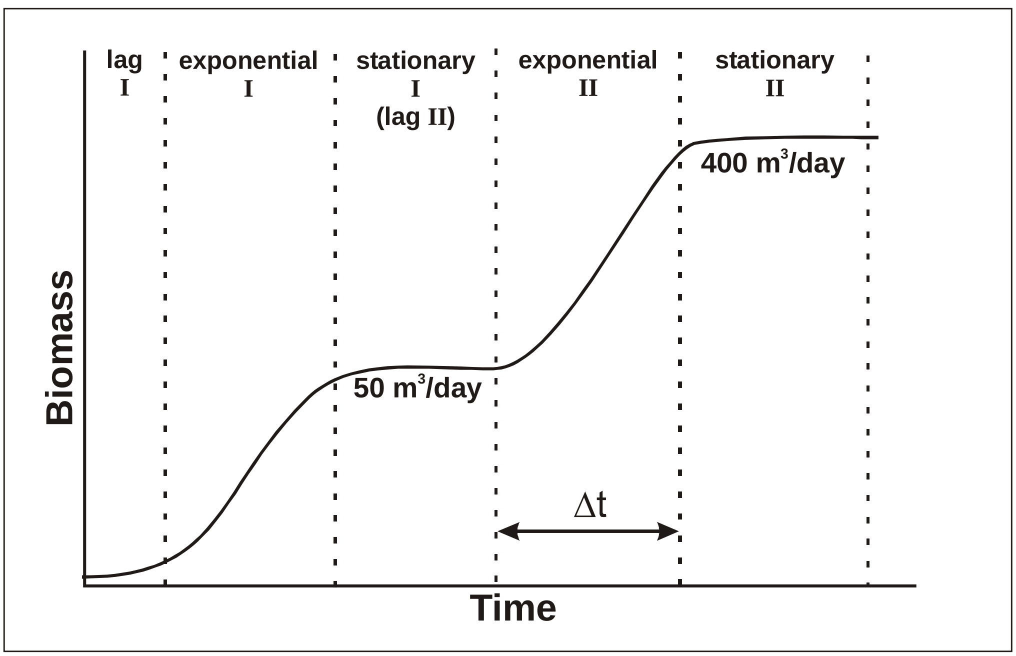

Figure 2. Bacterial growth curve showing the change in Biomass level with an increase in flow rate.

The time Δt for the population to reach **stationary II** is of interest when 'step-function' flow increases are met. Assuming that the population level is a direct function of the BOD loading rate, which is dependent on the flow rate, with an 8-fold increase in flow rate from 50 m^3/day to 400 m^3/day we can expect that the bacteria will duplicate in relation to the increase of food or substrate source. Therefore, using the median doubling time of 1 hour, the bacteria can theoretically adjust to the increased flow rate in about 3 hours (i.e., doubling from 50 to 100 to 200 to 400 in 3 growth phases of one hour each). This rapid growth is possible in an ideal environment, but it indicates that the catch-up can be attained in very quick time, possibly as little as one day.

This rapid adjustment to step-function type increased flow is demonstrated in the Rattlesnake data. Referring to the *Year 2 Graph – Rattlesnake Site: 2000 Theoretical Organic Mass Loading and Effluent Concentration*, for instance, a dramatic and sustained jump in the organic loading rate does not have an adverse effect on the BOD effluent concentration. This supports the theoretical calculation in the ideal environment above, and also shows that the Waterloo Biofilter can be designed to withstand periodic jumps in mass loading from 50 m^3/day to 400 m^3/day with little to no effect on the effluent quality.

References

TCHOBANOGLOUS, G., and E. D. SCHROEDER. 1985. *Water Quality*. Addison-Wesley Publishing Co., University of California at Davis

FARMINGDALE, S. 1997. *Fixed Film Operational Strategies.* Paper Presented at the Long Island Sound Nitrogen Removal Training Program www.dec.state.ny.us/website/dow/bwcp/module4.pdf

ATLAS, R. M. 1988. *Microbiology: Fundamentals and Applications.* Macmillan Publishing Co., New York, NY

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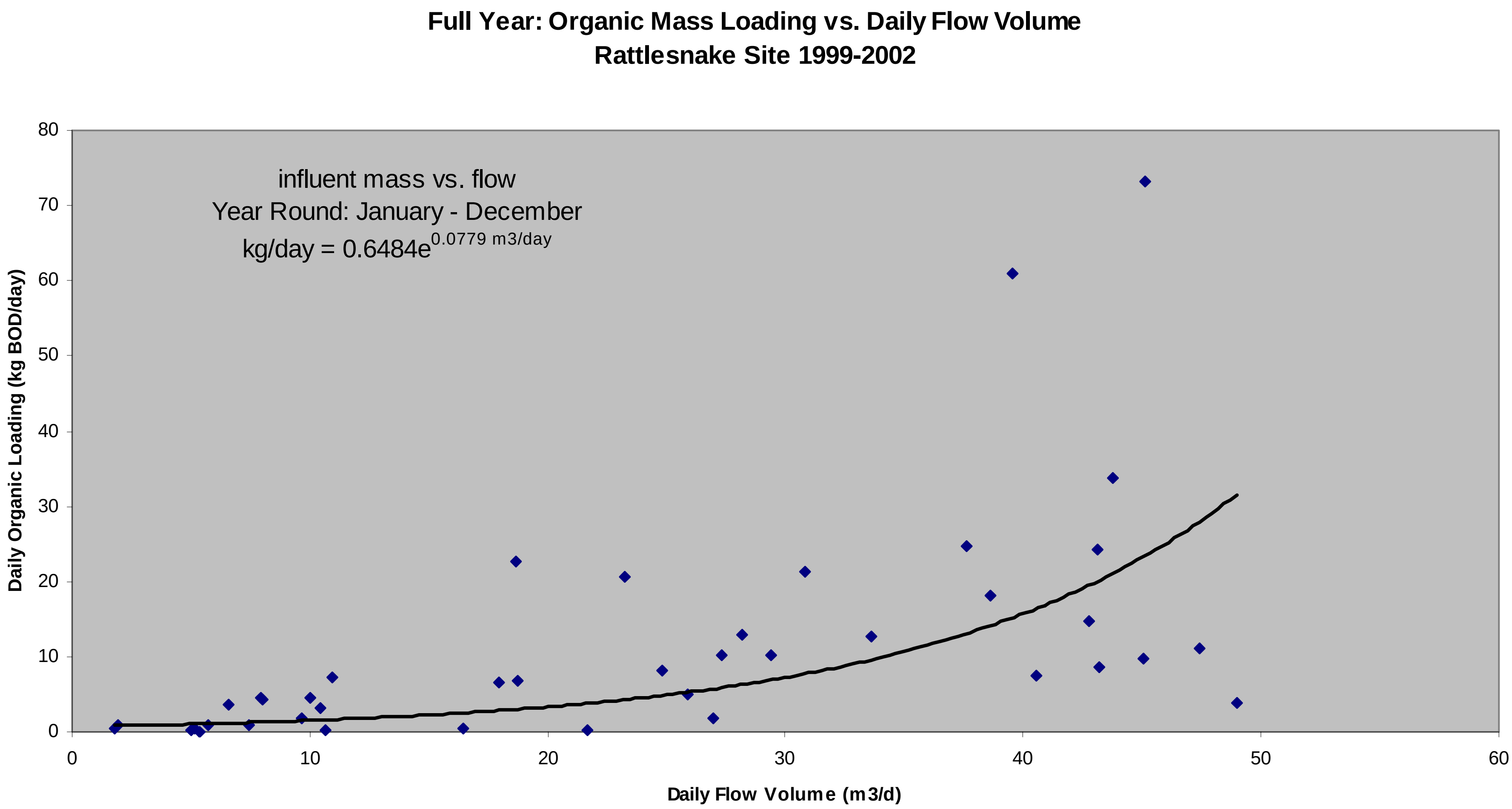
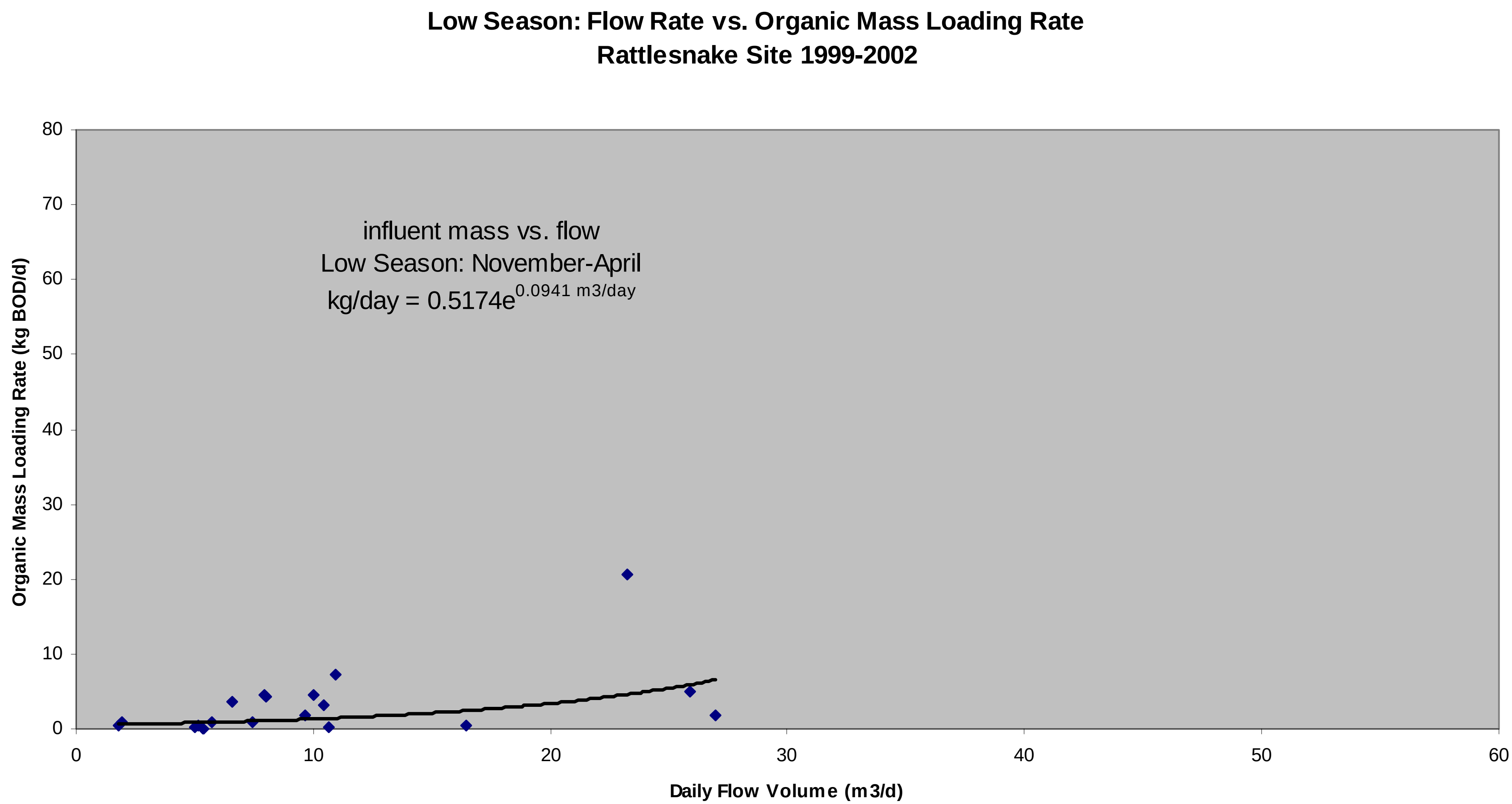
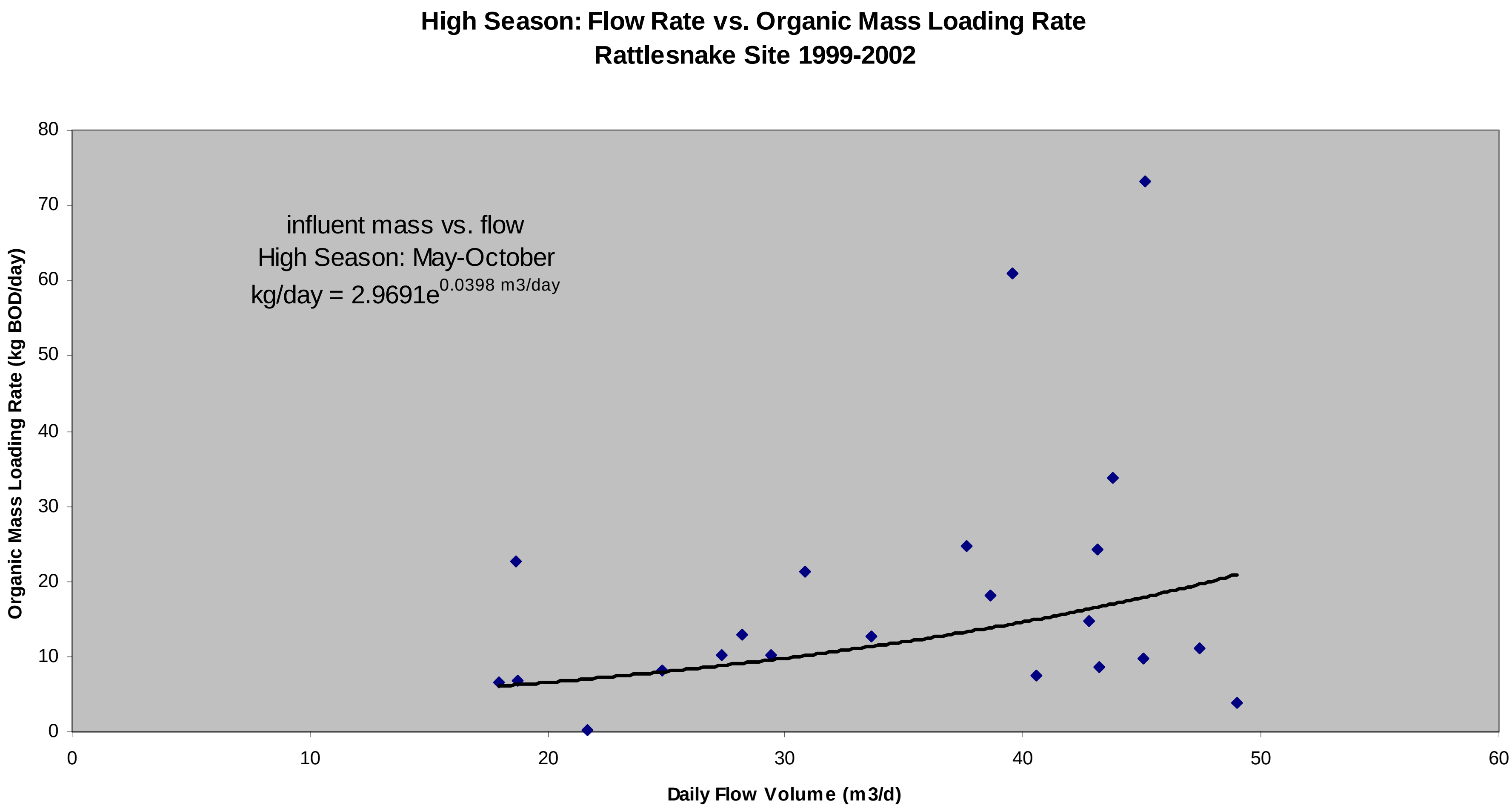
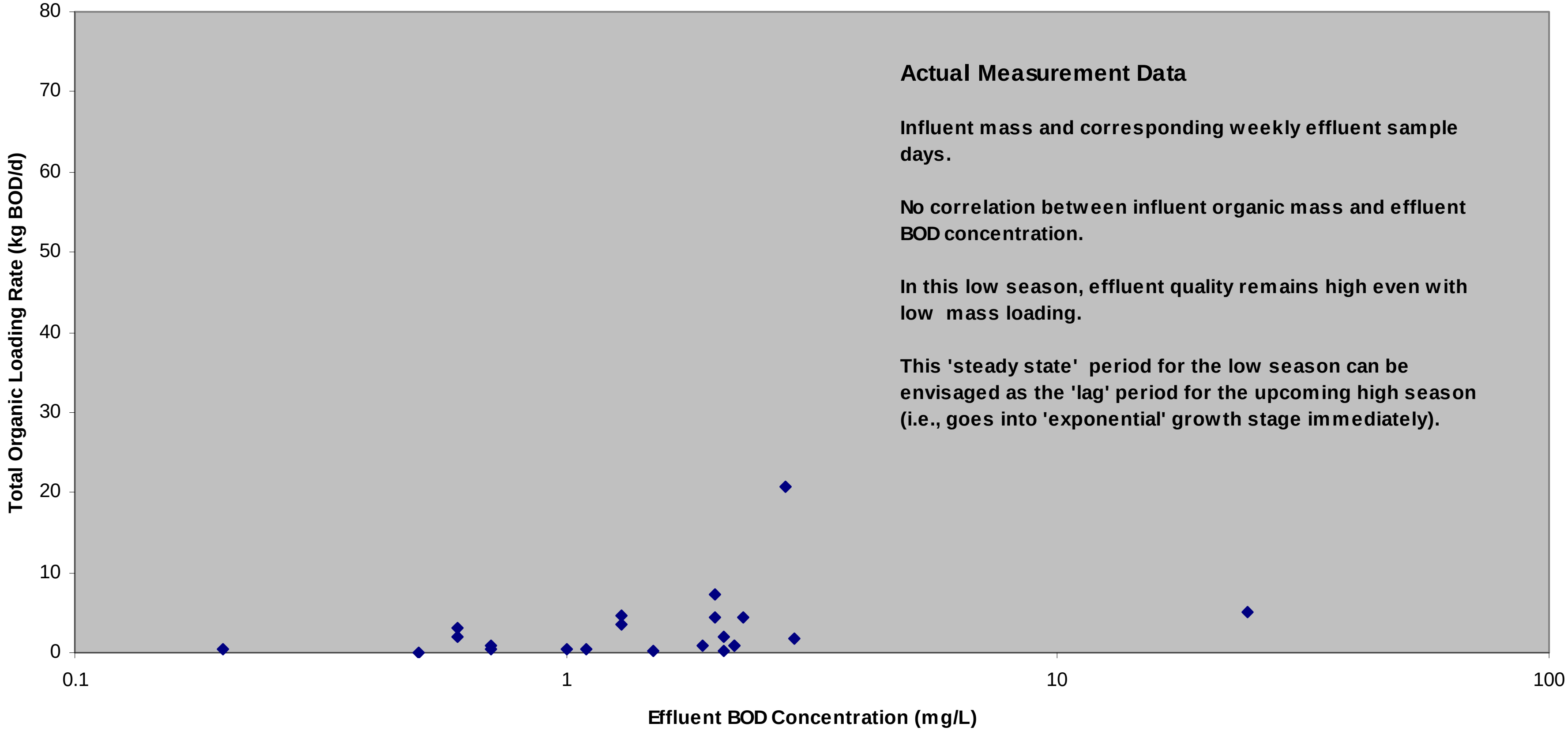

Full Year: Organic Mass Loading vs. Daily Flow Volume
Rattlesnake Site 1999-2002
influent mass vs. flow
Year Round: January - December
kg/day = 0.6484e^0.0779 m3/day
Daily Organic Loading (kg BOD/day)
Daily Flow Volume (m3/d)
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60


Low Season: Flow Rate vs. Organic Mass Loading Rate
Rattlesnake Site 1999-2002
influent mass vs. flow
Low Season: November-April
kg/day = 0.5174e^0.0941 m3/day
Organic Mass Loading Rate (kg BOD/d)
Daily Flow Volume (m3/d)
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60

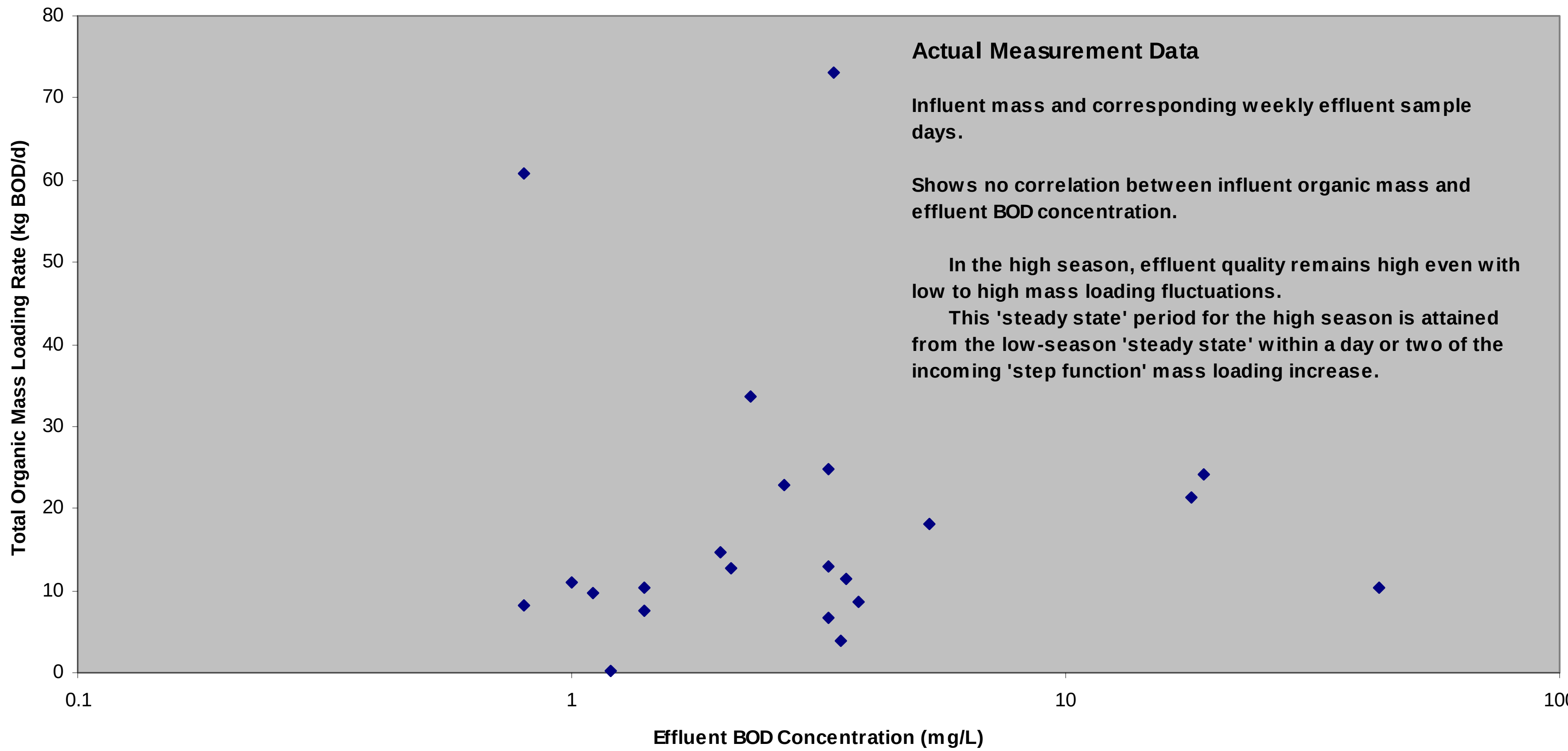


High Season: Flow Rate vs. Organic Mass Loading Rate
Rattlesnake Site 1999-2002
influent mass vs. flow
High Season: May-October
kg/day = 2.9691e^0.0398 m3/day
Organic Mass Loading Rate (kg BOD/day)
Daily Flow Volume (m3/d)
0
10
20
30
40
50
60
70
80

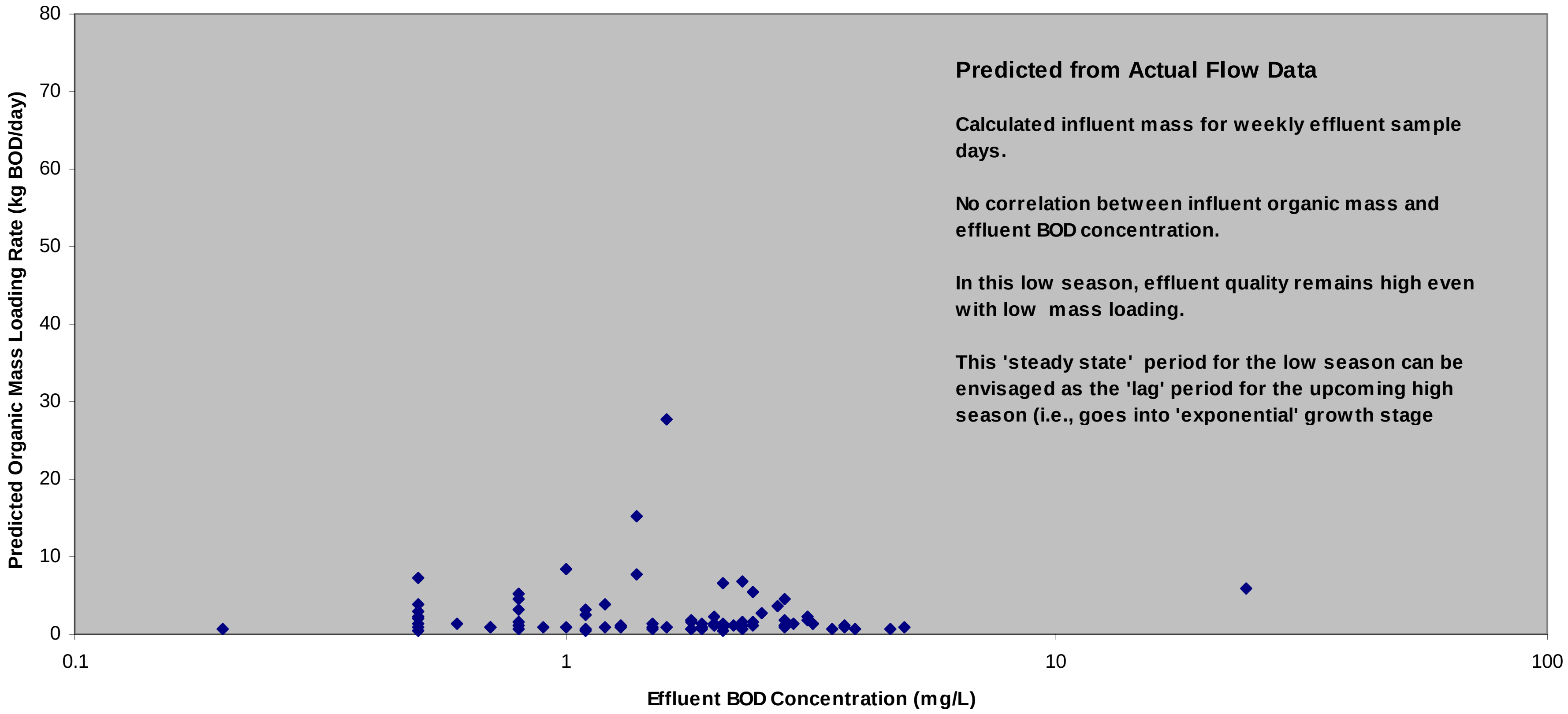
Low Season: November-April
Organic Loading Rate vs. Effluent BOD Concentration
Rattlesnake Site

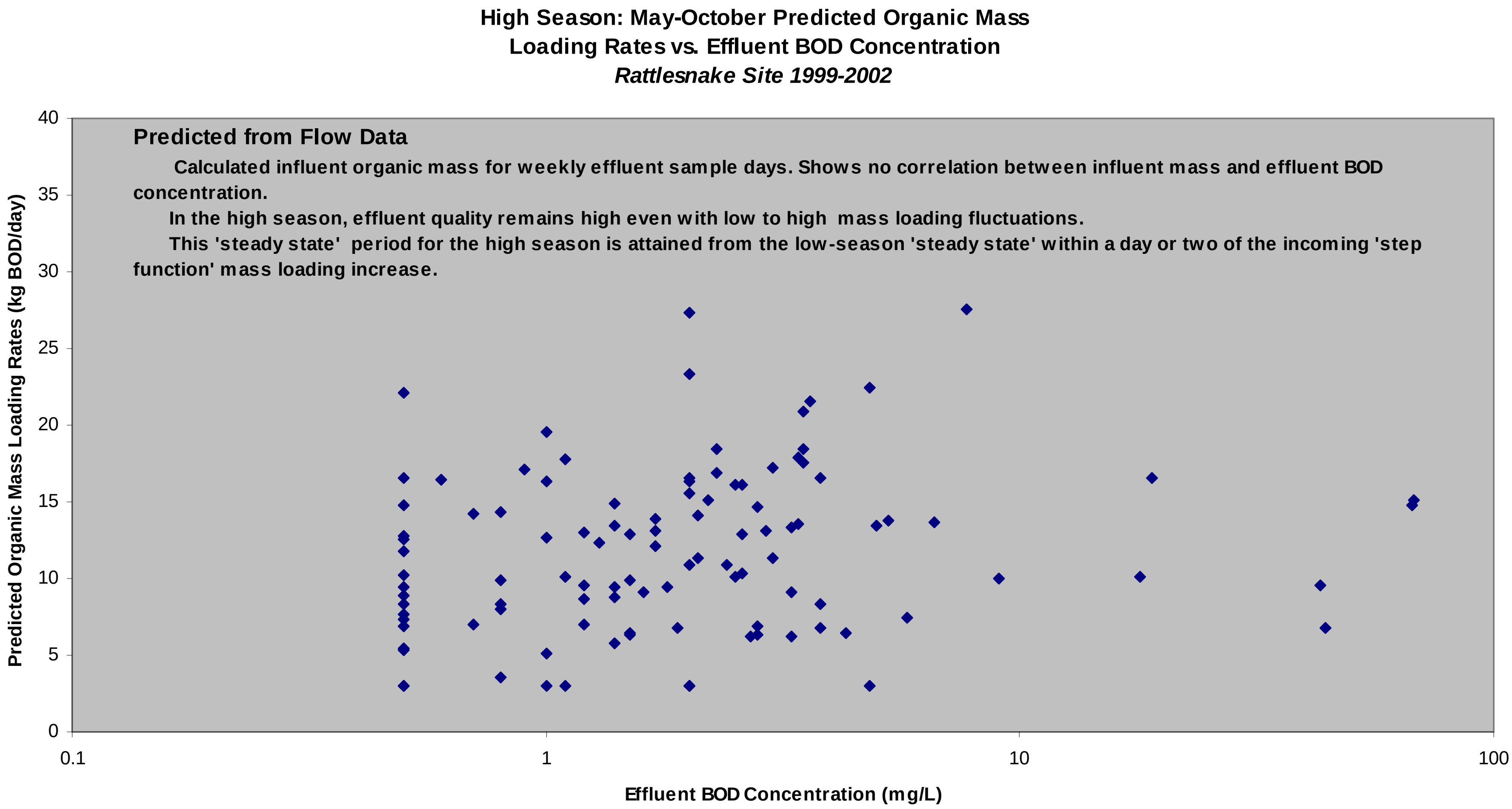


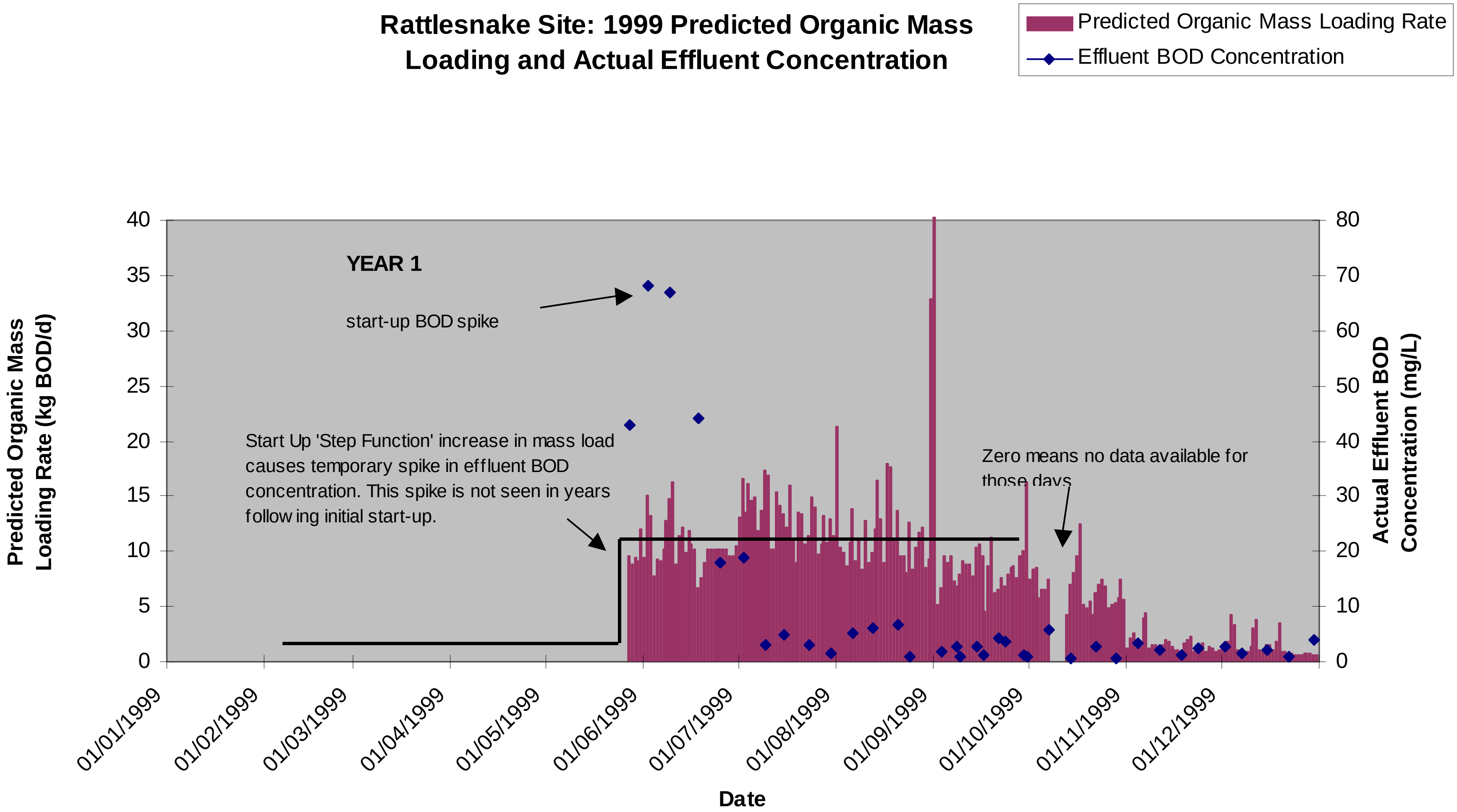
High Season: May-October
Organic Loading Rate vs. Effluent BOD Concentration
Rattlesnake Site



Low Season: November - April Predicted Organic Mass Loading Rates vs. Effluent BOD Concentration
Rattlesnake Site 1999-2002




High Season: May-October Predicted Organic Mass
Loading Rates vs. Effluent BOD Concentration
Rattlesnake Site 1999-2002
Predicted from Flow Data
Calculated influent organic mass for weekly effluent sample days. Shows no correlation between influent mass and effluent BOD concentration.
In the high season, effluent quality remains high even with low to high mass loading fluctuations.
This 'steady state' period for the high season is attained from the low-season 'steady state' within a day or two of the incoming 'step function' mass loading increase.
Predicted Organic Mass Loading Rates (kg BOD/day)
0
5
10
15
20
25
30
35
40
0.1
1
10
100
Effluent BOD Concentration (mg/L)



Rattlesnake Site: 1999 Predicted Organic Mass Loading and Actual Effluent Concentration
Predicted Organic Mass Loading Rate
Effluent BOD Concentration
YEAR 1
start-up BOD spike
Start Up 'Step Function' increase in mass load causes temporary spike in effluent BOD concentration. This spike is not seen in years following initial start-up.
Zero means no data available for those days
Predicted Organic Mass Loading Rate (kg BOD/d)
Actual Effluent BOD Concentration (mg/L)
Date
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
01/01/1999
01/02/1999
01/03/1999
01/04/1999
01/05/1999
01/06/1999
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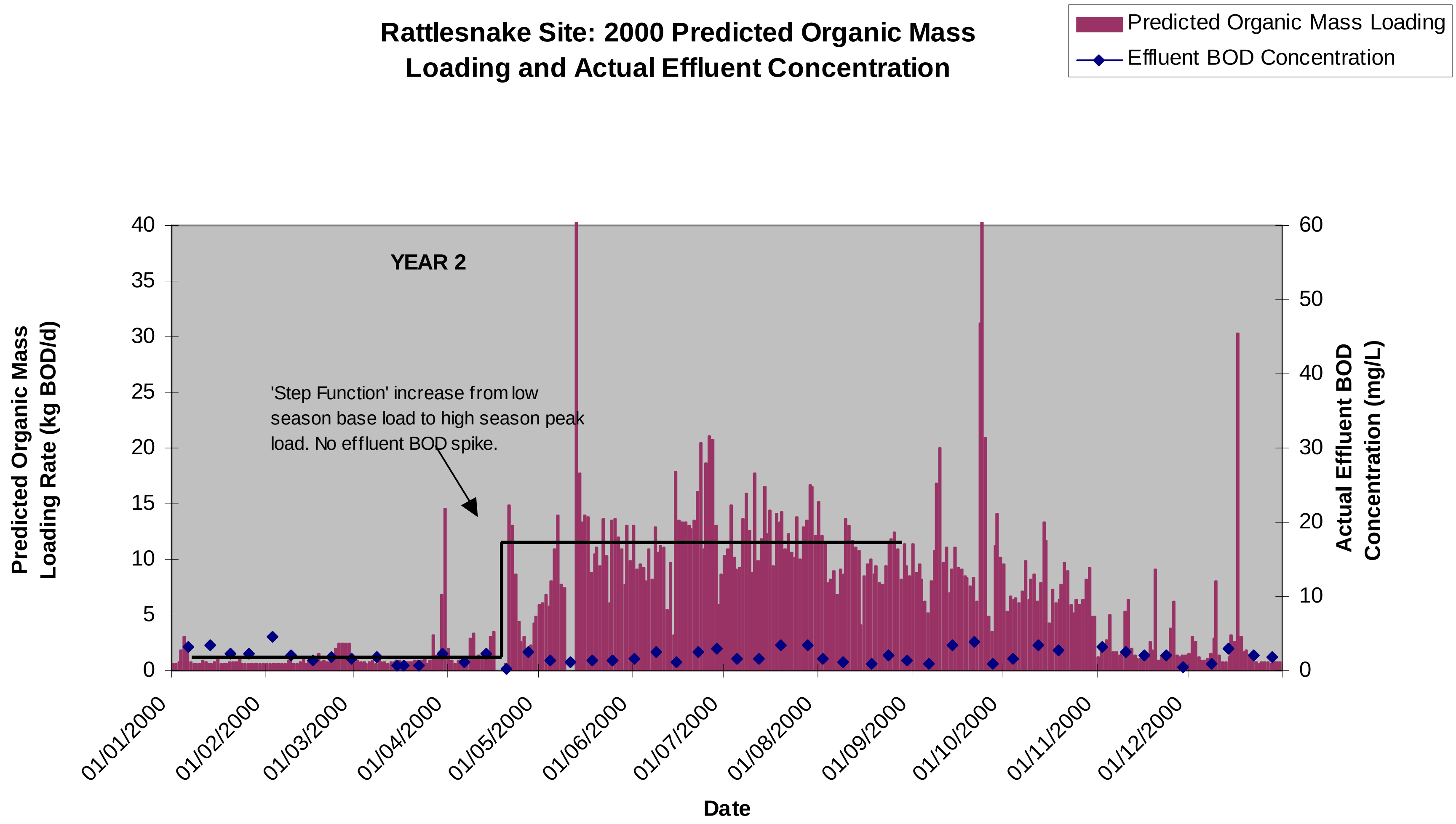
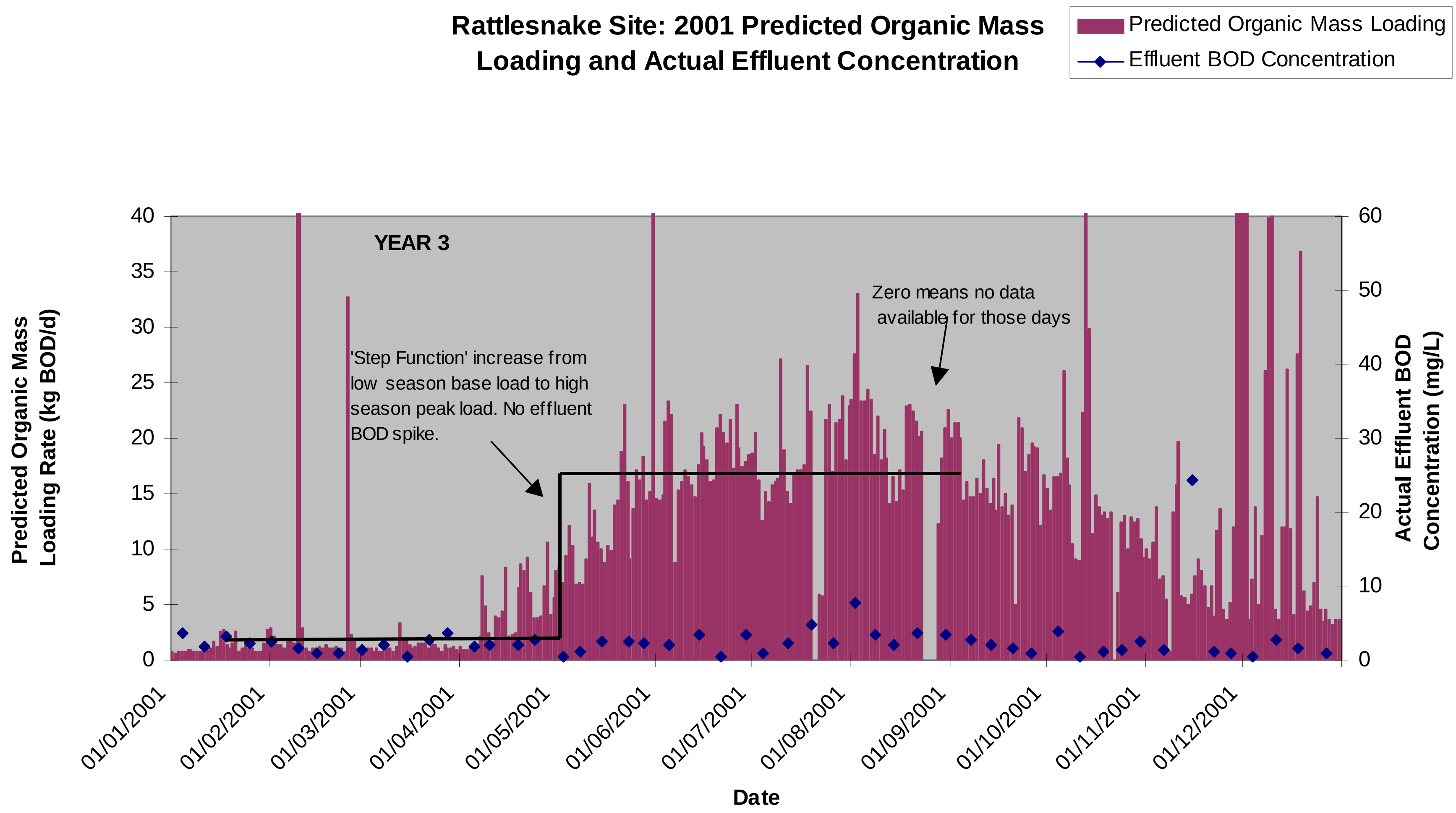
01/11/1999
01/12/1999



Rattlesnake Site: 2000 Predicted Organic Mass Loading and Actual Effluent Concentration
Predicted Organic Mass Loading
Effluent BOD Concentration
YEAR 2
'Step Function' increase from low season base load to high season peak load. No effluent BOD spike.
Predicted Organic Mass Loading Rate (kg BOD/d)
Actual Effluent BOD Concentration (mg/L)
Date
0
5
10
15
20
25
30
35
40
50
60
01/01/2000
01/02/2000
01/03/2000
01/04/2000
01/05/2000
01/06/2000
01/07/2000
01/08/2000
01/09/2000
01/10/2000
01/11/2000
01/12/2000



Rattlesnake Site: 2001 Predicted Organic Mass Loading and Actual Effluent Concentration
Predicted Organic Mass Loading
Effluent BOD Concentration
YEAR 3
'Step Function' increase from low season base load to high season peak load. No effluent BOD spike.
Zero means no data available for those days
Predicted Organic Mass Loading Rate (kg BOD/d)
Actual Effluent BOD Concentration (mg/L)
Date
0
5
10
15
20
25
30
35
40
60
50
40
30
20
10
0
01/01/2001
01/02/2001
01/03/2001
01/04/2001
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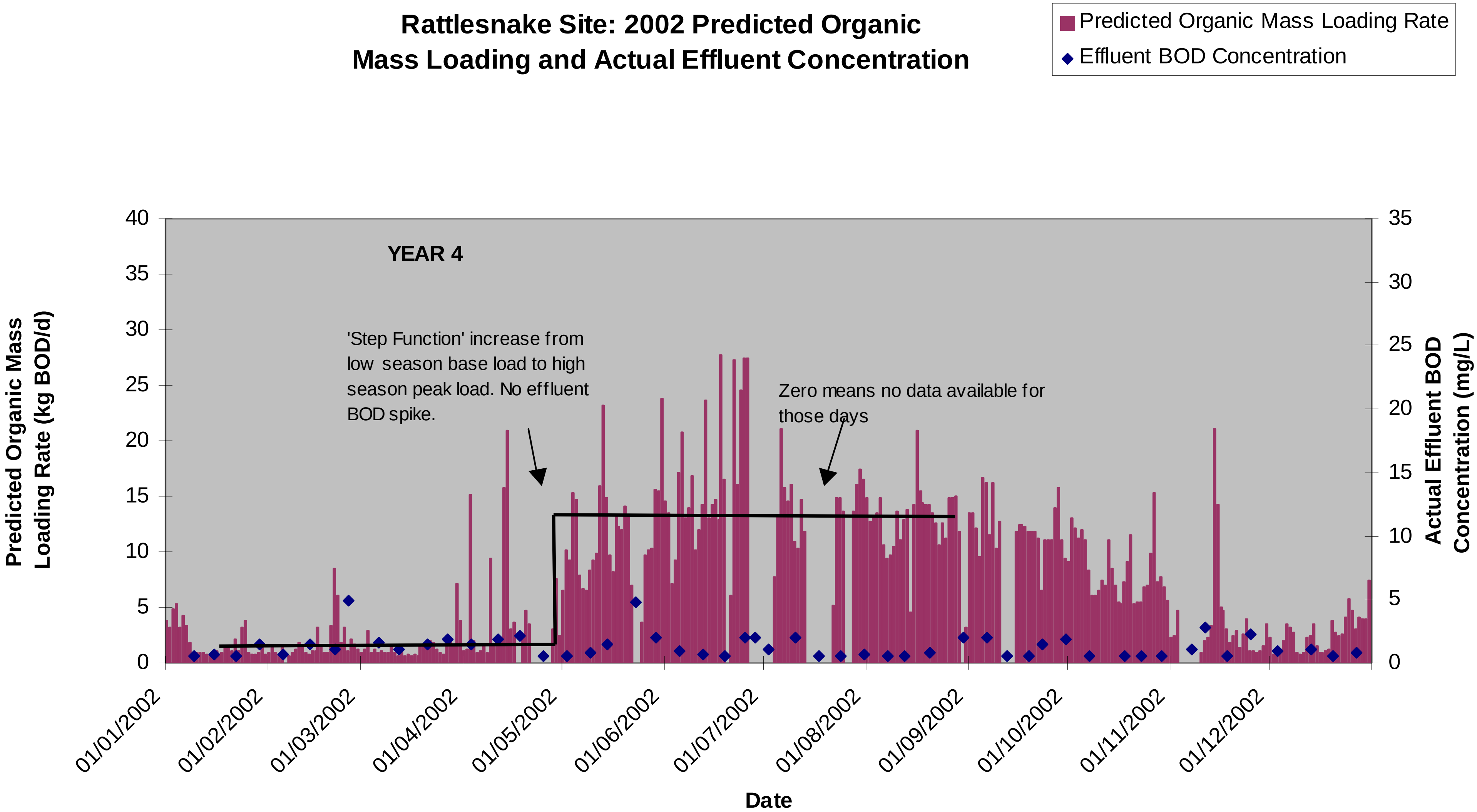
01/11/2001
01/12/2001


Rattlesnake Site: 2002 Predicted Organic Mass Loading and Actual Effluent Concentration
Predicted Organic Mass Loading Rate
Effluent BOD Concentration
YEAR 4
'Step Function' increase from low season base load to high season peak load. No effluent BOD spike.
Zero means no data available for those days
Predicted Organic Mass Loading Rate (kg BOD/d)
Actual Effluent BOD Concentration (mg/L)
Date
40
35
30
25
20
15
10
5
0
01/01/2002
01/02/2002
01/03/2002
01/04/2002
01/05/2002
01/06/2002
01/07/2002
01/08/2002
01/09/2002
01/10/2002
01/11/2002
01/12/2002