APPENDIX D

Determination of Microcosm Flow Rates and Sediment Surface Areas

The bathymetric information for four small, contiguous sections of the upper Occoquan Reservoir was investigated at the beginning of this study in order to design the microcosm reactors. Because it was desired to examine denitrification rates in microcosms having similar values of effective depth to the prototype system, the reactors were designed to be configured for a range of effective depths that might be encountered in the reservoir. Moreover, the objective of the study was to investigate the occurrence of denitrification moving down the reservoir, hence the reactors were designed to have the same detention times as reaches of the reservoir they represented.

The bathymetric information used was taken from the 2000 Occoquan Reservoir Bathymetric Survey (OWML, 2000a). The survey data were processed with a contouring, gridding, and surface-mapping package, Surfer 7 (Golden Software Incorporated, Golden, CO) to obtain the volume and sediment surface area in each investigated section. The first section began at the tail waters of the Bull Run arm of the reservoir and ended at Bull Run Marina (RE30). The second section continued from RE30 to the confluence of Bull Run and Occoquan Creek. The third and the fourth sections were in the main reservoir body. The third started from the confluence to some point downstream of RE20 and the forth section continued to some point upstream of RE15. The summary of each section is shown in Table D-1. The station locations may be seen in the watershed map shown in Figure 1.1.

Table D-1. Summary of Characteristics of the Reservoir from the Tail Waters of the Bull Run Arm to a Point above RE15

Section	Description	Sediment Surface Area (sq.ft)	Water Volume (cf)	Effective Depth (Feet)	Detention Time (Days)
1	Tailwaters to Bull Run marina	204,290	300,971	1.47	3.48
2	Bull Run marina to the confluence	639,097	1,728,791	2.70	5.76
3	The confluence to below RE20	2,015,483	16,655,184	8.26	5.80
4	Below RE20 to above RE15	2,394,959	20,485,332	8.55	6.49

Note:

- The detention times of the first and the second sections were calculated from the median summer flow at ST40 between 1982-2000. The flow was 51.1 cubic feet per second (cfs).

- The detention times of the third and the forth sections were calculated from the median summer flow at ST40 plus ST10 between 1982-2000. The median flow was 93.7 cfs.
- Effective Depth = Water Volume/Sediment Surface Area. In this case, both values are for the zone lying below the thermocline, which is taken to be at a depth of 10 feet. The pool elevation was assumed to be 119.3 feet.
- Detention Time = Water Volume/Flow Rate. As in the case of effective depth, this is taken to be the detention time in the zone below the thermocline
- sq.ft and cf are abbreviations for square feet and cubic feet, respectively.

In a later part of the study, in order to design a more representative microcosm of the Occoquan Reservoir, the Bull Run arm of the reservoir and the main reservoir—from the confluence of the Bull Run and the Occoquan Creek to the Occoquan Dam—were sectioned and the characteristics of each section was determined as shown in Table D-2.

Table D-2. Summary of Reservoir Characteristics from the Tail Waters on the Bull Run Arm to the Dam

Section	Description	Sediment Surface Area (sq.ft)	Water Volume (cf)	Effective Depth (Feet)	Detention Time (Days)
1	Tailwaters to Bull Run marina	204,290	300,971	1.47	2.59
2	Bull Run marina to the confluence	639,097	1,728,791	2.70	4.28
3	The confluence to RE20	1,520,815	12,440,774	8.18	4.09
4	RE20 to RE15	4,355,782	38,424,442	8.82	11.5
5	RE15 to Sandy Run	14,094,664	196,836,374	14.0	41.9
6	Sandy Run to the dam	9,610,610	230,384,041	24.0	28.4

Note:

- The detention times of Section 1 and Section 2 were calculated from the median summer flow at ST40 between 1996-2000. The flow was 68.2 cfs.
- The detention times of Section 3, 4, and 5 were calculated from the median summer flow at ST40 plus ST10 between 1996-2000. The median flow was 98.2 cfs.
- The detention times of Section 6 was calculated from the median summer flow at ST01 between 1996-2000. The median flow was 139 cfs.
- Effective Depth = Water Volume/Sediment Surface Area. In this case, both values are for the zone lying below the thermocline, which is taken to be at a depth of 10 feet. The pool elevation was assumed to be 119.3 feet.
- Detention Time = Water Volume/Flow Rate. As in the case of effective depth, this is taken to be the detention time in the zone below the thermocline

First Experiment

Experiment 1 was a preliminary effort with objective of becoming familiar with the experimental setup and to identify any operational problems. Therefore, in Experiement 1, the sediment surface area was not controlled and the detention time was set to be about the same as the reservoir section from the Bull Run marina to the confluence (5.76 days). To get this detention time, the feed water flow rate was set at 1,584 mL/day. This section was selected because the author speculated that it was where denitrification was active since it was the first section where low dissolved oxygen was observed during the summer months.

Second Experiment

In Experiment 2, a microcosm simulation was attempted of the reservoir section from Bull Run marina (RE30) to the confluence (above RE20). However, unlike the first experiment, the sediment surface area was restricted to obtain approximately the same effective depth as that of this section of the reservoir. In the section of the reservoir of interest, the effective depth was found to be 2.70 ft, which corresponded to an exposed sediment surface area in the reactor of *ca.* 117 sq.cm. By trial and error, it was found that the reactor could be assembled to have a sediment surface area of 125 sq.cm., an effective depth of 2.52 ft, and a detention time of 5.57 days by using eleven 50-ml beaker containing sediment, and pumping feed water in at 1,728 mL/day. Each beaker had internal diameters of 3.8 at the body and 4 cm at the opening, which corresponded to cross-sectional areas of 11.4 sq.cm. and 12.6 sq.cm., respectively. The total volume of each beaker was 86.9 ml.

Third Experiment

The setup for the third experiment was similar to that for the second, and represented the same portion of the reservoir. The only difference in the conditions was that the 50-mL beakers were filled to the rim with sediment, thereby resulting in a slight reactor volume change. Again, by trial and error, a sediment surface area of 113.04 sq.cm. was obtained, resulting in the effective depth of 2.72 ft. The flow rate was also slightly different, approximately 1,627 mL/day, which then corresponded to a detention time of 5.66 days.

Fourth Experiment

With the operational experience gained from experiments one through three, the fourth experiment was designed to be a three-CTSR-in-series system. The configurations of the first reactor remained exactly the same as the reactor in the third experiment, while the second and third were designed to represent Occoquan Reservoir Sections 3 and 4 as shown in Table D-1, respectively. As before, reactor sediment surface areas were determined by trial and error to obtain values close to the actual reservoir values. The as-built effective depths in the second and third reactors were both 8.53 ft, which may be compared to the computed effective depths of 8.26 and 8.55 ft in Sections 3 and 4 of the reservoir, respectively. The as-built detention times for Reactors Two and Three were both 6.01 days, compared to the actual detention times of 5.8 and 6.49 days, respectively, in the third and forth Sections of the reservoir. The flow rate (1,627 mL/day) was identical to that of the third experiment.

Fifth Experiment

The fifth experiment was a close replicate of the third experiment except that the reactors utilized were of the new design, which provided a better air seal and instrument accessibility. The design is shown in detail in Appendix B. Because the overall reactor volume was the same in both the old and new designs, the sediment surface areas and flow rates were the same as those of the third experiment.

Sixth Experiment

Two reactors in series were used in this experiment. In investigating the historical nitrate profile along the reservoir, it was found that most of the denitrification occurred in the portion of the reservoir above Ryan's Dam (RE15), as has been discussed in the "Results and Discussion" section of this thesis. This experiment was designed to simulate only that portion of the reservoir. The reservoir reach was separated into two sections of roughly equal detention times, and one reactor was assigned to simulate each section. The upstream section included the zone from the tail waters down to a point just below the confluence (RE20). The second part was taken to be the zone between Stations RE20 and RE15.

For the second zone, the reactor sediment area was computed from the volume of the reactor, and the effective depth for Section 4 given for the flow conditions described in Table D-2. However, the first reactor was being configured to represent Sections 1 - 3 of the reservoir, as shown in Table D-2, and configuring the detention time and exposed sediment area was more problematic because of the wide range of detention times and effective depths. By summing the volumes and surface areas, and calculating an effective depth of the combined reach, the general configurations of the two reactors would have been as shown in Table D-3. Because the hypolimnetic volume (12.44×10^6 cf) of Section 3 was about six times the sum of the hypolimnetic volumes ($2{,}03 \times 10^6$ cf) Sections 1 and 2 combined, the effective depth in the first reactor was nearly 2.5 times greater than that of the reactor used in the fifth experiment (2.72 ft.), while the detention time was only approximately a factor of 2 higher. Because it was observed that significant denitrification did not occur in the fifth experiment due to oxygen

Table D-3. Sixth Run Reactor Configurations (designed with the total effective depth)

Reactor No.	Represented Section	Detention Time (Days)	Influent Rate (ml/Day)	Effective Depth (Feet)
1	1,2,3	11.18	870.49	6.12*
2	4	11.23	870.49	8.52

* The effective depth was calculated by combining the volumes and sediment areas of the three sections

interferences, it was doubtful that the denitrification would ever occur with this configuration. In order to provide a more realistic experimental scenario, a weighted effective depth that took into account the dominant volume of Section 3 was used for the first reactor. The two reactors

Table D-4. Sixth Run Reactor Configurations (designed with the weighted average effective depth)

Reactor No.	Represented Section	Detention Time (Days)	Influent Rate (ml/Day)	Effective Depth (Feet)
1	1,2,3	11.09	864.4	4.18*
2	4	11.33	864.4	8.52

* The effective depth is the weighted average of the three sections.

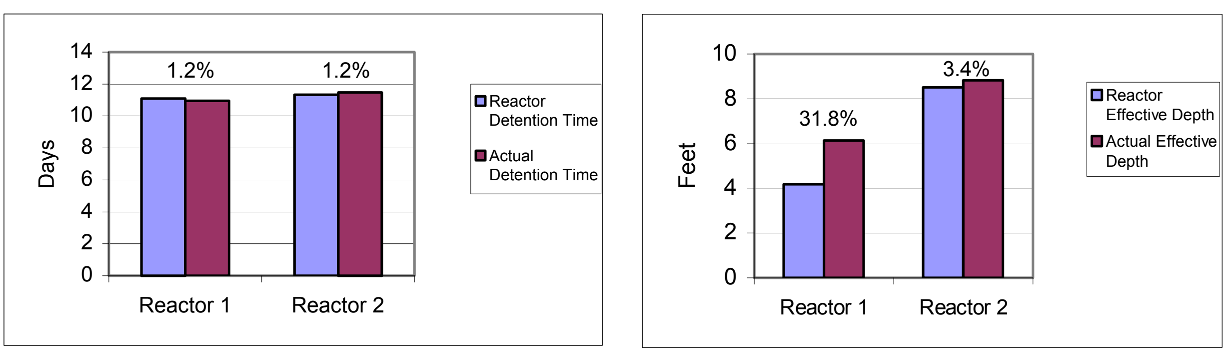

Figure D-1. Comparison between the actual reservoir and the sixth-run reactors were redesigned as shown in Table D-4. The comparison between the calculated reservoir's values and the designed reactors' values are shown in Figure D-1.

Another major issue in the reactor combination was the distribution of sediments from Sections 1, 2, and 3. Because sediment-water contact is directly related to detention time, and inversely related to effective depth, the relative sediment areas from Sections 1, 2, and 3 were calculated on both bases, and an arithmetic average taken between the two values. The results are shown in Table D-5. As may be seen from the table, there was some variation in the area ratios from the three zones. However, the areas could only be represented in increments of 12.6 sq.cm, which is the cross-sectional area of a 50 mL beaker. Because of this limitation, it was decided to set up the first reactor by area-weighting the sediments equally from the three zones.

Table D-5. The Sediment Mixing Ratio of the Six-Run First Reactor

Section	Based on Effective Depths	Based on Detention Times	Average
1	1	1	1
2	0.54	1.65	1.09
3	0.18	1.57	0.87