RESULTS OF A TRACER STUDY CONDUCTED WITHIN CONSTRUCTED WETLANDS WITH VARYING CELL CHARACTERISTICS

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Abstract. Constructed wetlands are designed to remove specific wastewater constituents. As a result, they are theoretically “sized” so that the mass of target constituent has ample time to contact wetland substrates, plants, and microbiota in order to improve effluent water quality. The amount of time wastewater remains within the cell (residence time) is critical to treatment efficiency (Dierberg et al., 2005). Unfortunately, engineering effective natural treatment systems is complicated. Many elements impact flow within the constructed wetland cell and can lead to the creation of preferential flow patterns and stagnant zones. These mechanisms create a significant deviation from the designed residence time and ultimately have an effect on treatment removal efficiency. The goal of this study was to determine the flow characteristics of constructed wetland cells with varying morphological characteristics in order to understand features that cause deviation from theoretical or plug flow.

Flow characteristics have typically been described by the following chemical engineering principles: nominal residence time, calculated residence time, residence time distribution variance, dimensionless variance, and numbers of tanks in series. Kadlec and Knight (1996) discussed how these principles applied to treatment wetlands. As a result, these principles have been the conventional method for analyzing wetland hydraulics and were used in this study. This study was conducted within the constructed wetland complex of the J.B. Messerly Wastewater Treatment facility in Augusta, GA. Two conservative tracers (lithium chloride and Rhodamine WT) and a network of thermistors were used to determine hydrologic differences in wetland cells that had different morphological characteristics.

The wetland complex generally had two different constructed wetland cell types, cells with a single, large open water pond located between two marshes (MPM) and cells with alternating marshes and smaller open ponds or “ditches” (MDM). For the MPM systems, the marsh:water ratio was 30:70 whereas in the MDM systems the ratio was 60:40. Other pertinent characteristics of the experimental cells included mostly linear to sinuous morphometry, small ditches (incidental to the planting scheme) within the marsh areas that were not perpendicular to flow, and deep water ponded sections (>1.2 m).

Wastewater entered individual cells via influent weirs located along the entire length of a distribution canal depending upon the location of the cell. Weirs were equipped with sharp crested plates that allowed standardization of wastewater volume to each cell. After entering the weir, water flowed through individual culverts. Culverts supplied water to the treatment cells via four equally spaced laterals located within the first marsh section at the head end of each cell. Lateral were designed to allow the water to upwell into the cell. Effluent at the end of each treatment cell exited through four, equally spaced, sharp crested weirs. Each weir height was controllable by a turn screw. Effluent weirs within the MPM cells were located within the final marsh section of the treatment cell whereas effluent weirs within the MDM cells were located within the final ditch portion of the treatment cell. Influent and effluent volumes were estimated by using a sharp-crested weir equation. Influent flows were continuously measured by using a water level logger within the distribution canal while effluent flows were measured once per day at each of the effluent weirs.

Prior to study initiation, all weir heights were surveyed and effluent weir heights were standardized for each individual cell. Automated samplers were located at each effluent weir. The hose for each weir was lowered into a PVC apparatus which allowed only the water flowing over the weir (nappe) to be sampled. Sampling intervals were set every six hours for day 0-12, every 12 hours for days 13-24, and every 24 hours for days 25-36. The study began at 4PM on September 23, 2005.

Thermistors (Hobo TidBit, Onset Computer Corporation) were set within the marsh and open water portions of the wetland cells and collected temperature data at 5 minute intervals. Three thermistors were equally spaced within the marsh, approximately 0.9 m from the marsh-pond interface, and at approximately mid-depth within the marsh water column. Three pairs of thermistors
were placed approximately 15 m downstream of each of the marsh thermistors and within the ponded portion of the cells. Each thermistor pair was fixed to a rod with one thermistor approximately 0.3 m below the surface and the other located approximately 0.3 m from the pond bottom.

Based upon the tracer data, residence time distributions were approximately equal for the two cells. However, the variance of those distributions was 75% less for the MDM cell, the number of tanks in series was 215% higher for the MDM cell, and the tracer peak occurred 36 hours later in the MDM cell compared to the MPM cell. These data indicated that flow through the MDM cell approximated plug flow better than in the MPM cell.

Within the MPM cell, the thermistor located at the center-marsh location had an average temperature of 24.14°C. Thermistors located within the pond directly downstream of the center-marsh logger had average temperatures of 25.36°C at the upper logger and 24.77°C at the lower logger. This indicated that water exiting the marsh, on average, would have descended to the bottom of the pond as a result of a temperature induced density difference (assuming that wastewater density due to dissolved and suspended solutes at each location was equal). According to the thermistor data however, water could also have flowed as an interflow or along the surface layer. This variability resulted from larger diurnal fluctuations of water temperatures exiting the marsh compared to the pond and higher daily maximum and lower daily minimum temperatures in the marsh compared to the pond.

Thermistor data was also used to assess the impact of wind mixing. Isotherm displacement calculations indicated that the 31°C isotherm was displaced by as much a 0.5 m as a result of steady wind speeds of 2.2 m/s for over an hour from a single direction. This may have also tilted the water column and contributed to short circuiting of water across the surface of the pond section of the cell.

Rhodamine data indicated that small, open water ditches within the marshes may have directed flow preferentially. These incidental ditches would have created a temporary path of least resistance, prior to flowing into the next section of vegetation (increased resistance), ultimately diverting flow toward one side of the marsh.

Deviation from plug flow in both cells was attributed to wind mixing, thermal stratification of the water column, and orientation of incidental, small, open ditches relative to flow within the marsh areas. This study indicated that significantly decreasing the open water area or increasing compartmentalization of the cells, as well as, planting rows of vegetation perpendicular to flow may significantly increase flow optimization within constructed wetlands.

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LITERATURE CITED
