Solids Separation-Reciprocating Wetland

Project Report
May 25, 2004

Mark Rice, Assistant Director
National Center for Manure and Animal Waste Management
North Carolina State University
Centennial Campus, Research Building IV, Suite 3100, Box 7927

Frank Humenik, Coordinator
College of Agriculture and Life Sciences Animal Waste Management Programs
North Carolina State University
Centennial Campus, Research Building IV, Suite 3100, Box 7927
Raleigh, North Carolina, 27695-7927, USA

Abstract

This technology employs wetland cells or basins in which alternating anaerobic and aerobic conditions are created to remove nitrogen and other pollutants from the waste stream. At steady state operation the ReCip cells had removal rates for total nitrogen and suspended solids of 87.5% and 94.5% respectively. The treated liquid recycled to flush the barns or requiring land application generally had low concentrations of TKN (47 mg/l) and suspended solids (120mg/l) with some nitrate present (4.7 mg./l). The ReCip cells require little operator oversight and maintenance and have redundancy built into the pumping system to allow for safety and operation flexibility.

General description

This project is located on Corbett Farm #2 in Duplin County, North Carolina (Figure 1). It was in operation from December 2002 until January 2004, and designed to treat the waste from approximately 1,840 finishing pigs. This technology employs wetland cells or basins in which alternating anaerobic and aerobic conditions are created to remove nitrogen and other pollutants from the waste stream. The technology provider is BioConcepts, Inc., Al Privette, President. The ReCip technology is a wastewater treatment technology and not a total treatment system and thus must be coupled with some type of a solids separation unit. For this evaluation the waste stream from the swine houses flows first to a solids separation unit, consisting of a settling tank, filter tank and dosing tank. The liquid is then pumped to the reciprocating wetland cells. The cells are earthen basins with synthetic liners each approximately 25.6 m x 25.6 m in size (Figure 2). Each cell is filled with aggregate, which acts as a surface on which microbes reside. The liquid from the solids separation unit is pumped back and forth between the cells. Under aerobic cell conditions nitrate is formed and under anaerobic conditions nitrate is converted to nitrogen gas by denitrification. Thus, the system is designed to remove nitrogen from the waste stream by turning it first into nitrate, and then into nitrogen gas as the wastewater is pumped back and forth between the cells. It is important to note that while plants play an important role in the remediation of wastewater streams in conventional constructed wetlands, plants are not required for ReCip to function, even while treating high-strength waste streams.

Loading of wastewater, approximately 20,000 gallons total per day occurs between 6 AM to 5 PM daily and represents 5 flush cycles for each barn. During the evaluation period, the liquid was being applied to the system in increments of approximately 4,000 gallons. Each increment of liquid from the solids separator is loaded into the first cell (Cell 1) of the two-cell treatment system. Both cells (Cell 1 and Cell 2) have a design capacity of 60,000 gallons, or a calculated retention time of 6 days for a 20,000 gallons daily load (total capacity = 120,000 gallons).

Liquid has a six-day hydraulic residence time in the cells. Approximately 20,000 gallons of liquid leave the cells each day of which 19,000 gallons is recycled to the pig houses to be used to flush waste from the houses. The remaining liquid flows by gravity to Lagoon 2 to be applied to land (Figure 1).

A start-up period with reduced treatment effectiveness is to be expected with biological treatment systems. Loading to the Solids Separation-Reciprocating wetland system was initiated when small pigs were placed in the barns and thus lower than design loading. The system took approximately 5 months to achieve steady- state conditions necessary for a valid evaluation. The start-up period may have been prolonged due to starting the system during winter when colder temperatures would reduce biological activity. To facilitate the evaluate of the system, grab sampling locations and Doppler flow meters were used as illustrated in Figure 1. The total flow was recorded at the time each grab sample was collected and used in the mass balance calculations.

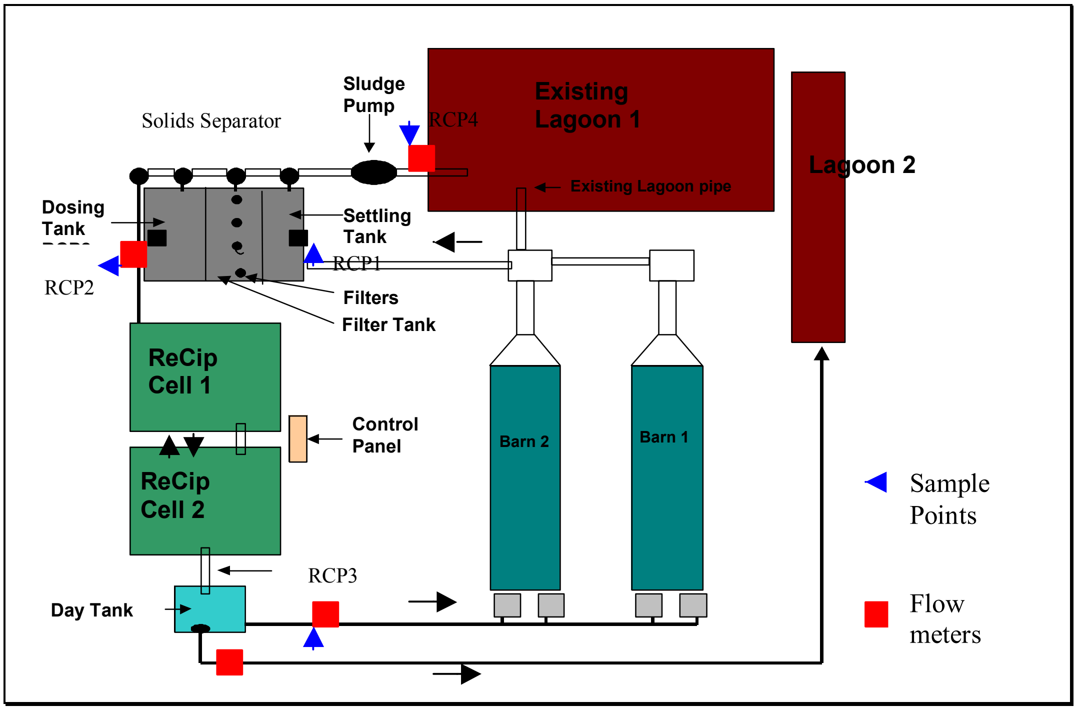

FIGURE 1. Flow-diagram of solids separation/reciprocating water technology system (ReCip).

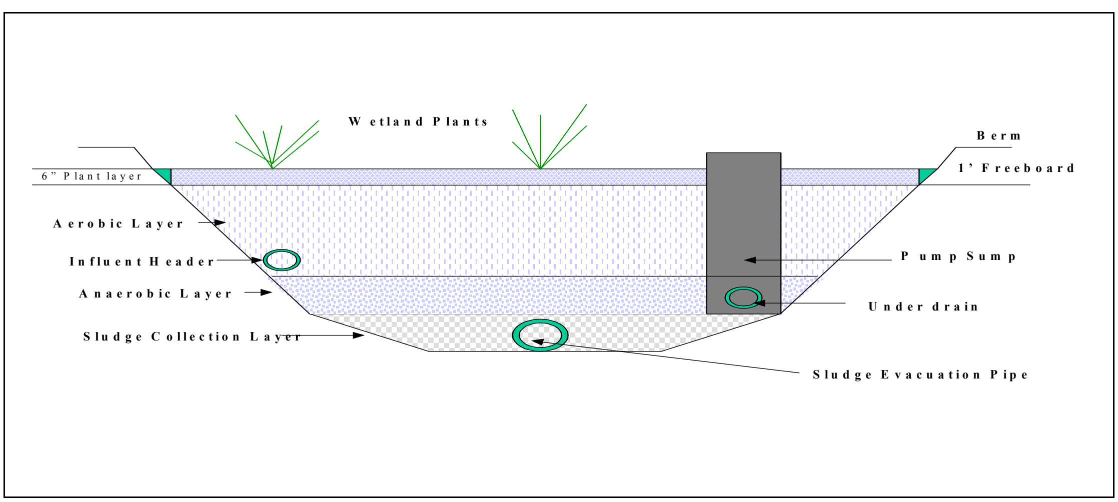

FIGURE 2. Cross Sectional diagram of the ReCip Cells.

Solid Separation Component

Description

Solids separation was not the environmentally superior technology candidate for this treatment system so the separation component utilized was the cheapest and simplest system that could be devised to provide initial removal of waste solids.

The solids separator is a 12,500 gallon tank divided into 3 compartments: settling tank, filter tank, and dosing tank. All three compartments have a pipe connection and valve at the bottom allowing the periodic removal of built up solids. The normal water level in the settling and filter tanks is about 3/4 full. Barn flush enters the settling tank and slows as it contacts the existing water. Solids begin to settle and influent must flow under a baffle wall then over another baffle wall, to facilitate solids settling, before flowing into the filter tank. The filter tank contains 3 large zabel filters. When the water level raises, the filters strain the wastewater and filtered water flows into the dosing tank. A high level switch activates a pump to dose ReCip cell 1.

Evaluation

The operation and maintenance associated with the solids separator and associated valves and pumps proved to be a significant challenge for the operation of the overall system.

The design of the system and the variability of the inflow waste stream (both volume and concentration) made it difficult to obtain representative samples of the inflow to the settling tank. Due to the difficulty associated with direct measurement of intermittent gravity flows, the inflow to the solids separator was calculated as the sum of the measured flows into the ReCip Cell 1 and the sludge pumped to Lagoon 1 (Figure 1). The average daily inflow total nitrogen (TN) mass of 215 lbs./day obtained from the bi-weekly sample analyses and flow data yields a value of more than twice what would be expected based on literature values of excreted swine waste (USDA, 1992). The nitrogen excretion by the animals of 101 lbs/day for this farm presented by the Team OPEN Report of the Year Three Progress Report for Technology Determination is consistent with the USDA data. If the data is limited to the steady-state evaluation period, the average inflow nitrogen of approximately 94 lbs/day seems more realistic.

The recognized difficulties in using grab samples to determine mass balances for non-homogeneous waste streams appear to cause these data inconsistencies. The daily inflow mass of each constituent was averaged for the evaluation period as well as the daily outflow mass of each constituent. These data were used to calculate the removal efficiency in Table 1 according to the following equation:

Equation 1: [(average mass in – average mass out)/average mass in] x 100

Where: mass = (concentration of constituent) x (volume)

Table 1. Average Mass Removal Efficiencies for the Solid Separation Component Under Steady-State Conditions (May 2003 – October 2003).

	TN (Std.Dev.)	TP (Std.Dev.)	Cu (Std.Dev.)	Zn (Std.Dev.)	Suspended Solids (Std.Dev.)	Total Solids (Std. Dev.)
Mass in[1] lbs./day	93.7 (39.4)	69.1 (11.0)	0.13 (0.05)	1.18 (0.52)	1101.1 (500.91)	1624.33 (671.91)
Mass out[1] lbs./day	72.3 (31.6)	17.8 (7.1)	0.04 (0.03)	0.34 (0.15)	260.3 (61.51)	712.66 (178.45)
Removal Efficiency %	22.8	74.2	69.2	71.2	76.4	56.1

[1]Average for 9 sampling events

Maintenance/management

The solids separation component required inspection and maintenance at least three times per week for about 1.5 hours per visit, for it to operate effectively. Mechanical problems with the pump and an ineffective design for removing accumulated solids from the bottom of the tank contributed to the necessity of routine onsite intervention. On one occasion, a soda can became lodged in a valve requiring the drain line to be excavated for repairs.

While the solid separation system proved to be relatively effective at separating the primary waste constituents from the wastewater stream the operational demands and problems associated with this unit process need additional attention.

ReCip Cell Component

Description

The ReCip treatment cells are designed to move water between cells on a regular cycle during each 24-hour period. Dosing of Cell 1 occurs in conjunction with these cycles. The movement of water between the treatment cells changes the depth of water within a cell by as much as 48 inches during a cycle.

During the evaluation period, the ReCip treatment system was operating with 10 cycles per day meaning that Cell 1 was pumped to Cell 2 ten times and Cell 2 was pumped to Cell 1 ten times per day. Each cycle lasts for approximately 1.5 hours, so water was constantly moving within both treatment cells 15 hours each day. For the remainder of the 24 hour period, the system was at rest and the water levels within each cell would eventually reach a constant level. The amount of effluent removed from the treatment cells daily, and into the Day Tank (Figure 1), is approximately equal to the amount wastewater influent into Cell 1 at the beginning of a loading cycle.

Evaluation

The wastewater that is pumped from the dosing tank to the ReCip cells is more homogeneous in nature than the settling tank influent and thus provides more justification for the use of grab samples.

As with most biological treatment systems, the nitrogen removal efficiency of the ReCip based system was reduced at start-up due to the lack of acclimated steady state microbial populations and to some extent colder temperatures. The removal efficiency was also hindered by not reciprocating frequently enough. The system was started in December 2002 with six (6) ReCip cycles per day. Based on sample results, the number of daily cycles was increased from 6 to 8 cycles per day starting Jan 31, 2003 and then from 8 to 10 cycles per day starting Feb 14, 2003. During the start-up and adjustment period the nitrogen removal efficiency averaged less than 40%. Following an approximate 5-month start-up period (Figure 1) the steady-state total nitrogen (TN) removal efficiency averaged approximately 88% (Table 2) for the evaluation period with a range from 81 to 94%. Data for the entire project period is presented in Appendix A. The presence of nitrate-nitrogen, which supports denitrification, in the effluent from the cells (Appendix A) verifies that biological nitrogen transformation is occurring in the cells.

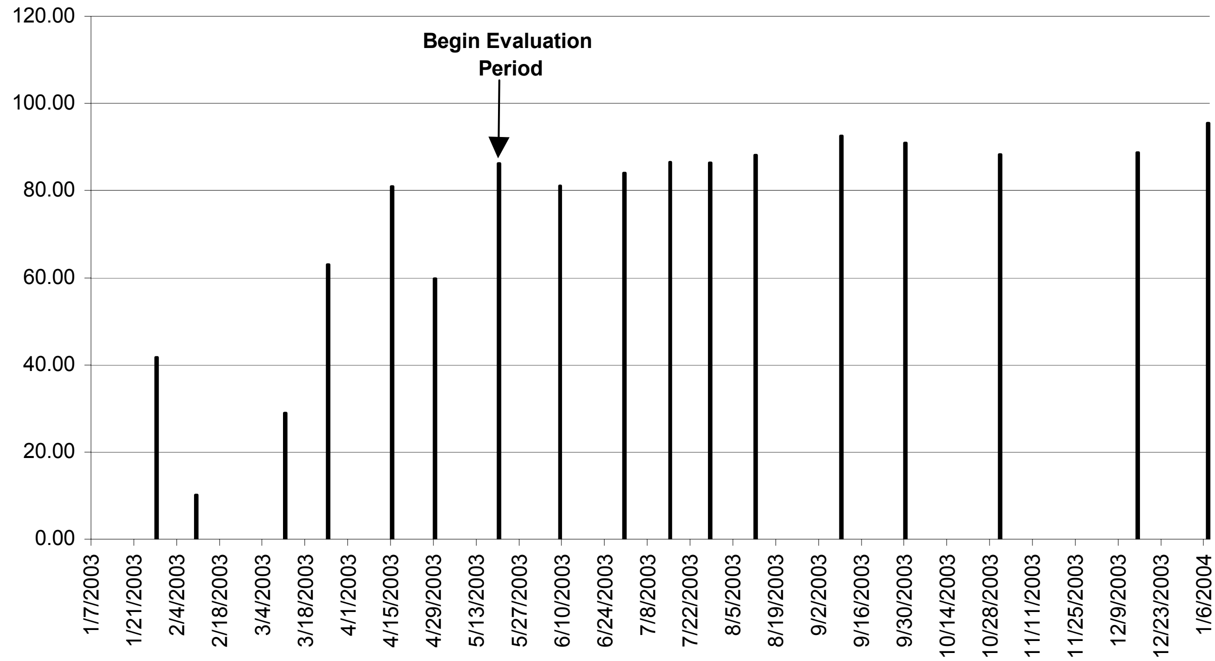

Figure 1. TN Removal Efficiencies for each sampling event of the ReCip Cells.

The data show relatively high removal rates of phosphorus, copper, zinc and suspended solids (Table 2). There are no long-term studies of the ReCip system but literature from other types of treatment wetlands suggests that the removal efficiencies of some of these elements such as phosphorus could decrease over time (Hammer, 1994 and Stone et al., 2002). The type of aggregate used in the cells has an affect on the phosphorus sorption and its long-term reduction capacity. This short-term evaluation does not define the long-term performance of the system.

The daily inflow mass of each constituent was averaged for the evaluation period. This, along with the averaged daily mass of each constituent in the outflow for the evaluation period, was used to calculate the removal efficiencies of each constituent (Table 2) as was done for Table 1.

Table 2. Average Mass Removal Efficiencies for the ReCip Cells Under Steady-State Conditions (May 2003 – January 2004).

	TN (Std. Dev.)	TP (Std. Dev.)	Cu (Std. Dev.)	Zn (Std. Dev.)	Suspended Solids (Std. Dev.)	Total Solids (Std. Dev.)
Mass in [2] lbs./day	72.3 (32.5)	17.8 (7.1)	0.04 (0.03)	0.34 (0.15)	260.3 (61.5)	712.7 (178.5)
Mass out [2] lbs./day	9.0 (3.1)	9.1 (1.8)	0.01 (0.01)	0.05 (0.02)	14.4 (5.7)	372.8 (62.0)
Removal %	87.5	48.9	75.0	85.3	94.5	47.7

[2]Average for 11 sampling event

A loss of plants, used for aesthetic in the ReCip cells, was high but plants are not required for the ReCip to function even while treating high-strength waste streams. The reason for this loss was not known but it may have had more to do with the water levels in the cells, rather than the TN and COD strength of the wastewater. Initial outflow weir adjustments caused the high water level within the cells to fall short of the root-levels of the newly installed plants, and they simply dried up. Additional plants, added later, survived well along with a few of the initial plants.

Maintenance/management

The ReCip cells have four pumps in each cell to provide redundancy and back up. Under normal operation only three pumps are necessary to transfer liquid between cells although four pumps are used. If a pump goes out of service, the remaining three pumps are able to handle the load. Float switches, working in conjunction with a programmable timer, insure that the correct liquid levels are maintained in the cells.

During the evaluation period no problems were experienced with the pumps or plumbing of the ReCip cells. On one occasion a large volume of runoff, due to heavy rainfall, flowed into the cells and the system was able to handle the additional liquid with no adverse impact to the system or result in an overflow. The accumulated solids were pumped from the sludge collection layer of the first wetland cell once per month. This feature was added to the design to address concerns about clogging of the cells due to the suspended solids in the influent wastewater. On the single occasion that the sludge pumped from Cell 1 was sampled (RCP5 in Appendix A), the analysis indicated concentrations similar to the settling tank solids during the same sampling period. The pump used to evacuate solids from the settling tank was also used to remove the material from Cell 1 and therefore that material volume was included in the total volume pumped to Lagoon 1. Since the volume of sludge pumped from Cell 1could not be measured independently, it is impossible to get a meaningful estimate of the mass of constituents removed from the sludge collection layer of the Cell 1.

The major operational components of the ReCip cells are pumps which are commonly used on swine production/waste management facilities and with which most farm workers are familiar. The main areas of required operator training would be associated with the actual control panel and overall system operation.

The ReCip cells were monitored daily via remote camera and computer connection to insure proper operation. Alarms associated with the controls alert the operator to potential problems within the system. This approach coupled with at least a weekly visit to the site should provide adequate system oversight for the ReCip component of the system. Accumulated solids and sludge should be pumped from the first cell monthly to reduce the risk of plugging of the cells.

Summary

If the ReCip treatment cells are coupled with a manageable solids separation component they provide a relative low-tech approach for the reduction of nitrogen and many other constituents found in swine wastewater. At steady state operation removals for TN and suspended solids were 87.5 and 94.5% respectively. The treated liquid recycled to flush the barns and requiring land application generally had low concentrations of suspended solids (120mg/l) and TKN (47 mg/l) with some nitrate present (4.7 mg./l). The ReCip cells require little operator oversight and maintenance and have redundancy built into the pumping system to allow for safety and operation flexibility.

REFERENCES

Hammer, D. A.. Guidelines for design, construction and operation of constructed wetlands for wastewater treatment. Tennessee Valley Authority, Knoxville, TN. April 25, 1994.

Stone, K.C., P.G. Hunt, A.A. Szogi, F.J. Humenik, J.M. Rice. Constructed Wetland Design and Performance for Swine Lagoon Wastewater Treatment. Transaction of the ASAE, Volume 45(3): 723-730. 2002 American Society of Agricultural Engineers.

USDA, Agricultural Waste Management Field Handbook, Natural Resources Conservation Service, Chapter 4

Development of Environmentally Superior Technologies: Year Three Progress Report for Technology Determination per Agreements Between the Attorney General of North Carolina, Smithfield Foods, Premium Standard Farms and Frontline Farmers, Reporting Period: July 26, 2002 - July 25, 2003

Appendix A

ReCip Project Laboratory Data Set
For the Entire Project Period

RCP1 – Barn Flush (Inflow to the settling tank)
RCP2 – Inflow to the ReCip Cells
RCP3 – Outflow from the ReCip Cells (Recycle to flush tanks and excess to lagoon)
RCP4 – Sludge from settling tank (Pumped to lagoon)

units = mg/L

CODE	MO	DAY	YR	TKN	NH3N	NO3N	TP	CL	COD	PH	%TS	FSS	CU	ZN
RCP1 is the barn flush														
RCP1	1	7	03	2748	1816	0	443	618	19260	8.2	1.89	12950	2.3	13.8
RCP1	1	28	03	1754	1278	0	297	435	14500	8.4	1.31	5075	0.7	5.9
RCP1	*2*	*10*	*03*	*8496*	*5320*	*0*	*1515*	*451*	*44200*	*8.12*	*0.8*	*2800*	*0.9*	*6.1*
RCP1	2	25	03	1471	1016	0	580	407	9980	8.17	0.91	11167	1.2	7.6
RCP1	3	11	03	1231	1039	0.02	149	589	7560	8.47	0.81	5983	0.72	3.48
RCP1	3	25	03	790	553	0.04	194	551	5360	8.49	0.74	3944	0.36	3.52
RCP1	4	15	03	575	124	0.01	184	247	11530	7.87	0.78	16000	1.1	11.4
RCP1	4	29	03	510	250	0.23	124	326	7990	8.15	1.09	7317	0.72	5.12
RCP1	5	20	03	685	454	0.09	165	419	9900	8.59	0.96	7733	1	6.92
RCP1	6	9	03	312	126	0.02	112	322	3570	7.96	0.51	2600	0.42	4.14
RCP1	6	30	03	658	338	0.02	228	373	893	7.8	0.97	10833	1.08	7.8
RCP1	7	15	03	639	251	0.01	307	357	13680	7.5	1.76	.	1.08	8.92
RCP1	7	28	03	393	208	0	112	286	3730	7.74	0.48	3867	0.33	2.73
RCP1	8	12	03	438	250	0.01	219	348	5720	7.61	1.07	7150	0.6	7.76
RCP1	9	9	03	454	131	0.03	196	331	7850	7.38	0.75	.	1.12	13.9
RCP1	9	30	03	554	230	0.01	2296	428	3540	7.03	1.18	9211	0.6	5.16
RCP1	10	31	03	1149	552	0.08	260	510	21220	7.26	1.48	.	1.15	9.35
			Ave. [1]	897.6	538.5	0.036	366.6	409.2	9143	7.9138	1.043	7987	0.905	7.344
			Std. Dev. [1]	643.9	494.4	0.058	529.4	108.7	5749	0.4721	0.404	3922	0.477	3.475
[1] 2/10/03 Data excluded														
RCP2 is the inflow to the ReCip Cells														
RCP2	1	7	03	980	901	0	146	286	3710	7.76	0.41	1353	0.38	1.88
REC2	1	28	03	1807	1580	0	82.8	461	5348	8.4	0.58	1967	0.32	2.32
RCP2	2	10	03	1319	1268	0	151	464	4808	8.32	0.56	2036	0.48	2.24
REC2	2	25	03	749	502	0.01	132	235	3580	8.22	0.35	1717	0.44	2.16
RCP2	3	11	03	1037	950	0.02	92.4	568	3676	8.4	0.57	2400	0.52	2.52
RCP2	3	25	03	559	472	0.17	81.4	512	3040	8.08	0.46	1180	0.17	1.13
RCP2	4	15	03	422	189	0	64.1	260	2056	8.22	0.32	936	0.14	1.1
RCP2	4	29	03	192	138	0.05	51	310	1448	8.14	0.32	694	0.14	0.8
RCP2	5	20	03	516	412	0.01	76.9	424	3280	8.61	0.47	1344	0.22	1.36
RCP2	6	9	03	409	237	0	99.5	346	3944	7.78	0.52	2367	0.4	3.32
RCP2	6	30	03	326	188	0.01	89.59	226	3060	7.52	0.33	1567	0.36	2.26
RCP2	7	15	03	442	296	0.01	105	386	3840	7.7	0.46	2267	0.3	2.58
RCP2	7	28	03	387	254	0	104	323	3050	7.53	0.4	1567	0.2	1.7
RCP2	8	12	03	453	292	0.03	155	345	4070	7.48	0.51	2211	0.12	2.32
RCP2	9	9	03	216	116	0.03	119	332	2330	7.55	0.38	1407	0.31	4.58
RCP2	9	30	03	399	255	0.01	171	447	3320	7.49	0.5	1778	0.27	2.04
RCP2	10	31	03	471	325	0	74.7	430	2732	7.66	0.45	1333	0.14	1.17
RCP2	12	15	03	777	544	0	92.25	483	4645	.	0.48	.	0.2	2.28
RCP2	1	7	04	983	889	0.04	233	522	.	.	0.8	.	0.8	1.4
			Ave.	654.9	516.2	0.021	111.6	387.4	3441	7.9329	0.467	1654	0.311	2.061
		Std. Dev.		412.8	411.9	0.039	44.14	101.6	971.2	0.3822	0.116	502.6	0.17	0.88
RCP3 is the outflow from the ReCip Cells (used for barn flushing with excess going to lagoon)														
RCP3	1	7	03	519	513	0	93.2	209	1240	7.7	0.23	280	0.16	1.2
RCP3	1	28	03	941	875	0	28.2	366	1400	8.37	0.31	270	0.08	0.56

RCP3	2	10	03	1060	994	0.01	38.6	417	1463	8.35	0.34	397	0.24	0.88
RCP3	2	25	03	737	656	0.18	97	325	892	8.25	0.26	232	0.16	0.28
RCP3	3	11	03	659	583	0.04	44.2	479	1157	8.07	0.33	380	0.17	0.44
RCP3	3	25	03	185	145	0.01	69.6	441	820	7.78	0.32	277	0.03	0.29
RCP3	4	15	03	72.1	25.9	0.32	57.4	228	358	7.47	0.2	88	0.02	0.24
RCP3	4	29	03	69	33.3	1.03	48.3	289	433	8.14	0.26	123	0.04	0.22
RCP3	5	20	03	63.5	46.9	0.47	40.9	345	431	7.81	0.29	149	0.06	0.32
RCP3	6	9	03	69.3	40.7	0.01	57.9	298	373	7.82	0.29	83	0	0.32
RCP3	6	30	03	46.57	30.36	2.95	45.75	203	153	7.91	0.18	76	0.08	0.28
RCP3	7	15	03	53.19	39.04	0.58	55.14	271	330	8.13	0.21	93	0.02	0.26
RCP3	7	28	03	47.34	29.37	5.67	51.35	237	292	7.78	0.19	105	0	0.56
RCP3	8	12	03	48.37	32.88	1.28	65.38	276	233	7.58	0.21	122	0	0.46
RCP3	9	9	03	14.5	9.33	3.04	56.62	310	184	7.93	0.21	47	0	0.22
RCP3	9	30	03	32.38	19.93	6.16	76.69	344	227	7.88	0.25	47	0	0.34
RCP3	10	31	03	49.69	28.59	7.56	63.36	469	219	7.47	0.24	60	0	0.16
RCP3	12	15	03	78.48	58.46	15.4	49.65	356	319	.	0.21	.	0	0.22
RCP3	1	7	04	40.31	25.4	8.41	42.78	317	.	.	0.2	.	0.22	0.18
			Ave.	251.9	220.3	2.796	56.95	325.3	584.7	7.9082	0.249	166.4	0.067	0.391
		Std. Dev.		343.6	325	4.136	17.72	82.63	449.8	0.2785	0.051	115.5	0.082	0.262

RCP4 is the sludge from the setting tank that is pumped to the lagoon

RCP4	1	7	03	1406	444	0	436	134	47600	6.56	1.97	16183	2.7	20.2
RCP4	1	28	03	1876	1334	0	271	418	8640	8.44	0.87	4225	0.4	5.2
RCP4	2	10	03	5910	1886	0	2905	419	2E+05	6.13	15	.	16	105
RCP4	2	25	03	2381	825	0	1484	364	56200	6.88	10.03	.	10	57
RCP4	3	11	03	2590	1087	0.01	1073	543	35400	7.08	5.83	.	5.00	30.40
RCP4	3	25	03	1810	652	0	1203	483	4970	7.16	3.4	20333	2.6	27.4
RCP4	4	15	03	2308	312	0.01	1017	284	40100	6.73	5.69	.	4	96
RCP4	4	29	03	1350	199	0.06	725	282	26800	7.18	2.99	15667	6	36.6
RCP4	5	20	03	4209	1023	0	2127	441	1E+05	7.01	8.84	.	9.6	69.4
RCP4	6	9	03	1780	436	0	921	367	45900	7.28	5.17	.	5.4	55
RCP4	6	30	03	644	125	0.04	287	287	15740	7.47	1.03	.	1.44	10.2
RCP4	7	15	03	1645	404	0	641	351	84500	7.13	3.84	.	3.6	32.1
RCP4	7	28	03	1747	393	0.01	967	323	57800	7.09	4.9	.	3.6	31.1
RCP4	8	12	03	1696	426	0	1138	349	40400	6.92	6.43	.	2.9	30.8
RCP4	9	9	03	1230	167	0.04	834	326	28100	6.69	3.74	.	5.4	70.2
RCP4	9	30	03	1805	352	0.07	1390	474	54000	7.67	6.4	TO	4.7	37.8
RCP4	10	31	03	1345	440	0.02	462	313	23000	7.25	1.57	.	1.15	11.4
			Ave.	2102	617.9	0.015	1052	362.2	50350	7.0982	5.159	14102	4.97	42.69
		Std. Dev.		1241	471.9	0.023	670.5	96.24	40327	0.4969	3.607	6908	3.853	28.86

RCP5 is sludge from the collection sump in cell 1

RCP5	5	20	03	2945	690	0	1276	408	79700	7.03	4.51	.	9	65.2