

and assistance of Gary Evink and Larry Barfield from FDOT and Byron Lord from FHWA are very much appreciated.

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Removal of Highway Contaminants by Roadside Swales

Y. A. YOUSEF, M. P. WANIELISTA, and H. H. HARPER

ABSTRACT

Removal of highway contaminants by roadside swales was investigated at the Maitland and EPCOT Interchanges with Interstate 4 (I-4) in Orange County, Florida. Runoff samples from highway and grassy swale areas at Maitland Interchange were collected for 8 months for comparison of highway runoff with runoff that passed through a grassy swale. Also, a controlled water flow from adjacent detention/retention ponds was dosed with nitrogen, phosphorus, and heavy metals to produce concentrations typical of highway runoff. The mixture was allowed to flow for a period of 3.0 to 5.5 hr over selected areas of adjacent roadside swales. Periodic grab samples were collected from several locations along the swale throughout the flow period and were analyzed to determine concentration and mass removal rates for various pollutants under several values of flow rates and experimental conditions. Hydraulic, hydrologic, and water quality parameters were evaluated. Removal efficiencies for dissolved heavy metals appeared to be higher than for nitrogen and phosphorus. Pollutants may be retained in swale areas by sorption, precipitation, coprecipitation and biological uptake processes; however, occasional increases in concentrations of highway contaminants were observed at intermediate stations during the swale experiments. Mass removal of heavy metals, nitrogen, and phosphorus was directly related to infiltration losses and on-site storage.

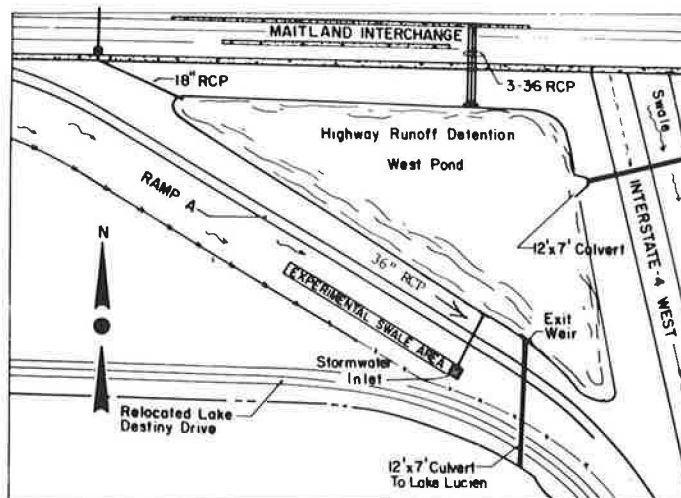


FIGURE 1 Location of experimental swale along Ramp A at Maitland Interchange and I-4.

Highways are routinely drained through broad, shallow, grassed channels, often termed swales, which attenuate runoff hydrographs and control roadside erosion. The hydraulic efficiencies of swales are based on the ability to infiltrate and percolate stormwater. However, their pollutant removal efficiencies, on the basis of quality considerations, have not been determined and little documentation on water quality effects is available. To the authors' knowledge, the only previous study on this subject was performed by Wang et al. (1). The Wang study was limited in scope and was designed to measure heavy metal concentrations in stormwater runoff that drained through a paved channel, a mud-bottomed ditch, and channels vegetated with grasses. No general conclusions were reached; however, it was reported that a 60-m-long grass channel of small slope reduced highway-runoff dissolved lead (Pb) concentrations by 80 percent or more during flow through the channel. Removal efficiencies averaged 60 percent for dissolved copper (Cu) and 70 percent for dissolved zinc (Zn) in the same channel. Samples from bare earthen channels of 15-m length and paved channels did not indicate significant reductions in heavy metal concentrations; however, no mechanisms were suggested for the observed results.

During this study, analyses of water quality of highway runoff and flow from grassy swales were conducted and the results compared. Also, a continuous flow of simulated highway runoff was pumped over the experimental area of a swale at the Maitland Interchange and I-4 and at the EPCOT Interchange and I-4 sites near Orlando in Orange County, Florida (Figures 1 and 2). Controlled experiments were designed to investigate changes in pollutant concentrations and mass balances for highway runoff that flows along swale areas. An attempt is made to answer some of the following questions:

1. Are swales efficient in phosphorus and nitrogen removal from stormwater runoff? If they are, to what extent and for how long do they retain those nutrients?
2. Are swales efficient in heavy metal removal from highway runoff? If they are, to what extent and for how long do they retain those metals? Also, are there different affinities for different metals and under what conditions are these metals released?

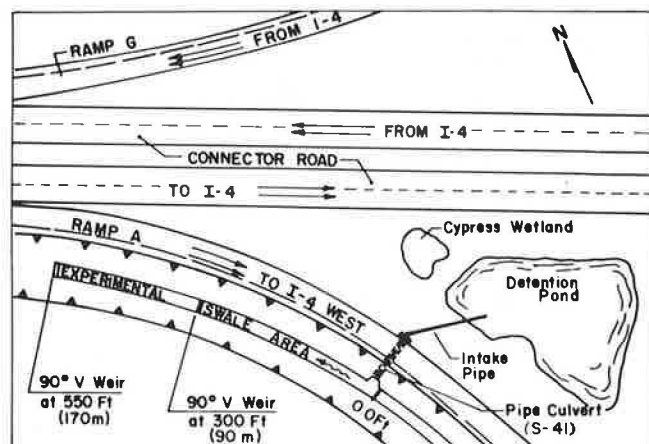


FIGURE 2 Location of Experimental Swale along Ramp A at I-4 and EPCOT Interchange.

3. Is it possible to develop design considerations on the basis of pollutant removal efficiencies?

FIELD EXPERIMENTATION

Concentrated solutions of heavy metals, such as Pb, chromium (Cr), cadmium (Cd), Nickel (Ni), Cu, Zn and iron (Fe) as well as nutrients such as phosphorous (P) and nitrogen (N), were dissolved in a 120-L polyethylene container. The chemical spikes were fed at a fairly constant rate into the flowing water before entering the swale area by using constant head gravity flow or a peristaltic dosing pump with controlled flow discharge. At the Maitland site, the chemical solution was fed by gravity near the inlet side of the submersible pump that was placed in the stormwater inlet (see Figure 1) and that was used for water intake. At the EPCOT site, the chemical solution was dosed by a peristaltic pump at the inlet of the 18-in. pipe culvert (S-41) shown in Figure 2 that crosses through ramp A to the start of the swale area. The spiked water was allowed to flow by gravity over the swale areas at selected discharge rates that were controlled by a gate valve attached to the PVC pipe near the suction side of the submersible pump.

TABLE 1 Hydraulic Characteristics of Swale Experiments

Experimental Swale					Flow Characteristics					
No.	Location	Date	Length (m)	Duration (hr)	Cross-Section Area (m ²)	Top Water Width (m)	Hydraulic Depth (m)	Q (m ³ /min)		Avg Calculated Velocity (m/min)
								In	Out	
1	Maitland	1/24/83	53	3.00	0.063	1.67	0.038	0.227	0.098	2.58
2	Maitland	2/07/83	53	4.00	0.045	1.35	0.033	0.086	0.038	1.37
3	Maitland	2/21/83	49	5.50	0.014	0.85	0.017	0.026	0.000	0.90
4	EPCOT	3/23/83	90	4.18	0.058	1.46	0.040	0.189	0.131	2.76
			80		0.060	1.49	0.040	0.131	0.118	2.08
5	EPCOT	5/16/83	90	4.00	0.056	1.37	0.041	0.189	0.145	2.98
			80		0.071	1.83	0.039	0.145	0.131	1.94
6	Maitland	5/31/83	53	4.00	0.056	1.79	0.031	0.145	0.118	2.35

The swale areas at the Maitland site were covered with predominantly Bahia grass that was approximately 2 to 4 in. high. A total of five flow-through experiments were conducted from January to May 1983. During January and February, the grass cover was dry and dormant. In late March, however, the grass cover was green and growing. The swale areas at EPCOT were newly constructed and consisted of bare soil with a 20 percent Bahia grass cover during the first experiment on March 23, 1983, and an 80 percent weed-and-Bahia grass cover during the second experiment on May 16, 1983.

Grab samples of water flowing over the swale area were periodically collected at several locations and transported to the Environmental Engineering and Sciences Laboratory at the University of Central Florida in Orlando for analysis. The analyses were conducted within the time frame recommended by the U.S. Environmental Protection Agency (3).

HYDROLOGIC AND HYDRAULIC PARAMETERS

The pumped inflow rates varied between 0.026 and 0.227 m³/min (7 to 60 gal/min) for the Maitland area and averaged 0.189 m³/min (50 gal/min) for the EPCOT area. The hydraulic characteristics of the swale experiments are listed in Table 1. The hydraulic water depth, which is defined as the cross sectional area divided by the top width of flow did not exceed 0.0041 m (1.6 in.). The calculated water velocity varied from 0.90 to 2.98 m/min (0.05 to 0.16 ft/sec) during the swale experiments under steady state conditions of flow.

After cessation of pumping, the flow through the exit weir was monitored until flow no longer occurred to produce the shape of the fall of the hydrograph. Flow hydrographs were then developed at each experiment. During the February 21, 1983 experiment at the Maitland site, the water did not reach the end of the swale and it was totally retained on the site. (Water is lost by infiltration, seepage, evaporation, transpiration and on-site storage.)

The hydrographs clearly reflect the water retention and the excess runoff from swale areas under various inflow rates. Hydrograph characteristics of the swale experiments are given in Table 2. The average loading rates varied from 0.036 to 0.154 m³/(m²·hr) (1.42 to 6.06 in./hr) on the Maitland swale area. The rates resulted in excess runoff averaging 0.0 to 0.068 m³/(m²·hr) (0 to 2.7 in./hr). The EPCOT site loading rates averaged 0.053 to 0.105 m³/(m²·hr) (2.08 to 4.13 in./hr) and the excess runoff averaged 0.039 to 0.071 m³/(m²·hr) (1.52 to 2.8 in./hr). The flow rates were calculated from the area under the hydrograph divided by the submerged area of the swale and the duration time of the flow. Under the experimental conditions, there was no excess runoff for flow less than 1.42 in./hr. Excess runoff reached more than 90

TABLE 2 Hydrograph Characteristics of Swale Experiments

No.	Mass Flow		Loading Rates [m ³ /(m ² ·hr)]	Infiltration [m ³ /(m ² ·hr)]	Excess Runoff [m ³ /(m ² ·hr)]
	In (m ³)	Out (m ³)			
1	40.9	17.6	0.154	0.088	0.066
2	20.7	8.3	0.072	0.043	0.029
3	8.14	0	0.036	0.036	0
4	57.7	39.2	0.105	0.034	0.071
	39.2	35.8	0.079	0.007	0.072
5	46.3	30.8	0.094	0.032	0.062
	30.8	23.0	0.053	0.014	0.039
6	35.1	26	0.092	0.024	0.068

percent of average input flow at the EPCOT site when the soil was saturated with moisture.

QUALITATIVE ANALYSIS

This study included the collection of water quality parameters from six different stations that surround the Maitland Interchange for approximately 8 months during 1982-1983 (3). Sampling stations were divided between stations that collect direct highway runoff and stations that collect flow from grassy swales. Comparison of average concentrations in water samples showed that both total and dissolved forms of every metal analyzed were lower in swale flow than highway flow as shown in Table 3. On the contrary, water samples from swale flow contained higher average concentrations of the nutrients, P and N than highway runoff.

TABLE 3 Comparison of Average Concentrations in Highway Runoff and Swale Flow During 1982-1983 at Maitland Interchange

Pollutant	Avg. Concentration (μg/L)					
	Highway Runoff (N=48)		Swale Flow (N=25)		Percent Change	
	Total	Dissolved	Total	Dissolved	Total	Dissolved
Zn	225	69	25	16	-90	-82
Pb	417	36	36	18	-91	-50
Cu	44	27	26	22	-41	-19
Fe	830	52	240	29	-71	-44
Cr	6.2	3.2	4.6	2.8	-44	-13
Cd	1.4	1.1	1.0	0.9	-29	-18
Ni	21	3.4	2.4	1.8	-86	-47
OP-P	136	84	239	195	+76	+132
TP-P	280	NA	351	NA	+25	NA
NH ₄ -N	NA	118	NA	172	+47	NA
(NO ₂ +NO ₃)-N	NA	280	NA	261	-7	NA
Organic N	NA	1732	NA	1784	+2	NA
Total N	NA	2130	NA	2217	+4	NA

Note: NA = Not available.

Zn concentrations were decreased to the greatest degree through swale areas with average reductions of 82 and 90 percent in dissolved and total species, respectively. Concentrations of Pb decreased 91 and 50 percent for total and dissolved species, respectively. Cu, Cd, and Cr concentrations decreased to the least degree through swale areas with an average reduction of 29 to 44 percent in total metal and 13 to 19 percent for the dissolved metal. It is assumed that the particulate metal fractions are removed through the swales at a higher percentage than the dissolved fraction as a result of filtration of particulate matter during transport through grassy covers.

Similar results were obtained during the simulated continuous flow swale experiments performed at the Maitland and EPCOT sites. Dissolved pollutants in flowing water at various locations along experimental sites of roadside swales are presented in Table 4. The Maitland site showed the greatest reduction in dissolved Zn and Fe with averages of 86 and 69 percent removal, respectively. Removals of dissolved Pb, Cu, and Cr were not significant. Under controlled conditions, however, reductions in nutrient (N and P) concentration were indicated that averaged 24, 25, 31, 13, and 6 percent for OP-P, TP-P, $\text{NH}_4\text{-N}$, $(\text{NO}_2 + \text{NO}_3)\text{-N}$ and TN, respectively. Organic nitrogen increased in concentration by 13 percent after flowing 53 m along the swale area.

TABLE 4 Average Concentrations of Dissolved Pollutants Flowing over Roadside Swales

Pollutant	Avg Concentration ($\mu\text{g/L}$)						
	Maitland Site			EPCOT Site			
	0.0 m	23 m	53 m	0.0 m	30 m	90 m	170 m
Zn	22	9	3	140	103	77	53
Pb	9	5	9	67	43	41	29
Cu	6	6	5	26	30	29	24
Fe	260	102	81	290	290	261	316
Cr	9	6	8	10	9	10	10
Cd	-	-	-	7	6	5	4
Ni	-	-	-	70	59	47	34
OP-P	368	290	279	580	546	514	530
TP-P	415	367	310	599	586	558	580
$\text{NH}_4\text{-N}$	1015	870	699	293	321	297	299
$(\text{NO}_2 + \text{NO}_3)\text{-N}$	192	188	167	147	151	147	163
Organic N	842	1337	951	1833	1994	1683	1973
Total N	2049	2395	1817	2273	2456	2127	2435

Removal rates of 62, 57, 43, and 51 percent for Zn, Pb, Cd, and Ni, respectively, were observed at the EPCOT site. All other measured parameters decreased slightly or increased after flowing 170 m. This site was a newly constructed swale with very little vegetation, a high water table elevation, and was nearly saturated with water during the swale experiments.

TOTAL MASS REMOVALS

Removal of pollutants in terms of a reduction in concentration is a useful approach because many water quality regulations are based on allowable concentrations that enter waterways rather than on a more difficult total mass approach. These regulations were presumably developed in this fashion to simplify enforcement. A small discharge that violates certain parameters of the regulation, however, may be far less damaging on a long-term basis than a continuous input that meets the regulations.

If the removal of pollutants in roadside swales

is considered on a total mass basis, the removal efficiencies will increase considerably as shown in Tables 5 and 6. Not only must the removal as a result of a change in concentration through the swale be considered, but also must the removal by infiltration into the ground be considered. This approach can be carried out to an extreme in a case such as the third Maitland experiment that showed 100 percent mass removal rates for all pollutants tested since the swale flow did not reach the outfall. It is interesting to note that some parameters such as Pb in the first Maitland experiment showed a 25 percent increase in concentration during passage through a swale area and was reduced in total mass by 46 percent.

Mass removal rates in terms of $\text{mg}/(\text{m}^2 \cdot \text{hr})$ for each of the Maitland and EPCOT experiments are also listed in Tables 5 and 6. These rates are calculated by dividing the total mass removed during travel through the swale area by the wetted area and experiment duration. It is important to note that these rates are highly site-specific. Mass is retained in the swale area by infiltration, seepage, transpiration, and soil-grass-water interactions. As runoff water is stored and retained in the swale area, the percent mass removal efficiency is increased. Water retention is a function of infiltration rate that may be related to surface water velocity or the residence time through the swale. Of course, infiltration is a function of many variables such as the antecedent dry period, soil porosity, and cover crop. However, it appears that the lower the surface velocity, the greater the infiltration rate along the swale, if other factors are assumed to be constant. Good correlations were found between mass removal rates of phosphorous, nitrogen species, and infiltration rates (3). Also, positive correlations between mass removal rates and total mass input were observed for most of the metals that were tested. This relationship is intuitively correct because the removal model is influenced by adsorption onto soil particles. This adsorption process should be expected to increase as the driving force in the form of total mass input increases.

DISCUSSION

The experimental swales were built with side slopes that were more than 6 horizontal to 1 vertical and longitudinal slopes of approximately 0.6 percent for the Maitland site and 0.1 percent for the EPCOT site. The field data included excess runoff, swale slope, average time of concentration, and length of travel; therefore, a relatively accurate estimate of the channel roughness measured by Manning's coefficient n could be calculated (4). The values for Manning coefficients varied from 0.055 to 0.096 for Maitland swale and from 0.035 to 0.059 for the EPCOT swale. The overall average value for n was 0.06. In the Maitland experiment conducted on February 7, 1983, the roughness coefficient was as high as 0.096. If this value was discarded when an average value for roughness was calculated, the mean coefficient would be 0.05. This value may help other designers of swale systems.

Also, when the rational formula was used, peak discharge for the shorter swale (53 m) was accurately predicted. However, for the larger swale (170 m), the calculated value was not as accurate when compared with the measured value. The average drainage area may be the variable that was difficult to measure accurately (4). The rational formula appears to be applicable for calculating peak discharges through swale areas.

TABLE 5 Removal of Dissolved Pollutants Flowing Over Roadside Swales at Maitland Interchange and I-4

Date	Pollutant	Mass Balance				Avg Concentration		
		In (g)	Out (g)	Percent Change	Removal [mg/(m ² · hr)]	In (μg/L)	Out (μg/L)	Percent Change
1/24/83	Zn	0.900	0.09	-90	3.1	22	5	-77
	Pb	0.49	0.26	-46	2.8	12	15	+25
	Cu	0.33	0.12	-62	0.8	8	7	-13
	Fe	1.43	0.30	-79	4.3	35	17	-51
	Cr	0.49	0.21	-57	3.4	12	12	0
	TP	25.60	9.47	-63	61	625	538	-14
	OP	23.80	8.98	-62	56	582	510	-12
	Ing-N	45.03	17.49	-58	104	1101	994	-9.7
	Org-N	8.27	3.57	-64	18	202	203	0
	T-N	53.21	2.09	-61	122	1301	1190	-8.5
2/7/83	Zn	0.54	0.02	-97	1.8	26	2	-92
	Pb	0.17	0.05	-70	0.4	8	6	-25
	Cu	0.15	0.03	-83	0.4	7	3	-57
	Fe	9.71	1.19	-88	30	469	143	-70
	Cr	0.12	0.03	-73	0.3	6	4	-33
	TP	12.15	2.55	-79	33	587	307	-48
	OP	9.89	2.10	-79	27	478	253	-47
	Ing-N	24.90	6.77	-73	62	1203	816	-32
	Org-N	6.56	2.65	-60	13	317	319	0
	T-N	31.46	9.41	-70	75	1520	1134	-25
2/2/83	Zn	0.15	0	-100	0.66	18	NA	NA
	Pb	0.05	0	-100	0.22	6	NA	NA
	Cu	0.02	0	-100	0.07	2	NA	NA
	Fe	2.56	0	-100	11.2	314	NA	NA
	TP	1.69	0	-100	7.4	207	NA	NA
	OP	1.64	0	-100	7.2	201	NA	NA
	Ing-N	7.12	0	-100	32	875	NA	NA
	Org-N	1.83	0	-100	9	225	NA	NA
	T-N	8.95	0	-100	41	1100	NA	NA
5/31/83	TP	8.39	5.77	-31	6.9	234	221	-6
	OP	7.41	5.46	-26	5.1	211	210	0
	Ing-N	57.8	37.1	-36	52	1646	1427	-13
	Org-N	92.0	71.6	-22	51	2621	2755	+5
	T-N	149.8	108.7	-27	103	4267	4182	-2

Note: NA = not available.

TABLE 6 Removal of Dissolved Pollutants Flowing Over Roadside Swales at EPCOT Interchange and I-4

Date	Pollutant	Mass Balance				Avg Concentration		
		In (g)	Out (g)	Percent Change	Removal [mg/(m ² · hr)]	In (μg/L)	Out (μg/L)	Percent Change
3/23/83	Zn	14.77	3.54	-76	10.7	256	99	-61
	Pb	5.25	1.15	-78	3.9	91	32	-65
	Cu	1.27	0.68	-46	0.56	22	19	-14
	Fe	28.22	18.54	-34	9.2	489	518	+6
	Cr	0.64	0.29	-55	0.33	11	8	-27
	Cd	0.64	0.25	-61	0.37	11	7	-36
	Ni	6.46	1.86	-71	4.4	112	52	-54
	TP	62.2	35.2	-43	25.8	1078	983	-9
	OP	62.1	34.4	-45	26.4	1077	960	-11
	Ing-N	15.5	10.7	-31	4.6	268	300	+12
	Org-N	100	59.4	-41	38.7	1733	1658	-4
	T-N	115	70.1	-39	42.8	2001	1959	-2
5/16/83	Zn	1.07	0.18	-83	0.82	23	8	-65
	Pb	2.04	0.60	-71	1.32	44	26	-41
	Cu	1.34	0.64	-52	0.64	29	28	-3
	Fe	4.21	2.62	-38	1.46	91	114	+25
	Cr	0.37	0.21	-43	0.15	8	9	+13
	Cd	0.09	0.02	-78	0.06	2	1	-50
	Ni	1.30	0.37	-72	0.85	28	17	-43
	TP	5.56	4.05	-27	1.39	120	178	+48
	OP	3.84	2.30	-40	1.42	83	100	+20
	Ing-N	28.3	14.3	-49	12.9	613	624	+2
	Org-N	89.5	52.6	-41	33.9	1932	2288	+18
	T-N	117.8	67	-43	46.7	2545	2912	+14

Data collected over an 8-month period from grab samples of both highway and swale runoff indicate lower removal efficiencies than were obtained in the experimental controlled flow situations. It is possible that certain metals may change forms between storm events and become soluble. This is particular-

ly likely in elements that have a change in species from a charged free ion to a neutral ion in the pH range of from 6.0 to 7.5.

From the results obtained in these swale experiments, it appears that the chemistry of heavy metals in natural waters is a fairly complex and site-spe-

cific phenomenon. In the studies conducted at Maitland in which only inorganic species were assumed to be present, the solubility and removal efficiencies that were obtained for dissolved species appeared to be related to the dominant inorganic complex present. Those metal species that were present as a charged ion, such as Zn and Fe, were removed to a significant degree. Those that were complexed with inorganic species and that carried either a diffuse or zero charge were not removed.

The importance of organic complexing in regulating solubility was demonstrated through the EPCOT experiments. Of the metal ions present, Cu, and Fe are known to form significant metal-organic complexes and, as a result, no removal was found to occur. Other metals that formed no important organic complexes were regulated by their inorganic species.

Ionic nitrogen species (NH_4^+ , NO_2^- , NO_3^-) and phosphorous species (H_2PO_4^- , HPO_4^{2-} , PO_4^{3-}) may similarly be retained on the swale site by sorption, precipitation, coprecipitation and biological uptake processes. By these processes, reductions of the nutrient concentrations in highway runoff that flows over swales can be made. In addition, a thin grass cover (20 percent or less) seems to be more efficient in decreasing contaminants than a thick grass cover (80 percent or more). It is believed that a thick grass cover may affect available soil sorption sites and increase organic debris (grass clippings, mower debris, litter). The organic debris is then subjected to decay processes and relocation. This was evident from the decline in the removal efficiency of soluble NO_3^- and NH_4^+ forms of N and organic-N in thick grassy swales that was observed on May 16, 1983 at the EPCOT site and on May 31, 1983 at the Maitland site. Also, the decrease in the removal of organic-N concentration may be attributed to an increase in organic deposition in the swale as a result of organic debris that exists during periods of rapid grass growth.

Occasional increases in highway contaminants were observed at intermediate stations during swale experiments, particularly at stations located close to the inflow point. This appears possible because of the initial flow effects on resuspension and resolubilization of loosely bound contaminants. The swale experiments showed better removal efficiencies at slow rather than high flow rates. The removal of nitrogen in swales on a concentration basis (measured in this study as micrograms per liter) was found to be inversely related to the velocity of the runoff through the swale (i.e., directly related to the residence time of the runoff in the swale). There seems to be very little removal of N concentrations when the excess runoff is above 3 in./hr. It is therefore apparent that if swales are designed to produce low inflow rates and velocities, some N concentration removal could be expected, with the amount of removal being a function of site conditions, such as swale cover and soil characteristics.

The removal of heavy metals, N, and P species on a mass basis, is directly related to infiltration losses through swales; therefore, retention of as much water as possible on the swale area will reduce the highway contamination loadings to adjacent receiving waters.

CONCLUSIONS

The following conclusions were reached:

1. Minimum observed infiltration rates were 0.5 and 1.4 in./hr and maximum rates were 1.3 and 3.4 in./hr for swales studied at EPCOT and Maitland Interchanges, respectively. These rates are much

lower than rates measured by the double-ring infiltrometer technique that shows values three to four times higher.

2. The measured runoff coefficients depend on the degree of soil saturation and the antecedent dry period. They varied between 0.41 and 0.91 during this investigation. Also, the calculated Manning's friction coefficient n for flow through the swale generally varied between 0.035 and 0.059 with an average value of 0.053 for most of the cases.

3. Swales built on high ground with good drainage and high infiltration rates showed better removal efficiencies for highway contaminants. Results from EPCOT suggest that removal of heavy metals decreases significantly in swale areas that are low and constantly wet.

4. Swales appear to be more effective in reducing concentrations of metals that N and P in a flow-through situation. These efficiencies are governed by the predominant ionic species and complexes. Charged species are retained by sorption processes. Swales filter out particulate heavy metal and incorporate them into the soil. Heavy metals in highway runoff with large particulate fractions show higher removal efficiencies.

5. Removal of heavy metals may be caused by precipitation and sorption processes; therefore, charged ions and complexes may be removed more efficiently than stable complexes and noncharged particles.

RECOMMENDATIONS

The efficiency of swale for removal of pollutants can be increased by increasing contact time and infiltration rates; therefore, the following recommendations are made:

1. Reduce longitudinal slopes of future roadside swales as much as possible;
2. Increase contact surface within the swale area by increasing the wetted perimeter-to-cross section area ratio by using relatively flat side slopes whenever possible;
3. Whenever possible, avoid building swales in areas where portions remain wet most of the time as a result of low ground and high groundwater tables;
4. Construct earthen cross barriers (swale blocks) at selected length intervals along the swale to retain additional water, so that the maximization of on-site retention by storage of runoff water in swales built on upland areas may be achieved; and
5. Plant a cover crop for erosion control and follow effective maintenance procedures; removal of grass clippings, loose debris, and litter is desirable if practical; also, consider slow growing grass species with low maintenance requirements.

ACKNOWLEDGMENTS

The authors wish to acknowledge with gratitude the financial support and technical assistance given by FDOT and FHWA personnel. In particular, the interest and assistance of Gary Evink, Larry Barfield, and Win Lindeman from FDOT and Byron Lord from FHWA were very much appreciated.

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