HIGH RUNOFFS POLLUTION LOAD: IMPLICATIONS AND CONTROLLING MEASURES

Er. Aijaz Ahmad Mir[1], Er. Kshipra Kapoor[2], Dr Javaid Ahmad Parray[3]
[1]M.Tech Scholar, [2]Assistant Prof. & Head, [3]Assistant Professor
[1,2]Department of Civil Engineering, Universal Institutions of Engineering and Technology, Lalru
[3]Environmental Science, Department of Higher Education, Jammu & Kashmir Govt.

***Abstract:* Stormwater management has become an important part of the field of water resources management. The traditional method of disposing of urban stormwater was to drain it away as quickly as possible. However, in recent years, questions concerning the impacts on the receiving waters began to arise, and in response to these concerns, some communities have elected to encourage capturing and treating stormwater runoff. Heavy metals in highway runoff continue to be a national concern for most transportation agencies including Jammu & Kashmir Department of Transportation and NHAI .The metal contaminants carried in the stormwater runoff and eventual snowmelt enters nearby surface waters and contributes to their degradation as well as threaten the survival of aquatic organisms at all levels of the food chain. This pathway of heavy metal contamination has become a significant concern due to increased urbanization and roadway construction. . The adverse impacts of the stormwater runoff can be minimized with structural and non-structural Best Management Practices (BMPs) or with a combination of them.**
***Keywords:* Non-point Source Pollution, Stormwater runoff, water pollution, ,water quality, highways, Best Management Practices (BMPs), environmental legislation**

I. INTRODUCTION

The ever-increasing concerns for the environment pooled with a rising demand for transportation have forced a number of studies of the environmental costs of motor vehicle transportation in order to inform public policies (Delucchi 2000). However most of these studies focus on air pollution, the main environmental externality associated with road transportation, or noise. But there is a great lacuna regarding the impacts of motor vehicles on water quality. There is currently no good estimate of the aggregate impact of motor vehicle transportation on water pollution, and some data suggests that water externalities resulting from motor vehicle transportation are based on educated guesses (Litman (2002; Delucchi 2000).

While the emphasis of recent regulations lead us to surmise that these impacts are substantial, it is still very difficult to quantify them reliably because motor vehicles are but one of many causes of non-point source pollution. Instead of trying to quantify the external costs caused by motor vehicle transportation on water quality, this research is concerned with the costs of controlling water pollution from motor vehicles focussing on various problems that have attracted considerable attention over the last few years particularly policy options for dealing with the non-point source pollution generated by the operation of motor vehicles. The negative environmental impacts of urban stormwater discharges are numerous and well documented (Driscoll et al. 1990; Bingham 1993; Mikkelsen et al. 1994; Pitt et al. 1995). In addition to carrying harmful substances into the environment, stormwater can cause flooding in urban areas during heavy rain events and other negative impacts resulting from the change in the natural hydrologic cycle.

Such problems are expected to increase in severity in the future due to an increase in urban construction, its density and climate change (Semadeni-Davies et al. 2008; Rosenberg et al. 2010). The residues from the operation of motor vehicles contribute heavily to non-point source and groundwater pollution (Davis et al. 2001; Kayhanian et al. 2003). Pollutants from motor vehicles or from transportation infrastructure include sediments (from construction or erosion), oils and grease (from leaks or improperly discarded used oil), heavy metals (from car exhaust, worn tires and engine parts, brake pads, rust, or used antifreeze ,road salts, as well as fertilizers, pesticide, and herbicides (used alongside roads or on adjacent land Hill and Horner 2005). A range of toxic contaminants (heavy metals, and polycyclic aromatic hydrocarbons) are produced by vehicles, road wear and road maintenance (Opher et al. 2009). Each year, approximately 185 million gallons of improperly discharged used motor oil pollute streams, lakes, and coastal areas (EPA 1999b) and is of major concern since one gallon of used oil can contaminate 1 million gallons of water. Groundwater quality is also threatened with more than 450,000 confirmed fuel leaks from underground storage tanks (USTs) in the U.S., including 44,000 in California (EPA 2005).

The current approach to dealing with motor vehicle externalities is typically reactive. Transaction costs are also frequently an issue because pollution often results from discharges of small amounts of pollutants in many different locations. Effective policies addressing water pollution from motor vehicles are likely to combine, in addition to best management practices (BMPs), public education campaigns, economic incentives, and enforcement. Better still, they should foster the integration of environmental considerations in the design of motor vehicles and the transportation infrastructure because addressing environmental problems after-the-fact is often much more costly than preventing them. The urban areas have been classified into main roads (including parking lots and airports), roofs, residential areas, commercial areas, industrial areas, parks and lawns, and open, undeveloped areas, all of which generate stormwater of different quality which transports different pollutants.

II. METHODOLOGY

Study area

This research was carried out in Summer city Srinagar(Jammu and Kashmir). The state of Jammu & Kashmir is strategically located in the north-west corner of India. The location was chosen as a study area because this research focuses on stormwater, heavy metal pollution to roadside soil and water bodies mainly due to transportation/ vehicular activities, etc on the road. Also, the strategic geographical location of the road makes it an important route.

Sample collection

Collecting a sample of sufficient volume was the most challenging aspect of monitoring for precipitation quality. Six storm events runoff were sampled in December(2016) and the rest events i-e January, February, March, April, and May in 2017,during a period of time whereby the study location was experiencing great rainfall events, and total rainfall recorded for these months were above monthly averages. For each event, 9 to 14 samples were collected to assess the water quality for each storm event.Prior to sample collection, the sample bottles were cleaned with conc. HNO_3, followed by complete washing with distilled water. Furthermore, the bottlesere rinsed thoroughly with sample water prior to its collection.

Methods and Physico chemical analysis for Storm water Roadway Pollutants

The water temperature, pH and conductivity were measured insitu using potable water analysis kit. The samples were filtered on spot through <0.45 µm Millipore membrane filters to separate the suspended sediments. Water samples were analysed using standard methods, in the Hydro geochemistry Laboratory, Department of Earth Sciences, University of Kashmir, Srinagar. Hardness was determined by EDTA titration using ammonium buffer solution and Erichrome black T as indicator. Ca^{2+} and Mg^{2+} were determined by EDTA titration using murciricoxide as indicator, Whereas$Cl^–$ ion was determined by titrating the samples against $AgNO_3$ (0.02 N) using potassium chromate (5%) as indicator.

The HCO_3 analysis was done by titration of the sample against HCl (0.01N) using methyl orange as indicator. The Na^+ and K^+ ions were determined by flame emission photometry. Spectrophotometer method was used for the determination of SO_4, $F^–$, SiO_2 and $NO_3^–$. All the samples were collected manually and stored in 1.0 L glass sample bottles with Teflon lined screw caps. Three identical water samples were taken at each sampling to ensure precision and accuracy. The samples were refrigerated and analyzed within 48 h after collection. The typical water quality pollutant parameters were measured, including total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN), ammonia nitrogen (NH_4^+-N), total phosphorus (TP), and heavy metals (Fe, Zn, Cu)etc .

III. RESULTS AND DISCUSSION

Various quality parameters were measured in highway runoff. The pollutants specifically related to the traffic are heavy metals, oil and grease, and hydrocarbons. The heavy metals most commonly detected in runoff water lead (Pb) and zinc (Zn). Chlorides are also important for the roads where deicing salts are applied. Nutrients (nitrogen and phosphorus) results from the contribution of fertilized soils, and coliforms from animal refuse. The research has resulted in the acquisition of a large number of data regarding the content of selected analytes in rain, road runoff and surface waters.

Heavy metals

Among heavy metals, Zn and Pb exhibited the highest concentrations, as expected for typical pollutants associated with vehicular traffic (Hares and Ward, 1999; Gnecco et al., 2005). The highest heavy metal concentrations were found in road runoff water. The main source of lead is fuel. However, it appears that only 5% of the lead is removed by runoff water. The largest fraction may, therefore, disperse in the atmosphere or settle on the soil by the roadside.

A relatively high level of Zn could be explained by the existence of metallic guardrails. According to Hewitt and Rashed (1992), the main sources of zinc are wear and tear from tires and brakes and from the corrosion of galvanized safety barriers, or from an alternative material (Barbosa and Hvitved-Jacobsen, 1999). As for Pb and Zn, concentrations increase in winter because of the use of chloride-based deicing salts, which generate supply and corrosion phenomena.

Direct Correlation between Pollutant Concentrations and Average Daily Traffic (ADT)

The pollution load in highway runoff depends on the average daily traffic, air quality and rainfall intensity and duration (Hvitved-Jacobsen et al., 1994). Traffic volume would seem to be an important factor for predicting runoff quality. Prior to storm events, roadways with ADT greater than 30,000 vehicles may produce runoff with two to five times the runoff pollutant levels found in that from rural highways. However, this highway runoff may not directly impact receiving streams.

This is true for both ADT and the number of vehicles during a storm. Naturally occurring surface winds and vehicular caused turbulence remove significant amounts of pollutants from road surfaces. These wind effects, therefore, lessen the impact traffic volumes have on runoff loadings to streams (Kayhanian et al., 2003). Simple linear regression analysis was performed to evaluate a direct correlation between ADT and the concentration of highway runoff pollutants (Figure 3).

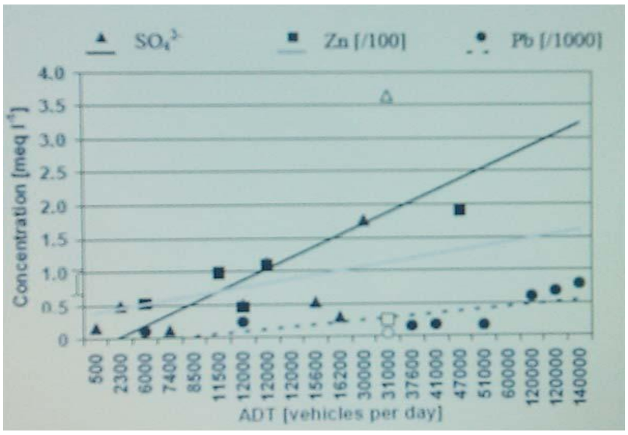

Figure Dependence of the average concentration of selected pollutants on the ADT (from literature data: Hares and Ward, 1999; Barbosa and Hvitved-Jacobsen, 1999; Pagotto et al., 2000; Legret and Pagotto, 1999; Hewitt and Rashed, 1992; Harrison and Wilson, 1985; Bäckström et al., 2003.

The results of this analysis revealed relatively higher values for all constituents, which may suggest a direct correlation between ADT and pollutant concentrations. However, most of the studies reported in the literature did not confirm strong correlations. For example, Chui et al. (1982) found only a weak correlation, and a study conducted by Driscoll et al. (1990) suggested that there is no strong and definitive relationship between differences in traffic density and the pollutant concentrations for a site. Other investigators found somewhat better correlations between ADT and highway runoff pollutants. For example, McKenzie and Irwin (1983) found that the concentrations of lead and zinc correlate well with ADT. The results obtained during the present research show that the physico-chemical nature of stormwater and water of the river Jehlum has been affected and the concentration of some of the constituents has crossed the permissible limit as recommended by WHO. The pH was found within the range of 7.60-8.99 with the highest recorded at site A followed by B ,C,D,E,and F respectively. The pH was decreasing while moving downstream from site A to site F. pH a measure of the acidity of the water, recorded remarkable decreasing trend from Khanabal in South to Ganderbal in North. At all the study stations the values of pH were higher in May (Table). pH recorded a tilt from alkaline to acidic side as the river progressed from south to north.. Like wise the conductivity was within the range of 205 µs cm-1 at site A in the month of January to 497 µs cm-1 at site F in the month of May, while site B recorded a conductivity of 356,site C 455, site D 457 and site E 464 The conductivity was found less than the permissible limits. Chloride in water is generally due to the salts of , potassium and calcium in the present study the chloride content was in the range group of 5.9- 16.48 /litre, being highest at siteF (16.48 mg/l) in the month of May and lowest (5.9 mg/l) at site A in the month of January. The comparison of chloride content of present values with that of the WHO reveals that it is much lower than the permissible limits. It was also observed that the concentration of nitrates was more than the permissible limits. The value ranged between 430mg/l at site B to 863mg/l at site C and it was 385 mg/l at site A,site D 756 mg/l , site E 543 mg/l and site F 699 mg/l respectively. Similarly the concentration of nitrite was within the range of 95- 227 mg/l with the highest concentration at site A (197.5 mg/l) followed by B (113.3 mg/l) site C (69.5 mg/l) , site D (76mg/l), site E (83 mg/l) , site F (95.7 mg/l) respectively. Furthermore it was also observed that the concentration of calcium was varying with respect to the sampling sites and was within the range of 39- 68 mg/l which is within the permissible limits. The average concentration was lowest at site A (39.2 mg/l) followed by site B (46.62mg/l) ,site C (53.75mg/l), D(60.5 mg/l), E (64.1mg/l) F (68.9 mg/l) respectively.

Table Physico-chemical properties of Water at different sites of Srinagar and River Jehlum (Mean of events)

Parameters	Sampling Sites					
	A	B	C	D	E	F
Ph	8.99	7.92	7.74	7.69	7.65	7.60
Conductivity (µs cm -1)	205	356	455	457	464	497
Alkanity (mg/l)	100	110	116	119	123	127
Free CO2 (mg/l)	25	28	24	11	16	19
Chloride (mg/l)	5.9	15	13	12	15.60	16.48
Nitrates (µg/l)	385	863	430	756	543	699
Nitrites (µg/l)	227	111.3	69.5	76	83	95.7
Calcium (mg/l)	39.2	46.62	53.75	60.5	64.1	68.9
COD (mg/L)	91.2	64.0	208.0	60.8	142.4	373.4
TP (mg/L)	0.79	0.37	1.01	0.62	3.14	0.68
TN (mg/L)	7.07	1.98	9.03	2.07	6.36	5.00
NH4+-N (mg/L)	2.07	1.26	0.75	5.14	1.31	2.55
NO_3^--N (mg/L)	1.04	1.59	4.67	1.04	3.08	4.99
TSS (mg/L)	314.2	211.0	874.0	564.8	950.2	120.1
DPb (mg/L)	0.0039	0.0022	0.0036	0.0042	0.0054	0.0046
DCu (mg/L)	0.0142	0.0049	0.0065	0.0019	0.0047	0.0036
DZn (mg/L)	0.0047	0.0057	0.0067	0.0101	0.0065	0.0081

Table Summary of Rainfall Events Sampled

Date	Duration (hr)	Antecedent Dry Days	Total Rainfall (in)
December 25, 2016	4	18	1.3
January16,2017	3.5	10	2
February2, 2017	1	03	3.7
March 27, 2017	7	20	8.2
April7, 2017	2.5	4	3.5
May 2,2017	1.5	8	3.1

Comparing the runoff quality between Srinagar , Macau, (Huang et al. 2007), and Guangzhou in China (Gan et al. 2008), Genoa, Italy (Gnecco et al. 2005), and Los Angeles, California (Han et al. 2006) and California in the USA (Kayhanian et al. 2007) (Table 3), the mean EMCs of TSS, TP, TN, and COD concentrations in urban road runoff in Srinagar were significantly higher than in Macau and Genoa. Compared with the highway sites, the mean EMC of

TSS concentrations in Srinagar was significantly higher than the other urban sites. In addition, the mean EMCs of TP, TN, and COD concentrations were also higher. It is assumed that this is because of the high slope of the road in this study (9°), and therefore, the vehicle tire and road surface friction are greater than that in the other urban roads/highways. As a result, the mean EMC of the TSS concentrations was higher than the other urban sites, even though their traffic volume was greater than in Srinagar. It was found that greater runoff concentrations of polycyclic aromatic hydrocarbons in a slope site compared to two other nearby sites are due to more fuel being burnt when driving uphill. The mean EMCs for the concentrations of the dissolved metals (Cu, Pb, and Zn) in Srinagar were significantly lower than in the other urban areas, probably because the traffic volume in Srinagar was lesser than in the other areas. Göbel et al. (2007 concluded that the heavy metal concentrations were higher for traffic areas. The mean EMCs for the TSS concentrations in Srinagar were observed to be significantly higher than those in the USA and Italy. This could indicate poor quality of either the atmosphere and/or the sanitary conditions in Srinagar.

Table Comparison of the water quality of surface runoff in various locations

Parameters	This study (2017)	Huang et al (2007)	Gan et al. (2008)	Gnecco et al. (2005)	Han et al. (2006)	Kayhanian et al. **(2007)**
Location	Srinaagar	Macau China	Guangzhou China	Genoa Italy Los Angeles,	Los Angeles California USA	California USA
Road/highway Highway	Highway	Road	Highway	Road	Highway	
Annual average daily traffic (vehicles/day)	27,000-67000	30,000-93500	22,170-112300	-	260,000–328,000	1,800–320,000
COD (mg/L)	163.2	117.8	308.0	129.0	252.5	–
TP (mg/L)	0.89	0.24	0.39	–	0.90	0.29
TN (mg/L)	4.74	3.58	7.32	–	–	–
TSS (mg/L)	461.1	417.2	415.7	140.0	67.7	112.7
DPb (mg/L)	0.0031	–	–	0.0132	0.0049	0.0076
DCu (mg/L)	0.0065	–	–	0.0194	0.0659	0.0149
DZn (mg/L)	0.0058	–	–	0.0811	0.4153	0.0688

IV. CONCLUSIONS AND RECOMMENDATIONS

With regard to the quality of storm water runoff, pervious and impervious surfaces collect hundreds of pollutants such as animal waste, bacteria, oil and grease, sediment, litter, pesticides and deposits from airborne pollutants. These hazardous materials can easily enter our commercial waterways, making our water sources unsafe for human use and hazardous for aquatic animals. The quantity of storm water is increased when impervious structures replace meadows and woodlands. Without nature to absorb the rainfall, its runs off on paved sidewalks and concrete rooftops, collecting the said pollutants. From the present study it is clear that the water quality of Srinagar and River Jehlum has been degraded qualitatively and the concentration of some constituents has passed the permissible limits and this could pose a great threat to the all kinds of life directly or indirectly therefore steps must be taken to protect this divine gift of nature and the present study is a step towards the same. Many people do not seem to realize how important water is to our survival and progress. Every country, business, community, and individual use it, and it affects all aspects of life. When the quality of water decreases, everything it affects fall behind it. That's why it is crucial that our world start managing our water consumption and handling. There is no single source we can target, so it will not be an easy issue to tackle. This can not be possible until local, state, and national storm water regulations are altered to allow for changes in our lifestyle. With the interest of money, most storm water regulations are very strict, not authorizing conservation practices or environmentally friendly systems; anything that can deplete a local community's budget. All the researchers in the world can come up with the best management practices ever developed, but if they aren't allowed to take effect, what good will they do? Building permits regarding the construction of BMPs must be easier to attain. The world is too afraid to change. If there is some chance that something can go wrong, most people won't even consider it, but if no one strives for a change, nothing will ever be improved. We need to take a chance on our strive to improve the Earth. Our environment is in danger because of us, and it is up to us to fix it.

REFRENCES

[1] Delucchi, M. A. (2000). Environmental externalities of motor-vehicle use in the US. Journal of Transport Economics and Policy 34

[2] Litman, T. (2002). Transportation Cost and Benefit Analysis: Techniques, Estimates, and Implications. Victoria Transportation Policy Institute, Victoria, Canada.

[3] Driscoll, E.D., Shelley, P.E., and Strecker, E.W., 1990a, Pollutant Loadings and Impacts from Highway Stormwater Runoff, Vol. 1: Design Procedure, Federal Highway Administration, Office of Research and Development Report No. FHW A-RD-88-006.

[4] Driscoll, E.D., Shelley, P.E., and Strecker, E.W., 1990a, Pollutant Loadings and Impacts from Highway Stormwater Runoff, Vol. 1: Design Procedure, Federal Highway Administration, Office of Research and Development Report No. FHW A-RD-88-006.

[5] Semadeni-Davies, A., Hernebring, C., Svensson, G., and Gustafsson, L-G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. Journal of Hydrology, 350(1), 114-25.

[6] Rosenberg, N. J., Epstein, D. J., Wang, D., Vail, L.,Srinivasin,R.& Arond, J. G. 2010 Possibleimpacts of global warming on the hydrology of theOgallala Aquifer region. Climatic Change, 42,677–692.

[7] Davis, A. P., Shokouhian, M. and Ni, S. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources

[8] Davis, A. P., 2007, Field performance of bioretention: water quality: Environmental Engineering Science, v. 24, no. 8, p. 1048-1064.

[9] Hill, K., Horner, R. (2005). Assessment of

Alternatives in Roadside Vegetation Management

[10] Opher, T., Ostfeld, A.& Friedler, E. (2009). Modeling highway runoff pollutant levels using a data driven model. Water Science and Technology, 60(1), 19-28

[11] Hoffman, E.J., Mills, G.L., Latimer, J.S., an C d Quinn, J.G., 1984, "Urban Runoff as a Source of Polycyclic Aromatic Hydrocarbons to Coastal Waters," Environmental Science and Technology, Vol. 18, No.8, pp. 580-587.

[12] Walker WJ, McNutt RP, Maslanka CA. The potential of urban runoff to surface sediments of the Passaic River: sources and chemical characteristics. Chemosphere 1999;38:363 – 77.

[13] Welker, Andrea L., Gilbert Jenkins, Jennifer K., McCarthy, Leslie, Nemirovsky, Evgeny. 2013. Examination of the material found in the pore spaces of two permeable pavements. Journal of irrigation and drainage engineering. 139(4): 278-284.

[14] Kobriger, N., and Gupta, M.K., 1984, Sources and Migration of Highway Runoff Pollutants, Vol. II: Methods, FHWA/RD-84/058 Federal Highway Administration, Washington, DC

[15] Barret, M. E., Irish, L. B., Malina Jr, J. F., & Charbeneau, R. J. (1998). Characterization of highway runoff in Austin, Texas, area. Journal of Environmental Engineering , 124 (2), 131-137.

[16] Barrett, Michael E. 2008. Effects of a permeable friction course on highway runoff. Journal of irrigation and drainage engineering. 134(5): 646-651.

[17] Roy, Allison H., Wegner, Seth J., Fletcher, Tim D., Walsh, Christopher J., Ladson, Anthony R., Shuster, William D., Thurston, Hale W., Brown, Rebekah R. 2008

[18] Peterson, S.A., Miller, W.E., Greene, J.C., and Callahan, C.A., 1985, "Use of Bioassays to Determine Potential Toxicity Effects of Environmental Pollutants," Perspectives on Nonpoint Source Pollution, pp. 38-45

[19] Yousef, Y. A. (1985). Consequential Species of Heavy Metals. BMR- 85-286 (FL-ER-29-85), Florida Department of Transportation, Tallahassee, FL.

[20] Wu, J. S., Allen, C. J., Saunders, W. L. and Evett, J. B. 1998 Stephenson et al., 1999). Characterization and pollutant loading estimation for highway runoff. Journal of environmental Engineering, 124(7), 584 592

[21] Young, G. K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. (1996). Evaluation and management of highway runoff water quality. FHWA-PD- 96-032. GKY and Associates Inc., Springfield, VA

[22] Burch, C. W., Johnson, F., and Maestri, B., 1985a, Management Practices for Mitigation of Highway Runoff Pollution: VOlume I, Guidelines, FHWA/RD-85-001, Versar Inc., Springfield, VA.

[23] Gan, H. Y., Zhuo, M. N., Li, D. Q., & Zhou, Y. Z. (2008). Quality characterization and impact assessment of highway runoff in urban and rural area of Guangzhou, China. Environmental Monitoring and Assessment, 140(1–3), 147–159.

[24] Gan, H. Y., Zhuo, M. N., Li, D. Q., & Zhou, Y. Z. (2008). Quality characterization and impact assessment of highway runoff in urban and rural area of Guangzhou, China. Environmental Monitoring and Assessment, 140(1–3), 147–159.

[25] Barbosa A.E. and Hvitved-Jacobsen T. (1999) Highway runoff and potential for removal of heavy Metals in an infiltration pond in Portugal, Sci. Total Environ., 235, 151-159.

[26] Hewitt C.N. and Rashed M.B. (1992) Removal rates of selected pollutants in the runoff waters from a major rural highway, Water Resolution, 26, 311-319

[27] Hares R.J. and Ward N.I. (1999) Comparison of the heavy metal content of motorway stormwater following discharge into wet biofiltration and dry detention ponds along the London Orbital (M25) motorway, Sci. Total Environ., 235, 169-178.

[28] Huang, J., Du, P., Ao, C., Ho, M., Lei, M., Zhao, D., et al. (2007). Multivariate analysis for stormwater quality characteristics

[29] identification from different urban surface types in Macau. Bulletin of Environmental Contamination and Toxicology, 79(6), 650–654.

[30] Hvitved-Jacobsen T., Johansen N.B. and Yousel Y.A. (1994) Treatment systems for urban and highway run-off in Denmark, Sci. Total Environ., 146/147, 499-506

[31] Driscoll E.D., Shelley P.E. and Strecker E.W. (1990) Pollutant loadings and impacts from highway stormwater runoff. Volume III: Analytical investigation and research report. Publication No. FHWA-RD-88-008, Federal Highway Administration, Washington, D.C

[32] Kayhanian M., Singh A., Suverkropp C. and Borroum S. (2003) Impact of Annual Average Daily Traffic on Highway Runoff Pollutant Concentrations, J. Environ. Eng., 129, 975-990.

[33] Chui T. W., Mar B.W. and Horner R.R. (1982) Pollutant loading model for highway runoff, J. Environ. Eng., 108, 1193–1210.

[34] Kayhanian, M., Suverkropp, C., Ruby, A., & Tsay, K. (2007). Characterization and prediction of highway runoff constituent event mean concentration. Journal of Environmental Management, 85(2), 279–295.

