ROad runoff Pollution
management and mitigation
of environmental RIsks

PROPER PROJECT
WP1 - PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.2. Critical review of the tools to predict road runoff

Conference of European Directors of Roads (CEDR)

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DELIVERABLE 1.2

Title

PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.2. Critical review of the tools to predict road runoff

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PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF

T1.2. Critical review of the tools to predict road runoff

Abstract

This report stands for the project deliverable 1.2 and concerns the results from task 1.2 of the Proper Project, namely *Characterization and critical review of the tools to predict road runoff*.

Following the literature review conducted in task 1.1 where the most important pollutants in road runoff were identified, the aim of the present task is to evaluate the models from a theoretic point of view in order to choose the most feasible to be used by operators or road designers to predict pollution in road runoff.

The selected predicting models were:

- PREQUALE (Barbosa *et al.*, 2011)
- Highways Agency Water Risk Assessment Tool (HAWRAT) (Crabtree *et al.*, 2008)
- Multiple linear regression by Kayhanian *et al.* (2007)
- Stochastic Empirical Loading and Dilution Model (SELDM) (Granato, 2013)
- Multiple linear regression by Higgins (2007)
- Risk Assessment of road stormwater runoff (RSS) (Gardiner *et al.*, 2016)

Each one was assessed taking into account the input data, the easiness of applicability and the consistency of the output results. These factors were classified by a score from 1 to 3 in order to have a global rating.

This methodology was used to select the four models to be implemented in task 1.4 of the PROPER Project: PREQUALE; HAWRAT; Kayhanian *et al*. (2007) and SELDM.

Keywords: Road runoff, pollution, predicting models

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1 | Introduction

The project PROPER is funded by the Conference of European Directors of Roads (CEDR) and it comprises the characterisation and prediction of the road runoff pollution, the evaluation of its potential impacts on receiving water bodies and related ecosystems and the evaluation of treatment systems for impact mitigation during operation and construction of roads. The project has a total duration of 24 months and it has started in September 2017.

The work programme is organised into 6 major Work Packages (WPs) where WPs 1 to 4 correspond closely with the scientific objectives of the project, namely:

- **WP1:** Prediction of pollutant loads and concentrations in road runoff;
- **WP2:** Assessing the vulnerability of European surface and groundwater bodies to road runoff during the building and operating of roads;
- **WP3:** Sustainable assessment of measures and treatment systems for road runoffs;
- **WP4:** Sustainable assessment of measures and treatment systems for road runoffs during construction work.

WP5 focuses on ensuring maximum impact through the implementation of a robust dissemination strategy with **WP6** outlining the project management activities which underpin successful project completion.

The present report stands for the project deliverable 1.2 and it concerns the results from task 1.2 of the Project, namely the *critical review of the models to assess the pollution characteristics in road runoff*. The aim of this task is to evaluate the models from a theoretical point of view in order to choose the most feasible to be used by operators or road designers to predict pollution in road runoff.

Based on the literature review (task 1.1) and on the comments from project partners and the IAB members, the first step of this task was the identification of existing models (including methods, software or simple equations) to predict road runoff pollution.

The second step was to assess these models. This assessment was based on criteria that included the input data, the easiness of applicability and the consistency of the output results. It should be pointed out that the assessment was mainly performed by analysing the manuals, papers and reports that represent the available knowledge and guidance to support the use and implementation of each model. The established criteria (i.e. input data requirements, easiness of applicability and consistency of the output results) will be analysed and rated to obtain a final score for each selected model. This score will enable the selection of the models to be further analysed and implemented.

The assessment of the models to predict pollution in road runoff will continue in the following two tasks of WP1 of the Proper Project. In task 1.3, several European case studies with available monitoring data will be selected and presented. In task 1.4, the predicting models selected in this report will be used to predict the road runoff quality, and the obtained results will be compared to the monitoring data, therefore providing insight on the accurateness of the model.

Task 1.5 of the Proper Project is focused on drafting the state of the art of models used for air emission calculations and air quality assessment. The objective of this task is to conclude whether this sort of models may be useful to support the prediction of road runoff pollution. For this purpose, they should as well accomplish the criteria for sound applicability.

2 | Methodology

The objective of task 1.2 is to characterize, review and assess the available open access models to predict the characteristics of road runoff pollution.

A first selection of the models was made according to the report on the Deliverable 1.1 of the Proper Project. A summary of the models was already presented in the report of Task 1.1 (deliverable D1.1). Meanwhile, the list of the models to be included in this task 1.2 was updated taking into account inputs from all partners. The list of the selected models is the following:

- PREQUALE (Barbosa *et al.*, 2011)
- Highways Agency Water Risk Assessment Tool (HAWRAT) (Crabtree *et al.*, 2008)
- Multiple linear regression (Kayhanian *et al.*,2007)
- Stochastic Empirical Loading and Dilution Model (SELDM) (Granato, 2013)
- Multiple linear regression (Higgins, 2007)
- Risk Assessment of road stormwater runoff (RSS) (Gardiner *et al.*, 2016)

In the next section of this report, each model is described, including its background and theoretical framework. When the model also includes the potential to evaluate road runoff impacts in the receiving water systems, and/or stormwater control strategies, these are described for the purpose of a complete overview of the model possibilities, although this task only focus on road runoff quality prediction.

The assessment will be focused on 3 criteria, namely (i) data requirement; (ii) applicability and (iii) output results.

It should be noted that the selection of the models generated a set of models with rather different applicability levels. Therefore, it is expected that a generic model that estimate site mean concentrations will have much less data requirements than a complete model that calculate the mean concentration of each event.

In order to have a systematic and global evaluation and ranking of the predicting models, each criterion will be assessed according to a score from 1 to 3.

Score	Data requirement	Applicability	Output	Global score
1	Difficult to get data	Hard to apply	Inconsistent output	Sum of all the score in the 3 parameters
↓	↓	↓	↓	
3	Data easily available	User friendly	Consistent output	

Figure 2.1. Score system for the evaluation of each parameter

Regarding the parameter “Data requirement”, the amount and availability of data from the road and from the weather conditions will be assessed. Therefore, if the requirements of a model are cumbersome and not easily obtainable from the road projects and from national meteorological monitoring networks, this information is classified as difficult to get and the model will receive a score of 1. On the other hand, if the data is easily available, the model will receive a score of 3.

Regarding the easiness of “Applicability” of the model, it will receive a score of 1 if it is hard to apply, up to 3 if it has a user friendly interface. Lastly, regarding the “Outputs”, if the model directly calculates the site mean concentration of key road runoff pollutants it will receive a score of 3. If not all parameters are addressed or if additional calculations have to be made, it will receive a score of 1.

Taking into account the assessment of the models and the sum of the scores in each item, at the end, the models to be implemented in task 1.4 will be selected, based on the ranking of the 6 models under evaluation.

3 | Characterization of the six selected models

3.1 Prediction of road runoff Quality (PREQUALE, 2011, Portugal)

In the scope of the research project G-Terra funded by the Portuguese Foundation for Science and Technology and coordinated by the National Laboratory for Civil Engineering (LNEC), several roads were monitored in terms of the pollution of road runoff between 2002 and 2006 (Barbosa *et al*. 2011). Using these data and the previous knowledge of LNEC on road runoff monitoring in Portugal, the model PREQUALE was developed.

PREQUALE is based on a set of monitored data for six Portuguese roads. These roads are located in different climatic regions within Portugal, located in areas with annual mean precipitation ranging from 560 mm to 1200 mm. The AADT also ranged from around 6500 up to 30300 vehicles per day. The data was generated with automatic and continuous road runoff sampling along precipitation events, combined with flow and rainfall measurements. The Site Mean Concentration (SMC) for each road is based on an average of 8-10 independent runoff events.

The applicability of the tool is rather simple as it is based on a multiparametric equation with the following input variables:

(i) Drainage Area (DA in km^2): area which contributes with runoff to the discharge point during a rainfall event;
(ii) Impervious fraction (IF in %): the percentage of the total drainage area which is impervious;
(iii) Average annual rainfall volume with the same duration as the time of concentration of the basin(AR in mm);
(iv) Annual average precipitation (P_{annual} in mm).

This tool aims at directly predicting SMCs. The multiparametric equation takes the following form:

$$SMC_p = a_i \left(DA^{\beta_1} \times IF^{\beta_2} \times AR^{\beta_3} \times P_{annual}{}^{\beta_4}\right)$$

where $SMCp$ is the estimated site mean concentration of each pollutant (mg/L) and a_i, β_1, β_2, β_3 and β_4 are the regression coefficients.

The current version of PREQUALE allows the prediction of SMCs for TSS, COD, Fe, Zn and Cu. The regression coefficients (and their r^2) to be used in PREQUALE are presented in Table 3.1.

Table 3.1. PREQUALE regression and correlation coefficients *(adapted from: Barbosa et al., 2011)*

Parameter	a_i	β_1 (DA)	β_2 (IF)	β_3 (AR)	β_4 (P_{annual})	Correlation Coefficient
TSS (mg/L)	$1{,}22\times10^{44}$	0,257	-5,085	-28,797	-2,945	0,9696
COD (mg/L)	$1{,}91\times10^{25}$	0,1644	-3,165	-16,914	-1,064	1
Fe (mg/L)	$9{,}20\times10^{44}$	-0,1491	-6,546	-28,229	-3,371	1
Zn (mg/L)	$1{,}15\times10^{05}$	-0,135	-1,08	-0,323	-1,296	0,8843
Cu (mg/L)	$3{,}08\times10^{01}$	0,036	-0,705	0,396	-0,702	0,9989

Some results are presented in Figure 2.1.

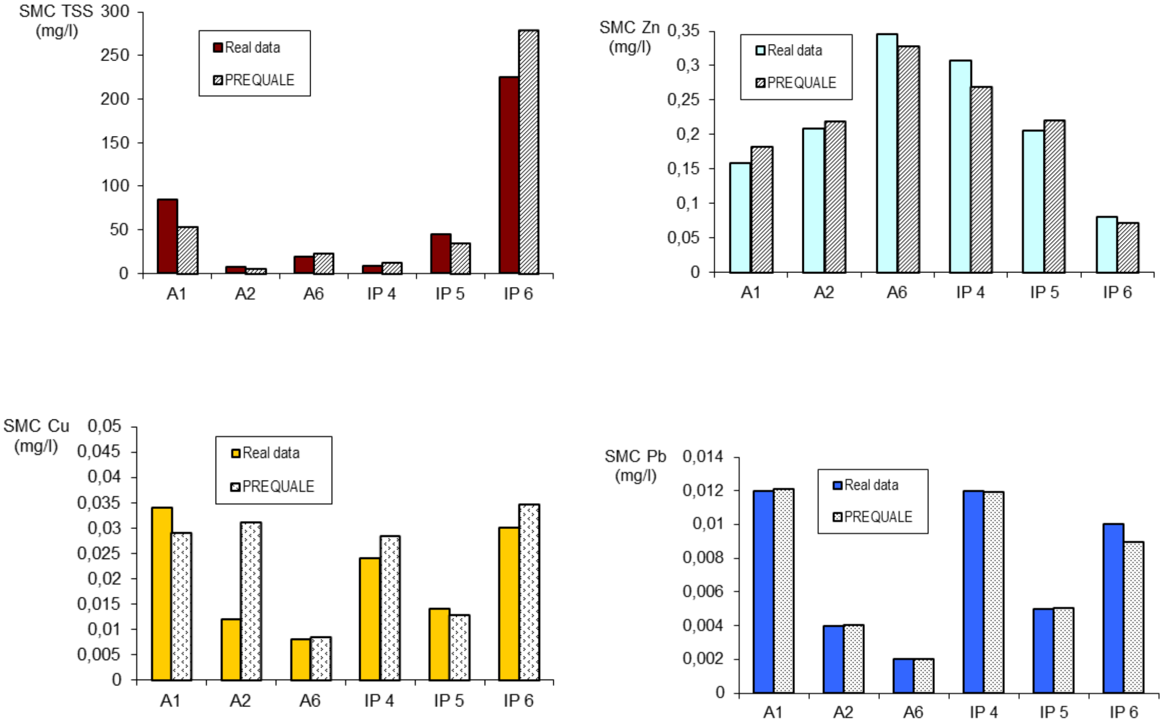

Figure 3.1. Results of Site Mean Concentrations for TSS, Zn, Cu and Pb for 6 Portuguese roads (A1, A2, A6, IP4, IP5 and IP6) predicted by PREQUALE

3.2 Highways Agency Water Risk Assessment Tool (HAWRAT, UK, 2008)

The Highways Agency Water Risk Assessment Tool (HAWRAT) was developed by the Highways Agency from the United Kingdom as a standalone application aiming at assisting highway designers and operators in the decision if whether or not pollution mitigation measures are needed in specific circumstances.

HAWRAT allows the prediction of (i) Soluble pollutants associated with acute pollution impacts, expressed as SMCs for dissolved copper and zinc and (ii) Total suspended sediments.

Besides the prediction of runoff quality, HAWRAT comprises equations for predicting the impact of the runoff on receiving rivers and streams. This assessment made by HAWRAT has three steps as shown in Figure 3.2: *Step 1* concerns road runoff pollution prediction, *Step 2* is related to the impacts on the receiving water bodies and *Step 3* deals with mitigation measures. For the objective of the current report, only step 1 is taken into consideration.

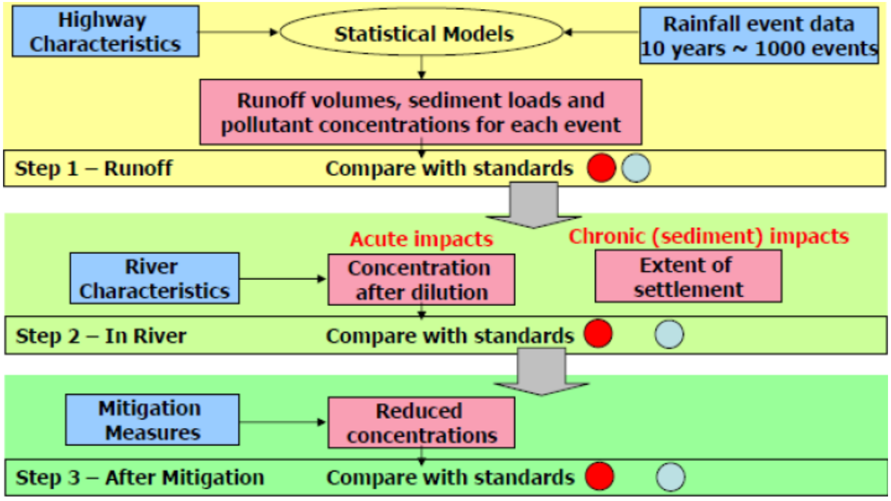

Figure 3.2. HAWRAT methodological scheme *(Jotte et al., 2017)*

The UK Highways Agency emphasizes that the tool can be applied in Wales, Scotland and Northern Ireland, although the basic data was generated in England, and recalls its limited ability to assess the impact on streams where the flow is intermittent or seasonal – as is common in Southern European countries.

Step 1 uses statistical models of monitoring data to determine pollutant concentrations in raw road runoff prior to any treatment or dilution in the receiving watercourse. For the calculation of SMC, EMCs are calculated taking into account the following multiple linear regression:

$$\log_{10}EMC = PC + CRC + AADTC + MC - \gamma_1 \times MHI + \gamma_2 \times ADP$$

Where:
PC is a pollutant constant (-);
CRC is a Climate region constant (-);
AADTC is a constant related to the annual average daily traffic (veh/day);
MC is the month constant (-);
MHI is the maximum hourly precipitation (mm);
ADP is the antecedent dry period (hours).

γ_1 and γ_2 are the regression coefficients. All constants and coefficients are presented in Table 3.2. CRC is defined for the UK and depends on the climate. The country is divided in 4 areas according to the climate regions, cold/wet, cold/dry, warm/dry and warm/wet.

Table 3.2. Constants used in HAWRAT *(adapted from: Dempsey et al., 2007)*

		EMC constants			
		Total Copper	**Total Zinc**	**Total Cadmium**	**TSS**
Site	Constant	1,394	1,91	-0,832	2,1
	Cold/Dry	0	0	0	0
	Cold/Wet	0,042	0	0	-0,217
	Warm/Dry	0,144	0	0	-0,248
	Warm/Wet	0,089	0	0	-0,163
Traffic	AADT<50000	0	0	0	0
	50000=<AADT<100000	0,018	0,045	0,093	0
	AADT>=100000	0,512	0,502	0,379	0
Months	1	0,402	0,662	0,773	0,535
	2	0,568	0,699	0,565	0,443
	3	0,526	0,704	0,625	0,324
	4	0,427	0,504	0,374	0,193
	5	0,559	0,716	0,579	0,288
	6	0,425	0,32	0,241	0,283
	7	0,258	0,27	0,064	-0,148
	8	-0,064	-0,154	-0,216	-0,108
	9	0,065	-0,098	-0,067	-0,101
	10	0	0	0	0
	11	-0,028	0,068	0,05	0,022
	12	0,085	0,231	0,181	0,491
Extra	γ_1 (MHI)	0	0,022	0	0,065
	γ_2 (ADP)	0	0	0	0

HAWRAT consists of an Excel spreadsheet and macros where the user selects and inputs the information related to the highway site under analysis. The equations and constants are embedded in the Excel file.

The runoff pollution model incorporated in HAWRAT was developed based on a sample dataset of 24 rural highway sites across England with traffic density ranging from 11000 – 159000 vehicles/day (Moy et al, 2002, Crabtree et al, 2007). For the impact models, non–tidal flow is simulated by the tool for the receiving watercourses for each rainfall event. Consequently, HAWRAT may not be applicable in the following scenarios: (i) urban highways; (ii) highways with traffic densities outside the 11000 - 159000 vehicles/day range; (iii) highways discharging to receiving watercourse that are tidal and/or saline.

The tool can be used for highways with traffic density less than 11000 vehicles/day but the result may be over conservative.

3.3 Multiple linear regression (2007, California, USA)

Kayhanian *et al*. (2007) proposed a multiple linear regression (MLR) to predict EMCs. This regression was established with the following specific objectives: (i) providing a statistical summary of highway runoff quality in California (USA); (ii) discussing the impact of selected independent event and site characteristics parameters on highway runoff constituent EMCs and (iii) evaluating the application of the MLR models as predictive tools to estimate the constituent EMCs.

Stormwater runoff data used in Kayhanian *et al*. (2007) were from 34 highway sites in California, covering a wide range of annual average daily traffic levels and environmental conditions. These data were obtained, on average, with up to eight storm events at each highway site during wet seasons, during a period from 2000 to 2003. Other characteristics that were identified in each site, are: surrounding land use, catchment area, impervious fraction, latitude and longitude and AADT.

The MLR equation established by Kayhanian *et al*. (2007) is the following:

$$\ln(EMC) = \beta_0 + a \times \ln(TER) + b \times \ln(ADP) + c \times \sqrt[3]{CSR} + d \times \ln(DA) + e \times (AADT \times 10^6)$$

where:
TER is the total event rainfall (mm);
ADP is the antecedent dry period (days);
CSR is the cumulative seasonal rainfall (mm);
DA is the drainage area (ha);
AADT is the annual average daily traffic (veh/day).
The equation was calibrated for several pollutants. Regression coefficients β_0, a, b, c, d, e are presented in Table 3.3.

Table 3.3. Regression coefficients *(adapted from: Kayhanian et al., 2007)*

	Constituent	β_0	a	b	c	d	e
Aggregates	Total Suspended Solids	4,28	0,124	0,102	0,099	—	4,934
	Total Dissolved Solids	4,73	0,309	0,126	0,05	—	2,582
	Dissolved Organic Carbon	4,11	0,404	0,123	0,129	—	—
	Total Organic Carbon	4,11	0,404	0,123	0,129	—	—
Metals (total)	Cu	2,9	0,161	0,163	0,079	—	6,823
	Pb	2,72	—	—	0,102	—	9,65
	Ni	2,51	0,196	0,141	0,075	0,155	1,013
	Zn	4,83	0,227	0,143	0,084	—	6,747
Metals (dissolved)	Cu	2,92	0,29	0,185	0,102	—	3,679
	Pb	2,04	0,248	—	0,101	—	0,007
	Ni	2,73	0,27	0,068	0,107	0,094	—
	Zn	4,74	0,343	0,164	0,112	—	1,676
Nutrients	NO_3-N	1,3	0,417	0,092	0,09	—	2,87
	P, total	1,2	0,143	0,128	0,051	—	0,9
	Total Kjeldahl Nitrogen	1,7	0,343	0,102	0,128	—	1,535

Model performance determined by comparing predicted and measured values showed good agreement for most constituents. The example for the prediction of Cu, in logarithmic scale, is presented in Figure 3.3.

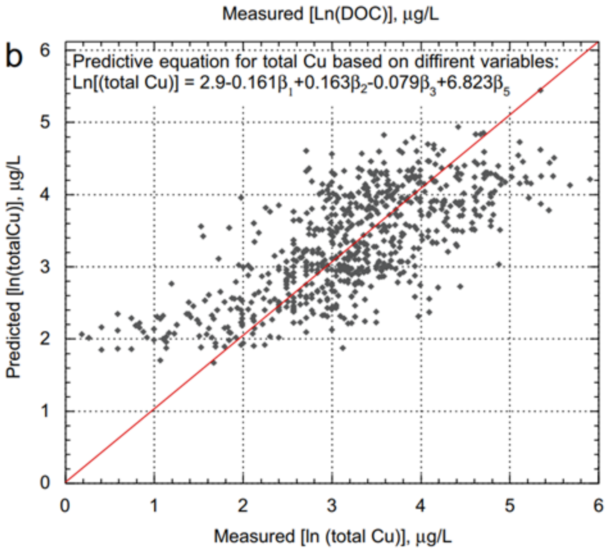

Figure 3.3. MLR model performance (per event) based on measured and predicted values for total Cu (adapted from Kayhanian *et al.* 2007)

3.4 Stochastic Empirical Loading and Dilution Model (SELDM, USA)

The Stochastic Empirical Loading and Dilution Model (SELDM) provides predictions of EMCs, flow and pollutant loads in stormwater from a highway site. Using input information based on site and catchment characteristics, rainfall, stormflow, water quality and the performance of mitigation measures, this tool generates statistical distributions of runoff quality in highway runoff and receiving water bodies. SELDM is based on a highway runoff database which contains data from over 4000 storm events, using a Monte Carlo analysis to generate the output results such as EMCs (Gardiner *et al.*, 2016).

SELDM was developed by the US Federal Highway Administration and uses analytical approximations to estimate the potential effects of runoff on receiving waters. SELDM also has a stochastic module to assess the potential benefits of the implementation of stormwater control that is not relevant for the objective of this report. SELDM is an open access software that can be downloaded and has the initial window as illustrated in Figure 3.4.

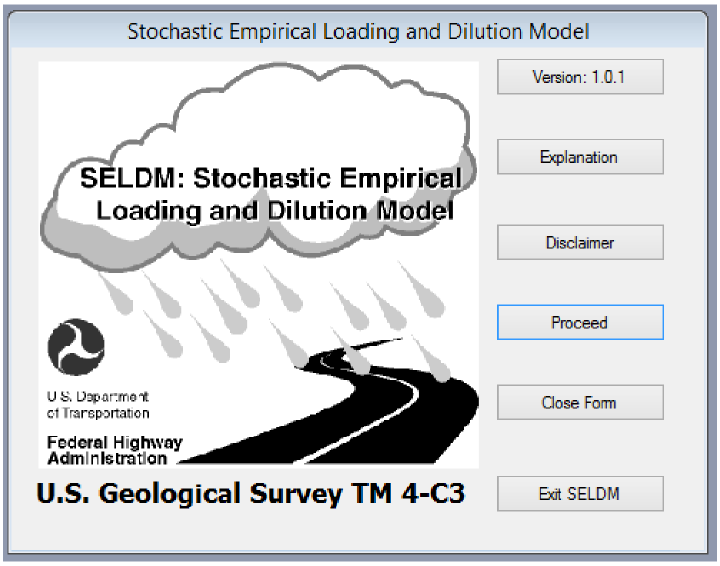

Figure 3.4. SELDM initial window (Granato, 2013)

SELDM is not calibrated by changing values of input variables to match a historical record of values. Instead, SELDM's input variables are based on site characteristics and representative statistics for each hydrological variable. To estimate the concentrations and loads of water quality constituents in receiving waters, a mass balance is commonly applied (Granato, 2013) as in Figure 3.5.

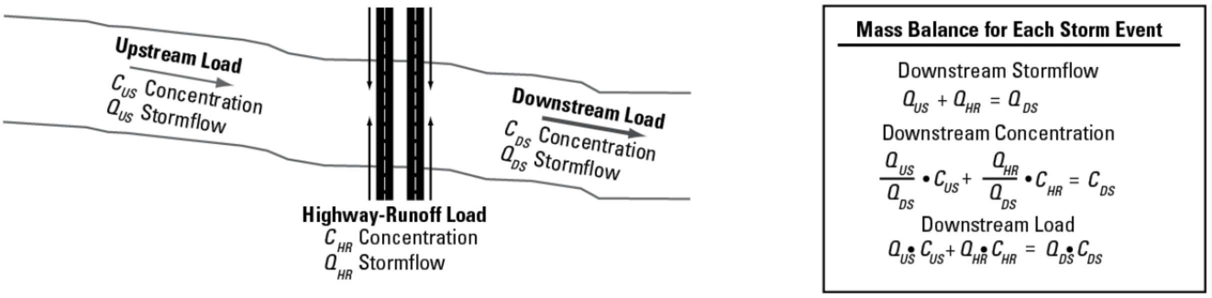

Figure 3.5. Mass balance for each storm event *(Granato, 2013)*

Storm events are defined as statistically independent events characterized by a volume, intensity, duration and time between midpoints of successive storms for the purposes of planning, analysis, and sampling efforts (Driscoll, 1990; Granato, 2013).

The fact that SELDM was designed to predict road runoff pollution in US areas represents a limitation to its use abroad. The model defines "Ecoregions" where the parameters are automatically implemented accordingly to the USA context. Nevertheless, the tool might be used elsewhere if the needed input information of weather conditions is inserted by the operator.

In order to use SELDM, the input layout is a sequence of graphical user interface (GUI). In total, 14 forms need to be completed with inputs information, namely:

(1) Information about the analyst, project and analysis;
(2) Highway physical characteristics;
(3) Ecoregion (when the site under study is in USA);

(4) Upstream basin characteristics;
(5) Lake basin characteristics;
(6) Precipitation statistics (when the ecoregion is settled this form is almost automatically filled);
(7) Streamflow;
(8) Runoff coefficient statistics;
(9) Highway runoff quality statistics;
(10) Upstream water quality statistics;
(11) Downstream water quality definitions;
(12) BMP performance statistics;
(13) Set of output files;
(14) Running SELDM form.

When the mandatory inputs are filled in, the user is able to run the tool. As for the road runoff pollution, only two of the up to 14 outputs are of interest for the current task, namely: (i) Precipitation event output file and (ii) Highway runoff quality output file.

To compute highway runoff quality SELDM uses regional water-quality statistics to facilitate generation of planning-level estimates. If needed, initial estimates can be refined with water-quality statistics based on available data collected at hydrologically similar sites or at the site of interest. SELDM uses the Highway Runoff Database (HRDB) as source of highway runoff statistics and data (Granato and Cazenas, 2009).

The HRDB application is designed as a data warehouse to document data and information from highway runoff monitoring studies and as a pre-processor for highway runoff data for use in SELDM. Available highway runoff data provide the basis for defining runoff quality and quantity at monitored sites and predicting runoff quality and quantity at unmonitored sites. HRDB includes data from 2650 storms, 39713 EMCs measurements of more than 100 water quality constituents monitored at 103 sites in USA (Granato and Cazenas, 2009).

3.5 Multiple linear regression (2007, Ireland)

Higgins (2007) and the related references Higgins et al. (2008), Desta *et al.* (2007) and Bruen *et al.* (2006) studied the road runoff quality in Ireland. The work comprised monitoring field work and a thorough investigation of the pollutant characteristics. During a two-year period, samples were collected in 4 different sites. The characteristics of the measured contaminants are comparable to those observed from similar conditions in other European countries.

According to a statistical analysis of the relationships between pollutant concentrations and the characteristics of storm events, the authors conclude that the main influencing factors are the rainfall intensity and the antecedent dry period while less relevant factors include the volumes of traffic and preceding storm conditions.

This model aims at predicting the concentration and the load of TSS and it was formulated based on a multiple linear regression. It indicated that 91% of the TSS pollutant load variation is explained by storm characteristics, rainfall intensity, total precipitation volume and duration of the dry period prior to the storm.

The simple equation to predict TSS load is the following:

$$TSS=(1.539 \times FLOW) + (21.98 \times I) + (0.009 \times ADP) - 4.158$$

Where:

FLOW is the discharge volume (l/m^2);
I is the rainfall intensity (l/m^2/min)
ADP is the antecedent dry period (hours).

3.6 Risk Assessment of road stormwater runoff (RSS, 2016, New Zealand)

The model "Risk Assessment of road stormwater runoff" (RSS) has been developed based on a combination of ESRI ArcGIS - used to determine data inputs and to map results - and MS Excel that provides the platform for prediction of contaminant loads and risk (Gardiner *et al.*, 2016).

The RSS model is intended for the specific purpose of screening road networks and their associated catchments for relative risk from stormwater (including road runoff) discharging to receiving environments. This model estimates the risk to waterbodies based on zinc and copper concentrations in stormwater runoff. It comprises two load models, one for estimating vehicle- derived zinc and copper road runoff and the other for non-road (urban) sources of these metals.

The prediction of the loads of zinc and copper are based on an analytical emission model and a reduction factors due to drainage systems. Loads of traffic-derived copper and zinc (referred to hereafter as 'road traffic' loads) are estimated for each road section, adjusted as necessary for traffic congestion and load attenuation (based on the road drainage and stormwater channel characteristics) and the individual section values summed for each sub-catchment.

The prediction of the road traffic contaminant loads is conducted taking into account the following procedure:

(i) The road network is divided in several road sections assigned to each sub-catchment.
(ii) The annual vehicle kilometres travelled (VKT) is calculated as the product of AADT and road length for each road section.
(iii) The road level of service (LoS – free-flowing, interrupted or congested) is calculated from the AADT and road capacity.
(iv) The road vehicle emissions factor (VEF) is selected from a lookup table based on LoS and contaminant (zinc or copper).
(v) The annual raw copper/zinc load (g/yr) is calculated as the product of VKT and VEF.
(vi) Load reduction factors (LRFs) are selected based on road drainage and the stormwater channel (SWC):

   a. A LRF is selected from a lookup table listing features of the network (*e.g*. catchpits, side drains) which 'treat' stormwater (*i.e.* remove sediment and thus copper/zinc).
   b. A LRF is selected from a lookup table for SWCs that attenuates contaminant loads (*e.g.* earth lined ditches, natural grass verges); the model allows for additional user selection of natural soil permeability (poor/good).

(vii) Annual loads of copper and zinc delivered from the road are calculated as the product of VKT, VEF, the (1-LRF) factor for drainage and the (1-LRF) factor for SWCs.

(viii) Annual loads of copper and zinc for each sub-catchment are summed from the individual road contributions.

4 | Assessment of the selected models

4.1 Input data

Road runoff quality predicting models aim at incorporating in their input the most important factors that determine the road runoff pollution concentrations. The most common factors are related to climate conditions, land use, road configuration, traffic volume and type, and hydrogeological features. Due to the complex phenomena that take place, it is not possible to establish a single and complete list.

Table 4.1 presents the input data for each of the 6 predicting models under evaluation.

Table 4.1. Input data (SMC – Site Mean Concentration and EMC – Event Mean Concentration)

Inputs		**SMCs**	**EMCs**			**Load**	
		PREQUALE	HAWRAT	Kayhanian *et al.* (2007)	SELDM	Higgins (2007)	RSS
Site and climate characteristics	Climate region		X				
	Drainage area	X		X	X		
	Impervious fraction	X			X		
	Annual average daily traffic		X	X	X		X
	Average rainfall event	X					
	Annual average rainfall	X			X		
	Other				Drainage Length; Basin Slope; Basin Develop. factor		Road length and capacity; vehicle emissions factor; road drainage; stormwater channel
Event Characteristics	Month		X				
	Total event rainfall			X	X		
	Rainfall intensity		X			X	
	Antecedent dry period		X	X	X	X	
	Cumulative seasonal rainfall			X			
	Other				Average storm duration; Number of storms per year	Flow	

Analyzing Table 4.1, it is concluded that PREQUALE has less requirements than any of the other models. Its input data are rather simple to obtain as they are related only to site and climate characteristics. As the output of PREQUALE are SMCs, in the implementation of the model it was not considered important to include event based characteristics.

Amongst the predicting models that calculate EMCs (HAWRAT, SELDM and regression by Kayhanian *et al.*, the event characteristics required by HAWRAT are easy to obtain. A time series of hourly precipitation is enough to calculate all inputs. The need to choose a climate region is a weak point for HAWRAT as the division between the four climate regions is only available for the UK context.

Regarding the model proposed in Kayhanian *et al.* (2007), there is only one input variable that is not easily obtained that is the cumulative seasonal rainfall. Nevertheless, all the remaining variables for this equation may be calculated with a time series of hourly precipitation.

SELDM needs the upstream basin characteristics, streamflow statistics, runoff coefficients and best management practices (BMPs) used in the road. It should be noted that some of these characteristics are not important for the prediction of pollutant concentration or loads but rather for the vulnerability and impact on the receiving waters. The model is quite cumbersome in the requirements related to the site and climate characteristics.

The models Higgins (2007) and RSS aim at predicting pollutant loads. The first model consists in a MLR equation (like PREQUALE and the Kayhanian *et al.*, 2007 model) and requires easily available data if hourly precipitation time series is available. The computation of the flow may be done taking into account the drainage area and the impervious fraction. RSS is based on a vehicle emission model and takes as input data the traffic and characteristics of road and drainage system. These figures may be rather difficult to obtain for most cases.

4.2 Easiness of applicability of the tools

The easiness of applicability of each of the 6 selected models is rather different, and is a relevant issue for the user of the tool.

PREQUALE, Kayhanian *et al.* (2007) and Higgins (2007) are based on multiparametric regression equations and are rather easy to apply. PREQUALE calculates directly SCM without the need to calculate several EMCs. If an hourly precipitation time series is available, the equations by Kayhanian *et al.* (2007) and Higgins (2007) can be easily implemented in a spreadsheet.

HAWRAT is already embedded in a spreadsheet. Since it was designed to be used in the UK, it includes the precipitation data from the meteorological gauges and retrieve the pollutant concentration after the selection of the other input data (*e.g.* traffic). Outside the UK, the model can be implemented in a spreadsheet.

SELDM has a complete Graphical User Interface that helps and simplifies the complexity of the model. It allows a systematic and interactive implementation of the model, but prevents from making changes in the equations behind the method.

RSS model integrates GIS application and a spreadsheet. For the first, ArcGIS is used to determine data inputs and to map results. The spreadsheet in Excel provides the platform for estimation of contaminant loads and risk. The combination of the two and the country specific input data makes this model difficult to apply in European countries.

4.3 Consistency of output results

In order to better analyze and compare the outputs given by each of the models under appraisal, Table 4.2 presents a summary of the output data for each one of them.

Table 4.2. Output data and type

Output		**PREQUALE**	**HAWRAT**	**Kayhanian *et al.* (2007)**	**SELDM***	**Higgins (2007)**	**RSS**
Type of result		SMC	EMC	EMC	EMC	Event Load	Event Load
Aggregates	TSS	X	X	X	X**	X	
	TDS			X			
	DOC			X			
	TOC			X			
	COD	X					
Metals (total)	Cu	X	X	X	X		X
	Pb			X	X		
	Ni			X			
	Zn	X	X	X	X		X
	Cd		X		X		
	Fe	X					
Metals (Dissolved)	Cu		X	X			
	Pb			X			
	Ni			X			
	Zn		X	X			
Nutrients (Total)	NO_3^-			X	X		
	P			X	X		
	KN			X			

* Besides these outputs, SELDM also has the following outputs: Urban TSS; Ultra Urban TSS; pH; suspended sediment concentration; Total chromium; Total Hardness

** SELDM generates as output Ultra urban TSS; Urban TSS and Non-urban TSS, in this case Non-urban TSS were used as TSS.

PREQUALE is the only model that calculates the highway mean concentration. HAWRAT, Kayhanian *et al.* (2007) and SELDM calculate EMCs which can be useful if the user needs to statistically characterize the road runoff pollution. Higgins (2007) and RSS calculate the pollutant load for each event.

All these models are calibrated with monitoring data from national roads. PREQUALE was based on data from 6 highways in Portugal; HAWRAT was developed based on 24 rural highway sites across England; Kayhanian *et al.* (2007) equation based on data from 34 roads in California and Higgins (2007) on 4 roads in Ireland.

SELDM and RSS are not multiple regression equations. The first is based on a highway runoff database which contains data from over 4000 storm events from the USA, using a Monte Carlo analysis to generate the output results such as EMCs. RSS is based on an emission model derived for New Zealand with load reduction factors related to the conditions of drainage of the road.

4.4 Review of the models

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A summary of the 6 models considered and the evaluation regarding each one of the 3 established criteria is presented in Table 4.3.

Table 4.3. Summary of the models considered in the present analysis

Parameter	Input data	Applicability	Output
PREQUALE	Easily accessible data	Equation	Predicts SMC of TSS, Zn, Cu, Pb and COD. Based on 6 roads from portugal
HAWRAT	Easily accessible data	Spreadsheet for the UK and Equation for non-UK countries	EMCs of a great set of pollutants
Kayhanian *et al.* (2007)	Accessible data	Equation	Great set of pollutants predicted. Established for California, USA (data 34 roads)
SELDM	There is the need to input of several parameters. Some requirements are automatically filled if a site in the USA is selected.	GUI application	The models predicts a great set of pollutant EMCs
Higgins (2007)	Easily accessible data except for the flow	Equation	The model only predicts EMCs of TSS and is based on data from just 4 roads
RSS	Great set of variables to be inputed	There is the need to use GIS and Excel to get data and to perform the calculations	Calculates the load of only Cu and Zn

Following the methodology presented in the Introduction, in order to select models each parameter (i.e. input data requirement; (ii) easiness of application and (iii) consistency of output results) was rated with a score from 1 to 3, for the 6 models and according to what was explained in the previous subsections of this chapter. Table 4.4 present these values and the global rating for each case.

Table 4.4. Rating per parameter and global rating of each model.

Parameter	PREQUALE	HAWRAT	Kayhanian *et al.* (2007)	SELDM	Higgins (2007)	RSS
Input data	3	3	2	1	2	1
Applicability	3	3	3	2	2	2
Output	1	2	2	3	1	2
Global	**7**	**8**	**7**	**6**	**5**	**5**

Taking into consideration the global scores, it was decided to proceed in the task 1.4 with the implementation of the 4 models with the highest scores, namely PREQUALE, HAWRAT, SELDM and Kayhanian *et al.* (2007).

5 | Conclusions

The prediction of pollutant concentrations in road runoff is not straightforward. This complexity is observed in the multiple predicting models that are available in the literature and in the choice for the input data that is required.

The aim of this report was to present and explain tools that predict road runoff pollution, and evaluate them. This evaluation was mainly theoretical i.e. the models were not implemented. It should be pointed out that all models were developed taking into account a specific area or country and it explains the limited monitored data used to calibrate each one.

Three parameters were the criteria to the assessment of the models: the input data, the easiness of applicability and the consistency of the output results. Each parameter was rated from 1 to 3. The sum of these 3 ratings allowed the classification of the models with a global rating. This methodology was used to select the four models to be implemented in task 1.4 of the PROPER Project: PREQUALE, HAWRAT, Kayhanian *et al.* (2007) and SELDM.

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