

Review of Stormwater Quality, Quantity and Treatment Methods Part 2: Stormwater: Quality Modelling

Rupak Aryal, J. Kandasamy, S. Vigneswaran[†], R. Naidu¹, and S. H. Lee²

Faculty of Engineering, University of Technology Sydney (UTS), P.O. Box 123, Broadway, NSW 2007, Australia

¹CRC CARE, University of South Australia, Adelaide, Australia

²School of Civil and Environmental Engineering, Kumoh National Institute of Technology, Gumi 730-701, Korea

Received June 2009, accepted September 2009

Abstract

In this paper, review of stormwater quality and quantity in the urban environment is presented. The review is presented in three parts. This second part reviews the mathematical techniques used in the stormwater quality modelling and has been undertaken by examining a number of models that are in current use. The important features of models are discussed.

Keywords: Stormwater, Quality and quantity, Mathematical models, Analytical technique

1. Introduction

A review of stormwater quality and quantity in the urban environment is presented. The review is presented in three parts. The first part reviewed the mathematical methods used in stormwater quantity modelling. This second part reviews the mathematical techniques used in stormwater quality modelling and has been undertaken by examining a number of models that are in current use.

2. Urban Runoff Quantity Problems and Models

2.1. Pollutant Build-up and Wash-off Model

2.1.1. Regression Model

Tasker and Driver (1988) developed simple regression model on the basis of long term urban runoff data and made it applicable for the unmonitored watershed based on some physical (drainage area, impervious percentage, percentage residential or/and industrial) and climatological data (total rainfall, storm duration, mean annual rainfall).¹⁾ The model uses the following generalized regression formula for calculating loads:

$$L = [\beta_o \times X_1\beta_1 \times X_2\beta_2 \dots \times X_n\beta_n] \times BCF \quad (1)$$

where, L = pollutant load, X_n = physical, land use or climatic characteristics, β_n = regression coefficients, and BCF = Bias Correction Factor

The model parameters are estimated by a generalized-least-square regression method that accounts for cross correlation and differences in reliability of sample estimates between sites. The regression models account for 20 to 65 percent of the total variation in observed loads.

2.1.2. Simple Empirical Model

Schueler (1987) introduced an easy empirical equation based model known as Simplified Urban Nutrient Output Model (SUNOM) for urban pollutants load prediction based on five years data collected by United States Environmental Protection Agency (USEPA). The method uses the flow-weighted mean concentration.²⁾ The generalized equation is as follows:

$$Lp = [H_r \times P_j \times R_v] \times [C][A] \quad (2)$$

where Lp = pollutant load, H_r = total rainfall (mm), P_j = percent of rainfall contributes to runoff (equals to 1 for individual storm events), R_v = runoff coefficients estimated as $0.05+0.009*$ (impervious percentage), C = flow-weighted pollutant mean concentration (mg/L), A = area (ha)

According to Schueler, the simple method does not consider base flow runoff and associated pollutant loads, and is better used at small watersheds. The model is rarely applied in the

[†] Corresponding author

E-mail: s.vigneswaran@uts.edu.au

Tel: +612-9514-2641, Fax: +612-9514-2633

literature. Recently, the model was applied by Flint (2004) to estimate water quality an ultra urban area in Maryland, US.³⁾

2.1.3. Sartor and Boyd Model

James Sartor and Gail Boyd first introduced this model in 1972 (Sartor and Boyd, 1972).⁴⁾ This model provides the knowledge of pollutants transport and their quantification. The model shows the dislodging of the particles during a rainfall event is dependent on the street characteristics, rainfall intensity and the particle sizes where the wash off can be described by the following equation:

$$P(t) = P_o (1 - \exp^{-kt}) \quad (3)$$

$$P(t) = P_o (1 - \exp^{-kQ}) \quad (4)$$

where,

$P(t)$ is the amount of the pollutants washed off in time t , P_o is the initial loading, k = wash-off coefficient, and I = rainfall intensity and t is the time and Q = rainfall volume

Many models such as PSRM-QUAL are based on equation 26 (PSRM-QUAL Users Manual, 1996) and kinematic wave equations.⁵⁾ Once the particle is dislodged the shear forces generated by the runoff cause its movement when the runoff is above the critical velocity (velocity at which drag force and resistance forces are equal). Critical velocity is given by

$$V_{cr} = \left[\frac{4}{3} \left(\frac{C_s}{C_d} \right) gr(SG-1) \right]^{1/2} \quad (5)$$

where

V_{cr} is the critical velocity, C_d is drag coefficient, C_s is static coefficient of friction, g is gravitational acceleration constant, r is the average sediment radius, and SG is sediment specific gravity.

United State Environmental Protection Agency (USEPA, 1979) estimated the pollutant load using the following equation.⁶⁾

$$M(t) = L(t - \Delta t) \left[1 - e^{-[K_w \Sigma R(t)]} \right] A \quad (6)$$

where,

$M(t)$ is the pollutant washoff for time period t (kg), $L(t - \Delta t)$ is the pollutant accumulation per unit area at the previous time period $t - \Delta t$ (kg ha⁻¹), A is the drainage area (ha), and K_w is the watershed washoff coefficient (mm⁻¹) which is a function of imperviousness of the watershed and the type of simulation, i.e., single event or continuous.

Haiping and Yamada (1996) applied Sartor and Boyd equation with refinement by adding some constants such as i) maximum amount of constituents on impervious areas (k_1) and ii) removal due to wind and vehicles as well as biological and chemical decay (k_2) besides wash-off coefficient.⁷⁾ The amount of pollutant accumulation on impervious surface is given by

$$P_o = P_{oR} \exp(-k_2 T) + k_1 [1 - \exp(-k_2 T)] \quad (7)$$

where,

P_{oR} is the residual amount of constituents on impervious surface after street sweeping or storm runoff in grams.

Residual amount of constituents on impervious areas (P_R) after wash-off in storm is given by;

$$P_R = \{P_{oR} \exp(-k_2 T) + k_1 [1 - \exp(-k_2 T)]\} \exp(-k_3 Q) \quad (8)$$

where,

k_3 is the wash-off coefficient in mm-1. Q is the total runoff volume (mm). The equation reflects both effects of accumulation in dry weather ($Q=0$) and wash-off in wet weathers ($Q>0$). This can be used as a tool for continuous simulation of urban non point source pollution for a long term prediction.

Furumai et al., (2003) applied Sartor and Boyd model with some modification in urban catchment in Japan. They assumed that the runoff from road and roof are different so that the wash-off behavior as follows.⁸⁾ They provided two different runoff coefficients for road and roof.

$$\frac{dP_1(t)}{dt} = -k_1 I_1(t) P_1(t) \quad \text{and} \quad \frac{dP_2(t)}{dt} = -k_2 I_2(t) P_2(t) \quad (9)$$

where,

$P(t)$ is the amount of the pollutants washed off in time t , k = wash-off coefficient, and I = rainfall intensity at time t , $i = 1$ and 2 the roof and road respectively.

The above model (Furumai et al., 2003) was applied by Murakami et al., (2004) to predict the wash-off behavior of particle-bound PAHs from road and roof and stated that the model could explain suspended solids and particle-bound PAHs runoff well except during and after heavy rainfall (>10mm/hr).

Aryal (2003) applied Sartor and Boyd model to predict the pollutants wash-off behavior in highway runoff. As this equation states that the quantity of the constituents available for wash-off decreases exponentially with runoff volume during the event, the model could not be applied to the events where the two or more pollutants loading pattern were observed due to the change in rainfall intensity (intermittent rainfall) during wet weather period.⁹⁾ The Sartor and Boyd model found not suitable to the events where two or more SS loading patterns observed. This indicated difficulty in applying the model in those runoff events where the rapid fluctuation of concentration occurred. The following equation establishes the relationship between concentration and the Sartor and Boyd model.

$$C(t) = \frac{1}{F(t)} \left(\frac{dP}{dt} \right) = -k * \frac{P(t) * R(t)}{A * R(t)} \quad (10)$$

$$C(t) = -k * \frac{P(t)}{A} \quad (11)$$

where,

$C(t)$ = concentration, quantity/volume

$F(t) = A * R(t) =$ Flow rate (L/sec)

$A =$ Area (ha)

$R(t) =$ Runoff rate (mm/hr)

This equation (11) shows that the primary difficulty of the Sartor and Boyd equation is that it always produces decreasing concentrations as a function of time regardless of the time distribution of runoff. This is counter-intuitive, since it is expected that high runoff rates during the middle of the storm might produce higher concentration than those proceeding. Aryal (2003) discretized the storm event and applied the model which he finally summed up to calculate the pollutant load.

Egodawatta et al., (2007) also applied the modified version of Sartor and Boyd model by introducing the capacity factor (C_F). They reported that a storm event has the capacity to wash-off only a fraction of pollutants available and this fraction varies primarily with rainfall intensity, kinetic energy of rainfall and characteristics of the pollutants. They then modified the Sartor and Boyd equation in order to incorporate the wash-off capacity of rainfall by introducing the 'capacity factor' C_F . According to them, the fraction wash-off can be written as

$$F_w = \frac{P(t)}{P_o} = C_F (1 - e^{-kt}) \quad (12)$$

where,

C_F is the value ranging from 0 to 1 depending on the rainfall intensity. Other factors such as road surface condition, characteristics of the available pollutants and slope of the road may also have influence on C_F .

Chen and Adams (2007) also applied the Sartor and Boyd wash-off with refinement by introducing the pollutants accumulation rate based on Osuch-Pajdzinksa and Zawilski (1998) that can accommodate the dry weather period also.^{10,11)} The rate of pollutant accumulation is:

$$\frac{dM_b}{db} = (1-h)m_d\beta_1 + h_m w\beta_2\eta - k_b M_b \quad (13)$$

where

M_b is amount of pollutant per unit area on catchment surface, h is the fraction of the impervious area of the catchment, m_d is a constant rate of pollutant deposition (dust fall), m_w is the quantity of street sweeping effectiveness parameter, η is the street sweeping effectiveness parameter, k_b is a constant pollutant removal rate, b is the time elapsed since the last rainfall, β_1 is the conversion of the mass of particulate matter into a parameter of a given type of pollutant and β_2 describe the conversion of a mass of sweeping into a parameter of a given type of pollutant.

Integrating the above equation, M_b is:

$$M_b = \frac{(1-h)m_d\beta_1 + hm_w\beta_2\eta}{k_b} (1 - e^{-k_b b}) + M_o e^{-k_b b} \quad (14)$$

where,

M_o is residual pollutant mass not washed off by the previous runoff event.

In their study they assumed that the rate of pollutant wash-off from the catchment surface is proportional to the amount of pollutant build-up on the catchment surface and is directly related to the volume of runoff.

$$\frac{dM_b}{db} = -k_w \bar{v}_r M_b \quad (15)$$

where

\bar{v}_r is the average runoff rate in mm/hr, k_w is the decay or wash-off coefficient, in mm^{-1} .

Performing integrated yields

$$M_w = M_b (1 - e^{-k_w \bar{v}_r b}) = M_b (1 - e^{-k_w v_r}) \quad (16)$$

2.2. Advective Diffusion Model (Mass Transport Equation)

It is the one dimensional conservative advective-diffusion equation, that incorporates the advection and diffusion process is to describe the behaviour of a pollutant in stream;

$$\frac{\partial(A_x C)}{\partial t} + \frac{\partial}{\partial x}(u A_x C) = \frac{\partial}{\partial x} \left(A_x D_x \frac{\partial C}{\partial x} \right) \pm S(C, x, t) \quad (17)$$

where,

C is the thermal energy or constituent concentration, t the time, x si the distance, u is the advection velocity, A_x the cross-sectional area, D_x is the diffusion coefficient and $S(C, x, t)$ are all sources and sinks.

This equation includes the advection of pollutants by the flowing water, diffusion of pollutants in the stream, constituent reactions, interactions and sources and sinks. Assuming that A_x and D_x are constants and using the flow continuity equation then:

$$\frac{\partial(A_x C)}{\partial t} + \frac{\partial}{\partial x}(u A_x C) = 0 \quad (18)$$

Then

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} = D_x \frac{\partial^2 C}{\partial x^2} \pm S \quad (19)$$

which is the form of the advective-diffusion equation used in model like HEC-5Q and WQRRS.

Shaw et al., (2006) proposed a new stochastic physical model that is primarily focused on the rain flow transportation.¹²⁾ The model was mainly based on Hairsine and Rose (1991) which states that the flow does not exceed the threshold for particles

entrainment, mass conservation of suspended particles in the water layer:

$$\frac{\partial M_s}{\partial t} + \frac{\partial M_g}{\partial x} = e - h \quad (20)$$

where,

e is rate of particles enter the shallow flow by raindrop-induced ejection, h is the rate of particle settle-out of the shallow, M_s is the suspended particle mass (g cm^{-2}), x is the down slope distance, and v is the fluid velocity (cm min^{-1})

Particles mass on the surface, M_g (g cm^{-2}), at a distinct spatial position is given by:

$$\frac{\partial M_g}{\partial t} = h - e \quad (21)$$

The value e was defined by

$$e = aPM_g$$

where,

a (cm^{-1}) is an experimentally determined “detachability” constant that accounts for mass loss per drop and P is the precipitation rate (cm min^{-1}). Similarly particle settling rate is given by

$h = \frac{\alpha v_{set} M_s}{D}$ where α adjusts bulk concentration to account for variations near the surface, v_{set} is the particle settling velocity (cm s^{-1}), and D is the depth (cm).

They also applied water balance at a pint x by using the equation

$$q|_x = Px + q_o \quad (22)$$

where,

P is the rain intensity per unit width ($\text{mL min}^{-1} \text{cm}^{-1}$), q is the flow rate per unit width ($\text{mL min}^{-1} \text{cm}^{-1}$) and q_o ($\text{mL min}^{-1} \text{cm}^{-1}$) is the constant upslope inflow per unit width.

2.3. Kinematic Wave Equation Model

It is another governing one-dimensional equation for pollutant transport on a unit width basis, where solute is injected instantaneously, can be written as

$$\frac{\partial(Ch)}{\partial t} + \frac{\partial(CQ)}{\partial x} = w\delta(t) \quad (23)$$

having boundary conditions

$$\begin{cases} C(x,0) = C_o(x) > 0 \text{ for } x > 0 \\ C(0,t) = C_1(t) > 0 \text{ for } t > 0 \end{cases}$$

where,

C is solute concentration defined as mass of solute per unit volume of water, w is the mass of solute (M) per unit area A of the plane (M/A), w is the mass of pollutant per unit surface area

and $\delta(t)$ is the instantaneous unit flux of the solute (I/T). The pollutant discharge Q_s is defined as

$$Q_s = CQ$$

2.4. Other Stormwater Quality Models

2.4.1. SWMM

SWMM is one of the most successful model produced by United States Environmental Protection Agency (US-EPA). This model is not exclusively designed for urban drainage and single-event or long term (continuous) simulation. The earlier SWMM model used the linear build up formulation. The model provides three options for pollutant build up as follows:

$$\begin{aligned} DD &= DDFACT * t^{DDPOW} \\ &\text{(power-linear) where } DD < DDLIM \\ DD &= DDLIM * (1 - e^{-DDPOW * t}) \\ &\text{(exponential)} \\ DD &= DDLIM * (t / (DDFACT + t)) \\ &\text{(Michaelis-Menton)} \end{aligned} \quad (24)$$

Among the above equation, exponential and Michaelis-Menton functions clearly define asymptotes or upper limits. Upper limits for linear or power function build-up may be imposed if desired.

The wash-off equation as follows: using an exponential wash-off equation as follows:

$$P(t) = K_w R^n P \quad \text{(wash-off)} \quad (25)$$

where,

$P(t)$ is the washoff load rate at time t , K_w is the washoff coefficient, R is the runoff rate (mm/hr), n is the power of runoff rate, and P is the amount of pollutant remaining on the catchment.

As mentioned above earlier, primary difficulty in this equation is always producing decreasing concentrations as a function of time regardless of the time distribution of runoff (Aryal et al., 2003). This problem is overcome in SWMM by making wash-off at each time step, $P(t)$, proportional to runoff rate to a power, K_w :

$$-P(t) = dP(t)/dt = -K_w / 3600 * r^{K_w} * P_o \quad (26)$$

where,

$P(t)$ is constituent load washed off at time, t , quantity/sec, $P_o(t + \Delta t)$ is quantity of constituent available for wash-off at time, t , (e.g., mg), K_w is wash-off coefficient and $R(t)$ is runoff rate.

It may be seen that if equation is divided by runoff rate to obtain concentration, then concentration is now proportional to $r^{K_w - 1}$. Hence, if the increase in runoff rate is sufficient, concentrations can increase during the middle of a storm even if PSHED is diminished.

From the basic equation (48), the wash-off parameters, wash-off coefficient and exponent are determined from a finite difference approximation (Nix, 1994) which produces:¹³⁾

$$P_o(t + \Delta t) = P_o(t) \exp \left\{ -K_w \Delta t^{0.5} [R(t)^n + R(t + \Delta t)^n] \right\} \quad (27)$$

where,

$P_o(t + \Delta t)$ is the amount of pollutant wash-off during simulation time step $((t + \Delta t)$, $P_o(t)$ is the amount of pollutant on land surface during a time step (t) , K_w is the wash-off or decay coefficient, Δt is the time step, $0.5 [R(t)^n + R(t + \Delta t)^n]$ is average runoff rate over a time step and n is the power function of runoff rate.

2.4.2. HydroWorks/Infoworks

HydroWorks/InfoWorks calculates the surface pollutant build up for each subcatchment, during a build up (or dry weather) period, before a rainfall event. The basic hypothesis is one of a time-linear accumulation of pollutant on the ground, which depends on the type of activities present on the catchment/subcatchment or in the vicinity. The build-up equation is based on hypothesis that on a clean surface the rate of pollutants accumulation is linear but as the surface mass increases the accumulation rate decays exponentially. The build-up equation is written as:

$$dM / dt = P - k_d M \quad (28)$$

where,

M is mass of the deposit per surface unit (kg/ha), P is build-up factor (kg/ha/day), k_d decay factor (1/day)

The software carries out the following process to determine the build up of pollution for each subcatchment:

- i. Determine the decay factor
- ii. Determine the build-up factor
- iii. Determine the mass of deposit at the end of the build-up period:

$$M_o = M_d * e^{k_d * N_j} + \left[P_s / K_d * \left(1 - e^{-k_d N_j} \right) \right] \quad (29)$$

where,

M_o is the mass of sediment at the end of the build-up period (kg/ha)

M_d is the initial mass of deposit in kg/ha (from catchment sediment data (.CSD) file), k_d is the decay factor (day^{-1}), N_j is the duration of the dry weather period (days), and P_s is the build-up factor ($\text{kg ha}^{-1} \text{day}^{-1}$).

The surface wash-off model is based, as the runoff module, on the single linear reservoir model. The model consists of sediment erosion and its wash-off. First the amount of sediment eroded from the surface and held in suspension in the storm water is calculated. Then the amount of sediment washed into the drainage system is calculated using a single linear reservoir routing method. The amount of sediment washed into the drain-

age system is calculated as

Sediment erosion

$$dM_e / dt = K_a M(t) - f(t) \quad (30)$$

where,

M_e is mass of sediments dissolved or in suspension per unit active surface (kg/ha), $M(t)$ is mass of surface deposit pollutants (kg/ha), K_a is erosion/dissolution coefficient (1/s) and is calculated as

$$K_a = C_1 * I(t)^{C_2} - C_3 * I(t),$$

where,

$i(t)$ is effective rainfall and C_1 , C_2 and C_3 are coefficients.

Sediment wash-off is given by

$$M_e(t) = k * f(t) \quad (31)$$

where,

k is linear reservoir coefficient

$f(t)$ is sediment flow

Then the sediment flow per subcatchment (kg/s) is calculated (sediment inflow to each node)

$$F_m(t) = C * A * f(t) \quad (32)$$

where,

C is portion of subcatchment, A is subcatchment area.

2.4.3. MOUSE Trap

The MOUSE TRAP model provides several submodules for the simulation of sediment transport and water quality for both urban catchments surfaces and sewer systems. Since pollutants are carried by sediment, the model tries its best to correlate sediment transport process and water quality in sewer systems. Mouse Trap can also model the first flush phenomenon based on temporal and spatial distribution of sediment on the catchment surface and sewer system. Surface Runoff Quality (SRQ) computes the pollutant build-up and transport on catchment surfaces. Two major processes that are involved in SRQ are:

1. Build-up and wash-off of sediment particles on the catchment.
2. Surface transport of pollutants attached to the sediment particles.

2.4.4. MUSIC

MUSIC is one of the most popular stormwater model used in Australia developed by Cooperative Research Centre for Catchment Hydrology (CRCCH) Australia (CRCCH 2005).¹⁴⁾ The model uses simple first order kinetics for the pollutant wash-off from the surface. According to the model the pollutant concentrations

in the parcel tend to move by an exponential decay process towards an equilibrium value for that site at that time.

$$((C_{out} - C^*) / (C_{in} - C^*)) = e^{-k/q} \quad (33)$$

where, C_{out} is the output concentration, C^* is the equilibrium value or background concentration, C_{in} is the input concentration, k is the exponential rate constant and q is the hydraulic loading (flow rate per surface area) of the treatment measure.

2.4.5. ASTROM

ASTROM model uses the following pollutant build up equation.

$$\frac{dM_b}{db} = k_o - k_b M_b \quad (34)$$

where,

M_b is the amount of pollutant per unit area on the catchment surface (kg/m^2), k_o is constant rate of pollutant deposition ($\text{kg}/\text{m}^2 \cdot \text{h}$), k_b is constant pollutant removal rate (h^{-1}), and b is inter-event time.

Integrating above equation yields

$$M_b = M_m (1 - e^{-k_b b}) + M_o e^{-k_b b} \quad (35)$$

where,

$M_m (= k_o/k_b)$ represents the maximum amount of pollutant build-up (kg/m^2) and M_o is residual amount of pollutant after the previous runoff or street sweeping event (kg/m^2).

The pollutant washoff model is defined as

$$l = M_b (1 - e^{-k_w v_r}) \quad (36)$$

where,

l is mass of pollutant washed off per unit area per rainfall event (kg/m^2), v_r is runoff event volume (mm) and k_w is pollutant wash-off coefficient.

The model assumes that rainfall event pollutant wash-off load is proportional to, or dependent upon, the accumulated pollutant mass on the catchment surface before the runoff event, and the pollutant wash-off load is a direct function of runoff volume.

Besides, there are several literatures appeared to describe the wash-off behaviour of pollutants during wet weather period. Here, few are described.

Kim et al., (2005) introduced new wash-off model for highway stormwater runoff that incorporates many parameters such as antecedent dry weather periods, rainfall intensity and runoff coefficient.¹⁵⁾ The equation can be initially expressed as

$$\frac{d[C(t)]}{dt} = -\alpha \frac{Q(t)C(t)}{V_{TRu}} \quad (37)$$

where,

$C(t)$ is pollutant concentration; $Q(t)$ is runoff flow rate discharged at time t , α is wash-off rate coefficient, $C(t)$ is pollutant concentration at time t ; V_{TRu} is total runoff volume ($\int_0^T Q(t)dt$ (m^3))

which they solved and rearranged in the form

$$C(t) = \frac{1}{\beta V_{nRu}(t)} \cdot \frac{\int_0^t M(t)dt}{V_{TRu}} \quad (38)$$

where,

$M(t)$ is the pollutant mass emission rate at time t , $V_{nRu}(t)$ is the normalized cumulative volume, $0 \leq V_{nRu}(t) \leq 1.0$

$$NewConc.[V_{nRu}(t)] = \delta + V_{nRu}(t) \cdot \{\gamma^* + \beta^* \cdot Exp[-\alpha V_{nRu}(t)]\} \quad (39)$$

where,

δ is an initial concentration related to antecedent dry weather period. The parameters α and γ^* are related total runoff. The β^* is related to rainfall, runoff coefficient, and storm duration.

This model has two different functions. The first is linear, $\gamma^* V_{nRu}(t) + \delta$, and the second takes the form of a gamma type function, $\beta^* V_{nRu}(t) \cdot Exp[-\alpha V_{nRu}(t)]$. To use this model it is necessary to predict the total runoff volume, which must be based upon weather forecast or other information.

Kanso et al., (2006) applied simple classical pollutant accumulation followed by the wash-off model to describe the water quality.¹⁶⁾ He described two accumulation behaviours. The first equation calculates the accumulation of pollutants assumed to follow an asymptotic behaviour that depends on two parameters: an accumulation rate Da ($\text{kg}/\text{ha}/\text{day}$) and a dry erosion rate D_e (day^{-1}).

$$\frac{dM_a(t)}{dt} = D_a S_i - D_e M_a(t) \quad (40)$$

$$\frac{dM_a(t)}{dt} = K_a (M_1 S_i - M_a(t)) \quad (41)$$

where,

$M_a(t)$ (kg) is the available pollutant's mass at time t and S_i (ha) is the impervious area. The model depends on two parameters: an accumulation coefficient K_a and maximum accumulated mass M_1 . It is supposed that the accumulation is proportional to the mass still to be accumulated before reaching the maximum M_1 , which is equivalent to the (D_a / D_e) .

He described the evolution of the available pollutant mass during the stormwater period by applying the following equation.

$$C(t) = \frac{1}{q(t)} \frac{dM_a(t)}{dt} \quad \text{and} \quad \frac{dM_a(t)}{dt} = -W_e I(t)^w M_a(t) \quad \text{where } C(t)$$

(mg/l) is the SS concentration produced by erosion, $q(t)$ is the discharge (m^3/s) at the outlet of the watershed at time t , and $I(t)$ is the rainfall intensity (mm/hr).

3. Conclusion

This paper reviews mathematical methods used in stormwater quality modelling and has been undertaken by examining a number of models that are in current use. The analytical techniques are presented in this paper. The important feature of models is discussed.

Acknowledgement

The research is funded by CRC for Contaminant Assessment and Remediation of the Environment (CRC CARE) Australia through the Grant Number 2.5.07-07/08.

References

1. Tasker, G. D. and Driver, N. E., "Nationwide regression models for predicting urban runoff water quality at unmonitored sites," *J. Ame. Water Res. B.*, **24**(5), 1091-1101 (1988).
2. Schueler, T. R., "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs," Metropolitan Council of Governments, Washington, DC. (1987).
3. Flint, K. R., "Water quality characterization of highway stormwater runoff from an ultra urban area," Master Thesis, University of Maryland (2004).
4. Sartor, J., Boyd, G., "Water pollution aspects of street surface contaminants," EPA-R2-72-081, US EPA (1972).
5. PSRM-QUAL Users Manual (1996).
6. USEPA, "1978 Needs Survey-Continuous stormwater simulation model," Water Planning Division, US Environmental Protection Agency, Washington, D. C. (1979).
7. Haiping, Z. and Yamada, K., "Estimation for urban runoff quality modelling," *Water Sci. Technol.*, **34**, 49-54 (1996).
8. Furumai, H., Hijioka, Y., and Nakajima, F., Modelling and field survey of wash-off behaviour of suspended particles from roof and roads, *Urban Drain. Model.*, ASCE, pp. 225-230 (2003).
9. Aryal, R. K., Dynamic behaviour of suspended solids and particle associated micropollutants in a highway runoff, Ph.D. Thesis, University of Tokyo, Japan (2003).
10. Chen, J. and Adams, B. J., "Development of analytical models for estimation of urban stormwater runoff," *J. Hydrol.*, **336**, 458-469 (2007).
11. Osuch-Pajdzinksa, E. and Zawilski, M., "Model of storm sewer discharge, I: description," *J. Env. Eng. ASCE*, **124**(7), 593-598 (1998).
12. Shaw, S. B., Walter, M. T. and Steenhuis, T. S., "A physical model of particulate wash-off from rough impervious surfaces," *J. Hydrol.*, **327**, 618-626 (2006).
13. Nix, S. J., "Urban Stormwater Modeling and Simulation," Lewis Publishers, Boca Raton (1994).
14. CRCCH, MUSIC Users Manual, Australia (2005).
15. Kim, L. H., Kayhanian, M., Zoh, K. D. and Stenstrom, M. K., "Modeling of highway stormwater runoff," *Sci. Total Environ.*, **348** (2005).
16. Kanso, A., Chebbo, G. and Tassin, B., "Application of MCMC-GSA model calibration method to urban runoff quality modeling," *Reliabil. Eng. Syst. Saf.*, **91**, 1398-1405 (2006).