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DEVELOPMENT OF EXCEL VBA PROGRAM FOR SMALL DRAINAGE NETWORK EVALUATION BASED ON RATIONAL METHOD OF MSMA 2

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Abstract

Torrential rainfall and resulting flood causing widespread life disruptions and material losses are real and recurring problems in Malaysia. These catastrophes have usually been attributed among others to the inadequacy of the existing drainage network and lackadaisical maintenance efforts. It would be interesting to point out that much of the inherited and currently operational drainage system was designed and developed using the conventional concept of rapid disposal, localized reactive and mono-functional drainage with the consequent of unchecked non-permeable surface growth, unimpeded runoff generation, and perpetual and eventually unrealized drainage upgrade further downstream. The advent of MSMA now in its 2nd edition is meant to provide a paradigm shift in storm water management thinking specifically with the containment of runoff at the source and doing away with the unsustainable policy of perpetual system upgrade following adjoining land development. As in many an application in the industry as well as academia, migration to a new thinking or work process would be greatly facilitated and expedited with the aid of ICT tools. Excel VBA provides such a familiar, common, and convenient platform to develop intensive and quite engaging computational processes occasionally with the look and feel of commercial software but at fraction of the cost and practically reutilizing existing resources. Such development was addressed in this paper and used to solve a real world project, the results of which were in agreement with manual computations.

Keywords: *small catchment; drainage network; rational method; MSMA 2; Excel VBA; software*

1.0 INTRODUCTION

Due to its geographical location near the Equator, Malaysia has essentially experienced tropical rainforest climate with uniform temperature, copious rainfall and high humidity throughout the year (Malaysian Meteorological Department, 2017). This is attributed to cyclic Northeast and Southwest monsoons that blow from November to March and May to September respectively which carry heavy and regular rainfall in their wake. This natural phenomenon has occasionally resulted in floods across parts of East and West Malaysia, and the inadequacy of the drainage system due to absence or neglect would further enhance its effects. Some historical manifestation of these events occurred as recently as 2015 in Kelantan, Terengganu and Pahang due to intense torrential rains causing inundation of low-lying areas and forcing evacuation of thousands of affected residents. More recently would be the spell of flooding in 2017 most notably in Kelantan, Terengganu, Johor, Perak and Pahang which should have reminded us that the route towards complete resolution is still far from accomplished (Utusan Online, 2017).

In hydrologic and environmental sense, rapid urbanization which has resulted in accelerated growth and spread of impervious areas and diversification of urban land use practices has contributed towards storm water build up particularly in urban centres (Department of Irrigation and Drainage [DID], 2000). Conventionally, this problem would be treated in non-sustainable fashion through rapid disposal, and localized, reactive and mono-functional drainage concept. In essence, it is a simple matter of problem transference to another system further down the flow lines regardless of its capacity to receive such input. As a result, flash flood frequency and water quality problems are persisting in spite of that, and thus invalidating further continuation of these ineffective practices.

New strategies in storm water management for sustainable development involve incorporation of interalia, runoff source control, management and delayed disposal on catchment wide, proactive and multi-functional basis. This should result in flood flow reduction, water quality improvement and ecological enhancement in downstream receiving waters. In the effort to support such paradigm shift, DID has published a set of manual called “Urban Storm Water Management Manual for Malaysia”, which is currently at its 2nd edition (referred as MSMA 2 in this paper).

The transition into a new thinking or work process would naturally be problematic or undesirable to those accustomed to the status quo both in the industry as well as academia. The challenges faced include realigning routine, relearning new processes, retraining manpower, retuning existing and acquiring new resources, and negotiating changing requirements over constricting timeframe. Commercial software could greatly facilitate and expedite the required paradigm shifts among individuals and organizations if they were available in the market and could be obtained at a reasonable pricing. Alternatively, Excel VBA could provide a more efficient and effective platform due to its pervasiveness and established familiarity among end users, and can be customized to conduct intensive and quite engaging computational processes while having the look and feel of commercial software at fraction of the cost and practically reutilizing existing resources.

2.0 THEORETICAL FRAMEWORK

Urban Storm Water Management (SWM) practices in which storm water would be managed as close as possible to its source have been around for decades through mandatory guidelines imposed by regulatory bodies for new urban development especially in developed and developing countries. This is because good SWM practices would ensure sustainable development, and prevention of resource wastage, widespread pollution and natural disaster. These guidelines promote Best Management Practices (BMPs) with respect to SWM, and include Low Impact Development (LID) for United States, Water Sensitive Urban Design (WSUD) for Australia, Sustainable Urban Drainage System (SUDS) for United Kingdom, Low Impact Urban Design and Development (LIUDD) for New Zealand, Green Manual for China and of course Manual Saliran Mesra Malaysia (MSMA) which would be the gist for the rest of the discussion. With respect to quantitative and qualitative design of the MSMA-compliant system, the computational process involved may be quite complex, intensive and engaging, and may require specialists’ competency in order to manage the required workloads.

There are several parallel works in the right direction in order to address this issue. Zoppou had reviewed several storm water models including stochastic model, deterministic model, distributed model and lumped model although deterministic-distributed model would be the most preferred model for urban runoffs (Zoppou, 2001). Lariyah et al. have developed software modules for MSMA-related analysis involving rainfall database and hydrology, quantity and quality control, and conveyance system (Sidek, Haris, Mohiyaden, Basri, Roseli, Norlida, 2016). The focus of this paper is to develop an Excel VBA program that could perform a small rainwater conveyance system using the Rational Method as outlined in MSMA 2. As such, it is meant to complement the existing computer-assisted hydrological models currently available in the market and provide as close an interpretation as possible to intended meaning of the guideline.

2.1 Rainfall Estimation

Average Recurrence Interval (ARI) is the average length of time between rain events that exceed the same magnitude, volume and duration, which can be expressed in this form (Chow, 1964):

$$T_r = \frac{1}{P}$$

where :

T_r = Average Recurrence Interval, ARI (year)

P = Annual Exceedance Probability, AEP (%)

The selection of ARI is based on the economy and level of risk that the facility offers as prescribed on Table 1. It is assumed that the storm water design flow of a given ARI is derived from the design storm rainfall of the same ARI.

Table 1 Quantity of design storm ARIs

[redacted]		
Residential – Bungalow & semi-detached dwellings	5	50
Residential – Link house/apartment	10	100
Commercial and business centre	10	100
Industry	10	100
Sport field, park and agricultural land	2	20
Infrastructure/utility	5	100
Institutional building/complex	10	100

As a whole, the process of catchment discretization into segments of homogeneous land use and surface slope would facilitate determination of the time of the concentration at the final discharge point and estimation of peak runoff flow for the entire catchment. However, at individual drain level, the process of catchment discretization into directly contributing sub-areas would facilitate determination of on-point runoff discharge and hence check for the adequacy of the affected drain.

Time of concentration is the travel time of runoff from the most hydraulically remote point upstream in the contributing catchment area to the point under consideration upstream, which can also be expressed in this form:

$$t_c = t_o + t_g + t_d$$

$$t_o = \frac{107 n_o L_o^{1/3}}{S_o^{1/5}} \begin{cases} S_o > 10\% \rightarrow L_o \leq 50 \text{ m} \\ S_o < 5\% \rightarrow L_o \leq 100 \text{ m} \\ S_o < 1\% \rightarrow L_o \leq 200 \text{ m} \end{cases}$$

$$t_g = \frac{L_g}{40\sqrt{S_g}}$$

$$t_d = \frac{n_d L_d}{60 R^{2/3} \left(\frac{S_d}{100} \right)^{1/2}}$$

where:

t_c = time of concentration (min)

t_o, t_g, t_d = time of overland sheet flow, curb gutter flow and drain flow respectively (min)

L_o, L_g, L_d = length of overland sheet flow, curb gutter flow and drain flow respectively (m)

n_o, n_d = Horton's (from Table 2) and Manning's (from Table 3) roughness coefficient respectively

S_o, S_g, S_d = slope of overland sheet flow, curb gutter flow and drain flow respectively (%)

R = hydraulic radius (m) (from Table 4)

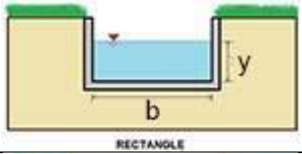
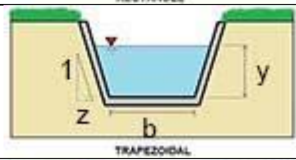
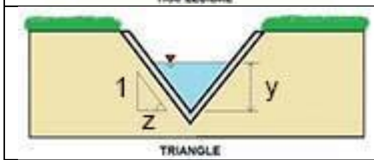
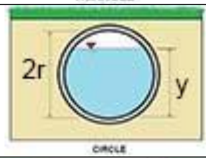
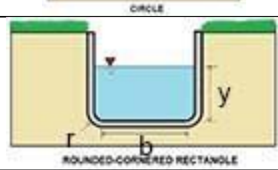
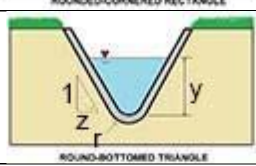
Table 2 Values of Horton's roughness coefficient (Department of Energy and Water Supply, 2013)

Land Surface	Roughness Coefficient
Paved	0.015
Bare soil	0.0275
Poorly grassed	0.035
Average grassed	0.045
Densely grassed	0.060

Table 3 Values of Manning's roughness coefficient for open drains and pipes (Chow, 2009)

Drain/Pipe Material	Roughness Coefficient
Grassed drain – Short grass cover (<150 mm)	0.035
Grassed drain – Tall grass cover (≥150 mm)	0.050
Lined drain – Concrete (Smooth finish)	0.015
Lined drain – Concrete (Rough finish)	0.018
Lined drain – Stone pitching (Dressed stone in mortar)	0.017
Lined drain – Stone pitching (Random stones in mortar or rubble masonry)	0.035
Lined drain –Rock riprap	0.030
Lined drain –Brickwork	0.020
Pipe material – Vitrified clay	0.012
Pipe material – Spun precast concrete	0.013
Pipe material – Fibre reinforced cement	0.013
Pipe material – UPVC	0.011
Grassed drain – Short grass cover (<150 mm)	0.035

Table 4 Geometric element of channel sections

	by	$b+2y$	$\frac{A}{P}$	y
	$(b+zy)y$	$(b+2y)\sqrt{1+z^2}$	$\frac{A}{P}$	$\frac{(b+zy)y}{b+2zy}$
	zy^2	$2y\sqrt{1+z^2}$	$\frac{A}{P}$	$\frac{1}{2}y$
	$\frac{1}{8}(\theta-\sin\theta)d_o^2$	$\frac{1}{2}\theta d_o$	$\frac{A}{P}$	$\frac{1}{8}\left(\frac{\theta-\sin\theta}{\sin\frac{1}{2}\theta}\right)d_o$
	$\left(\frac{\pi}{2}-2\right)r^2+(b+2r)y$	$(\pi-2)r+b+2y$	$\frac{A}{P}$	$\frac{(\pi/2-2)r^2}{b+2r}+y$
	$\left(\frac{T^2}{4z}-\frac{r^2}{z}\right)(1-z\cot^{-1}z)$	$\frac{T}{z}\sqrt{1+z^2}-\frac{2r}{z}(1-z\cot^{-1}z)$	$\frac{A}{P}$	$\frac{A}{T}$

It is assumed that the storm water peak flow is derived from the design storm duration that equal or greater than the time of concentration.

Intensity-duration-frequency (IDF) curves are the form of design rainfall data commonly adopted to estimate storm water peak flow. From the curves, the rainfall intensity can be estimated from the following expression:

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$$

where:

i = average rainfall intensity (mm/hr)

T = ARI ($0.5 \le T \le 12$ mth and $2 \le T \le 100$ yr)

d = storm duration (hr) ($0.0833 \le d \le 72$ hr)

$\lambda, \kappa, \theta, \eta$ = fitting constants dependent on the rain gauge location

The values of λ, κ, θ and η can be obtained in tabulated or plotted form through Chapter 2 or Annex 3 of MSMA 2 respectively (Department of Irrigation and Drainage (DID), 2011).

2.2 Peak Discharge Estimation

For the catchment size of up to 80 ha and with the assumption of uniform rainfall intensity across entirely contributing catchment, the simplistic Rational Method can provide a reasonable estimate for peak storm water or runoff flow through the following expression provided storage requirement is treated separately:

$$Q = \frac{CiA}{360}$$

where:

Q = peak runoff flow (m³/s)

C = runoff coefficient dependent on land use and its imperviousness (from Table 5)

i = average rainfall intensity (mm/hr)

A = drainage area (ha)

In the case of mixed development, the average runoff coefficient should be used by combining contribution from various segments of different land use as follows:

$$C_{avg} = \frac{\sum_{j=1}^{m} C_j A_j}{\sum_{j-1}^{m} A_j}$$

Table 5 Quantity of design storm ARIs

Land Use	Runoff Coefficients (C) For Minor System (≤10 year ARI)	For Major System (>10 year ARI)
Residential – Semi-detached bungalow	0.70	0.75
Residential – Link and terrace house	0.80	0.90
Residential – Flat and apartment	0.80	0.85
Residential – Condominium	0.75	0.80
Commercial and business centres	0.90	0.95
Industrial	0.90	0.95
Sport fields, park & agriculture	0.30	0.40
Open space – Bare soil (No cover)	0.50	0.60
Open space – Grass cover	0.40	0.50
Open space – Bush cover	0.35	0.45
Open space – Forest cover	0.30	0.40
Roads and highways	0.95	0.95
Water body (Pond) – Detention pond (with outlet)	0.95	0.95
Water body (Pond) – Retention pond (no outlet)	0.00	0.00

3.0 SOFTWARE DEVELOPMENT

The programming procedures which attempted to mimic the manual computational processes are illustrated below on Figure 1 via a logical flow chart. Firstly, the drain presence is established first through user-defined start-end nodal reference entries in the appropriate fields, which are independent of the program. Linkage to immediate tributary upstream and by implication the larger drainage network come next using program-prescribed notations with up to 3 entries. Then, the surface type and area of the sub-catchment should be entered for the runoff coefficient. At this juncture, should the development be of mixed type with multiple land uses, further sub-catchment distinctions to up to 3 entries could be contemplated to obtain the total contributing area and average runoff coefficient. Next input includes overland, curb gutter and drain flow descriptions involving flow length, surface condition and/or roughness coefficient. This would enable overland, curb gutter and drain time computations, the summation of which would give the required time of concentration. To generate peak discharge, rainfall intensity would need to be calculated by entering the relevant rain gauge location and ARI, which would enable procedural referencing to the prescribed IDF curves. Basic drain geometric parameter and survey levels would be necessary at this point to determine its derived geometric parameter, invert levels, depths, flow velocity and discharge capacity. Finally, check would be conducted for the following compliance: 0.6 m/s ≤ Velocity ≤ 4 m/s and discharge capacity ≥ peak discharge. The same process may be repeated for other drain stretches.

With respect to programmatic implementation, the program was developed over a standard MS Excel worksheet and utilizing as much as the parent application platform and functionality for unassisted input-output processes and relatively simple computational tasks as shown in Figure 2. Furthermore, since the program is implemented in left-to-right row-wise manner, this allows for systematic expansion of the computational process for other distinct design processes through simple replication (i.e. standard copy-and-paste procedures) in the row direction of the worksheet without necessitating multiple data file processing and storage. For more assisted input-output processes and complex computational tasks, automation would be provided through VBA in the guises of user forms, Form/ActiveX controls, subroutines and user defined functions (Figure 3 to 6). In this case, care should be taken to place the cursor on desired singular row in order to apply the necessary changes to it. The program is saved into a single macro-enabled workbook file called Drain10.xlsm.

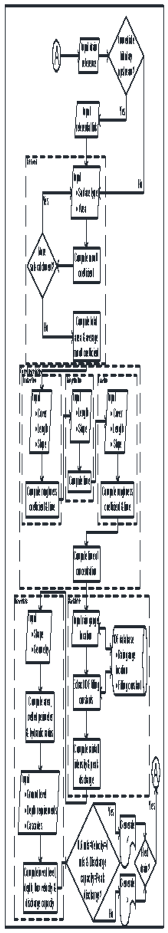


Figure 1 Flow chart of Drain10 programming procedures

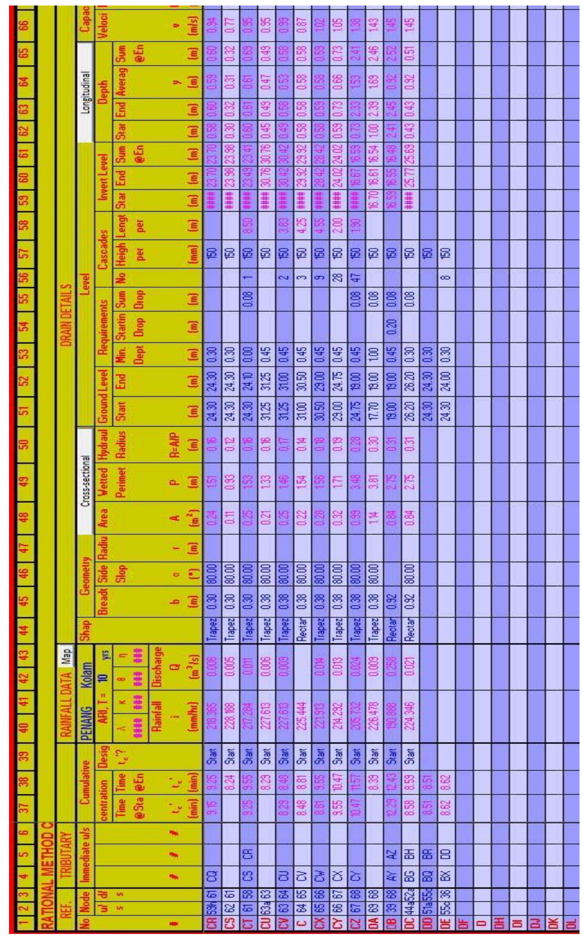


Figure 2 Common Drain10 worksheet opening template

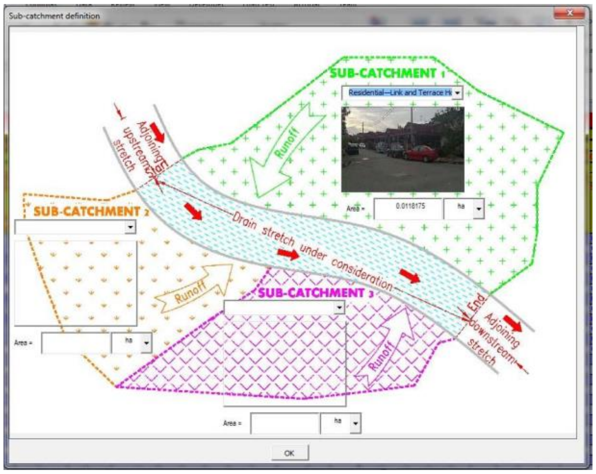


Figure 3 Catchment assisted-input interface

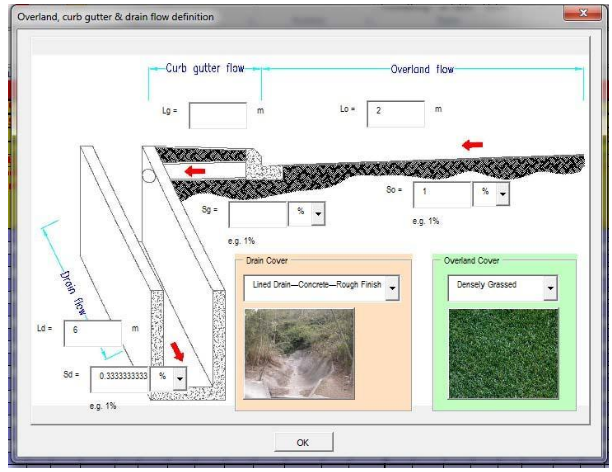


Figure 4 Flow assisted-input interface

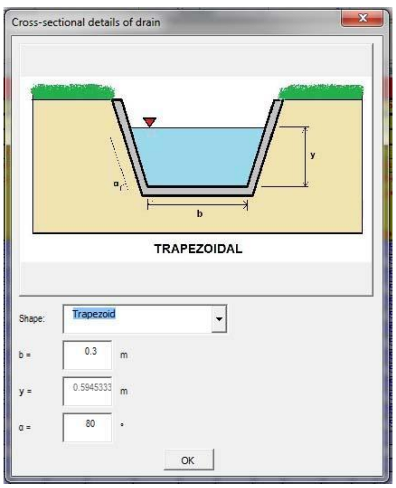


Figure 5 Channel (Cross-sectional properties) assisted-input interface

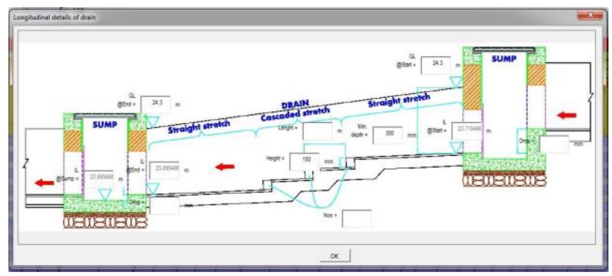


Figure 6 Channel (Longitudinal section properties) assisted-input interface

4.0 CASE STUDY

A 91 unit of 2, 3 and 4-storey townhouses and a 3-storey clubhouse have been constructed at Bandar Air Itam, Penang with the total land area of about 3.22 ha. The natural terrain was essentially hilly, ascending towards the eastern and north-eastern part of the site at elevation of about RL 60-80 m, and gradually descending towards the western and south-western part at elevation of about RL 15-30 where it encounters a stream. The surface was initially covered with thick secondary forest, and largely uninhabitable and practically untouched by prior human activities. Upon development, short but tall reinforced and adequately protected slopes of about 45°-70° have be formed on the upper incline to bring the level down to about RL 35-40 m. In the same measure, retaining structures have been constructed on the lower decline just short of the stream reserve to raise the level to about RL 20-30 m. The built-up, flattened platforms for the buildings have been arrayed in such a way so as to make full use of the elevation variations with the help of retaining structures whenever necessary, and access roads are similarly adapted to the ground profile.

In the context of drainage, elements of drain, culvert and sumps have been constructed along the edges of impermeable surfaces such as buildings and roads to keep these dry and cut short the overland travel distance. In addition, the slopes were similarly well drained with the provisions of crest, berm and foot drains in order to mitigate erosion potentials. To negotiate difficult ground profile, cascades of drain were extensively used to normalize the resulting invert gradient and depth. Where sheer drop was encountered particularly in the cross-retaining-structure direction, vertically raised steel pipe was used and connected to a sump at each end to facilitate anticipated maintenance works. In keeping with MSMA 2 requirements, the drainage system was designed and constructed to drain into a detention pond at the south-western part of the site to control the outflow to the prescribed stream. Figure 7 illustrated the afore-mentioned post-developmental scenario.

The segment of drainage element analysed using the developed program was that segment most emphasized in Figure 7 and enumerated as ref. 30-68. This stretch constitutes one of the more critical elements due to its terminal position at the lower reaches of the project site where most of the captured runoff would eventually be channelled to. To initiate the analysis process, this segment has to be discretized into shorter stretches bounded by a pair of nodes that constitute its hydraulic junctions. These nodes were uniquely enumerated to define the respective drain stretches; the properties of the latter are listed Table 6 the direction of flow.

Table 6 Quantity of design storm ARIs

Drain (D) / Culvert (C) Stretch Ref.	Geometry (Shape-Width-Depth)	Length (m)	Gradient	Cascades (No-Drop height)
30-7 (D)	Trap-0.45 m-0.76 m	20.50	1:300	10-150 mm
7-11 (C)	Rect-0.76 m-0.76 m	11.00	1:300	-
11-31 (D)	Trap-0.60 m-1.73 m	20.00	1:300	7-150 mm
31-32 (C)	Rect-0.76 m-0.76 m	9.00	1:300	-
32-34 (D)	Trap-0.60 m-2.08 m	44.00	1:300	17-150 mm
34-35 (C)	Rect-0.76 m-0.76 m	9.00	1:300	-
35-36 (D)	Trap-0.75 m-2.23 m	26.50	1:300	14-150 mm
36-37 (D)	Trap-0.75 m-2.40 m	20.50	1:300	7-150 mm
37-38 (C)	Rect-0.92 m-0.92 m	9.00	1:300	-
38-39 (D)	Trap-0.75 m-2.32 m	55.00	1:300	24-150 mm
39-68 (C)	Rect-0.92 m-0.92 m	11.00	1:300	-
30-7 (D)	Trap-0.45 m-0.76 m	20.50	1:300	10-150 mm
7-11 (C)	Rect-0.76 m-0.76 m	11.00	1:300	-
11-31 (D)	Trap-0.60 m-1.73 m	20.00	1:300	7-150 mm
31-32 (C)	Rect-0.76 m-0.76 m	9.00	1:300	-

Based on these results, it can be deduced that the drainage capacity of the investigated segment is sufficient to handle the projected runoff from the development in the order of excess that would provide a comfortable cushion. This supposition is further proven by the observation of the running system on site which displays remarkable operation and functionality for the intended purpose that it was built. In addition, these conclusions were verified through manual computations.

5.0 CONCLUSION

The research has shown that Excel VBA program is a suitable platform for repetitive and complex engineering computations. This work should be continued to incorporate more hydrological concepts, customizable databases as well as technical correlations and models to make data entry and application usage as seamless a process and intuitive as possible.

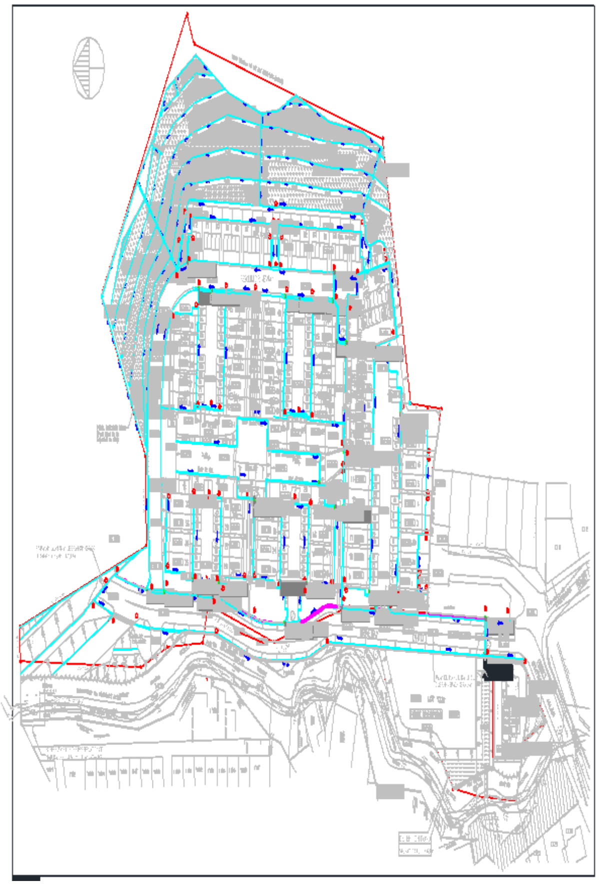


Figure 7 Site plan with drainage elements and lot boundary emphasized

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