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Mathematical Modelling of Watershed Wetland Crossings for Flood Mitigation and Groundwater Enhancement – Case of the Attanagalu Oya River Basin

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Abstract: Recurrent flooding mostly experienced in urbanized lower floodplains is a major problem faced by many of the river basins. In the developed countries, flood retention/detention is effectively practiced as a flood management option which also enhances groundwater recharge. However, this approach requires sufficient land with provision for storage and acquisition of land for incorporation of these facilities is a major issue in built up areas. Present modelling work analysed the possibility of utilising the distributed temporary storage zones that exist at wetland crossing locations of the road network. The mathematical model calibrated and verified for the Attanagalu Oya watershed of Gampaha District at Karasnagala and extended to the outlet at Ja-ela, investigated the possibility of storage enhancement by raising the road surface together with an engineered drainage structure to detain the floods. Model simulations for the rainfall event of May 2010, revealed that the trial interventions of 0.3 m road formation level increase with a 0.2 m drainage outlet sill level increase at feasible wetland crossings lead to a 14.2% reduction in peak flow while the enrichment of groundwater was 8.7%, and the flooded area reduction at Ja Ela/Elenegoda exit point was 9.2%. This demonstrated that a network of engineered wetland crossings provides an eco efficient infrastructure solution for sustainable management of floods and groundwater enhancement.

Keywords: Sri Lanka, Flood, Groundwater, Wetland, Mathematical Modelling, Hydrology, Reservoir, Channel, Routing

1. Introduction

Flooding is a major problem faced by many of the river basins and floods are mostly experienced in the lower floodplains where there is significant urbanization. Pressures of population growth, issues such as unemployment, the need to be at close proximity to water supply, electricity and transport services create stress on the land requirement. Increasing need for land makes most people to fill the lowlands, wetlands and flood retention areas to build dwelling units and related infrastructure. The drainage water that would normally occupy these areas would then move to locations further downstream. Apart from the need for land, most people would opt to keep their own land dry by quickly draining any rain or drainage water to the closest waterway. Therefore, in areas of human occupation, no sooner the rain reaches the ground, runoff diversions facilitated by drainage networks gush towards the lower terrains. As a result there is high runoff leading to floods and less infiltration resulting in poor groundwater replenishment. In the lower floodplains bounded by the sea, this will result in higher floods and floods of exceptionally prolonged durations.

The target of most engineering infrastructure designers is drainage enhancement as a means of flood management. It has been noted that in most cases where gravity drainage is not a feasible option, the next preferred option for lowland flood management is the combination of a pump-levy system.

In the developed countries, flood retention/ detention is a flood management option [1], [2], which also enhances groundwater recharge. Incorporation of flood detention/ retention reservoirs require sufficient land with provision for storage but in most areas population pressure poses great difficulties when trying to find such lands. Therefore, provision of flood detention/ retention facilities in populated areas without adequate building regulations becomes a serious problem.

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In populated watersheds, there are many roads to cross the valleys and at these crossings there are paddy fields or wetlands to discharge stream flow through the road embankment either with one or several drainage crossings. At these wetland crossings there is only very little storage but since these are located in a spatially distributed manner, even with a little storage enhancement there is a possibility to incorporate flood retention/detention. In cases where there is room for storage enhancement, it is possible to raise the road surface together with an engineered drainage structure to detain the floods. Such flood detention/retention storages if suitably designed would trap the fertile sediments, enhance groundwater, enrich soil moisture and maintain biodiversity, while providing a pleasant environment.

The objective of the present work is to mathematically model Attanagalu watershed in the Gampaha District to evaluate the potential of utilizing the road crossings as an eco efficient infrastructure network so that sustainable management of floods and groundwater could be achieved.

2. Background

Gampaha District draining towards the west of the island and bordering the sea receives approximately 2,400 mm of rainfall annually. Attanagalu Oya watershed in the Gampaha District experiences the inadequacy of water resources, reduced groundwater in the upper watersheds and floods in the flatter urbanized watersheds in the downstream. Negombo lagoon acts as the downstream control for the Attanagalu Oya (Fig. 1). Upstream water which reaches the downstream floodplains get restricted access to the ocean due to downstream control. Such water makes attempts to occupy the flat lowlands until the passage becomes favourable. Under these conditions, it is quite natural for floods to threaten the dwellings and economic activities of the people living at close proximity to the lowlands. In most watersheds there are many localized flat plains facing flooding situations. Therefore, it does not appear wise or desirable for the upstream users to urbanize, clean and widen the drainage paths because such actions would facilitate surface waters to rapidly reach the downstream locations. Since the flatter regions close to the streams are usually with higher groundwater tables, when floodwaters reach such area, there is relatively low infiltration taking place. Under these conditions, the floodwater removal in the downstream low-lying areas close to the sea gets restricted to a single option, which is draining to the sea. As such, most prudent option would be to gradually release the stormwater from individual compounds meaning a gradual release from the regions of origin.

In the present study, investigations were carried out to identify options available in the Attanagalu Oya basin to carryout surface water retention and detention. It was noted that in the upstream catchments, there are many man-made catchment crossings developed for transport purposes and at many locations, either the wetlands or the paddy fields were providing service as flood detention/retention basins.

At these locations it could be noted that when the structures linking the waterway through the road embankment were inadequate to pass the floodwater, then water pools were created in the upstream and the excess was spilled over the road sections creating flooding of roads. At many locations the storage was very limited and in all locations the flow discharges were not engineered. A flood control functions that had taken place at the road crossings were noted as inadvertent actions. It could also be noted that either with urbanization or due to construction of housing units, public have reclaimed the retention spaces and facilitated rapid drainage of these wetlands.

The initial surveys in the Attanagalu Oya basin identified a significant flood retention effect that could be generated from the wetland crossings and especially in the catchments where the upstream lands are yet to be occupied by either the construction of dwelling units or other important infrastructure. There is also a need to restrict upstream retention to about 3 days when the wetlands are presently under paddy cultivation. Incorporation of suitably engineered retention/detention infrastructure would facilitate the retardation of floodwater resulting automatic enrichment of the lands with eroded soils and nutrients.

In this study, a mathematical model was developed to identify the water retention capability if the available intermittent storages are enhanced with an increase of the formation level by about 300 to 600 mm.

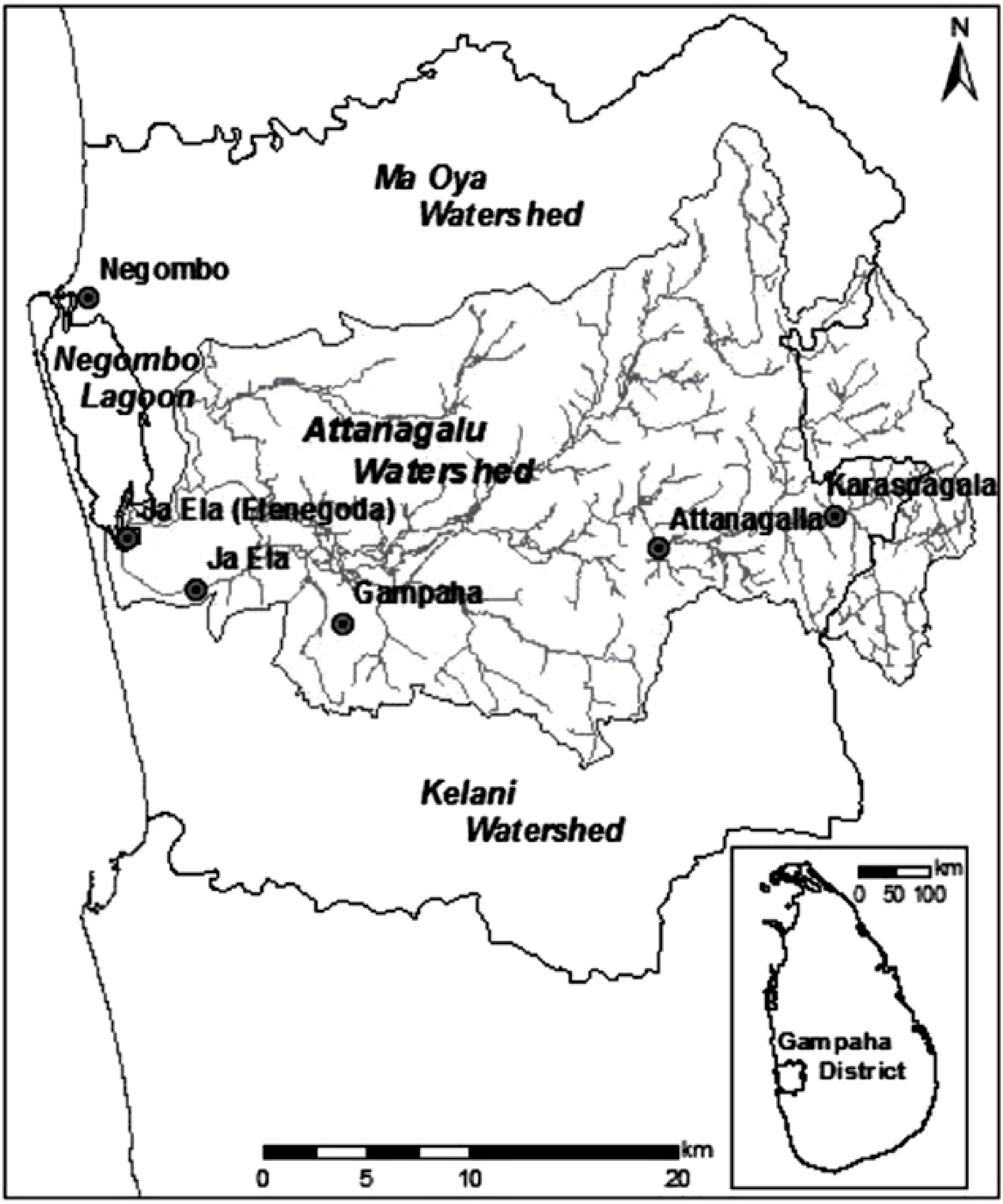

Figure 1 - Attanagalu watershed draining to Negombo Lagoon in Gampaha District

In the model the direct runoff computed through the concepts of Unit Hydrograph [3], was first routed through the wetland using a storage function and then routed along the river network utilizing the Muskingum method. The distributed model developed for Attanagalu Oya in order to study the engineering interventions was compiled using FORTRAN 90 and could be effected to micro catchments defined by road crossings to determine structure opening size and other parameters to optimise flood retention/detention. The model was calibrated and verified for Karasnagala watershed (54 km^2) using available daily flow measurements. The model was then extended to the entire Attanagalu Oya basin which included 676 sub watersheds. Flow computations at each node included (i) the direct land area runoff contributions from lands within the parent watershed, (ii) the component reaching from other upstream catchments routed through the adjacent and upstream water quantities through the detention/retention storage. Watershed wetland storage values, elevations and slopes were estimated using available satellite imagery, and 1:10,000 topographic data of the Survey Department. These estimations were then compared with over 1,400 technical field observations to estimate travel distances, slopes, runoff coefficients, wetland storages, etc.

3. Model Concept

The mathematical watershed model conceptualized the flow through a wetland crossing in a manner similar to the reservoir routing concept of the Irrigation Department Guidelines [4]. Mass balance equation for the retention and detention area is simulated as given below in Eq. (1), where, $S_{(t)}$ & $S_{(t+1)}$ are initial and final storage volumes (m^3) respectively during time period t (s); $I_{(t)}$ is inflow into the reservoir due to runoff component (m^3/s); $E_{(t)}$ is the evaporation loss (m^3/s); $P_{(t)}$ is the percolation contributing to groundwater recharge (m^3/s); $QC_{(t)}$ is the culvert discharge (m^3/s); $QS_{(t)}$ is the overflow or spill discharge at paddy crossing (m^3/s), and; nt is the total simulation duration (s).

Total inflow to each sub watershed is computed using the hydrograph estimated from peak flow and time of concentration computations, watersheds. Peak flow estimation for each sub watershed by the Rational Method considering a uniform rainfall intensity for a duration equal to the time of concentration, t_c, is given by, $Q=P_{ijk}\times R\times A_{ijk}$ where, R = Rainfall (mm/hr), A_{ijk} = Area of concern with given factors i,j,k (ha), i representing the land use/cover, j representing slope category and k indicating soil type. In the study area, five types of land uses as forest, garden, grass & chena, cultivations, rock, and reservoirs were taken while three slope classes as flat, average and steep were used. Soil types in the area were approximated to two as Red Yellow Podzolic and Alluvial. A composite runoff coefficient for each watershed was computed by taking the area weighted average of the runoff coefficients for each land cover. Runoff coefficients for each land cover, slope, and soil type were taken from [5]. Time of concentration (t_c) was determined by applying Kirpich Formula [6]. The accumulated flood in the downstream most point of the sub watershed was then used to estimate the inundation depth and area for the particular sub watershed. The model then routes the accumulated flood through the detention/retention storage, while considering simultaneous culvert flow and spill discharge.

The culvert is the exit structure or the sluice of detention/retention storage. The flow through the culvert is controlled by many variables including the inlet geometry, roughness, size,

$$S_{(t+1)} = S_{(t)} + I_{(t)} - E_{(t)} - P_{(t)} - QC_{(t)} - QS_{(t)} \quad \text{for all } t = 1, 2, \ldots, nt \qquad \ldots(1)$$

$$QC_{Box} = N_{Box} * W * {}^{2}/_{3} * C_d * C_v \sqrt{{}^{2}/_{3} * 9.81 * (H_t - H_{Sill})^{3/2}} \qquad \ldots(2)$$

$$QC_{Pipe} = N_{Pipe} * {\{D * 0.432 * \sqrt{9.81} * (H_t - H_{Sill})^{1.9}\}}/{D^{0.4}} \quad for\ {}^{H_t}/_{D} < 0.8\ and \qquad \ldots(3)$$

$$QC_{Pipe} = N_{Pipe} * D * 0.432 * \sqrt{9.81} * (H_t - H_{Sill})^{1.5}\ for\ {}^{H_t}/_{D} \geq 0.8 \qquad \ldots(4)$$

$$Q_t = C_1 I_{t-1} + C_2 I_t + C_3 Q_{t-1} + C_4(q_L \Delta x) \qquad \ldots(5)$$

$$K = -Qt/[dQ/dt(1-x)] \ \ or\ K = \Delta t\,(C_1 + C_2)/(1 - C_2) \qquad \ldots(6)$$

slope, approach, tail water conditions and also whether the flow is full or partly full [7]. Field surveys revealed that present system of drainage is through box culverts and hume pipes. In the model, culvert discharge was calculated taking into account the inlet control conditions based on the effective depth of headwater causing the flow. For box culverts, the discharge was estimated as given in Eq. (2), where, N_{Box} is the number of culvert boxes, W is the width of culvert, H_t is the Depth of water above datum, H_{Sill} is the Culvert sill height, C_d is the Coefficient of discharge, C_v is the Coefficient of velocity. In case of pipe culverts or hume pipes, the two equations given as Eq. (3) and Eq. (4) abow were used [7], where, N_{pipe} is the number of culvert boxes, D is the Culvert diameter, H_t is the Depth of water above datum, and H_{Sill} is the Culvert sill height.

The hydraulic conditions downstream of the culvert site were evaluated based on downstream canal width to determine the tail water depth for the calculated discharge and the culvert discharge was iteratively modified accordingly. Once the culvert headwater elevations exceed the roadway crest elevation the overtopping of the road is considered as a flow over a spillway. The spillage is calculated using the equation $Q_{Spill} = C_d \times L \times (H_t - H_{Sill})^{1.5}$ where Q_{Spill} is the overtopping flow rate (m^3/s), C_d is the overtopping discharge coefficient, L is the length of spill (m), H_t is the depth of water (m) and H_{Sill} is the Culvert sill height (m) [7]. The flow along the stream network was computed with the Muskingum channel routing equation [8], given as Eq. (5) above, where Q_t, Q_{t-1} are outflow at time *t and t-1*, I_t, I_{t-1} are inflows at time *t and t-1*, C_1, C_4 are coefficients of wave celerity, q_L is lateral inflow and Δx is length of channel.

Evaporation loss, $E_{(t)}$, is calculated based on the flooded area estimated by interpolating the stage-capacity-area curves while the seepage contributing to the groundwater recharge, $P_{(t)}$, is estimated in proportion to available total storage at the time interval [4]. At the end of each time step, total outflow from the watershed is routed using reservoir continuity, Muskingum linear channel routing, while accounting the hydraulic limitations including outlet capacities and outlet control due to backwater effect. In the model runs, Muskingum discharge weighting factor x and average reach travel time parameter K for river routing were taken as $\Delta t/K \approx 2x$ (x=0.3~0.5) and estimated as given in Eq. (6) above.

Physical parameters of model also included the backwater inundation area and its storage capacity, culvert dimensions, sill level and dead storage, spilling elevations and length, terrain slope and length of stream sections. Initial water depth at each micro watershed for base storage estimation was assumed during data initializing stage of model computations. The stream network of the watershed at Karasnagala, the delineated 19 sub catchments, the schematic watershed, and river network are shown in the Fig. 2.

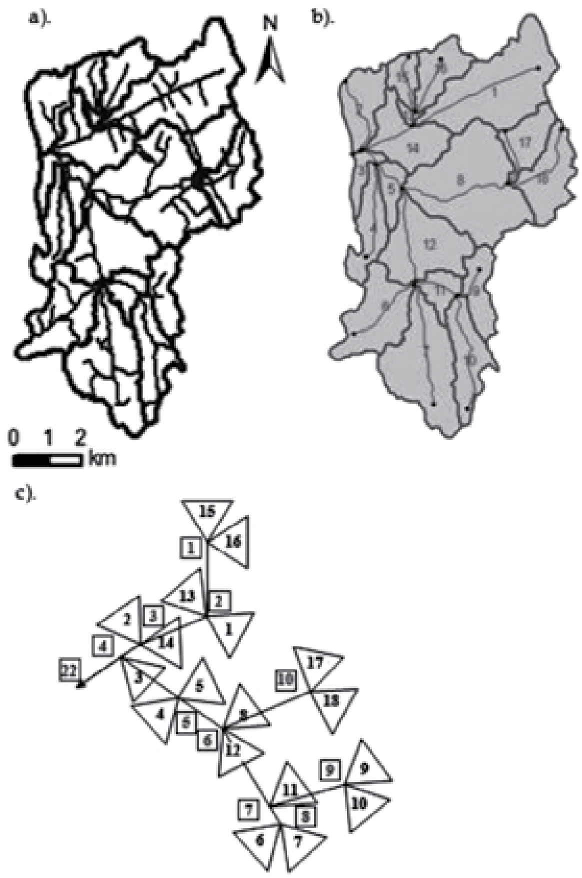

Figure 2 - Watershed at Karasnagala - a) River Network, b) Schematic used for model, c) Watershed and nodal connectivity

Using available observed data, the model was calibrated and verified for Attanagalu Oya watershed at Karasnagala. Model computations with the data of daily temporal resolution used the 1972-1973 observations as the calibration data set while verifications used the data from 1974-1975. Thiessen averaged aerial rainfall computed with daily rainfall measurements from the Department of Meteorology rainfall stations at Vincit, Karasnagala, Pasyala represented the spatial variability of rainfall. Model calibration used the culvert and spill discharge coefficients and seepage enhancement factor, as model parameters, and runoff coefficient was slightly adjusted where necessary. Model evaluations were done using the Mean Relative Absolute Error (MRAE) [9], the Nash–Sutcliffe model efficiency coefficient, and coefficient of correlation (reference).

The calibrated model parameters (initial and final) are shown in Table 1. Values of the Nash–Sutcliffe model efficiency coefficient, correlation coefficient, R^2, and Mean Ratio of Absolute Error (MRAE) with calibration and validation are given in Table 2. Flow duration curves showed a very good matching of observed and modelled flows for the watershed (Fig. 3).

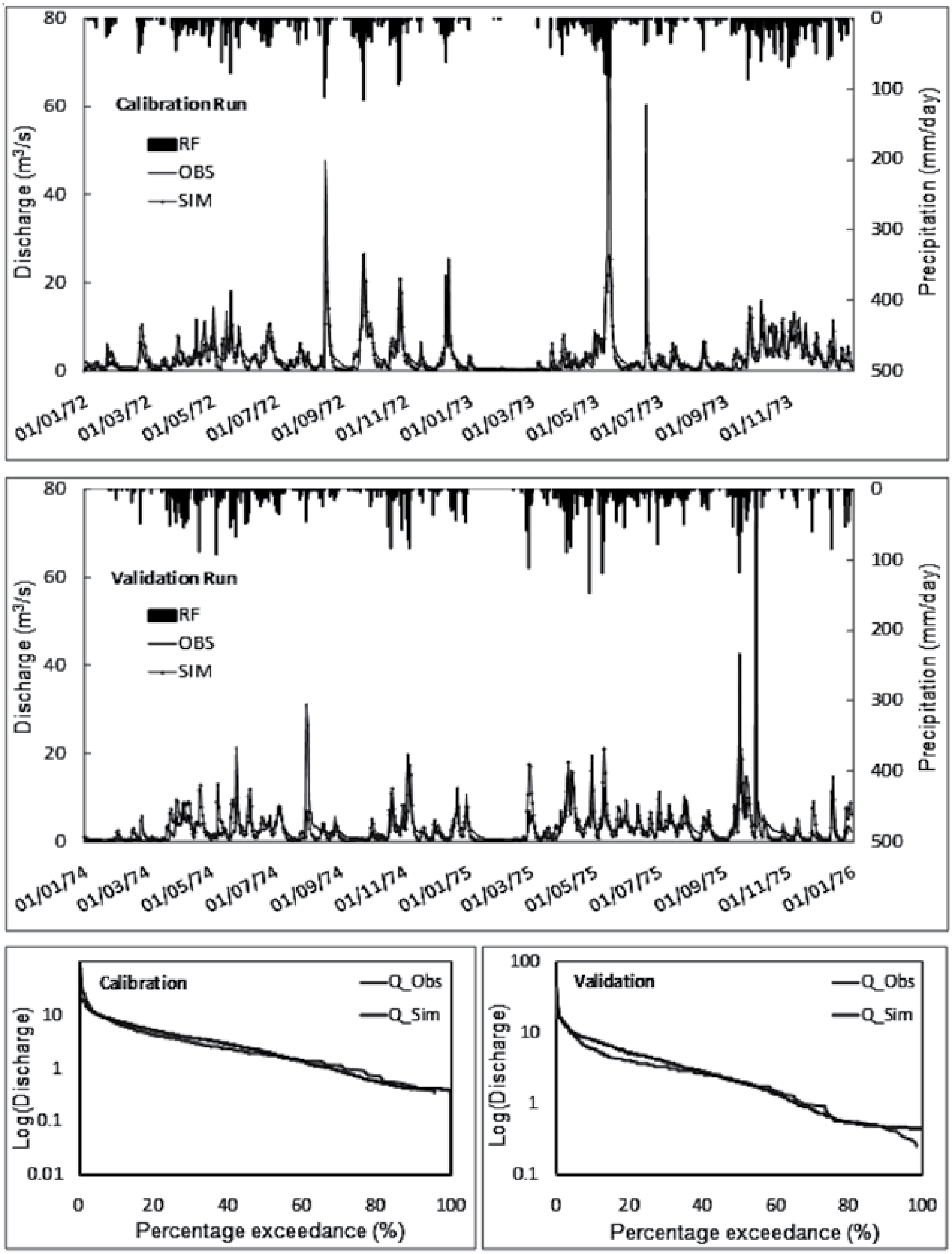

Figure 3 - Comparison of Model Calibration and Verification; a). Calibration run b). Validation run; Flow duration curves for c). Calibration run d). Validation run

Table 1 - Calibrated Model Parameters

Parameter	Before Calibration	After Calibration
Coefficient of discharge, C_d (Culvert)	0.70	0.76
Coefficient of velocity, C_v (Culvert)	1.00	1.02
Coefficient of discharge, C_d (Spillway)	0.70	0.78
Runoff Coefficient, C	0.450	0.483

Table 2 - Calibration and Verification Results

Coefficient	Calibration	Validation
Nash coefficient	0.46	0.30
Correlation coefficient	0.69	0.64
RSQ	0.47	0.41
MRAE	0.66	0.70
MRAE-U	0.62	1.25
MRAE-M	0.62	0.53
MRAE-L	0.84	0.66

4. Model for Attanagalu Oya

After the calibration and verification at Karasnagala, Mathematical Modelling was extended to the downstream most point of the Attanagalu Oya watershed (Fig. 4). The Objective of the extension of the model to a near coast location is for the demonstration of the effects of desired flood management interventions and to quantify potential benefits through inundation depth reduction, and demonstrate the recovery of land extent which might undergo flooding with present conditions and if no interventions are introduced. The watershed of Attanagalu Oya at Ja-Ela (790 km^2) was selected by considering the topographic features, land use, and downstream conditions

The satellite imagery, contour and spot heights and site inspections were used to capture the number of watershed crossings in the basin. Initially, these were identified from the 1:10,000 maps and then field staffs were deployed for model parameter data collection. Collected field data and map based information were used finalise the delineation of 688 micro catchments in the Attanagalu Oya basin. Drainage directions were drawn for each sub catchment while undertaking field visits to clarify ambiguities. Most of such visits were to the flood plains and to locations either close to the coast or next to the major stream sections. Drawing of drainage direction maps enabled the easy assembly of flow path network for watershed stream flow routing. Desk studies included the comparison of watershed crossings and identification of the risk of upstream inundations. Field data collectors were instructed to visit all wetland crossings and collect the spilling length, the upstream slope and storage parameters, number of drainage structures and their dimensions, the flooding durations and flow depths, coordinates and digital photographs.

The field work and desk studies combined all available information to classify the wetland crossings according to the risk associated with the inundation of the upstream of a wetland crossing as a result of increasing the storage when raising its formation level. Classification results showed that out of the set of wetland crossings in the Attanagalu Oya, 48 locations fall into the High Risk category, 100 as Risky, 191 as Low Risk category and 349 as No Risk group. A risk category indicates the degree of difficulty in raising the elevation of a wetland crossing by 0.3 m to increase the stream flow retention/detention due to upstream habitat inundations. The two categories, No Risk and Low Risk consisting of 540 units which causes no or minimum inconvenience to the upstream users, were considered for verifying the option of increasing the upstream detention. Interconnected river network for Attangalu Oya used in the estimation of flow accumulation in the model consisted of a total of 346 river/stream segments, with a 73.1 km longest river course and a 1057 km total flow conveyance distance. The Fig. 5 shows the set of micro watersheds along the longest river course.

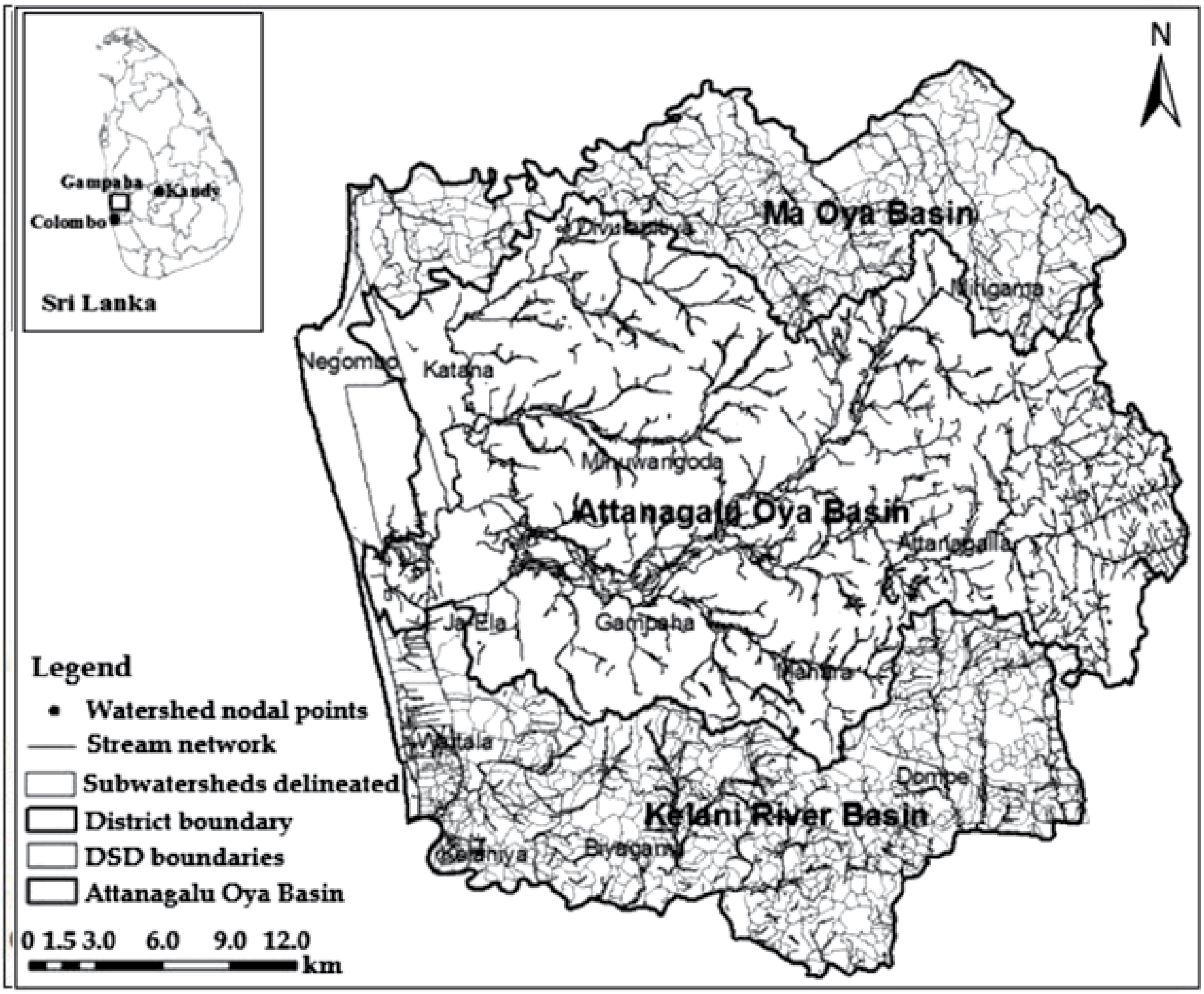

Figure 4 -Attanagalu Oya Watershed and Stream Network

The model extended to the Attanagalu Oya basin at Ja Ela/Elenegoda (790 km^2), was used for an event based simulation of 2010 May hourly rainfall with a 15-minute model simulation interval. Due to the limitations in availability of high resolution rainfall data in the catchment, Colombo station data with one hour resolution was used for the model runs and output evaluations were done using engineering judgment. The distributed mathematical model was initially run with the existing field data and micro watershed features for each wetland crossing apprehended during the Technical Field Survey.

5. Study of Available Options

The model predictions for the existing situation was compared with the case where the formation levels of No Risk and Low Risk wetland crossings were raised by 0.3 to 0.6 m to achieve increased flood retention capacity along the cascade. Comparison of without intervention stream flow with the case of 0.3 m increase in formation level of crossing is shown in the Fig. 6. As another alternative, the dead storage at each wetland crossing was enhanced with an increase of drainage discharge structure sill elevations by 0.1 to 0.3 meters. The Fig. 7 shows the comparison of present status with that due to a formation level increase of 0.3 meters and a sill level increase of 0.2 meters. The effect of these interventions for the rainfall event of May 2010 indicated a 14.2% reduction in peak inflow to the wetland crossing, while the enrichment of groundwater was 8.7%. The flooded area reduction at Ja Ela/Elenegoda exit point was 9.2%. These results are shown in the Table 3. Cumulative watershed inflow, nodal outflow, and groundwater enrichment along the longest river course are shown in the Table 4. Inundation area computation at each of the stated nodes was not carried out because of the inadequacy of topographic data to capture the associated magnitudes in a meaningful manner.

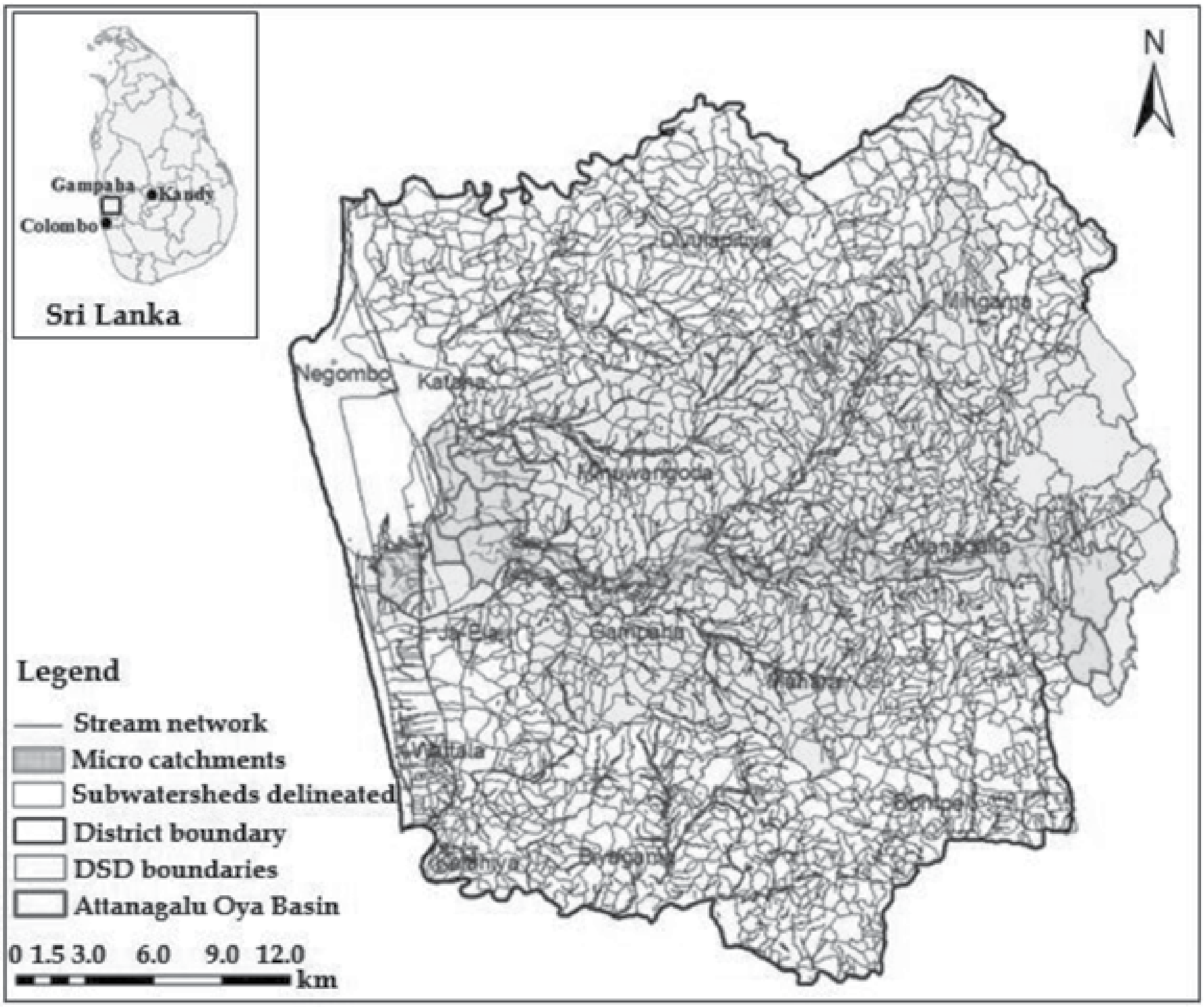

Figure 5 - Micro catchments along the longest river course in Attanagualu watershed

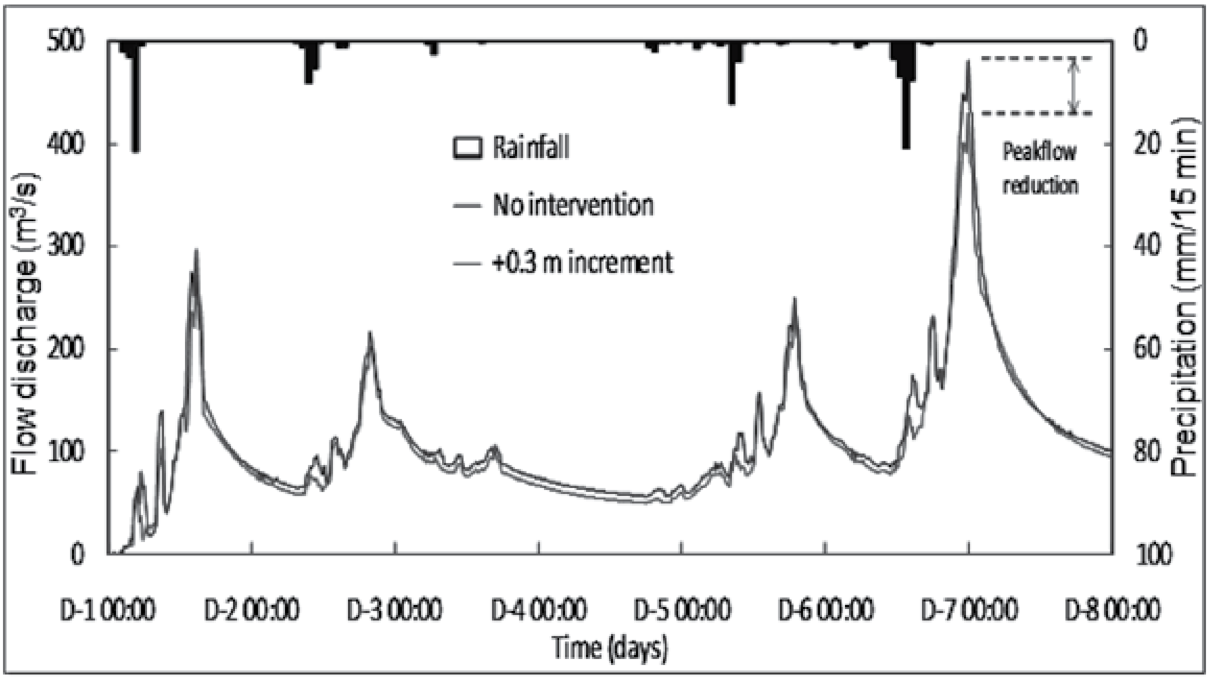

Figure 6 - Peak Flow Reduction due to a 0.3 m Inundation Increment at Low and No-Risk Wetland Crossings

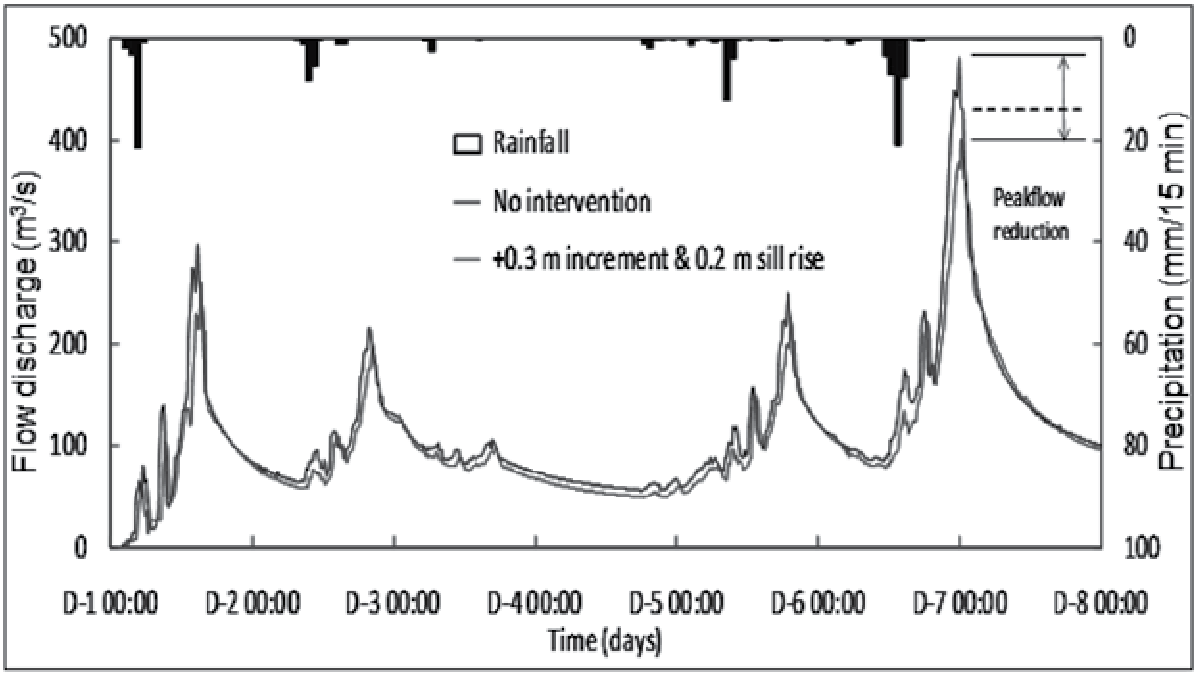

Figure 7- Peak Flow Reduction due to a 0.3 m Inundation Increment and a 0.2 meter Sill Level Increase

Table 3- Summary of Effects of the Intervention of Raising Upper Watershed Formation Levels by 300 mm in Attanagalu Oya Basin

	Intervention		
	No Intervention	0.3 m Increment	Effect (%)
Maximum Inflow (m^3/s)	480.5	412.3	-14.2
Maximum Outflow (m^3/s)	48.8	45.8	-6.1
Maximum Water Depth (m)	1.65	1.53	-7.2
Maximum Flood Area (ha)	822.6	746.4	-9.2
Maximum Inundation Time (hours)	23.3	21.4	-7.9
Groundwater Enrichment (mil. m^3)	47.7	51.8	8.7

Inundation area variation at the Ja Ela/Elenegoda river node was compared with the effect on the Gampaha Divisional Secretary Division. This was carried out to demonstrate the potential of the GIS based distributed watershed model to extract the results in a manner that would create an impact within the existing land administration framework.

Total flood inundation area recovery within Gampaha DSD was approximately 53.9 ha for an intervention of 0.3 m formation level increase. An approximate inundation area recovery of 12 % could be noted within Gampaha DSD (Fig. 8). Summary results are shown in Table 5.

Table 4 - Watershed Inflow, Nodal Outflow, and Groundwater Enrichment along the Longest River Course of the Attanagalu Oya at Ja Ela/Elenegoda

Description	Quantity
Total number of micro watersheds (no.s)	132
Total converging river length (km)	664.3
Maximum river length (km)	44.8
Total inundation area with no intervention (ha)	462.3
Total inundation area (after 0.3 m increment) (ha)	408.4
Inundation area recovery (ha)	53.9
Inundation area recovery (%)	11.66%

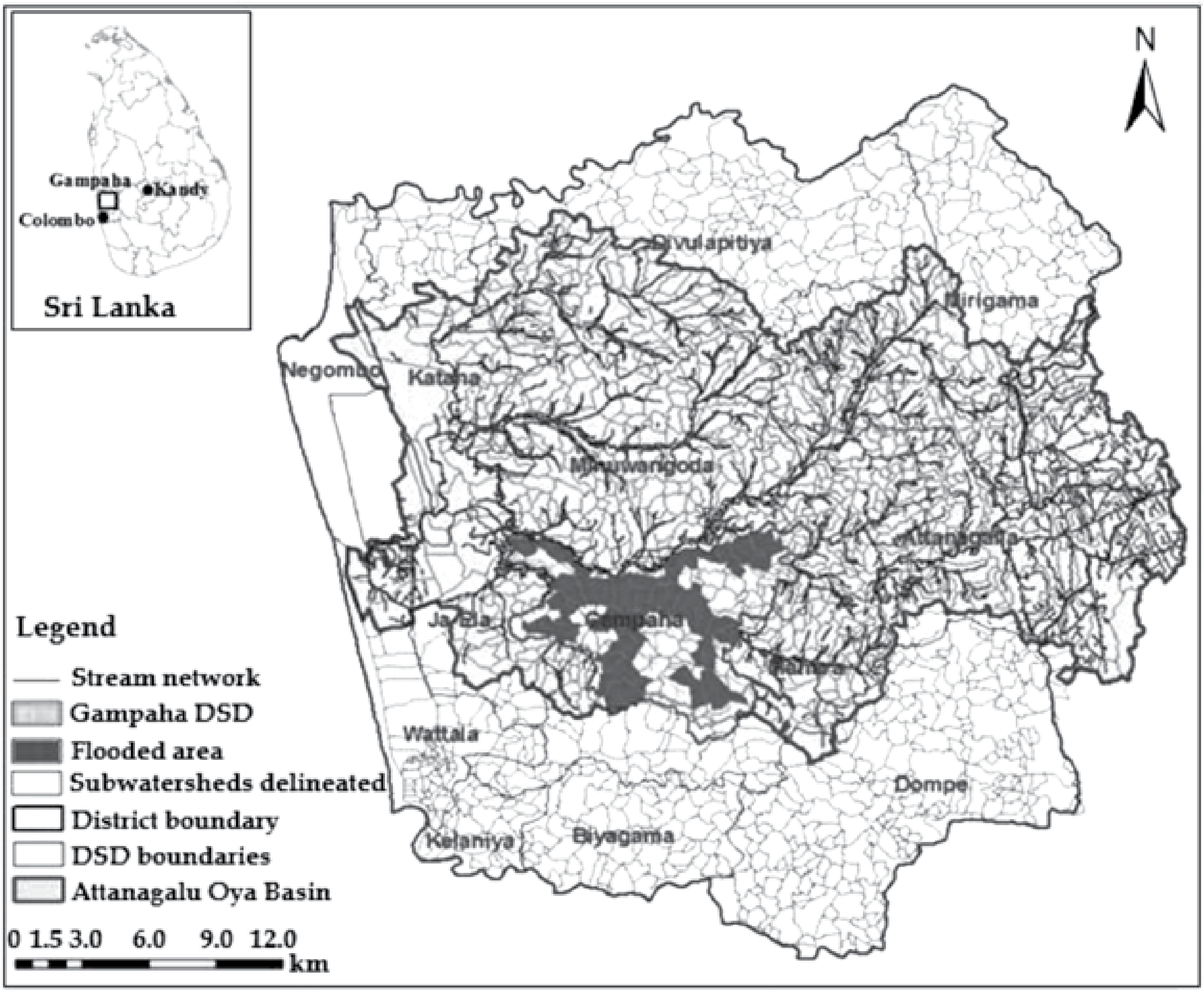

Figure 8 - Flood Area Modelling Result for Gampaha DSD

Table 5 - Summary of Simulation Results for Gampaha Divisional Secretariat Division

		Name of Watershed Exit Point			
		Karasnagala	Attanagalla	Gampaha	Ja Ela
Catchment Area (km^2)		54.2	165.6	345.8	791.2
Main River Length (km)		14.3	26.1	40.8	55.2
No Increment	Maximum Inflow (m^3/s)	166.2	255.3	420.5	453.6
	Maximum Outflow (m^3/s)	46.2	73.8	109.3	127.0
	Groundwater Enrichment (1000 m^3)	9,230	11,529	21,818	30,498
0.3 m Increment	Maximum Inflow (m^3/s) & Percent Increment (%)	161.8 (-2.7%)	245.9 (-3.7%)	373.3 (-11.2%)	387.8 (-14.5%)
	Maximum Outflow (m^3/s) & Percent Increment (%)	41.4 (-10.3%)	64.9 (-12.0%)	94.1 (-14.0%)	101.2 (-20.3%)
	Groundwater Enrichment (1000 m^3) & Percent Increment (%)	10,177.8 (10.3%)	13,084.4 (13.5%)	25,052.8 (14.8%)	35,328.7 (15.8%)

Table 6 - Summary of Micro Watershed Parameters

Parameter		Attanagalu Oya
Slope	Max	0.2919
	Min	0.000038
	Average	0.01743
Wetland Crossing Length (m)	Max	1745
	Min	15
	Average	165
Area (ha)	Max	1590
	Min	4
	Average	116
Wetland Retention or Detention Volume (m^3)	Max	8000×10^3
	Min	0
	Average	188×10^3

6. Discussion

The distributed watershed model calibration and verification for Karasnagala watershed indicated good reproduction of observed stream flows. The model which included channel and reservoir routing through a combination of hydrologic and hydraulic modelling for stream flow estimation in flood plains, the hilly terrain and the available data resolutions pertaining to the test catchment provided limited capacity to fully test the model. The performance of the model extended for the Attanagalu Oya showed realistic results when applied to a single rainfall event. In the present work, this approach was taken to overcome the data inadequacies pertaining to spatial and temporal resolutions. Encouraging performance of the model warrants the establishment of gauging stations to acquire necessary data for testing the stream flow and inundation predictions.

The model uses several physically based parameters for flow computations. Regional parameters of the unit hydrographs, estimation of runoff ratios, discharge coefficients, groundwater recharge coefficients based on literature reported values. However such parameters need to be tested prior to the design of the proposed interventions. Wijesekera [10] summarizing over a hundred water research publications, has indicated the limited research in the case of stream flow modelling and also with respect to the stated parameters. Therefore, it is necessary to evaluate such recommendations to establish a field data collection program to improve the capability of the model. One of the most important element is the verification of the groundwater recharge coefficient recommended by the Guidelines of the Irrigation Department [4].

The model also used several field survey based rules to estimate the storage values, spill lengths over wetland crossing sections, dead storage values, downstream boundary conditions at the drainage structure etc. Field data collection programs need to carefully study the establishment of these relationships and then capture data to obtain desired accuracies.

The present work utilized already available wetland storage facilities to enhance the infiltration and temporarily store small quantities of the flood runoff at spatially distributed locations. Model results indicated that the proposed intervention is to enhance the elevation of the road embankment by about 300 mm with the inclusion of a suitably designed drainage structure to control the outflow limiting the upstream inundation durations. In engineering terms, design and construction of proposed improvements to the embankment and its drainage structure is easy compared to a new system of flood retention/detention because part of the system has been already in place over a significant period of time.

These interventions are eco-friendly because the other than the primary objective of flood mitigation, there is spatially distributed water storage enhancing the groundwater in a spatially distributed manner. This capability to arrest runoff at upstream locations and the resulting soil moisture enhancement facilitates growth of vegetation, filtering of groundwater at less polluted locations, and generation of reliable base flows in the stream network. In contrast to the usually preferred drainage improvement option for flood management, which necessitates increased drainage sizes as the runoff factors get increased with infrastructure development, while contributing to more flooding at the downstream locations, the present model provides a quantification based eco-friendly system of simple water infrastructure network which would lessen soil erosion, enhance soil water, reduce water peaks and increase time to peak.

The present work is contributing towards the development of a spatially distributed network of water infrastructure that looks at the sustainability of freshwater resources, sustainability of flood management and sustainability of the ecosystems. One of the important characteristics of this work is that the proposed water infrastructure is utilizing the road embankment and its drainage structure to ensure the environmental sustainability. Therefore this work is also an eye opener for the road developers to incorporate environmentally sustainable infrastructure by deviating from the present method of simply providing drainage across the road embankment.

7. Conclusions

- An Eco friendly distributed watershed model was developed, calibrated and verified with very good reproduction of observed stream flows. The Mean Ratio of Absolute Error during calibration was 0.66 while the same at validation was 0.70.
- Using a key rainfall event which caused heavy flooding in the watershed, the model demonstrated that the incorporation of a distributed flood detention and retention model could reduce the flood peak by

14.2% , the groundwater enrichment could be enhanced by 8.7% and the flooded area could be reduced by approximately 9.2%

- The present work demonstrated the possibility of incorporating a road embankment enhancement with an engineered drainage structure to use wetland crossings as sustainable flood retention infrastructure.

8. Acknowledgements

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References

1. Morris, J., Bailey, A., Alsop, D., Vivash, R., Lawson, C.S., Leeds-Harrison, P.B., "Integrating Flood Management and Agrienvironment through Washland creation in the UK", *Farm Management*, Vol. 12 (1), pp. 1–16, 2004.
2. Leschine, T.M, Wellman, K.F. and Green, T.H., *The Economic Value of Wetlands: Wetlands' Role in Flood Protection in Western Washington*, Final Report prepared for: Washington State Department of Ecology, Ecology Publication No. 97-100, 1997.
3. Wijesinghe, W.M.D. and Wijesekera, N.T.S., "Comparison of Rational Formula Alternatives for Streamflow Generation for Small Ungauged Catchments", *Engineer, Journal of the Institution of Engineers, Sri Lanka*, Vol XXXXIV, No 04, pp. 29-36, October 2011.
4. Ponrajah, A.J.P., *Design of Irrigation Head-works for Small Catchments*, Irrigation Department, Sri Lanka, 1984, pp. 107.
5. Perera, K. R. J. and Wijesekera, N.T.S., "Identification of the Spatial Variability of Runoff Coefficients of Three Wet Zone Watersheds of Sri Lanka", *Engineer, Journal of the Institution of Engineers, Sri Lanka*, Vol XXXXIV, No 03, pp. 1-10, July, 2011.
6. Chow, Ven Te, *Handbook of Applied Hydrology*, McGraw-Hill, New York, 1964, pp. 1418.
7. FHWA, *Hydraulic Design Series 5: Hydraulic Design of Highway Culverts (HDS-5)*, U.S. Department of Transportation, FHWA-NHI-01-020 Revision, May 2005, pp. 368.
8. Ponce, Victor M., *Engineering Hydrology, Principles and Practices*, Prentice Hall, Englewood Cliffs, New Jersey, 1989, pp. 640.
9. Yu, P.S., Yang, T. C., "Fuzzy Multi-Objective Function for Rainfall-Runoff Model Calibration", *Journal of Hydrology*, 238, pp. 1-14, 2000.
10. Wijesekera, N. T. S., "Surface Water Resources and Climate Change" in *Proceedings of the National Forum on Water Research 'Identification of Gaps and Priorities'*, National Science Foundation, Colombo, pp. 68-98, 2010.