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APPLICATION OF DUFLOW SURFACE WATER HYDRODYNAMIC MODEL

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Abstract

Duflow surface water hydrodynamic model aims to describe the behaviour of rivers in their natural conditions or state. As in all natural conditions inhomogenites and inconsistencies do prevail, thus proving difficult to integrate all sub systems making up a single system. Despite that, Duflow within its limits generate results that can be applied in real life situations such as planning and construction of engineering structures, decision-making, and environmental conservation and wetlands management. The objective of this case study was to establish a design flood recommendable for mitigation by using duflow surface hydrodynamic model. Various design flows are simulated against the different proposed structures hence, the optimal structure is finally recommended when economical, social and environmental constraints are considered in the decision making process. The measure of building a green-storage is the best and optimal structure for flood mitigation.

Keywords: *Duflow, Design Flood Mitigation, model, hydrodinamics, river.*

Aplikasi Model Hidrodinamis Duflow Air Permukaan

Abstrak

Aplikasi Model Hidrodinamis Duflow Air permukaan bertujuan untuk menjelaskan perilaku sungai secara alami atau tetap. Seperti berlaku di semua kondisi alam yang inhomogenitas dan inkonsistensi, sehingga sulit untuk menyatukan semua sub sistem menjadi satu sistem. Walaupun demikian Duflow dalam bantasan tertentu menghasilkan hasil yang dapat diterapkan dalam kehidupan situasi nyata seperti perencanaan dan konstruksi di bidang teknik struktur, pengambilan keputusan, dan pelestarian lingkungan dan pengelolaan peraiaran. Tujuan dari studi kasus ini adalah untuk membuat desain banjir yang dianjurkan untuk mitigasi dengan menggunakan model duflow hidrodinamis permukaan. Berbagai desain aliran disimulasikan terhadap struktur-struktur yang berbeda, struktur yang optimal yang dianjurkan adalah yang memiliki nilai ekonomi, social dan lingkungan yang menjadi pertimbangan dalam proses pengambilan keputusan. Green-Storage adalah struktur bangunan pengukur yang terbaik dan teroptimal untuk mitigasi banjir.

INTRUDUCTION

The catchment that was used was Nyando catcment area. It cactment is an ideal source of subsistence faming, rice cultivation, cattle grazing, human resettlement, drinking water supply, irrigation, navigation and a discharge point for all organic and inorganic matter. Moreover, pollution from the sugar mill is a major concern.

The Nyando catchment is categorised in to three main sub catchments, comprising of;
(a)   Ainmotua in the north (200 km^2), sloping from eats to the west,
(b)   Kipchoriet in the central (1712km^2), sloping from east to west, and
(c)   Cherongit, Kabletach and with minor stream (888km^2), sloping southeast to northwest (Wanjohi, 1999).

The upper catchment of Ahero was pre schematised, as time was insufficient to develop a detailed river network. The Nyando River at downstream Ahero was schematised into 6 nodes with 5 sections. Node 1 represented Ahero at the road bridge, Node 5, the wetland (swamp) and Node 6, Lake Victoria. Figure 1 shows the drainage network. The downstream network with the nodes was obtained from the 1:100000 and 1:50000 topographic and geological maps repectively. The distance from the outlet of Ahero to the estuary was estimated to be 20.7km. The sections were divided equally into 4140m with an elevation difference from Ahero to the lake as 12m.

Using the outcome from the various flood mitigation options, a final structure will be recommended to authorities as a measure to retard flood. The final deduction however, is to minimise damage caused to building and structures, the environment, and to reduce loss of human lives and livestock at Kano plain.

Data interpretation and analysis was performed, using standard statistical procedures and tests, hence missing data filled in as and when appropriate. Preliminary steps included testing of trends, homogeneity and consistency, establishing correlation between stations, defining relationship between rainfall and discharge, sorting extreme data, and finally executing the flood frequency analysis.

Based on the results obtained from the Kenya Meteorological Department, the average rainfall in the catchment is varying from 1000mm in the Kano plain to 1600mm at the base of Nyando escarpment. The mean annual temperature is estimated to be 23^{0}C (**Njogu, 2000**) with annual mean rainfall of 1184mm.

Dominant features are scarps in the north, east and south trespassing the footslopes and piedmont palineds to the Kano plain. The downstream of Nyando escarpment is typified by lacustrine alluvial plains featuring smooth rolling surface marked by minor irregularities linked to the renewal of fluvial activity that commenced most probably in the late quarternary (**Wanjohi, 1999**).

The aim of study was to establish a design flood recommendation by using duflow surface hydrodynamic model.
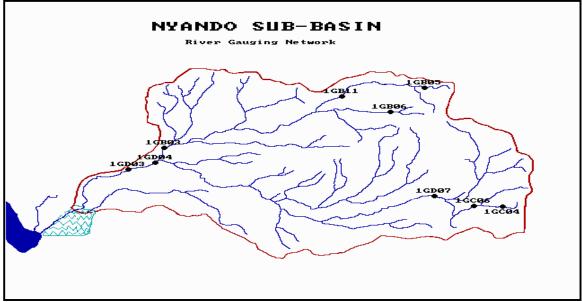

Figure 1.
Drainage system and discharge station *(Courtesy of W .Spaans' notes, 2003)*

METHODS

Duflow surface water hydrodynamic model has been applied using a case study from **Nyando** catchment in the western part of Kenya in Africa to firstly, simulate various extreme flood behaviours, and secondly, to simulate their retardation levels by using selected structural measures as flood mitigation techniques.

Network design

Levels
The initial bed level was taken as 170.87m from the last bed level in Ahero. Each advancing downstream level was linearly interpolated from the slopes 0.001m/m for first reach (section) and 0.00055m/m for reaches (sections) 2 to 5.

The surface water slope as assumed to be parallel to the bed slopes hence, intermediate surface levels were interpolated using the same slopes, but using the water level at Ahero of 173.0 m as the initial starting point. Table 1 provides the result of the levels, while Figure 2 provides the outline of the whole Nyando network.

An extra section from node 3 to node 7 was added to represent the by-pass, and another extra section from node 2 to node canal $N^0$2, canal $N^0$3 and return node 3 was added to represent green-storage.

Table 1.
Floor and water surface levels

Section No	Section distance (m)	Floor level (m)		Surface level (m)	
		Initial	End	Initial	End
Section-1	4140	170.87	166.73	173.0	168.86
Section-2	4140	166.73	164.45	168.86	166.56
Section-3	4140	164.45	162.17	166.56	164.30
Section-4	4140	162.17	159.90	164.30	162.03
Section-5	4140	159.90	157.62	162.03	159.75

Manning's roughness coefficient
Because the Nyando River resembles rivers of the forest with dense bushes in the upper catchment, the meandering characters with varying slopes, the manning roughness (*n*) at the cross sections throughout seemed high and variable. For downstream component from sections 1 to 4 (between nodes 1 to 5) the *n* was estimated to be 0.08, and *n* equals 0.1 for section 5 (between node 5 and 6) (**Boiten, 2000**).

Chezy coefficient (*C*) was estimated from the given formulation, $C = \dfrac{R^{1/6}}{n}$, where R is the hydraulic radius and *n* as described before.

Boundary conditions
The boundary condition at the Ahero was taken as the 20-year design storm of 14 to 22 April 1988, and simulated as an output flow hydrograph from the upper catchment (peak flow of 439.072m^3/s). The downstream boundary condition was taken as constant level of the Lake Victoria at 160m (**Agha, 2000**). Because, our task was related to determining the levels downstream of Ahero, the boundary condition used at Ahero was flow hydrograph and not water levels.

Initial conditions
Sectional flows were taken to be either 0.1 or 5m^3/s, consistently both as initial and end flows. The surface levels were taken as the levels given in Table 1. However, the initial conditions varied depending on the flood mitigation structure that was modelled.
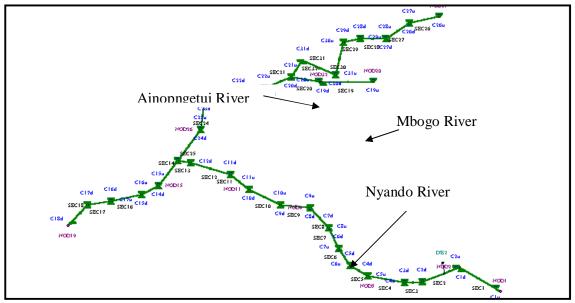
Figure 2.
Schematic view of the Nyando catchment network u/s Ahero
(Courtesy of W. Spaans' notes, 2003)

Design hydrograph

The design hydrograph was derived from the flood frequency analysis using the EV1 method (**Hall, 2000**), and using the annual data series from station 1GD03 at Ahero. The choice on which designed hydrograph rested on their peak magnitudes, and the catastrophic effects felt downstream of Ahero. Naturally, higher the peak the greater the risk it poses downstream. Using this concept the adapted design peak discharge for a 20-year average recurrence interval flood obtained from EV1 frequency distribution was 411.904m^3/s, while 10-year and 5-year designed peaks discharges were 279.445m^3/s and 347.053m^3/s respectively. The 20-year design peak discharge was then compared against the observed peak events. A through search revealed that the nearest observed peak was 417.028m^3/s generated by a storm of 14/08/1988 to 22/04/1988. Figure 3 shows the simulated and observed hydrographs at 1GD03.
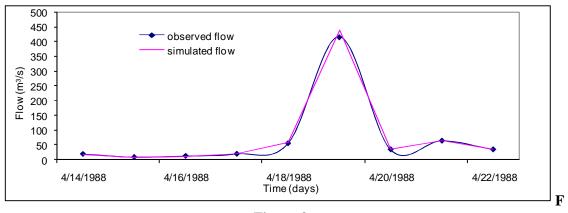

Figure 3.
20-year simulated and observed hydrographs in 1GD03

RESULTS

Proposed flood mitigation schemes

The proposed four flood mitigation structures *flood plain extension*, *embankment (dykes)*, *channel by-pass*, and *green-storag*e were simulated for 20-year recurrence interval flood to determine their individual responses in storing excess water. Model can be seen at appendix.

The concept behind flood plain extension was to widen one bank from Ahero Bridge to Lake Victoria, while the concept of embankment was to heighten the bank of the main river. Moreover, the concept behind by-pass was to build a channel by-pass directly connecting Ahero Bridge to the Lake Victoria to divert excess water from the main river during high flood periods. The concept for green-storage was to construct a retention reservoir beside the main river, linked by inlet and outlets canals with weirs respectively. The structures were designed to cater for 20-year recurrence interval flood, however, simulations were also conducted for 5 and 10-year recurrence interval floods to assess the model sensitivity.

Figures 4, 5 and 6 depict the base-case scenario against the two likely opted mitigation schemes.
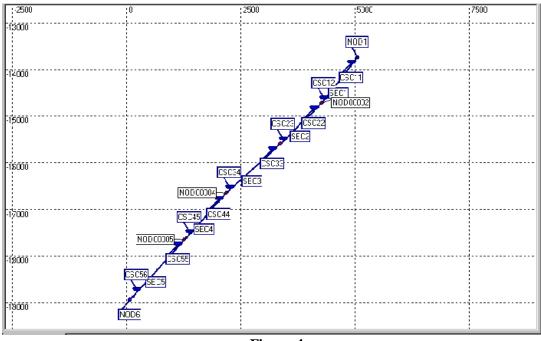

Figure 4.
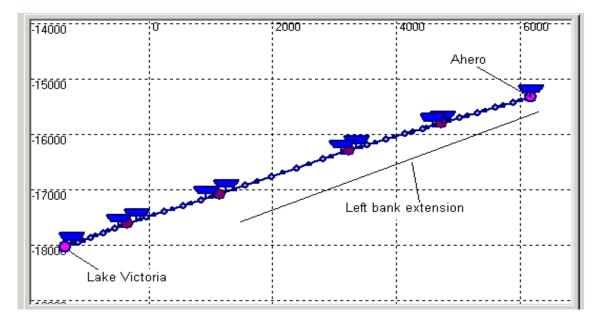**Schematisation of river network for base-case**

Figure 5.
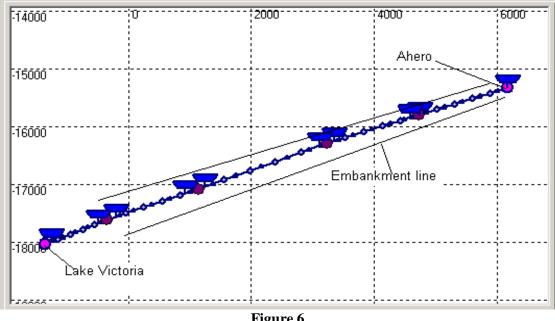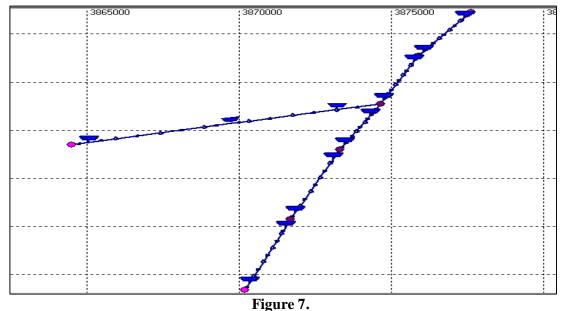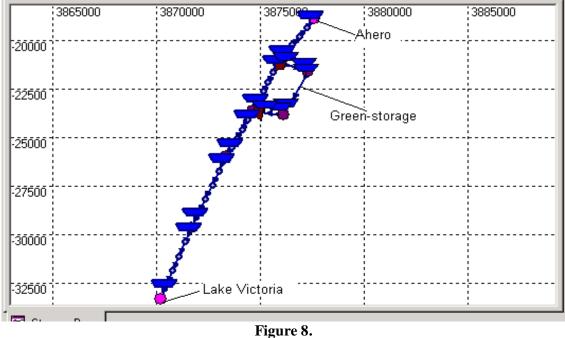**Schematisation of river network for flood-plain**

Figure 6.
Schematisation of river network for embankment

Figures 7 and 8 show the water depth comparisons at Ahero (node 1), and 10-12 km downstream of Ahero (node 3).

Figure 7.
Schematisation of river network for channel by-pass

Figure 8.
Schematisation of river network for green-storage

Simulation results

If the water depth at Ahero exceeds 5m, then the area downstream will expect pronounced flooding. Analysis for the base-case and all other flood mitigation schemes was carried for the 14-22 April 1988 flood period, taken also as the 20-year recurrence interval flood (design flood). For the Base-case at Ahero's bridge (node 1), water depth was 10.9m, and at 10kmdownstream Ahero (node 3), the water depth was 6.0m. Water depths were then compared against the base-case by running the proposed mitigation schemes:

- Flood plain result showed that the water depth at node 1 and 3 was 4.8m and 4.2m respectively. This means that Kano plain has a better chance of not been flooded with maximum discharge equalling 434.173m^3/s (modelled).
- By constructing embankment (dykes) the water depth at node 1 increased to 10.6m and at node 3 to 3m. The result therefore suggests that the nominal height of the dykes to be constructed is 5.6m, while water depth at downstream is further reduced.
- By-pass result showed that the water depth would be below 5m with a diversion located 8.28km downstream of Ahero. The width of the diversion in this simulation was 25m.

- Green-storage result showed that the water depth at node 1 was 9.8m and at node 3 4m. In this situation, the upstream will continue experience flooding, but downstream not flooded in any form.
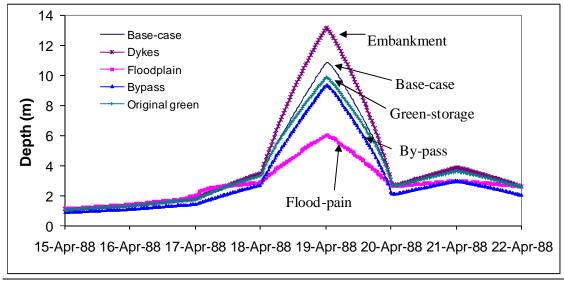

Figure 9.
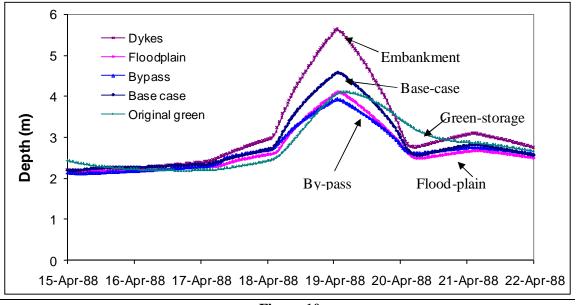**Comparison of water depth at Ahero (node 1)**

Figure 10.
Comparison of water depth at 8.28km d/s Ahero (node 3)

From Figures 9 and 10, it can be seen that the water depth of downstream nodes are higher than that of upstream nodes. It is mainly because that the river bed slope along the channel is not same, the bed slope of first section is 0.001m/m, and others are 0.00055m/m, according to manning formula, the velocity of section 2 to section 5 is less than that of section 1, so the water depth increased in node 3.

Dimensions of flood mitigation measures

For 20-year recurrence interval flood, the size and anticipated occupied area of every structure are shown in Table 2.

Table 2.
Scheme dimensions

Structure	Length (km)	Width (m)	Height (m)	Area (km^2)
Flood plain	20.70	1250.00	-----	25.90
Embankment	20.70*2	10.00	5.62	0.23
By-pass	8.00	25.00	4.00	0.20
Green storage	1.50 (for each canal)	20 (for each	4.00	0.06
Weir-1	4.140 (reservoir)	canal)	6.00	2.07
Weir-2	-----	500 (reservoir)	171 (level)	-----
	-----	20	167 (level)	-----
		20		

Sensitivity Analysis

To determine the sensitivity of the model at varying extreme flood levels, 5-year and 10-year peak flow hydrographs were converted to 20-year recurrence interval (T) peaks. The Tables 3 and 4 below, gives indication of the maximum water depths variations for the aforementioned recurrence intervals.

Table 3.
Result of sensitivity analysis at Ahero (node 1)

Flood shape	Upstream flow (m^3/s)	Maximum water depth (m)				
		Base case	Bypass	Flood plain	Embankment	Green-storage
1990 (5 years)	439	10.536	9.683	5.844	12.778	9.621
1989 (10 years)	439	10.520	9.668	5.851	12.747	9.601
1988 (20 years)	439	10.858	9.967	6.003	13.151	9.883

The sensitive analysis: Same flood peak, different hydrograph shapes

Table 4.
Result of sensitivity analysis at node 3

Flood shape	Upstream flow (m^3/s)	Maximum water depth (m)				
		Base case	Bypass	Flood plain	Embankment	Green-storage
1990 (5 years)	439	4.513	4.205	4.044	5.530	4.138
1989 (10 years)	439	4.506	4.197	4.037	5.519	4.081
1988 (20 years)	439	4.568	4.255	4.094	5.621	4.043

Generally, the model is not very sensitive with hydrographs of multiple peaks and broader base lengths. For the 5-year and 10-year average recurrence interval floods, the maximum depths simulated are fairly consistent, while changes observed in the 20-year average interval recurrence interval do not deviate much from the former cases. The model thus simulates well the sharp peaks with shorter base lengths.

When there is no structure for flood mitigation (base case), disastrous floods cause loss of life and property damage, with high monetary costs. It is expansive in term of finance and other resources (labour and machinery) to clean up the debris, and to restore the damaged structures. Opting for flood mitigation structures, on the other hand attenuates peaks propagating downstream but magnitudes vary, depending on which mitigating scheme is used.

Some notable inclusions for flood-plain extension, channel by-pass and green storage are;
- Reduction of the size of arable and grazing land,
- Desertifying the useable land,
- Developing resettlement schemes for displaced local people, and
- Depriving people of their rights to use the land in whatever forms that is beneficial.

Furthermore, if the water in the green-storage and flood plain extension is not drained out in adequate time it has the potential of breeding mosquito (since tropical area), which will pose health hazard to the people. The earth excavated may not be stored or disposed into proper designated areas, but if there are possibilities, the artificial dunes created will be exposed to weathering by rain and erotion forces. The fauna and flora life will be disturbed during the construction period. The wild life that once existed may be forced to migrate elsewhere to find new habitat. The once rich organic sediment transported by flood-waters will no longer enrich the soil.

Constructing embankments (dykes) should not be a viable option since its linear extension is unpredictable, hydraulic components not accounted for (backwater curve, foundation strength, risks of failure), and material required for construction is seemingly dear.

By-pass may serve as a shortcut navigation route to reaching Ahero. Green-storage will always maintain certain amount of water, which in turn can be used for recreation, fishing, other water sports, and maintenance of the environment.

Deduction from the analysis and comparisons of the mitigation schemes

In order to be assured on which mitigation scheme is economically, socially and environmentally viable, the following comparisons were made.

- Flood-plain extension requires the largest lateral expansion area ($25.9km^2$). The potential effects are that large area of green land or agricultural land will be given away, people resettled, arable land desertified, and money and other resources will be required to resettle the people.
- Embankment (dykes) needed to heighten on both side's bank of the main river at 5.62m from Ahero Bridge to the Lake Victoria, covering a distance of 20.7km. Although it may occupy a smaller area, the amount of labour and work required to heighten the banks will be demanding. Construction material, such as stone, cement and others needed to be transported from other sources, which otherwise will be immensely expensive. Without careful handling spillage might occur and may degrade the environment.
- Constructing by-pass structure will require a minimum amount of labour, with a light machinery to dig a 4 m ditch at a distance of 8km. Although, it is simple and does not need a big area ($0.20km^2$), the time required to complete the task may seem long, and the attenuation of flood peak is comparably higher than green-storage.
- Green-storage needs an area of about $2.07km^2$. Despite the size of the area, the storage basin has the potential of serving two functions; (i), diverting water during flood periods, and (ii), maintaining sustainable quantities of water for dry season. Construction requirements are similar to by-pass scheme with lower peak attenuation.
- By-pass serves only has one function, that is diverting water during flood periods, but the question that needs answering is, which mitigation scheme is able to cater for water needs when there is deficit of water resources during the dry season?
- The measure of building a green-storage is the best and optimal structure for flood mitigation.

CONCLUSION AND RECOMMENDATION

Conclusions:

The following conclusions were made from the study results:
- Average discharge is 17.6 m^3/s at the outlet station 1GDO3.
- Flood plains are fairly well known in their lateral and linear extensions. However, topographical details were not available.
- The measure of building a green-storage is the best and optimal structure for flood mitigation.
- The Duflow surface water hydrodynamic package enabled a good modelling and is very efficient to quickly assess results for designing and modelling. However, thorough knowledge is required to fully understand its applications.

Recommendations:

- The results of Duflow model should be compared with the results of other similar models.
- The excess amount of water should be released as soon as possible from green storage, so that any oncoming recurring floods can be mitigated without difficulty and delay.

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