OBASI, N.L., OLOKE, D.A. / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 2, March -April 2013, pp.1395-1403

Flow Distribution Design Charts For Bifurcation At Convex Channel Curvature.

OBASI[1], N.L. and OLOKE[2], D.A.

Department of Civil Engineering, Enugu State University of Science and Technology, Nigeria. Built Environment, School of Technology, University of Wolverhampton, WV1 1LY, UK

Abstract

A model with meandering features was constructed and used to investigate the effect of off-take angles on flow distribution at convex channel bifurcation. Artificial channel bifurcation was created on the convex section of the channel to study the flow distribution patterns by using seven off-take angles with four different main channel flow rates. Results obtained were processed and correlations between the off-take angles, specific discharges and depth ratios were used for the preparation of the design charts. The design charts' application results suggest that the possible water allocations ranged from 0.60% to 5.40% of the minimum main channel discharge while for maximum main channel discharge the water allocations ranged from 3.50% to 26.40% for the off-take angles considered. This implies that for the convex channel bifurcation, the minimum expected off-take discharge for 10^o off-take angle is about 0.60% of the main channel discharge while the maximum for 90^o off-take angle is about 5.40%. Similarly for the maximum expected off-take discharge for 10^o off-take angle is about 3.50% while the maximum for 90^o off-take angle is about 26.40% for maximum main channel flow rate.

Keywords: channel bifurcation, convex section, flow rates, off-take angles, and off-take discharges.

NOTATIONS

Q_1: Main channel discharge upstream
Q_2 : Main channel discharge downstream
Q_3 : off-take discharge and θ: Off-take angle
Q_{16},: Upstream discharge of 16cm depth of flow
Q_{17},: Upstream discharge of 17cm depth of flow
Q_{18},: Upstream discharge of 18cm depth of flow
Q_{19} : Upstream discharge of 19cm depth of flow
y_1**:** Upstream flow depth.
y_2: Downstream flow depth.
y_3**:** Off-take flow depth.

I. Introduction

Leopold and Wolman (1957) reported that bifurcations are typical features in alluvial rivers as well as in estuaries and the morphological behavior of rivers at bifurcations is not yet a properly understood phenomenon. A bifurcation occurs when a river or stream splits into two branches and naturally it occurs when a middle bar forms in a channel or a distributary carries flow from the main river.

In a meandering river/stream, the inner part of the curve is referred to as the convex section of the channel curvature. Yasuo et al (1976) stressed that the methods available for analyzing alluvial streams are based largely on data obtained from flows in straight channels and therefore cannot be expected to predict the effect of channel curvature on the flow and sediment transport characteristics of rivers. Flows in meandering channels are usually complicated by several features including super elevation of the water surface, occurrence of secondary currents, redistribution of velocity and boundary shear stress, the possibility of flow separation from the banks and interaction between the flow and the bed topography.

According to Shettar and Murthy (1997), at any channel bifurcation with a known upstream discharge (Q_1), it is usually difficult to predict correctly the downstream discharges (Q_2 and Q_3) because they depend mostly on factors such as off-take angle, cross sectional areas, slope of downstream channels and shape of inlet section. They equally proposed that the flow which results when a channel bifurcates from the main channel has many complex features such as transverse motion accompanying the main flow, extensive separation zone that develops in the branch channel and re-circulation zone that appears in the main channel at higher discharge ratios.

Research on division of flows has received the attention of hydraulic engineers like Apman (1972), Bower (1950), Chang (1984), Dekker and Voorthuizen (1994), Krishnappa and Seetharamiah (1963), Grace (1958), Rao et al (1968), Sridharan (1966); Hager (1983, 1992), Roasjen and Zwanenbury (1995), Ramamurthy et al (1990); Thiruvengadam (1962), Williamson and Rhone (1973) and Toffaletti (1969) but most of their works were restricted to finding out the discharge distribution downstream of the bifurcation when the flow conditions upstream and downstream of the bifurcation are known. Law and Reynolds (1966) noted that both the theoretical and experimental studies of a dividing flow in open channel reveal that the walls of the channels are mostly not the effective boundaries of the flow region resulting to the occurrence of separation zone. Taylor (1944) conducted the first comprehensive study on a dividing flow in open channel and suggested that for a given angle of intersection of the branch channel, it was possible to correlate the discharge and depth ratios with the ratios of the kinetic energy head to depth in the main channel.

Pattabhiramiah and Rajaratnam (1960, 1966), studied the branch channel problem by treating the branch flow as flow through a side weir of zero sill height while Law (1965) used both analytical and experimental investigations to study the features of the dividing flow.

Many fluid flow problems cannot be solved mathematically due to the complex nature of the equations and boundary conditions inherent in them. It has been highlighted in most literature that even with modern computing facilities, many complex fluid problems still defy complete theoretical analysis. In such situations, physical models seem to be the most appropriate research tool to be employed. Essentially, physical models are constructed to mirror the actual physical behaviour of the original phenomenon or prototype. The aim of this study is therefore to develop a design chart for the prediction of flow distribution at convex channel bifurcation and also verify its application to the proposed Amoli irrigation scheme.

II. Model Construction and Experimental Setup

A model was constructed using the scale ratios of 1:50 for horizontal and 1:15 for the vertical with a distortion of 3.30. The model covered about 200m of the river channel. The detailed plan views of the model and its cross section are shown in Figure 1. Three structural metal sheets having a width of 30cm each were welded together to form the base and side walls of the rectangular main channel which represents fixed banks and bed of a natural river/stream. The main channel was 850cm long with straight and meandering sections. Similarly three structural metal sheets having a width of 10cm and length of 90cm were welded together to form the base and side walls of the branch rectangular channel. Seven branch channels were constructed for the convex channel curvature and each of them was cut at the fitting end to be welded to the main channel in a manner that it represented one of the off-take angles to be investigated in the study. The off-take angle θ, was defined as the angle between the outer bank of the main channel and the inner bank of the branching channel at the bifurcation point. According to this definition the suggested off take angles used in the study were 10^0, 15^0, 20^0, 30^0, 45^0, 60^0 and 90^0. The upstream and downstream ends of the main channel were covered with 30cm by 30cm sheet metals by welding to retain the water in the main channel during the experimental work. The downstream part was provided with a spillway to allow excess water to flow out of the channel. At the bifurcation point a rectangular opening was created on the main channel at the convex section of the model. A difference in invert levels of –15cm between the main and branching channel was created to resemble a natural situation. The meandering section of the model had an outer radius of 135cm and inner radius of 105cm indicating a mild bend that would not require future channelization.

The experimental materials consisted of the main channel, branch channels, two elevated water tanks, pump, current meter kit, water, stop watch, measuring tape, beakers, plastic containers and electronic weighing balance. The experimental set up comprised of two major components namely the water supply unit and the regulatory/measuring unit. The circulation of water within the model was a closed system with a sediment trap provided at downstream where the flow passed through a filter medium before being diverted back to the sump.

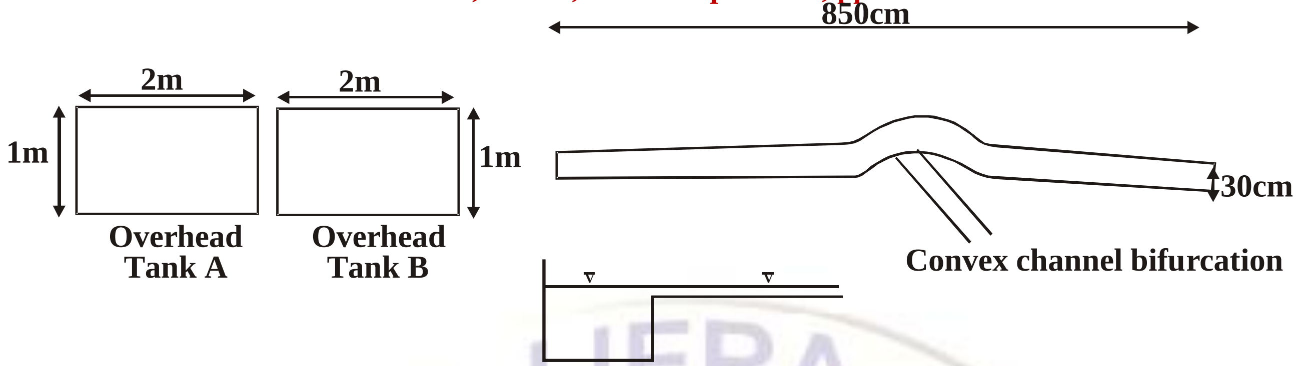

Fig. 1: Plan views of main channel, off-take channel and cross- section.

III. Experimental procedure

The experiment was carried out at the hydraulic laboratory of the Civil Engineering Department, University of Nigeria, Nsukka in Enugu State of Nigeria. This study concentrated mainly on the investigation of the discharge distribution patterns at convex channel bifurcation by varying the off-take angles and the main channel flow rates. Four flow rates with corresponding flow depths in the main channel of 16cm, 17cm, 18cm and 19cm represented by Q_{16}, Q_{17}, Q_{18}, and Q_{19} respectively were used throughout the experimental work as discharge for main channel flow. The flow depths corresponding to each of the flow rates were established and marked on the walls of the main channel as bench marks to ascertain each of the flow rates required. Water in the sump was pumped to the first elevated tank that supplied water to the second overhead tank. The second overhead tank supplied water directly to the model at controlled rates in line with the established points on the walls of the main channel while the weir and spillway provided at the downstream maintained the required water level in the main channel. The flow rates in the main channel were obtained by measuring the mean velocities of the flow with the current meter apparatus at the marked points on the channel walls and multiplying the values with the corresponding wetted cross sectional areas of the channel.

IV. Flow distribution measurement at the convex channel bifurcation.

Each of the seven off-take channels representing the recommended off-take angles of 10^0, 15^0, 20^0, 30^0, 45^0, 60^0 and 90^0 was fixed at the opening created on the convex section of the main channel under each of the main channel flow rate conditions. Because the resulting off-take discharges were low when compared with the main channel flows, the discharge measurements were determined volumetrically by collecting the flows discharging freely into the air at the end of the channel in plastic containers at a specified time intervals. The volumes of the collected water were measured with graduated measuring cylinders and recorded against both the main channel flow rates and the off-take angles.

V. Design chart development

Manning's equation employed in the design of open channels was used to calculate the desired channel parameters. The hydraulic radius, slope, and cross sectional area of the channel are usually substituted into the Manning's equation for the determination of the channel parameters if the required discharge is known. Since the values of the hydraulic radius of the off-take channel by simple calculation is not constant due to the effect of the off-take angles, it is then necessary to rely on experimental data for its evaluation. Experimental tests results have shown that the off-take discharge is dependent on both off-take angles and channel curvatures. The study also concentrated on such intakes where the invert level of the off-take channel is higher than that of the parent channel. It is however noticed that for any given off-take angle θ; it is possible to correlate the dimensionless ratios Q_3/Q_1 and y_3/y_1 using the obtained experimental data. Firstly, the ratios of Q_3/Q_1 and y_3/y_1 are determined for each of the off-take angles considered. The correlations between the off-take angles, specific discharge ratios and flow depth ratios are then used in the preparation of the design charts. Then determine the percentage off-take discharges from the specific discharge ratios (q_1/q_3) and plot these values against the main channel discharge (Q_1) for all the off-take angles considered which include 10^o, 15^o, 20^o, 30^o, 45^o, 60^o and 90^o. This is shown graphically in Fig.2 featuring different inclined lines representing the various off-take angles. From this relationship, it could be seen that for minimum main channel discharge, the percentage off-take discharges for the off-take angles are 0.6, 0.9, 1.2, 1.8, 2.6, 3.6 and 5.4% while for the maximum main channel flow rate, the percentage off-take discharges are 3.5, 7.1, 9.3, 11.0, 12.1, 15.0, and 26.4%

respectively. It implies that for the convex channel bifurcation, the minimum expected off-take discharge for 10^o off-take angle is about 0.60% while the maximum for 90^o off-take angles is about 5.40% for minimum main channel flow rate. Similarly the maximum expected off-take discharge for 10^o off-take angle is about 3.50% while the maximum for 90^o off-take angle is about 26.40% respectively for maximum main channel flow rate.

Secondly, these percentage off-take discharges were related to the off-take flow depths through the flow depth ratios (y_3/y_1). Also, a graphical representation of the off-take depths with the percentage off-take discharges is shown in Fig.3 which equally features different inclined lines for all the off-take angles considered.

Once the available water from the stream or river and the water requirement for the engineering purpose are known, then the required percentage off-take discharge would be calculated and used to locate the desirable off-take angle to be recommended.

The percentage off-take discharge would be (Q_{req}/Q_{avail}) x 100% and with the off-take angle known, the feasible off-take discharge will be used in determining the channel dimension by using the most economic section analysis.

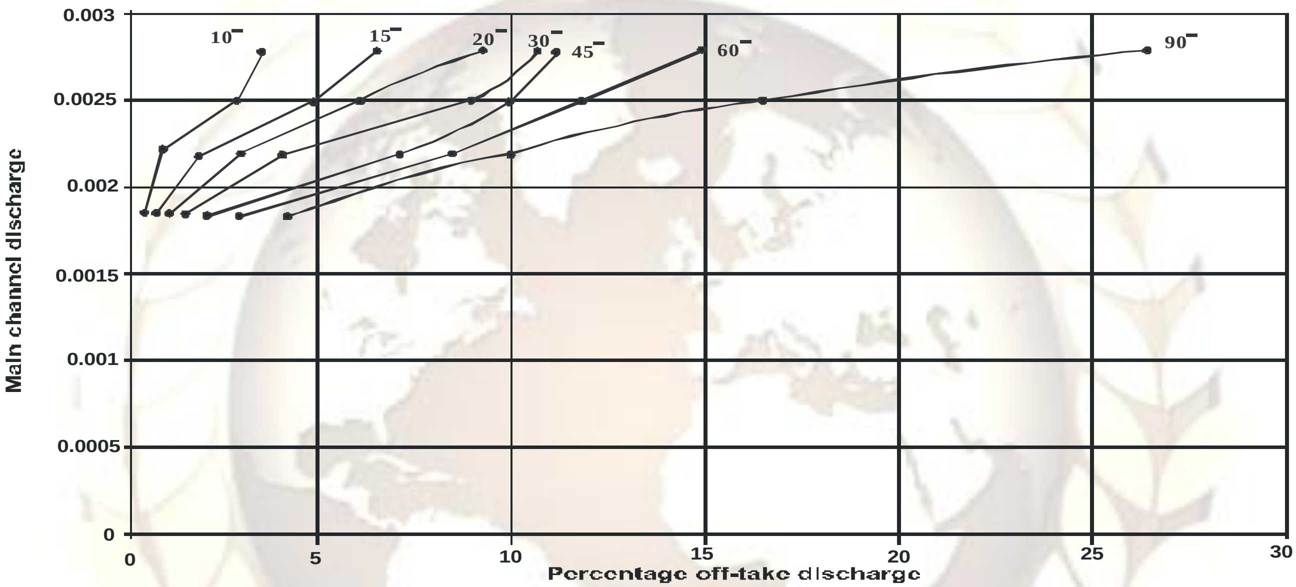

Fig. 2: Effect of off-take on flow distribution at convex channel bifurcation.

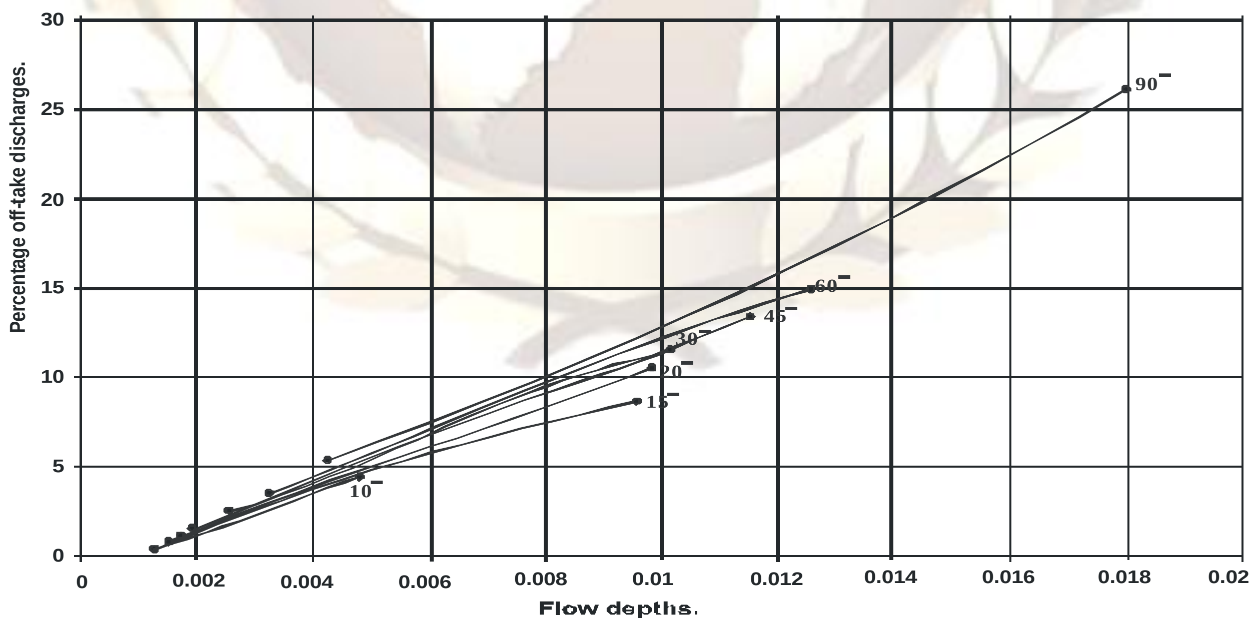

Fig.3 : Variation of flow depths with off-take discharges at convex channel bifurcation.

VI. Design Application

A water resources survey in Amoli town, Awgu Local Government Area of Enugu state, Nigeria indicates that there are five streams that could serve as source of water supply for the irrigation of the community farmland at Ezi agu having boundary with Ihe community also in Awgu Local Government Area. The crop water requirement study shows that a discharge of 1.5m^3/s will be adequate for the irrigation scheme but requires about 2000m length of irrigation canal with a slope of 1:6000m and Manning's roughness coefficient of 1.7% for effective coverage of the farm land. The streams and available discharges as obtained from the survey study are presented in Table 1.

Table 1: Available Water Sources for irrigation scheme in Amoli.

S/N	Name of Stream	Available Discharge	Water Requirement
1	Anizi stream	2.0m^3/s	1.5m^3/s
2	Ntuta stream	3.5m^3/s	1.5m^3/s
3	Oji stream	4.0m^3/s	1.5m^3/s
4	Ndegwu stream	5.0m^3/s	1.5m^3/s
5	Nchalam stream	6.0m^3/s	1.5m^3/s

VII. Normal design

The normal design would ensure that the water available in the main channel is higher than the water requirement and then uses the water requirement in determining the channel dimensions but without reference to the channel curvature and proper off-take angles. Any of the empirical formulae such as Manning's Equation could be used thus:

$Q = 1/n\,(AR^{2/3} S^{1/2})$ Use $n = 0.017$ and $S = 1: 6000$

$Q = 1/0.017 \times by \times (R)^{2/3} \times (0.00017)^{1/2}$

But for best economic rectangular section, $R = y/2$, and $b = 2y$

Where A – area, R – hydraulic radius, S – channel slope and n – Manning's roughness coefficient

$Q = 1/0.017 \times 2y^2 \times (y/2)^{2/3} \times (0.00017)^{1/2}$

$Q = 0.966y^{8/3}$

Using the required discharge for the irrigation purposes, the channel dimensions can be obtained thus:-

$1.5m^3/s = 0.966y^{8/3}$ and $y = (1.5/0.966)^{0.375}$

$y = 1.18m$ and $b = 2.36m$

It is obvious that the channel dimensions calculated above will be applicable to all the streams because the same water requirement is needed from all the streams. This design approach will also assume that the off-take angle is aligned at 90^o for easy construction. The problem with normal design is that the angle at which the off-take channel will be aligned to the main channel for this particular discharge has not been specified in this design. Also the effect of curvature has not been mentioned. Major defect is that the designed channel may not be hydraulically efficient. This implies that the carrying capacity of the channel may be less than that provided leading to overflow of banks and flooding of the environment.

However, the design chart would view this problem in a different dimension by considering both the off-take angle and channel curvature. The results of the design calculations under normal design are presented in Table 3.

VIII. Design Chart for convex channel bifurcation

Using the same design information for all the surface water resources available within the community for the irrigation scheme, the design chart is firstly applied to the Anizi stream. With the knowledge of the available discharge of 2.0m^3/s and the water required for irrigation scheme of 1.5m^3/s, then the next step would be to determine the percentage off-take discharge which is calculated from (1.5/2.0) x (100) = 75%. But the result of the design chart for convex channel bifurcation indicates that the maximum percentage off-take discharge is 26.40% which implies that any percentage off-take discharge greater than 26.40% should be ignored and replaced by the 26.40% maximum limit. Having obtained the percentage off-take discharge, the design chart for convex channel bifurcation Fig.2 was used to obtain the off-take angle required by simply moving along the x – axis to locate the 26.40% off-take discharge and then move vertically upwards along the y-axis to locate all the possible off-take angles that would be intersected by the vertical line. In this case the only off-take angle intersected is the 90^0, otherwise the least off-take angle among the intersected inclined lines or the calculated angle by interpolation would be recommended on the basis of the most economic section. Having known the required off-take angle, Fig.3 was used to obtain the depth of flow by moving along the y-axis to locate the percentage off-take discharge and then moving horizontally along the x-axis to locate the required depth of flow which can as well be obtained from the Manning's equation, thus:-

$Q = 1/n(AR^{2/3} S^{1/2})$; Use $n = 0.017$ and $S = 1: 6000$

$Q = 1/0.017 \times by \times (R)^{2/3} \times (0.00017)^{1/2}$

But for best economic rectangular section, $R = y/2$, and $b = 2y$

$Q = 1/0.017 \times 2y^2 \times (y/2)^{2/3} \times (0.00017)^{1/2}$
$Q = 0.966y^{8/3}$
Using the required discharge for the irrigation purposes, the channel dimensions can be obtained thus:-
$0.53m^3/s = 0.966y^{8/3}$ and $y = (0.53/0.966)^{0.375}$
y = 0.80m and b = 1.60m

Similarly, the percentage off-take discharges with their corresponding off-take angles as well as the required channel dimensions with respect to the other streams are carried out by repeating the same method used for the Anizi stream and the results are presented in Tables 2, 3 and 4.

Table 2: Calculated percentage off-take discharges for convex channel bifurcation.

S/N	Stream	Q_{av} (m^3/s)	Q_{req} (m^3/s)	% off-take discharge	$Q_{provided}$ (m^3/s)	Remarks
1	Anizi	2.0	1.5	75 but 26.4 is feasible	0.53	Discharge not sufficient for scheme
2	Ntuta	3.5	1.5	43 but 26.4 is feasible	0.92	Discharge not sufficient for scheme
3	Oji	4.0	1.5	37.5 but 26.4 is feasible	1.10	Discharge not sufficient for scheme
4	Ndegwu	5.0	1.5	30 but 26.4 is feasible	1.32	Discharge not sufficient for scheme
5	Nchalam	6.0	1.5	25	1.5	sufficient for scheme

IX. Discussion

The results of the water resources survey conducted for Amoli town as shown in Table 1 indicate that all the streams in the community has flow rates ranging from $2.0m^3/s$ to $6.0m^3/s$. However the water requirement for the community irrigation scheme is $1.5m^3/s$. It can be seen from Table 1 that the existing streams in the community have flow rates higher than $1.5m^3/s$ required for the irrigation scheme. It may not be out of place to assume that the available discharges from the various streams would satisfy the irrigation water demand. This is actually one of the assumptions usually adopted in the normal design which would first investigate if the water requirement is less than the water available regardless of the magnitude of the difference.

Table 2 presents the values of the percentage off-take discharges as obtained from the design chart for all the streams which is necessary for assessment of the suitability of the streams in terms of having sufficient flow rates for the design purpose. The result of the assessment (Table 2) indicates that only Nchalam stream has sufficient discharge for the irrigation scheme while the rest have discharges ranging from $0.53m^3/s$ to $1.32m^3/s$. These streams namely Anizi, Ntuta, Oji and Ndegwu have calculated percentage off-take discharges from the design chart of 75, 42.8, 37.5 and 30 respectively which can only supply about 26% of the parent channel discharge for convex channel bifurcations.

Similarly, Tables 3 and 4 show the summary of the design chart application results and channel parameters for all the streams. Anizi, Ntuta, Oji and Ndegwu streams have feasible off-take discharges of 0.53, 0.92, 1.1 and $1.32m^3/s$ respectively at 90^o off-take angles. These are not adequate for the irrigation scheme. However, the normal design assumed an off-take discharge of $1.5m^3/s$ at 90^o off-take angle for all the streams. This assumption indicates that the normal design provided wetted areas of $2.78m^2$ each for Anizi, Ntuta, Oji and Ndegwu streams instead of $1.28m^2$, $2.0m^2$, $2.42m^2$ and $2.50m^2$ as provided by the design chart which were over design of the off-take channels by 53.6, 27.5, 12.23 and 9.42% respectively. The over design of the off-take channels for Anizi, Ntuta, Oji and Ndegwu streams would lead to low flow velocities of 0.19m/s, 0.32m/s, 0.40m/s, and 0.48m/s instead of 0.41m/s, 0.46m/s, 0.45m/s and 0.53m/s respectively as provided by the design chart which may cause siltation and subsequently decrease in water supplied to the off-take channels.

Table 3 shows also that Nchalam stream has sufficient discharge for the Amoli irrigation scheme and the required discharge can be obtained from the design chart at the least off-take angle of 86^o with wetted perimeter, area and flow velocity of 4.72m, 2.78m^2 and 0.54m/s respectively. On the other hand, the normal design assumed an off-take discharge of 1.5m^3/s but at an off-take angle of 90^o which is slightly an under design of the off-take channel by 6.5%. The result of the normal design provided wetted perimeter, area and flow velocity of 4.72m, 2.78m^2 and 0.54m/s instead of 4.8m, 2.88m^2 and 0.56m/s respectively which would lead to over topping of the channel banks, flooding of the adjourning areas and scouring effect of the channel structure due to slightly high flow velocity.

X. Conclusions

The experimental flow distribution data were processed and utilized for the preparation of the design chart to predict the off-take discharge at convex channel bifurcation. The design chart prediction result indicates that for minimum main channel discharge, the off-take discharges ranged between 0.60 to 5.40% of the main channel discharge while for the maximum main channel discharge, the off-take discharges ranged between 3.5 to 26.4% of the main channel discharge for all the off-take angles considered. The results of the design chart application showed that each of the available water resources for Amoli community has insufficient discharge for the irrigation scheme except Nchalam stream while the normal design assumed that all the water resources available would each satisfy the discharge requirement for the community irrigation scheme. The problem with normal design application is that the angle at which the off-take channel will be aligned to the main channel and the channel curvature for any particular discharge are usually not specified which may lead to either over design or under design of the channel.

Table 3: Calculated off-take channel parameters for convex channel bifurcation.

S/N	Stream	Q_{av} (m^3/s)	Q_{req} (m^3/s)	$Q_{provided}$ (m^3/s)	Wetted Area (m^2)		Wetted Perimeter (m)		Flow velocity (m/s)	
					Normal	Design chart	Normal	Design chart	Normal	Design chart
1	Anizi	2.0	1.5	0.53	2.78	1.28	4.72	3.20	0.19	0.41
2	Ntuta	3.5	1.5	0.92	2.78	2.00	4.72	4.00	0.32	0.46
3	Oji	4.0	1.5	1.10	2.78	2.42	4.72	4.40	0.40	0.45
4	Ndegwu	5.0	1.5	1.32	2.78	2.51	4.72	4.48	0.48	0.53
5	Nchalam	6.0	1.5	1.5	2.78	2.78	4.72	4.72	0.54	0.54

Table 4: Summary of Design Chart application results for convex channel bifurcation.

Stream Name	Main channel discharge	Water requirement	Feasible off-take discharge		Channel dimensions		Off-take angle		Remarks	
			Normal design	Design chart	Normal design	Design Chart	Normal design	Design Chart	Normal design	Design Chart
Anizi	2.0m^3/s	1.5m^3/s	Assumed 1.5 m^3/s instead of 0.53 m^3/s	0.53 m^3/s	y = 1.18m b = 2.36m instead of y=0.80m b=1.60m	y = 0.80m b = 1.60m	Assumed 90^0	90^0	Over design	Best economic section
Ntuta	3.5 m^3/s	1.5 m^3/s	Assumed 1.5 m^3/s instead of 0.92 m^3/s	0.92 m^3/s	y = 1.18m b = 2.36m instead of y=1.0m b=2.0m	y = 1.0m b = 2.0m	Assumed 90^0	90^0	Over design	Best economic section
Oji	4 m^3/s	1.5m^3/s	Assumed 1.5 m^3/s instead of 1.10 m^3/s	1.10 m^3/s	y = 1.18m b = 2.36m instead of y=1.10m b=2.20m	y = 1.10m b = 2.20m	Assumed 90^0	90^0	Over design	Best economic section
Ndegwu	5 m^3/s	1.5m^3/s	Assumed 1.5 m^3/s instead of 1.32 m^3/s	1.32 m^3/s	y = 1.18m b = 2.36m instead of y=1.12m b=2.24m	y = 1.12m b = 2.24m	Assumed 90^0	90^0	Over design	Best economic section
Nchalam	6 m^3/s	1.5m^3/s	Assumed 1.5 m^3/s instead of 1.6 m^3/s	1.5m^3/s	y = 1.18m b = 2.36m instead of y=1.20m b=2.40m	y = 1.18m b = 2.36m	Assumed 90^0	86^0	Under design	Best economic section

REFERENCES

[1] Apman, R. P. (1972) Flow Process in Open Channel Bends, Jour. Of Hydr. Engrg. ASCE, 98(5), 795-810.

[2] Bower, C.E.,(1950) Study of Open Channel Junctions Hydraulic Model Studies for Whiting Field Naval Air Station, Milton, Florida, Part V, St Anthony Hydraulic Laboratory, Minneapolis, Minn pp 57 - 62.

[3] Chang, H.H. (1984) Modeling of river channel, Journal of Hydr. Engrg. ASCE. 110(2):157.

[4] Dekker, P.D., and van Voorthuizen, J.M.(1994) “Research on the Morphological Behavior of Bifurcations in Rivers”, Delft University of Technology, The Netherlands.

[5] Grace, J.L. (1958) Division of flow in open channel junction, thesis presented to the Alabama Polytechnic Institute, at Anburn, Ala., in partial fulfillment of the requirements for the degree of Master of Science.

[6] Hager, W.H. (1992) “Discussion of dividing flow in open channels” Journ. Of Hydr. Engrg. ASCE, 113(4): 543-544.

[7] Hager, W.H. (1983), “An approximate treatment of flow in branches and bends”, Proc. Institute of Mathematical Engineers, 1980 (4): 63-69.

[8] Krishnappa, G., and Seetharamiah, K. (1963) A new method of predicting the flow in a 90^o branch channel, La Houille Blanche, 18(7), 775-778.

[9] Law, S.W. (1965), Dividing flow in open channels. Thesis presented to McGill University, at Montreal, Quebec, Canada, in partial fulfillment of the requirements for the degree of Master of Engineering.

[10] Law, S.W. and Reynolds, A.J. (1966). “Dividing flow in an open channel”, Journal of Hydr. Division, ASCE, 92: 207-231.

[11] Leopold, L.B., and Wolman, M.G., (1957). River channel pattern; braided, meandering and straight. US Geol. Survey, Washington, D.C., Prof. Paper 282-B.

[12] Pattabhiramiah, K.R., and Rajaratnam, N. (1966), A new method of predicting flow in a branch channel, Jour. Inst. of Engineers, New Delhi, India, 46(7): 337.

[13] Ramamurthy, S. A and Satish, M.G. (1988), “Division of flow in short open channel branches”, Journal of Hydr. Engineering, ASCE, 114: 428-438.

[14] Ramamurthy, S. A, Tran, D.M and Carballada, L.B. (1990) “Dividing flow in open channels”. Journ. of Hydr. Engrg. ASCE. 116(3): 449-455.

[15] Rao, S.N, Sridharan, K. and Baig, M.Y.A. (1968). “Experimental Study of the division of flow in an open channel.” Proc. Conf. Hydr. and Fluid Mech., Institution of Engineers, Australia, 139-142.

[16] Roasjen, R.and Zwanenburg, C.(1995). “Research on bifurcation in rivers”, M.Sc. Thesis, Faculty of Civil Engineering Delft University of Technology, The Netherlands.

[17] Satish, M.G. (1986), “Discharge characteristics of some diverging lateral flows”, Thesis presented to Concordia University, at Montreal, Quebec, Canada, in partial fulfillment of the requirements for the degree of Doctor of philosophy.

[18] Shettar, A.S., and Murthy, K.K., (1997). “A Numerical Study of division of flow in open channels”, Journal IAHR, 34: 651-675.

[19] Sridharan, L. (1966), “Division of flow in open channels”, Thesis presented to the Indian Institute of Science, at Ban galore, India, in partial fulfillment of the requirements for the degree of Master of Science.

[20] Taylor, E. (1944), Flow characteristics at rectangular open channel junctions”, Trans., ASCE, 109: 893-912.

[21] Thiruvengadam, A., (1962). “Flow in a Branch channel”, Water Power, 14,

[22] Toffaletti, F. B. (1969). Flow in a branch channel, Water Power, 14.

[23] Williamson, J. V. and Rhone, J. J. (1973) Dividing Flow in Branches and Wyes, Journ. of Hydr. Division, ASCE, 99(5), 747-769.

[24] Yasuo, O. M.; Sabhash, C. J. and Kennedy, J. F. (1976) Effects of Meandering in Alluvial streams, Journ. of Hydr. Division, ASCE, 102(7): 899-917.