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Scenario Analysis to Improve Ammonia Concentrations Along the Rosetta Branch in the Nile Delta, Egypt

تحليل السيناريو لتحسين تركيزات الأمونيا على طول فرع رشيد في دلتا النيل، مصر

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Abstract: A physico-chemical water quality model has been developed for the Rosetta Branch in the Nile Delta, making use of the MIKE11 river modeling software of DHI Water & Environment (DHI, 2002). The physico-chemical water quality (WQ) module of MIKE11 was linked with a detailed full hydrodynamic (HD) model developed for the same Rosetta Branch, and also implemented in the MIKE11 modeling system. The WQ model aims to describe and predict concentrations of dissolved oxygen (DO), biochemical oxygen demand (BOD) and nitrogen in the form of ammonia (NH4-N) and nitrate (NO3-N), taking into consideration advection, dispersion and the most important biological, chemical and physical processes. All significant pollution sources along the Rosetta Branch were considered. The paper discusses scenario analyses carried out with the model. Scenarios of ammonia concentration reduction along the drains by 30%, 50% and 70% have been simulated, according to suggested treatment scenarios. Also the effect of an increase in the upstream inflow discharges at Delta Barrage during low flow conditions, have been analyzed. Based on these analyses, most efficient measures were suggested to improve the current status of the branch water quality.
Keywords: *Ammonia, Nile Delta, scenario analysis, water quality modeling*.

المستخلص: مما لا شك فيه إن من أهم التحديات التي تواجه قطاع الموارد المائية في مصر هو تدني نوعية المياه حيث أن نشاط الإنسان وتدخله المستمر والمباشر مع الموارد المائية له أثر فعال في تلوث وتغير نوعية المياه يفوق العوامل الطبيعية وخاصة في ظل التقدم التكنولوجي. تمثل مصارف الرهاوي – سبل – تلا – جنوب التحرير- زاوية البحر بالإضافة إلى مصنع الماليا ومصنع الملح والصودا بؤر التلوث الأساسية لفرع رشيد في دلتا النيل حيث يعاني الفرع من التلوث الشديد. في هذا البحث، تم تحليل ودراسة عدة سيناريوهات لتحسين الوضع الحالي لنوعية المياه في فرع رشيد عن طريق افتراض تقليل تركيز الامونيا في الثلاثة مصارف الرئيسة ﴿مصرف الرهاوي – مصرف سبل – مصرف تلا﴾ التي تصب على الفرع بنسب 30 %، 50 %، 70 % من خلال استخدام نموذج رياضي حيث يناقش البحث تحسين تركيز الامونيا على طول فرع رشيد عن طريق إعداد نموذج رياضي تمت معايرته باستخدام طرق إحصائية لتحليل نتائج المحاكاة ومقارنتها بالقياسات الفعلية. بعد معايرة نتائج النموذج وتحسينه أظهرت هذه النتائج دقة عالية لذا يمكن اعتبار النموذج وسيلة فعالة ومفيدة لمساعدة متخذي القرار في مجال إدارة نوعية المياه المستقبلية وتحليل سيناريوهات مختلفة لتقييم تأثير تطبيقها علي نوعية المياه بالفرع. هذا وقد أوضحت نتائج السيناريوهات المختلفة أن مصرف الرهاوي هو المصدر الرئيسي المؤثر علي نوعية المياه بالفرع حيث أن تقليل تركيز الامونيا بهذا الفرع له تأثير كبير على تحسين نوعية المياه بالفرع. وقد خلصت الدراسة إلى أن معالجة الامونيا بمصرف الرهاوي سيؤدي إلى تحسين تركيزات الامونيا بفرع رشيد بنسبة 37 %.
كلمات مدخلية: *الأمونيا، دلتا النيل، تحليل السيناريو، نمذجة نوعية المياه.*

INTRODUCTION

The Nile downstream in Egypt strongly suffers from water quality deterioration due to domestic, agricultural and industrial pollution. The pollution mainly originates from the drains, but also from the upstream boundary (pollution from the more upstream Nile reaches). In order to investigate the problem, a physico-chemical water quality simulation model has been set up as decision support system for the Rosetta Branch in the Nile Delta. The model covers the Delta Barrage, downstream Cairo, till the outflow point in the Mediterranean Sea (Figure 1). The model is integrated with a detailed full hydrodynamic model, set up earlier for the Rosetta Branch by Willems *et al*. (2005), and extended with a physico-chemical water quality model developed by Radwan *et al*. (2005). The model describes and predicts concentrations of dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrogen in the form of ammonia (NH4-N) and nitrate (NO3-N) and total dissolved solids (TDS), taking into consideration advection, dispersion and the most important biological, chemical and physical processes. All significant pollution sources along the Rosetta branch were considered.

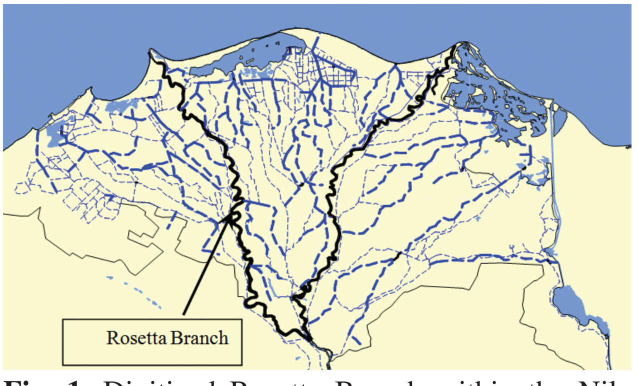

Fig. 1. Digitized Rosetta Branch within the Nile Delta.

The model is currently being used as decision support system to investigate scenarios for water quality improvement in the Nile Delta. This paper focuses on the analysis of the problem of high ammonia (NH4-N) concentrations in the Rosetta Branch, and to propose most efficient water management actions. Three drains (El-Moheet, Sabal, and Tala) along the Rosetta Branch are monitored for different water quality variables and for the discharge measured on a monthly basis within the framework of the National Water Quality and Availability Management Program (NAWQAM) in Egypt. The measured concentrations and discharges along the drains are used as inputs in the model, using linear interpolation for the periods with missing data. Based on these inputs, first order differential equations are used to model the concentrations of the water quality variables DO, BOD, NH4-N, NO3-N and TDS. The processes are described with process velocities of 1st order and the dependence on temperature with Arrhenius-terms.

NITROGEN PROCESSES

First an overview is given of the nitrogen processes considered in the model, which are of main importance for the study on ammonia reduction scenarios.

The differential equation describing ammonia reactions is:

$$\begin{aligned}\frac{d\,NH_4\text{-}N}{dt} = &+Y_b\, k_b\, BOD_b\, \Theta_b^{(T-20)} \quad (BODdecy)\\ &+Y_d\, k_d\, BOD_d\, \Theta_d^{(T-20)}\\ &+Y_s\, k_s\, BOD_s\, \Theta_s^{(T-20)}\\ &+K_{nitr}\, NH_4\text{-}N\, \Theta_{nitr}^{(T-20)} \quad (nitrification)\\ &-y_{resp}\,(P_h - R_s) \quad (respiration\ and\ photosynthesis) \quad (1)\end{aligned}$$

where:
BOD: BOD concentration (mg/l)
NH4-N: NH4-N nitrogen concentration (mg/l)
T: water temperature (degrees C)
Yb, Yd, Ys: nitrogen content in deposited organic matter (b), dissolved organic matter (d) and suspended organic matter (s) (mg NH4-N/mgBOD)
Kb,Kd, Ks: BOD decay rate for deposited organic matter (b), dissolved organic matter (d) and suspended organic matter (s) (/day)
θb, θd, θs: Arrhenius temperature coefficients for BOD decay of deposited organic matter (b), dissolved organic matter (d) and suspended organic matter (s) (-)
yresp: nitrogen release/uptake during respiration/ photosynthesis (mg N/mg DO)
Ph: oxygen production (gO2/m^2/day)
Rs: respiration rate of plants, bacteria and animals (gO2/m^2/day)

The reactions influencing nitrate concentration are given by:

$$\frac{d\,NO_4 - N}{dt} = + K_{nitr}\,NH_4 - N\Theta_{nitr}^{(T-20)} \quad (nitrification)$$
$$+K_{dnitr}\,NO_3 - N\,\Theta_{dnitr}^{(T-20)} \quad (denitrification) \quad (2)$$

where:

NO_3-N : nitrate nitrogen concentration (mg/l)

K_{denitr}: denitrification rate (1/day)

θ_{denitr}: Arrhenius temperature coefficient for the denitrification process (-)

For the model parameters in the processes above mentioned, default values were selected based on standard values found in literature (DHI, 2002).

Water quality input data and model boundaries

At the different drains water quality loads were specified (the pollution load, split up in discharge and concentration for the different water quality variables). This was done for the three monitored drains based on the monthly measurements of discharge and concentrations for the period 19972003-. In between the time moments where the water quality samples have been taken, linear interpolations are assumed.

Also at the upstream boundary of the model (the inflow), time series were specified for the discharges and the different water quality variables. For temperature, no measurements were available at the upstream boundary. Because similar values were observed along the different drains, the average temperature value was calculated from the measurements along the drains and assumed at the upstream boundary.

For the concentrations of the water quality variable NH4-N at the upstream boundary, constant monthly values were used as first approximation. They were estimated based on the water quality measurements upstream of Delta Barrage. Because these values are limited to few (2) samples per year, upstream concentrations were basically assumed constant and equal to the long-term mean values. It is clear that this assumption, due to the very limited sampling frequency, introduces a significant error in the model. The DO concentration at the upstream boundary was calculated based on the equation of APHA (1985) for the DO saturation value (C_s) making use of the temperature values.

Water quality model validation

Model results are shown hereafter for the concentrations and loads of DO, BOD, NO3-N and TDS and for the temperature. Validation of these results was made by comparison with available measurements. At the different locations along the Rosetta Branch where water quality samples are available, the full simulated hourly time series for the period 19972003- was compared with the limited number of water quality sampling results during the same period. The locations are: km 0 (at Delta Barrage), km 122, km 124, km 170, km 183, and km 203. At these locations, 9 measurement campaigns were carried out within the framework of the National Water Quality and Availability Management Program (NAWQAM). Only the first 6 periods were considered for model validation as the last ones are outside the model simulation period (hydrodynamic simulation till end 2003).

Results were validated by means of the following types of plots:

- Longitudinal profiles: variation of the concentration or load versus the distance along the Rosetta Branch: comparison of model derived profiles with observed data at the 6 locations of the measurement campaigns;
- Scatter plot of modelled versus observed concentrations and loads for all 6 measurement campaigns and for all 6 locations;
- Modelled and observed concentrations or loads versus discharge;
- Difference in load from up- to downstream along the different reaches (in between locations where water quality measurements are available).

Given the data limitations for calculation of the model input and for model validation, the simulation results could be considered acceptable. The water quality model could be considered useful as decision support tool in water management. Decisions could be based on prior simulation of scenarios in the model.

SCENARIO ANALYSIS

Along the Rosetta Branch pollution mainly originates from the drains (El-Moheet, Sabal, and Tala). Different scenarios were analyzed to check the effect of the pollution reduction from the drains and analyze the effect of water management scenarios inducing pollution reduction on the Rosetta Branch status. One of the scenarios simulated was an increase in the discharge at the upstream inflow point at the Delta Barrage. Ammonia concentrations were changed accordingly, based on the relationship identified between the discharge and ammonia concentration (see Figure 3). This relationship is based on the historical ammonia and discharge time series at Delta Barrage. For different ranges in the discharge values, the mean ammonia concentration was calculated and plotted in Figure 2. In the scenario analysis, the Delta Barrage inflow was increased by 50%, only during flow periods where the inflow is <100 m.m3/day.

To examine which drain is more sensitive to the Branch quality, different scenarios were studied. The scenarios were reduction of the pollution along each drain by 30%, 50% and 70%. The effect of each change was checked individually. Figures 3, 4 and 5 present the results of the model runs for the four different scenarios. The results were plotted for location km 121 which is located downstream the three studied drains. It was concluded that El-Rahawy drain was the most sensitive pollution source, obviously because of its largest discharge. The highest improvement on the Rosetta Branch quality was recorded as the effect of the pollution reduction at El-Rahawy drain.

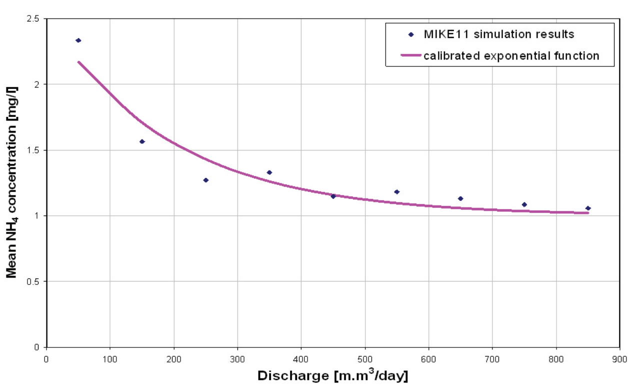

Fig. 2. Relationship between discharge and ammonia concentration.

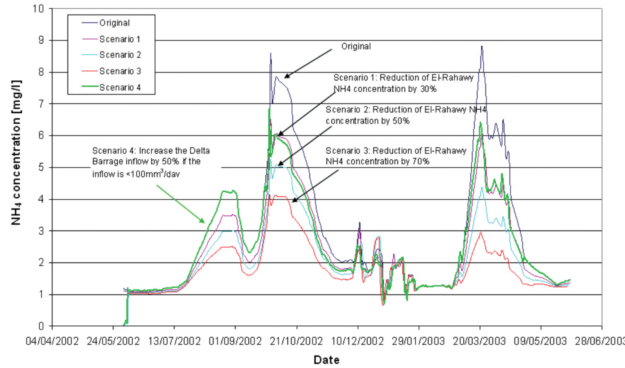

Fig. 3. Ammonia concentrations in the Rosetta Branch at km 122 for different scenarios of treatment along the El-Rahawy drain.

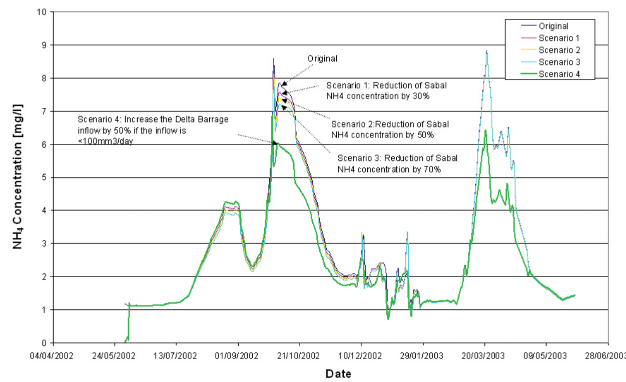

Fig. 4. Ammonia concentrations in the Rosetta Branch at km 122 for different scenarios of treatment along the Sabal drain.

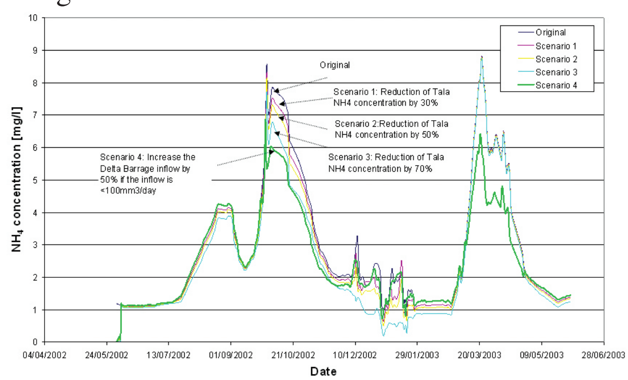

Fig. 5. Ammonia concentrations in the Rosetta Branch at km 122 for different scenarios of treatment along the Tala drain.

THE TREATMENT ALONG EL-RAHAWY DRAIN

Among the different methods for ammonia removal, treatment based on nitrification is an efficient method. Nitrification is the biological oxidation of ammonia with oxygen into nitrite followed by the oxidation of these nitrites into nitrates. This oxidation of ammonia by compound reduction is performed by two different bacteria (Ramadan, 2006):

- The first step is done by bacteria of (amongst others) the genus Nitrosomonas:

$$NH3 + O2 \xrightarrow{\text{Nitrosomonas}} NO2^{-} + 3H+ + 2e^{-} \quad (3)$$

- The second step (oxidation of nitrite into nitrate) is mainly done by bacteria of the genus Nitrobacter:

$$NO2^{-} + H2O \xrightarrow{\text{Nitrobacter}} NO3^{-} + 2H+ + 2e^{-} \quad (4)$$

All organisms are autotrophs, which mean that they take carbon dioxide as their carbon source for growth.

Nitrification also plays an important role in the removal of nitrogen from industrial wastewater. The conventional removal is nitrification, followed by denitrification. The cost of this process resides mainly in aeration (bringing oxygen in the reactor) and the addition of an extra organic energy source (e.g. methanol) for the denitrification. In most environments both organisms are found together, yielding nitrate as the final product. Nitrate is not considered toxic unless it accumulates in high concentrations. There are numerous commercial products claiming to contain nitrifying bacteria that will facilitate the conversion of toxic ammonia to non-toxic nitrate within aquaria.

In this study, also investigation of the efficiency of both nitrification and de-nitrification was undertaken. Efficiency was defined by measuring the conversion of ammonia to nitrate for nitrification and by measuring the reduction of NO3 for de-nitrification. Studies in our laboratory at the National Water Research Center, Cairo, Egypt, have indicated in what way factors (temperature, pH, DO concentration, BOD concentration, chemical inhibition of nitrifying bacteria) affect nitrification and denitrification processes.

Given the daily variation of these factors along the Rosetta Branch, the high and the low efficiency of the removal of ammonia was estimated to be 27% to 60%. This was the range of reduction % considered in the sensitivity runs presented in Figures 3, 4 and 5. Applying the high treatment efficiency to the ammonia concentrations in the El-Rahawy drain (assuming treatment is only installed downstream of this most important drain) and rerunning the model, the effects presented in Figure 6 are derived.

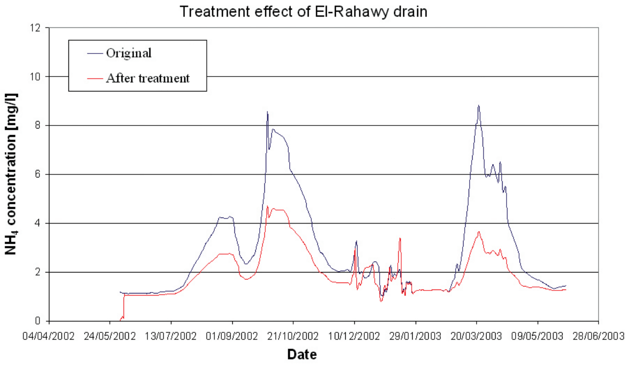

Fig. 6. Ammonia concentrations in the Rosetta Branch at km 122 before and after the treatment for El-Rahawy drain.

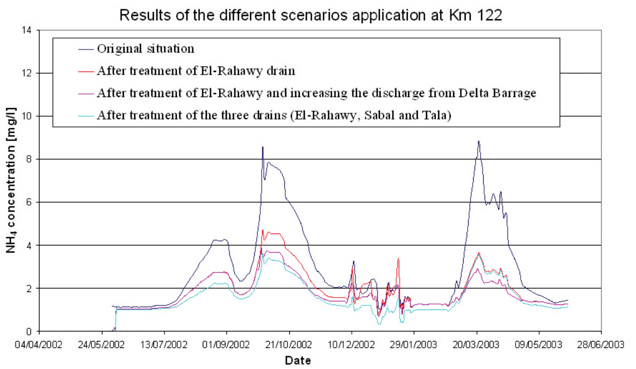

Fig. 7. Ammonia concentrations in the Rosetta Branch at km 122 before and after application of the different scenarios for treatment.

From Figure 6, it can be concluded that application of the treatment process (the high efficiency of ammonia removal of 60%) along the El-Rahawy drain reduces the ammonia concentration in the Rosetta Branch downstream the drain (km 122) by 34%. In Figure 7, the results are shown for the Rosetta Branch location downstream of the El-Rahawy drain for the original situation, after treatment of the El-Rahawy drain, after treatment of the El-Rahawy drain and increasing the Delta Barrage inflow by 50% (if the inflow is <100 m.m3/day), and after treatment of the three drains (El-Rahawy, Sabal and Tala).

The results of the different scenarios results are presented in Figure 7. It can be concluded that treatment of El-Rahawy drain will reduce the average ammonia concentration by 34%, while if the treatment is combined with increasing the Delta Barrage discharge, the reduction will be 44%. If the main three drains will be treated together, the average ammonia concentration will be reduced by 53%.

CONCLUSION

Based on the physico-chemical water quality model developed for the Rosetta Branch in the Nile Delta, and linked to a detailed full hydrodynamic model, scenario analyses were carried out in order to investigate the water quality deterioration problem along the Branch from the point of view of the high ammonia (NH4-N) concentrations, mainly originating from the drains along the Branch. To examine which of the main drains is more sensitive to the Branch quality, different scenarios are studied. The scenarios are reduction of each drain pollution by 30%, 50% and 70%, and increase in the upstream inflow discharges during low flow conditions (dilution increase). The effect of each change was checked individually. The results concluded that the El-Rahawy drain is the most sensitive pollution source. The highest improvement on the Rosetta Branch quality was recorded as the effect of the pollution reduction at the El-Rahawy drain by treatment. An ammonia removal of 60% along this drain, according to the highest treatment efficiency scenario, would improve the ammonia concentrations in the Branch with 37% on average, which is a very significant improvement in comparison with current conditions.

REFERENCES

American Public Health Association (1985) *Standard methods for the examination of water and wastewater*. 16th edition. American Public Health Association, Washington D.C.

DHI (2002) *MIKE11 Reference & User Manual*. DHI Water & Environment. Denmark.

El-Sadek, A (2001) *Engineering approach to water quantity and quality at field and catchment scale*. Ph.D thesis, Catholic University of Leuven, Leuven, Belgium.

NRI (2000) Water quality data report for NAWQAM project in September 2000. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2001) Water quality data report for NAWQAM project in February 2001. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2002a) Water quality data report for NAWQAM project in March 2002. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2002b) Water quality data report for NAWQAM project in August 2002. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2003a) Water quality data report for NAWQAM project in February 2003. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2003b) Water quality data report for NAWQAM project in August 2003. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2004a) Water quality data report for NAWQAM project in February 2004. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2004b) Water quality data report for NAWQAM project in August 2004. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

NRI (2005) Water quality data report for NAWQAM project in February 2005. Nile Research Institute, National Water Research Center, Delta barrage, Egypt.

Radwan, M (2002) *River quality modelling as water resources management tool at catchment scale*. Ph.D thesis, Catholic University of Leuven, Belgium.

Radwan, M, Willems, P, El-Sadek, A, and Abdel-Gawad, S (2005) Physico-chemical water quality modelling of the Rosetta branch in the Nile Delta. Towards a better cooperation. *International conference of Unesco Flanders fit Friend/Nile project*, 12-15 November, Sharm El-Sheigh, Egypt.

Ramadan, A (2006) Efficiency of nitrifying bacteria in wastewater treatment plant. *The*

Middle East Company for Maintenance and Operation (MIDOM).

Willems, P, Huysentruyt, H, and Berlamont, J (1996) A water quality model as a management tool. *Proceedings WEF conference on Urban Wet Weather Pollution*, Quebec.

Willems, P (2000). *Probabilistic immission modelling of receiving surface waters*. Ph.D thesis, Catholic University of Leuven, Belgium.

Willems, P, Radwan, M, El-Sadek, A, and Abdel-Gawad, S (2005) Hydrodynamic modelling of the Rosetta branch in the Nile Delta. *International Conference of UNESCO Flanders FIT FRIEND/Nile Project – "Towards a better cooperation"*, Sharm El-Sheikh, Egypt, 20-23 November 2005.

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