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HISTORICAL AND PRESENT DAY MANAGEMENT OF THE RIVER RHINE

G. H. Broseliske, J. de Jong and H. Smit

Institute for Inland Water Management and Waste Water Treatment, P.O. Box 17, 8200 AA Lelystad, The Netherlands

ABSTRACT

The river Rhine has undergone changes in morphology, chemistry, and ecology. They represent the results of historical management of the river.
An overview of the river management from 1815 on is given together with an analysis of the present situation and the changes necessary to meet the final objectives of the Rhine and North Sea Action Programmes.
The complexity and level of the present problems make it necessary that an integrated problem approach and a multinational decision making is used for an adequate future management of the river basin.

KEYWORDS

Rhine; international river management; morphology; chemistry; ecology; North Sea; action programmes; integrated; spills.

INTRODUCTION

Todays river management has become a complex process involving many aspects of use by man of legislation and of policy making.
The river Rhine has a long history of national and international river management as a result of its position in a densely populated and highly industrialised area and its transboundary character. The changes in the morphology, chemistry and ecology of the riversystem are in most cases caused by human interference and represent the results of the historical river management. After a description of these changes the river management itself will be analyzed with respect to possibilities for ecological rehabilitation of the Rhine.

THE RHINE

General aspects

The river Rhine is one of the major European rivers. It originates in the Swiss Alps and flows to the North Sea.

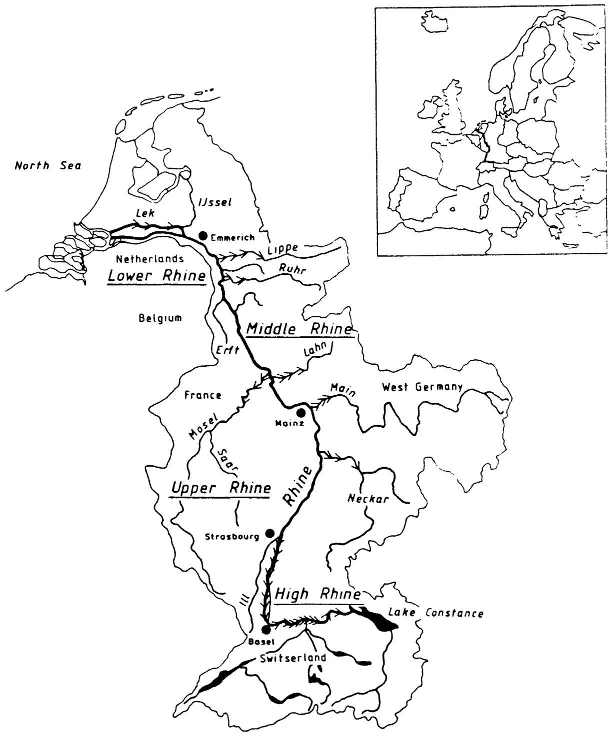

Fig. 1 The Rhine and its catchment area (in the tributaries not all locks and weirs are indicated)

The catchment area includes parts of Switzerland, Germany, France, Luxembourg and The Netherlands. These countries belong to the highly developed, densely populated parts of Europe.

Some present day data concerning the Rhine catchment area, are given in table 1.

TABLE 1

Mean discharge	Basel	1,000 m^3/sec
	Lobith	2,200 m^3/sec
Highest discharge	Lobith	13,000 m^3/sec
Lowest discharge	Lobith	620 m^3/sec (1947, open river)
		575 m^3/sec (1929, under ice)

Catchment area of the major Rhine states:

Rhine State	catchment area in km^2	population (million)	gross national income per year per capita in 1986 (in US$)
Switzerland*	9,500	3,0	17,840
Western Germany	100,000	31,9	12,080
Luxembourg	2,500	0,3	15,920
France	22,000	3,7	10,740
The Netherlands**	6,500	3,1	10,050

* catchment area below the inner lakes

** Lake IJssel excluded

Morphological changes

Although human interference with parts of the Rhine dates back to the Roman era, the first important intervention of man was the construction of dykes in the floodplain. This started in the middle ages. In time the floodplain, formerly tens of kilometres wide, became restricted to narrow zones on both sides of the river.
Dyking seemed to ensure protection against flooding, but new problems arose. In the Upper Rhine the smaller riverbed increased bed erosion, which caused a considerable fall of the waterlevel. This in turn decreased the flooding frequency in the higher floodplains but created new flooding problems downstream. The fall of the waterlevel also resulted in a lowering of the groundwater tables in adjacent areas with associated ecological changes. Riverbed erosion and mining activities (fig. 2) caused a lowering of the mean waterlevel near Duisburg of more than two meters since the beginning of the century (Anonymous, 1987).

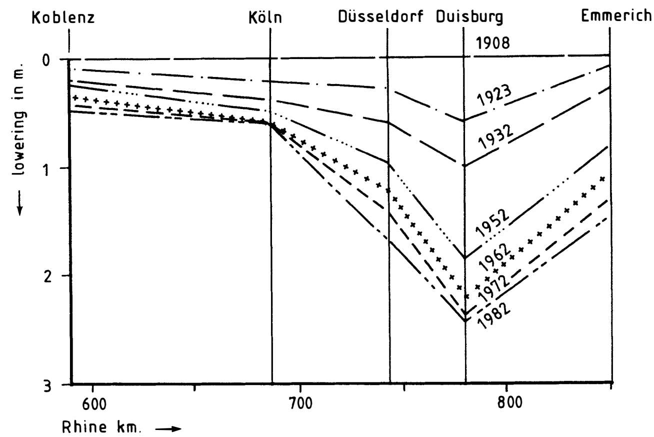

Fig. 2 Changes in the mean water level in the Middle and Lower Rhine (modified after Anonymous (1987))

The Rhine became navigable up to Basel at the turn of the century. The result was that low waterlevels had to be regulated to facilitate transport in periods of low discharge.
For this purpose, and for the production of energy, many weirs and locks have been built along the river. In the Upper Rhine a lateral canal has been constructed as well.

In this century catastrophic floodings by the sea in the downstream regions of the Rhine have led to the execution of large projects in the Netherlands aiming at a reduction of the length of the coastline which has to be protected.
Finally all along the river the increased intensity, size and velocity of navigation caused bank erosion. For protection purposes many banks of the river have been changed into stony shores.
All in all these man-induced alterations of the original river have far reaching consequences for the morphology and hydrology of the Rhine.

The most important ecological consequences were:
- the dramatic decline of the floodplain and the drying out of the part which remained;
- the disappearance of diversity in sediments and flow velocities in the river itself;
- the reduction of the open connections of the Rhine with the sea.

Developments in water quality

The history of the water quality of the river Rhine is a history of severe pollution.
Major organic pollution started when the cities along the river constructed sewerage systems.
Furthermore, industries along the river discharged their waste water directly into the river.

The intensification of industrialisation and the increase of inland water shipping resulted in an increase of spills. The estimated quantity of spills in all Dutch inland waters is approximately 1,500 tons of various products every year (J.H. Jansen, 1988).
Lifeless zones downstream of large cities and industrial sites have been reported since the beginning of the century (Lauterborn, 1916-1918). Organic pollution increased till the beginning of the seventies, when biological waste water treatment started. From 1971 to 1988 the mean oxygen level increased from about 50% to 90% saturation level. An overview of the produced quantity of oxygen consuming pollution, expressed in population equivalents (pe's), and the discharged pe's (total of treated and not treated discharges) in the Rhine catchment area is given in table 2.

TABLE 2 Production and discharge of population equivalents in the Rhine catchment area caused by both municipalities (including connected industries) and directly discharging industries (source: International Rhine Commission)

Rhine state	production of pe's in 1985	discharge of pe's in 1985	expected discharge in 1995
Switzerland	6,050,000	799,000	721,000
Western Germany	90,400,000	13,500,000	5,700,000
France	11,400,000	4,700,000	2,500,000
Luxembourg	550,000	63,000	62,000
The Netherlands	7,055,000	1,840,000	1,270,000
Total	115,455,000	20,902,000	10,253,000

Industrial activities also changed the nature of pollution. The Rhine became seriously polluted by heavy metals and organic micropollutants, which for the greater part absorb to the suspended matter. Although in recent years reductions of the loads of several heavy metals can be observed (van Broekhoven, 1987) (fig. 3), the sediments, deposited in the forelands and in the sedimentation areas of the Lower Rhine, still contain large quantities of pollutants.

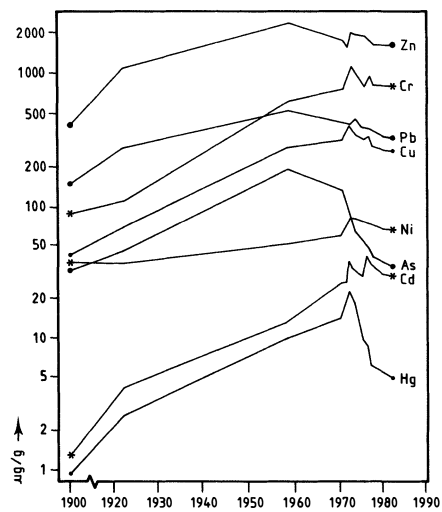

Fig. 3 The content of heavy metals in Rhine sediments deposited in the Netherlands

Laws on the prevention of pollution of both land and the North Sea impede the discharge of 10 million m³/year of polluted dredge spoil from the Rotterdam harbour into the sea or its application on land. For the next few years the Netherlands central and local government has been obliged to invest large amounts of money in the so called Slufter project, to store this polluted sediment. However, this expensive project provides merely a temporary solution which is expected to be in operation only until the end of this century. Urbanization, industrialization, intensivation and expansion of agriculture, mineralisation of organic com-

pounds, have all increased the content of nutrients in the river. The mean ortho-phosphate concentration in the Lower Rhine has increased from about 0.15 mg/l in 1950 to about 0.4 mg/l in 1980 and has been slightly decreasing since then.
Nitrate concentrations still continue to increase: mean concentrations have increased from 2.5 mg/l in 1970 to 4.4 mg/l in 1987. In the period 1972-1977 it proved that 75% of all nitrate discharges were of agricultural origin (Scholte-Ubing, 1979).
An inventory of the discharges of various pollutants entering from various sources into the Netherlands' part of the river (table 3) shows that for several pollutants the non-point sources, including agriculture, have an important contribution.

TABLE 3 The discharge in 1985 of various pollutants in the Netherlands' part of the Rhine catchment area (in kg/year)

compound	Industrial discharge	Municipal discharge (including industries connected to sewerage)	diffuse discharge (including agriculture)
Aldrin, Dieldrin Endrin, Isodrin	32	1	< 100+pm*
Endosulfan	< 1	2	≳ 400+pm*
Parathion	< 1	0	≈ 300+pm*
Mercury	470	360	80
Cadmium	15,100	440	210
Lead	16,500	23,500	16,800
Phosphorus (PO_4-P)	11,800,000	3,300,000	750,000
Ammonium (NH_4-N)	2,300,000	6,500,000	4,700,000

* pm for the application of remainder which is still in various stocks and leaching from soil and dredge spoil

The industrial and municipal discharge quantities are mainly based on measurements; the diffuse discharge is estimated using present day knowledge. For the diffuse discharge of Aldrin, Endosulfan, Parathion, etc. caused by agricultural application, a model is used to estimate the discharge taking into account the agricultural application sector (including the used quantity of agrochemicals), and as the proporties of the chemicals such as degradability and soil adsorption.
Stream regulation over the catchment area, increased drainage of the agricultural areas, the use of pesticides, and the still increasing use of fertilizers, enhance the leaching of both nutrients such as nitrate and pesticides, which makes this water increasingly unfit for the production of drinking water. Wells are being closed or will have to be closed in future.

Effects on the ecosystem

What have been the effects of the physical, morphological and chemical changes? Generally speaking the river ecosystem has been impoverished in terms of diversity. This is for example reflected in the number of invertebrate species present in the river when compared with the situation at the beginning of this century (table 4).

TABLE 4 Changes in the species-richness of some macro-invertebrate taxa in the Rhine (After van den Brink et al. (in press), Caspers, (1980a, 1980b)).

	Upper Rhine		Middle Rhine		Lower Rhine	
	1916	1980	1916	1980	≈1900	1981-1987
Gastropoda (snails)	8	4	8	5	11	10
Lamellibranchiata (mussels)	11	4	10	4	14	7
Crustacea (crustaceans)	3	2	3	2	3	13
Heteroptera (beetles)	2	1	1	0	1	1
Odonata (dragonflies)	2	1	1	0	3	2
Ephemeroptera (mayflies)	11	4	3	0	21	2
Plecoptera (stoneflies)	13	0	12	0	13	0
Trichoptera (caddisflies)	11	5	11	2	17	5
Total	61	21	49	13	83	40

But higher organisms have disappeared also, such as the salmon and the otter. Both are species representing a food chain in the water and are susceptible to pollution, making them sensitive indicators for the quality of the ecosystem.

Considering the extinction of the salmon population of the Rhine, many individual causes have been put forward, but the combination of overexploitation by fishery, increasing water pollution causing local oxygen depletion in the river, and the increasing number of dams, locks and weirs which the fishes had to pass, all have contributed.
To enable the actual return of a salmon population not only should water quality be improved to enable the growth of young salmon, but also should spawning grounds be restored and meet the requirements concerning water quality, water regime and flow conditions. The possibilities for the upstream migrating adult fishes also have to be improved. Finally the salmon fisheries on the North Sea and the Atlantic Ocean must be regulated in order to prevent the Rhine from being rehabilitated while the Atlantic salmon grows extinct.
The otter once lived in many places in the floodplain of the Rhine system.
In these places all requirements for the otter habitat were met. The numerous bushes of softwood trees and marsh vegetation supplied enough shelter, and the (temporarily) stagnant waters were very productive in terms of fish, providing also the third requirement of an otter habitat: clean water.
The return of the otter depends on the restoration of suitable otter habitat in the forelands and a foregoing reduction of pollution especially by micropollutants.

<u>Effects of nutrients discharges on the North Sea</u>

In the North Sea the discharges of nutrients have led to excessive blooms of algae, resulting in oxygen depletion in the German Bight and near the Danish coast, with significant, negative, effects on fish and shellfish production. The eutrophication of the sea also gave rise to blooms of toxic algae threatening fisheries.
From the information in the Quality Status Report of the North Sea of 1987 it can be shown that 90-95% of the nutrient entering the North Sea originates from a few major rivers (fig.4). More than half of the total nutrient load comes from the Rhine/Meuse system. This stresses the necessity of a good coordination between the management of the North Sea and the Rhine catchment area as well as the necessity of the development of similar plans for other rivers.

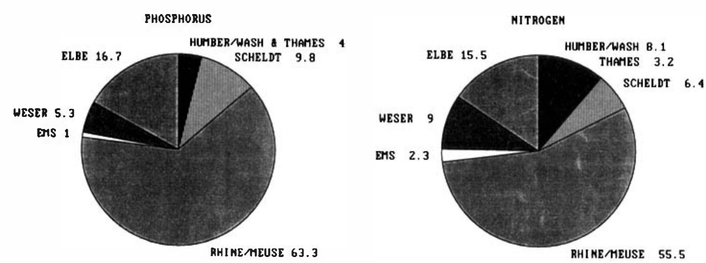

Fig. 4 The distribution of the input Phosphorus and Nitrogen to the North Sea via rivers, presented in percentages of the total discharges (Hoogweg and Van de Wetering, in press).

MANAGEMENT ASPECTS

<u>History</u>

The necessity of international management of the Rhine was first recognized for shipping. At the end of the 18th century the necessity of freedom of navigation was mentioned as an element of a conflict between the Netherlands and France, which resulted in an international system of shipping rights in 1815. An international treaty on the navigation was concluded in 1831. This treaty is still in force.
Another economic asset of the river Rhine is fishery, especially the salmon fishery. At the end of the 19th century it was recognized that co-operation between the Rhine-states was necessary to protect the stocks against overfishing and to allow for a more equal distribution

of catches between the nations. To this end the Salmon-treaty was agreed upon in 1885. Unfortunately salmon fishery reduced rapidly despite actions to protect the salmon stock. The last salmon was caught in 1957.
The aspect of transboundary pollution of the Rhine was first given attention in 1932 when the Dutch government protested against the issuing by France of a permit to discharge residual salt into the river. After the second world war, pollution problems increased further and an international commission charged with the study of the waste water and water quality problems, the International Rhine Commission (IRC) was formed.
The international co-operation against pollution was strengthened by two treaties, one for the protection of the Rhine against chemical pollution (1979) and one for protection against pollution by chlorides (1985).

Recent developments

The work of the international commission proves very useful with regard to the exchange of information on national pollution abatement techniques, the joint monitoring of Rhine water quality, the co-operation of research, and the coordination of warning in case of spills.
The position of the commission is somewhat weaker with regard to its power to lay down binding international rules. The commission can only agree unanimously on recommendations to the national governments, which subsequently come into force only after acceptance by all contracting parties. However the impact of the commissions work has been increased by regular meetings of the responsible ministers which ensured the political acceptance of the various necessary measures.
Regarding the reduction of discharges, the execution of the chemical pollution treaty has led to agreements on the discharges of Mercury, Cadmium, Carbon tetrachloride, Chloroform, Aldrin, Dieldrin, Endrin, Isodrin, Hexachlorobenzene, Hexachlorobutadiene, Endosulfan, Chromium, and to agreements regarding restrictions on the use of certain substances like PCB's and Pentachlorophenol. The directives established by the European Community do also apply to the greater part of the Rhine catchment area and the decisions of the International Rhine Commission are in concordance with the E.C. directives.
The Chloride treaty has thus far only led to a small reduction of the salt discharges by France. The effectiveness of this treaty is doubted by the governments involved.

The protection of the river Rhine against chemical pollution has recently been speeded up by the responsible ministers. During the ministerial-conference held in December 1986 in Rotterdam the execution of a Rhine Action Programme was agreed upon, which should aim at the following three goals:

- the ecosystem of the river Rhine should be improved to such an extent that higher species (e.g. the salmon) that formerly existed but have now disappeared from the river, may become indigenous again;
- the production of drinking water from Rhine water must be equally guaranteed in future years;
- the pollution of the Rhine by toxic and polluting agents must be so far reduced that the sediments can be used as filling material on land or else can be dumped into the sea without causing harm to the environment.

For this purpose it was agreed that for about 30 priority substances (mostly micropollutants but also phosphorus and ammonium) a reduction for approximately 50% of the pollution will have to be realised by 1995, taking into account the best available technology. The year of reference is 1985.
As has been indicated, the management of the North Sea may depend largely on the management of the Rhine and other rivers. With respect to this, important decisions have been taken during the Second international Conference on the Protection of the North Sea, held in London in November 1987. It was agreed that measures will be taken with the objective to reduce the input of nutrients and pollutants to this sea by about 50% in the period 1985-1995. This implies a reduction of all nutrients by about 50% including nitrogen which was not included in the Rhine Action Programme.

The future management

The present river management as executed by the countries along the Rhine, including the multinationally coordinated measures to be taken, is insufficient to meet the final objectives of the Rhine and North Sea action programmes.
Why?

1. To achieve the necessary ecological conditions for species such as the salmon and the otter, the discharge of municipal and industrial waste water will have to be reduced much further. This not only requires improved treatment facilities at sufficiently low costs but even more a strong emphasis on policies and technologies to prevent pollution.

The same holds for the agricultural pollution. In the Netherlands for instance plans are in development to ban the use of environmentally unacceptable agrochemicals (quality aspect), to reduce the use of agrochemicals (volume aspect) and to improve the application methods of agrochemicals (emission aspect).
Morphological adaptations, necessary for habitat restoration of e.g. the salmon, are only a secondary goal in the Rhine Action Programme and will have to be given more emphasis.

2. To meet the demands of the North Sea Action Programme, a 50% reduction of the discharge of all nutrients by the Rhine and other rivers must be realised by 1995. The nitrate load, being mainly of agricultural origin can only be sufficiently reduced if land use and agriculture are incorporated in river basin management. This would not only be in the interest of the ecology of the Rhine and the North Sea but also in the interest of human health. The pollution of ground water with nutrients such as nitrate makes this water increasingly unfit for the production of drinking water, and wells are being closed or will have to be closed in the future.

3. Air pollution is increasingly influencing river basin management in both a direct and an indirect way. Directly air pollution contributes to water pollution as one of the non-point sources. Indirectly the air pollution, caused in the Rhine catchment area or elsewhere by urban and industrial activities, by agriculture and traffic, has a large impact on the forests. During the conference of the European Union of Forestry, held in 1988, it was concluded that only 40-50% of the forests in western Europe, including those in the Rhine catchment area, have not been negatively affected by air pollution. The results may be acidification of soils, the leaching out of metals towards surface and ground water, soil erosion and an additional deposition of (polluted) sediments into the river and also increased danger of floodings.

The future management of the Rhine catchment area, whatever way it will be organized, must be able to tackle these problems.

DISCUSSION

Observing the historical and present problems and management of the Rhine, and taking into account the problems to come, some developments can be distinguished very clearly.

1. The scale of problems tends to increase.
The danger of flooding and (organic) pollution problems have for a long time been differing per river stretch.
The bad navigability of the Rhine became at the beginning of the 18th century the first problem on a river scale. Afterwards other problems on this scale arose, such as the decreasing salmon catches (after 1885) and the transboundary pollution (1932). The present problems involve agriculture in the river basin, accidental spills in the river basin, air pollution in and outside the catchment area and boundary conditions set by the North Sea management; the problems have now grown to the scale of the river basin and its surroundings.

2. The level of decision making tends to increase.
Until the beginning of the 19th century most decisions were made on a local or regional level. The international treaty on the navigation marks a transition to decision making on a national level with multinational coordination. The Salmon treaty and even the two treaties concerning the protection of the Rhine against chemical pollution and chlorides are examples of this way of decision making.
The establishment of EC guidelines for black and grey list substances may be seen as a gradual shift towards international decision making. The Rhine Action Programme and North Sea Action Programme may also be seen as important steps in this direction. The last few years a worldwide coordination level has even been established to tackle global environmental problems like the destruction of the ozone layer and the rise of the sea level.

3. The approach to decision making changes.
For centuries the local authorities had to solve above all separate problems: how to prevent flooding, how to cultivate the forelands, how to organize the transport on and across the river. It was a unisectoral approach, considering few interrelations. During the 19th and 20th century the use of the river intensified, the river being used for fisheries, as a shipping route, a source of drinking water, and a receiver of various discharges, beside its natural function for the transport of water, ice and sediments.
All these uses increasingly started to conflict, so that more sectors of river use had to be involved in decision making, e.g. the drinking water supply was related to the salt discharges. A multisectoral approach became obligatory. To solve the present problems however even this may not be adequate. The river today serves not only the above-mentioned functions but is also considered to be a river ecosystem, where the salmon and the otter

must be able to live, and where man can recreate. Furthermore the river may exert negative influences on the quality of the North Sea. Multisectoral decision making implies a large number of interrelationships and conflicts to be solved.
The Rhine Action Programme signified an important change: for the first time an ecological objective was formulated for the whole river, and the measures to be taken were related to this objective. It can be seen as the first step towards an integrated approach to decision making. The complexity of the present and the future problems, combined with an increasingly intensive use, urgently ask for such an approach.

Summarizing, the present management situation of the river Rhine (see table 5.) can be characterized by management problems on the scale of the river basin and its surroundings while the level of decision making is gradually changing from the national to the international level and the problem approach has changed from multisectoral to integrated.

TABLE 5 Developments in the scale of problems and level approach in decision making in the management of the river Rhine

PROBLEM	DECISION MAKING	
SCALE	LEVEL	APPROACH
RIVER STRETCH	LOCAL	SECTORAL
↓	↓	↓
RIVER	NATIONAL	MULTI SECTORAL

↓	↓	↓

RIVER BASIN + SURROUNDINGS	MULTINATIONAL	INTEGRATED

-------- : present situation

CONCLUSIONS

If the final objectives of the Rhine and North Sea Action Programmes are to be realised, the following conditions have to be met:

1. pollution has to be reduced much further than the 50% agreed to in the action programmes. The necessary morphological conditions for indigenous species such as the salmon must be at least partly restored.
2. discharges caused by agriculture, accidents and air pollution must be included in the river management.
3. new technologies should improve purification levels and enable industry to introduce new production processes. The same holds for agriculture, which also should be considered as an industry, with the same rights and obligations.
4. river management and policy making must change from a multisectoral to an integrated problem approach and from a national to an international level of decision making. Both action programmes are important steps in this direction.
   The sustainability of the river system i.e. the environmental conditions for man and nature, should set boundary conditions for all human use.
5. an effective international management of an important river such as the Rhine calls for a strong body with sufficient back-up from responsible governments to make the necessary decisions.

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