1. Purpose of the Rhine-Atlas

The results of the effective flood protection of the past 150 years and of increasingly dense urban settlements in the Rhine valley are that people are less and less aware of living in areas at risk of flooding. The preventive evacuation measures in the Netherlands during the floods in January 1995, the numerous dike breaches along the R. Odra in the summer of 1997, along the R. Danube in 1999 and the R. Vistula in the summer of 2001 have again highlighted that nature cannot be controlled and that higher floods than those observed so far and an overtopping or a failure of hydraulic protection structures cannot be excluded. **The residual risk of flooding subsists latently.**

The target of the atlas at hand is to draw the attention of the citizens affected along the Rhine and in the Rhine valley to this residual risk. This atlas is part of the Rhine Action Plan and is a further development of the Rhine Atlas on ecology and flood protection published in 1998 representing maps of the inundated areas and the areas of ecological importance in the Rhine valley.

On 22nd January 1998, the 12th Conference of Rhine Ministers held in Rotterdam decided to implement the Action Plan on Floods. This Action Plan bundles all national as well as international measures aimed at improving flood prevention along the Rhine.

The target of the Action Plan on Floods is to provide better protection of man and material assets against floods and, at the same time, to ecologically improve the Rhine and its floodplains. The Rhine bordering countries will implement this phased action plan bundling vast interdisciplinary categories of measures until 2020. A first report on the implementation of the Action Plan on Floods by 2000 is available.

The performance targets based on the situation in 1995 are:

- **To reduce damage risks** – no increase of damage risks by 2000, a reduction by 10 % by the year 2005 and by 25 % by 2020

- **To reduce flood levels** – reduce extreme flood levels downstream the impounded section (downstream of Baden-Baden) by up to 30 cm by 2005 and by up to 70 cm by 2020

- **To increase flood awareness** – increase flood awareness by drafting risk maps for 50 % of the floodplains and the flood prone areas by the year 2000 and for 100 % of these areas by 2005

- **To improve the flood warning system** – a short term improvement of the flood warning systems with the help of international co-operation. Prolong the warning lead time by 50 % until 2000 and by 100 % by 2005.

The new Rhine Atlas represents potential areas at risk of inundation and the related possible damages. It is thus a data basis and a basis for measures within the first and the third performance target of the Action Plan on Floods under implementation. The atlas invites to consider further measures supporting the target of reducing the residual risk.

Maps representing the danger of flooding (basic maps) illustrate the possible flood depth in blue colours of different intensity and visualise the flood danger for man and material assets in cases of extreme flooding. An overlay foil (covering foil) represents the possible damages in cases of extreme floods under present conditions of use. Distinction must be made between two cases:

Protected areas with a high level of protection

With respect to these surfaces, floods are mainly conceivable in connection with dike breaches, which mostly limits the area hit. This mainly applies to the Upper Rhine, the Lower Rhine and the Rhine delta. Along the French-German Upper Rhine between Basel and Iffezheim, flood protection works protect against floods up to a recurrence interval of 1,000 years. In the Rhine delta, flood protection even covers statistic recurrence intervals between 1,250 and 10,000 years. Since the locations of dike breaches cannot be determined in advance, the entire surface lying below the river water level must be regarded as flood prone area. This amounts to the hypothesis that the dikes do not offer any effective protection. On the whole, this hypothesis is highly unlikely, but individual dike breaches must be reckoned with. The representation of both the flood risk and the potential damage highlights the most unfavourable situation of each surface share and thus represents the envelope for different extreme events. It thus represents the protection effects of the dikes.

Unprotected areas or areas with a low level of protection

In cases of extreme floods, low lying areas along a river section are hit. This largely applies to the High and Middle Rhine. Along these river sections, the surfaces represented may be flooded during one single event, which, as far as diked surfaces are concerned, is only probable on a local scale.

Since the monetary assessment is highly uncertain, indications are limited to orders of magnitude. The rough scale of 1:100,000 which is unsuitable for planning precise local projects is however suitable for the targeted overview representation.

Particular attention has been paid to the representation of the consequences of potential extreme floods by indicating the possible flood depth for these events, while, as far as comparably frequent events, such as floods with a recurrence interval of 10 or 100 years are concerned, only the outer limits of the surfaces hit are indicated. Life-threatening damages are rather caused by very rare events, when water levels overtop the dikes or the stability of dikes is threatened by lasting pressure. Until they occur, such damages are normally not believed to be possible. The atlas represents the **worst case** flood depth at any given point and it must be taken into account that one and the same event cannot hit all surfaces represented along the entire Rhine, as the effects of retention and cutting the crest make floods downstream more unlikely.

Thus, the Rhine Atlas does not represent the flood situation liable to occur due to a certain event along the entire course of the Rhine. The maps rather represent a synthesis of many possible extreme events, the most unfavourable flood situation for any given point and thus the threat posed to any individual and not the overall threat. This overall view is based on a statistic assumption, factors related to time are not taken into account.

2. Area of consideration

Traditionally, according to the surrounding landscape and the development of the river course, the Rhine is split up into the following sections, which also differ from one another with respect to flood protection.

The ***High Rhine*** (Lake Constance to Basel – Rhine km 0 – 170) flows in a valley the major part of which is deeply cut into the rock and consists of a number of dammed stretches. In isolated locations, particularly at the confluence with tributaries and in larger settlements traditionally built on the river banks, potential damage exists.

Along the ***Upper Rhine*** (Basel to Bingen – Rhine km 170 – 529) the system of dikes created when training the course of the Upper Rhine between 1817 and 1880 still exists and still performs protection downstream of Iffezheim. Between 1932 and 1977, 10 barrages were built between Basel and Iffezheim with a view to producing hydroelectric power and to improving navigation conditions. The lateral dams along the Rhine protect against floods occurring once in 1000 years. Dikes continuously follow the northern Upper Rhine between Iffezheim and Bingen at a distance of 500 – 1000 m from the channel. Protection against floods with a 200 year recurrence interval will only be granted once all planned retention measures have been implemented along the southern Upper Rhine.

The ***Middle Rhine*** section (Bingen to Bonn – Rhine km 529 – 642) is characterised by the Rhine valley of the Rhenish Slate Mountains which partly becomes as narrow as 150 m. There are few local flood protection works. Only the flood protection dike in the basin of Neuwied offers protection against a one in 100 year flood.

In the course of the many river training measures of the past century, the ***Lower Rhine*** (Bonn to Lobith – Rhine km 642 to 857) has been constricted by dikes. Protection by the more than 330 km of flood protection works varies between a one in 20 years event and a one in 500 years event.

In the ***Delta area*** (Lobith to Rotterdam – Rhine km 857 – 1030) the Rhine splits up into the rivers Waal, Nederrijn/Lek and the IJssel at the German-Dutch border. Settlement areas are all protected by ring dikes, the basis for assessment of which is founded on a probability of flooding of 1 : 1250 per year in the east and 1 : 10,000 per year in the west of the Netherlands.

Section of the Rhine	Stretch	Rhine km	Countries / Länder
High Rhine	Konstanz to Basel	0 - 170	CH, D (BW)
Impounded southern Upper Rhine	Basel to Iffezheim	170 - 334	F, D (BW)
Northern Upper Rhine protected by dikes	Iffezheim to Bingen	334 - 529	F, D (BW,HE, RP)
Middle Rhine	Bingen to Rolandswerth	529 - 642	D (RP, NRW)
Lower Rhine, protected by dikes	Rolandswerth to Lobith	642 - 857	D (NRW), NL
Rhine delta, protected by dikes	Lobith to estuary	857 - 1030	NL

3. Maps representing the danger of flooding

3.1 Contents of the maps

The topographic maps represent:

3.1.1 The limit of one in 10 years floods (HQ10):

Surfaces along the river are frequently flooded. Mostly, floodplains are hit, wetland sites, forests and more rarely agricultural surfaces. The danger of flooding is known and, if exceptionally there should be buildings on these surfaces, they must be adapted to the danger of flooding. These surfaces must under all circumstances be preserved as flooding zones, as they serve as retention areas and represent valuable biotopes.

3.1.2 The limit of one in 100 years floods (HQ100):

Surfaces between the limits HQ10 and HQ100 are flooded once in 10 to once in 100 years. Normally, only residents having lived there for a large number of years are aware of the danger of flooding, and therefore not only older buildings adapted to the risk of flooding, but also more recent ones with a higher damage potential may be found in these areas. The surfaces concerned are often used for agricultural purposes. Only in exceptional cases should they be used for settlements – if appropriate preventive construction measures are taken. Due to the transition from aquatic to terrestrial vegetation, these surfaces represent valuable biotopes. Apart from the High Rhine, the Middle Rhine and lesser parts of the Lower Rhine, dikes protect most surfaces against a HQ100 or even higher floods, so that this limit normally coincides with the line of dikes. Surfaces between the river and the dike must at all events be preserved as natural floodplains and flood retention areas.

Along the southern Upper Rhine, the HQ100-line is represented along the dikes parallel to the Rhine at the barrages and along the accomplished dams of the retention areas or along those under construction. These dams or dikes are designed for a higher level of protection (up to 1,000 years). The management of flood retention works permits to respect the intended surface level even during higher, extreme flows of the Rhine.

3.1.3 Limits and flood depth of extreme events

During these very rare events, flood depths are distinctly higher than what has been observed so far and/or locally overtop existing flood protection works or these works fail to perform. It is so unlikely that such an event will occur that no probability of occurrence (as for a one in 100 year event – HQ100) may be indicated. Neither do direct restrictions of use arise, but the possibility of a flood should be taken into account within a preventive strategy and emergency planning. In particular, this applies to vulnerable objects, such as hospitals, museums and certain industrial sites, but also private oil reservoirs which may cause considerable damage in case of flooding. Emergency prevention should in particular be prepared in larger settlements. As it is difficult to quantify this danger and the importance of potential preventive measures (such as evacuation plans in cases of flooding) is highly dependant on the flood depth, not only the limits of the flooded areas, but also the most important categories of flood depth are represented. The choice of categories of flood depth is based on the following considerations:

0 – 0.5 m	Simple means may avoid water penetrating buildings. This category may also be considered to be a category of uncertainty, as a precise indication of flood limits is hardly possible.
0.5 – 2.0 m	Flood level at which tangible damages must be reckoned with, however presenting only a low threat to the life of man, in particular if there is a possibility of gaining higher floors.
2.0 – 4.0 m	Increased threat to the life of man, as not only the ground floor, but also the first floor is liable to be flooded. Flood depth at which high damages may hardly be avoided.
Above 4.0 m	High threat posed to man; high threat for total losses.

These categories apply to stagnant or slowly flowing waters, which is in general true of the Rhine.

For reasons of representation, the maps illustrating flood danger indicate different sizes of categories of persons liable to be hit by the flood depths of extreme floods or who may be in danger.

3.2 Hydrological assumptions for extreme flood events

Due to the varying hydrological and topographic situation, the assumptions for the different sections of the Rhine had to be fixed separately as listed in the annexed table. These assumptions are limited to extreme water levels. Other parameters, such as flow velocity, examinations into stability, effects of retention and cutting of the flood crest following a breach of dikes have deliberately not been taken into account.

With a view to assessing these events along the **High Rhine**, the limits of the floods of 1999 were increased by 1 m – within the scope of Lake Constance by ½ m.

Along the **Upper Rhine between Basel and Maxau** the calculations are based on the historic surface levels of the Rhine floods in December 1882 and the flooded areas following the many breaches of the lateral dams, as represented in the monography of the Rhine of 1889. For reasons of simplification, the model calculations neither take into consideration the deepening of the river bed which has since occurred in certain parts nor the effects of river training measures (canalisation). Downstream of Iffezheim, the calculated surface level of the one in 200 year event increased by 0.5 m was chosen as extreme water level (see chapter: Particularities of the representation of the trained southern Upper Rhine).

On the **northern Upper Rhine** and the **Middle Rhine**, between Rhine-km 362,5 (gauge Maxau) and km 642 the water level of a one in 200 year event was increased by 0.5 m while, along the **Lower Rhine** between Rhine km 642 and 857 calculations base on water levels of a one in 500 year event.

In the branched **Rhine delta** between Lobith (Rhine km 857) and the outlet of the rivers Waal, Nederrijn/Lek and IJssel into the North Sea (Rhine-km 1030) water levels corresponding to a HQ1,250 to HQ10,000 as well as the influence of the North Sea were considered.

3.3 Topographic assumptions

The assessment of the inundated areas and of flood depth depends on hydraulic assumptions and the degree of precision of the indicated area elevation distribution. Road embankments, canals or old flood dams may have decisive influence on the extension of flooded areas. As the chosen scale only permits an imprecise assessment of the contours, the indication of flooded areas must be considered to be rather rough. On a local scale, precise calculations with the help of hydraulic models permitting to precisely determine the surfaces at risk are essential. Digital contour models used for the simulation are represented in the annex. The water surfaces calculated have been combined with terrain models of the topographic maps at a scale 1 : 25,000. The surfaces thus gained and checked were then generalised for the representation on a scale 1 : 100,000.

3.4 Particularities of the representation of extreme floods on the trained southern Upper Rhine

For the trained Upper Rhine, the model calculation represents the limits of the surfaces inundated during the 1882 floods (corresponding to the discharge of a 1 in 100 year event) which has been reconstructed on the basis of flood marks observed and present topography.

These calculations do not take into account:

- the deepening of the river bed in certain stretches of the river
- the creation of transverse bars created by roads running vertically to the axis of the Rhine and no longer permitting the unhindered inundation as in former times. Due to these transverse bars, the flooded surfaces and the flood depth would locally be much bigger.

3.5 Particularities of the Rhine delta

Without any protection measures, two thirds of the Netherlands would be inundated in case of a flood. This particular situation is represented by the flood hazard maps coloured blue. For an assessment of these maps it is important to know that the degree of protection is highest in this part of the Rhine catchment.

4. Maps of potential damage

4.1 Contents of the maps

The maps of potential damage are meant to represent where great assets are at risk at what flood depth. They are thus to be considered as an indication of possible effects of inundation. Since the height of damage depends on the flood depth, transparent foils were chosen for the maps representing the potential damage, permitting an easy and simultaneous recognition of the danger (flood depth) and potential damage.

For reasons of representation, risks posed to man which, from the point of view of contents would belong to this chapter, have been integrated in the maps of flood risk.

The representation of potential damage distinguishes between

Persons affected: irrespective of flood depth this category comprises all inhabitants of the surface at flood risk.

Persons at risk: this category is a subset of that of persons affected and comprises all inhabitants in settlements where the flood depth exceeds 2 metres.

Material assets: as far as potential damages are concerned, a distinction is first of all made between the kinds of use affected (agriculture, industry and settlements) and then between the height of damage, as those affected are supposed to react. Additionally, it must be shown who is affected to what extent and it must be avoided that the sums for the different areas disappear in one total sum.

The atlas represents:

In yellow damages to agricultural yield amounting to between 2 and 10 €/m² which are thus considerably lower than in other areas

In violet damages to industrial sites, trade sites and traffic infrastructure in two categories (above and below 25 €/m²). The isolated representation of the industrial area is justified by the fact that the environmental risks these surfaces pose may often not be quantified.

In red damages to settlements (above and below 50 € /m²). The settlement not only includes damage to private housing estate, but also to business and service institutions, public buildings, parts of traffic infrastructure and trade. This is necessary, as these forms of use are closely interlocked. Varying population density is taken account of on the basis of the number of inhabitants per 1,000 m².

4.2 Calculation of potential damage

The calculation of potential damage in cases of extreme floods is based on the following steps:

1. Determination of land use in the areas at flood risk

2. Determination of people affected and persons at risk on the inundated surfaces

3. Determination of assets and values on the inundated surfaces

4. Determination of potential damages by applying a damage function to the different goods depending of flood depth.

Due to the size of the surfaces and the overview scale, the below listed simplifications were required for each of these steps.

4.2.1 Determination of land utilisation

This determination is based on the CORINE set of data standardised for the whole of Europe. According to their relevance for determining the damage, the 44 categories of land utilisation were bundled in 6 categories of use (settlement, industry, traffic, agriculture, forest and other surfaces). The pan-European representation has been generalised so that only surfaces of land use above 25 ha are represented. As a consequence, linear structures such as roads, railways, water bodies and smaller oblong settlements along roads may be neglected.

The inclusion of the use of smaller surfaces, in particular of traffic infrastructures into the surrounding large surface categories is balanced by an analogous transfer of assets into these categories when calculating the damage.

4.2.2 Determination of persons affected and at risk

The numbers of inhabitants per municipality were available for the entire area of investigation. These were evenly spread to the settlement areas in CORINE in order to be able to calculate a mean density of inhabitants per municipality. By combining settlement areas and inundation areas, the inhabitants affected could be calculated for each municipality. Since casualties rarely occur at flood depths below 2 m and are then due to carelessness, the limit between persons at risk and persons affected by flooding have been fixed to this flood depth. Casualties liable to occur under these circumstances were not calculated as, on the one hand, the basis of assessment is too uncertain and, on the other hand, the task to provide security to everybody persists regardless of the probability of occurrence.

The assessment of affected employees failed due to the non-homogenous set of data. Inventories in the different countries were drafted at different periods, varied in structure and could not always be affected to the municipalities. As, in cases of vast floods, a not to be determined part of the employees also lives in the flooded area, they were not assessed so as to avoid to count them twice.

4.2.3 Determination of affected assets

In large-scale inventories, the objects affected (e.g. number of buildings, km roads) cannot be determined. Therefore, mean values had to be determined for each category of use. As far as the German Länder Baden-Württemberg, Hesse, Rhineland-Palatinate and North Rhine-Westphalia are concerned, the capital stock (total value of all goods) listed in the economic statistics was distributed upon the categories of use, distinguishing between investments in buildings and movable assets (household effects, supplies, equipment, machines). As these data are only available for the German Länder, the values were adapted to the other countries by applying specific factors for each of them. For real estate, these values were determined according to the purchasing power, for the economic sector according to the gross national product. Thus, for each category of use, mean values applicable to a Land or a country were determined per surface unit. With a view to taking account of the influence of building density on the concentration of values, these values were then adapted to each municipality according to the number of inhabitants per ha settlement area.

4.2.4 Determination of material damage

It is only in cases of extreme flood depth that all material assets found on a surface are destroyed. Normally, the degree of damage depends of the flood depth, that is, the percentage of damage mathematically determined with the help of a so called damage function. A number of such functions exists for the different objects and assets, the results of which may vary within large limits. Within this analysis, damage functions had to be adapted to the chosen categories of use and the existing summary declaration of value. Regardless of the intended use, the same function may be applied to buildings. That means that, for settlement areas, the value of which is a mixture of trade, services, settlement, administration and infrastructure, a uniform damage function may be assumed for real estate capital (buildings). Therefore, within a settlement area, distinction had to be made – all depending on the economic branch – between different damage functions for the mobile assets (household effects, furniture, equipment, supplies). A mixed function was determined (60 % living, 35 % economy and 5 % state) on the basis of the different functions. The relations applied, listed in annex, are based on the HOWAS data bank, studies made in the Netherlands, expert discussions and experience of the consortium in charge.

On the basis of the maps of inundation and the values for each category of use of the CORINE record of data adapted to each municipality, a grid record was produced with cells of 1000 m² (L = 31,62) containing the flood depth and the existing values. The result of the following application of the damage function is the potential damage in one cell.

The **comparison with earlier damage appraisals** must take into account that this determination of damage does not take into consideration different other aspects which may lead to distinct divergences from other inventories. The following aspects are concerned:

- The replacement value (new value) is not considered - The current value at today's market price is taken into account. A comparison with the data of insurance contracts which refer to the new value results in differences up to a factor 2.

- No consideration of an interruption of production and operational failure – for trade and services, business and industry the kind of damage is often more important than the sustained material damage. The data of past events reveal that damages due to the interruption of production and operational failure may be up to four times as high as the direct damage in this category. An investigation was not carried through, as, during large-scale floods, even enterprises not directly hit may sustain damages following an interruption of production.

- No consideration of damages to vehicles – These may amount to 2 – 7 % of the damage sum.

- No consideration of expenses for emergency prevention and the intervention of the fire brigade or rescue services – The great floods of the German Odra in 1997 and of the Rhine in the Netherlands in 1995 gave rise to expenses for rescue services amounting to several hundreds of million €.

- No consideration of damages to flood protection works and their subsequent strengthening. Often, damages to flood protection works amount to 30 % of the total damage sum and may exceed damages to private property. Their estimation is difficult, in particular if new flood protection works are required.

- No consideration of damage reduction measures.

- Limitation of damages sustained by agriculture due to loss of yield without taking into account intensive cultures and damage to works of infrastructure, as these special uses are not separately identified in the CORINE set of data.

5. Results

5.1 General considerations

The damages inventoried are merely material damages based on the current value of the affected goods.

For each surface taken into consideration the damages to material assets indicated represent the lower limit value at the flood depth determined.

It is recalled that the damages represented will not all occur during one single event; the indications are only realistic for the different sections of the river. The sum of damages does not refer to any concrete event and was only chosen with a view to simplifying the representation and to underlining the potential damage.

5.2 Surfaces at risk

Table 1: surfaces at risk in km²

Sections of the Rhine	According to flood depth				According to units of land use			
	Total surface	Depth < 0.5 m	Depth 0.5 – 2 m	Depth > 2 m	Settlement	Industry and traffic	Agriculture	Miscellaneous (incl. forest)
High Rhine	78,8	62,4	15,7	0,7	1,5	0,4	10,8	66,1
Upper Rhine	1.839,5	223,0	685,4	931,1	166,3	82,6	1.108,3	482,3
Middle Rhine	52,5	4,1	11,2	37,2	17,5	4,6	18,7	11,7
Lower Rhine	1.355,9	119,3	320,9	915,7	218,1	74,6	952,2	111,0
Rhine delta	11.272,2	2.459,2	1.784,0	7.029,0	1.186,9	291,8	8.785,7	1.007,8
Sum	14.598,9	2.868,0	2.817,2	8.913,7	1.590,5	454,0	10.875,7	1.678,9

During extreme flood events, flood depths occurring on 20 % of the total surface of 14,600 km² liable to be flooded are low (0 – 0,5m) to moderate (0,5 – 2m). Surfaces at much higher risk (flood depth above 2 m) are above all found in the areas protected by dikes. 79 % of the surfaces liable to be hit by high flood depth are situated in the Rhine delta, they partly even lie below sea level.

Along the Middle Rhine, the share of settlements at risk is indicated with 34 % and is thus distinctly higher than along the other sections of the Rhine (between 9 and 16 %), which is due to the cities built on the banks of the Rhine as early as the Middle Ages. The intensity of use of the valley bottoms at risk of flooding is highest along the Lower Rhine and in the Rhine delta. Damages (to settlements, industry, traffic infrastructures and agriculture) are liable to occur on 90 % of the total area at risk. As a matter of comparison, along the Upper and Middle Rhine only 74 % of the surfaces are at risk.

5.3 Persons at risk

Table 2: persons at risk

Section of the Rhine	Persons at risk	Persons at risk
	on the inundated surfaces	from a flood depth > 200 cm
High Rhine	7.400	100
Upper Rhine	777.400	322.400
Middle Rhine	73.300	45.200
Lower Rhine	1.264.200	557.400
Rhine Delta	8.564.000	4.576.900
Sum	10.686.300	5.502.000

More than 10 million people are living in the areas at risk of extreme floods along the Rhine. A comparison of the areas along the Upper with those along the Lower Rhine highlights the varying density of population. The surface at risk of flooding is much larger along the Upper Rhine (+ 36 %), but the number of persons at risk is distinctly lower (- 39 %) than along the Lower Rhine.

Due to the high density of population in the Rhine delta, the share of persons at risk is higher (+ 3 %) than what would correspond to the surface share. There is an increased risk for about half of the persons affected.

5.4 Potential danger determined for extreme events

Table 3: Potential material damage in million euro

Section of the Rhine	Settlement	Industry and traffic	Yields in agriculture	Sum
High Rhine	32,6	4,8	0,8	38,3
Upper Rhine	8.224,5	3.671,9	81,7	11.978,0
Middle Rhine	1.336,3	350,1	1,0	1.687,4
Lower Rhine	16.458,9	3.788,5	85,6	20.333,0
Rhine Delta	111.011,8	19.244,0	610,6	130.866,4
Sum	137.064,2	27.059,2	779,7	164.903,1

Material assets hit mean the total sum of all assets on the inundated surfaces. For all sections of the Rhine they were determined at 750,000 million €. Depending on flood depth and vulnerability, only a certain share of this surface will be damaged.

Due to the high share of settlement areas, the damages per surface unit are considerably higher along the Middle Rhine (32 Euro/m²) than along the Lower Rhine (15 Euro/m²) or in the Rhine delta (12 Euro/m²). The average damage lowers to 6.5 Euro/m² along the Upper Rhine and to 0.5 €/m² along the High Rhine. These numbers give evidence of the considerably lower intensity of use along the last-named sections of the river.

Today, 74 % of the surfaces affected are used for agricultural purposes, but 83 % of all damages hit settlement areas which only occupy 11 % of the surface.

With 16 %, industry and traffic infrastructure have a surprisingly low share in the total damages (3 % of the surface). This is above all due to the fact that – as already mentioned – the calculation does not take account of operational failures. Supposing a multiplying factor of 3 to 4 for these not recorded damages in cases of operational failure, the potential damage sum of this category rises to 80,000 to 110,000 million € and attains the total damage to be expected for this category.

5.5 Particularities in the Rhine delta

Different Dutch studies have determined a considerably higher damage potential than what is mentioned above for the Rhine delta. This is due to the fact that, as earlier mentioned, for settlements and the industrial sector indications are limited to direct material damage and do not take into account losses of value added and consequential damages. Furthermore, for the agricultural sector, indications are limited to mean losses of yield leading to considerably lower damage sums. The approach chosen gives too little consideration to the particularities of Dutch agriculture with intensive livestock breeding and large-scale intensive cultures (greenhouses). Due to the high flood depth occurring in the Rhine delta, considerable consequential damages must be reckoned with (destruction of infrastructure, loss of yield during several harvests), damages which, in the rest of the Rhine area, do not occur to the same extent.

6. Annexes

The annexes contain the tables of importance for the comprehension of the atlas. These tables are drawn from the final report of the consortium entitled "General maps of the risks of inundation and of possible damages due to extreme floods of the Rhine – procedure to determine the surfaces at risk of inundation and procedure to determine the assets" – (2001). Upon request, this report is available (in French or German) at the ICPR.

Gauging station	Rhine-km	HQ10	HQ100	HQ200
	km	m³/s	m³/s	m³/s
Maxau	362	4030	4790	5000
Worms	444	4470	5880	6000
Mainz	498	5480	7410	7960
Kaub	546	5680	7530	8090
Koblenz	592	6140	8200	8830
Andernach	614	8740	11730	12700
Bonn	655	8760	11700	12600
Köln	688	8900	12000	12900
Ruhrort	781	9200	12400	13400
Rees	837	9170	12300	13300
Emmerich	852	9100	12200	13100

Recurrence intervals and discharge rates at different monitoring stations

Procedure when drafting the maps of the risk of inundation

The regional water resources management services disposed of the represented flood limits for floods with a recurrence interval of 10 and 100 years in the entire area of consideration.

The flood depths represented for extreme events are results of simple hydraulic modelling. A simplified flood model was used which, based on the given surface level in the river bed at a given point of the river, transfers the flood towards the exterior until the flood limit in the terrain was determined for a stationary level. Obstructions, such as railway embankments and culverts were taken into account as long as they were represented in terrain models. Flood depth is the result of the subtraction of ground level from water surface level.

Along the impounded stretches of the Rhine protected by dikes, breaches were supposed at the most unfavourable point of a dike. This was again done by extrapolating the water level into the terrain, which, as a matter of simplification, corresponds to the assumption that there are no protection dikes and that water levels remain unchanged. In the Netherlands, the reference level at which the entire polder is flooded is given by the lowest dike.

The result of such a procedure is an envelope of many possible scenarios for dike breaches, representing the maximum water level expected for any section at a given stationary final state. This can however only occur in a limited area, as normally the overtopping of dikes or dike breaches have a retention effect and the downstream water level of the Rhine would immediately sink significantly.

Table: basic hydrological data

	Hydrological basis					
Sections of the Rhine	**High Rhine**	**Impounded southern Upper Rhine**	**Northern Upper Rhine protected by dikes**	**Middle Rhine**	**Lower Rhine**	**Rhine delta**
Rhine-km	**0 - 170**	**>170 - 334**	**>334 - 529**	**>529 - 642**	**>642 - 857**	**>857 - 1030**
Country, Länder	Switzerland, Baden-Württemberg	France, Baden-Württemberg	France, Baden-Württemberg, Rhineland-Palatinate, Hesse	Rhineland-Palatinate, Hesse, North Rhine-Westphalia	North Rhine-Westphalia	Netherlands
HQ_{10}	Corresponds to the bankline at a scale 1 : 100 000	Corresponds to the bankline at a scale 1 : 100 000	Corresponds to the bankline at a scale 1 : 100 000 and partly to the line of the summer dikes	Corresponds to the bankline at a scale 1 : 100.000	The major part corresponds to the bankline	Corresponds to the bankline
HQ_{100}	Corresponds to the limit of inundation during the flooding of May 1999	Corresponds to the first line of dikes	Corresponds to the line of winter dikes	Corresponds to the bankline at a scale 1 : 100.000	Corresponds to the line of the main dike	Corresponds to the line of the main dike
HQ_{Extrem}	Determined at one metre above the floods of May 1999, along Lake Untersee at ½ metre above this line	Determined at the surface line measured during the historic flood of 18821	Corresponds to the HQ200 + 0.5 metre surface line; dike failure at the most unfavourable point of a closed system2	Surface line HQ200 + 0.5 metre at a scale 1:100.000, in some places identical with the bankline	Surface line HQ500, failure of dike at the deepest part of a system of dikes (polder)	Surface line HQ1250, dike failure at the deepest part of a system of dikes (polder)

[1] Due to the hydraulic particularities of the impounded section of the Rhine between Basel and Iffezheim, partly with a two-axed system of dikes and a level of protection corresponding to a recurrence interval of 1000 years, scenarios for dike breaches have been chosen in order to determine the inundated surfaces due to $HQ_{EXTREME}$

[2] In Hesse, the island Kühkopf is flooded at HQ_{100}

Table: terrain models used

	Switzerland	France	Baden-Württemberg	Hesse	Rhineland-Palatinate	North Rhine-Westphalia	Netherlands
DHM	DHM25 matrix model	Base de données altimétrique (Bd Alti)	DHM Baden-Württemberg	DHM 40	DGM Rhineland-Palatinate	Terrain model of the study entitled "Po-tential damages due to floods of the Rhine in NRW" made up of individual models based on different basic data. Sometimes, the data bases DGM5 and DGM25 have been completed by terrain models of third parties, by digital contour lines or by models interpolated on the basis of data from canal land registers. The degree of vertical precision varies. Within the model DGM 5, it lies between 2 to 5 m	Digital terrain model and model of inundation of the study entitled "Over-stromingsrisico's Buitendijkse Gebieden" of the Directoraat-General Rijkswaterstaat (1999)
Horizontal definition	25 m	50 m	50 m	40 m	20 m		
Vertical definition	1 m	1 m	1 m	1 dm	dm		
Precision of indications of altitude	Average of 1 to 2 m, about 1.5 m in the Mittelland and 5 to 8 m in the Alps	Average 2.5 m	Between ± 2 to 3 m	Between ± 1 – 3, partly 5 m	Average precision of altitude of 0.5 m and of ± 2 to 5 m in forest areas		
Source	Interpolation based on the national map at a scale 1 : 25.000	Contours of topographic maps at a scale 1:25.000 and an equidistance of 5-40 m	Photogrammetric interpretation of aerial views of the 70s	Photogrammetric interpretation of aerial views	Interpolation based on the general map of Germany at a scale of 1:5 000		
Remarks			Additionally, laser scanner data for the cities of Mannheim and Karlsruhe as well as altitudinal data from DGK5 were added for the area of authority of the Lahr water management office				

Table: specific property assets in the German Länder

Specific property assets in Baden-Württemberg			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	268,- Euro per m²	54,- Euro per m²	322,- Euro per m²
2 Industry	262,- Euro per m²	83,- Euro per m²	345,- Euro per m²
3 Traffic	246,- Euro per m²	2,- Euro per m²	249,- Euro per m²
4 Agriculture			6,- Euro per m²
5 Forestry			2,- Euro per m²
6 Miscellaneous			No value

Specific property assets in Hesse			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	231,- Euro per m²	51,- Euro per m²	282,- Euro per m²
2 Industry	258,- Euro per m²	80,- Euro per m²	338,- Euro per m²
3 Traffic	300,- Euro per m²	3,- Euro per m²	303,- Euro per m²
4 Agriculture			7,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			No value

Specific property assets in Rhineland-Palatinate			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	181,- Euro per m²	41,- Euro per m²	222,- Euro per m²
2 Industry	259,- Euro per m²	81,- Euro per m²	340,- Euro per m²
3 Traffic	143,- Euro per m²	1,- Euro per m²	144,- Euro per m²
4 Agriculture			5,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			No value

Specific property assets in North Rhine-Westphalia			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	231,- Euro per m²	59,- Euro per m²	289,- Euro per m²
2 Industry	231,- Euro per m²	80,- Euro per m²	311,- Euro per m²
3 Traffic	263,- Euro per m²	2,- Euro per m²	265,- Euro per m²
4 Agriculture			9,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			No value

For the agricultural surfaces, the mean annual yield is represented, completed by the share of “public civil engineering” not included in the assets of the CORINE data.

Table: specific property assets in Switzerland, France and the Netherlands

Specific property assets in Switzerland			
Category of use	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	275,- Euro per m²	65,- Euro per m²	340,- Euro per m²
2 Industry	287,- Euro per m²	96,- Euro per m²	383,- Euro per m²
3 Traffic	292,- Euro per m²	3,- Euro per m²	294,- Euro per m²
4 Agriculture			7,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			kein Wert

Specific property assets in France			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	217,- Euro per m²	51,- Euro per m²	268,- Euro per m²
2 Industry	229,- Euro per m²	76,- Euro per m²	305,- Euro per m²
3 Traffic	232,- Euro per m²	2,- Euro per m²	234,- Euro per m²
4 Agriculture			7,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			kein Wert

Specific property assets in the Netherlands			
Category of use:	Value per m² immobile	Value per m³ mobile	Total
1 Settlement	252,- Euro per m²	59,- Euro per m²	311,- Euro per m²
2 Industry	262,- Euro per m²	87,- Euro per m²	350,- Euro per m²
3 Traffic	266,- Euro per m²	2,- Euro per m²	268,- Euro per m²
4 Agriculture			7,- Euro per m²
5 Forestry			1,- Euro per m²
6 Miscellaneous			kein Wert

Table: damage functions

Damage function	Type of function
DF Settlement, immobile	Y = 2x² + 2x
DF Industry, immobile	Y = 2x² + 2x
DF Traffic, immobile	{0..1} Y=10x ab 1 Y=10
DF Economic equipment – ICPR	Y = 11*x + 7,5
DF Settlement equipment	Y = 12 *x + 16,25 {x=1...7}
DF Equipment, public goods	Y = 7 * x + 5
DF Settlement, mobile (35 % economy, 60 % settlement, 5 % public goods)	Y = 11,4 * x + 12,625
DF Industry, mobile	Y = 7 * x + 5
DF Traffic, mobile	{0..1} Y=10x ab 1 Y=10
DF Agriculture	Y = 1
DF Forestry	Y = 1
X = water level in metres	**y = damage degree in %**

The low degree of damage to agricultural surfaces is a result of the great property assets in public civil engineering which is little vulnerable to damage but which is included in this category of use due to its low degree of definition. A value between 0.05 to 1.0 Euro/m² corresponds to the average loss of yield of fields and meadows due to floods.