Submerging vehicles

An account of descriptive and experimental research undertaken for the Minister of Social Affairs and Public Health

Institute for Road Safety Research SWOV

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Report 1973–1 E

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Preface

Some forty years ago, the volume of traffic was very low compared with the present day. Although there are no exact data, it is fair to assume that car-in-water accidents did not often occur.
For the road user of those days who nevertheless was involved in such a accident, the problem of how to escape from his vehicle was just as important as for the motorist of today. In other words, even then there was a need for guiding rules that would offer most scope for escape. But because cars rarely crashed into water and the only guidance came from some personal experience or witnesses' statements, there was no sound basis for clear, objective and unanimous opinions. In the main, there was a lack of analyses on how cars reacted when they crashed into water under various circumstances.
Since car-in-water accidents were less frequent in other countries, there was no initiative there for comprehensive (experimental) research. The pioneering work on this typically 'Dutch' problem would therefore have to be done in this country.
Fire brigades have been most involved in their daily duties in rendering assistance in car-in-water accidents. It was therefore obvious that they would be the first to take steps towards further research. In the 'thirties the first series of tests, about fifty in number, were conducted by the Amsterdam Fire Brigade in co-operation with the Naval Divers Department. The results of these tests, plus practical experience already gained, led to recommendations being drawn up. These were made by the Royal Dutch Life-Saving Association KNBRD and were regarded as correct and effective until 1967.

Experience gained by the Hague Fire Brigade during their diving training in the years 1966 and 1967, however, provided decisive arguments necessitating further study of the problem. It was found, for instance, that cars nearly always sank in vertical position and that partly because of this there could hardly ever be any question of a 'bubble of air that saved the situation'. Consequently, the recommendations that had so far applied did not offer the optimum chances of escaping. Articles in the daily press, especially a report by J. J. Velthuis who, together with the photographer P. de Nijs, attended a number of tests by the Hague Fire Brigade, drew public attention to this subject.
Obviously, great confusion was caused by the public existence of two controversial opinions on the behaviour of cars in water (including whether or not there was an air bubble in a submerged vehicle) and consequently different rules for escaping.

These considerations led in 1968 to instructions being given to the Institute for Road Safety Research SWOV by the then Minister of Social Affairs and Public Health to examine more closely the problems dealt with car-in-water accidents, in order to formulate guiding rules which would give the occupants the best chances of escaping from their vehicle.

As no systematic research had been done previously regarding cars in water, not only organisational problems had to be solved but research facilities also had to be created. In both respects, the SWOV received the assistance of various bodies, to which we should now like to record our thanks.
For the descriptive research, information was made available by the Central Bureau of Statistics in the Netherlands CBS, The Hague, and the Royal Dutch Life-Saving Association KNBRD, Haarlem. Supplementary information was obtained through the co-operation of various divisions of the Municipal and State Police Forces and the Royal Dutch Touring Club ANWB, The Hague. The testing ground for the experimental research and the equipment for guiding the test vehicles were made available in The Hague by the Hague Municipal Power Company, and in Amsterdam by the Department of Docks and Trade Facilities and the Municipal Transport Department. Assistance in the form of providing equipment and specialists was given by the Hague and Amsterdam Fire Brigades. The supplementary work on the testing ground was carried out by the firms of Habold, Zevenhuizen, and Gerritse, Badhoevedorp.
For recording a number of under-water tests, the swimming pool of sports centre 'De Vlieger-

molen', was made available by the Municipal Department of Culture and Recreation, Voorburg. Van Doorne's Automobile Factories N.V., Eindhoven, provided a new Daf station car for these tests. Considerable assistance was obtained from the Holland-Diving team, Amsterdam, and from Mr. G. B. Heuvelman, Utrecht, and Mr. W. C. van Asperen, Hoogkarspel. The filming was done in The Hague by the Central Technical Institute TNO, CTI-TNO, Delft, in Amsterdam by the Foundation Film and Science SFW, Utrecht. The former Institute also undertook the analysis of the high-speed films from which the decelerations occurring in impacts with the water surface were determined. The latter Foundation made a film on the Submerging Vehicles research in close collaboration with the SWOV.
In addition to the compiler of this report, Mr. A. A. Vis, the following members of the SWOV staff worked on the project: Mrs. T. C. Meerkerk-Schoonbrood and Mrs. M. Vis-Bakker and Mr. A. Blokpoel, Mr. A. Lans, Mr. W. H. P. Metselaar and Mr. H. P. Scholtens.

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Introduction

Critical consideration soon shows that too little is in fact known about the behaviour of cars in car-in-water accidents and the best methods of escaping from them. Practical experience (including that of fire brigades) in recent years had moreover cast doubt on the representativeness of the recommendations so far existing, as compared with reality. This was in itself not surprising, as these recommendations were based on the fifty tests mentioned in the Preface, which had gradually become outdated for a number of reasons. The limitations in the recommendations were caused, among other things, by the test procedure. Lowering a car into the water with a crane, as was the case in those tests, completely disregarded the fact that crashing into water is a dynamic event, in which for instance the impact speed may play an important part. Nor has the structural development of cars stood still since the 'thirties. The then existing type, with fairly heavy chassis beams, thick body plating and a high, rounded roof, in which the location of the engine did not very much influence the way of floating or sinking and in which there was indeed a chance of an air bubble being trapped under the roof, has not been made for the past twenty years or more. Modern cars have self-supporting bodies, and light plating and do not have heavy chassis beams. Consequently the location of the engine has much more influence on the way of floating and sinking. Most present-day cars also have flat roofs, with the doors running up to them. The chance of an air bubble remaining in the car is thus much smaller.
All the above differences affected the reliability of the existing recommendations so much that fresh research was justified.

Before going into this research further, a consideration first follows of the facts that (may) play a part in an accident, and hence in a car-in-water accident.
As road accidents are determined multiconditionally and their occurrence is often highly complicated, there is a need for a more detailed sub-division. A generally accepted approach to analysing the factors which (may) play a part in an accident is to sub-divide these factors into those relating to three phases: the pre-crash phase, the crash phase and the post-crash phase. Factors that (may) play a role in the pre-crash phase are regarded as all those that have contributed to the occurrence of the accident. Factors in the crash phase are those of importance in the impact itself (i.e. not in the lead-up to it or in its consequences). In the pre-crash phase they relate to everything that the accident gives rise to.
This sub-division can also be made for the Submerging Vehicles research. The crash can in this case be regarded as the impact with the water surface. This means, for instance, that an impact with another vehicle or with an obstacle near the water's edge which occurred before the car crashed into water (normally a crash factor) is looked upon as being a pre-crash phase factor for present purposes. Escape or rescue from a car in water takes place in the post-crash phase.

The relevant factors in the pre-crash phase comprise the causes of the accident and any preventive measures taken to reducing the number of accidents.
However, no useful purpose is generally served by investigating the causes of each type of accident separately because they often display great similarity with or are the same as those of other types of accidents. Fighting the causes of accidents caused with and by cars crashing into water therefore can hardly occupy an independent place, but will have to be integrated in the totality of measures and efforts conducive to road safety (such as applying or improving road marking, signposting, lighting, crash barriers, etc.).
Also as regards the requisite preventive measures there is great similarity between car-in-water accidents and other types of accidents involving these vehicles (such as central reservations accidents, obstacle accidents). Every open stretch of water (a ditch, canal, etc.) in the immediate vicinity of a road open to traffic can be regarded as a danger zone. The most obvious preventive measure is to shield such danger zones with barriers. Requirements a good barrier should satisfy are contained in the SWOV report on 'Roadside safety structures' (SWOV, 1970-6).

The factors in the post-crash phase viz. the consequences of crashing into water, can however be investigated separately. Such investigations will have to concentrate on the behaviour of cars in water and the possibilities of the occupants have of escaping. In addition, attention will have to be paid to those details of vehicle construction and equipment which may increase the occupants' chances of escape.
The results of these investigations may lead to the formulation of certain guiding rules which will provide motorists involved in car-in-water accidents with the best chances of escaping, and may also result in recommendations for improving some vehicle details.

Summary

Each year in the Netherlands an estimated 1250 to 1500 cars crash into water and about 90 occupants are killed (mostly by drowning). Although this latter figure is only a small percentage compared to the total number of traffic fatalities, the ratio between the number of deaths and the number of accidents is relatively high for this type of accident when compared to that for all other types of road accidents. It is not known whether this might be due (partly) to the fact that a number of these victims were unable to save themselves because they could not swim or were poor swimmers. Nor do we know what percentage drown because they have been injured or knocked unconscious in, say, a prior collision with another vehicle or obstacle or in the impact with the water surface.
And yet, a more detailed investigation of the behaviour of cars in car-in-water accidents and of the chances of escaping from them seemed desirable, especially since a number of bodies had differing opinions on what exactly happened when a car crashed into water and what the best method of escaping was. Not only did this investigation seem desirable, but it even became a necessity when it was found that the current guiding rules conflicted with reality in some respects. The present investigation makes it possible for better-based verdicts to be made as regards the (structural) requirements applying to cars and the best methods of escaping from such vehicles which have crashed into water and/or sunk. The investigation was conducted in two sections, viz. descriptive and experimental research.

The descriptive research provides an answer to the question of whether experimental research is necessary and, if so, how this should be structured and conducted. To this end an analysis was made of all the available data, including those from the Central Bureau of Statistics in the Netherlands CBS and the Royal Dutch Life-Saving Association KNBRD as well as the data from SWOV case studies of a number of fatal accidents and those from an investigation into black spots.
The results of the descriptive are as follows:
1. There are indications that more cars crash into water in winter than in summer.
2. The deaths/accidents ratio is higher at night than during the daytime in this type of accident.
3. A number of places may be regarded as black spots.
4. The installation of crash barriers as a preventive measure will have the optimum positive effect in these cases.
5. It does not appear possible to make use of research conducted abroad.
6. Many occupants are already injured and/or unconscious before the impact with the water, or have been thrown out of the car due to a prior collision with another vehicle or roadside obstacle.
7. The (correct) use of safety belts will presumably lead to a drop in the number of fatalities.
8. The majority of the vehicles crashed into water (about 75%) are passenger cars and it is in this category of vehicle that practically all the fatalities are to be found.
9. By no means all cars land horizontally on their wheels on the surface or end up under water.
10. The most fatalities occur in cars which disappear completely under water and/or end up tipped on one side.
With regard to these results, it must be stated that they are based on data, of which the completeness and reliability is unknown, and on collections of very small numbers.
But conclusions 6, 7, 8, 9 and 10 are suitable working hypotheses for the experimental research which has been proved necessary.

In the experimental research the findings from the descriptive research are checked on in more detail and an investigation is made of the individual effect of a large number of variables on the behaviour of vehicles (cars) which have crashed into water and of the possibilities of escape for the occupants. For this purpose about 50 tests were conducted under very differing conditions and using a collection of vehicle types representative of the Dutch vehicle park.

In the experimental research a differentiation has been made between factors which are of importance in the crash phase (i.e. solely those relating to the impact of the vehicle with the water surface) and the factors in the post-crash phase (including such things as the floating and sinking of the vehicle and the escape of the occupants).
A prime condition for the chance of escaping (or of being rescued) is that the occupants of the vehicle are in any event free from (serious) injury so that they are able to get out of the vehicle. Consequently, the vehicles should not become too much deformed, not even when the car hits the water surface on its roof or side. Most modern vehicles with a 'cage structure'—i.e. a deformable front and back, but a strong and/or rigid cabin—provide sufficient protection, at least if they hit the water in the normal horizontal position. In the case of vehicles that hit the water on their roof or on their sides the deformations, especially those of the roof, are so great that (too) little freedom of movement is left for the occupants.
Wearing a safety belt is essential because of the decelerations which occur, even at low impact speeds.

As regards the possibilities open to the car occupants in the post-crash phase—or in this context the escape phase—the investigation has shown that a number of hitherto held opinions need revising. It is true that, irrespective of the way in which they crash into the water, most vehicles return to an approximate horizontal floating position after the initial plunge. But almost all vehicles then sink in a vertical position, forwards or backwards, according to whether the engine is at the front or the rear. The air escapes from the sinking vehicle via the top part of the cab and via the boot. At the moment that the vehicle came to rest on the bottom (completely under water) an air bubble was hardly ever found.
In contrast to what was sometimes stated previously, one should certainly not wait until the car has sunk before trying to escape. When the car is still afloat—the duration of the floating time may vary, depending on the circumstances, from a few seconds to 2–3 minutes—the best chance of escaping is present, and most vehicles offer the occupants a number of good escape possibilities. These possibilities include the windows, sliding or folding roofs and rear door (if present), provided the latter can be opened from the inside. It was found in tests that it was not possible to open the door during the floating period, even immediately after impact with the water, because of the increasing water pressure on the outside. It may happen that the above means of escape are blocked or not present. One possibility is to shatter the windscreen or the back window or to force them out of their frames. The best chance of success in this case is to press against the corner of a window from the inside using the feet or the shoulder.
In principle, the above escape routes can also be used under water, for instance in those instances where the floating time is short. And on the understanding that it will then also be possible to open the door if this has remained intact. If help is being given from the outside, however, it must be remembered that the chance of successfully shattering a window or pushing one of the windows out of its frame is very small when the car is under water. It is therefore wrong to drive with the doors locked from the inside, as external assistance is practically impossible in such a case.

In the third section of this report (Conclusions, recommendations and discussion), the results and the conclusions based on them are converted into a number of recommendations. These recommendations are sub-divided into three groups: those relating to the (road) situation, those relating to the vehicle and those relating to the behaviour of the occupants.
The widespread distribution of the latter group of recommendations in particular (guides to escape action) is extremely important. Consequently, during the actual investigation, allowance was made for the possibilities offered by the filmed material needed in the research for incorporating these results in an instructive type of film. This film is distributed by the Foundation Film and Science SFW, Hengeveldstraat 29, Utrecht, the Netherlands and is obtainable on request.

1. The descriptive research

1.1. Introduction

In the foreword we explained the reasons that led to this research assignment being given to the Institute for Road Safety Research SWOV. This was to involve systematically structured and scientifically guided experiments. But before we could decide whether such experimental research was needed and what structure this ought to have, we required a preliminary study, in which all the available data on car-in-water accidents were classified, sorted and quantified. These available data can be sub-divided into five categories, viz.:

1. General data on the trend in the number of car-in-water accidents and the occupants killed (Source: Central Bureau of Statistics in the Netherlands CBS).
2. Data on cars crashed into water (Source: Royal Dutch Life-Saving Association KNBRD).
3. Investigation into black spots for car-in-water accidents (Sources: KNBRD, CBS and the police).
4. Case studies on fatal car-in-water accidents (Carried out by the SWOV, in collaboration with the Royal Dutch Touring Club ANWB and various police forces).
5. Experiences abroad.

Unfortunately, these data were mostly not very reliable, did not give enough detail and were sometimes too limited to allow clear-cut conclusions to be drawn. But they did provide a sufficient number of indications which, in the form of working hypotheses, formed the basis for further (experimental) research.

1.2. Trend in the number of car-in-water accidents and the number of occupants killed

Table 1 and Figure 1 show the increase in the number of (serious) road accidents and fatalities, and of the number of car-in-water accidents and the number of occupants killed in such accidents. The figures cover the 1964–1968 period and are related to the increase in traffic density on weekdays over this same period. The CBS data show that the total number of traffic fatalities in this period increased from 2375 to 2907 per year, whereas the number of car occupants killed in car-in-water accidents went up from 37 to 80 per year.
In order to draw conclusions with regard to the assumed high fatality (ratio of the number of fatalities to the number of accidents) involved in car-in-water accidents, we need to have reliable data (in the same order) on the number of accidents. However, the records of single-vehicle accidents, which include most of the car-in-water cases, have never been really complete, because not all the persons involved report such an accident. Moreover, in the remainder of the accidents many cases involving solely material damage and/or (slight) injury have been omitted from the statistics since 1967, because of the restricted accidents registration which was introduced in that year. In view of the relativity of the data, therefore, it would be going too far to give an exact indication of how many times higher the fatality is in car-in-water accidents compared to other types of accident. There are, however, clear indications that the fatality in car-in-water accidents is worse than that in all other traffic accidents. It is not known to what extent this is (partly) due to the fact that a number of these victims were unable to save themselves because they were poor swimmers or non-swimmers. But it may be stated that investigation has revealed that about half the Dutch population are non-swimmers or can hardly swim (SWOV, 1972). Nor do we know exactly what percentage drown because they may have been injured and/or knocked unconscious in a prior collision with another vehicle or obstacle or in the impact with the water surface.

1.3. Data on cars crashed into water

A major step towards a possible reduction in the number of road-users killed in car-in-water

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Total number of road accidents (CBS-6)[1]	177,469	190,280	204,984	231,198	258,621	277,426	304,520	340,570	355,240	388,200
Total number of serious road accidents (CBS-6)[1]					52,289	54,896	57,375	62,290	62,730	66,260
Total number of traffic fatalities (CBS-6)[2]	1,926	1,997	2,082	2,007	2,375	2,479	2,620	2,862	2,907	3,075
Total number of cars crashed into water (KNBRD)					829	794	990	1,031	1,067	
Total number of fatalities in cars crashed into water (KNBRD)					43	62	83	77	95	
Total number of fatalities as a result of drowning in car-in-water accidents (CBS-11)[3]	28	37	36	25	37	56	64	58	80	
Traffic density on main roads (weekdays average, index 1960 = 100) (CBS-6)	100	109	118	128	144	158	173	183	197	211

Table 1. The numbers of cars crashed into water and the fatalities due to such accidents, compared to the total number of (serious) road accidents and the number of fatalities due to these (see also Figure 1).

Notes:

1. The figures for 1966 and later are estimates of the total number of road accidents and the total number of serious road accidents (i.e. those involving fatalities and/or casualties) which would have been registered by the CBS if the accidents registration had not been restricted (Blokpoel et al., 1972).

2. In the CBS traffic statistics (CBS-6) the total number of fatalities in road accidents includes all persons who die within 30 days as a result of injuries suffered in a road accident in the Netherlands.

3. In the CBS health statistics (CBS-11) only Dutch nationals are included (also those killed in accidents abroad).

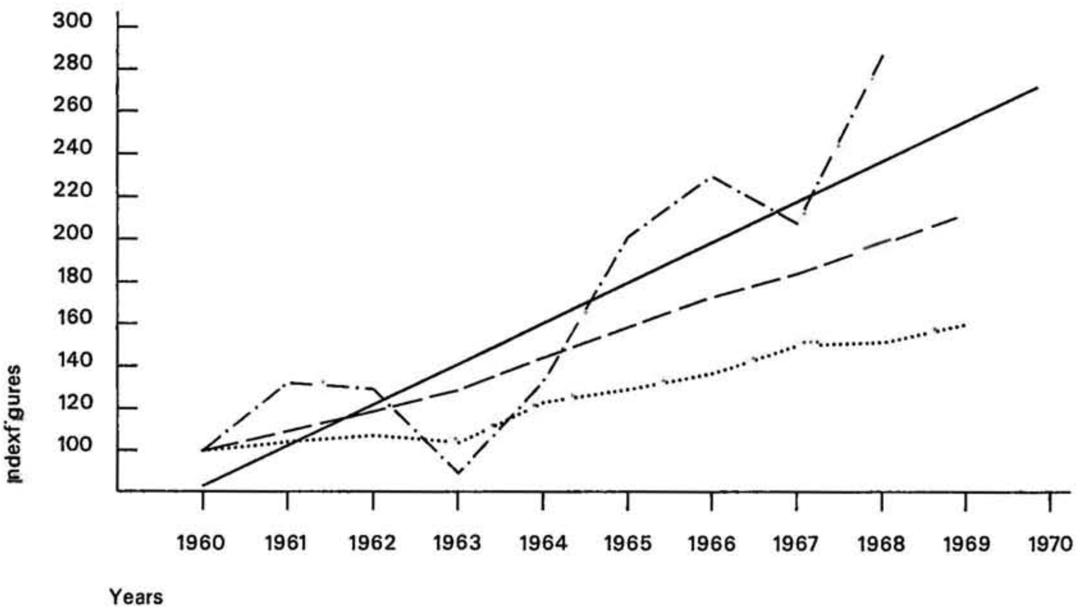


Figure 1. Trend in the total number of traffic fatalities, the number of car occupants killed through drowning and the density of road traffic on main roads in the years 1960–1969 (1960 = 100) (Source: CBS).

— — — = traffic density
.... = traffic fatalities
— · — · — · = drowned car occupants
———— = regression line drowned car occupants

accidents would be gained by learning more about the high (or higher) fatality. The data set out in section 1.2. are not detailed enough for further analysis. The KNBRD data on cars crashed into water for the period 1964–1968 can be used as a basis for forming the following conclusions:

1. The majority (approx. 75%) of the vehicles crashed into water are passenger cars (see Table 2).

2. There is a slight seasonal effect on the number of cars crashing into water (Tables 3, 4 and 5).

3. As can be seen from Tables 6, 7 and 8, there is an obviously demonstrable difference between daytime and nighttime accidents: the fatality is higher at night. The reason for this may be that assistance cannot be given as often and as quickly at night, but it is also possible that it is much easier to get back on to the bank unnoticed at night, which means that the records of the total number of accidents of this type are more incomplete than those of solely the fatal accidents.

4. As regards the position in the water of the crashed cars (completely or partially under water, and resting on the bottom in normal or titled position), there were unfortunately no full details available for the same period. But there are indications that the fatality is higher in those cases where the vehicle disappears completely under water and/or ends up in a tilted position on the bottom; quite a number of deaths also occur in vehicles which end up in a tilted position, but only partially under water. In these latter cases the effect of the local conditions may be an important factor. However, this is difficult to ascertain. Nor can such cases (i.e. cases of shallower water) really be included and interpreted in an experimental investigation.

Vehicle type	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Lorry	159	19	116	15	159	16	133	13	110	10	677	14
Delivery van	54	7	59	7	47	5	88	8	47	4	295	6
Passenger car	600	72	602	76	740	75	810	79	898	84	3650	77
Others/unknown	16	2	17	2	44	4	–	–	12	2	89	3
Total	829	100	794	100	990	100	1031	100	1067	100	4711	100

Table 2. The numbers and the percentages of cars crashed into water in the 1964–1968 period, broken down according to type of vehicle (Source: KNBRD).

Season	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Summer	374	45	322	41	468	47	412	40	499	47	2075	44
Winter	455	55	472	59	522	53	619	60	568	53	2636	56
Total	829	100	794	100	990	100	1031	100	1067	100	4711	100

Table 3. The numbers and the percentages of cars crashed into water in the 1964–1968 period, broken down according to season (summer: April–September; winter: January–March + October–December) (Source: KNBRD).

Season	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Summer	18	47	22	46	38	54	18	32	31	40	127	43
Winter	20	53	26	54	33	46	39	68	47	60	165	57
Total	38	100	48	100	71	100	57	100	78	100	292	100

Table 4. The numbers and the percentages of fatal accidents resulting from cars crashed into water in the 1964–1968 period, broken down according to season (summer: April–September; winter: January–March + October–December) (Source: KNBRD).

Season	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Summer	20	47	30	48	42	51	25	32	45	47	162	45
Winter	23	53	32	52	41	49	52	68	50	53	198	55
Total	43	100	62	100	83	100	77	100	95	100	360	100

Table 5. The numbers and percentages of persons killed in cars crashed into water in the 1964–1968 period, broken down according to season (summer: April–September; winter: January-March + October–December) (Source: KNBRD).

Time	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Day	625	75	632	80	765	77	743	72	787	74	3552	75
Night	204	25	162	20	225	23	288	28	280	26	1159	25
Total	829	100	794	100	990	100	1031	100	1067	100	4711	100

Table 6. The numbers and the percentages of cars crashed into water in the 1964–1968 period, broken down according to the time of day (Source: KNBRD).

Time	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Day	23	61	36	75	52	74	31	54	42	54	184	63
Night	15	39	12	25	19	26	26	46	36	46	108	37
Total	38	100	48	100	71	100	57	100	78	100	292	100

Table 7. The numbers and the percentages of fatal accidents resulting from cars crashed into water in the 1964–1968 period, broken down according to the time of day (Source: KNBRD).

Time	1964		1965		1966		1967		1968		1964–1968	
	number	%	number	%	number	%	number	%	number	%	number	%
Day	28	65	47	76	60	72	38	49	47	51	220	60
Night	15	35	15	24	23	28	39	51	48	49	140	40
Total	43	100	62	100	83	100	77	100	95	100	360	100

Table 8. The numbers and percentages of persons killed in cars crashed into water in the 1964–1968 period, broken down according to the time of day (Source: KNBRD).

1.4. Cars crashed into water analysed according to location (municipality): investigation into black spots for car-in-water accidents

One of the methods that can be used in combatting the causes of road accidents is the black spot study.
Although the original meaning of the term black spot—a concentration of accidents in one specific location—is fairly clear, what one should understand by it precisely is a matter for discussion. For a high absolute number of accidents in one location does not necessarily make that place a black spot in the customary sense of the word. What is needed is a specific comparison criterion, to which that (high) number of accidents can be related. For instance, is a road junction where 50 cars pass per year and five fatal accidents take place a black spot? Or should the term be used rather for a junction where 50,000 cars pass per year and fifty fatal accidents occur? Particularly when the financial resources are not unlimited, the 'yield' factor is extremely important. It may be that the first junction is much more dangerous, but the second one will nevertheless be given priority when reconstruction is carried out.

Table 9 gives an alphabetical list of the municipalities where 15 and more cars crashed into water during the 1964–1968 period (Source: KNBRD); these figures are related to the numbers of registered serious accidents (those with fatalities and/or casualties) in the same munipalities during 1967 (Source: CBS). One useful factor which can indicate the importance of car-in-water accidents as the cause of injury or death in these municipalities is the ratio between the number of serious accidents and the number of cars crashed into water. These figures are given in the third column of the same table. In municipalities where this ratio is high, car-in-water accidents play a subordinate role as causes of injury, and where the ratio is low this type of accident occupies an important position. Further analysis of the car-in-water accidents in this latter category of municipalities may indicate the existence of black spots in these places. A few examples of such municipalities are (see also Figure 2);

1. Anna Paulowna (Noordhollands kanaal)
2. Appingedam (Damsterdiep)
3. Assen (Drentse Hoofdvaart)
4. Assendelft (Ringvaart)
5. Avereest (Dedemsvaart and Reest)
6. Beemster (Ringvaart)
7. Coevorden (Coevorder kanaal and Stieltjes kanaal)
8. Haskerland (Engelenvaart)
9. Heerenveen (Engelenvaart)
10. Lemsterland (Lemsterrijn)
11. Reeuwijk (Dangerous canals with soft verges)
12. Schagen (Noordhollands kanaal)
13. Texel (unknown).

In almost all the places mentioned here a major road runs almost immediately alongside the water. A few examples have been analysed in more detail.

1. Anna Paulowna and 12. Schagen (Noordhollands kanaal)

This canal and National Highway 9 which runs alongside is a striking example of a black spot. Table 10 and Figure 3 give a picture of the fatal accidents and/or cars crashed into water on this National Highway in the period from 1st January, 1968 to 31st March, 1970, between kilometre posts 33 and 70.2 (Source: the police). The installation of a crash barrier as a preventive measure will bring a great increase in safety along this road. Along a few sections of this road and along the roads alongside the Voornse kanaal and the Zuid-Willemsvaart such crash barriers have already been put into position.

5. Avereest (Dedemsvaart and Reest)

According to the available figures, 51 vehicles crashed into the water here in the 1964–1968

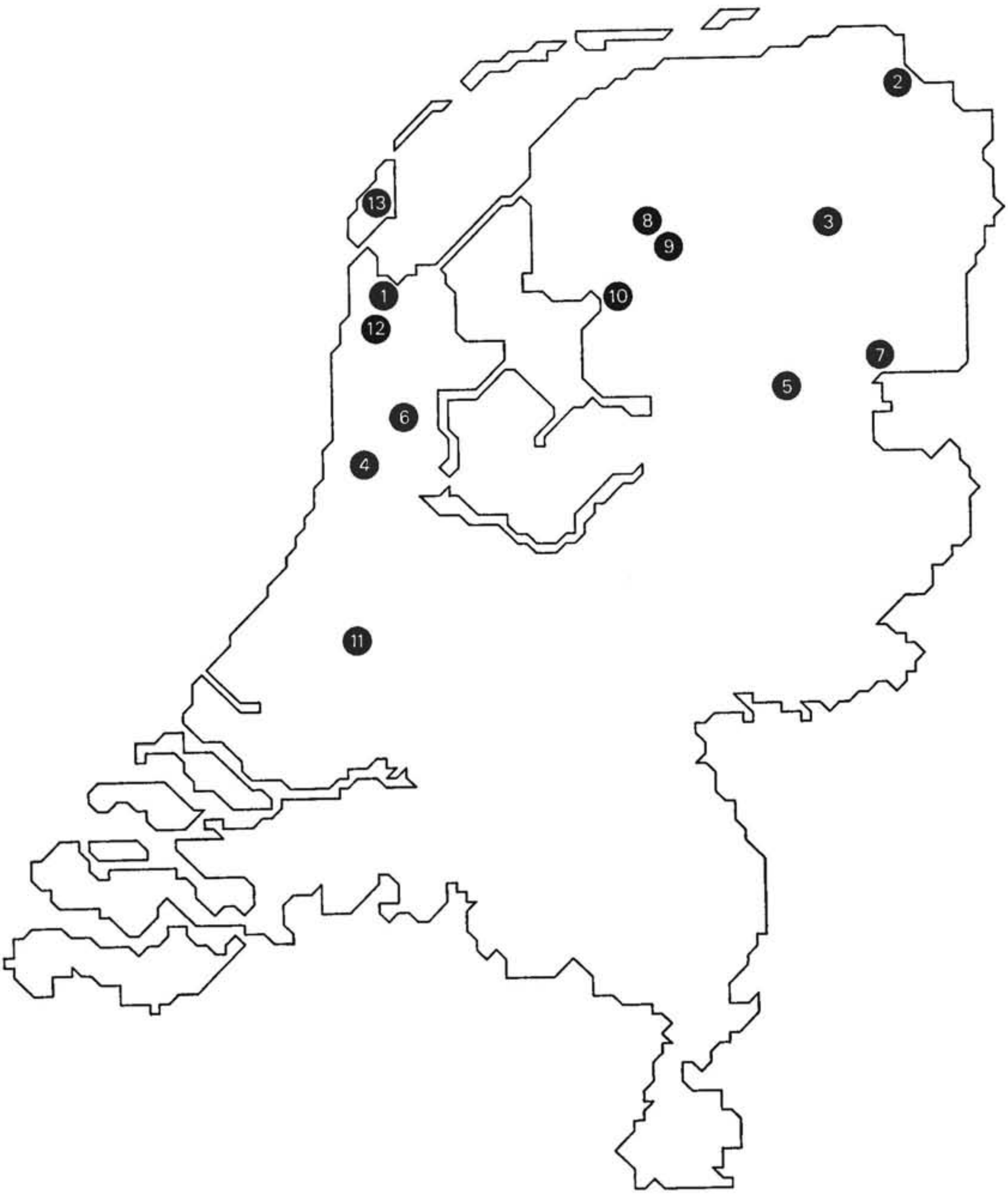


Figure 2. A few examples of possible black spots.

Municipality	Number of cars crashed into water in 1964–1968	Number of serious accidents in 1967	Approximate ratio between serious accidents/cars in water
Alkmaar	46	172	4
Almelo	17	238	14
Alphen a/d Rijn	20	143	7
Amstelveen	21	277	13
Amsterdam	118	5682	48
Anna Paulowna	17	17	1
Appingedam	21	20	1
Assen	16	112	7
Assendelft	16	20	1
Avereest	51	39	<1
Axel	23	38	1.5
Barneveld	26	151	6
Beemster	43	47	1
Breda	22	649	29.5
Coevorden	15	23	1.5
Dantumadeel	15	44	3
Delft	56	364	6.5
Dordrecht	19	355	18.5
Ede	19	374	19.5
Emmen	44	296	7
Enschede	23	434	19
Gorinchem	17	66	4
's-Gravenhage	79	2808	35.5
Groningen	21	645	31
Haarlem	41	853	21
Haskerland	16	28	1.5
Heerenveen	28	41	1.5
Heerhugowaard	25	56	2
Helder Den	72	197	3
Hengelo	23	271	12
Hoogezand/Sappemeer	25	89	3.5
Hoorn	20	54	3
Leeuwarden	43	233	5
Leiden	35	563	16
Leidschendam	32	98	3
Lemsterland	20	19	1
Meppel	20	71	3.5
N.O. Polder	26	130	5
Nijkerk	24	82	3
Onstwedde	32	122	4
Opsterland	28	77	3
Raalte	15	66	4.5
Reeuwijk	15	20	1
Rotterdam	80	3317	41.5
Schagen	25	25	1
Smallingerland	33	130	4
Sneek	15	38	2.5
Texel	40	40	1
Tiel	15	62	4
Tietjerksteradeel	19	65	3.5

Municipality	Number of cars crashed into water in 1964–1968	Number of serious accidents in 1967	Approximate ratio between serious acci- dents/cars in water
Uitgeest	29	44	1.5
Uithoorn	18	65	3.5
Utrecht	56	1978	35
Veendam	17	60	3.5
Velsen	28	372	13
Weststellingwerf	17	91	5
Winschoten	24	74	3
Woerden	29	81	3
Wijmbritseradeel	16	41	2.5
Zuidwolde	16	21	1
Zwolle	17	256	15
Zijpe	16	49	3

Table 9. The numbers of cars crashed into water during the 1964–1968 period, related to the numbers of serious accidents (with fatalities and/or casualties) in 1967, for some municipalities where 15 and more cars crashed into water were registered in the 1964–1968 period (Source: KNBRD and CBS).

period, 11 such accidents taking place in 1967. In 1967 there were 39 serious accidents in the municipality. In 1968 a section of the Dedemsvaart was filled in.

11. Reeuwijk (Dangerous canals with soft verges)

Here, 15 vehicles crashed into the water in the 1964–1968 period, or at least that was the registered number. The local police informed us that by no means all accidents were reported, as often a local garage was contacted directly. In actual fact, the police say, there will easily have been 50 car-in-water accidents over that period.

No.	Date	Municipality	Km-post	Time	Fatalities	Car crashed into water
1	17- 7-68	Schagen	53.4	20.25	1	–
2	4- 8-68	Schagen	44.2	0.40	1	–
3	4- 8-68	Schagen	45.4	16.45	2	x
4	19- 8-68	Bergen	35.8	4.10	1	–
5	28-10-68	Bergen	34.6	0.10	1	–
6	9-11-68	Schoorl	42.2	18.00	2	x
7	27-11-68	Anna Paulowna	60.4	15.45	–	x
8	17- 2-69	Den Helder	66.4	4.30	–	x
9	23- 5-69	Bergen	35.8	15.45	–	x
10	11- 8-69	Schagen	48.0	14.00	–	x
11	17- 8-69	Schoorl	40.2	21.15	1	–
12	5- 9-69	Anna Paulowna	59.8	19.15	–	x
13	3-10-69	Bergen	35.8	14.50	4	–
14	11-10-69	Schagen	50.8	4.30	1	–
15	14-10-69	Schagen	45.4	?	1	x
16	29-10-69	Den Helder	65.0	2.00	1	x
17	22-11-69	Bergen	36.2	2.15	–	x
18	13-12-69	Den Helder	69.2	18.20	4	x
19	1- 1-70	Schoorl	43.0	22.00	–	x
20	1- 1-70	Den Helder	70.2	12.30	–	x
21	10- 1-70	Bergen	36.6	2.00	1	–
22	15- 1-70	Bergen	35.8	8.10	1	x
23	4- 2-70	Den Helder	66.6	8.05	–	x
24	15- 3-70	Bergen	38.2	15.05	4	x

Table 10. Fatal accidents and/or cars crashed into water on National Highway 9 (km-post 33 to km-post 70.2) over the period from 1st January, 1968 to 31st March, 1970 (Source: the police).

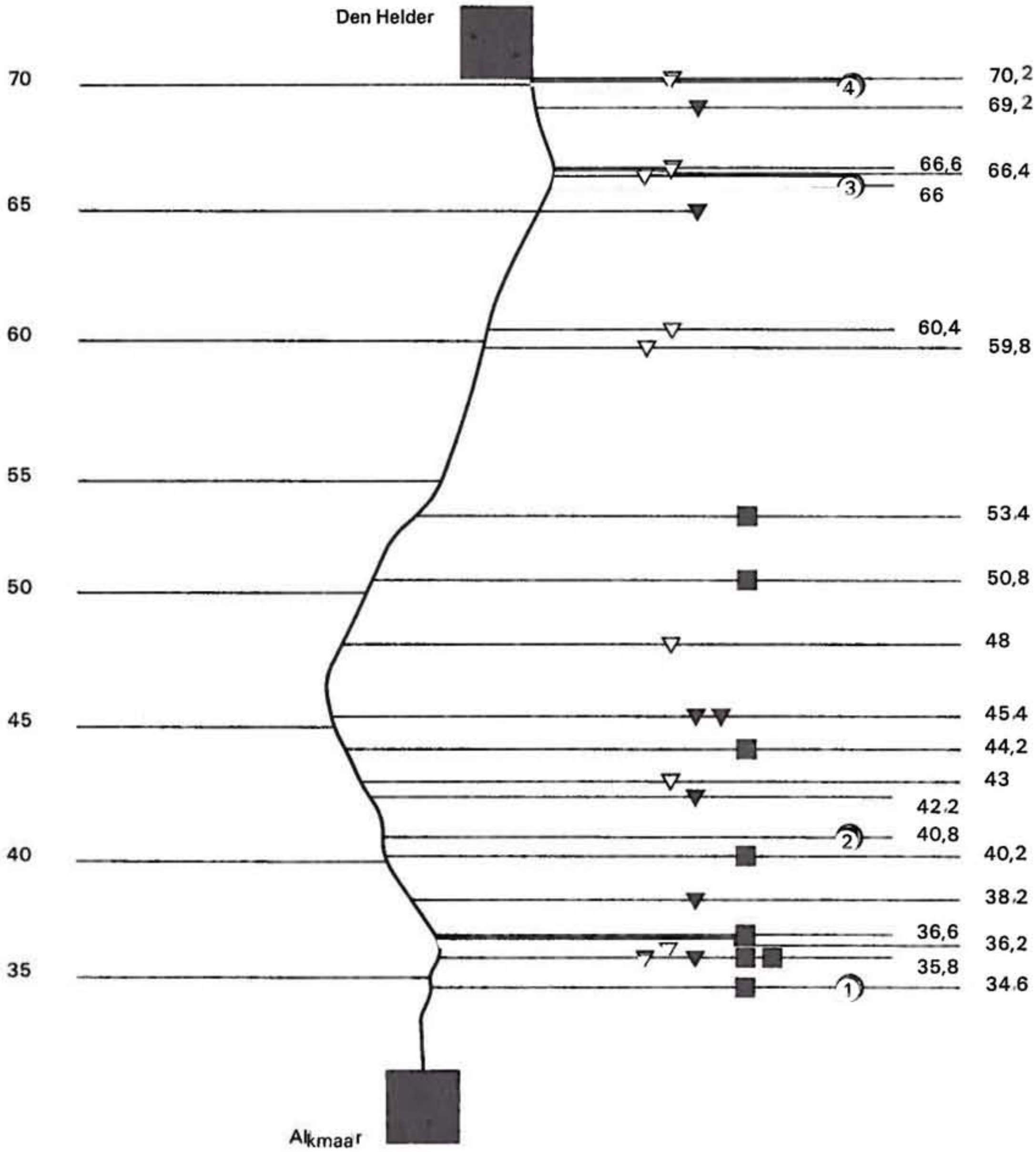


Figure 3. Spread of accidents on National Highway 9 (km-post 33 to km-post 70.2) during the period from 1st January, 1968 to 31st March, 1970 (total 354 accidents) (Source: the police).

▽ = car crashed into water (16 cases)

▼ = fatal accident with car crashed into water (7 cases, a total of 15 fatalities)

■ = other fatal road accidents (8 cases, a total of 11 fatalities)

○ = Concentrations of accidents: 1 = 30 accidents

2 = 25 accidents

3 = 21 accidents

4 = 15 accidents

No.	Date	Municipality	No. of occupants	Thrown out of vehicle	Of whom injured/ unconscious	Of whom killed	Inside vehicle	Of whom injured/ unconscious	Of whom killed	Total no. of fatalities
1	11- 7-67	Muntendam	3	–	–	–	3	2	3	3
2	19- 7-67	Wieringerwaard	4	4	4	1	–	–	–	1
3	27- 8-67	Sexbierum	2	–	–	–	2	–	2	2
4	29- 8-67	Noorddijk	3	1	1	1	2	–	2	3
5	4- 9-67	St. Maartensbrug	3	–	–	–	3	–	3	3
6	25- 9-67	Utrecht	1	–	–	–	1	–	1	1
7	26- 9-67	Oosterhout	1	1	–	1	–	–	–	1
8	29- 9-67	Oldebroek	2	1	1	1	1	–	–	1
9	29- 9-67	Otterleek	1	–	–	–	1	1	1	1
10	5-10-67	Wieringermeer	1	1	1	1	–	–	–	1
11	5-10-67	Winkel	2	1	1	1	1	–	–	1
12	22-10-67	Haarlemmermeer	1	–	–	–	1	–	1	1
13	30-10-67	Diepenheim	1	–	–	–	1	–	1	1
14	1-11-67	The Hague	1	–	–	–	1	–	1	1
15	4-11-67	Vianen	4	–	–	–	4	–	1	1
16	12-11-67	Hellevoetsluis	3	–	–	–	3	1	1	1
17	18-11-67	Vinkeveen	1	–	–	–	1	–	1	1
18	14-12-67	Nw.-Weerdinge	2	–	–	–	2	–	2	2
19	14-12-67	Beerta	2	–	–	–	2	–	1	1
20	16-12-67	Vriezenveen	1	1	–	1	–	–	–	1
21	23-12-67	Breda	2	–	–	–	2	1	1	1
22	27-12-67	Maarssen	1	–	–	–	1	–	1	1
23	28-12-67	Den Helder	1	–	–	–	1	–	1	1
24	31-12-67	Nederweert	3	–	–	–	3	3	3	3
25	31-12-67	Zwiggelte	2	–	–	–	2	–	2	2
26	1- 1-68	Berkel	10	–	–	–	10	–	4	4
27	1- 1-68	Schiedam	3	–	–	–	3	–	3	3
28	3- 1-68	Leiden	3	2	–	2	1	–	–	2
29	8- 1-68	Haarlem	1	–	–	–	1	–	1	1
30	11- 1-68	Amsterdam	3	1	1	1	2	–	–	1
31	16- 1-68	Stadskanaal	2	–	–	–	2	–	1	1
32	21- 1-68	Winschoten	2	–	–	–	2	–	2	2
33	22- 1-68	Vianen	1	–	–	–	1	–	1	1
34	26- 1-68	Maastricht	1	–	–	–	1	1	1	1
35	17- 3-68	Leidschendam	8	8	8	3	1	–	–	3
36	17- 3-68	Nijkerk	1	–	–	–	1	1	1	1
37	26- 3-68	Moerdijk Bridge	1	1	–	1	?	?	?	1

Table 11. Results of case studies relating to fatal accidents resulting from cars crashed into water in the period from July 1967–May 1968.

Safety belts fitted	Prior collision	Speed in km/h	Position on bottom	Water		Bank	
				depth m	width m	height m	width m
	–	90–100	front downwards	2.5	10	2	1
	x	45	normal	1.5	8	2.5	–
	–	high	on roof	3	50	1.5	>10
	x	35	normal	3.5	12	2.5 à 3	–
	x	?	on roof	1.5	20	1	–
	–	20	normal	2	20	2	–
	–	?	front downwards	?	?	2.5	2
	x	high	on side	0.6	2.5	?	2
	x	80–100	on side	1	3	?	1
	x	?	?	1.5	10	4	–
	x	?	on roof	0.4	2.5	1	3
	–	high	?	3	40	1	3
	x	140	front downwards	4	25	1.5	12
	–	35	?	4	>100	2	–
	x	80–90	on roof	1	4	1	5
	–	90	on side	0.4	1	1.5	2
	–	70–80	on roof	1.5	100	1	6
	–	65	normal	3	20	1.5	2
	–	50	on roof	0.6	2.5	2.5	30
	–	?	?	3	30	1	3
	x	30	on roof	2	4	2	–
	–	80	on roof	4	40	2	?
	–	?	?	?	?	?	?
	x	50	normal	3	30	7	10
	–	?	on roof	2	8	2	5
	–	50–60	on roof	1.5	12	0.2	2
	–	35	front downwards	6	40	3	–
	–	10	normal	4	50	?	2
	x	10	normal	?	?	1.5	3
	x	30	on side	2	40	8	10
	x	60	on roof	2.5	20	1.5	1.5
	x	?	on roof	3	?	0.2	1.5
	–	low	front downwards	4	30	1	0.5
	–	low	normal	6	25	?	6
	x	80	normal	0.5	5	0.4	4
	x	100	normal	4	5	?	6
	x	80	?	6	>100	6 à 8	–

		Number	%
Total number of cases analysed		37	
of which in December/January		17	46
prior collision		18	49
safety belts fitted		1	3
Total number of occupants		84	
Total number of fatalities		57	
inside vehicle		43	
of whom injured/unconscious		10	
thrown out of vehicle		14	
of whom injured/unconscious		8	
Total number of casualties (thrown out of vehicle)		9	
Rescued (escaped) from vehicle		18	
Probable impact speed	0–30 km/h	7	19
	30–60 km/h	8	22
	60–90 km/h	7	19
	faster than 90 km/h	7	19
	unknown	8	22
Position under water	front downwards	5	14
	normal	10	27
	on side	4	11
	on roof	12	32
	unknown	6	16
Water depth	below 3 metres	24	65
	3 metres or more	10	27
	unknown	3	8
Water width	below 3 metres	5	14
	3 metres or more	28	75
	unknown	4	11
Height of bank	below 2.5 metres	22	59
	2.5 metres or more	9	25
	unknown	6	16
Width of verge	below 3 metres	11	30
	3 metres or more	14	38
	none	10	27
	unknown	2	5

Table 12. Summary of results of case studies relating to fatal accidents with cars crashed into water in the period from July 1967–May 1968.

1.5. Case studies relating to fatal car-in-water accidents

By a case study we understand as detailed an analysis as possible of an actual accident, in which all possible sources of information are used. In order to trace car-in-water accidents, which could be used for case studies, all the accidents mentioned in Dutch national, regional and local daily newspapers were collected over the period from July 1967–May 1968 (with the aid of the ANWB newspaper extracts service). The results of the fatal accidents selected from these data are given in Tables 11 and 12.
We should make it clear straight away that the following conclusions can only be made under certain reservations, as they are based on only 37 cases.
1. An obvious seasonal influence can be shown to be present. This apparently conflicts with the results of the analysis of the KNBRD data (section 1.3. point 2), where only a slight seasonal influence was found to exist. However, upon closer consideration, we see that the winter of 67/68 contained a relatively high proportion of adverse weather conditions. Moreover, the KNBRD data cover a calendar-year period, which means that the effect of the severe 67/68 winter must be spread over these two years, whereas the influence is reflected even less in the total figures for the years 1964–1968.
2. In the 37 cases analysed there was only one where safety belts were found in the vehicle. A comparison with the results of the SWOV report Safety belts; their fitting-and use (SWOV, 1970-7)—safety belts were fitted in 22% of the cars investigated—was not possible on the basis of the (too limited) data.
3. In 9 cases the occupants were probably already unconscious, either due to the impact of the vehicle hitting the water surface, or due to a prior collision. The police could tell this from the injuries suffered by the occupants.
4. In 11 cases occupants were thrown out of the vehicle. The use of safety belts might have prevented this. To what extent the outcome of these accidents might have been more favourable cannot be predicted with the aid of the available data.
5. In 18 cases there had been a collision with another vehicle or an roadside obstacle prior to crashing into the water. In these cases wearing a safety belt would almost certainly have had a positive effect.
6. In 12 of the 37 cases the vehicle came to rest with its wheels upwards. This finding corresponds approximately with the KNBRD data.
7. The impact speeds were very varied. Since the speeds indicated were estimates, and consequently not too reliable, and since the normal average speeds at the locations of the analysed accidents are unknown, we cannot speak of any speed being 'dangerous'. But we can state that in experimental research the impact speed must be considered as a major variable (variation from 0 to 80 km/h).
8. Lastly, there were also great variations as regards water depth, water width, height of bank and width of verge. Allowance also has to be made for these variables in experimental research.

1.6. Experiences abroad

1.6.1. General

Generally speaking, the number of car-in-water accidents abroad is very low in comparison to the situation in the Netherlands. Consequently, this problem played such a relatively minor role in improving road safety in other countries that no initiatives were taken for setting up more wide-scale research. The activities were limited to a few single experiments, including those of Albrecht Schwieder in Germany (1966) and those of Dennis Österlund in Sweden. These experiments, both with a (moderate) impact speed of about 35 km/h, were intended more as a sort of demonstration. They therefore did not lead to the preparation of effective guiding rules for action, the most they achieved was to make it clear that getting out of a submerged vehicle was a tricky business and that one could not count on an air bubble being present.

1.6.2. American research

Much more attention is warranted by an American investigation in 1961, which was more of a programmed experimental nature. In the report by Bernard J. Kuhn (1962) on this investigation in which the Michigan State Police, the Michigan State Highway Department, the American National Red Cross and the Department of Health and Safety of Indiana University took part, it is stated that in car-in-water accidents about 400 car occupants are killed per year in the United States; this corresponds to approximately 1% of the total road fatalities. (For the Netherlands these figures amounted to 90 and 3% respectively in 1970).

Basic principles of the American investigation

What exactly happens when a vehicle crashes into water?
What is the most critical moment?
Should passengers attempt to escape immediately or should they wait?
At what time can the doors be opened?
Does an air bubble form in all vehicles and under all conditions and can this then be used in the escape?

Procedure of this investigation

The investigation was conducted in the following manner. The test vehicles, a 1961 two-door sedan, a 1961 four-door sedan, a 1954 four-door station car and a 1953 two-door compact car, were driven into the water along a sloping bank, except in those instances where the simulation involved cars landing in the water on their sides or on their roof. In these cases a crane was used. The heights of the bank varied from about 0.5 metres at an impact speed of about 22 km/h to about 1.5 metres at an impact speed of about 26 km/h. Variations in the vehicles were: closed windows, both front windows wound down and left window only open. Variations in position of hitting water were: normal position (on the wheels), on the roof and on the left side. The water was 3.6 metres deep in all tests. All the test vehicles had the engine in the front and closed doors. There were no test persons in the vehicles.

Conclusions from this investigation (brief summary)

1. The height of the bank and the impact speed have an adverse effect on what happens to the vehicle. The higher the bank and the faster the impact speed, the greater the risk of the windscreen shattering and the back seat coming loose. The floating time also drops if the impact speed is faster and the bank higher.
2. The floating time is partly determined by the age and state of maintenance of the car. Older cars, which are usually in poorer condition as well, sink faster than new cars which have been well maintained. The longest floating time observed was 6 min. 3 sec. This was achieved by one of the test cars of the most recent manufacture. This same test car also had the longest period between the impact with the water and coming to rest on the bottom, viz. 8 min. 24 sec.
3. After the impact with the water all vehicles first moved into a horizontal position and stayed afloat like that for some time. Then they all sank in a vertical position with the engine pointed downwards. The exceptions to this were the vehicles which landed on their side or on their roof in the water and had one or more windows open. These did not return to a horizontal floating position, but submerged in almost the same position as they had hit the water surface.
4. In some vehicles the roof was pressed in at the moment that they were three-quarters submerged.
5. The doors could be opened after the pressure had levelled off. In the case of vehicles with closed windows this moment was reached when the water level inside the vehicle had reached its maximum. This coincided approximately with the moment that the vehicle disappeared completely under the surface. In the case of vehicles with one or more windows wound down, the levelling-off of pressure approximately coincided with the moment that

the water surface was level with the edge of the open window. Lastly, it was possible in all cases to open the doors normally when the vehicles had reached the bottom.
6. During the sinking, which almost always occurred vertically, the air in these test vehicles (all with engines at the front) was forced to the back of the cabin and then forced out of the vehicle mostly via the boot. Only sometimes (including in the compact car) did some air return to the cabin after the vehicle had returned to a horizontal position at rest. The quantity and position of this air was determined by the position of the vehicle and the state of repair. The biggest air bubble found in these tests amounted to approx. 180 liters. Twenty per cent, or 36 litres of this was oxygen and, since only two-third of that amount is usable there was in fact only 24 litres available for breathing. Under normal conditions a person uses about 0.4 litres of oxygen per minute. In panic situations or when great efforts are being made, as will often be the case in a submerged vehicle, breathing can become ten times faster. In the biggest air bubble observed, therefore, it would have been possible to keep breathing effectively for 6 minutes. In practice this time will be even shorter, because the air in the cabin is often polluted by oil and petrol fumes.

Recommendations from this investigation

1. Get out of the vehicle which has crashed into water as quickly as possible.
2. Safeguard against injury (say, in the impact with the surface of the water) by using safety belts.
3. Try first of all to get out of the vehicle through the windows, either already open or quickly wound down.
4. If you have no success with the front windows move quickly to the windows in the back doors. These stay longer above the water surface (in cars with front engines) and the air stays a little longer in the back of the cabin.
5. If escape is not possible through the back or front windows, creep as far towards the back of the cabin as possible, for that is where the air stays longest. Try to shatter the back window with a hard, pointed object.
6. If the vehicle landed upside down or on its side in the water, it will usually tipple back into a horizontal position before it starts sinking (provided, of course, the windows and the roof are closed). In this case the same action can be taken as with normal horizontally-landed vehicles. Vehicles with their windows open which land on their roof or side before they sink offer few prospects of escape.
7. An additional chance of escape is offered by a station car with a tailgate but it must be possible to open this from the inside.

Objections to this investigation

1. Static method of letting the vehicle in the water.
2. Limited variation in vehicle types.
3. Limited variation in impact speed and height of bank.
4. No tests with test persons.

Consequently, the recommendations on escape methods are simply hypotheses.

1.6.3. New American research

The Department of Transport in Washington (U.S.) assigned a contract in 1969 to the University of Oklahoma for further research into escape possibilities from vehicles involved in accidents. This research consists of three partial investigations.
1. Investigation into the way in which a crashed 4-persons vehicle can be escaped from as quickly as possible under various conditions.
2. Investigation into the way in which 66 children aged from 0 to 18 years can escape as quickly as possible from a school bus under various conditions (including tipped over at an angle of 90°).

3. Investigation into the way in which people can escape from a 4-persons vehicle in water as quickly as possible, both whilst the vehicle is still afloat and when it is submerged.

The latter partial investigation is led by Dr. J. L. Purswell of the College of Engineering, University of Oklahoma, who contacted the SWOV whilst the Dutch research was still in progress. One of the results of this contact was that the provisional data from the Dutch research formed the basis for the starting points of the US research project.
Since this American research will be directed mainly at the typical car types on US roads, the results may be useful as a supplement to, and a comparison with the Dutch research, because in our research the emphasis is on the cars on Dutch roads, amongst which there are a relatively small number of American-made cars.
When the Dutch research was completed and the report had been drawn up, however, the results of the American research were still not available.

1.7. Conclusions from the descriptive research

1. The accidents records of cars crashed into water are far from complete.
2. The numbers to which the case studies are related are small, and sometimes too small to yield clear-cut conclusions.
3. Despite the above limitations, the impression was gained that the fatality of car-in-water accidents is higher than that in the total number of road accidents.
4. The majority of vehicles crashed into water are passenger cars (approx. 75%).
5. Weather conditions (determined by such things as the season) have an influence on the numbers of car-in-water accidents.
6. The fatality of car-in-water accidents is higher at night than in the daytime.
7. Chances of escape may be minimised before impact with the water due to a prior collision, in which the occupants may have been injured, knocked unconscious or even thrown out of the vehicle. The wearing of safety belts would have a favourable effect on this.
8. The analysis of the available accident data led to the discovery of a number of black spots. The installation of crash barriers has already reduced this number of black spots.
9. The impact speed appears to be extremely varied in practice (between walking-space and faster than 100 km/h). The consequence of this for experimental research is that the impact speed also has to be incorporated as a variable in the test programme.
10. There have been practically no initiatives taken to set up comprehensive research abroad. Only in the United States has an investigation been conducted, being more than a demonstration. This investigation showed that the bank height, impact speed, model of car and the state of maintenance of the car are of influence on the floating time of a car that has crashed into water. These findings underline the fact that the above factors have to be incorporated as variables in any experimental research.

2. The experimental research

2.1. Introduction

The descriptive research was not found sufficient to achieve the ultimate aim of the research project. For this aim was to draw up reality-based guiding rules for car drivers and to formulate recommendations with regard to the improvement of some vehicle details. It was therefore decided to conduct the experimental research.
In order to set up such research the minimum requirement is a knowledge of what factors may play an important part. The descriptive research provided us with a number of conclusions which could be used as working hypotheses. The factors have been sub-divided according to their relevance for the pre-crash, crash and post-crash phases. They are shown in Table 13, also differentiated according to conditions, vehicle and occupants. They formed the basis for the formulation of the test programme.

2.2. The problems set

The wisest approach is, of course, to tackle the problem of cars crashing into water in the first (pre-crash) phase (prevention). Because of policy and economic considerations, however, complete prevention is often unattainable.
A second step is to regard the conditions prevailing in the pre-crash phase as initial conditions in the crash phase. In the case of cars crashing into water, the relevant factors in the crash phase are those relating to the impact with the water surface. The analysis of the impact has to show how the vehicle and the occupants react and in what ways the consequences of the impact can be lessened in their severity. If this analysis provides some clarification on the behaviour of the vehicle and occupants during the impact and if the conditions which guarantee that the impact is survived without injury are also known, then what is called for is the investigation of the third phase, the post-crash phase. For in car-in-water accidents it is not only important that the occupants survive the impact uninjured, but that they can also get out of the (sinking) vehicle. Especially the third phase, the escape phase, will have to be concentrated on in the experimental research.

The experimental research will therefore have to provide indications on how to survive the impact uninjured as well as recommendations on the most efficient methods of escaping from a vehicle in the water.
The first category of indications will in the main be related to the vehicle and are thus mostly intended for car designers and manufacturers, but the second category of recommendations will relate almost exclusively to the behaviour of the occupants and the way in which they can make use of the various possibilities offered by every vehicle.

2.3. Description of the tests

A complete summary of the dynamic water-crash tests is given in the Appendix. Tests 1–13 took place on the site of the former gasworks along the Trekvliet in The Hague (for diagram of the lay-out see Figure 4), whereas the remaining tests (15–45) took place at the Sumatrakade on the River IJ in Amsterdam (see diagram in Figure 5). On the first site the tests were conducted with a fairly low bank (under 2 m) and a water depth of 2–4 m, and at the latter site the bank was higher (2–4 metres), whilst the water depth was 7–10 metres.
The test vehicles were driven using winching gear, the power for which was supplied by a passenger car (U.S. model) with automatic gears (Figure 6). The winching cable was passed round a pulley (Figure 7) and attached to the test vehicle. The vehicles were guided by rails. The angle of impact was varied by using different tracks.
The impact speed was measured on the speedometer of the car driving the winching gear.

Conditions	Vehicle	Driver/occupants
PRE-CRASH		
Collision with another vehicle (or obstacle)	Damaged in prior collision	Dead, injured or unconscious due to prior collision
Prevention factors	**Prevention factors**	**Prevention factor**
Crash barriers (presence and quality) Obstacles (presence and quality)	Construction of cabin (cage structure, reinforced roof) Construction of interior (impact-absorbing steering column, flush or flexible door handles and control knobs, impact absorbing dashboard covering) Proper safety belts fitted	Correct use of safety belts
CRASH		
Speed of vehicle on hitting water (dependent on impact speed, verge width and height of bank) Position of vehicle (normal, nose or tail downwards and/or tilted, dependent upon angle of impact, impact speed, height of bank and prior collision) Water depth (if shallow: impact with the bottom)	Deformation of vehicle (including windows, roof, doors)	Dead, injured or unconscious and/or thrown out of vehicle due to impact with water surface
	Prevention factors	**Prevention factor**
	Construction of cabin (cage structure, reinforced roof) Construction of interior (impact-absorbing steering column, flush or flexible door handles and control knobs, impact-absorbing dashboard covering) Proper safety belts fitted	Correct use of safety belts
POST-CRASH		
Depth of water Width of water Temperature and pollution of water Position of vehicle on bottom (normal, on roof, on side) Escape methods (presence and quality)	Weight distribution (including engine position, load) Floating capacity (deformation, state of maintenance, weight/volume ratio)	Injured or unconscious Trapped Panic (e.g. several occupants, non-swimmers)
	Prevention factors	**Prevention factors**
	Vehicle construction (size of windows, sliding or folding roof, presence of tailgate, type of windscreen) Uniform safety belt closure No loose seats, cushions etc. in cabin	Knowledge of escape routes Able to swim Doors are not locked

Table 13. Summary of factors which may be of influence in car-in-water crashes and are of importance for research; classified according to phase (pre-crash, crash and post-crash), conditions, vehicle and driver/occupants.

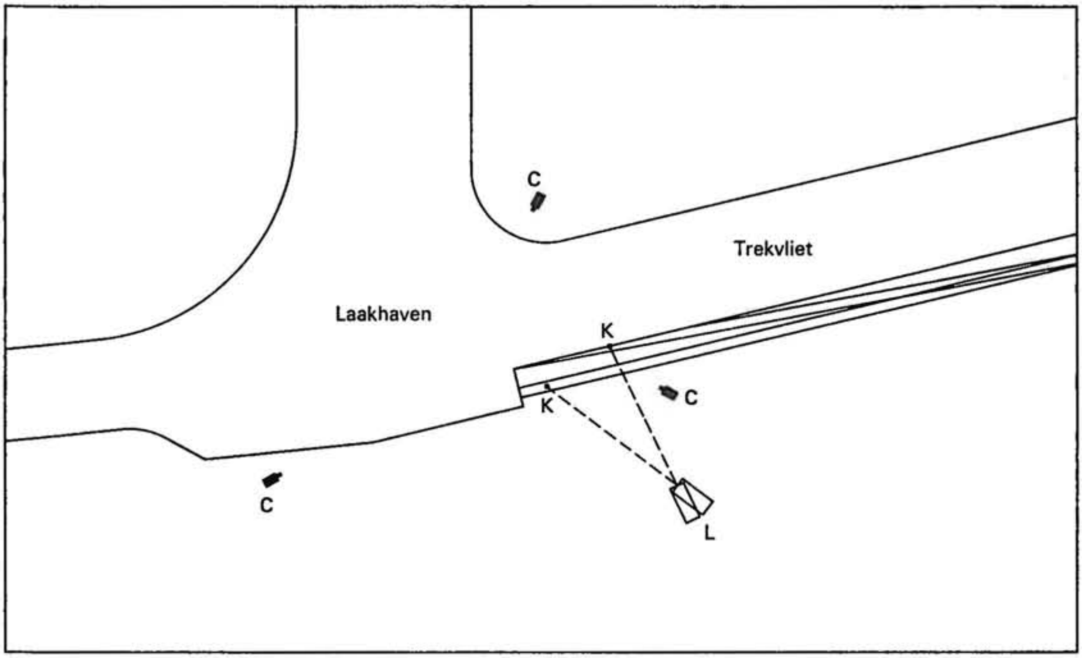


Figure 4 · Diagram of test site in The Hague. L = winching gear; K = pulley; C = camera ·

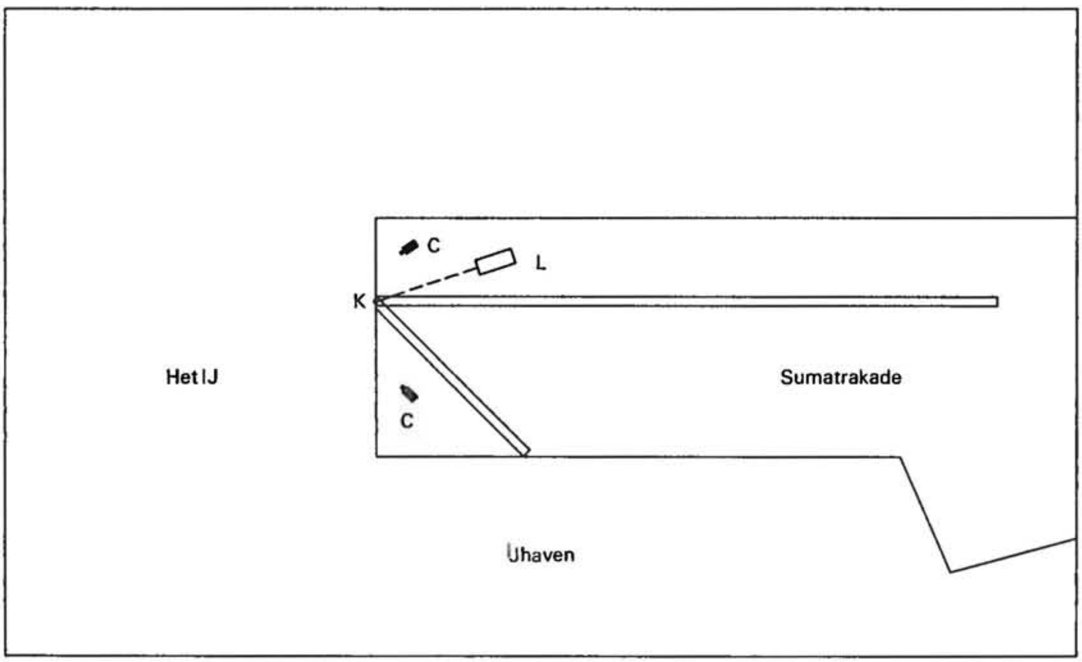


Figure 5 · Diagram of test site in Amsterdam · L = winching gear; K = pulley ; C = Camera ·

In a number of tests this speed measurement was checked with the aid of radar equipment. The test vehicles were marked with lines (in a few cases light points) to enable the decelerations to be determined from the films of the tests. In order to record the behaviour of the car and its occupants under water a special camera was mounted in a few tests.
After every test the vehicle was hoisted out of the water and on to the bank by the fire brigades of either The Hague or Amsterdam. An inspection of the car body supplied us with information on the effects of the impact and on possible improvements to the various parts and structures of the vehicle.
All possible methods of escaping from a vehicle crashed into water were tried out under realistic conditions by test persons (mostly fire brigade divers). Unfortunately, the conditions were such (including polluted water) that it was scarcely possible to obtain acceptable film material of these escape methods. Since the films were considered necessary for studying the escape methods, the process was repeated in a swimming pool.

Apart from the (dynamic) impact tests, a few test vehicles were also lowered slowly in normal position into the water using a crane.
The sole aim of these tests was to ascertain how big the chance is of an air bubble remaining behind in a submerged vehicle. The lack of an air bubble of reasonable size in a vehicle which had been sunk under such optimum conditions (slowly and horizontally) would be good evidence that the chance of an air bubble being found in a car which had crashed into water under more realistic impact conditions was practically non-existent.
These static tests made it possible for us to use a simple method of recording the pressure (build-up) in the cabin as the vehicle sank. For this purpose a flexible pipe was passed through the roof of the car into the cabin (immediately under the roof). The other end of this pipe was attached to an open manometer (above water).
For the sake of convenience, these tests are referred to as 'static pressure measurements'. The word 'static', however, refers solely to the method of lowering the vehicle into the water, and does not refer to the way in which it sank. This latter action remains a dynamic occurrence until the vehicle comes to rest on the bottom.
The water depth was 3.5 m at the place where the pressure measurements were made.

2.4. Limitations of the experimental research

On the basis of the results of the discriptive research and because of practical considerations, the experimental research was subjected to a number of limitations.
1. The only test vehicles used were passenger cars and light delivery vans, because about 75% of vehicles crashing into water are passenger cars. Buses were not included in the test programme as it is very seldom that a bus crashes into water in the Netherlands. Nor is it often that lorries crash into water. In any event the load of lorries will be the main factor affecting their behaviour in the water.
2. In drawing up the test programme and choosing the test vehicles, we took into account the composition of the Dutch vehicle park. For reasons of economy, however, we made an exception for the vehicle age in this respect. The age of the test vehicles was therefore a few years higher than that of the average vehicles on Dutch roads. This was not thought to be a great drawback, since checks had shown that the use of older vehicles only had a slight influence (shorter floating time). But the test vehicles did have to meet certain requirements as regards their state of maintenance (for instance, not rusted through, windows working properly) and their fittings (for instance, an open roof).
3. Because of practical and economic considerations, the number of tests had to be limited, despite the large number of variables.
4. It was not feasible in practice to incorporate in the experimental research all the variables which may play a part when a vehicle crashes into water. Only those variables which, on the basis of the descriptive research, could be assumed to have a major influence on the seriousness of the outcome of the accident were included in the test programme. For instance, we did not include case involving shallow water or a very narrow ditch. Although such cases are

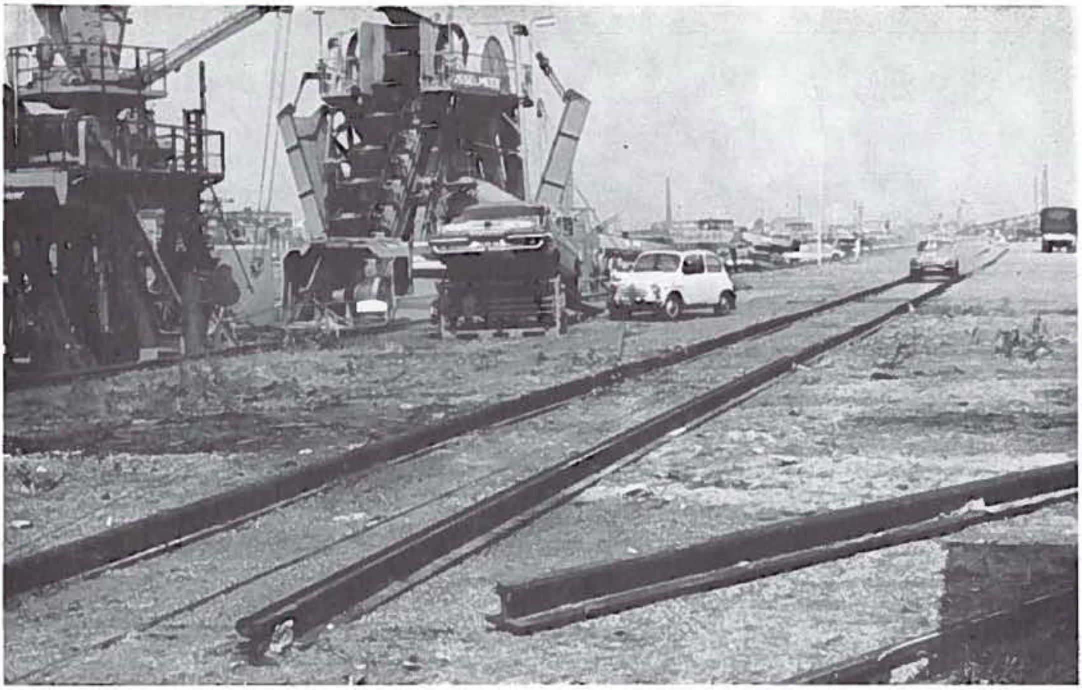


Figure 6. The test vehicles were driven with the aid of winching gear and were guided by rails.

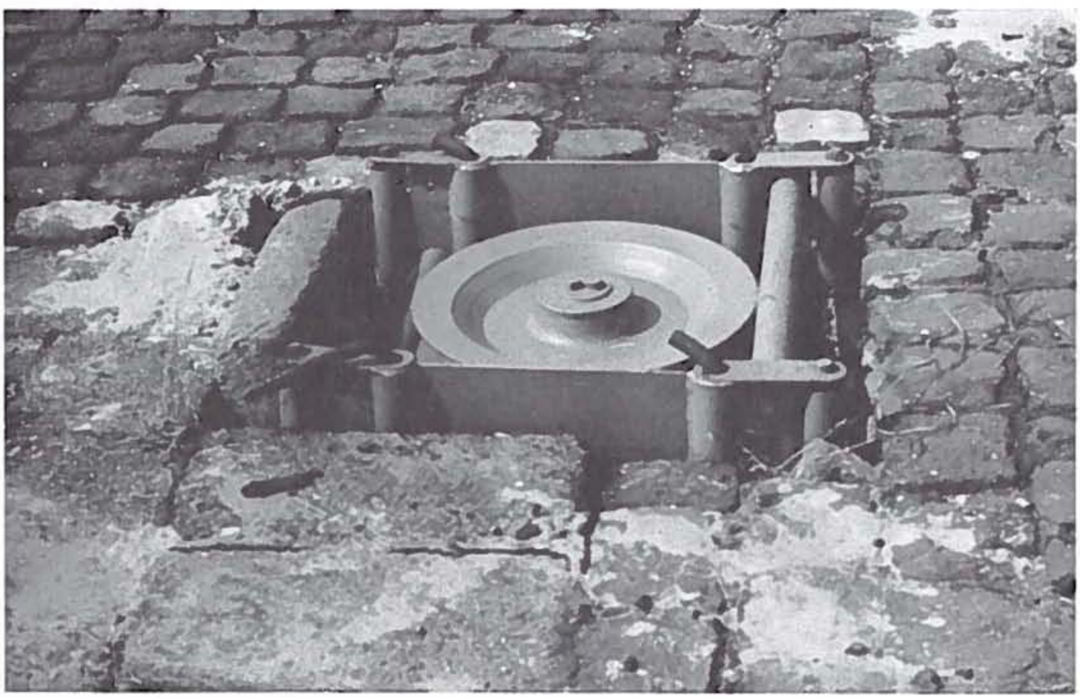


Figure 7. The winch cable was passed round a pulley and attached to the test vehicle.

known to occur quite frequently in practice, their exclusion from the test programme was thought justified due to the fact that the influence of local conditions is very great in such cases, whilst simulating such conditions in the tests could not be realised in practcie. Moreover, fatalities in such accidents are not so high.

5. The angle of impact was the first variable to be classified as of importance. In a number of tests prior to the actual research, however, it was found that the angle of impact (in this case, the angle between the rail track and the edge of the bank) influenced the manner (and thus the outcome) of the crash into the water only when the car was driven at very low speeds. Consequently, it was possible to restrict the number of tests with different angles of impact.

6. In view of the risk for the occupants it was not thought wise to make tests with test persons at impact speeds of more than 35 km/h. But, so that we could still get an impression of what movements an occupant would make in the vehicle interior at high impact speeds and what injuries he might sustain in impacts with the vehicle interior when the vehicle hits the water surface, we made use of (anthropomorphic) dummies in this cases including the test-dummy Olivier of the Research Institute for Road Vehicles TNO (IW-TNO, previously RAI–TNO). Dummies were also used to ascertain whether the use of safety belts would reduce the seriousness of injuries suffered by car occupants involved in car-in-water accidents.

7. Nor were the test persons representative of the normal occupants of cars to be found on the roads (there were no women, children or old people among them). But, in order to gain an impression of the possibilities of various escape methods, we instructed the test persons to carry out the escape at extra low speed, avoiding as much as possible making use of their special professional experience and training in underwater conditions. Moreover, the diving gear that they usually took with them in case of emergencies formed an additional handicap. Although we attempted in this way to get as close to reality as possible, it was of course not possible for us to simulate panic situations.

8. The season and, closely related to that, the water temperature might also have influenced the occupants' chances of escape. Because of practical considerations, however, we did not make tests under wintery conditions (for instance, because of the risks for the test persons).

2.5. Results

As was stated in section 2.2., the experimental research is related almost exclusively to the factors which may be of influence in the crash and the post-crash phases. Although some factors have an influence on both periods, the results have, where possible, been specified one by one according to this phase sub-division.

2.5.1. Results with regard to the crash phase

1. The speed at which a vehicle hits the water depends a great deal on the speed it is travelling immediately prior to the crash. At high impact speeds bigger deformations occur than at lower speeds. Most test vehicles were, and certainly at impact speeds of above 50 km/h, fairly badly damaged at the front (see Appendix and Figures 8 and 9). Due to the impact with the water surface, the wings, aprons, radiator grilles and bonnets were dented, front bumpers were sometimes ripped off and a few times the front suspension assembly was buckled. The damage is usually comparable to what would have been sustained in a moderately severe head-on collision.

2. The position of the vehicle immediately before impact with the water greatly influences the subsequent events. Here, the following aspects can play a part: the angle of impact, the impact speed, the height of the bank and the possible occurrence of a prior collision with another vehicle or with obstacles (Figures 10 and 11).

Whereas the cabins of most cars normally remain intact when they crash into the water in the normal position (i.e. horizontally with the wheels downwards), the situation is completely different if, due to certain circumstances, the vehicles hit the water on its side (Figure 12) or on its roof (Figure 13). In the first case, the side of the car can be pressed in to such an extent that the doors on that side cannot be opened (see Figure 14). In the second case the roof

Figure 8 and 9 · Bonnet and boot can be deformed, provided the cabin remains intact.

Figure 9·

may be pushed inwards – by as much as 40 cm, as was found in one of the test vehicles (Figure 15). It was also found in the tests that if a car with a closed sliding roof landed upside down on the water this roof was often so badly damaged that it could not be opened, or only with difficulty.
Note: It is important for the severity of the outcome of an accident that the deformations mentioned under 1 and 2 above should remain within certain limits. In any event the vehicle must be so constructed that the cabin does not deform too much and the doors can still be opened even after the impact with the water surface. Vehicles with a 'cage' construction, in which the front and the rear are able to deform whilst absorbing the impact energy, but the cabin itself remains intact, provide sufficient protection in this respect.
Almost all the vehicles used in the tests met with this structural requirement; apart from two cases, the doors could always be opened after the impact with the water surface.
3. The deformations observed indicated that any occupants would very probably have been exposed to considerable decelerations. Analyses based on high-speed films showed that values of 40–50 m/s^2 were reached for a few tenths of seconds, even at fairly low impact speeds. These decelerations, which are many times higher than the value of about 8 m/s^2 reached in an emergency stop on a dry road surface, will throw the passengers forward violently. If this causes the passengers to bang their heads on the dashboards and/or through the windscreen (Figure 16), then they face a higher risk of injury.
Note: It is quite clear that occupants who are thrown forward in the car cabin by the decelerations which occur and are injured and/or knocked unconscious in the process will have worse chances of escaping.
Wearing safety belts will in most cases be sufficient to protect against (serious) injury. Moreover, the belts keep the occupants better in their place so that at the start of the escape phase they will be able to find their way about better and will therefore have better chances. There is much in favour of safety belts having a uniform type of fastening, which can also be undone easily when the material is wet. It must also be a fastening which is simple for others to open.
4. If the crash phase is to be survived uninjured, it is also essential that there are no projecting parts in the cabin. The presence of such things as an impact-absorbing steering column and flush of flexible door handles can reduce the risk of (serious) injury.

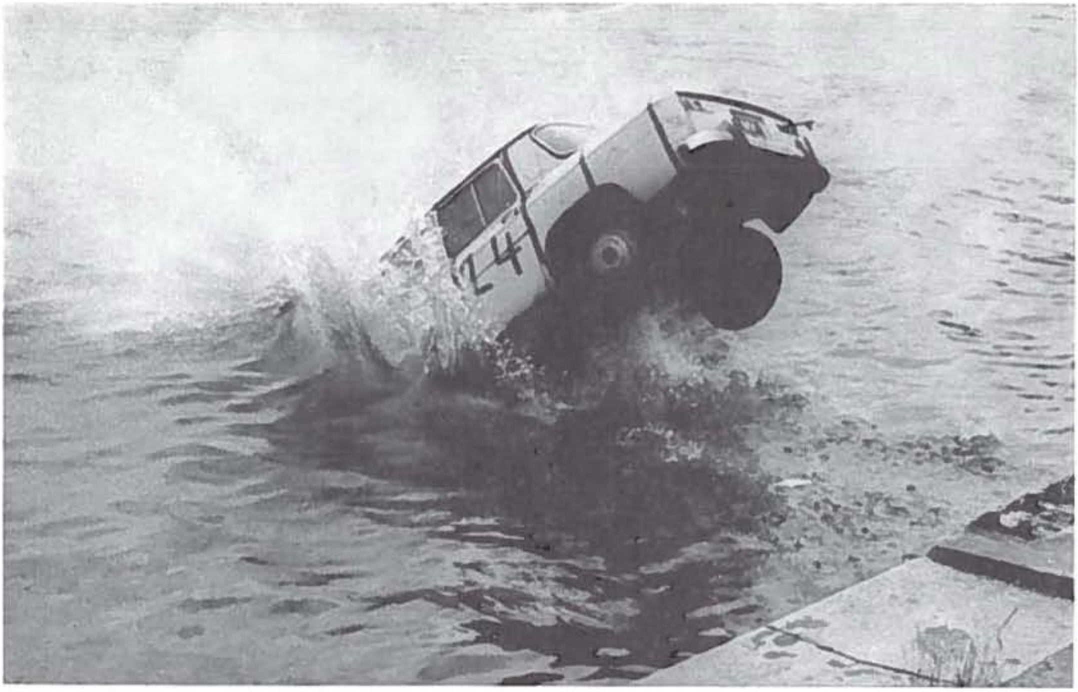


Figure 10. Even at an impact speed of about 25 km/h a deceleration of as much as 30–40 m/s^2 was achieved if the bank was high.

Figure 11. Often the vehicle collides with an obstacle just before crashing into the water; this may cause it to hit the water in strange positions.

Figure 12. Not all vehicles land normally on their wheels.

Figure 13 - It is quite possible for a vehicle to hit the water on its roof, say, because of a prior skid.

Figure 14. The result of hitting the water sideways: all the doors are jammed on the impact side.

Figure 15. The cabin was badly pressed in because the vehicle landed on its roof.

Figure 16. If the occupants are not wearing safety belts they greatly reduce their chances of survival.

2.5.2. Results with regard to the post-crash phase

As regards the vehicle

1. Irrespective of the way they hit the water, almost all the test vehicles after the impact with the water surface first returned to a more or less horizontal floating position (usually tilting slightly towards the engine). Even if the vehicle hit the water on its roof, the normal position was returned to in most cases (see Figures 17 and 18, different stages in the same test).
Exceptions to this rule were those vehicles fitted with a canvas roof which landed on this roof and those vehicles with a shattered windscreen which hit the water surface at a fairly steep angle. Such vehicles sank so quickly that there was hardly any floating time worth mentioning.
2. The floating times of the test vehicles varied from a few seconds to two to three minutes (see Appendix).
From an analysis of the relevant data it was found that the floating time is shortened by bad deformations to the vehicle, open side windows, shattered windscreens, the bad conditions of the bodywork on the underside and partly by a higher bank as well (a decrease of the floating time to one quarter of what it would have been under more favourable conditions is possible). Also a vehicle landing on its roof, which is open, has a greatly reduced floating time.
A comparison of the floating times of some types of passenger cars at approximately the same impact speed shows that the floating time increases in proportion to the increasing weight of the model of car. The number of impact tests was, however, too small to regard this as more than an indication. The longer floating time of the heavier models is attributable in part to their greater resistance to deformations during the impact, which means that the water will flow into the vehicle more slowly.
The main factor determining the duration of the floating time is the inflow rate of the water

Figures 17 and 18. Most vehicles which hit the water upside down return first to an almost horizontal position before they sink.

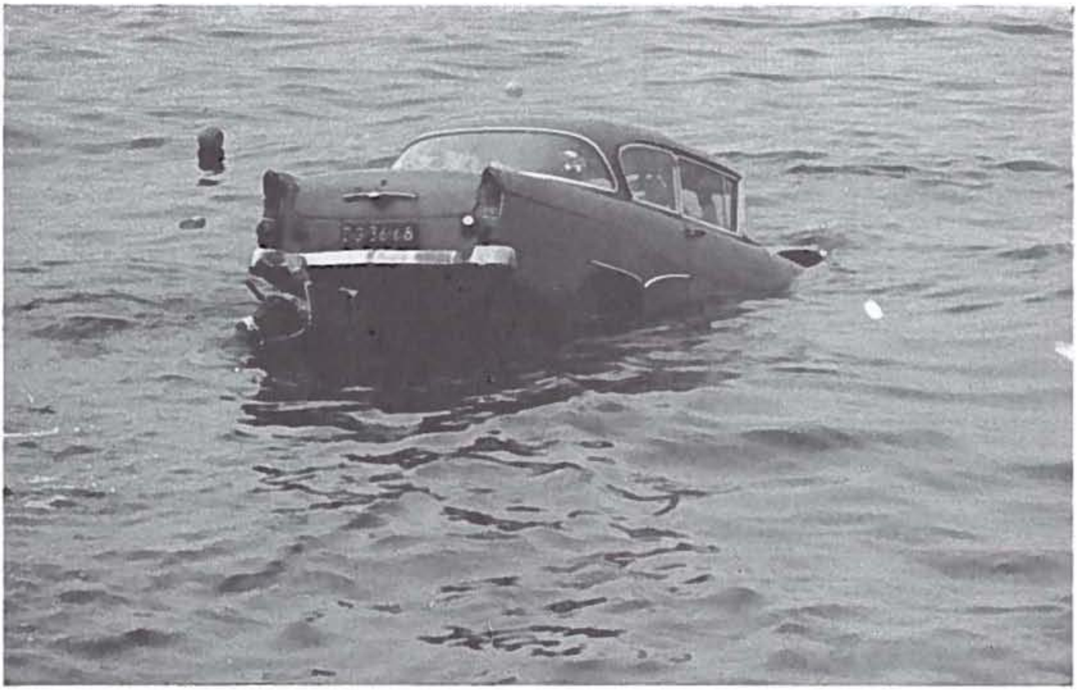


Figure 18.

and not the displacement possibilities for the air. Furthermore, the weight/volume ratio can also influence the floating behaviour. The position of the engine does not have any apparent effect on the floating time.
3. Almost all vehicles then sank in a vertical position with the engine pointed downwards (Figure 19 and 20).
4. As the vehicles sank the air was first forced to the highest part of the cabin (Figure 21). In vehicles with front engines, the air moved into the space near the back seat, and in rear-engined vehicles towards the space near the front seat.
In all vehicles almost all this air escaped during the further sinking process through the boot as well as via all sorts of openings in the car's bodywork (including the ventilation slits present in quite a number of modern vehicles, the door frames which are never really airtight, gaps between the boot lid, holes for pedals and wires, holes in the underside, etc.). Only for a very short time, therefore, is there any question of a (quickly dwindling) amount of air in part of the cabin. At the moment that the vehicle came to rest on the bottom an air bubble was found in almost none of the test vehicles (Figure 22). An exception to this may be formed by vehicles which, due to the conditions, do not sink vertically (for example, in shallow water). But even under such 'ideal' conditions, which seldom occur in reality, the water rose in statically and horizontally submerged vehicles to a few centimetres below the roof. After some more time had passed, even these small quantities of air had disappeared as well.
5. In the static pressure measurements it was found that both test vehicles (Daffodils) were totally submerged after about 1.5 minutes. The maximum excess pressure compared to atmospheric pressure was about 240 mm water pressure (see Figures 23 and 24). Since the roof of the vehicle was about 200 cm under the water surface, the said excess pressure was only a fraction of the water pressure on the outside of the roof (2000 mm water pressure). As soon as the water level in the submerged vehicle had reached the opening of the flexible pipe leading to the manometer, further measurement using the described method was impossible (due to capillary phenomena). Since the slight pressure build-up in the cabin does not take place until the vehicle has disappeared under water, it has no noticeable effect on the floating time and the manner of sinking.
6. In a few cases it was found that the roof of the test vehicle had been pressed in even when the vehicle had not hit the water on its roof. By means of a film analysis we investigated as accurately as possible the exact moment when this denting occurred. It was found that this took place at about the time the car disappeared under water. The denting of the roof was only found in car models with a fairly wide, flat roof without reinforcing ribs, and only took place if there was still quite a lot of air in the vehicle at the moment it sank and if the windows were closed.
Note: In practice, therefore, open windows will usually prevent this frightening side-effect from occurring.

As regards the occupants and the escape methods

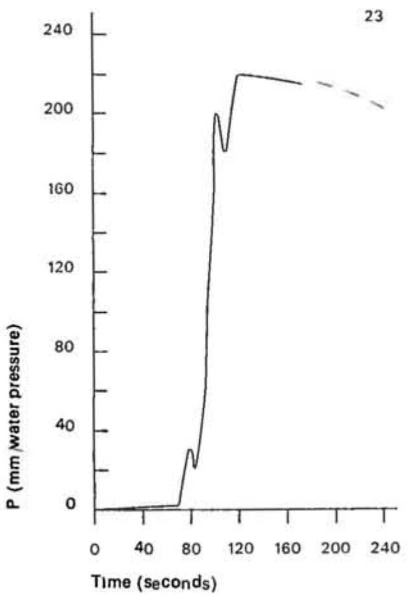
1. Escape
It was found that with the use of safety belts there was a good chance that the occupants would survive the pre-crash and the crash phase without injury. They will then have to try to escape from the vehicle in the post-crash phase. Most vehicles offer numerous escape possibilities. An escape can often be effected whilst the vehicle is still floating.
1. It is obvious that the first attempt is to leave the vehicle by opening a door. However, the pressure on the doors is usually too great for them to be opened, even when the car has only just landed in the water (Figure 25). Often, when the water level on the outside has scarcely risen to halfway up the door, there is already a force of 75–100 kgf pressing against this door. This means that an occupant would have to use a comparatively great amount of force to get this door open and this is usually impossible in view, of the difficult position the occupant would be in.
Depending on the way in which some types of vehicles sink, either the front or the back doors may be almost completely above water in a number of cases. This would then be the right moment to open these doors and escape.

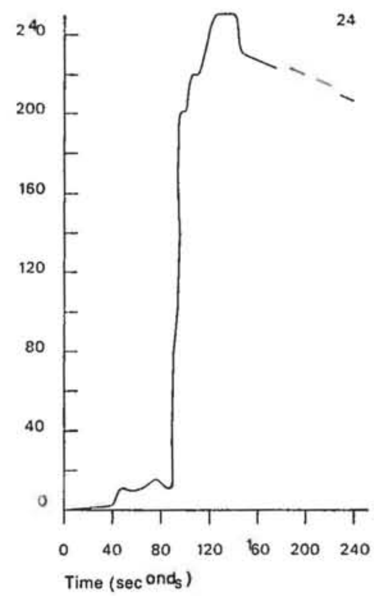
Figure 19. Cars with front engines almost always sink nose-downwards.

Figure 20. Rear-engined cars almost always sink tail-down.

Figure 21. As the car sinks the air is forced to the highest part of the cabin so that one has a chance to fill one's lungs.

Figure 22. By the time the vehicle has come to rest on the bottom there will hardly ever be any air left in it.





Figures 23 and 24. The build-up of excess pressure in a submerging vehicle compared to atmospheric pressure (Figure 23 = test vehicle 1; Figure 24 = test vehicle 2).

Figure 25. Fairly soon after impact with the water it is no longer possible to open the doors.

2. But not all vehicle sink in such a way that this manner of escape is possible. In such cases open windows can serve as an escape route provided they are big enough (Figure 26).
A number of popular car models, however, have door-windows which are divided by a (central) post, whereas the opening of the windows in models where they are electrically operated may cause problems unless manual operation facilities were retained. (This latter assumption was not checked on in the experimental research, since vehicles with such electrically operated windows are very seldom in the Netherlands).
3. A number of passenger cars and delivery vans are fitted with a tailgate, also called the 'fifth door'.
Especially in combination with an engine at the front such a door is a very handy escape route if it can be opened from the inside (Figure 27).
4. The test programme also included various types of open roofs. Unfortunately, only a few types of cars have a sliding-type roof as a standard fitting. This is unfortunate because it was found in the tests that roofs of this type can provide especially good escape chances (Figures 28 and 29).
Most steel sliding roofs, though, are somewhat on the small side for occupants who are at all corpulent, and it is tricky for back-seat passengers to reach them. Roll-back roofs (made of canvas) are generally bigger. In some tests it was found that the winding mechanism and the lock of (steel sliding) roofs did not always function trouble-free, particularly if the roof covering had become wet and had thus swollen slightly. If a vehicle with its roof already open hits the water surface in the normal manner (i.e. horizontally and with the wheels downwards), then the water hardly comes inside through the roof, if at all, during or after the impact, at least not at speeds below 50 km/h.
5. In practice it is possible that (due to such things as bad deformation of the vehicle) none of the above escape routes can be used. That is why we also investigated whether it was possible to escape by forcing one of the windows (the windscreen or the back window) out of its frame. It was found that the best chance of achieving this was to start pressing outwards in a corner of the window using the feet or the shoulder.

II. Outside rescuers
It may happen that the occupants of a vehicle crashed into water may be injured or unconscious or that they cannot make use of the said escape methods for some other reason. They must then be helped by outside rescuers.
1. Whilst the vehicle is still afloat, effective help can often be given. The tests showed, for instance, that vehicles which were still floating could be towed fairly easily. It is certainly possible, therefore, to use a towing cable to 'anchor' a floating vehicle to the bank until the occupants can be rescued in some other manner.
2. In the tests we found that locating a submerged vehicle was made somewhat easier if the headlamps had been switched on. In the tests the lamps kept functioning for some time even under water. The interior lighting may help the occupants to find their bearings inside the vehicle.
3. In three instances where the vehicle came to rest on the bottom in the normal position, the divers were not able to open the doors (two cases with a smashed lock or a jammed door and one case where the car had sunk too deep into the mud). In the cases where the vehicle had come to rest on the bottom on its roof, it was often very difficult to open a door because the car had sunk too deep down into the mud. In the other cases the doors could be opened normally under water.
Note: It is regrettable that many car drivers have the habit before they are going to drive of locking the doors from the inside. This is quite a useless habit probably based on a misconception, and it means that such doors cannot be opened from the outside by potential rescuers. It is completely wrong to think that locking the doors is better and 'safer'. For in emergencies, such as crashing into water or catching fire, it simply makes it more difficult for people to provide outside assistance, especially if none of the occupants is able to unlock the doors. Locking the doors is therefore only useful to protect the car against theft when it is parked.

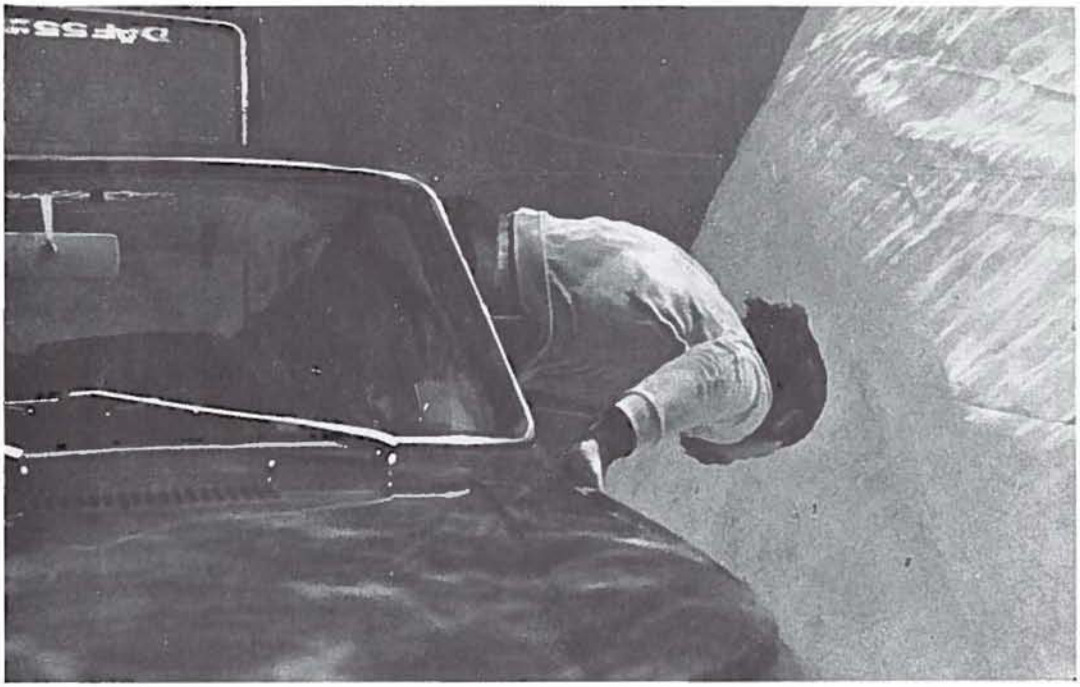


Figure 26. Escaping via an opened front window is possible both above and under water.

Figure 27. If a tailgate can be opened from the inside, it often proves to be a good escape route.

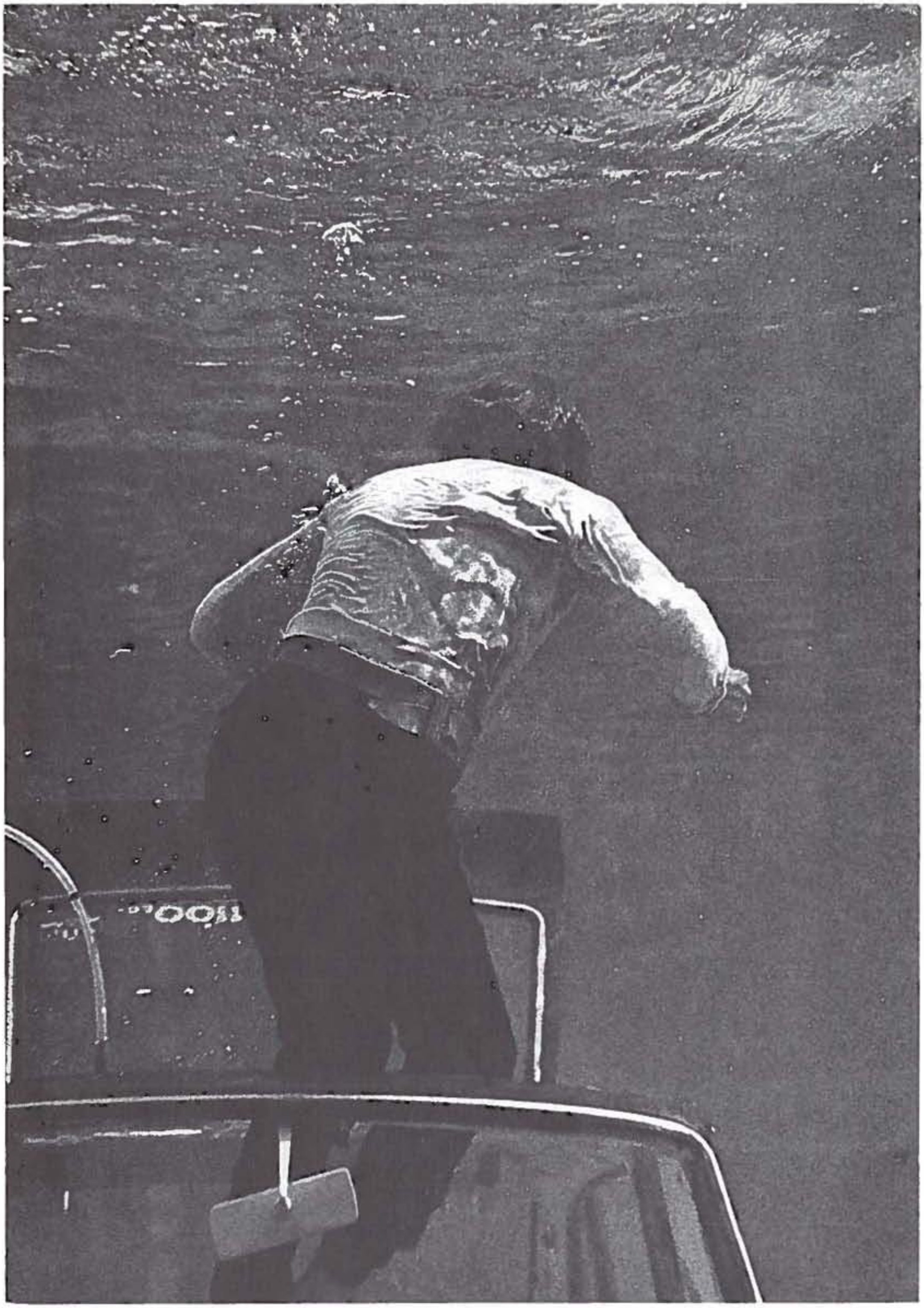


Figure 28. If all the doors are jammed under water or if the vehicle has sunk too deep into the mud, one can easily get out of the submerged vehicle through the open roof.

Figure 29. It might even be possible to escape through an open roof without getting wet.

4. The last rescue method, in cases where no door can be opened, is to attempt to break one of the windows. But one should certainly not think that smashing in car windows under water is an easy matter, for during the tests the test persons without diving gear did not once succeed in breaking the window of a car using a jack. They were hardly capable of striking a blow under water and were very soon faced with breathing difficulties. Fully-equipped divers eventually succeeded after a number of attempts in shattering a window using a jack.

5. Lastly, the tests showed that as regards the post-crash phase as well there were a number of negative points related to the vehicle interior.

Freedom of movement is a major precondition for successful chances of escape. This freedom of movement is very much restricted if loose seats or cushions or luggage carried in the cabin (say, on the shelf behind the back seat) are floating about in the submerged vehicle.

For back-seat passengers in two-door models the locking levers for the backrests of the front seats were often very difficult to reach.

In older cars with poor upholstery and foam-rubber cushions, the backrests of the front seats sometimes jammed due to water absorption. In both cases the fact that the backrests of the front seat cannot be pushed down may from an extra handicap for back-seat passengers (in two-door cars). In modern cars the upholstery and the seats usually do not absorb much water.

3. Conclusions, recommendations and discussion

3.1. Conclusions from the descriptive and the experimental research

1. As regards car-in-water accidents, a number of black spots are to be found on Dutch roads.
2. The fatality (deaths/accidents ratio) is comparatively higher in this type of accident than in all road accidents.
3. There are indications that more cars crash into water in winter than in summer.
4. The fatality is higher at night than in the daytime.
5. Taking measures to prevent vehicles crashing into water is the most effective method of reducing the number of deaths in accidents of this type.
6. In a sizeable percentage of fatal car-in-water accidents there has been a prior collision with another vehicle or obstacle.
7. In the impact with the water surface considerable decelerations occur, even at low impact speeds.
8. If there are to be realistic escape chances from a vehicle in the water, it is essential that the driver or occupants are not injured or knocked unconscious in the impact with the water surface (or in a prior collison with another vehicle or obstacle).
9. The (correct) use of safety belts usually decreases the severity of the outcome of the crash into water and, consequently, increases the chances of escape.
10. Vehicles which hit the water in a (practically) horizontal position generally offer the occupants sufficient protection.
11. In the case of vehicles which hit the water on their roof or sides, there are quite substantial deformations to roof and doors.
12. After the impact with the water surface and irrespective of the landing position, almost all vehicles return to the normal position, floating more or less horizontally.
13. The floating time of vehicles may vary, depending on the circumstances, from a few seconds to two to three minutes.
14. The duration of the floating time is determined by:
a. the state of maintenance of the vehicle (especially of the (bottom) bodywork);
b. the extent of the deformation caused by a possible prior collision;
c. the extent of the deformation caused by the impact with the water surface, determined by the speed at which and the position in which the vehicle crashed into the water;
d. whether the windows are open (or broken);
e. (possibly) the weight/volume ratio of the vehicle.
15. Almost all vehicles sink in a vertical position, nose-down or tail-down depending on the position of the engine (see Figures 30 and 31).
16. As the vehicle sinks, the air is forced to the highest part of the cabin and finally leaves this via various gaps and openings in the vehicle.
17. At the moment that a vehicle comes to rest on the bottom (completely submerged), there is hardly ever an air bubble of any size left behind in the vehicle.
18. A vehicle which has crashed into water should be left as quickly as possible, preferably whilst it is still afloat.
19. The doors of a vehicle which is still floating can hardly ever be opened because of the rapid build-up of water pressure on the outside.
20. Good escape routes are: sufficiently big wind-down windows, sliding or roll-back roofs and the tailgate (provided it can be opened from the inside). The windscreen or the back window can also be pushed out of their frames (start forcing outwards using shoulder or feet).
21. These escape routes can also be used under water, keeping in mind that it will then be possible to open the doors as well (provided these are still intact and are not blocked by the bottom or obstacles on the bottom).
22. Switched-on interior lighting and headlamps help the occupants find their bearing inside the vehicle and help rescuers locate the position of a submerged vehicle.
23. Loose seats, cushions and luggage in the cabin may hamper the escape attempts.

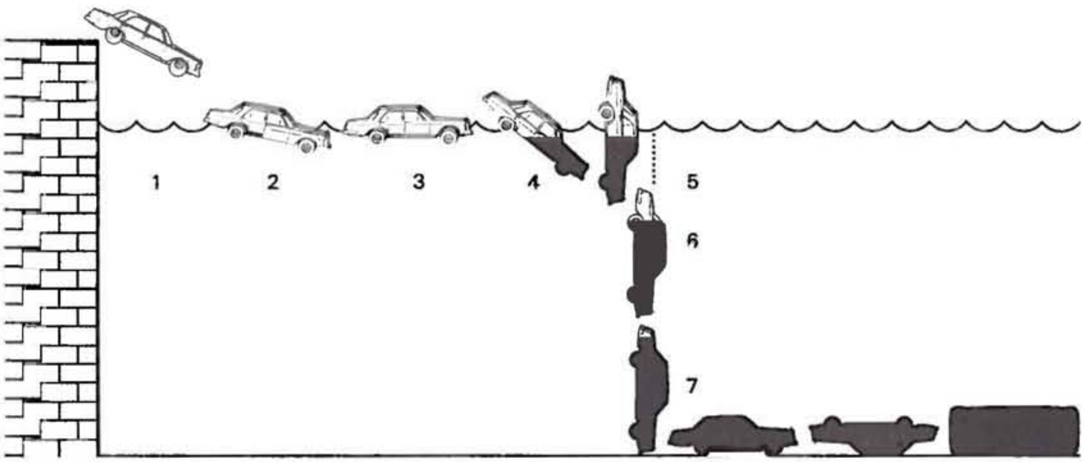


Figure 30. Behaviour of a *front*-engined vehicle crashing into water.
1. Vehicle plunges nose-first into water.
2. Nose of vehicle dips under water.
3. Vehicle returns to horizontal position and stays afloat like that for a while.
4. Vehicle starts to sink nose-downwards.
5. Vehicle in vertical position, engine downwards; the remaining air is forced to the back of the cabin.
6. As the vehicle sinks nose-downwards, the remaining air is forced out via the the boot and the ventilation slits.
7. Roughly speaking, there are four possible positions of resting on the bottom: on the nose, on the wheels, on the roof or on one side. Combinations of these may also occur. In the final positions all the air has almost always disappeared.

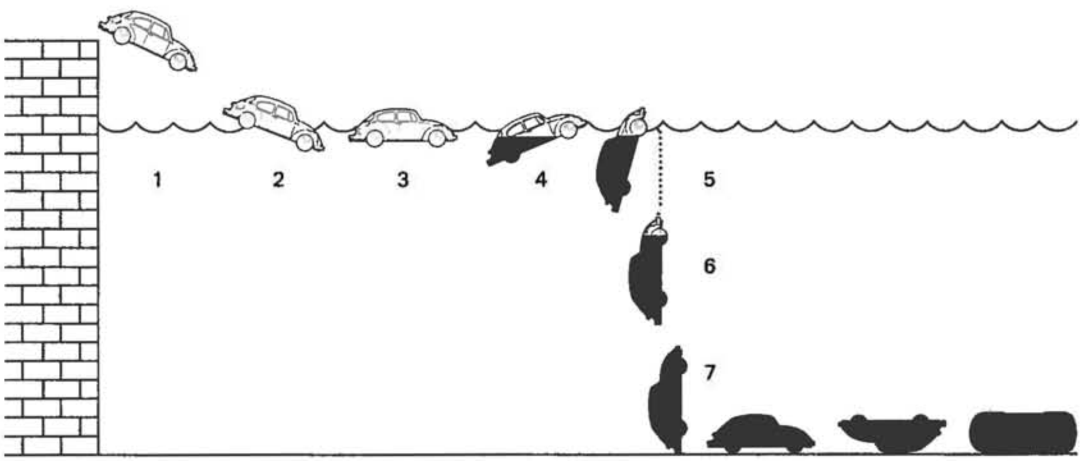


Figure 31. Behaviour of a *rear*-engined vehicle crashing into water.
1. Vehicle plunges nose-first into water.
2. Nose of vehicle dips under water.
3. Vehicle returns to horizontal position and stays afloat like that for a while.
4. Vehicle starts to sink tail-downwards.
5. Vehicle in vertical position, engine downwards; the remaining air is forced to the front of the cabin.
6. As the vehicle sinks tail-downwards, the remaining air is forced out via the bonnet and various opening under the dashboard.
7. Roughly speaking, there are four possible positions of resting on the bottom: on the tail, on the wheels, on the roof or on one side. Combinations of these may also occur. In the final positions all the air has almost always disappeared.

24. Especially in older vehicles the backrests of the front seats may jam due to water absorption. A wet roof covering can also make it difficult to open sliding roofs.
25. The locking levers of the front-seat backrests are often difficult to reach for back-seat passengers.
26. Car windows cannot be shattered under water from the outside (divers were able to shatter them, but only with the greatest difficulty).

3.2. Recommendations

On the basis of the above conclusions a number of recommendations can be formulated which in fact cover three fields. There are recommendations relating firstly to the (road) situation, secondly to the vehicle and lastly to the (behaviour of) the occupants.

Relating to the (road) situation

Recommendations relating to the (road) situation are mainly in the sector of the road authorities and are linked with the prevention of accidents. On the basis of the first five conclusions and in view of the fact that about half the Dutch population are poor swimmers of non-swimmers, the following recommendations on prevention may be formulated:
1. An effective measure for reducing the number of deaths and casualties in cars crashing into water, especially in black spots, is to put up a good (roadside) crash barrier (see Figures 32 and 33).
2. Measures for the (possible) improvement of the road surface, the lay-out, the marking and the signposting, and the erection or improvement of public lighting may also increase traffic safety in this respect.

Relating to the vehicle

Recommendations relating to vehicle construction are usually in the territory of the car manufacturer as regards execution and in the field of the legislator as regards the regulations and their enforcement. But the car-driver himself can also increase his chances and possibilities of escaping from a vehicle which has crashed into the water by paying attention to the following points when purchasing and maintaining his vehicle.
1. The vehicle should be constructed in such a way that it provides the occupants with adequate protection in an impact (with the water surface or with another vehicle or obstacle).
a. This means that the nose and tail may deform and absorb the (impact) energy, but that the cabin must remain intact under all circumstances, whilst the possible 'escape routes' (wind-down windows, sliding or roll-back roof, tailgate and, possibly, the doors) must still function even after the impact. Most modern cars with the 'cage' structure meet with this requirement.
b. In the case of cars with a (too) weak or a canvas roof, a reinforcement of the roof structure is desirable (or should be fitted).
2. The wearing of safety belts usually diminishes the severity of the outcome, even in car-in-water accidents:
a. Belts should therefore be fitted in every vehicle.
b. They should also retain their original (good) properties and functioning, even when they come under pressure or become wet. This applies in particular to the fastening.
c. The great many types of fastening on the market, usually with differing closing and operating systems, may seriously hamper rescue (or escape) attempts. It is therefore recommended that safety belts be fitted with a uniform fastening which can easily be opened by others.
3. If the occupants are to survive the impact (or impacts) without getting injured it is also important that there are no projecting parts in the cabin. An impact-absorbing steering column, flush or flexible door handles and control knobs and an impact-absorbing covering on the dashboard can minimise the risk of (serious) injury.

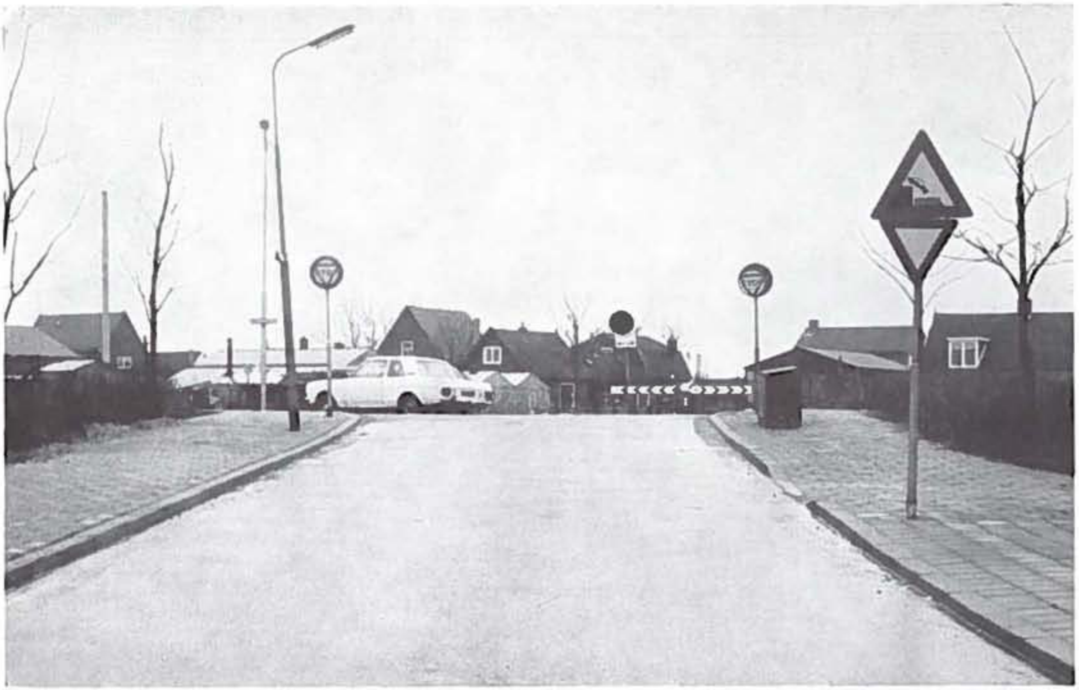


Figure 32. The preventive effect is not high in this instance.

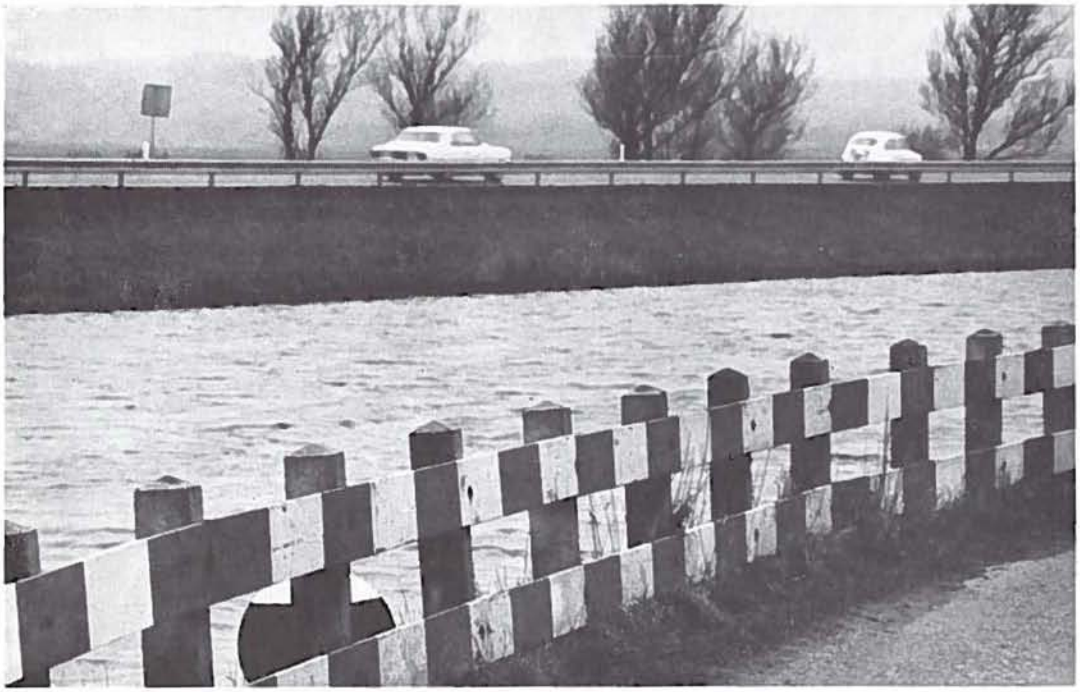


Figure 33. The proper (steel) crash barrier should lead to a drastic reduction in the number of vehicles crashing into the water.

4. The vehicle should have a maximum floating capacity. It should therefore be as watertight as possible.
a. Particularly the (bottom) bodywork and the various rubber seals in the frames should be in good condition.
b. A few individual items, such as the openings for the cables and pedals and any openings for the air-circulation system, should be given more attention than hitherto as regards their watertight properties.
5. Most modern vehicles do have one or more escape routes which can certainly be used in principle.
a. The often (too) small size of wind-down windows and (sliding) roofs or the fact that they cannot be opened hamper their use in emergency situations.
b. An excellent escape route can be achieved simply and cheaply by making sure that in vehicles with a tailgate this can be opened from the inside.
6. Lastly, it is extremely important that there is sufficient freedom of movement available.
a. Loose objects or objects which may work loose in a cabin (seats, cushions —which are dangerous during an impact as well—may hamper the escape attempts.
b. The upholstery of the vehicle interior, especially that of the seats, should absorb little or no water.
c. The backrests of the front seats should have locking levers which are easy to operate for back-seat passengers.

Relating to (the behaviour of) the occupants

In view of the observed behaviour of vehicles crashed into water, the maximum chances of survival for the occupants will exist if a number of rules (for action) are followed. Three categories of rules can be differentiated, viz.: those relating to prevention, escape and rescue by others.
1. Here, too, prevention is better than cure. From the viewpoint of prevention, the following aspects are of importance.
a. Always wear safety belts (even when alongside water). Make sure you know how they have to be unfastened.
b. Never lock the doors. Locking the door does not mean that it is closed 'better' or 'safer'. Doors locked from the inside make it practically impossible for outside help to be given.
c. Before your trip make sure you know what escape possibilities the vehicle offers, i.e. wind-down windows, sliding or roll-back roof, tailgate or emergency exit (in buses), and find out how they can be operated.
d. Being able to swim is of course essential for the success of almost every escape (or rescue) attempt.
2. If you find yourself in a vehicle which has crashed into water, you must take the following action:
a. Immediately after the impact with the water surface unfasten the safety belt(s).
b. Start preparing for the escape straight away by winding down the windows (at least if they are big enough to escape through) and/or opening the roof or the tailgate. (Do not wait until the vehicle has sunk before doing this!) It is usually possible to get out of the vehicle via one of these escape routes while it is still floating. Side effects of the rapid opening of one of the said escape routes are: there is then only a very slight risk that the roof will be pressed inwards, and the vertical position of the vehicle as it submerges will be of shorter duration.
c. As the vehicle sinks it is sometimes still possible to fill your lungs in the highest part of the cabin.
d. Switch on the vehicle's interior lighting and the headlamps. This helps people to get their bearings in the car and also helps rescuers to locate its position.
e. When the vehicle has come to rest on the bottom all the air has almost always disappeared. It is usually then possible to open the door. Should this not be possible for some reason, then you must get out of the vehicle as quickly as possible via the wound-down windows, the roof or the tailgate.

f. If the vehicle is so badly damaged that none of the above escape routes can be used, then attempts must be made to force the windscreen or the back window out of their frames. The best way of achieving this is to start pressing the corner of the window using your feet or shoulder.
g. In the rules mentioned above no account was taken of the fact that there may be several occupants. If it is possible to leave the vehicle whilst other occupants have not yet made good their escape, you must remember that a floating or submerging vehicle is extremely unstable and may turn over at the slightest movement. If this does happen then the chances of escape for those left behind are reduced. You can help your fellow-passengers by indicating which escape route you have used, and by giving them a (helping) hand.
h. Check to see whether there is anyone still missing.
3. Occupants of a vehicle in water are often not able to free themselves from the vehicle for various reasons (injuries, etc.). If you find yourself confronted with an accident of this type, you can offer effective aid if you remember the following points:
a. A vehicle which is still afloat can easily be towed to the bank (using a towing cable, for instance). It may then be possible to 'anchor' the vehicle which means that it will stay floating for a longer time. Should the vehicle sink despite this, the attached cable may perhaps be used to pull it into a more favourable position.
b. A submerged vehicle is often difficult to locate. Marking the place where the vehicle sank may be of help when it is being located by divers.
c. It is possible that the occupants were unable to get out of the submerged vehicle in time and that an under-water inspection shows that there is nothing than can still be opened on the vehicle. Shattering one of the windows would then be the last resort. However, car windows put up quite a bit of 'resistance', panoramic windscreens in particular are difficult to break in even with a car jack.

3.3. Discussion

Both the results of the descriptive research and those of the experimental research led to a number of conclusions. A number of recommendations were based on these conclusions. The report on these conclusions and recommendations might be regarded as the termination of the research.
And yet, so that we were able to make a few marginal comments on these conclusions and recommendations, we have added a discussion. This relates to the following questions:
1. What will be the anticipated yield of the recommendations in practice or, in other words how many occupants of vehicles crashed into water will eventually be able to make their escape (or be rescued) thanks to the recommendations?
2. How representative is the research as regards reality or, in other words, can we expect a lot of cases which are not covered by the research?
3. In what fields might improvements be realised through further research and to what extent would such improvements also be realisable in an economic respect?

1. Determining the yield, expressed as a reduction in the number of victims, is always an uncertain and well-nigh impossible matter, especially in the research field we are concerned with here. If guiding rules for action are to have an optimum effect, they should meet with the following requirements; they must be simple, clear and concise. On looking through the rules for action mentioned in this report we find that, although the requirements relating to simplicity and clarity have been met as much as possible, we were unable to prevent the recommendations from becoming fairly lengthy. This is not surprising when one remembers that a vehicle crashing into water is frequently a complicated event. In addition, there is also the possibility that in some instances local conditions will play such a predominant role that even strict adherence to the rules of action would not lead to a successful escape. Moreover, an occupant who had been injured or knocked unconscious in a collision (prior to the impact with the water) would find that even the best rules for escape action would be of little use.
2. In the limited programme of about 50 tests it was not possible to simulate all the possible

situations which may occur in practice nor to make a separate investigation into the influence of all the possible factors. For example: the deceleration measurements should not be regarded as exact analyses of motion (because of the limited accuracy of the equipment and the method used). Nor was it our intention to get accurate measurements. The order of magnitude and the effective duration of the deceleration which occurs in the impact with the water surface was thought in itself to be quite a convincing argument for recommending the use of safety belts (but, of course, this motive should also be placed alongside the already known arguments in favour of the use of safety belts).
Although test persons were present in the vehicles in a number of tests, we are not sure how near this was to a realistic situation. Test persons (such as the ones taking part in the said tests) are certainly able to investigate and check on the (technical) possibilities as regards methods of escape, but they cannot imitate, or only badly imitate the behaviour of real occupants of cars crashed into water. It is of course impossible to investigate how such occupants would react under differing circumstances and in a panic situation.
3. If a substantial reduction in the number of victims of car-in-water accidents is to be achieved, therefore, the emphasis will have to be placed mainly on (general) accident prevention. This is of course largely an economic question. Prevention in the form of improvements to the vehicle will also be determined to a great extent by economic motives. Since few vehicles, relatively speaking, crash into water, especially outside the Netherlands, the car industry will not be very much inclined to make improvements which will only serve a purpose when the vehicle crashes into water. And especially not when such improvements might greatly increase the price. Furthermore, many car buyers will not be willing to pay this extra price because, in view of the low risk of crashing into water, they will be convinced that they will not derive any useful benefit from their investment.
There are, however, some possible improvements which will only cost a small amount, such as a tailgate which can (also) be opened from the inside and a back window or windscreen which can be easily pushed out of its frame.
Improvements which call for bigger investments are probably more likely to be accepted if they increase the comfort of the vehicle or if they also minimise the risk of injury and increase the chance of survival in other types of accidents. One precondition in the development of new safety provisions is that their use should not introduce *any* new risks. Nor should newly developed safety provisions conflict with existing safety requirements.

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Appendix

Summary of the dynamic crash tests

Test-number	Date	Make	Type	Vehicle weight	Vehicle condition	Location of engine	
						front	rear
1	11/7	Volkswagen 1200	private car	800 kg	bodywork fairly poor		•
2	18/7	Renault Dauphine	private car	675 kg	moderate		•
3	18/7	Volkswagen 1200	private car	800 kg	poor		•
4	18/7	Renault Dauphine	private car	675 kg	underside bodywork bad		•
5	18/7	Ford Anglia	private car	750 kg	solid	•	
6	19/7	Opel Rekord	private car	925 kg	reasonable	•	
7	26/7	Renault Dauphine	private car	675 kg	reasonable; bottom bad		•
8	26/7	Renault Dauphine	private car	675 kg	reasonable		•
9	26/7	Renault Dauphine	private car	675 kg	bodywork poor		•
10	26/7	Opel Caravan	station car	975 kg	reasonable	•	
11	23/8	Opel Rekord 1200	private car	925 kg	reasonable to poor	•	
12	23/8	Opel Rekord 1200	private car	925 kg	good	•	
13	23/8	Opel Rekord 1200	private car	925 kg	good	•	
15	4/7	Ford Zephyr	private car	1225 kg	reasonable	•	
16	4/7	Renault Dauphine	private car	675 kg	good		•
17	17/7	Opel Kapitän	private car	1350 kg	good	•	
18	11/7	Peugeot 203	private car	1050 kg	bottom bad	•	
19	16/7	Fiat 600	private car	600 kg	very poor		•
20	16/7	Opel Rekord 1200	station car	975 kg	reasonable	•	
21	17/7	Opel Rekord 1200	private car	925 kg	good	•	
22	21/7	Opel Rekord	station car	975 kg	all windows broken	•	
22A	30/7	Opel Olympia	station car	925 kg	reasonable	•	

Doors		Windscreen		Side windows		Roofconstruction				
						Steel	Sliding		Rollback/Folding	
2-doors	4-doors	intact	broken	open	closed		open	closed	open	closed
•		•			•				•	
	•	•			•			•		
•		•		•					•	
	•	•			•			•		
•		•			•	•				
•		•		•		•				
	•	•			•			•		
	•	•			•			•		
	•	•		•				•		
	•	•		•		•				
	• + tailgate		•		•	•				
•			•		•	•				
•		•			•		•			
	•	•			•			•		
	•	•			•	•				
	•	•			•	•				
	•	•			•			•		
•		•			•					•
• + tailgate		•			•	•				
•		•			•	•				
•		•			•					
• + tailgate			•	•		•				

Test-number	Date	Make	Type	Vehicle weight	Vehicle condition	Location of engine	
						front	rear
23	21/7	Ford Taunus 17M	private car	900 kg	reasonable	•	
24	30/7	Renault 8	private car	725 kg	bottom bad		•
25	30/7	Volkswagen	private car	800 kg	good		•
26	31/7	Daf	private car	675 kg	good	•	
27	30/7	Volkswagen	private car	800 kg	good		•
28	31/7	Fiat 500	private car	475 kg	poor		•
29	31/7	Mercedes	private car	1250 kg	good	•	
30	7/8	Opel Caravan	station car	975 kg	good	•	
31	7/8	Ford Taunus Transit	delivery van	1075 kg	reasonable	•	
32	12/8	Ford Taunus 17M	station car	975 kg	bottom bad	•	
34	28/8	Opel Caravan	station car	975 kg	good	•	
35	28/8	Volkswagen	private car	800 kg	reasonable; roof slightly dented		•
36	28/8	Opel Rekord 1200	private car	925 kg	good	•	
37	28/8	Opel Rekord 1200	private car	925 kg	reasonable; bottom bad	•	
38	5/9	Fiat 500 Sunroof	private car	475 kg	reasonable		•
39	5/9	Opel Kapitän	private car	1350 kg	reasonable	•	
40	5/9	Daf	private car	675 kg	good	•	
41	14/10	Volkswagen 1200	private car	800 kg	good		•
42	14/10	Volkswagen 1200	private car	800 kg	reasonable to good		•
43	22/10	Volkswagen 1200	private car	800 kg	good		•
44	22/10	Daf	private car	675 kg	good	•	
45	22/10	Opel Rekord	private car	925 kg	good	•	

Doors		Windscreen		Side windows		Roofconstruction				
						Steel	Sliding		Rollback/Folding	
2-doors	4-doors	intact	broken	open	closed		open	closed	open	closed
●		●			●					●
	●	●			●	●				
●		●			●	●				
●		●			●	●				
●		●			●	●				
●		●			●					●
	●	●			●	●				
● + tailgate			●	●		●				
● + tailgate			●		●	●				
● + tailgate		●			●	●				
● + tailgate		●			●	●				
●		●			●	●				
●		●			●	●				
●		●			●					●
●		●			●					●
	●	●			●	●				
●		●			●	●				
●		●			●	●				
●		●			●	●				
●		●			●					●
●		●			●	●				
●		●			●	●				

Test-number	Load none	persons	luggage	Angle of impact	Impact speed	Bank height	Position impact with water
1		2 front	•	90°	35 km/h	85 cm	normal (slightly nose-down)
2	•			15°	45 km/h	85 cm	normal (slightly nose-down)
3			•	90°	57 km/h	85 cm	normal (slightly nose-down)
4		1 front		90°	75 km/h	85 cm	almost horizontal
5	•			90°	76 km/h	85 cm	almost horizontal
6		1 front		90°	76 km/h	85 cm	almost horizontal
7	•			90°	52½ km/h	85 cm	normal (slightly nose-down)
8	•			90°	64 km/h	85 cm	normal (slightly nose-down)
9	•			90°	83½ km/h	85 cm	30° (nose-down)
10	•			90°	75 km/h	90 cm	normal (slightly nose-down)
11		1		90°	48 km/h	85 cm	45° (nose -down)
12			•	90°	55 km/h	90 cm	45° (nose-down)
13			•	90°	64 km/h	90 cm	30° (nose-down)
15		2 front		90°	35 km/h	350 cm	45° (nose-down)
16	•			90°	90 km/h	350 cm	almost vertical
17			•	90°	85 km/h	200 cm	normal (slightly nose-down)
18		2 front		90°	80 km/h	200 cm	almost horizontal
19		1 front		90°	60 km/h	200 cm	normal (slightly nose-down)
20		2 front		90°	80 km/h	200 cm	almost horizontal
21		1 front		90°	80 km/h	200 cm	almost horizontal
22	•			90°	90 km/h	200 cm	almost horizontal
22A	•			90°	90 km/h	200 cm	almost horizontal

floating	on bottom	Floating time	Manner of sinking		Air bubble		Amount of air
			nose-down	tail-down	yes	no	
horizontal	normal	120 s	•			•	
horizontal	normal	120 s		•		•	
horizontal	normal	37 s		•		•	
horizontal		32 s		•		•	
horizontal	normal	120 s	•			•	
horizontal	normal	60 s	•			•	
horizontal	normal	120 s		•		•	
horizontal	normal	90 s		•		•	
turned upside down in water	on roof	15 s	tilting sidewards			•	
horizontal	normal	150 s	•			•	
slightly nose-down	normal	37 s	•		•		3 cm under roof
horizontal	normal	75 s	•		•		3 cm under roof
horizontal	normal	138 s	•		•		3 cm under roof
sank vertically	45°; 1 m in mud	20 s	• (vertical)			•	
horizontal	tail-down in mud	50 s		•		•	
horizontal	on roof	180 s	•			•	
horizontal	vertical	40 s	•			•	
horizontal for moment; tail-down	tail-down in mud	20 s		•		•	
horizontal	vertical	120 s	•			•	
horizontal	on roof	80 s	•			•	
horizontal		115 s	•			•	
horizontal		46 s	•			•	

Test-number	Load none	persons	luggage	Angle of impact	Impact† speed	Bank height	Position impact with water
23		1		on crane		200 cm	horizontal
24	•			90°	28 km/h	200 cm	45° (nose-down)
25	•			90°	80 km/h	200 cm	almost horizontal
26	•			40°	20 km/h	200 cm	nose-down
27			•	90°	77 km/h	200 cm	nose-down
28	•			40°	40 km/h	200 cm	nose-down
29	•			40°	30 km/h	200 cm	vertical
30		2		90°	75 km/h	220 cm	normal (slightly nose-down)
31		2		90°	80 km/h	220 cm	horizontal
32		2		90°	75 km/h	200 cm	normal (slightly nose-down)
34	•			90°	65 km/h	220 cm	horizontal
35	•			90°	75 km/h	220 cm	normal (slightly tail-down)
36			•	90°	70 km/h	220 cm	almost vertical (nose-down)
37	•			90°	80 km/h	220 cm	vertical (nose-down)
38	•			90°	55 km/h	300 cm	nose-down
39	•			90°	75 km/h	300 cm	on left side
40	•			90°	70 km/h	300 cm	on roof
41	•			90°	80 km/h	350 cm	normal (slightly nose-down)
42	•			90°	90 km/h	350 cm	normal (slightly nose-down)
43			•	90°	80 km/h	350 cm	on roof, spinning towards horizontal
44	•			90°	80 km/h	350 cm	on roof
45	•			90°	30 km/h	350 cm	vertical (nose-down)

		Floating time	Manner of sinking		Air bubble		Amount of air
floating	on bottom		nose-down	tail-down	yes	no	
horizontal		50 s	•			•	
horizontal	normal	128 s	•			•	
horizontal	on roof; nose upwards (30°)	62 s		•		•	
horizontal		90 s		•		•	
horizontal	on roof	19 s	•			•	
horizontal	on right side	49 s				•	
horizontal	on roof	61 s	•			•	
horizontal	aslant on right side, wheels up	60 s	•			•	
horizontal	normal (on right front side)	85 s	•			•	
horizontal	normal (slightly nose-down)	55 s	•			•	
horizontal	on side	95 s	•			•	
horizontal		15 s		•		•	
horizontal	normal	40 s	•			•	
slightly nose-down	nose-down in mud	15 s	•			•	
horizontal for moment; tail-down	tail-down in mud	10 s		•		•	
horizontal for moment	nose-down in mud (1 m)	8 s	•			•	
sank immediately vertical	nose-down in mud (1 m)	5 s	•			•	
horizontal		80 s		•		•	
horizontal		60 s		•		•	
horizontal for moment		25 s		•		•	
hardly floated at all		8 s	•			•	
horizontal		160 s	•			•	

Test-number	Deformations	
	internal	external
1		slight bodywork damage at front
2		wings pressed against front wheels
3		front against wheels
4	dashboard dented in	severe damage to front
5		front slightly dented
6	dashboard dented in	front severely dented
7		severe damage to front
8	dashboard dented in	severe damage to front
9	dashboard dented in	severe damage to front; roof and side dented in
10		wings dented in; bonnet closure loose
11	dashboard dented in; seats loose	front and wings dented in; bonnet buckled; left door dented in
12	seats loose	front and bonnet dented in; steering assembly buckled
13		front and bonnet dented in
15	dashboard dented in	windscreen smashed; bonnet missing
16	dashboard dented in; steering column buckled	front severely dented
17		
18	dashboard dented in; back seat loose	severe damage to front; frontwheel suspension damaged
19	dashboard dented in; back seat loose	severe damage to front; roof construction dented in
20		front dented in; windscreen smashed; roof dented in
21	steering column buckled; back seat loose	front and roof dented in
22		front dented in
22A		front dented in

Doors could be opened		Comments
yes	no	
•		car still usable; water did not come in through open roof
•		car still usable
•		car still usable
•		
•		car still usable
•		wheel lining damaged; deceleration in horizontal direction max. 50 m/s^2
•		car still usable
•		wheel lining damaged; deceleration in horizontal direction max. 40 m/s^2
	•	car no longer usable
•		roof pressed in under water
• right	• left	
•		
• right	• left	sliding roof banged shut at moment of impact with water
•		passengers escaped under water via open roof
•		
•		
•		also tested statically with divers; divers escaped via open roof
•		also tested statically with divers; divers escaped via open roof
•		also tested statically with divers; one diver escaped via tailgate while car was still afloat
•		doors with closed windows difficult to open; with opened windows doors could only be opened once car was under water
•		
•		roof dented in under water

Test-number	Deformations internal	external
23		front dented in
24		front suspension assembly severely buckled
25		front and roof dented in
26		front severely dented
27		right front, roof, wing and left door dented; back window smashed
28		bonnet and roof dented in
29		windscreen smashed
30	dashboard dented in	grille and front dented in; windscreen smashed
31	dashboard dented in	front dented in; windscreen smashed
32		front slightly dented; bonnet closure broken
34		front dented in; bonnet deformed
35		
36		front and wings dented in; windscreen and back window smashed
37		chassis buckled; windscreen broken; metal part of roof dented inwards roll-back roof torn and partially blocked
38		front dented in; bottom bodywork ripped; folding roof damaged
39		windscreen, side windows and ventilation windows on right side broken
40	steering column buckled	roof partially pressed in; right side and bonnet dented
41	dashboard dented in	front dented in
42		front dented in; front left wing torn off; back window smashed
43	dashboard dented in	
44		
45	dashboard dented in	

Doors could be opened		Comments
yes	no	
•		because of steep forward tilt, car immediately filled with water when roof was opened
•		deceleration in horizontal direction max. 40 m/s²
• front left	• right	
•		extra heavy ballast in front to compensate for engine; roof dented in under water
• front left	• front right	
• front left	• right	door could be opened when water was halfway up it
	• in mud	dummies through windscreen; probable injuries to driver: broken neck and crushed chest; passenger: stomach injuries, internal bleeding and shattered left leg
• front left	• front right in mud	no safety belts used; right dummie thrown through windscreen; brain damage, facial and internal injuries
•		3-point safety belts used; dummies did not hit windscreen; injuries probably slight; passenger possibly experienced 'whiplash' effect; roof pressed in under water
		obstacle before hitting water: 60 cm ditch
		obstacle before hitting water: 45×45 cm beam placed 60 cm before bank
•		obstacle before hitting water: 45×45 cm beam at 60 cm before bank with 60 cm ditch in front of beam; roof pressed in under water
•		obstacle in the form of a raised ramp
•		obstacle in the form of a raised ramp; bottom of car scraped over ramp so that bottom was ripped open; because of this floating time was very short
• right	• left	car sent off course so much by raised ramp that it hit water on left-hand side; roof dented in under water
• left	• right	ramp caused car to hit water on its roof
•		
•		
	•	ramp caused car to hit water on its roof
	•	
•		

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