western european cross-country oil pipelines 30-year performance statistics

Prepared on behalf of CONCAWE oil pipelines Management Group (OPMG) by:

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ABSTRACT

CONCAWE has collected 30 years of performance data on Western European cross-country oil pipelines, which currently comprise 30.8 thousand km transporting 672 million m^3 per year of crude oil and oil products. This report shows how the pipeline system reported on has developed. The data on safety-related incidents are reported and the levels and trends of spillage incidence, gross and net spillage volumes and the significant features of individual cause categories: mechanical failure, operational, corrosion, natural hazard and third party. The pipeline system has always been considered to be a safe and reliable way of transporting oil in bulk. Most European pipeline spillages are small and effects are generally localised and temporary. Moreover, integrity is on an improving trend with spillage frequency over the period reduced from 1.2 to 0.25 spillages per 1000 km of pipeline. Subject to continuing performance monitoring and the use of improved and new techniques such as internal inspection using intelligence pigs, safe and reliable operation of the pipelines should remain possible for the foreseeable future.

KEYWORDS

Clean-up, CONCAWE, oil spill, performance, pipeline, safety, spillage, statistics, trends

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SUMMARY

CONCAWE has collected data over a 30-year period on the performance of cross-country oil pipelines in Western Europe with particular regard to spillages of 1 m^3 or more, the clean-up carried out and the environmental consequences. The results have been published in annual reports since 1971. The data have now been assembled and analysed for the whole period to record the reported-on pipeline system development over time, quantify environmental performances and reveal trends in causes of spillages.

Pipelines are one of the main methods of transporting oil throughout the region. the length of the pipeline system covered has grown from 12,800 km carrying 310 million m^3 in 1971 to 30,800 km transporting 672 million m^3 in 2000. Over this same period, 121 pipelines with a total length of 5550 km have been permanently shut down. The system is ageing. Whereas in 1971 70% was 10 years old or less, by 2000 only 11% was 10 years old or less and 42% was over 35 years old.

Pipelines are generally considered to be the safest way of transporting oil in bulk. Almost inevitably, with such a massive undertaking operating for over 3 decades, a handful of incidents has occurred that have resulted in a small number of fatal injuries and fires. Unlike marine and road traffic accidents, so far in Western Europe nothing of large enough scale or frequency has occurred with oil pipelines to draw them to the attention of the general public.

Pipeline spillages have averaged 12.6 per year and most are very small. Just over 5% of the spillages are responsible for 50% of the gross volume spilled. The frequency of spillages has been improved over the 30 years from 1.2 spills per 1000 km of pipeline per year to 0.25 spills per 1000 km per year. Pipelines carrying hot oils such as fuel oil have in the past suffered very severely from external corrosion due to design and construction problems. Many have been shut down or switched to cold service. The great majority of pipelines carry unheated petroleum products and crude oil.

The two most important causes of spillages are third party incidents and mechanical failure, with corrosion well back in third place and operational and natural hazards making minor contributions. Third party accident frequency has been significantly reduced progressively over the years. However, after having made great progress reducing mechanical failure frequencies during the first 20 years, by the mid ‘90s it appeared that something of an upward trend could be setting in. The occurrence of so few mechanical failures over the last 5 years has allayed that concern and has brought the overall progress on mechanical failure back into line with that for the third party category.

Overall there is no evidence to show that the ageing of the pipeline system poses any greater level of risk. The development and institution of new techniques, such as internal inspection using intelligence pigs, hold out the prospect that pipelines can continue reliable operations for the foreseeable future. Future monitoring of CONCAWE pipeline performance statistics will be necessary to confirm the position.

1. INTRODUCTION

The CONCAWE Oil Pipelines Management Group (OPMG) has collected data on the performance of oil pipelines in Europe since 1971 and the results have been categorised by cause, analysed and published annually in a series of reports [1,2]. Over these 30 years also, CONCAWE has held a number of seminars to disseminate information throughout the oil pipeline industry on the developments in techniques available to pipeline companies to help improve the safety, reliability and integrity of their operations. These seminars have included reviews of spillage and clean-up performances to cross communicate experiences so that all can learn from each other's incidents.

Aggregation of the spillage data and statistical analysis provides evidence of a progressive improvement in performance and helps to focus attention on the residual risks of the various categories of spillages. This indicates the priorities for future efforts.

The basic definition of pipelines to be reported in the CONCAWE inventory has remained unchanged since 1971:

- In Western Europe, i.e. OECD Europe as originally defined comprising 19 countries but excluding Turkey, i.e. in practice EU-15 plus Norway and Switzerland.
- Used for transporting oil, i.e. crude oil or petroleum products.
- Length of 2 km or more in the public domain.
- Cross-country, including short estuary crossings but excluding other under-sea pipeline systems.

The pipeline inventory monitored by CONCAWE has changed over the years as discussed in ***Section 2.*** The changes are due to the physical changes to the system, changes to country status (specifically the inclusion of the former East Germany), the pipelines actually reported on as distinct from the total in existence, and ownership status (originally only commercial companies were included). It is believed that at least 99.5% of all the pipelines meeting the CONCAWE definition are currently reported on. Year on year performance comparisons should account for these variations in the inventory, e.g. length of pipeline reported on, to remove distortions from the analysis.

CONCAWE has set a minimum spillage size at 1 m^3 for reporting purposes (unless there are exceptional serious safety/environmental consequences to be reported for a < 1 m^3 spill). As far as CONCAWE is aware, this spill size reporting criterion is more rigorous than commonly used in other region's reports e.g. published spillage performances in the USA [3] use a criterion of 100 barrels (15 m^3 approx.). Direct comparison of differently defined spillage data sets would be invalid. Steps need to be taken to compare only the data applicable to the same cut-off spill size (see ***Figure 16***).

The performance statistics reported here cover the 30-year period, 1971 to 2000. During this period there have been 379 reported spillages.

2. PIPELINE INVENTORY

The CONCAWE database covers crude oil and petroleum product pipelines that run cross-country including estuary crossings but not submarine sections running cross-sea, nor from offshore crude oil production facilities and offshore tanker loading/discharge facilities. In general, pipelines of less than 2 km in length in the public domain are not included. The geographical region covered is that set in 1963 by CONCAWE's original terms of reference. This is OECD Western Europe, which then included 19 member countries. However, the database lacks data from Turkey because CONCAWE has traditionally not had oil company representation there. Following the reunification of Germany, the pipelines in the former East Germany (DDR) have been added to the database since 1991. From 1971 to 1987, only pipelines owned by oil industry companies were included but from 1988, non-commercially owned pipeline systems have been covered also.

Since 1990, CONCAWE has commenced gathering data from eastern European countries, but they are not included in the results reported here. The initial findings indicate that the performance in certain respects is not directly comparable with the Western European data series.

The number of companies/non-industry bodies reporting data to CONCAWE in 1971 was unrecorded but in 1980 approximately 70 companies participated in the CONCAWE survey. The number has declined somewhat since with several new companies taking over and others closing down or amalgamating with others. In 2000, 66 companies reported results. Affiliates and other operating entities of certain large companies are counted individually in these numbers.

The length of the pipelines reported on has increased from 12,800 km transporting some 310 million m^3 in 1971 to 30,780 km transporting 672 million m^3 in 2000. Currently, there are some 250 pipelines with physical details recorded in the inventory, reported in terms of some 557 discrete sections. The annual throughput and traffic, the spillage data and the intelligent pig inspection activity are gathered by CONCAWE via questionnaires sent out to the pipeline operating companies early in the year following the year of report.

2.1. PIPELINE SERVICE

There are three pipeline service populations: unheated crude oil, ambient temperature petroleum products (white oils) and oils transported at elevated temperature comprising hot crude oil, lubricating oils and heavy fuel oils (black oils). A few pipelines transport both crude oil and products. Although these are categorised separately in the database they are considered to be in the crude oil category for aggregation purposes. These three populations are referred to as crude, product and hot in this report.

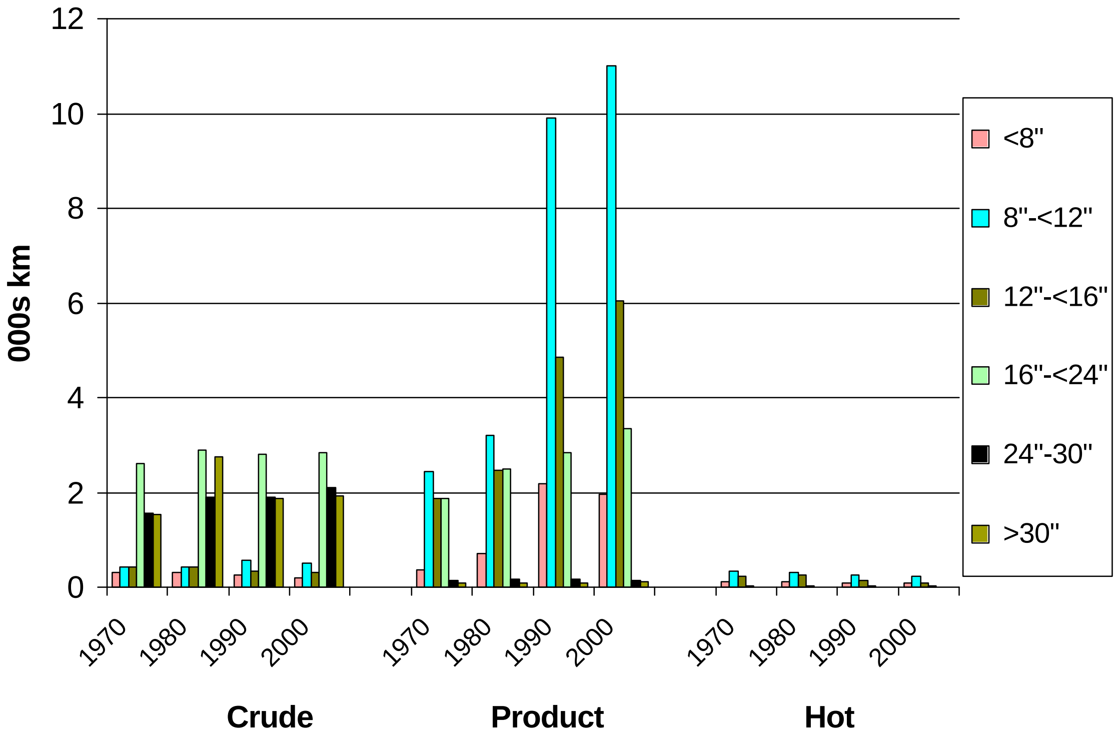
2.1.1. Pipeline service, length and diameter

Table 1 shows the pipeline system breakdown by length and service as recorded in 5-year intervals between 1971 and 2000. Over this period, the total length of pipeline in crude service is relatively static, whereas the product pipelines inventory increases dramatically due to the reporting changes and the use of hot pipelines declines steadily.

Table 1 Length of pipeline and service (000s km)

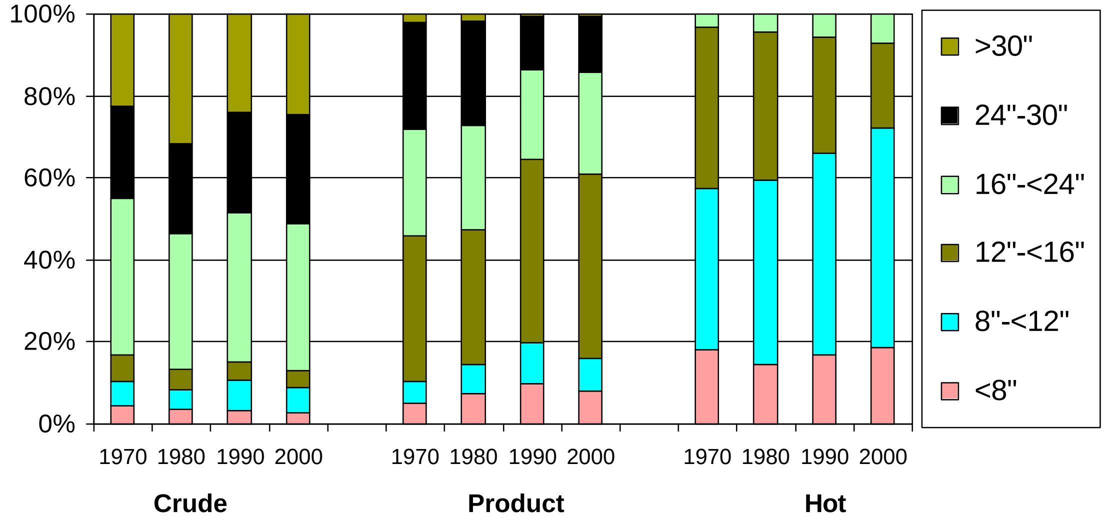
	1971-75	1976-80	1981-85	1986-90	1991-95	1996-00
Crude	7.9	8.7	8.7	8.0	8.6	8.1
Product	7.4	8.6	9.3	15.6	20.8	21.7
Hot	0.7	0.7	0.6	0.5	0.5	0.5
Total	**16.1**	**18.0**	**18.7**	**24.1**	**30.0**	**30.3**

Figure 1 Development of pipeline length, diameter and service (000s km)



In general, the diameters of the crude pipelines are significantly larger than the other two categories. Some 85% of the crude pipelines are 16” (400 mm) or greater up to a maximum of 48” (1200 mm) whereas around 45-65% of the product and some 95% of the hot pipelines are less than 16”. The smallest diameter product pipelines are typically 6” (150 mm) but a very few go down to 3” (75 mm).

Figure 2 Pipeline diameter and service **(%)**



Some 120 pipelines totalling 5500 km have been permanently shutdown during the 1971-2000 period. Of these, 21 pipelines totalling 380 km were in hot service. This is a much larger proportion of the hot inventory than for the other services and reflects action taken by operating companies because of the poor reliability experienced with several of these pipelines (see **Section 5.3.2**) and the severe decline in the fuel oil business since the mid 1970s.

2.2. THROUGHPUT AND TRAFFIC

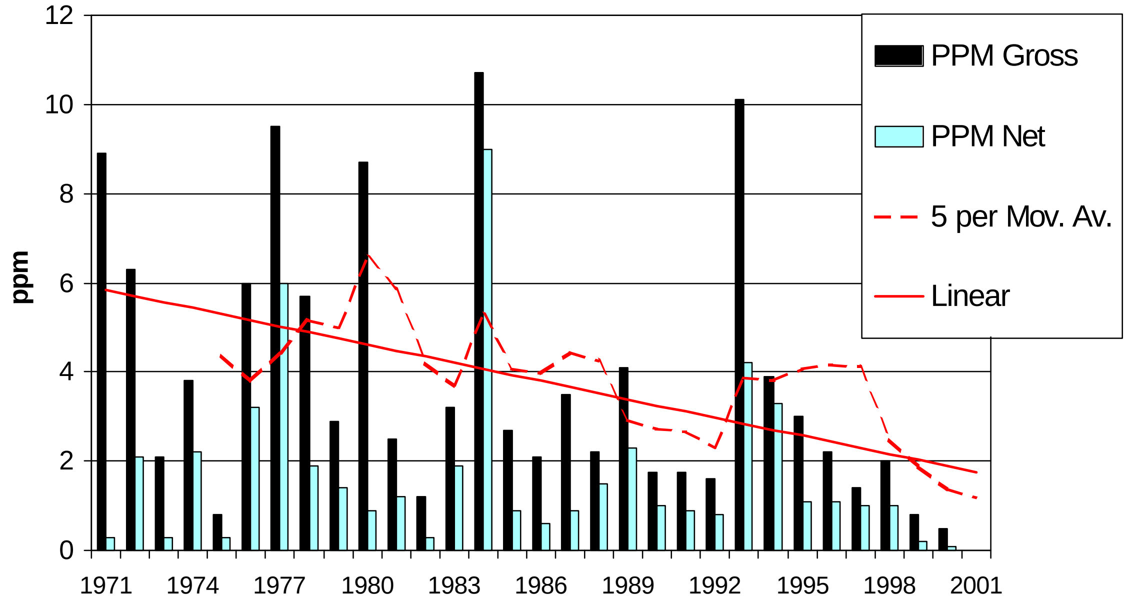
The reported throughput of the pipeline systems has increased from $310x10^6$ m^3 per year (which was largely crude) in 1971 to $672x10^6$ m^3 ($444x10^6$ m^3 of crude and $228x10^6$ m^3 of product) in 2000. The current throughputs are equivalent to over 60% of the total crude run in the region and to roughly 30% of the products marketed.

Traffic, the product of volume carried and the distance transported, in 1971 was $90x10^9$ m^3xkm at that time comprising very largely the crude transfers from ports to inland refineries. By 2000, the total traffic had risen to $126x10^9$ m^3xkm of which crude was $89x10^9$ m^3xkm and product $37x10^9$ m^3xkm.

Very few (if any) pipelines are believed to suffer from deterioration due to throughput related effects, for example, metal fatigue. Any such deterioration would be a function of the cumulative number of pressure cycles and how closely they approach the elastic limits of the pipeline material. Fatigue failures do sometimes occur when pipelines have suffered some construction fault or subsequent damage such as dents. These are relatively infrequent causes of spillages. In general, spillages do not correlate in any systematic way with the average pumping rate or the traffic.

Thus throughput and traffic are not significant factors to take into account when comparing spillage frequencies or sizes. However, the spillage volume shown on the basis of parts per million (ppm) of throughput, see **Figure 3**, could be compared with the performances of other modes of transportation if these should become available.

Figure 3 Gross and net pipeline spillage volumes (ppm)



The overall performance of the Western European oil pipeline system is considered to provide the safest and most reliable way of transporting oil in bulk. The alternative transportation modes: road, rail or sea/river/canal, face collision risks absent in pipeline transportation. The net pipeline spillage (oil remaining in the environment at the end of the clean-up response) has averaged 2 parts per million (PPM), or 0.0002%, of the oil transported.

2.3. PIPELINE LENGTH AND AGE

When the CONCAWE pipeline inventory was assembled in 1971, the pipeline system already had quite a wide age distribution. The oldest pipelines were already in the 26-30 year age bracket although they represented only a tiny fraction of the inventory. However, the system was comparatively new with some 9000 km out of the total 13,000 km (70%) being 10 years old or less.

The inventory has grown due to new pipelines being commissioned and because of reporting additions of already existing pipelines either individually or as entire pipeline systems. The non-commercial pipelines (9700 km) were added-in from 1988 onwards and the eastern German pipelines (1700 km) in 1991. Deletions of pipelines permanently withdrawn from use have also been a factor. All the additions/deletions have contributed their own specific age profiles. The overall age profile has developed as shown in **Figures 4** and **5**, and as tabulated in **Appendix 1**.

Figure 4 Pipeline length and age

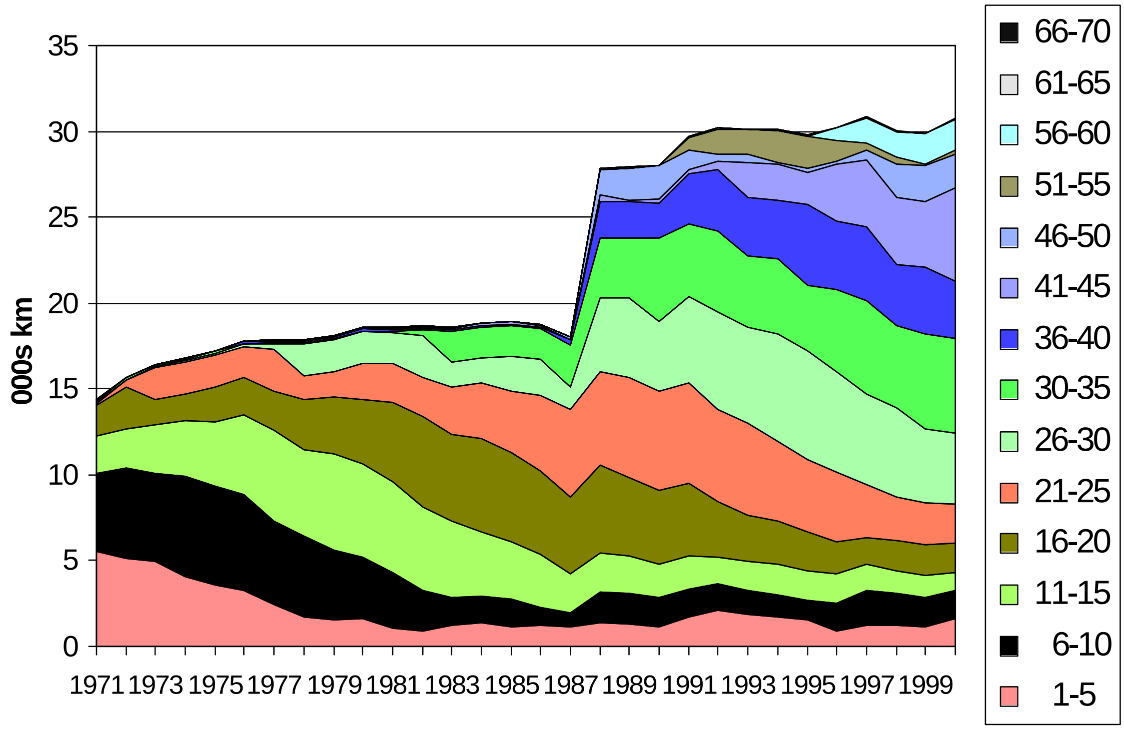
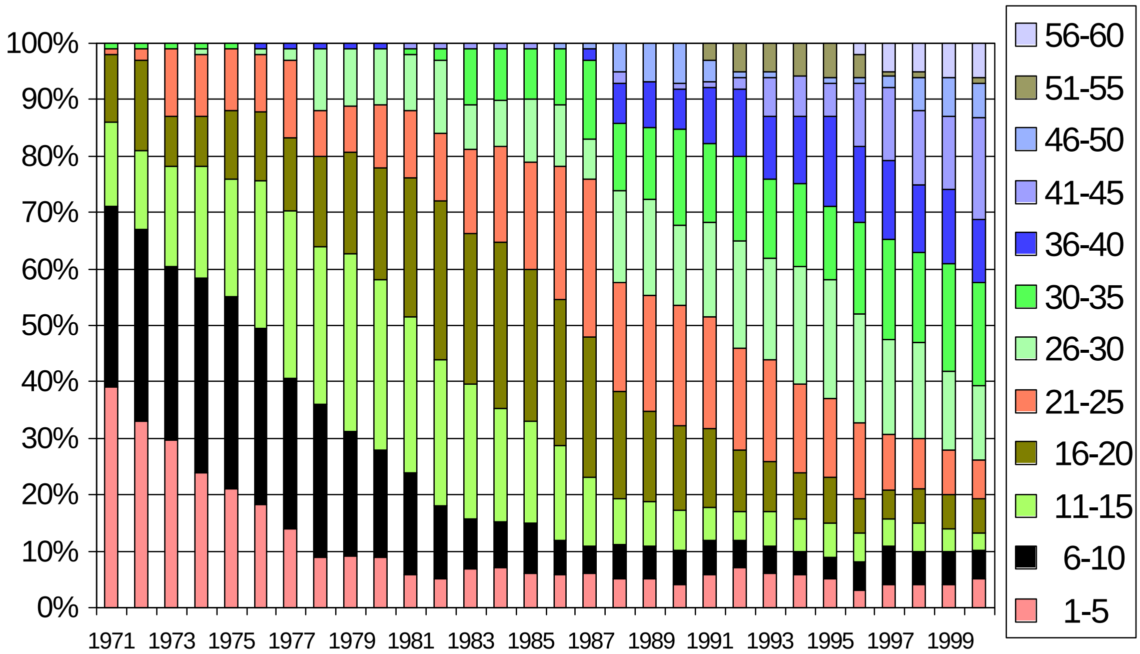


Figure 5 Percent of pipeline length in age bracket by year



The system has been ageing progressively. By 2000, only some 3300 km out of the total 31,000 km, i.e. 11%, was 10 years old or younger and some 12,800 km (42%) was over 35 years old. To assess whether age is a significant factor in spillage performance, the inventory of the pipeline lengths in each age bracket (1-5 years, 6-10 years, etc) each year is used to calculate the relative frequency of the reported spillages per unit of length in each age bracket over the 30-year period. Only the potentially age-related spillage causes are included in the analysis. If the occurrence of spillages were increasing with increasing age, the plot of spillage frequencies per year per 1000 km of pipeline in the same age bracket would increase in successively older age brackets. These data are shown in **Section 5.3.1**. As yet there is no evidence to show that the ageing (up to 45 years old at least) is affecting environmental security. Sometime in the future this may start to happen. Thus there is a need for continued monitoring of performance on this basis. However, inspection methods are now available to monitor pipeline condition such that any upturn in age-related spillages is likely to be prevented or delayed for many years.

3. PIPELINE SAFETY

The CONCAWE database includes numerical records of fatalities and injuries and the paper files contain notes on the occurrences of fires following spillages.

3.1. FATALITIES AND INJURIES

There have been five incidents in the 30 years in which fatal injuries have occurred. These incidents involved a total of 14 fatalities, all but one as a result of people being caught up in fires following the spillages.

In all but one of these four fire cases the ignition was a delayed event hours or days after the detection and demarcation of the spillage area had taken place. In two incidents, bystanders (3 people) and people entering inside marked spillage boundaries (4 people) received fatal injuries. The bystanders themselves were the probable ignition source in one of the incidents involving a spillage of chemical feedstock naphtha. In the other, ignition of spilled crude oil occurred during attempts to repair the damaged pipeline. The repairers escaped but the spread of the fire caught other people some distance away. The third incident also involved a maintenance crew (5 people) carrying out repair activities following a crude oil spill, none of whom escaped. These fatalities all occurred after the spillage flows had been stemmed, during the subsequent incident management and reinstatement period. It appears that the spillages themselves did not cause the fatalities. Stronger management of spillage area security and working procedures might well have prevented the fires and fatalities.

Just one fire resulted when ignition of a gasoline spillage followed almost immediately when a bulldozer doing construction work damaged a pipeline. A truck driver engaged in the works received fatal injuries.

The single non-fire fatality was a person engaged in a theft attempt who was unable to escape from a pit dug to expose and drill into the pipeline, causing a leak that filled the pit with product.

It is apparent that the casualties were not members of the general public going about their normal lives in locations where they should have been allowed to be at the time. Thus these occurrences should not be used inappropriately for the statistical assessment of societal risk inherent in oil pipeline operations.

Two spillage reports recorded non-fatal injuries. The two incidents each reported one injury. Both resulted from inhalation/ingestion of oil spray/aerosol.

3.2. FIRES

Apart from those mentioned above, five other fires are on record:

- An ignition of a large spill of crude oil near a motorway probably set off by the traffic.

- An untypical section of pipeline located on a pipe bridge was subjected to a gasoline theft attempt. The thieves may have ignited it.

- A slow leak in a crude production line in a remote country area was found to be burning when discovered. It could have been ignited purposely to limit the pollution.

- A tractor and plough that had caused a gasoline spill caught fire, which also damaged a house and a railway line.

- A mechanical digger damaged a gasoline pipeline and also an electricity cable, which ignited the spill.

There were no casualties reported in any of these incidents.

3.3. MALICIOUS DAMAGE

There have been 10 spillages caused by malicious damage by third parties.

Cause	Number of spills	Gross spillage (m^3)	Net spillage (m^3)
Terrorist bombs	2		
Vandalism	5		
Theft	3		
Totals	**10**	**2597**	**1716**

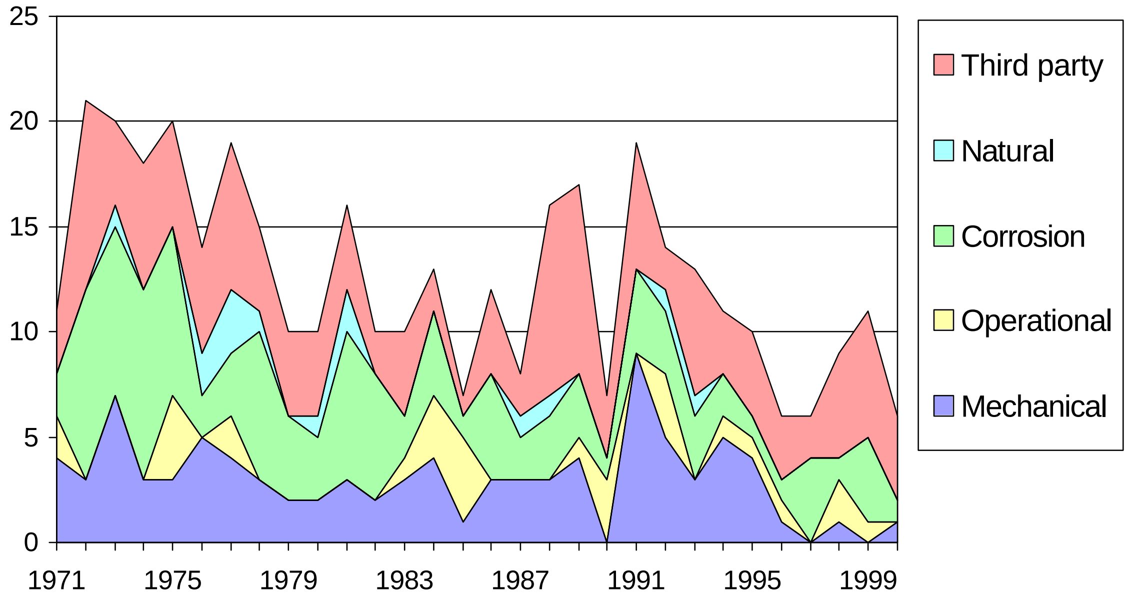
Only one of these was from underground pipe; the attempted theft and fatality noted above. One was from an above ground section of pipeline, all the rest were at valves or other fittings at pump stations or road/river crossings, etc. This category of spillages represents 2.6% of the total number of spillages and is responsible for about 4% of the total gross spillage loss and 6% of the total net loss.

4. OVERALL SPILLAGE PERFORMANCE

4.1. SPILLAGE FREQUENCY

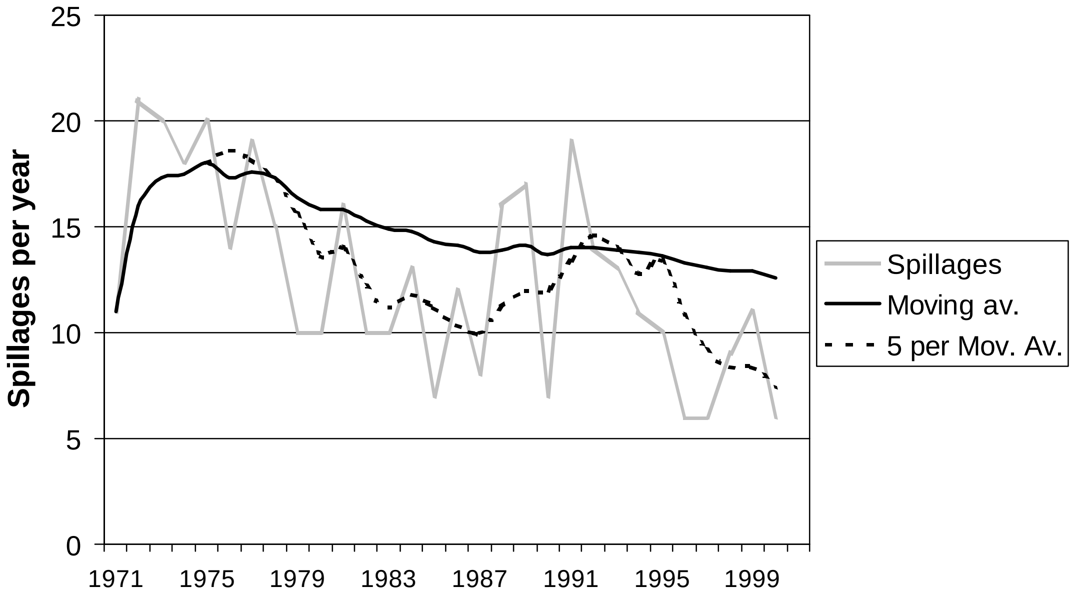
The significant progress made over the years on pipeline spillage performance is demonstrated by the reduction over the time period in the number of spillages and the spillage frequency per unit length of pipeline. **Figure 6** shows the annual number of spillages broken down into major cause categories, **Figure 7** shows the number of spillages, moving average and 5-year average trends over 30 years and **Figure 8** shows the same data per 1000 km of pipeline

Figure 6 Number of spillages by major cause category



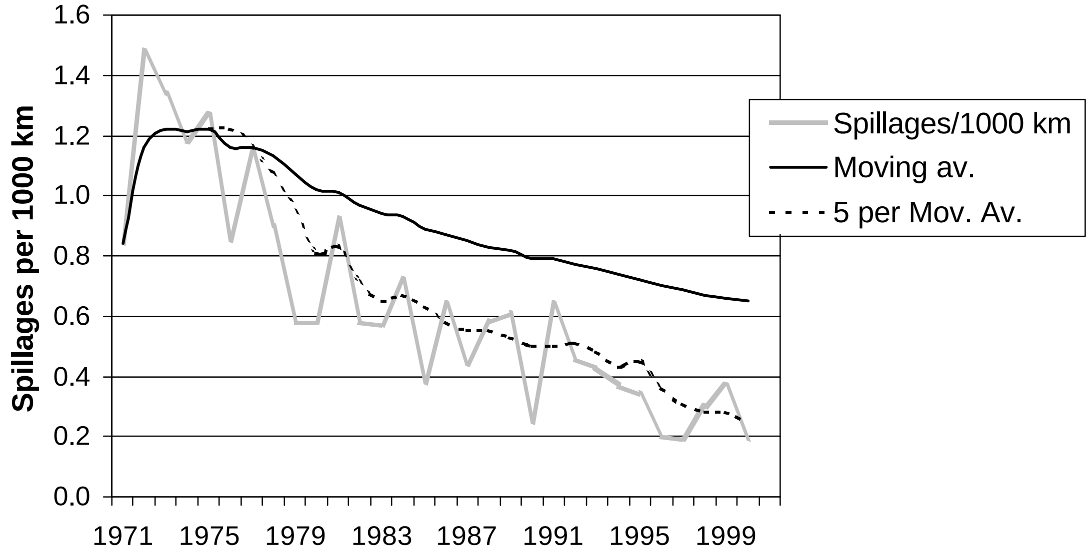
The largest number of spillages recorded in any one year is 21 and the smallest number is 6.

Figure 7 Trends over 30 years in the annual number of spillages



The overall moving average has reduced from being in the region of 18 per annum in the early 1970s to 12.6 by 2000. The 5-year averages clearly show the improving trend. Apart from the up turn in the late ‘80s/early ‘90s due to the large increases in the pipeline inventory monitored, there is a strong downward trend in the 5-year annual average number of spillages to below 8 per annum for 1996-2000.

Figure 8 Trends over 30 years in the number of spillages per 1000 km



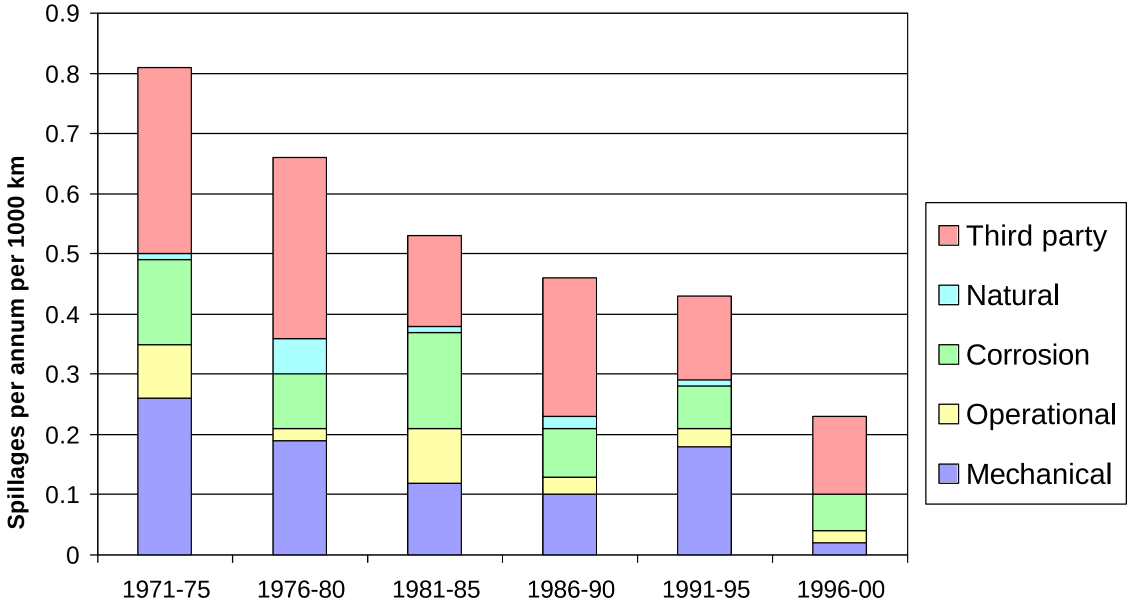
The frequency of spillages has been progressively reduced from about 1.2 per 1000 km per year to about 0.25 over the 30 years, i.e. the incidence of spillages has reduced to a fifth of what it was at the start of the 1970s.

Hidden within this overall performance is the relatively very poor performance of hot pipelines, particularly in the early part of the period. The relative frequencies of corrosion-caused spillages for cold (crude and product) and hot pipelines are: -

	All Causes	Corrosion All	Corrosion Cold	Corrosion Hot
30-yr av. p/l length (x1000 km)	22.26	22.26	21.65	0.61
Number of spills	379	113	60	53
Spills per year	12.6	3.77	2.00	1.7
Spills per year per 1000 km	0.57	0.17	0.09	2.79

Clearly, the cold and the hot have demonstrated completely different corrosion performances and should be assessed separately, see **Figures 9 & 10**.

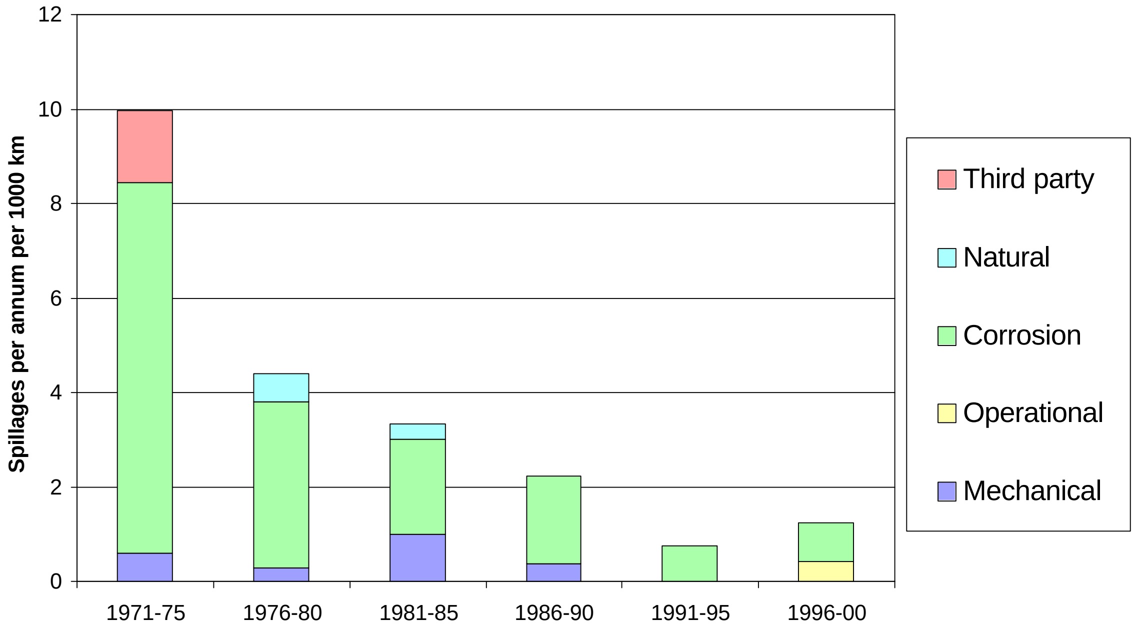
Figure 9 Cold pipelines spillage frequencies by cause



The spillage frequencies by cause and their proportions shown over the three decades are:

Cold pipelines	1971-1980		1981-1990		1991-2000	
	Spillages per 1000 km	% of total	Spillages per 1000 km	% of total	Spillages per 1000 km	% of total
Third party	0.31	41%	0.19	38%	0.14	41%
Natural	0.04	5%	0.02	3%	0.01	2%
Corrosion	0.12	16%	0.12	24%	0.07	20%
Operational	0.06	7%	0.06	12%	0.03	8%
Mechanical	0.23	31%	0.11	22%	0.10	30%

Figure 10 Hot pipelines spillage frequencies by cause



The hot pipeline spillage frequency starts from a much higher base than the cold pipelines and the improvement of the 5-year average spills/year/1000 km for the hot pipelines is much stronger than for the cold pipelines. In the 1970s and early '80s, due to design and construction deficiencies several hot pipelines suffered repeat external corrosion failures and they were shutdown or switched to product service. These actions have greatly contributed to the performance improvement. However, the hot pipelines spillage frequency per 1000 km in 1996-2000 remains worse than that for the product pipelines in 1971-75.

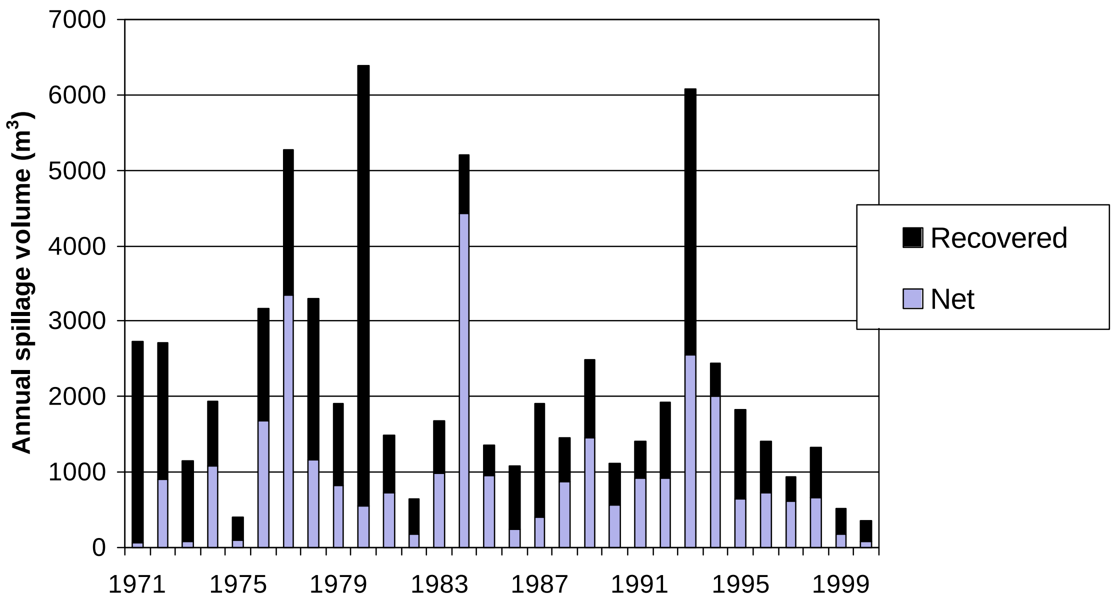
When the hot pipeline data are excluded, the cold pipelines show a somewhat weaker improvement trend than the all pipelines data. Over the last 30 years the incidence of spillages shows a reduction to around 30% of that experienced in the early 70s. This statistic best represents the performance improvement achieved by the operators of the bulk of the pipeline system.

4.2. SPILLAGE VOLUMES, SPILL SIZES, AND AREA AFFECTED

4.2.1. Gross and net spillage volumes

Another indication of overall performance is given by the data on gross and net spillage volumes shown in **Figure 11.**

Figure 11 Annual gross and net spillage volumes (m³)



The trend is somewhat obscured by the few very large spillages that have occurred randomly across the years. However, as shown in **Figure 12**, the improvement in the spillage annual gross volume trend appears to be similarly strong as that for the cold pipeline spillage frequency. (This is an appropriate comparison rather than the all pipelines data because the hot pipeline spillages are only a tiny proportion of the total spillage volumes.) As a consequence, shown in **Figure 13**, it appears that not much progress is being made in reducing the average size of the spillages that occur. This is partly due to the mix of the spillage causes changing over the years, e.g. the proportion of corrosion spillages, which on average are smaller ones (see **Figure 15**), have decreased relative to third party spillages which are among the largest. The average spillage gross volume is 172 m^3 per spill.

There are insufficient data on record to determine any trend in the speed of detection or the response time to stem leakages.

Figure 12 Development of gross spillage volume (m^3) per 1000 km

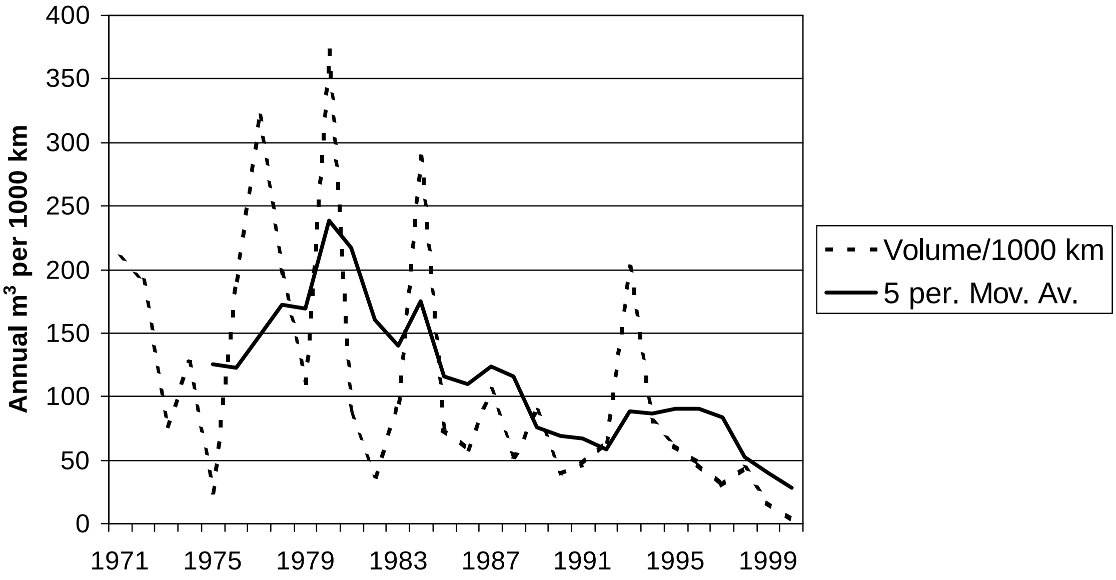
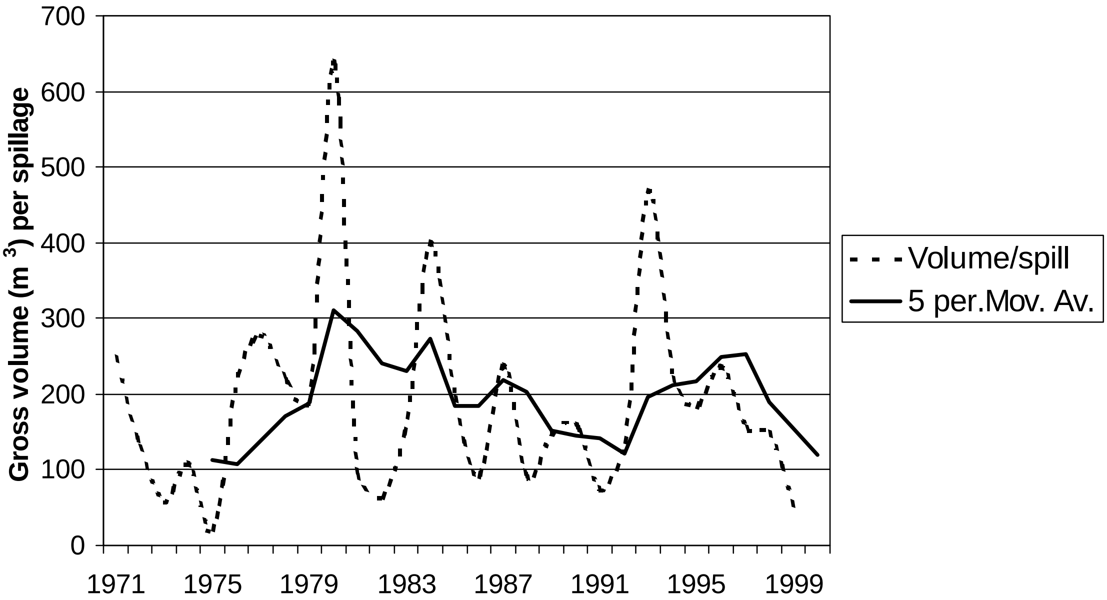


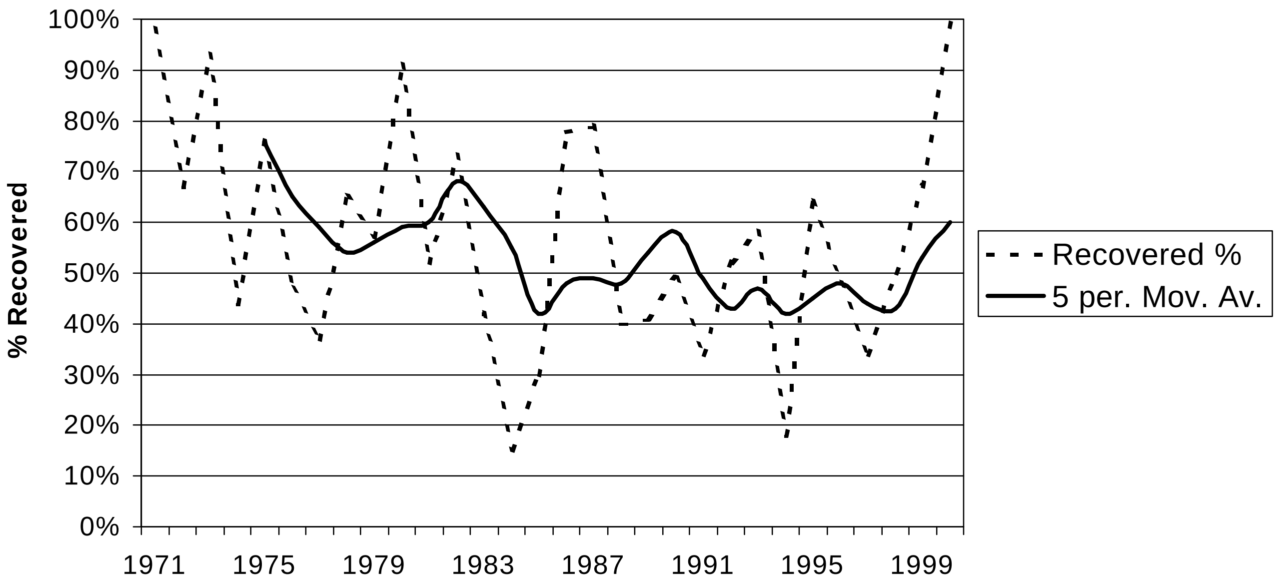
Figure 13 Development of gross spillage volume (m^3) per spillage



4.2.2. Spillage recovery

It might be expected that the trend in the differences between the annual gross volume spillage and the net volume spillage, i.e. the recovered spillage, would indicate the degree of success in improving clean-up performance. In practice this is not a very sound proposition. For one thing, maximum removal by excavation of spilled oil, which is biodegradable, is not necessarily the correct response to minimise environmental damage and this is now better understood than it once was. Another compounding factor is that the growth in the pipeline inventory has been predominantly for refined product pipelines and it can be anticipated that less invasive recovery techniques are justified for white oil products than for black crude oil to achieve a given visual and environmental standard of clean-up. The development of annual recovery percentages ({gross minus net}/gross) is shown in **Figure 14**. This indicates that no significant trend is evident. The average spillage net volume is 79 m^3 per spill, i.e. the average recovery of the spilled oil is 55%.

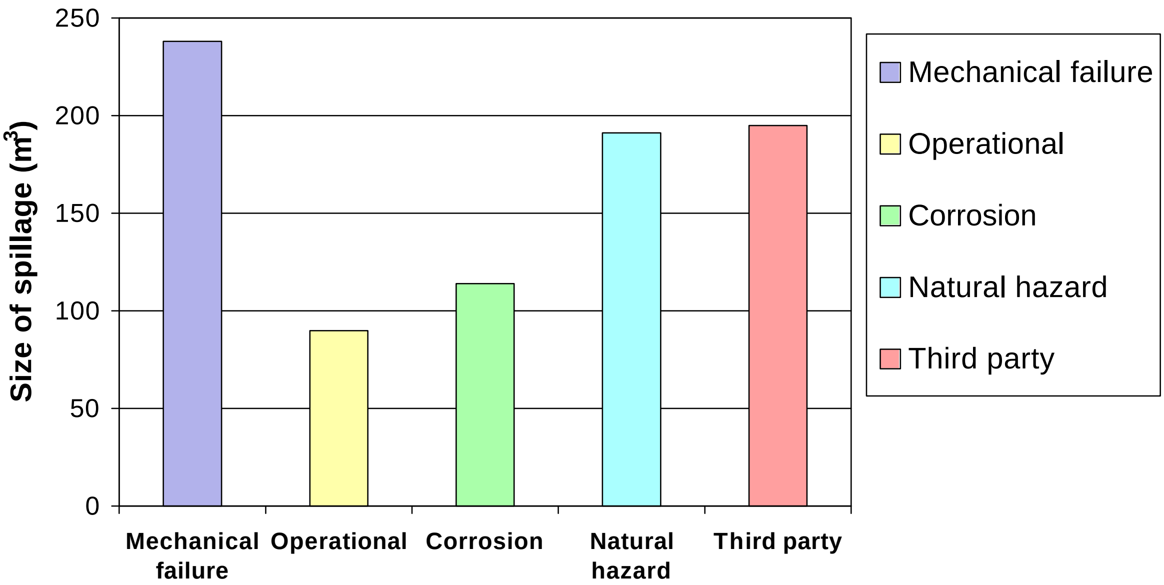
Figure 14 Development of spillage recovery (%)



4.2.3. Spill sizes

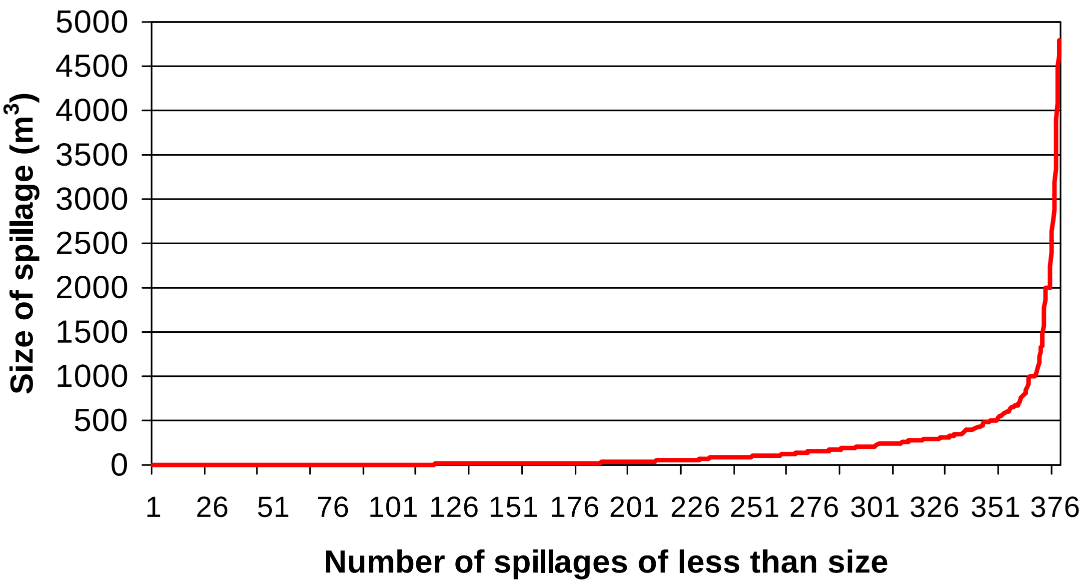
The largest spillages on average have resulted from the mechanical failure, third party and natural hazard categories whereas the smallest come from the operational and corrosion categories. As a rule of thumb, on average the three 'largest spill' categories result in spillages that are twice the size of the two 'smallest' spill categories.

Figure 15 Average gross spillage size (m^3) by cause of spill



The importance of considering the cut-off spillage size before comparing data sets taken from different sources is shown by the spillage size distribution, see **Figure 16**. Also, when considering the risks posed by pipelines to the environment and to society in particular, it should be recognised that a majority of the spillages recorded in the CONCAWE database are so small that they have been significant only in terms of local nuisance value.

Figure 16 Distribution of gross spillage sizes



Just over 5% (20 spillages) of the spillages were responsible for 50% of the gross volume spilt. Whereas some 60% (230 spills), the largest of which was 66 m^3, caused less than 5% of the total gross volume spilt.

When spillages of less than 15 m^3 are excluded, e.g. for comparison with a USA data series based on 100 barrels and over, instead of 379 spills over 30 years (0.65 spills per year per 1000 km), the comparable Western Europe number of spillages would decrease to 220 spills (0.38 spills per year per 1000 km). Alternatively, if a cut-off of 50 m^3 and above is used, as in a recent societal risk study [4], the number of spillages reduces to 157 (0.27 spills per year per 1000 km).

For sectored studies, for example concerning only gasoline spillages in the case of the societal risk study mentioned above, exclusion of the crude and non-gasoline product spillages (assuming gasoline is spilled in 50% of product spillages) further reduces the relevant number to around 50 spillages. The average length of clean products pipeline in the inventory over the 30 years is about 14,000 km. Hence the spillage frequency for gasoline spills of 50 m^3 and above is some 0.12 spills/year/1000 km. Taking into account the improvement in spillage incidence performance over the 30 years (50% reduction versus the early '70s performance, 25% reduction versus the average performance, say), the current incidence of these spillages is below 0.05 spills/year/1000 km.

4.2.4. Spillage discovery

The way in which the occurrence of a spillage was detected is reported in nine categories. The pattern for spillages from pump stations differs from that from pipelines.

Detection of spillages from pump stations

	Number of spills	**%**	**Average gross spill size (m^3)**
Right of way survey by p/l staff	-	-	-
Automatic detection system	9	15%	55
Third party passer-by	11	19%	35
Routine monitoring by p/l staff	18	31%	138
Pressure testing	3	5%	18
Contractor working for p/l company	0	0%	0
P/l maintenance staff	18	31%	38
Third party worker	0	0%	0
Pipeline internal inspection survey	-	-	-
TOTAL	**59**	**100%**	**69**

Pipeline company resources detected some 81 percent of the pump station spillages. When third party passers-by have detected spillages, 19% of the total, the spills have tended on average to be the smaller ones; presumably those that are below the warning capabilities of the instrumentation.

Detection of spillages from pipelines

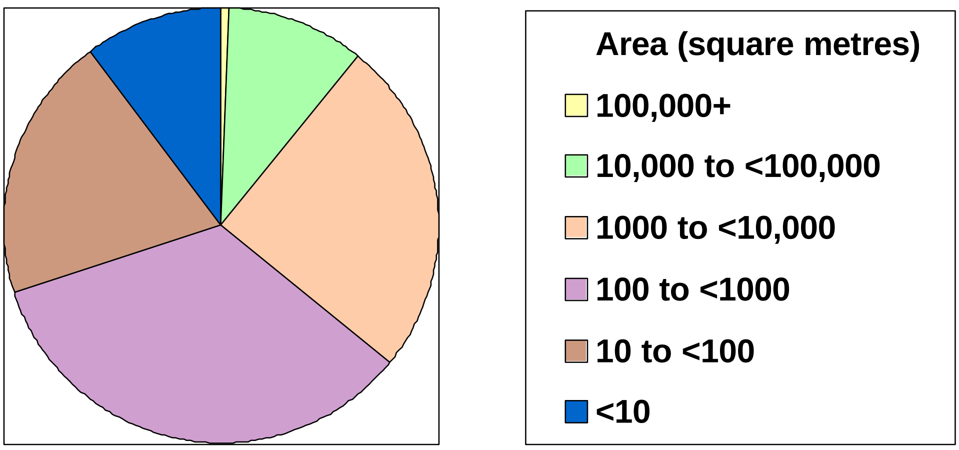
	Number of spills	%	Average gross spill size (m3)
Right of way survey by p/l staff	29	9%	229
Automatic detection system	25	8%	188
Third party passer-by	144	45%	120
Routine monitoring by p/l staff	64	20%	388
Pressure testing	17	5%	157
Contractor working for p/l company	5	2%	482
P/l maintenance staff	13	4%	60
Third party worker	20	6%	110
Pipeline internal inspection survey	3	1%	6
TOTAL	**320**	**100%**	**192**

The most common means of detection of pipeline spillages was third party passer-by (45%) who warned of spillages that on average were about 60% of the average size. Pipeline instrumentation, measurement and control systems were involved in detecting only 28% of the spillages.

4.2.5. Area and location affected

The current CONCAWE performance questionnaire, in use since 1983, requests that data be reported on the area of ground (m^2) affected by the spillage. Before that date, area data were reported infrequently. Out of the 379 recorded spillages, no area data are available for 195 (51%). For the remaining 184 spills, the percentages that fall within the area ranges are shown in **Figure 17**.

Figure 17 Ground area (m^2) affected by spillages (% of number reporting)



Average spill size leading to ground area affected:

Ground area affected (m^2)	Number of spillage reports	Average gross spill size (m^3)
<10 m^2	19	25
10 to <100 m^2	36	46
100 to <1000 m^2	63	89
1000 to <10,000 m^2	46	238
10,000 to <100,000 m^2	19	704
100,000+ m^2	1	172

In the CONCAWE annual spillage reports, where the area of ground affected is reported as 1000 m^2 or more the spillages are categorised as causing serious soil pollution. Hence, some 36% of the spillages that reported on the area of ground affected fell into this arbitrary "serious" category.

Except for the very largest category that has only a single modestly sized spillage in it, on average there is a direct relationship between spill size and area affected. Bigger areas affected result from bigger spillage volumes.

However to some extent this relationship is fortuitous. There are two ways in which small spillage volumes can affect larger areas of ground. Fine sprays directed upwards can be spread around by winds. This factor tends to be more prevalent in the smaller area ranges. Other smaller spillages can be spread over larger areas by the influence of groundwater or surface water flows. This is the main mechanism by which small spillages affect very large areas. Conversely, comparatively large spillages, particularly ones that occur over extended periods of time and in the lower quadrants of the pipeline circumference, can have their main effect underground with relatively little impact on the surface. Porous ground and hot arid conditions can also lead to the surface consequences being limited.

The geographical characteristics of the spillage locations have been reported for a total of 310 spillages.

	Pump station spillages		Pipeline spillages	
	Number	**%**	**Number**	**%**
Commercial/Industrial	48	86%	56	22%
Residential	0	0%	16	6%
Rural	8	14%	179	70%
Forest/Mountain	0	0%	3	1%
Total	**56**	**100%**	**254**	**100%**

The bulk of the spillages from pump stations occur in industrial areas by nature of the location and classification of the majority of the pump stations in the pipeline system. For spills from pipelines, the number of spills in residential areas seems to be about in line with what could be expected from consideration of the proportion of the pipeline system located in such areas. The number of spillages in commercial/industrial areas, however, is clearly much higher than would be expected from consideration of installed length alone. Evidently, the conditions in these areas lead to the vulnerability of the pipelines being increased by a factor that probably lies in the region of ten times higher.

4.2.6. Potable water affected

The spillage reports record the incidents where oil pollution of the water table and underground aquifers and surface watercourses has had consequences for the abstraction of potable water. Some 12 spillages, representing 3.2% of the total, have had some effect. It is believed that all of these effects have been temporary.

4.2.7. Pipeline Hole Data

Out of the 379 pipeline spillages, hole size data exists for 176 (45%).

Arbitrary definitions for type of hole classification:

Pinhole = less than 2 mm x 2 mm,
Fissure = 2+ mm up to 75 mm long x 10% max wide,
Hole = 2+ mm up to 75 mm long x 10% min wide,
Split = 75+ mm up to <1000 mm long x 10% max wide,
Rupture = >75 mm long x 10% min wide.

	Pinhole	Fissure	Hole	Split	Rupture	Overall
Number	20	21	58	27	50	176
%	12%	12%	34%	16%	29%	100%
Length x Width range (mm^2)	0.01 - 4	0.7 - 400	6 - 3600	20 - 81,000	4500 – 500,000	
Length x Width ave. (mm^2)	1	64	626	11,242	47,687	11,422
Hole Area/ Pipe cross section (%)	0.003%	0.08%	0.9%	12%	48%	15%
Gross spillage ave. (m^3)	59	205	169	174	363	220
Spillage/Hole area (m^3/mm^2)	42	3	0.3	0.02	0.01	
Hole caused by (%)						
Mech. Failure	5%	19%	12%	22%	24%	17%
Operational	0%	5%	2%	11%	4%	4%
Corrosion	90%	33%	29%	30%	18%	34%
Natural hazard	0%	5%	2%	11%	2%	3%
Third party	5%	38%	55%	26%	52%	43%
Sizes of hole by cause (%)						
Mech. Failure	3%	13%	23%	20%	40%	100%
Operational	0%	14%	14%	43%	29%	100%
Corrosion	31%	12%	29%	14%	15%	100%
Natural hazard	0%	17%	17%	50%	17%	100%
Third party	1%	11%	43%	9%	35%	100%

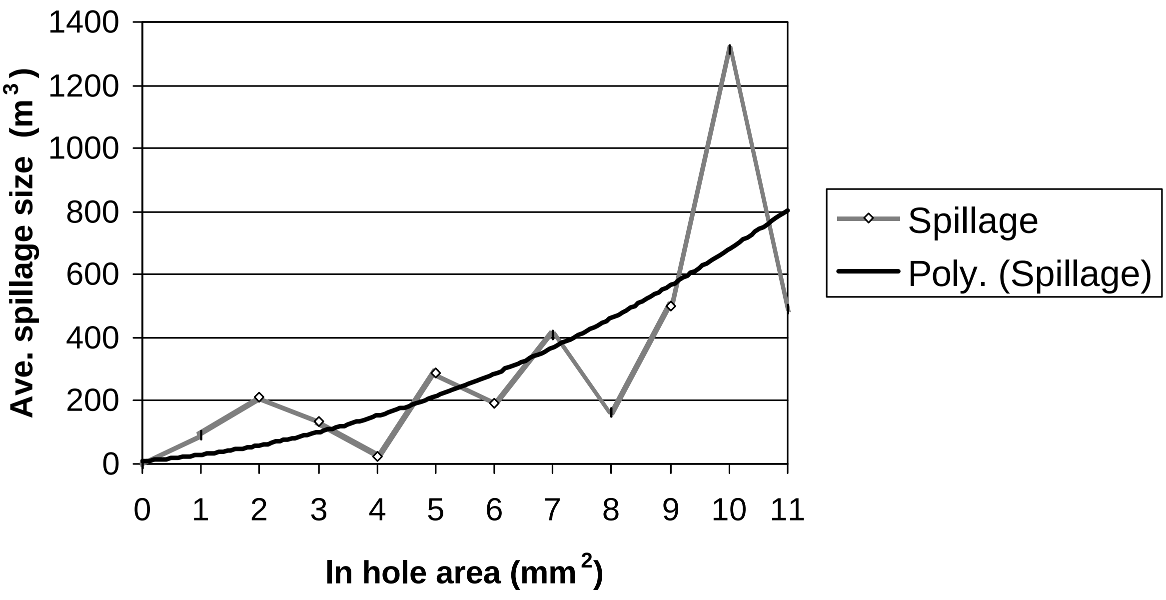
As expected, pinholes result in the smallest spillages and ruptures in the largest. For the other three hole type categories, other factors are clearly more important as determinants of the spillage outcome.

Pinholes are nearly always caused by corrosion. Mechanical incidents tend to result in an excess of ruptures whilst operational and natural hazard incidents tend to cause more than their share of splits. Otherwise hole types follow similar patterns to the cause incidences.

A majority of mechanical, operational and natural hazard incidents cause the largest two types of hole whereas third party is equally divided and the corrosion preponderance is with the smaller hole types.

It would be expected that the larger the size of the hole the larger on average the spillage would be, on the proviso that the pipeline was pumping i.e. not static at the time of the incident. The two rather obvious reasons for this are that higher leakage rates come out of larger holes and the hole sizes are to an extent related to the pipeline diameter which in turn tends to set the potential flow rate available for leakage. The relationship for the not static pipeline leakages, given by the average gross spillage size (m^3) versus the natural logarithm (ln) of the hole size (mm^2) is indicated in **Figure 18**. The solid line drawn through the data points is a polynomial fitted curve.

Figure 18 Relationship of spillage size with hole area

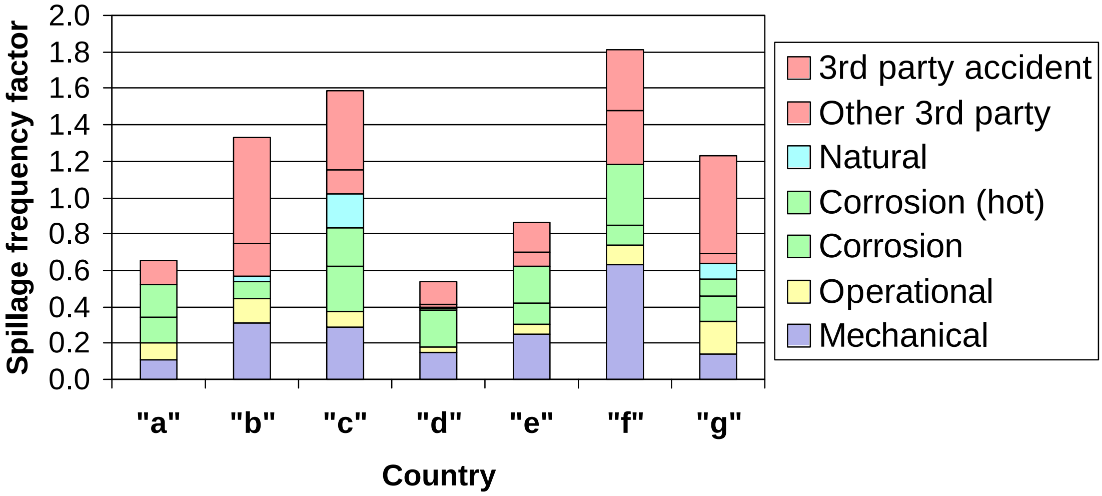


5. SPILLAGE CAUSES

CONCAWE categorises spill causes into five major categories: mechanical failure, operational, corrosion, natural hazard and third party. These are further divided as discussed in the sections below to give a total of 13 subsets.

The spillage records in different countries exhibit quite different mixes of relative frequencies of these different causes. The spillage frequency factors are defined in relative terms by the number of spillages per 1000 km per country per year divided by the overall average number of spillages per 1000 km per year. Thus the average performance factor is 1.0 with lower numbers representing better performances.

Figure 19 Relative frequency factors of spillage causes



Countries “a” to “f” are individual countries and “g” represents the rest. It seems likely that in the main the over-riding reasons for different performances relate back to particular characteristics of the country’s pipeline inventories and to the severity of the environment from a pipeline viewpoint e.g. intensity of excavations locally. It can be seen that the hot pipeline corrosion occurred exclusively in countries “a”, “c”, “e” “f” and “g”. The natural hazard incidents experienced are largely focussed in country “c”. Countries “a” and “d” have achieved the best all round performances by doing consistently better in all categories except corrosion.

5.1. MECHANICAL FAILURE

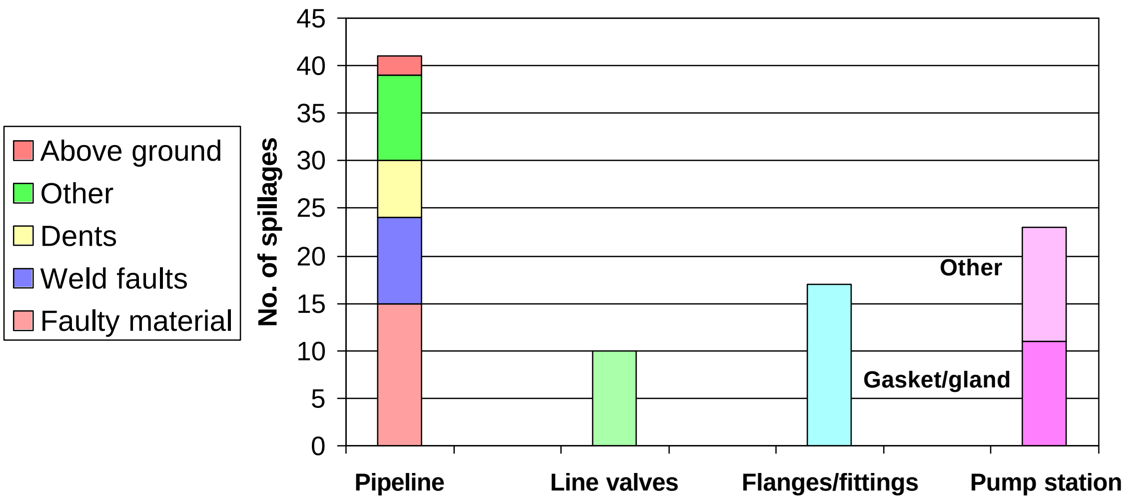
There have been 91 mechanical failures out of the total of 379 spillages. Thus this category has averaged 3.0 spillages per year, 24% of the total. Their average sizes are 237 m^3 gross and 93 m^3 net per spill. Mechanical failures have contributed 33% of the gross and 28% of the net totals of spillage from all causes.

Mechanical failures are categorised into two causes: Construction Fault and Materials Fault: 32 spillages are in the former category and 59 in the latter.

5.1.1. Causes of mechanical failures

The most common causes of mechanical failures are illustrated in **Figure 20**.

Figure 20 Causes of mechanical failures



It should be noted that by definition the dents that cause mechanical failure have to have been made during the pipeline's construction. Dents made subsequently that eventually lead to spillages are categorised as third party (see **Section 5.5.2**).

Although there is no available figure on it, by far the greatest part of the material in place in the pipeline system is the underground pipe itself. The fact that only 41 out of the 91 spillages occurred from the line pipe indicates by contrast that the relatively vulnerable features from a mechanical standpoint are pipeline valves, flanges and other fittings and the pump stations. In particular, gaskets and glands in flanges (11 spillages) have given trouble. This finding indicates that adding apparently useful items such as more section block valves can also have a negative impact on spillage frequency. Thus the minimisation of such features is not only an economic factor. Where it is possible, these more vulnerable features should be designed out of the pipeline system.

After the first half of the '90s, the rate of improvement in mechanical failures had fallen behind the improvements in the other spillage causes probably because of the one-off nature of many mechanical failures. They figure in nearly all of the 20 primary and most of the 11 secondary categories used to describe the causes of the majority of spillages (See **Appendix 2**, page 39). Also, these leakages occurred from 16 out of the 17 categories used to describe what part of the pipeline actually leaked. Of these, only a few, such as line pipe flaws, pipe seam and butt welds and bends, are open to control by modern internal inspection techniques using intelligence pigs. Additionally the trend has been to increase the complexity of control systems, volume and quality measurement and suchlike, which have required the addition of further, potentially more vulnerable fittings. CONCAWE does not have a detailed inventory recorded over time of the numbers of fittings, flanges etc. so no quantified trends can be calculated. However, only 4 mechanical failures have occurred in the last five years, so it is now again apparent that the ongoing efforts to improve the mechanical reliability of individual equipment items are bearing fruit.

As yet there is no evidence of any increase in those mechanical failures that are potentially age-related, such as metal fatigue failures of pipelines that are operated close to their elastic limits under cycling pressure conditions. If any such pipelines exist, they are only a very small part of the inventory and the zero spillage record shows that no pipeline has reached an age where repeat failures are being experienced.

5.2. OPERATIONAL

This category covers operation problems of system malfunction and human error. These have caused 29 spills (19 human error, 10 systems failure), i.e. 1 per year or 8% of the total. They have resulted in the a spillage of 2617 m^3 gross, 1270 m^3 net, equivalent to 4% of the gross and of the net total spillage from all causes.

Except for their propensity to cause smallish sized spillages, there is no general trend apparent. However, there is something of a pattern: just 3 pipeline operators (out of some 70) have been responsible for nearly half of the human error and only 2 other operators incurred 60% of the systems faults. The underlying causes of this pattern are impossible to determine. Over the past 30 years, some pipeline systems have been more highly dependent on manual operations and others on control systems. Also, there is a wide variation in the complexity of the pipeline systems operated. The records provide no way of weighting these very different populations. Moreover, the number of occurrences is probably not sufficient to draw any firm conclusions on the operating standards of individual companies.

5.3. CORROSION

Since the CONCAWE 25-year performance report [5] an additional corrosion category has been formed for stress corrosion cracking. Although there have only been three of these spillages so far (one re-categorised from external corrosion), they have been big spillages for the corrosion cause, totalling 1957 m^3 gross and 1353 m^3 net.

There have been 90 occurrences of spills due to external corrosion resulting in the spillage of 7217 m^3 gross, 1793 m^3 net. Thus the average spill is 80 m^3 gross, 20 m^3 net, which shows that in general, external corrosion results in smaller sized spills than any of the other causes except for operational.

There have been 20 occurrences of internal corrosion resulting in the spillage of 3763 m^3 gross, 1691 m^3 net, corresponding to 188 m^3 gross and 84 m^3 net per spill. These figures are influenced by the occurrence of one particularly large spillage in this category (2000 m^3 gross, 500 m^3 net). Otherwise the internal corrosion spill size pattern is very similar to external corrosion.

Overall, corrosion has contributed 3.8 out of the total of 12.6 spillages per year, almost 30%. However, the spillage volume contributed only 20% of the gross and 16% of the net totals from all causes.

Out of all the possible permutations of pipeline service sub-divisions (hot, cold, external, internal) and corrosion categories (external and internal) there are three particularly useful combinations that highlight particular aspects: cold pipelines external and internal corrosion, hot pipelines external corrosion; and all pipelines internal corrosion.

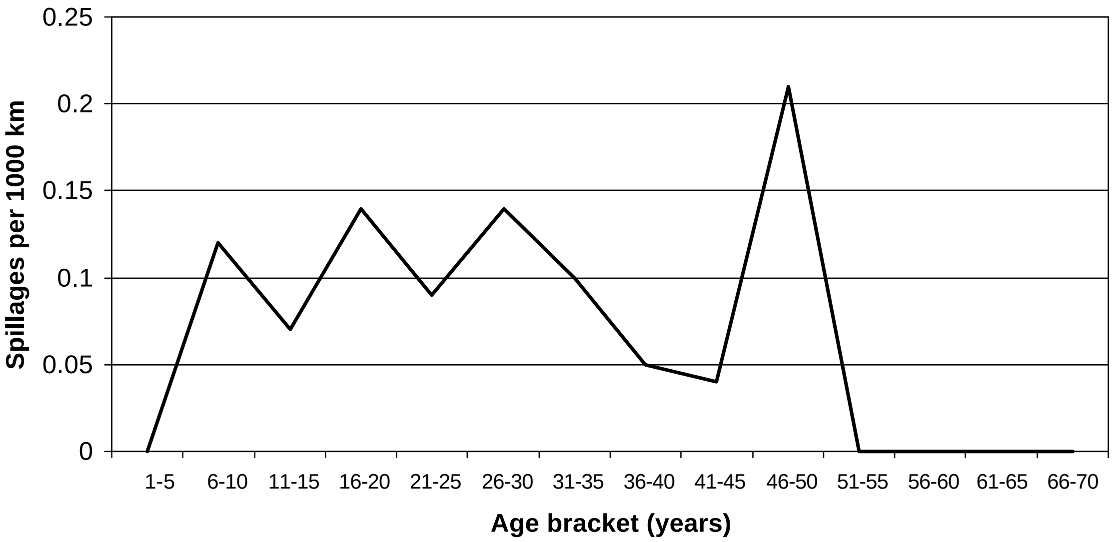
5.3.1. External and internal corrosion in cold pipelines

The main interest in this category concerns whether there is any evidence that pipelines are starting to reach the end of their lifetimes due to general corrosion. The age/spillage frequency relationship (spillages per year per 1000 km in the same age bracket) has been calculated by counting for cold pipelines the number of spillages per year due to corrosion that have occurred in each 5-year age bracket from 1-5 years through to 66-70 years.

Age	1-5	6-10	11-15	16-20	21-15	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-66	66-70
Spills	0	9	6	13	8	11	7	2	1	3	0	0	0	0
'000 km	1.89	2.58	2.77	3.01	3.03	2.70	2.25	1.44	0.93	0.47	0.33	0.24	0.01	0.00

The number of spillages in each age bracket is then divided by the average length in each age bracket over the 30-year period and by the 30 years in the period. The results are shown in **Figure 21**.

Figure 21 Cold pipelines corrosion spillage frequency/age relationship



The average of such a plot is around 0.1, i.e. 60 spills divided by 30 years = 2, divided by 21.65 thousand kilometres of cold pipeline on average in the inventory. It can be seen that up to 45 years of age where there are sufficient data to be meaningful, there is no sign yet of any increasing trend. The odd result in the 46-50 year age bracket is not of comparable robustness, being largely the result of two spillages from a single pipeline whose design, construction and service conditions all bear hallmarks of being atypical. Thus its performance is not indicative of the prospects for the other pipelines.

An important factor in cold pipeline corrosion is the much higher incidence of corrosion attacks in features of the pipeline such as road crossings, anchor points, sleeves, etc. Only 34 out of the 60 incidents occurred from normal underground pipe runs which, given the very great lengths in the inventory, implies that the other pipeline features are much more vulnerable.

It is anticipated that inspections using intelligence pigs should improve preventative intervention by identifying the development of corrosion attack. This should prevent any occurrence of ‘end of life takeoff’ in spillage numbers. Indeed, there is the strong prospect of reducing corrosion spillage incidents by catching the corrosion before it gets too far advanced.

5.3.2. External corrosion in hot pipelines

About half a dozen fuel oil pipelines with particularly severe design and construction problems with heat insulating coatings which allowed water ingress, were responsible for the majority of the 37 hot external corrosion spills (out of the 30-year total of 52) during the 1971-80 10-year period. These pipelines were closed down or changed service due to the combination of their poor performance and the rapid decline in the fuel oil business that took place in the late ‘70s.

Those hot pipelines remaining in service and the few new ones added have been better performers, but have still been responsible for the 15 external corrosion spillages during the 1981-2000 20-year period. On a frequency per 1000 km basis, even this more recent performance for hot pipelines (average length 0.55 thousand km) is 16 times worse than for cold pipelines (average length 24.5 thousand km).

5.3.3. Internal corrosion in all pipelines

Internal corrosion is much less prevalent than external corrosion, with only 20 occurrences versus 90. One of the pipelines suffering a spill reported that inhibitor was used, one did not report and the other 18 did not use inhibitor. Some 74% of the cold pipeline internal corrosion incidents occurred in crude service compared with only 23% for cold pipeline external corrosion. Thus km for km, crude pipelines are 3 times more vulnerable to internal corrosion than product pipelines.

5.4. NATURAL HAZARD

Natural hazards have caused only 14 spillages, 10 of which were due to landslides or subsidence, 2 to flooding and 2 to other hazards. This category contributes 4% of the total number of spillages. The resulting spillage volume was 2671 m^3 gross, 1004 m^3 net, 4% of the gross spillage and 2% of the net spillage totals from all causes. The natural hazard- caused spill sizes are 191 m^3 gross, 71 m^3 net per spill, i.e. very close to the overall average spill sizes.

No less than 10 of the natural hazards spills have occurred in the same country. This appears to be a direct consequence of the difficult terrain and hydrological conditions that apply to a significant part of that country's pipeline network.

5.5. THIRD PARTY

Third parties have caused 132 spillages: 100 accidentally, 10 maliciously and 22 incidentally (or prior) damaged. The category therefore contributes 4.4 spillages per year, 35% of the total number of spillages. The amount spilled as a result is 25,784 m^3 gross, 14,318 m^3 net, being 39% of the gross and 48% of the net spillages from all causes. The average third party spill size is 195 m^3 gross and 98 m^3 net.

The third party category, therefore, is the largest single cause of spillages and is also responsible for the largest proportion of the volume spilled.

5.5.1. Third party accidental

The most common causes of accidental third party spills are shown in **Figure 22** and their sizes are shown in **Figure 23**.

Figure 22 Causes of accidental third party spills

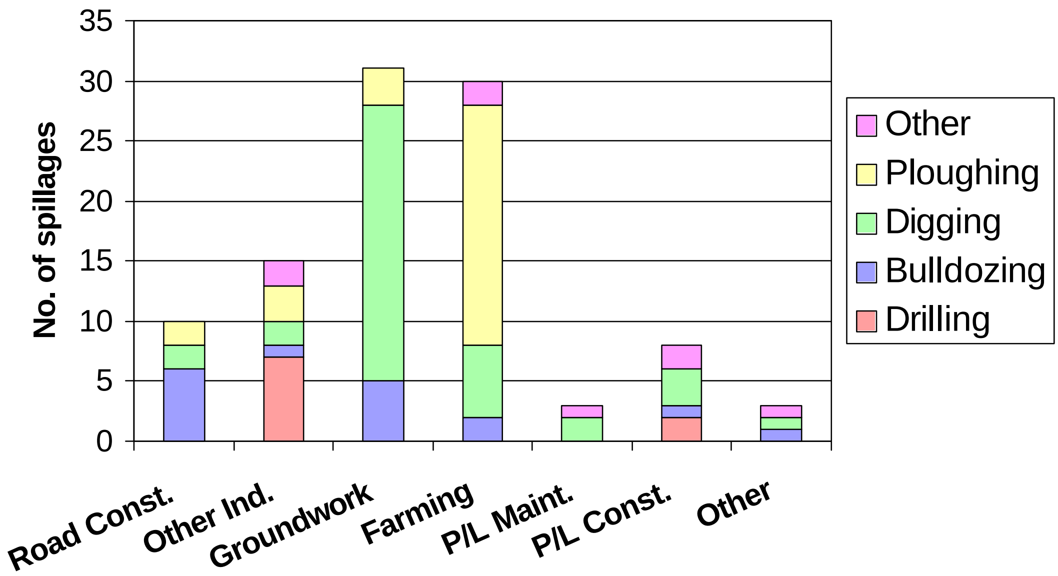
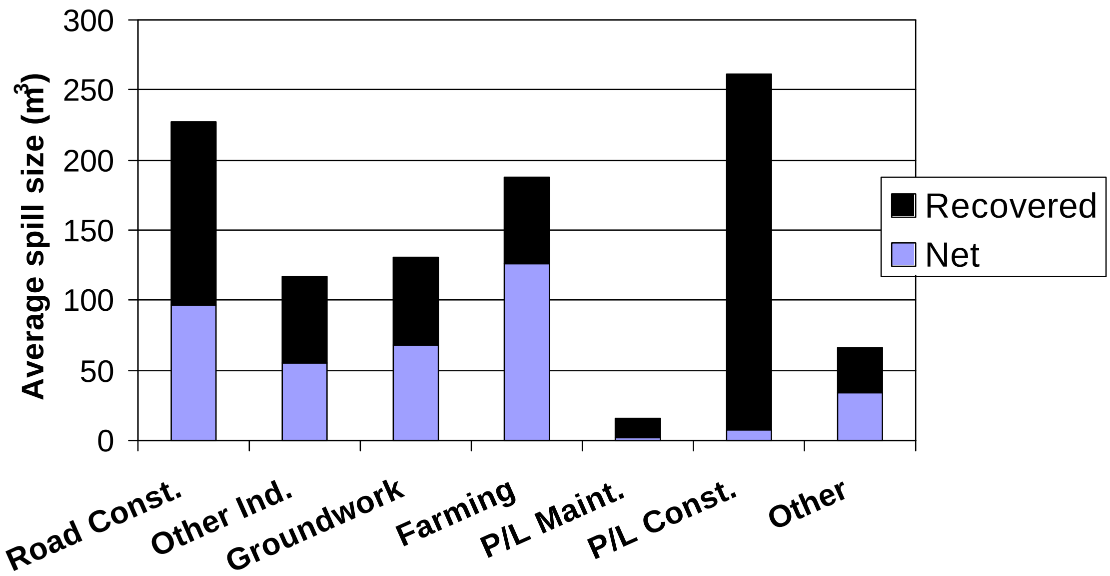


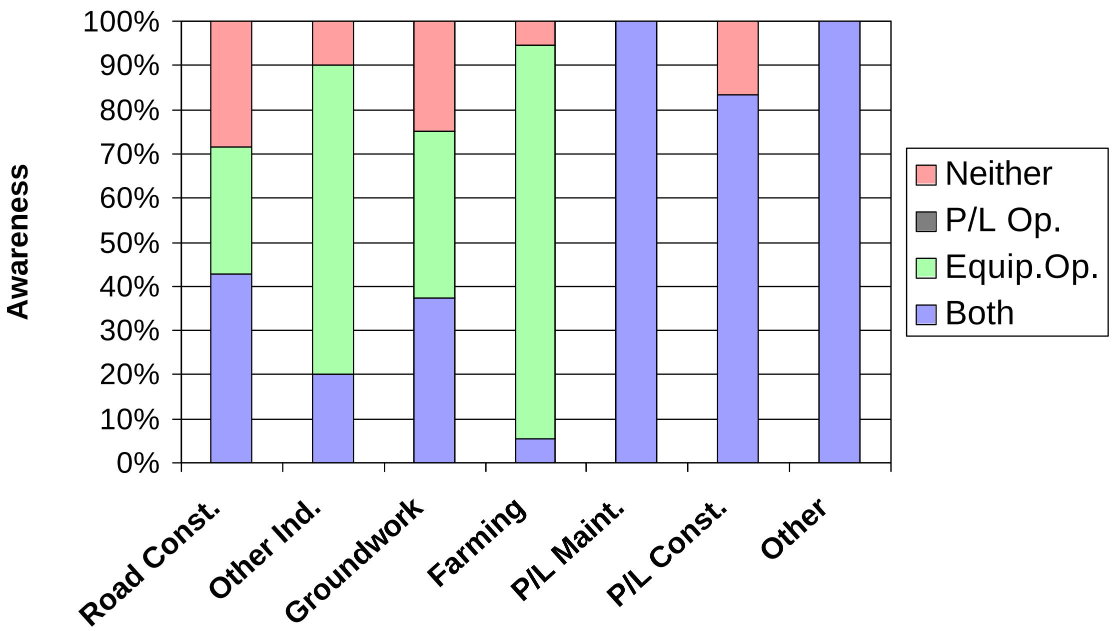
Figure 23 Spillage sizes (m^3) by type of work causing spillage



Only one of these spillages was not caused by direct damage from operating machinery. In that case an electrical earthing deficiency had arisen on a pipeline with no previous problem as a consequence of the electrification of an adjacent electric railway line.

The operation of machinery causes damage to pipelines through one or other or a combination of just two factors: (i) lack of awareness and (ii) lack of care or skill. Any lack of advance awareness by a pipeline operating company of an impending ground working job leads to inadequate site advice on pipeline location, insufficient working procedures and lack of appropriate supervision for machinery operators. The operator may be left partially or completely unaware of a pipelines existence, a recipe for problems no matter how well the work is managed and machinery is operated. Then again, with or without the involvement of the pipeline operating company, the works management and the machinery operators may be partially or fully aware of the pipeline's existence but either the manager or the operator may fail to apply the requisite care or skill to their role in works planning or execution. The awareness of pipeline operators and machinery operators has been reported for 69% of the spillages and are shown in **Figure 24**. It should be noted that there are no occasions where the pipeline operator was aware of the works but the machinery operator was not aware of the pipeline.

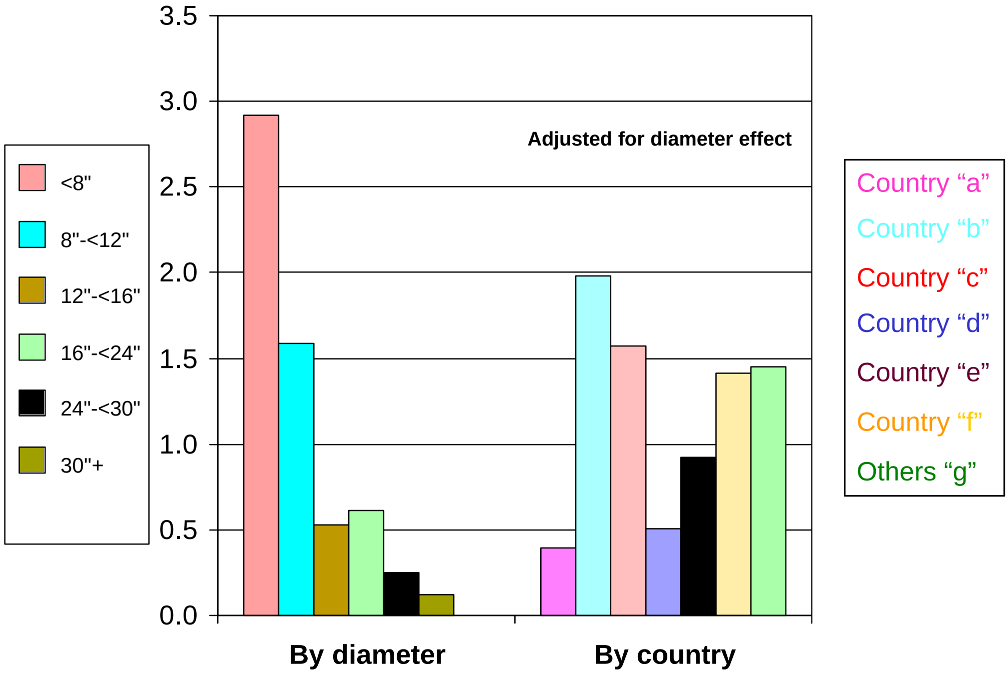
Figure 24 Awareness about impending works and of pipeline location



Lack of awareness by pipeline operating companies is an almost universal factor behind spillages caused by farming and in 60-80% of all other not pipeline-related works. Overall some 65% of the 3rd party accidental spillages would most probably have been prevented by proper communication to pipeline operators by the 3rd parties. Lack of care or skill by the 3rd party works management or machinery operators is responsible for 35% of the spillages.

An analysis has been made of the relationships between the vulnerability to third party damage and various physical attributes. The two strongest relationships, i.e. with pipeline diameter and with the country of operation, are shown in **Figure 25**.

Figure 25 3rd party accidental relative frequency factors



The frequency factor is a measure of the vulnerability determined by calculating the average frequency of third party accidental spillages per unit length (factor = 1.0) so as to compare the frequency of the spillages per unit length of the various populations.

Smaller pipeline diameter is strongly related to higher vulnerability. The below 8" size range is nearly three times more vulnerable than average whilst the 30"+ population suffers only about one tenth of the average frequency of incidents. A number of possible reasons for this could be postulated but there is no way of determining from the available data what each risk-increasing factor might contribute. Neither is there sufficient data on depth below surface to indicate how much the risk is reduced by deeper coverage. It is not recorded if larger pipelines have greater coverage than small ones.

There is also a considerable disparity between the third party incident experiences of different countries. In this comparison, the frequency factors have been adjusted according to the degree of vulnerability inherent for the pipeline inventory in each country depending on whether the pipeline systems are smaller or larger in diameter than the average. Taking Country "e" as an example, its inventory is of a larger diameter than the average with vulnerability 0.67 of the average. Thus the unadjusted spillage frequency factor of 0.62 becomes 0.92 after adjustment. On this basis two countries have records which taken over the 30 year period are more than 50% worse than the average. The best country has experienced only about 40% of the average, i.e. is five times better than the worst one. The performance gap between countries now is probably closer than it has been in the past. There appears to be no particular piece of national legislation in the good performers that is missing in the worse performers.

The prevention of third party accidental spillages is of the highest priority due to its place in the spillage cause league. It is also the most amenable to improvement by sharing experiences and comparing operating and work control practices between pipeline operators from different companies and countries.

5.5.2. Third party incidental damage

This category is somewhat of a catchall and includes those incidents where damage was done at some unknown point in a pipeline’s lifetime, which subsequently suffers deterioration over time resulting eventually in a spill. In general they result from unreported damage done after the original construction when a pipeline has been knowingly or unknowingly hit during some or other third party’s groundwork activities.

There have been 22 incidental damage incidents. They all started off from dents, scrapes and suchlike. Thus they share the characteristic that they may well be detectable by intelligence pig inspections.

6. INTELLIGENCE PIG INSPECTIONS

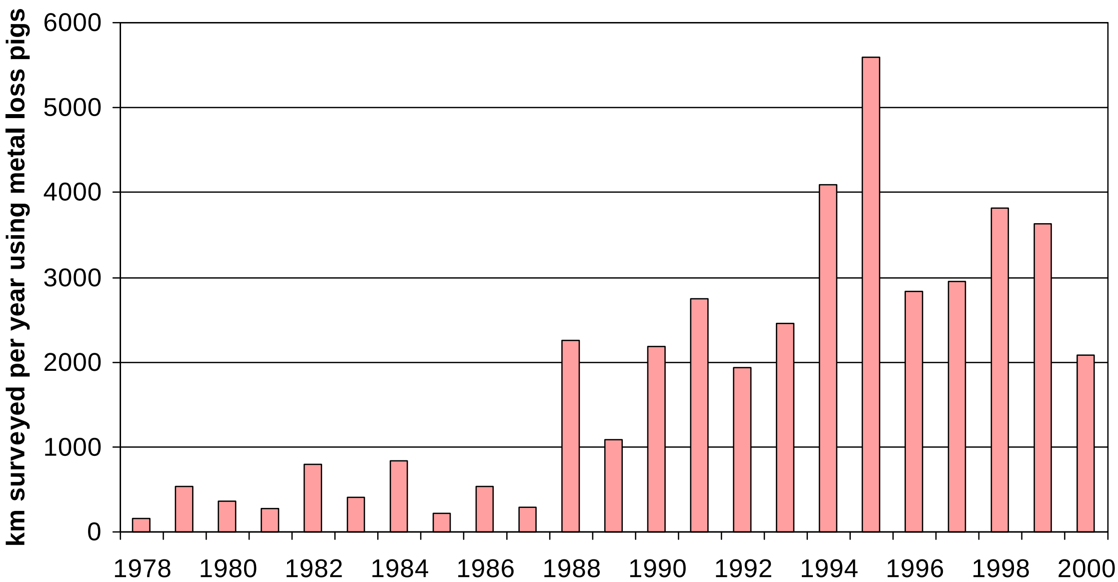
6.1. INTELLIGENCE PIG INSPECTION ACTIVITY

CONCAWE has been collecting data on intelligent pig inspection activity for the past ten years, including a one-off exercise to collect back data from the time intelligence pigs were first used back in 1977. Separate records are kept for metal loss pig (currently including crack detection pigs) and for geometry (calliper) pig inspections. Each inspection may entail one or more passes of a pig along a piggable pipe section.

Leak detection pigs are also sometimes used but their function is quite different. They can reduce the consequences from a leak that has already started by helping to catch it earlier. They do nothing to help prevent the leak occurring in the first place.

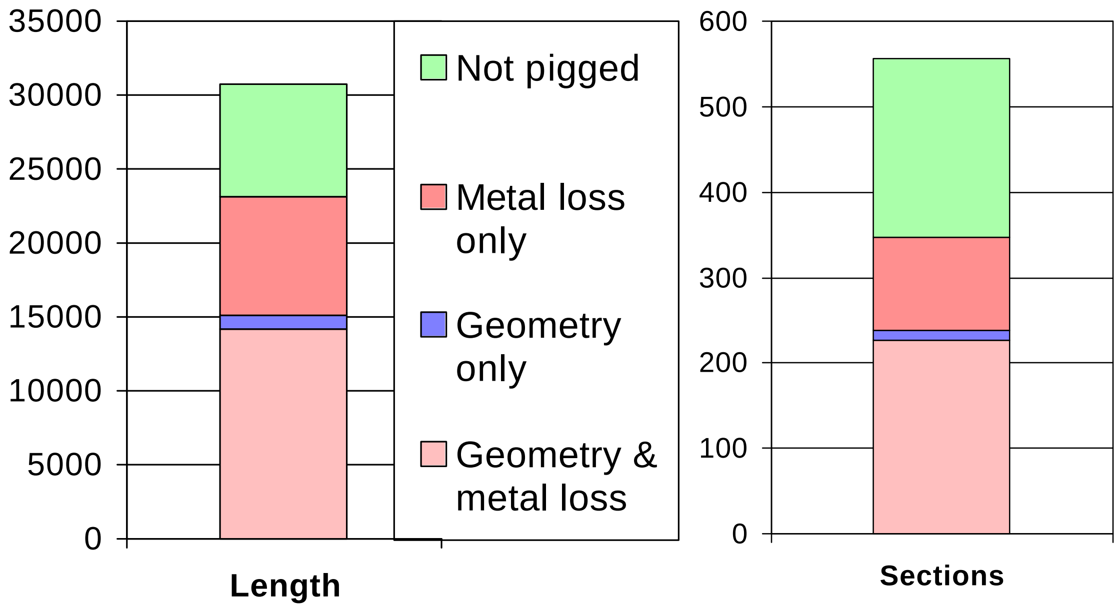
As shown in **Figure 26**, the growth in intelligence pig use for internal inspection of pipelines has been spectacular, and is now reducing to levels that maintain inspection integrity.

Figure 26 Growth in the use of intelligence pigs



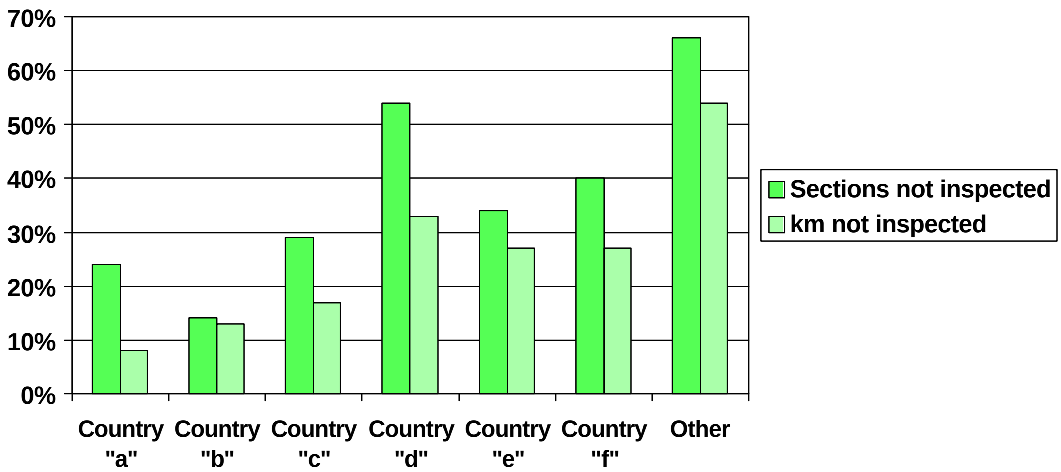
In the 23 years of use of the technique the length of pipeline surveyed has grown from nothing to peak at 19% of the total system in 1995. Now that the backlog of first inspections is much reduced, the rate of inspections has fallen to around 10% of the inventory annually.

Figure 27 Pig-inspected pipelines at end 2000



It can be seen that some 72% of the length of the total system has been intelligence pig inspected at least once. In terms of the number of pipeline sections inspected, some 60% has been done at least once. The difference between these two percentages indicates that a majority of the not-inspected pipelines lies with the shorter pipelines and pipeline sections. The pig inspected pipeline status by country is shown in **Figure 27**. The relatively recent introduction of pigs to inspect 150 mm (6 inch) diameter pipelines means that small diameter is no longer a bar to pig inspections. Less than 150 mm diameter pipelines comprise a negligible percentage of the pipeline inventory.

Figure 28 Pig-inspected pipeline status by country



As expected, all these countries show higher percentages of pipeline sections not yet inspected than the corresponding km percentages. It is now the shorter sections of low throughput product pipelines that predominate in the not inspected category.

The spread (8% to 54% km not inspected) over the seven countries is quite wide. There is no indication from the records why this should be so.

6.2. SCOPE FOR PERFORMANCE IMPROVEMENT

The intelligence pig inspection technique only finds flaws, corrosion and other sorts of damage in or on the pipe inner or outer walls. Over the past 30 years, as shown in the table below, there have been 102 spillages, some 3.5 per year, where the trouble might have been discovered by internal inspection before the failure had occurred.

Spillages (over 30 years) preventable by internal inspections:

Mechanical failures (line pipe welds, pipe material faults)	34
Corrosion (excluding excess historic hot incidents)	50
Third party incidental (non-construction scrapes and dents)	18
TOTAL	**102**

These categories will all tend to increase with age at some point in the future. Internal inspections will ensure that repairs will be made before they become spillages.

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APPENDIX 1 LENGTH OF PIPELINE IN EACH AGE BRACKET BY YEAR

	1-5	6-10	11-15	16-20	21-25	26-30	30-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	Total
															kmx10^3
1971	5.02	4.42	2.11	1.79	0.12	0.03	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	13.63
1972	4.68	5.10	2.18	2.43	0.38	0.03	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	14.95
1973	4.55	4.88	2.79	1.39	1.91	0.03	0.11	0.00	0.04	0.00	0.00	0.00	0.00	0.00	15.70
1974	3.74	5.53	3.20	1.46	1.87	0.08	0.11	0.00	0.04	0.00	0.00	0.00	0.00	0.00	16.02
1975	3.40	5.39	3.52	2.08	1.87	0.06	0.14	0.00	0.04	0.00	0.00	0.00	0.00	0.00	16.48
1976	3.25	5.05	4.52	2.14	1.79	0.13	0.03	0.11	0.04	0.00	0.00	0.00	0.00	0.00	17.05
1977	2.40	4.42	5.10	2.18	2.43	0.38	0.03	0.11	0.04	0.00	0.00	0.00	0.00	0.00	17.08
1978	1.66	4.30	4.87	2.79	1.39	1.91	0.03	0.11	0.00	0.04	0.00	0.00	0.00	0.00	17.10
1979	1.58	3.76	5.25	3.19	1.47	1.87	0.08	0.11	0.00	0.04	0.00	0.00	0.00	0.00	17.34
1980	1.55	3.40	5.11	3.63	2.08	1.87	0.06	0.14	0.00	0.04	0.00	0.00	0.00	0.00	17.86
1981	1.00	3.25	4.76	4.62	2.14	1.79	0.13	0.03	0.11	0.04	0.00	0.00	0.00	0.00	17.87
1982	0.81	2.37	4.42	5.15	2.18	2.43	0.38	0.03	0.11	0.04	0.00	0.00	0.00	0.00	17.93
1983	1.16	1.64	4.07	4.82	2.82	1.39	1.84	0.03	0.11	0.00	0.04	0.00	0.00	0.00	17.91
1984	1.28	1.58	3.50	5.19	3.23	1.46	1.79	0.08	0.11	0.00	0.04	0.00	0.00	0.00	18.26
1985	1.12	1.55	3.28	4.87	3.52	2.04	1.79	0.06	0.14	0.00	0.04	0.00	0.00	0.00	18.40
1986	1.19	1.00	3.09	4.43	4.44	2.06	1.79	0.06	0.03	0.11	0.04	0.00	0.00	0.00	18.23
1987	1.09	0.81	2.24	4.14	5.03	1.27	2.43	0.31	0.03	0.11	0.04	0.00	0.00	0.00	17.48
1988	1.38	1.70	2.26	4.84	5.22	4.39	3.46	2.07	0.44	1.48	0.00	0.04	0.00	0.00	27.27
1989	1.30	1.74	2.13	4.40	5.55	4.67	3.50	2.10	0.08	1.89	0.00	0.04	0.00	0.00	27.38
1990	1.11	1.70	1.89	4.24	5.46	3.96	4.87	2.08	0.23	1.91	0.01	0.04	0.00	0.00	27.48
1991	1.71	1.63	1.83	4.24	5.47	5.06	4.10	2.92	0.23	1.16	0.75	0.04	0.00	0.00	29.15
1992	2.11	1.53	1.51	3.22	5.03	5.65	4.59	3.59	0.48	0.43	1.48	0.04	0.00	0.00	29.65
1993	1.83	1.38	1.70	2.64	5.04	5.41	4.17	3.43	2.07	0.43	1.48	0.00	0.04	0.00	29.61
1994	1.71	1.30	1.74	2.45	4.47	5.94	4.40	3.47	2.07	0.07	1.89	0.00	0.04	0.00	29.53
1995	1.54	1.11	1.70	2.19	4.22	5.94	3.83	4.65	1.88	0.22	1.91	0.01	0.04	0.00	29.22
1996	0.89	1.65	1.63	1.80	4.05	5.48	4.85	3.88	3.30	0.22	1.16	0.75	0.04	0.00	29.69
1997	1.20	2.06	1.52	1.48	3.11	4.88	5.46	4.24	3.90	0.48	0.43	1.48	0.04	0.00	30.28
1998	1.18	1.87	1.35	1.67	2.56	4.84	4.65	3.61	3.93	1.92	0.44	1.48	0.00	0.04	29.53
1999	1.12	1.75	1.27	1.72	2.44	4.13	5.32	3.87	3.88	2.05	0.08	1.80	0.00	0.04	29.48
2000	1.70	1.63	1.06	1.69	2.20	4.13	5.19	3.32	5.36	1.97	0.23	1.82	0.01	0.04	30.32

Note Excludes hot pipelines, i.e. these data are used in calculating **Figure 20**.

APPENDIX 2 LIST OF SPILLAGES BY YEAR

KEY

Col.1 **Spill Cause Category**

A Mechanical failure
A(A) = Construction fault A(B) = Materials fault

B Operational
B(A) = System malfunction B(B) = Human error

C Corrosion
C(A) = External C(B) = Internal C(C) = Stress cracking

D Natural hazard
D(A) = Landslide/subsidence D(B) = Flooding D(C) = Other

E Third party activity damage
E(A) = Direct accidental E(B) = Direct malicious E(C) = Incidental

Col 4 **Service**

1 = Crude oil 2 = Clean Product 3 = Fuel oil (hot)
4 = Crude oil + Clean product 5 = Lubes (hot).

Col 5 **Geographical characteristics of spill location**

1 = Commercial 2 = Industrial 3 = Residential
4 = Rural 5 = Forest 6 = Mountainous.

Col 6 **System associated with the spillage**

1 = Line pipe 2 = Pump station 3 = Valve (line)
4 = Road crossing 5 = Manifold 6 = River crossing
7 = Terminal 8 = Fitting (other) 9 = Pipe fitting
10 = Pump 11 = Above ground pipeline.

Col 7 **Discovered by**

1 = Right of way survey by P/L staff 2 = Automatic detection system
3 = 3rd party passer-by 4 = Routine monitoring by P/L staff
5 = Pressure testing 6 = Contractor working for P/L company
7 = P/L maintenance staff 8 = 3rd party worker
9 = Internal inspection survey

Col 11 **Injuries and fatalities**

Injuries: Number injured e.g. 1 (i) = one injury
Fatalities (f) are included in this same column, e.g. 2 (f) = two fatalities.

Col 13 **Detailed definition of leaking equipment**

1 = Line pipe	2 = Line pipe bend (manufact.)	3 = Line pipe weld
4 = Line pipe flange	5 = Line pipe bend (field made)	6 = Fitting flange
7 = Valve	8 = Line pipe dent	9 = Vent/drain
10 = Pump	11 = Pig trap	12 = Fitting hose/valve
13 = Surge/relief valve	14 = Line pipe gland	15 = Fitting weld
16 = Slop tank	17 = Instrument	18 = Manifold pipework.

Col 14 **Primary cause/Operational fault/Pipe coating type**

Primary cause - All spillage categories except B(a), B(b) & C(a)

1 = Dent	2 = Faulty weld (undetected)	3 = Faulty weld (repair)
4 = Faulty heat treat	5 = Pipe fitting failure	6 = Gasket failure
7 = Pipe material lamination		8 = Faulty material
9 = Temperature effect	10 = Gland failure	11 = Traffic effect
12 = Mining related	13 = Over pressurized	14 = Vibration
15 = Temperature change	16 = Bolt/screw/plug loose/failure	
17 = Design fault	18 = Bypass/dead leg related	19 = Electric current effect
20 = Other		

Item causing operational spillage - Categories B(a) and B(b)

1 = Human error	2 = Mechanical problem	3 = Control system fault
4 = Instrument system fault		

Coating type - Category C(a)

1 = Bare	2 = Asphalt	3 = Thin film
4 = Coal tar	5 = Tape	6 = Extruded
7 = Heat insulation	8 = Concrete	

Col 15 **Secondary contributing cause/ Fault type/Coating application/Hazard nature**

Secondary contributing cause - Categories A(a), A(b), E(a) & E(c)

1 = Fatigue crack	2 = H_2 stress crack	3 = Thermal shock
4 = Near weld	5 = Settlement	6 = Over pressurized
7 = Faulty installation	8 = External damage	9 = Vibration
10 = Aged	11 = Traffic effect	

Fault type - Categories B(a) & B(b)

1 = Valve malfunction	2 = Computer hardware	3 = Computer software
4 = Design fault	5 = Instrument malfunction	6 = Not de-pressurized
7 = Incorrect valve operation		
8 = Incorrect construction/maintenance procedure/execution.		

Application method used for coating - Category C(a)

1 = Mill	2 = Yard	3 = Field	4 = Not known.

Inhibitor use - Category C(b) only 1 = Yes 2 = No

Hazard nature - Categories D(a), D(b), D(c) & E(b)

1 = Landslide	2 = Subsidence	3 = Flooding,	4 = Terrorist activity
5 = Vandalism	6 = Frost	7 = Pipe bridge collapse	8 = Product theft

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
AA	1971		1		2	7	4	0		0		6	16	
AA	1971	10.8	2		6	3	0	0		0	6	1	6	7
AA	1971	10.8	2	4	1	7	1	1		0	3	4	3	
AB	1971	20	1		2	2	40	5	60000	0	5	6	6	
BA	1971		1	2	2	7	350	0		0	9	16	4	5
BB	1971		1		2	7	25	0		0	0	9	1	7
CA	1971	8	2		1	4	6	6		0	20	1		
CA	1971	4.5	3		1	3	3	0		0	8	1	7	
EA	1971	20	1		1	6	300	50	1000	0	5	1		
EA	1971	34	1		1	6	2000	0		0	9	1		
EB	1971	8	2			3	2	2		0	20			5
AB	1972	28	1	2	2	4	800	150		0	12	2	2	
AB	1972	12	2	4	9	3	70	39		0	5	4	5	8
AB	1972	16	2		1	7	5	0		0	4	12	6	
CA	1972	10	1	2	11	7	1	1		0	39	1		
CA	1972	8.6	1		4	3	10	5		0	29	1		
CA	1972	10	1	2	11	7	1	1		0	39	1		
CA	1972	8.6	1		4	3	40	35		0	29	1		
CA	1972	10	2		1	4	150	50		0	7	1		
CA	1972	4	3	2	1	3	0	0		0	15	1		
CA	1972	12	3	1	1	3	5	1		0	12	1		
CA	1972	6	3		1	3	1	0		0	15	1		
CA	1972	12	3	1	1	3	500	0		0	12	1		
EA	1972	10	1		1	8	90	0		0	6	1		
EA	1972	20	1	1	1	7	200	60		0	8	1		
EA	1972	20	1		1	7	250	100		0	8	1		
EA	1972	8	1	4	1	8	7	0		0	8	1		
EA	1972	28	1		1	8	60	12		0	16	1		
EA	1972	8	2	4	1	4	400	350		0	2	1		
EA	1972	10	2		1	8	30	0		0	9	1		
EA	1972	10	2	4	1	8	99	96		0	6	1		
EC	1972	12	3		1	3	0	0		0	5	1	11	8
AA	1973	20	1	2	2	3	25	3		0	1	4	6	3
AA	1973	4.5	3		1	1	4	0		0	8	1	15	1
AB	1973	16	1	2	2	7	0	0		0	3	7	14	1
AB	1973		1	2	2	7	4	0		0	11	15	10	
AB	1973	18	1	2	2	4	11	1		0	13	10	14	1
AB	1973	6	2	2	1	3	12	6		0	1	6	6	
AB	1973	24	2	2	2	7	25	0		0	2	4	6	
CA	1973	8.6	1		1	1	12	12		0	32	1		
CA	1973	12	3		11	1	150	2		0	13	1	7	
CA	1973	12	3	1	1	3	310	10	30000	0	13	1	7	

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
CA	1973	4.5	3		1	1	15	0		0	8	1	7	
CA	1973	12	3		11	3	250	5		0	13	1	7	
CA	1973	4.5	3		1	1	15	0		0	8	1	7	
CA	1973	12	3		11	7	12	2		0	13	1	7	
CA	1973	12	3		1	3	200	2		0	13	1	7	
DA	1973	28	1		1	3	100	40		0	16	1		2
EA	1973	10	3	4	1	8	8	0		0	9	1		
EC	1973	12	3		1	3	0	0		0	6	1	11	8
EC	1973	12	3		1	3	1	0		0	6	1	11	8
EC	1973	12	3		1	1	0	0		0	6	1	11	8
AA	1974		1	2	2	4	3	2	1000	0	5	9	11	5
AA	1974		1	2	2	7	1	0		0	4	9	15	1
AA	1974	6	1		9	3	20	0		0	15	2	14	1
CA	1974	8.6	1		1	1	10	0		0	33	1		
CA	1974		2		8	7	2	2		0	6	9		
CA	1974	12	3		1	3	5	0		0	8	1	7	
CA	1974	10	3	2	1	4	1	0		0	9	1	7	
CA	1974	4	3	2	1	3	1	0		0	17	1	7	
CA	1974	6	3		1	3	0	0		0	16	1	7	
CA	1974	12.8	3		1	3	5	0		0	8	1	7	
CB	1974	6.6	1	4	1	3	1	0			8	1		2
CB	1974	16	3	4	1	3	1	0		0	9	1		2
EA	1974	16	1		4	8	500	0		0	10	1		
EA	1974	10	2		1	4	668	668		0	18	1		
EA	1974	5	2		1	8	1	0		0	21	1		
EA	1974	8	2		6	4	30	4		0	22	1		
EA	1974	8	2		1	8	200	2		0	22	1		
EA	1974	10	2	4	1	4	489	405		0	18	1		
AB	1975	34	1		1	3	30	2		4 (f)	12	3	2	
AB	1975	20	2	4	8	5	30	10		0	11	15	2	
AB	1975	10	3	3	8	4	3	0		0	5	4	6	
BA	1975		1	2	2	7	10	2		0		16	2	1
BA	1975		2	2	2	2	4	0		0		9	3	5
BB	1975		1	2	2	7	5	0		0		9	1	7
BB	1975	8	2	2	2	7	20	10		0	4	9	1	7
CA	1975	10	3		4	4	50	0		0	11	1	7	
CA	1975	6	3		1	1	25	0		0	9	1	7	
CA	1975	12	3		1	3	3	0		0	9	1	7	
CA	1975	4	3		1	3	1	0		0	18	1	7	
CA	1975	8	3		1	9	0	0		0	6	1	7	
CA	1975	8	3	4	1	1	0	0		0	6	1	7	
CA	1975	12	3	2	2	7	0	0		0	6	1	7	
CA	1975	10	3	2	2	4	1	0		0	6	11		
EA	1975	8	1		1	4	120	3		0	9	1		

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
EA	1975	6	1	4	1	3	15	0		0	23	1		
EA	1975	18	1		1	4	5	0		0	12	1		
EA	1975	6	1	4	1	3	15	6		0		1		
EA	1975	8	2		1	4	60	60		0	23	1		
AA	1976	8	2		1	3	0	0		0	9	15	3	4
AA	1976	8	3	4	3	3	0	0		0	13	7	8	7
AB	1976		1	2	3	4	9	0		0	13	12	8	
AB	1976	16	1		1	4	1322	433		0	13	3	13	
AB	1976	24	2	2	8	3	17	1		0	17	6	6	6
CA	1976	4	2		1	3	90	90		0	16	1	8	
CA	1976	10	3		1	4	80	0		0	11	1	7	
DA	1976	24	1		1	4	200	0		0	10	1		3
DA	1976	10	3		1	4	50	25		0		1		3
EA	1976	10	1	4	1	8	40	2		0	13	1		
EA	1976	18	1	4	1	8	802	606		0	7	1		
EA	1976	8	2	4	1	4	153	153		0		1		
EA	1976	8	2	4	1	4	44	14		0	24	1		
EC	1976	14	2	4	6	3	358	358		0	23	1	12	5
AB	1977	36	1	2	3	7	0	0		0	3	7	10	
AB	1977		2	2	2	7	28	0	140	0	9	6	6	
AB	1977	20	2	4	1	3	2	0		0	8	3	6	
AB	1977		2	2	2	7	32	0	150	0	9	13	8	1
BB	1977		1	2	2	7	1	0		0	7	12	1	7
BB	1977		1	2	2	4	50	0		0	19	12	1	7
CA	1977	12	2	4	1	5	350	220		0	10	1	4	2
CA	1977	10	3	3	1	4	315	90		0	8	1	7	
CB	1977		1	2	2	7	6	0	0	0	9	9		
DA	1977	12	2		1	3	103	0		0	19	1		1
DB	1977	20	1	4	6	1	550	500		0	13	1		3
DC	1977	24	1	4	6	2	600	25		0	11	1		7
EA	1977	10	1	4	1	4	160	0	1500	0	12	1		
EA	1977	18	1	4	1	4	80	0	400	0	5	1		
EA	1977	8	2	4	1	4	3	1		0	13	1		
EA	1977	8	2	4	1	4	3	3		0	25	1		
EA	1977	12	2	4	1	4	191	0		0	19	1		
EA	1977	8	2	4	1	3	269	0		0	19	1		
EC	1977	20	2	4	6	4	2530	2500		0	9	3	12	5
AB	1978	34	1	4	6	3	2000	300		0	16	3	8	
AB	1978	22	1	4	1	3	19	0	1800	0	7	1	7	
AB	1978	8	2	4	3	4	235	205		0	16	7	8	
CA	1978	6	2	1	1	3	12	6		0	18	1		
CA	1978	10	2	4	6	4	100	10		0	14	1	7	1
CA	1978	8	3	4	1	5	120	60		0	7	3	7	3
CA	1978	12	3	4	4	3	2	0		0	14	1	6	3

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
CA	1978	18	3	2	1	3	4	1		0	6	1	7	2
CA	1978	12	3	2	1	1	2	0	0	0	12	1	7	2
CA	1978	8	3	4	1	5	80	40		0	7	1	7	1
DA	1978	16	4	4	1	4	400	250		0	14	1		3
EA	1978	16	1	4	1	4	255	245	5865	0	15	1		
EA	1978	24	1		3	3	1	0		0	4	9		
EA	1978	10.8	2	4	1	3	3	0		0	10	1		
EA	1978	12	2	4	1	5	58	40		0	10	8		
AA	1979	24	1		1	3	100	1	2700	0	5	1	1	
AA	1979	22	1	4	1	5	100	40	16000	0	8	1	1	
CA	1979	12	2	4	1	1	300	200		0	23	1	7	3
CA	1979	8.5	2	4	1	3	50	0	350	0	17	1	4	1
CA	1979	18	3	1	1	1	20	0	500	0	12	1	7	3
CA	1979	18	3	1	1	1	5	0	100	0	12	1	7	3
EA	1979	8	1	4	1	3	245	150		0	23	1		
EA	1979	18	1	4	1	3	50	1	2500	5 (f)	16	1		
EA	1979	12	2	4	1	3	90	50		0	23	1		
EB	1979	10.8	2	2	1	4	950	380	6400	0	15	1		8
AB	1980	40	1	4	1	3	4800	400	10000	0	9	1	8	1
AB	1980	12.8	2	2	2	4	8	1		0	12	6	6	7
CA	1980	10	3	4	1	1	10	0		0	10	1	7	
CA	1980	10	3	4	4	3	80	0		0	10	1	7	
CA	1980	6.6	3	4	1	1	1	0	10	0	15	1	7	1
DA	1980	12	3	4	4	3	111	12	10000	0	15	1		2
EA	1980	12	2		1	3	270	0		0		1		
EA	1980	8	2		1	4	313	0		0		1		
EA	1980	10	4	4	1	4	762	135	10000	0	15	1		
EB	1980		1	2	2	3	30	0		0		12		5
AB	1981	40	1	2	5	3	10	0	80	0	5	6	6	
AB	1981	10	2		1	4	600	150		0		1	8	4
AB	1981	34	4		3	3	10	2		0	6	7	10	
CA	1981	20	1	2	1	3	5	3		0	15	9	5	3
CA	1981	20	1	4	1	3	19	1		0	17	1	7	3
CA	1981	10	2	4	1	4	92	58		0	25	1	3	1
CA	1981	10	2		4	3	10	0		0		1		
CA	1981	8	3	4	10	5	5	0		0	12	3	7	
CA	1981	12	3	2	1	3	5	2	50	0	15	1	7	
CA	1981	8	3	4	10	5	19	0		0	12	3	7	
DA	1981	26	2	4	1	3	125	45		0	18	3		1
DC	1981	24	3	2	10	5	30	10		0	14	15		6
EA	1981	6.6	1	4	1	4	132	132		0	15	1		
EA	1981	5	1		1	3	96	0		0		1		
EA	1981	8	2	4	1	4	322	317		0	24	1		
EC	1981	28	1	2	4	1	5	0		0	16	1	11	

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
AA	1982	8	2	4	11	3	12	12		0	20	1	1	1
AB	1982	24	1	4	1	3	9	0	1000	0	18	1	8	
CA	1982	8	1	4	1	1	2	0		0	20	1	3	4
CA	1982	12	3	2	1	3	8	0	30	0	16	1	7	
CA	1982	10	3	4	1	3	400	16		0	19	1	4	1
CB	1982	22	1	3	4	3	15	5		0	18	1		2
CB	1982	6.6	1	4	1	3	140	140	3000	0	16	1		2
CB	1982	4.5	1	2	2	3	20	0		0	10	1		2
EA	1982	6.3	1	4	1	3	31	0		0	20	1		
EC	1982	8	2	2	1	4	7	1		0	30	1	1	6
AA	1983	4	5	4	1	2	1	0	9	0	22	3	9	
AA	1983	4	5	4	1	4	10	0	100	0	22	14	9	
AB	1983	4	5	4	9	3	4	0	80	0	22	3	9	
BB	1983	16	4	4	1	5	442	111		0	18	1	1	1
CA	1983	6	2	2	4	5	12	0	3600	0	15	1	2	4
CB	1983	6.6	1	4	1	4	182	120	20000	0	17	1		2
EA	1983	6.8	1	4	1	3	148	110	18000	0	17	1		
EA	1983	10	2	4	1	3	213	171		0	29	1		
EB	1983	14	2	4	4	3	675	470		0	3	7		4
EC	1983	12	1	2	1	3	1	0	15	0	20	1		
AA	1984	24	1	4	1	3	141	0	4500	0	18	5	1	1
AA	1984	28	1	4	1	1	4363	3928	6500	0	10	1	4	1
AB	1984	28	1	4	8	2	3	0	120	0	11	12	8	
AB	1984	8	2	4	8	3	16	3	720	0	17	4	8	
BA	1984	16	1	4	2	4	10	0	50	0	18	11	2	1
BA	1984	34	1	2	2	4	5	2	1000	0	13	13	2	1
BB	1984		1	4	1	7	10	10	50	0	21	1	1	6
CA	1984	6	1	2	1	3	20	16	250	0	24	1	4	4
CA	1984	16	2	2	2	3	5	1	10	0	11	1	4	1
CA	1984	12	3	2	4	1	2	0		0	17	1	7	3
CB	1984	8.6	2	4	1	3	236	236	200	0	11	1		2
EA	1984	10	1	5	1	3	150	1	100	0	23	1		
EB	1984	10.8	2			2	244	240		0	21	7		4
AA	1985	24	1	4	1	1	1	1	18	0	14	8	1	1
BA	1985	20	1	2	2	3	25	4		0	9	10	4	5
BA	1985	10	2	2	2	2	7	0	0	0	17	6	2	1
BA	1985	10	2	2	2	2	16	0	0	0	17	7	3	3
BA	1985	6	2	2	2	2	4	0	0	0	17	7	3	4
CA	1985	16	1	4	1	4	1100	756	13000	0	9	1	2	3
EC	1985	8	2	4	1	4	211	195	1000	0	33	1	1	1
AB	1986	20	1	4	1	4	53	6	3000	0	12	1	7	1
AB	1986	16	2	4	2	2	160	6	200	0	17	6	6	5
AB	1986	24	2	4	3	7	292	4	3000	0	26	4	6	
CA	1986	20	2	3	1	3	2	2		0	22	1	2	1

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
CA	1986	16	3	3	4	3	20	5		0	38	1	2	4
CA	1986	8	3	4	1	5	10	0	20	0	25	1	7	3
CB	1986	8.6	1	4	1	3	10	10	180	0	45	1		2
CB	1986	34	1	2	1	1	7	7	84	0	14	4		2
EA	1986	14	2	4	1	2	280	56	100	0	18	1		
EA	1986	8	2	4	1	3	192	95	1500	0	15	1		
EA	1986	6	2	4	1	2	52	41	10	0	13	1		
EB	1986	8	2	4	6	2	11	6	3	0	19	6		5
AA	1987	20	2	2	1	5	1000	120		0	20	3	3	3
AA	1987	26	4	4	1	3	2	1	1000	0	25	1	4	4
AB	1987	8.6	1	4	1	3	25	2	200	0	46	2	5	
CA	1987	16	3	4	4	4	550	150	200	0	39	1	2	4
CB	1987	8.6	1	3	1	3	8	1	280	0	46	1		2
DA	1987	12	2	4	1	3	12	10	2000	0	21	1		1
EA	1987	22	2	2	1	6	3	1	10	0	20	9		
EC	1987	16	2	2	1	3	300	115		0	18	8	1	1
AB	1988	34	1	2	9	3	10	1	200	0	26	4	6	
AB	1988	12	2	3	1	3	90	42	1500	0	30	2	8	1
AB	1988	8	2	4	2	4	97	21	500	0	28	4	6	10
CA	1988	28	1	3	8	3	5	1	400	0	31	3	2	3
CA	1988	34	1	2	4	3	81	1	5000	0	17	1	8	
CA	1988	10.8	2	3	1	4	80	80	0	0	35	1	4	3
DA	1988	10	2	4	6	4	305	5	5000	0	23	1		1
EA	1988	10	1	4	1	3	14	1	100	0	23	1		
EA	1988	3	1	4	1	3	2	1	100	0	28	1		
EA	1988	16	1	3	4	2	650	650	550	1 (i)	23	1		
EA	1988	16	2	4	1	3	3	1	150	0	16	1		
EA	1988	8	2	3	4	3	3	1	20	0	35	1		
EA	1988	4	2	4	1	3	2	1	9	0	26	1		
EA	1988	6	2	4	1	3	63	56	1200	0	33	1		
EA	1988	6	2	4	1	3	18	1	1800	0	33	1		
EA	1988	20	2	2	1	3	40	10	30	0	24	1		
AA	1989	26	1	4	1	3	3	2	100	0	26	3	2	
AA	1989	1	2	4	11	3	25	7	10000	0	1	9	6	7
AA	1989	12	3	2	9	3	1	0	6	0		3	2	7
AB	1989	26	1	4	1	3	155	5	2000	0	26	1	2	
BB	1989	10	2	4	1	4	66	16		1 (i)	27	3	1	7
CA	1989	8.6	1	4	1	5	25	5	50	0	48	1	4	3
CA	1989	12	3	2	6	4	240	150		0	17	1	7	3
CB	1989	10	2	4	1	2	400	90	2000	0	24	1		2
EA	1989	8	2	4	1	3	186	126		0	29	1		
EA	1989	8	2	4	1	6	3	0	66	0	32	1		
EA	1989	12	2	4	1	4	298	298	6000	0	32	1		
EA	1989	10	2	4	11	2	82	4	200	0	24	1		

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
EA	1989	16	2	4	1	2	660	472		0	20	1		
EA	1989	6	2	4	1	3	52	27	2000	0	33	1		
EA	1989	16	2	4	1	3	253	253	500	3 (f)	22	1		
EC	1989	10.8	1	4	6	3	2	0		0	26	1	17	7
EC	1989	40	1	4	1	3	40	5	4000	0	17	1	1	8
BB	1990	8	2	4	8	7	9	0	10	0	48	7	1	8
BB	1990	12.8	2	4	3	6	105	105	30	0	0	12	1	7
BB	1990	10	2	4	2	3	252	221	1500	0	33	11	1	8
CA	1990	10.8	3	2	4	4	325	11		0	22	1	7	1
EA	1990	10	2	4	1	3	189	34		0	24	1		
EA	1990	10.8	2	4	1	8	225	194	2.5	0	11	1		
EA	1990	6	2	4	1	3	3	1	324	0	34	1		
AA	1991	20	1	4	1	3	20	13	4500	0	24	1	1	7
AA	1991	12	2	2	2	4	25	7	150	0	20	17	16	9
AA	1991	20	2	4	1	2	275	118	14000	0	24	1	17	
AA	1991	12	2	4	3	8	5	2	320	0	21	9	16	7
AA	1991		2	4	3	3	50	38	1200	0	10	15	17	5
AB	1991		2	2	2	2	4	1	250	0	31	17	5	1
AB	1991	12	2	4	1	3	29	29	600	0	38	1	8	
AB	1991		2	4	8	3	2	0		0	0	6	8	
AB	1991		2	2	2	2	172	68	100000	0	11	13	6	
CA	1991	10	2	4	1	3	80	4	1500	0	26	1	7	1
CB	1991	7	1	4	9	3	20	0	300	0	30	14		2
CB	1991	8	2	2	1	5	15	10	25	0	17	1		2
CB	1991	8	2	4	4	5	100	60	10000	0	17	1		2
EA	1991	8	2	4	1	8	4	0	6	0	49	1		
EA	1991	6	2	4	1	3	21	13	500	0	34	1		
EA	1991	6	2	4	1	8	1	0	2	0	37	1		
EB	1991		2	4	2	2	84	75		0	1	7		5
EB	1991	12.8	2	4	2	4	485	485	7000	0	24	1		5
EC	1991	8	2	4	1	3	10	1	30	0	24	1	1	1
AA	1992	8	2	2	1	4	1000	400		0	34	1	1	8
AB	1992	8	2	5	1	9	5	5	10	0	13	1	2	
AB	1992	8	2	2	5	7	30	15		0	33	3	8	1
AB	1992		2	4	3	4	128	98	5400	0	0	6	6	
AB	1992		2	2	2	7	113	8	0	0	12	13	8	
BB	1992		2	2	5	4	5	1	1350	0	22	16	13	6
BB	1992		2	2	2	4	275	248	1100	0		7	1	7
BB	1992	10	2		3	7	2	0	0	0	30	12	5	
CA	1992	6	2	4	1	5	3	3	2	0	49	1	1	
CA	1992	24	2	2	24	3	13	1	250	0	27	3	5	1
CA	1992	8	3	4	1	3	200	0	300	0	25	1	7	
DB	1992	12	2	4	1	3	75	75		0	28	1		3
EC	1992	8	2	4	1	5	50	50	20	0	25	1	1	1

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
EC	1992	8	2	4	1	5	25	25	60	0	25	1	1	1
AA	1993	34	1	4	1	5	248	18	45000	0	31	1	8	
AB	1993	12	2	2	3	1	2	1	400	0	23	7	16	
AB	1993		2	2	2	3	3	0	80	0	2	6	6	
CA	1993	18	2	1	4	9	14	13	400	0	27	1	2	2
CB	1993	20	1	4	4	4	2000	500	25000	0	19	1		2
CB	1993	12.8	2	4	6	4	580	500	800	0	26	18		1
DA	1993	26	2	6	1	3	10	7		0	31	1		1
EA	1993	8.6	2	4	1	3	8	6	50	0	30	1		
EA	1993	24	2	4	1	3	49	39	40000	0	33	1		
EA	1993	8	2	4	1	8	3	1	100	0	37	1		
EA	1993	12	2	4	6	8	101	19		0	31	1	19	
EC	1993	6.6	2	3	1	3	3	3	6	0	13	1	1	1
EC	1993	20	2	2	1	4	3050	1450		0	29	1	1	1
AB	1994	16	1	4	1	4	1350	1295	25000	0	31	1	8	
AB	1994	16	1	4	1	2	200	160	6000	0	31	1	8	
AB	1994	10.8	2	4	8	3	5	5	100	0	9	4	6	
AB	1994	6	2	2	1	1	1	1	25	0	16	1	8	
AB	1994	6	2	2	2	4	250	14	50	0	16	4	6	
BA	1994		1	2	2	3	2	2	100	0		16	4	5
CA	1994	12	3	4	1	3	90	60		0	24	1	7	1
CB	1994	32	1	2	7	4	10	5	500	0	21	1	18	2
EA	1994	10	2	4	6	3	285	285		0	26	1		
EA	1994	8.6	2	4	1	2	195	170	8000	0	37	1		
EA	1994	8	2	4	1	3	46	0	1150	0	36	1		
AA	1995		2	1	5	4	280	80	10000	0	22	11	8	7
AA	1995	10	2	4	4	3	30	30	750	0	35	3	2	11
AB	1995		2	4	9	3	53	41		0	5	9	8	
AB	1995	6	2	4	1	1	115	0	500	0	36	1	8	
BB	1995	16	1	4	1	2	132	82	6500	0	30	1	1	7
CA	1995	10	2	2	1	1	1000	270	55000	0	31	1	4	1
EA	1995	8.6	2	4	1	2	48	18	1500	0	28	1		
EA	1995	8.6	2	2	1	2	20	20	100	0	39	1		
EA	1995	6	2	4	1	2	12	0	30	0	37	1		
EA	1995	12.8	2	4	1	3	139	113	300	0	5	1		
AB	1996	8.6	2	2	2	4	165	99	40	0	5	4	6	
BB	1996	14	2	3	1	3	292	209	300	0	40	1	1	6
CA	1996	12	3	1		3	1	0	16	0	30	1	2	3
EA	1996	6.6	2	4	1	8	19	19	350	0	40	1		
EA	1996	8.6	2	2	1	4	437	343	20	1 (f)	40	1		
EC	1996	10	2	2	1	3	500	62	23000	0	64	1	20	8
CA	1997	12	2	4	1	1	19	3	2800	0	27	1	2	1
CB	1997	10	1	2	1	1	2	0.3	20	0	7	3		2
CC	1997	12	2	3	1	4	435	267		0	30	1	2	3

CAUSE CAT.	YEAR	DIAM. (INCHES)	SERVICE	LEAK ENVIRON.	LEAK LOCATION	HOW DISCOVERED	GROSS SPILL (M^3)	NET SPILL (M^3)	GROUND AREA AFFECTED (M^2)	INJURY (i) FATALITY (f)	AGE AT FAILURE	EQUIPMENT CONCERNED	PRIMARY CAUSE	SECOND. CAUSE
CC	1997	12	2	4	1	4	422	341		0	30	1	2	3
EA	1997	8	2	4	1	4	13	2	150	0	33	12		
EC	1997	12	2	2	1	3	40	1		0	24	1		
AB	1998		1	2	2	7	30	4	400	0	30	10	5	9
BB	1998	12.8	2	4	1	4	486	247	100	0	42	1	1	7
BB	1998	6	3	4	1	3	0	0.2			34	1	1	7
CA	1998	16	2	2	1	3	250	20		0	30	1	2	
EA	1998	8.6	2	4	1	2	176	67	160	0	42	1		
EA	1998	8	2	4	1	8	0	0	4	0	25	1		
EA	1998		2	4	9	2	30	2	650	0	0	9		
EA	1998	10	2	4	1	1	15	14	600	0	4	1		
EA	1998	10	2	3	1	2	340	313	500	0	6	1		
BB	1999		1	2	2	4	7	0	200	0		11	1	7
CA	1999	4	1	2	2	3	1	1		0	35	18	5	4
CA	1999	10.8	2	4	1	4	167	64	60	0	32	1	4	3
CA	1999	6	2	4	1	2	1	1	5	0	25	1	5	2
CA	1999	1	3	2	4	4	30	0	300	0	32	1	7	3
EA	1999	8	2	4	1	3	80	20	500	0	48	1		
EA	1999	12.8	2	2	1	2	84	13		0	10	1		
EA	1999	6	2	4	1	3	29	14		0	40	1		
EB	1999	8	2	4	1	3	80	30	1000	1(f)	35	1		8
EB	1999	10.8	2	4	1	2	36	28	100	0	5	17		8
EC	1999	12	2	2	1	4	1	0		0	36	1	1	1
AB	2000		2	2	8	3	175	3	60	0	24	12	5	
CB	2000	12	1	2	1	3	10	7	150	0	30	1		2
EA	2000	12	2	3	4	8	7	1		0	26	1		
EA	2000	12	2	4	1	3	8	8		0	31	1		
EA	2000	10.8	2	4	1	2	159	64	5000	0	8	1		
EC	2000	24	2	4	1	3	1	1	150	0	41	1	1	8