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MANAGEMENT OF RESIDUAL MATERIALS: 1997

PETROLEUM REFINING PERFORMANCE

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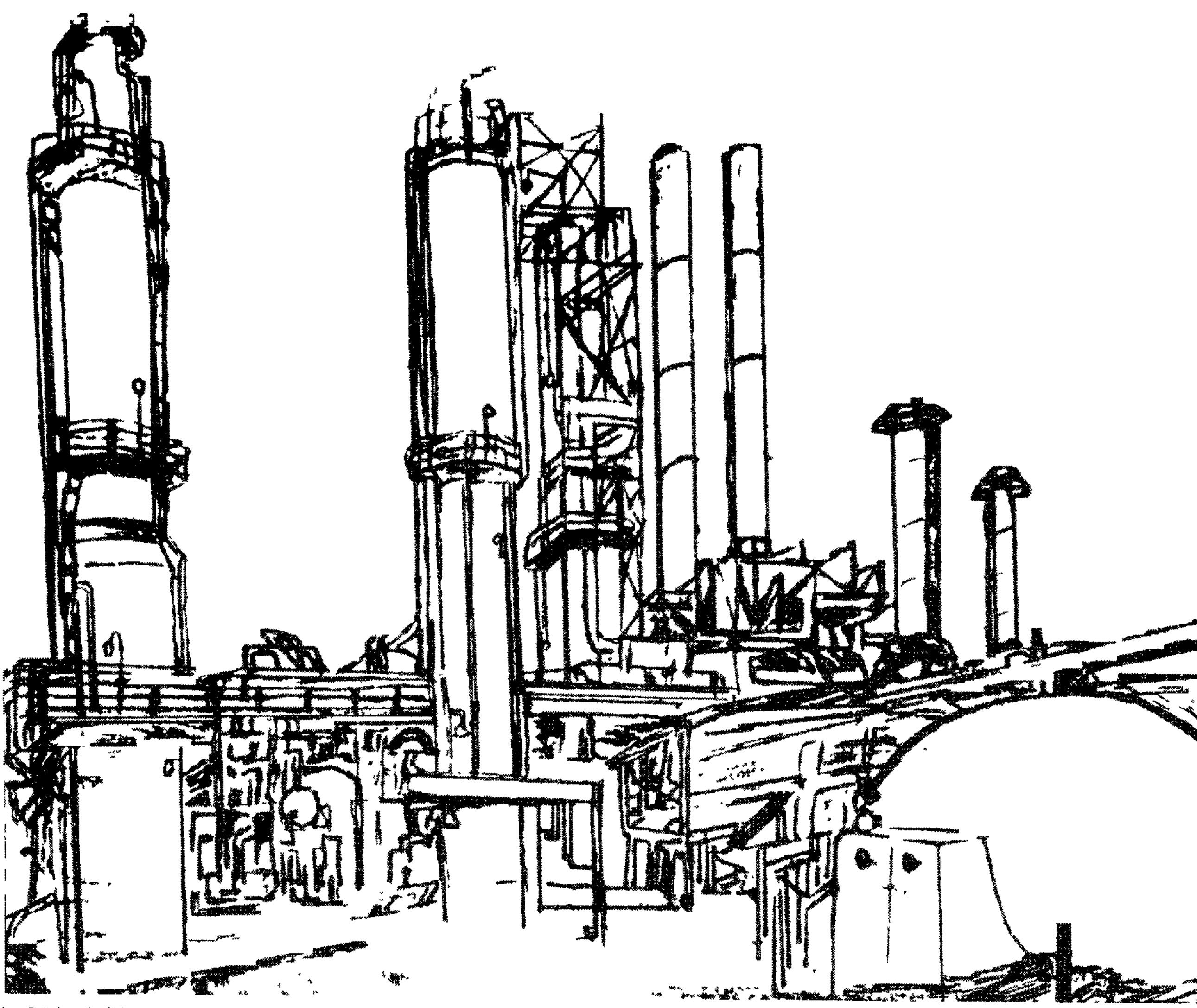

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Management of Residual Materials: 1997

Petroleum Refining Performance

Regulatory and Scientific Affairs

API PUBLICATION NUMBER 352

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EXECUTIVE SUMMARY

The 1997 API Refining Residual Survey collected data on the manner in which U.S. petroleum refineries manage their residual materials. This report summarizes the characteristics of the facilities that responded, and presents nationwide trends in residual management practices. The nationwide estimates were determined from a regression analysis of the respondent data in terms of residual quantity in wet tons by refinery capacity in barrels per stream day (bsd).

1997 Refining Residual Survey–Response Level

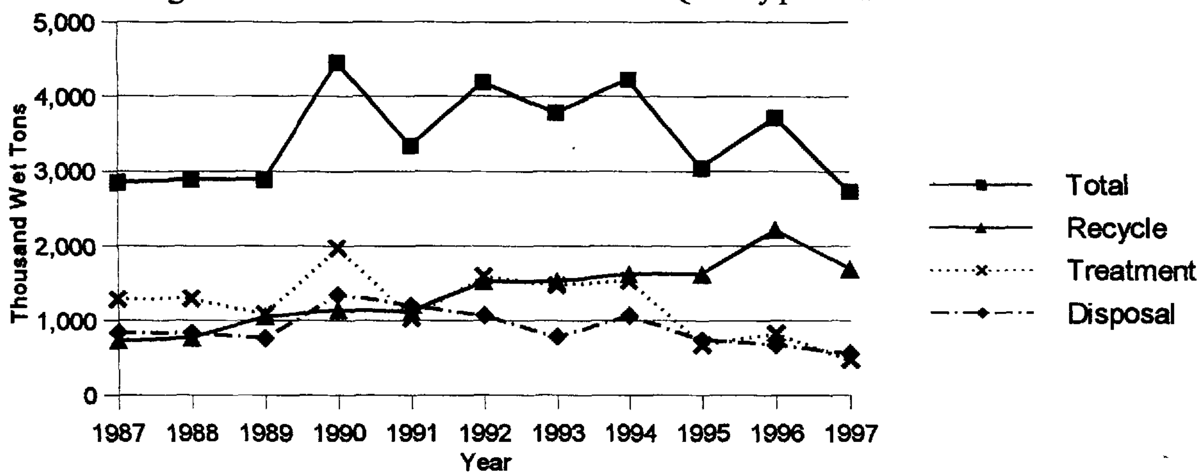
	Estimated U.S. Total	Survey Respondents	Percent
No. of Facilities	152	70	46%
Refining Capacity	16,086,100 bsd	7,328,500 bsd	46%
Residual Quantity	2,736,000 wet tons	1,179,000 wet tons	43%

The 1997 survey collected data on the management of 14 residual streams and requested cost data on six of these streams. By comparison to the quantities reported for 30 residual streams in the surveys prior to 1994, these 14 streams are believed to represent nearly 80% of the total quantity of residuals managed at U.S. refineries. As with previous surveys, data were collected on the age, size, location, and type of refinery, and on the configuration of the wastewater treatment systems.

DIFFERENCE FROM PRIOR YEAR RESULTS

This year's survey continued to seek improvement in the consistency of reported data. Prior to the 1997 survey, the management techniques had included recycling to the *cat cracker*, which referred to routing a residual to a catalytic cracking unit (regardless of whether fluidized bed or other type). Most of the entries for this technique were for *FCC catalyst*. Telephone follow up revealed that this response was generally meant to indicate catalyst either having been cascaded to another cracking unit or sent to another facility for continued use as catalyst. By definition, however, if the material was still in use for its original purpose, it was not yet a residual. Furthermore, entries for other residual streams to the *cat cracker* management technique were generally found to have belonged in a different recycle category. It seemed, then, that the quantity of residuals actually recycled to a cracking unit was very small, and perhaps nonexistent. The *cat cracker* category was therefore deleted from the 1997 survey. Data for prior years were adjusted by deleting quantities shown as *FCC catalyst* routed to a *cat cracker*, and moving all other quantities reported under *cat cracker* to the *other recycle* management technique category.

Trends in Management Practices–Nationwide Estimates of Quantity per Year



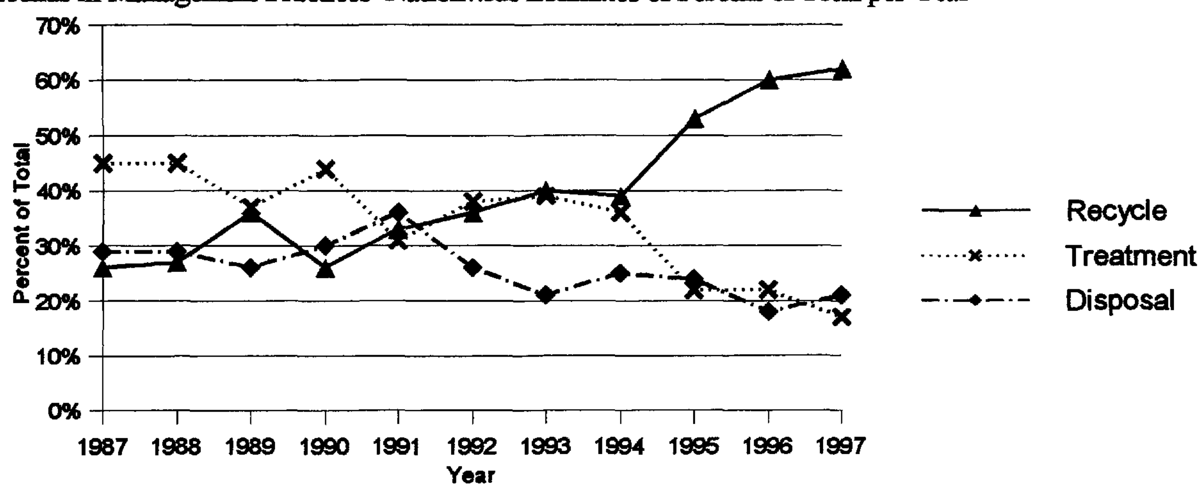
As in the 1995 and 1996 reports, the data for 1987 through 1994 in the preceding chart have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals. Prior to the 1995 survey, some facilities had reported the quantity of residual generated prior to dewatering, while others had reported the quantity managed after dewatering. The 1995 survey, however, had specified that only the quantity of residual remaining after dewatering was to be reported, without the recovered water or oil, thus providing for a consistent basis of response and more accurately reflecting quantities of residuals managed. This approach was continued with the 1996 and 1997 surveys.

The specific adjustments made to the 1987 through 1994 data were to delete the amounts shown as managed by *wastewater treatment* from the streams that are reduced by dewatering, which are the *tank bottoms*, *API separator sludge*, *DAF float*, *primary sludges*, *slop oil emulsion solids*, *biomass*, and *pond sediments* streams. Amounts listed as recycled to a crude unit were deleted from these same streams, with the exception of *DAF float* and *slop oil emulsion solids*. The latter two streams had entries in the *crude unit* category for 1995 (and again in 1996), and therefore this category was retained for these two streams in the adjustments of prior years' data.

The reporting units of wet tons indicate that the stream volumes are taken in their as-managed condition, rather than on a dry-solids basis. While residuals that have been dewatered will have a higher percent-solids content than if they had not been dewatered, they may nevertheless include a significant amount of water.

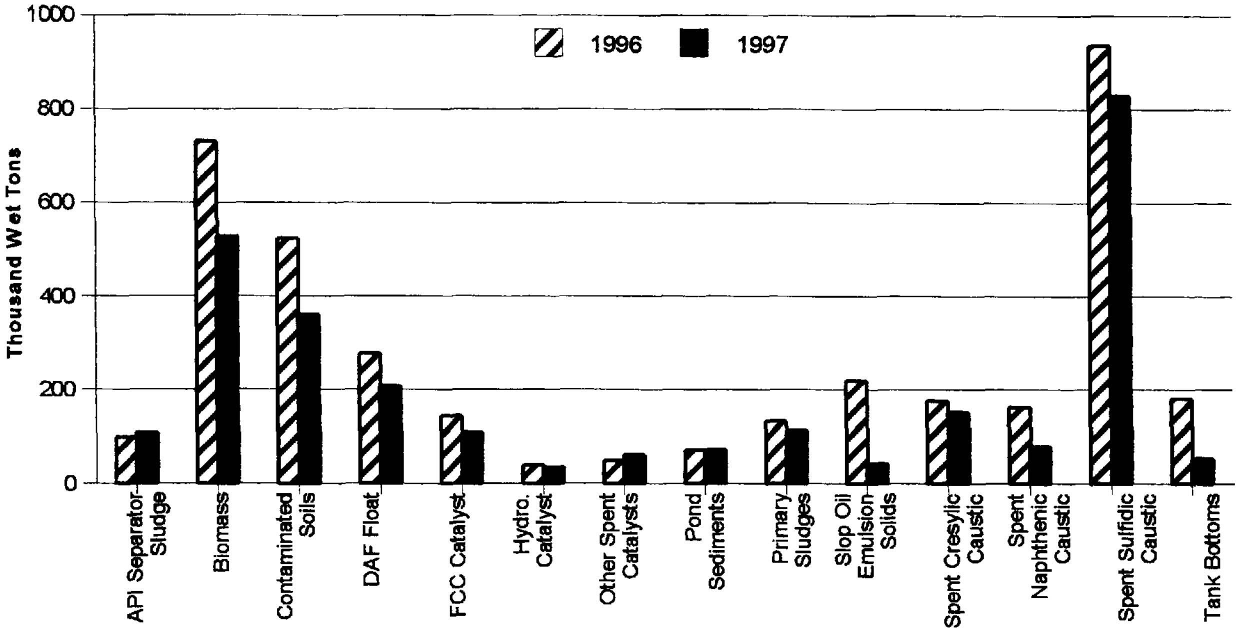
The estimated total quantity of residuals managed at U.S. refineries decreased from 3,721,000 wet tons in 1996 to 2,736,000 wet tons in 1997, a decrease of 985,000 wet tons. The 1997 nationwide estimate continues the downward trend that is evident for the 1990s. The portion of residual material reported as having been *recycled* continues the strong upward trend of recent years, with well over half of the total quantity managed now shown as *recycled*, as shown in the following chart.

Trends in Management Practices–Nationwide Estimates of Percent of Total per Year



The next chart compares residual quantities by stream for 1996 and 1997. Several facilities reported a combined amount of certain residuals associated with wastewater treatment facilities (i.e., *API separator sludge*, *DAF float*, *primary sludges*, and *slop oil emulsion solids*), in that they commingle these streams for management. The sum of these *oily wastewater* residuals decreased from 723,000 wet tons in 1996 to 467,000 wet tons in 1997.

Nationwide Estimates of Residual Quantity by Stream–1996 versus 1997



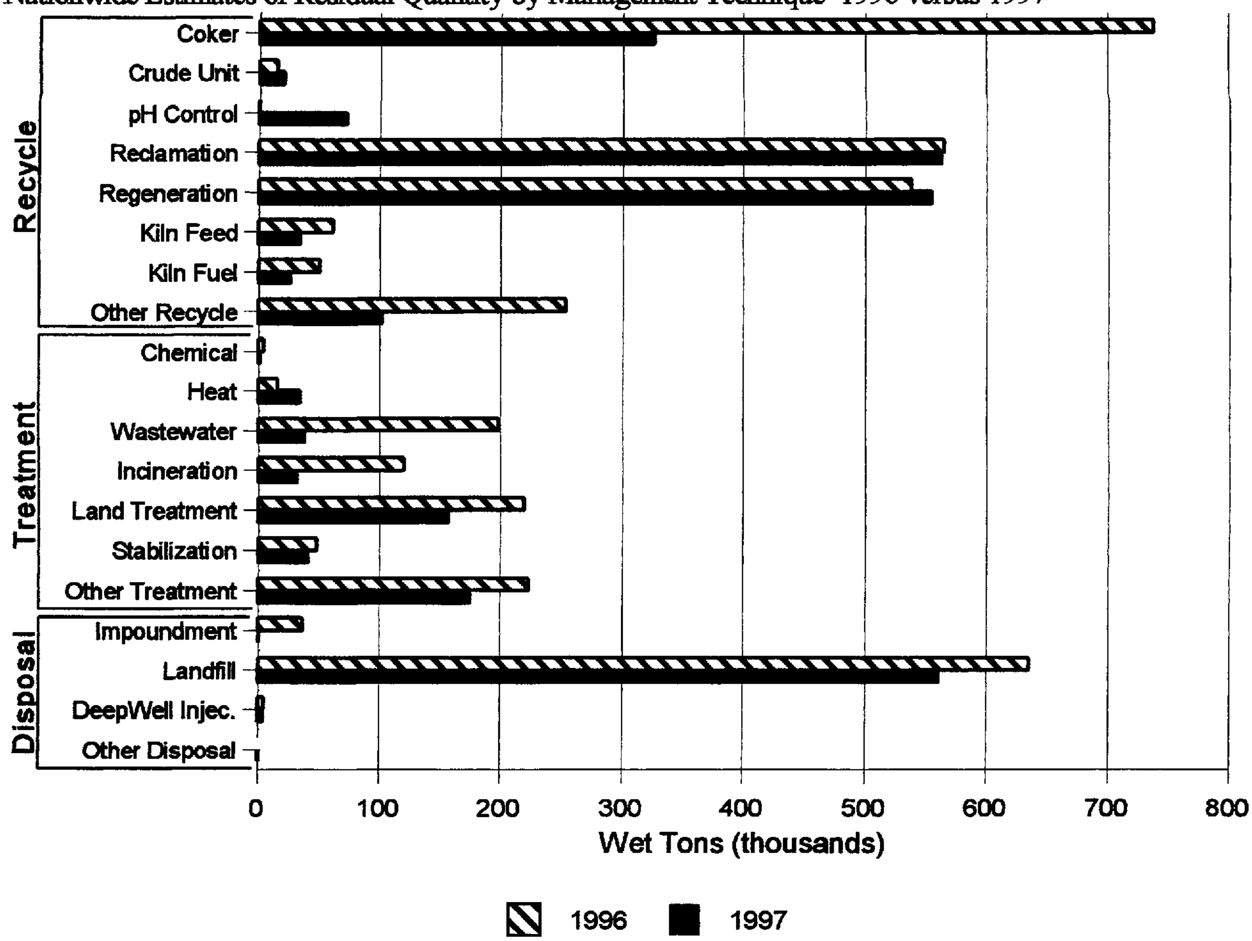
It is apparent that the most significant differences in the quantity per residual stream from 1996 to 1997 are the decreases in the quantities of *biomass*, *contaminated soils*, *slop oil emulsion solids*, *spent sulfidic caustic*, and *tank bottoms*. These five streams, in fact, account for nearly 80% of the total decrease in estimated quantities from 1996 to 1997. Two of these streams (*biomass* and *spent sulfidic caustic*) had accounted for a significant portion of the increase reported in 1996. The subsequent drop suggests that the trend for the 1990s is still downward, despite the one-year increase observed in 1996.

A comparison of the 1996 and 1997 nationwide distribution of residual quantities by management technique is shown in the next chart. Quantities reported as recycled for *pH control* are included in the *other recycle* category in 1996, whereas this technique is a separate category in 1997.

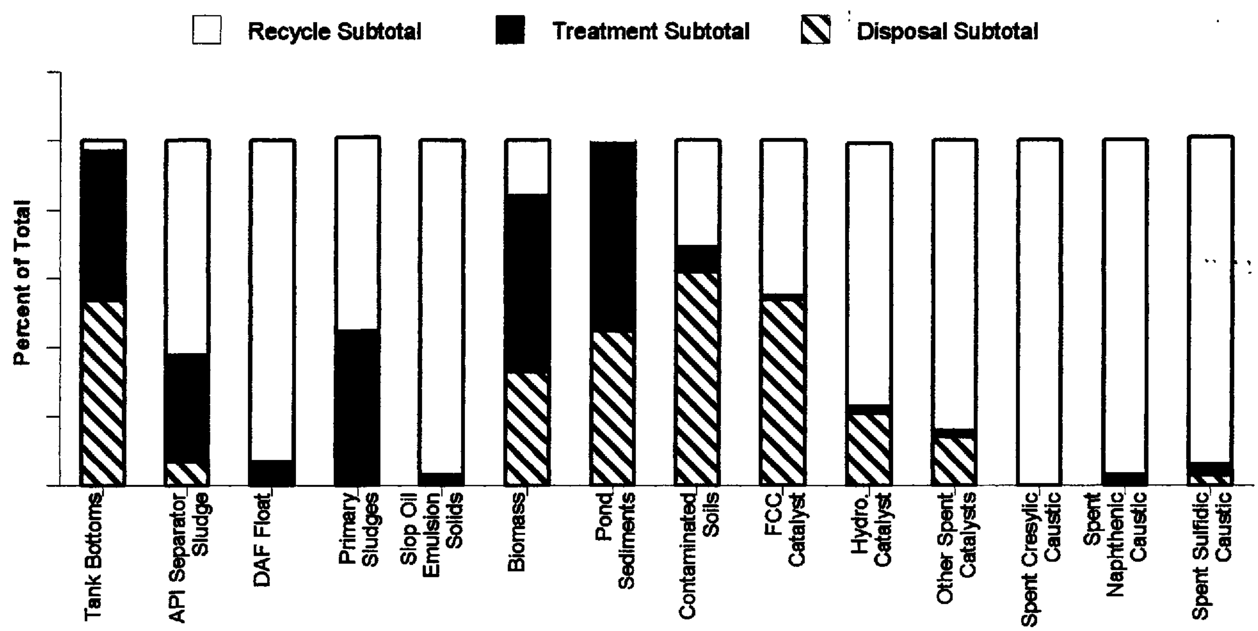
The final chart in this Executive Summary displays the nationwide distribution by management practice for each stream, as estimated from the 1997 survey. The streams that are sometimes dewatered, which include *tank bottoms*, the *oily wastewater* residuals, *biomass*, and *pond sediments*, are on the left side of the chart.

The overall trend of the 1990s continues to be a decline in the total quantity of residuals managed by U.S. petroleum refineries, and the most evident trend of the last three years is the movement toward *recycling* as the dominant management practice.

Nationwide Estimates of Residual Quantity by Management Technique–1996 versus 1997



Nationwide Estimates of Distribution by Management Practice–1997



Section 1
METHODOLOGY

LISTING OF REFINERIES

The term 'petroleum refinery' is used differently in various contexts. For purposes of the 1997 API Refining Residual Survey, a refinery is defined as a facility that currently processes crude oil. Facilities that do not have crude units are not included in the survey.

The 1997 survey was distributed in electronic format (i.e., computer software on diskettes), in a similar manner to the 1995 and 1996 surveys. Selected screens from the electronic survey form are presented in Appendix A.

The survey was sent to those U.S. refineries listed as processing crude oil in the *Worldwide Refineries-Capacities as of January 1, 1998* published by the Oil & Gas Journal. Excluding those refineries that were found to not actually process crude or to have been shut down resulted in a final count of 152 refineries. Of these, 70 responded to the survey.

RATIONALE FOR SURVEY CLARIFICATIONS

As was explained in the 1995 and 1996 reports, the survey now specifies that only the quantity of residual remaining after dewatering is to be reported, without the recovered water or oil, thus providing for a consistent basis of response and more accurately reflecting quantities of residuals managed. The quantity reported for each stream, then, is that remaining after any dewatering of the sludge. For those streams that are not defined as RCRA-listed hazardous wastes, the quantity may include both hazardous and nonhazardous materials. Where it was determined that a facility had reported both the quantity of material that was treated and the quantity that was disposed of after treatment, only the quantity treated was included in the analysis.

The reporting units of wet tons indicate that the stream volumes are taken in their as-managed condition, rather than on a dry-solids basis. While residuals that have been dewatered will have a higher percent-solids content than if they had not been dewatered, they may nevertheless include a significant amount of water.

RESIDUAL STREAMS

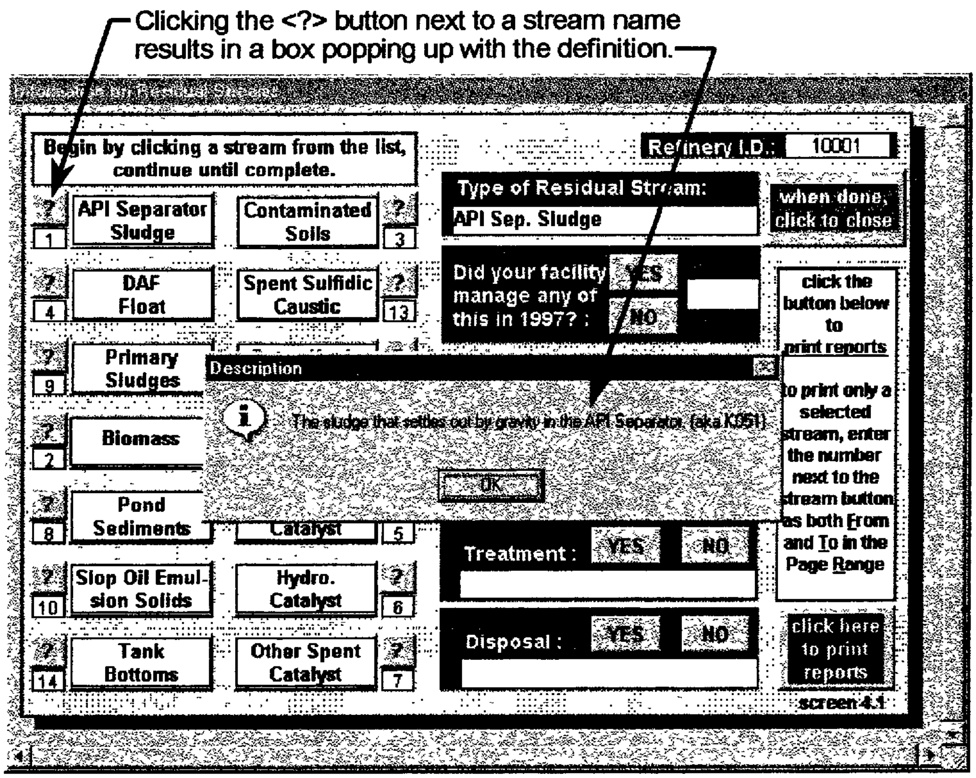
Earlier annual surveys had collected data on 30 separate residual streams, but the 1994 survey reduced the number of streams to 15 for simplification. These 15 streams were believed to represent approximately 80% of the total quantity of refinery residuals. The 1994 survey had included two separate categories for *primary sludges* (i.e., the F037 and F038 RCRA categories). Combining these two streams into a single *primary sludges* category resulted in 14 streams in the 1995 survey. The 1995 survey also collected information on the cost of managing six of the 14 streams in the survey, compared to three streams having had cost data questions in the 1994 survey. The 1996 and 1997 surveys continued to collect data on these 14 residual streams, as well as soliciting cost data on the same subset of six. The definitions assigned to each stream are listed in Appendix A.

It should be understood that the residual stream labels used in this survey are NOT used in a regulatory sense. Whereas the Environmental Protection Agency (EPA) regulations implementing RCRA have given these terms special meaning, the usage here is in a broader, more generic sense. API's intent is to have survey participants report the management of all residual type materials (e.g., materials that are

byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as materials that are discarded.

In order to facilitate consistency of response, definitions are provided as pop up messages attached to buttons on the survey form, as shown in the following figure.

Figure 1—Sample Screen from the Survey Form



MANAGEMENT PRACTICES AND TECHNIQUES

The 1997 survey continued to group management techniques into three categories of management practice–recycling, treatment, and disposal. The management techniques from the 1996 and 1997 surveys, with the definitions assigned to them for the 1997 survey, are listed in Appendix A. *Each of these management techniques is allowed under certain regulatory scenarios*.

Note that the *cat cracker* category has been discontinued as a separate management technique. The results of prior years' surveys have had the quantities from this category added to *other recycle*, for streams other than *FCC catalyst*, to accommodate comparison with the 1997 data. Quantities for *FCC catalyst* that had been assigned to the *cat cracker* category have been deleted from prior years' results, in that catalyst routed to another cracking unit for continued use as catalyst is still performing its initial function, and is therefore not yet a residual.

DATA ANALYSIS

Completed survey forms were received from respondent facilities in the form of data files on diskettes. Data cleaning included a check of the data for self-consistency. For example, if a facility indicated that its classification is 'topping', then it should not have reported any spent FCC catalyst; or if it did not report having an API separator, then there should not be any API separator sludge. The data were also reviewed visually and statistically for outliers. Follow up phone calls resolved apparent discrepancies, such as whether the quantity had been reported in the correct units and, if so, why the amount differed from expected levels.

As with previous surveys, the data from the respondents were extrapolated to nationwide estimates by applying a regression analysis in which throughput capacity is taken as the explanatory variable. For consistency with previous years, the following form of equation was retained.

$$\sqrt{R} = b_0 + b_1 C$$

Where:

R = total residuals managed by a facility (wet tons),
b_0 = the y-intercept of the regression line,
b_1 = the slope of the regression line, and
C = the throughput capacity of the facility (bsd).

The equation developed from the 1997 survey is

$$\sqrt{R} = 22.8 + 7.17 \times 10^{-4} C$$

with an R^2 measure of correlation equal to 0.58 and a percent error of 9.8%. The statistical analysis is described in more detail in Appendix B.

Section 2
RESULTS

RESPONSE RATE

The 1997 survey response rate is illustrated by several parameters in the following charts.

Figure 2—Response Rate by Refinery Capacity.

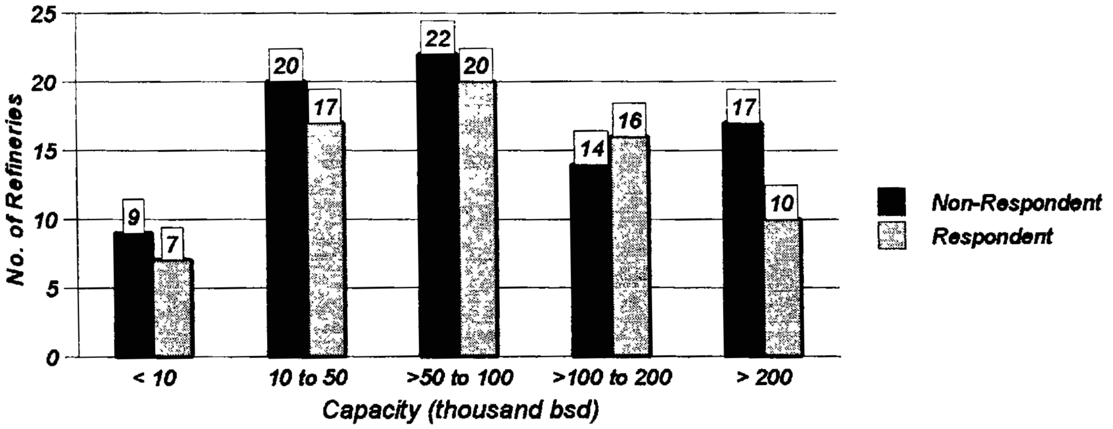


Figure 3—U.S. Department of Energy's Petroleum Administration for Defense (PAD) Regions.

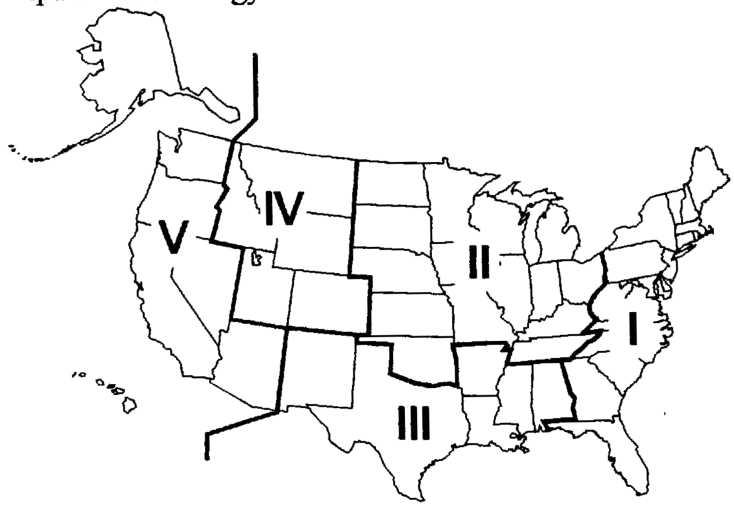


Figure 4—Response Rate by PAD Region.

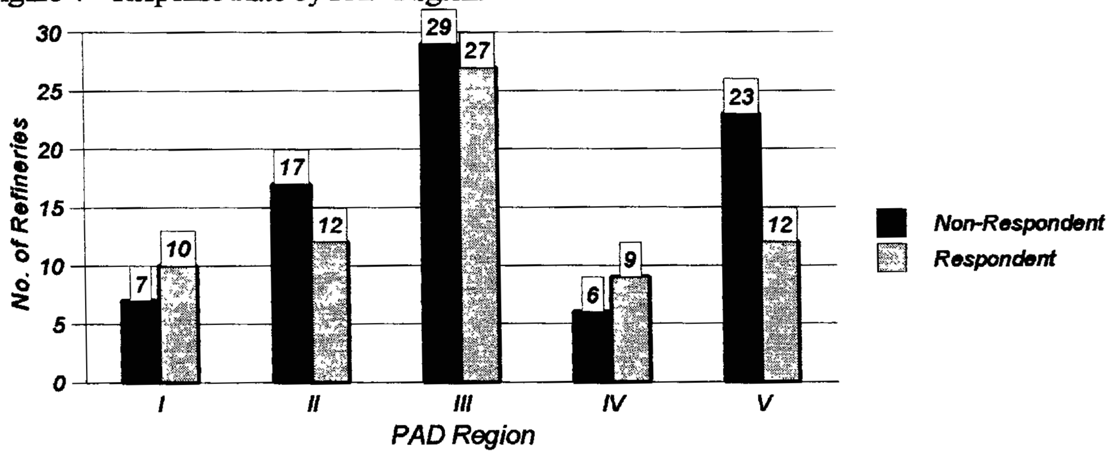


Figure 5—Response Distribution by Complexity of Facility.

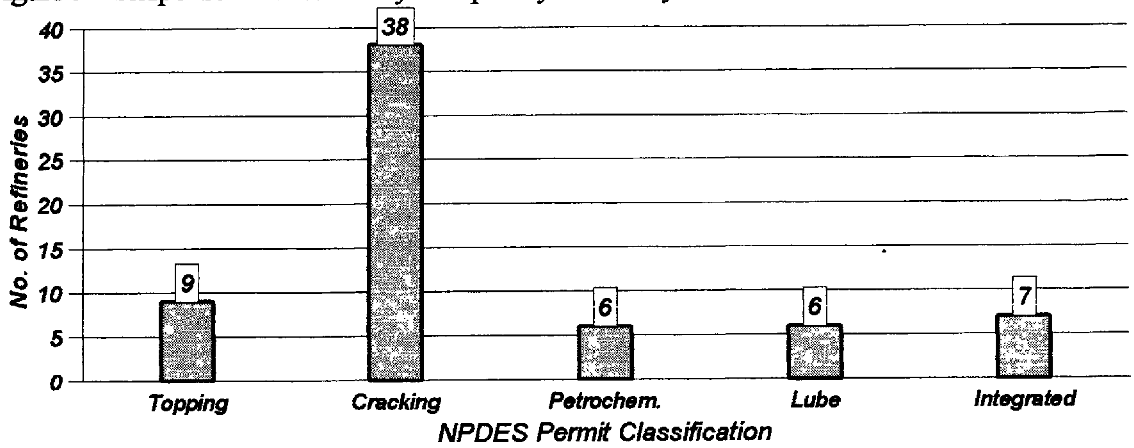


Figure 6—Response Distribution by Age of Facility.

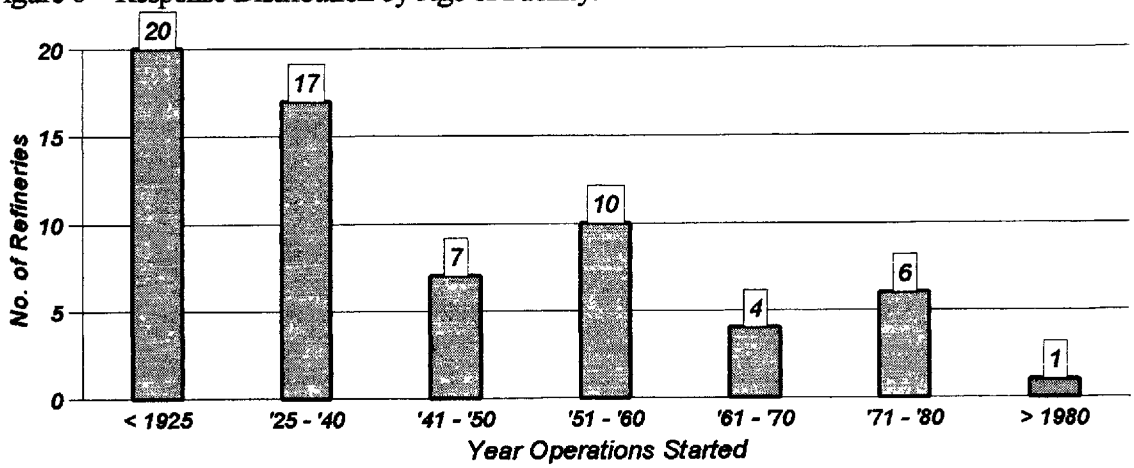
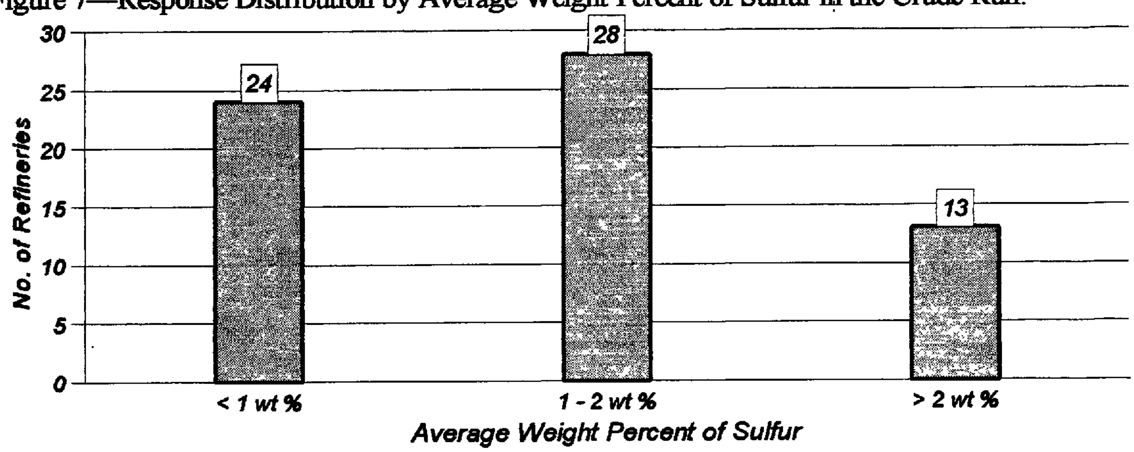


Figure 7—Response Distribution by Average Weight Percent of Sulfur in the Crude Run.



The number of responses for individual categories is sometimes less than the total number of responses, due to some facilities not answering certain questions.

The number of responses from each NPDES Permit Classification for each residual stream is summarized in Table 1 and presented on a percentage basis in Table 2.

Table 1—Number of Facilities in Each NPDES Classification Reporting Each Stream.

	NPDES Permit Classification				
	Topping	Cracking	Petrochemical	Lube	Integrated
Total No. of this type:	9	38	6	6	7
Distribution by Residual Stream:					
API Separator Sludge	4	26	5	3	3
Biomass	1	20	4	4	5
Contaminated Soils	6	33	6	5	7
DAF Float	0	14	1	1	4
FCC Catalyst	0	29	6	3	7
Hydro. Catalyst	2	32	5	4	5
Other Spent Catalysts	1	31	5	2	3
Pond Sediments	1	5	1	0	1
Primary Sludges	5	32	6	5	6
Slop Oil Emulsion Solids	0	12	4	4	3
Spent Cresylic Caustic	0	16	2	2	3
Spent Naphthenic Caustic	1	4	0	0	1
Spent Sulfidic Caustic	2	28	3	4	4
Tank Bottoms	3	25	5	4	7

Table 2—Percent of Facilities in Each NPDES Classification Reporting Each Stream.

	NPDES Permit Classification				
	Topping	Cracking	Petrochemical	Lube	Integrated
Distribution by Residual Stream:					
API Separator Sludge	44%	68%	83%	50%	43%
Biomass	11%	53%	67%	67%	71%
Contaminated Soils	67%	87%	100%	83%	100%
DAF Float	0%	37%	17%	17%	57%
FCC Catalyst	0%	76%	100%	50%	100%
Hydro. Catalyst	22%	84%	83%	67%	71%
Other Spent Catalysts	11%	82%	83%	33%	43%
Pond Sediments	11%	13%	17%	0%	14%
Primary Sludges	56%	84%	100%	83%	86%
Slop Oil Emulsion Solids	0%	32%	67%	67%	43%
Spent Cresylic Caustic	0%	42%	33%	33%	43%
Spent Naphthenic Caustic	11%	11%	0%	0%	14%
Spent Sulfidic Caustic	22%	74%	50%	67%	57%
Tank Bottoms	33%	66%	83%	67%	100%

WASTEWATER MANAGEMENT

Each of the 66 facilities that reported their wastewater plant configurations indicated that their wastewater is treated prior to discharge. They all reported having primary oil-water separation equipment, with 49 indicating that they use an API Separator. The remaining 17 facilities listed various types of equipment for primary separation, with the most frequent mention being a corrugated plate interceptor. The survey asks whether the facility discharges to a publicly-owned treatment works (POTW), a joint treatment facility (i.e., a privately-owned wastewater treatment facility shared by multiple users), or neither. This question allows a determination of whether the onsite treatment is pretreatment prior to additional treatment offsite, or is the complete treatment process for the facility's wastewater. The schematic in Figure 8 (on the following page) illustrates the distribution of equipment in the wastewater treatment facilities, as well as indicating whether effluent discharged prior to advanced treatment is sent to another treatment facility.

Three facilities reported having primary separation only, two of which discharge to a POTW. An additional ten facilities reported discharging after secondary separation, of which eight discharge to a POTW and one to a joint treatment facility. Of the remaining 53 facilities, 50 have some form of biotreatment and the three without biotreatment have some form of advanced treatment. Thus 64 of the 66 facilities (97%) report having biotreatment and/or advanced treatment, or discharging to another facility for further treatment.

The most common equipment configuration (reported by 50% of respondents) includes primary separation, gas flotation, and biotreatment. The following list summarizes the responses.

Primary separation . . .	100% (typically an API Separator)
Secondary separation .	74% (typically some type of gas flotation)
Secondary biological treatment .	76% (typically includes activated sludge)
Advanced treatment . .	45% of all reporting facilities (filtration is most common), and 59% of those not subject to posttreatment.

The survey previously sought to differentiate among stormwater, process wastewater, and combined flow by asking for information on holding structures for segregated sewers separately from combined sewers. This question was revised in the 1996 survey to ask what percent of the facility is served by segregated sewers. In addition, the 1996 survey asked whether the effluent parameters were measured at the discharge from the wastewater treatment plant, or for the combined discharge of wastewater and untreated stormwater. The 1997 survey sought to further clarify this question by differentiating between dry and wet weather flow for combined sewers.

Figure 9 illustrates the type of structures used to hold stormwater and wastewater. The predominant type of structure reported for holding wastewater-only was tanks and for stormwater-only was impoundments. Eighteen facilities reported having 100% segregated sewers, and another 25 facilities reported having some segregated sewers and some combined sewers. Three respondents did not report their sewer configurations, and the remaining respondents indicated having 100% combined sewers. These responses are summarized below.

100% Segregated Sewers	18 facilities
Some Segregated/Some Combined .	25 facilities
100% Combined	20 facilities

In that some facilities have both segregated sewers and combined sewers, the total number of responses in Figure 9 exceeds 63.

Figure 8--Wastewater Treatment System Summary. (total number of responses = 66)

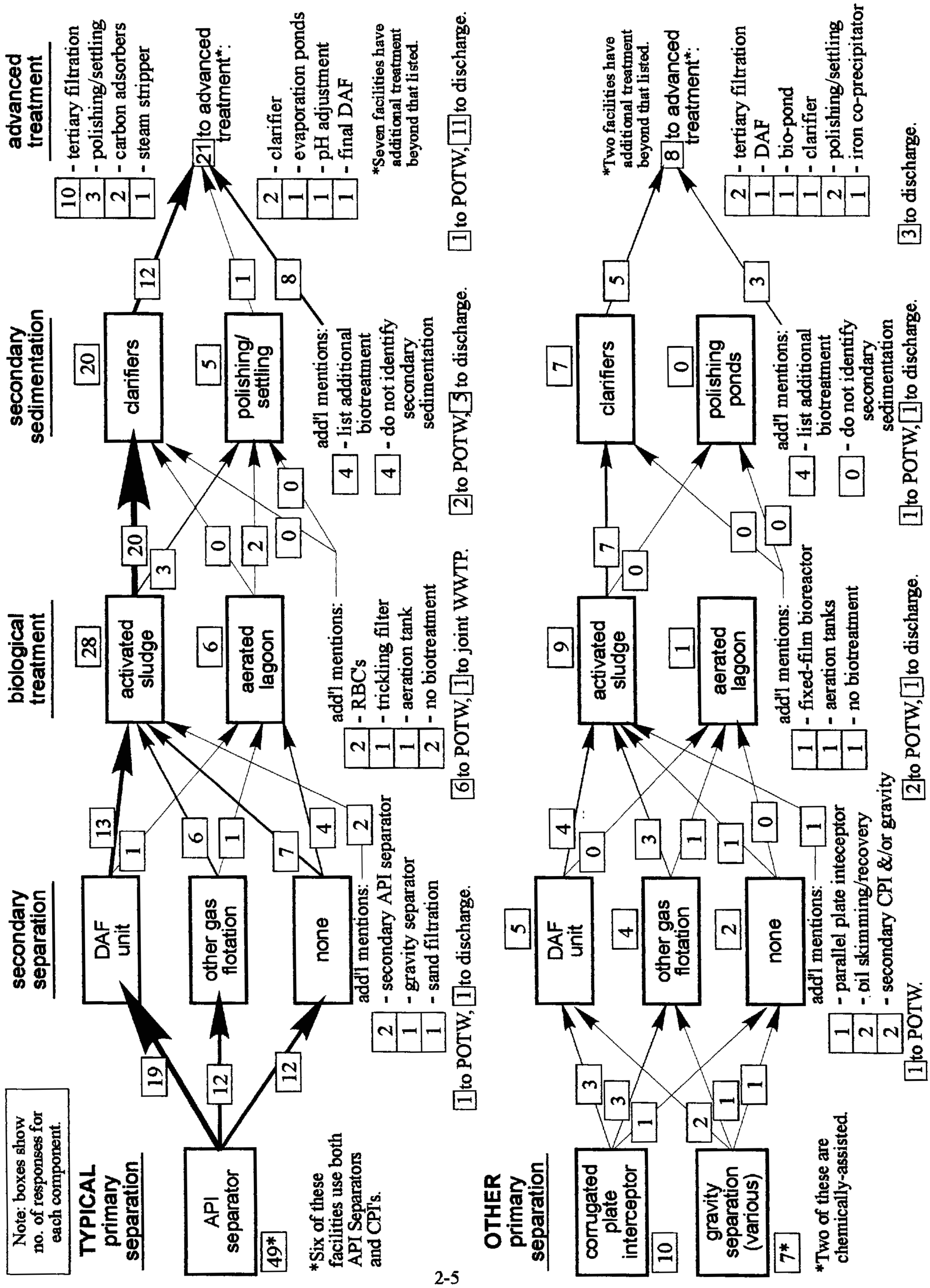
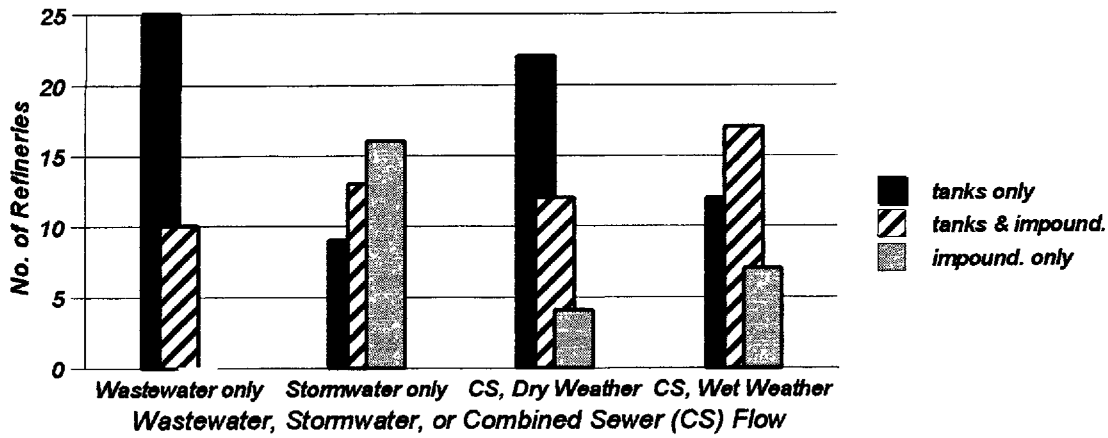


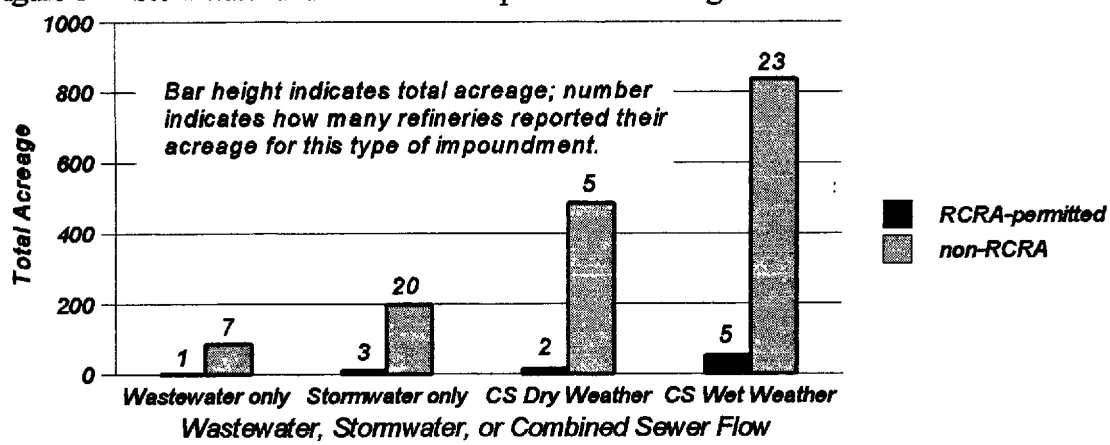
Figure 9—Stormwater and Wastewater Holding Structures.



Most of the facilities that reported using impoundments also reported the estimated acreage, which varied from 0.01 to 350 acres per facility. Figure 10 shows the total acreage having RCRA permits or interim status versus the acreage of impoundments that are not RCRA regulated. The chart also indicates the number of facilities that reported their acreage for each category. The average size of impoundments is summarized in the following list.

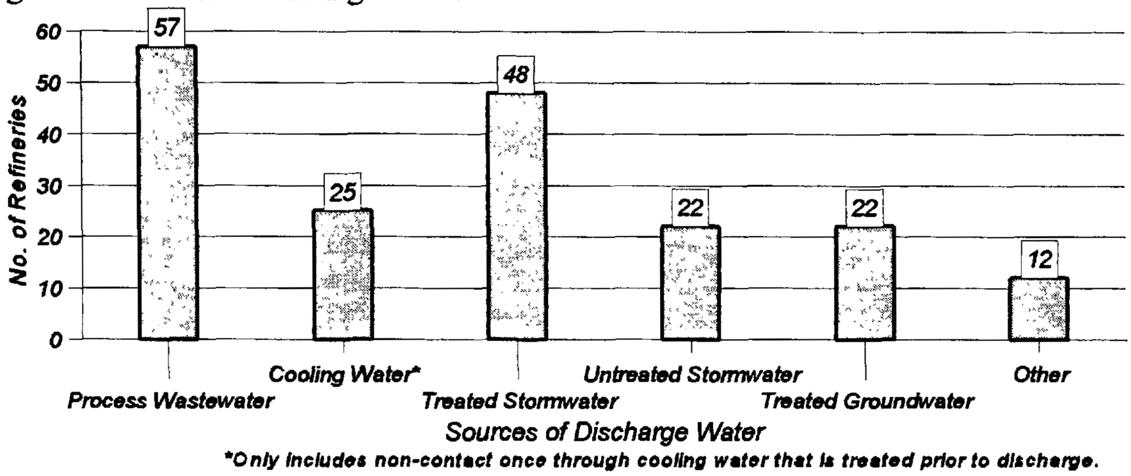
	average of all responses	average without largest & smallest
RCRA-permitted:	6.8 acres	4.3 acres
not RCRA regulated:	29.1 acres	23.6 acres

Figure 10—Stormwater and Wastewater Impoundment Acreage.



Every responding facility listed the quantity of wastewater discharged daily. The average of the reported daily discharge rates was 2.5 million gallons per day (MGD), and the median rate was 1.0 MGD. Two facilities indicated that their wastewater is routed to evaporation ponds, resulting in no offsite discharges. Most of the remaining respondents gave a breakdown of the sources of their discharge water, with all but one reporting some contribution from process wastewater. The number of facilities reporting each source of discharge water is shown in Figure 11. Note that most facilities report more than one source of discharge water. Of those listing 'other' sources, the most frequently mentioned source was blowdown water. Sanitary wastewater was also mentioned in several responses.

Figure 11—Sources of Discharge Water.



Additional detail on the sources of discharge water is provided in Table 3. In this table, the contribution of each source is shown as a percent of total discharge water, for those facilities reporting that source.

Table 3—Sources of Discharge Water as a Percent of Total.

	No. of Respondents reporting this source	Range	Median	Median Flow 1997 (MGD)	Median Flow 1996 (MGD)
Process Wastewater	57	10 – 100 %	70%	0.8	1.0
Noncontact Cooling Water*	25	2 – 80 %	20%	0.3	0.1
Treated Stormwater	48	0.5 – 100 %	9.9%	0.1	0.1
Untreated Stormwater	22	0.01 – 25 %	5%	0.05	0.08
Treated Groundwater	22	0.01 – 80 %	3.1%	0.03	0.04
Other	12	0.1 – 57 %	6.5%	0.2	0.1

* only includes non-contact once through cooling water that is treated prior to discharge.

Levels of eight discharge parameters were requested in the question on effluent quality. The levels are presented as an amount (pounds per year) in Table 4, and as a concentration (pounds per million gallons) in Table 5.

Table 4—Water Quality Discharge Parameters (pounds per year).

	No. of Respondents reporting this parameter	Median-1997	Median-1996
Total Suspended Solids (TSS)	58	84,000 lbs	73,000 lbs
Biochemical Oxygen Demand (BOD)	56	49,000 lbs	49,000 lbs
Chemical Oxygen Demand (COD)	51	435,000 lbs	380,000 lbs
Ammonia	58	9,100 lbs	9,700 lbs
Oil & Grease (O&G)	60	14,000 lbs	13,000 lbs
Chromium	42	22 lbs	26 lbs
Nickel	18	180 lbs	100 lbs
Selenium	22	200 lbs	120 lbs

Table 5—Water Quality Discharge Parameters (pounds per million gallons of wastewater discharge).

	Median-1997	Median-1996
Total Suspended Solids (TSS)	165 lbs/MG	140 lbs/MG
Biochemical Oxygen Demand (BOD)	92 lbs/MG	87 lbs/MG
Chemical Oxygen Demand (COD)	667 lbs/MG	750 lbs/MG
Ammonia	25 lbs/MG	26 lbs/MG
Oil & Grease (O&G)	28 lbs/MG	27 lbs/MG
Chromium	0.07 lbs/MG	0.04 lbs/MG
Nickel	0.16 lbs/MG	0.13 lbs/MG
Selenium	0.32 lbs/MG	0.12 lbs/MG

In addition to the effluent parameters, the survey solicited measurements of certain wastewater parameters at intermediate points in the system. The survey requested the levels of oil and grease after primary separation and again after secondary separation, as an indicator of the effectiveness of secondary oil/water separation. In a similar manner, the survey asked for levels of both BOD and COD before and after biotreatment. Approximately one third of the respondents supplied this information. The average levels of these parameters at the intermediate points indicated, as well as the average effluent levels, are summarized in Table 6. The effluent values do not match those reported in Table 5, in that only those facilities reporting these parameters at all three points were included in Table 6. These, then, comprise a subset of the facilities reported in Table 5.

Table 6—Water Quality Parameters at Intermediate Points (pounds per million gallons of wastewater flow).

	No. of Respondents reporting this parameter	Total Level* (pounds/MG)	1997 Average Level* (pounds/MG)
Oil and Grease (O&G)			
After primary separation	24	49,506	2,250
After secondary separation	24	10,222	465
At effluent	24	2,553	116
Biochemical Oxygen Demand (BOD)			
Before biotreatment	27	45,183	1,807
After biotreatment	27	6,306	252
At effluent	27	5,684	227
Chemical Oxygen Demand (COD)			
Before biotreatment	28	145,934	5,405
After biotreatment	28	31,108	1,152
At effluent	28	28,832	1,068

*Two outliers were deleted from the O&G summary, two outliers were deleted from the BOD summary, and one outlier was deleted from the COD summary.

POLLUTION PREVENTION

The simplified pollution prevention question introduced in the 1995 survey and used again in the 1996 survey was retained in the 1997 survey. Rather than soliciting pollution prevention practices for each residual stream, a single listing was requested for the entire facility. The question asked for a description of those pollution prevention activities undertaken in 1997. Most respondents listed only those projects brought on line in 1997, but it is evident from other portions of the survey that virtually every facility practices certain pollution prevention techniques, such as recycling.

Many of the pollution prevention techniques relate to recognizing that waste streams are often comprised largely of water and dirt that have been contaminated by being combined with process materials. Accordingly, the pollution prevention techniques include:

- reducing the amount of dirt that enters the oily wastewater stream,
- reducing the amount of water that enters the oily wastewater stream,
- dewatering to reduce the volume of oily sludges, and
- minimizing the contamination of dirt by reducing spills and leaks.

In addition to reducing the volume of water and dirt in the wastewater residuals, the industry has continued to implement strategies to better manage the process residuals, including:

- source reduction,
- waste segregation, and
- recycling.

Each of these practices is enhanced by education and training. The specific responses from the 1997 survey are listed in Table 7.

Table 7—Pollution Prevention Activities.

General Practice	Survey Response
Reduction of dirt to the oily water sewer.	Improved housekeeping. Improved site drainage. Modify sewer systems to reduce solids entering the sewer.
Reduction of water to the oily water sewer.	Eliminating and/or rerouting drains to reduce the flow of water entering the sewers.
Dewatering of oily sludges.	Installed new dewatering equipment. Replaced or improved existing dewatering equipment. Expanded the use of dewatering equipment.
Education and training.	Raised awareness of the facility's pollution prevention practices. Improved the FCCU waterwash program. Initiated a study of MEK and toluene losses to identify opportunities for reducing losses. Improved operations of the thermal desorption unit. Reviewed operating procedures to reduce the amount of acid soluble oil generated in the Alkylation Unit. Completed an NPDES point source study baseline.

Table 7—Pollution Prevention Activities (continued).

General Practice	Survey Response
Reduction/Containment of spills and leaks.	Improved housekeeping. Tagged and entered components for LDAR program. Installed double bottoms in storage tanks. Improved or expanded leak inspection programs for tanks. Upgraded rim seals on storage tank floating roofs. Installed high level alarms on tanks. Replaced underground piping with either double-walled piping or aboveground piping. Installed hydrocarbon recovery trenches. Replaced leaking seals and gaskets. Replaced/repaired concrete on hydrotreater and dewaxer units. Upgraded and/or relocated sewer lines.
Source reduction/process modification.	Reduced flaring from units through process changes. Upgraded the catalyst separator at the FCCU. Discontinued use of Freon® 12 (replaced with Freon® 134). Phase out of tetraethyllead. Permanently removed methylene chloride from the refinery's obsolete vapor recovery unit. Improved oil/water separations in the process units. Improved sulfur processing. Substituted less toxic chemicals for certain uses. Cleaned or replaced crude heat exchangers and fin fan air-product coolers. Purchased solvent-free parts washer. Replaced heavy atmospheric gas oil (HAGO) seal flush with nitrogen pump seals. Installed a filter to reduce particulate loadings from the intake water. Utilized a dry paint-removal system to reduce the use of hazardous abrasives. Replaced caustic and cresylic treating of crack stock gasoline with merox treating to meet -RSH specifications. Desalted Amine Solution and Stretford Solution. Changed the configuration of the burner system to increase the destruction efficiency of VOCs from the asphalt operation.
Waste segregation.	Kept nonlisted residuals from combining with listed wastes. Utilized containers and tanks to retain contaminated water and settle out solids prior to discharge to the wastewater treatment plant.

Table 7—Pollution Prevention Activities (continued).

General Practice	Survey Response
Recycling.	Utilized Delayed Coking unit to recycle DAF flock and tank bottoms. Recycled recovered oil from the process sewers back to the crude unit. Converted wastes into products or for use as intermediates. Installed equipment to inject the emulsion precursor directly into the pipestill crude feed pump suction. Initiated use of chemical treatment for tank cleaning to dissolve and recycle hydrocarbons from the sludge. Began a paper recycling program. Recycled ethylene glycol. Recycled activated alumina. Recycled spent catalysts. Recycled dessicants. Recycled non-hazardous sandblast abrasives. Recycled Freon®.
Improved treatment.	Used antifoulants in the heat exchanger systems. Added odor/emission control equipment to units. Improved pH control in the ASU. Upgraded the metering system for treated wastewater effluent. Enhanced water treatment by the installation of a solvent extraction system upstream of the DAF unit and by the downstream addition of microorganisms. Installed a unit to treat tail gas from the sulfur recovery unit. Replaced a flare with a new, taller flare. Installed more efficient tertiary cyclones to control particulates from the FCC unit stack. Installed a waste gas chiller. Installed a vapor recovery system at the NGL loading rack. Installed a treatment unit to remove benzene from the crude desalter effluent.

Section 3
RESIDUAL STREAM PROFILES

The U.S. refining industry managed an estimated 2.74 million wet tons of material from the 14 residual streams included in the 1997 API Refining Residual Survey. A summary of the total quantity of residuals managed per year is presented in Figure 12. The data for 1987 through 1994 have been adjusted in Figures 12 and 13 by deleting the quantities considered to be recovered oil or water rather than true residuals. Quantities reported as FCC catalyst recycled to a cat cracker have been deleted for the years 1991 through 1996, in that the material was still in use as a catalyst and therefore was not a residual.

Figure 12—Nationwide Estimate of Residual Quantity per Year: 1987-1997.

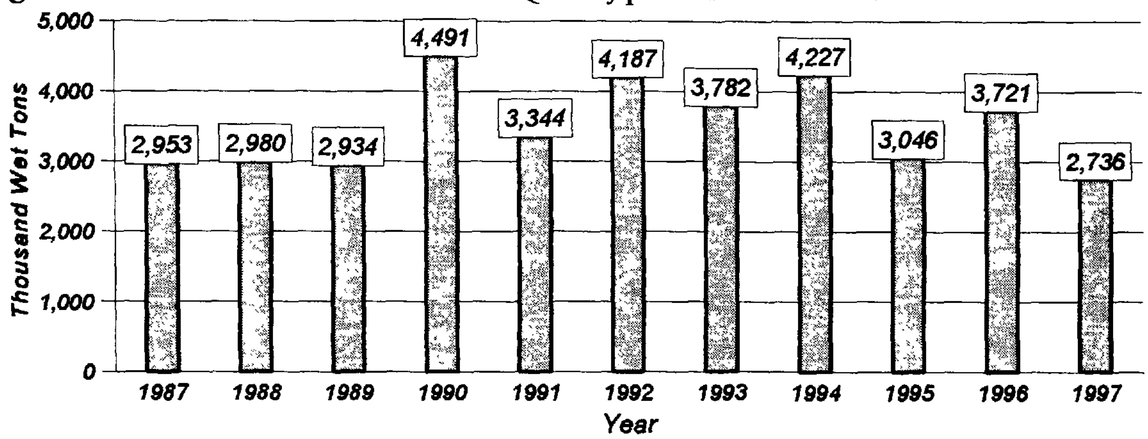
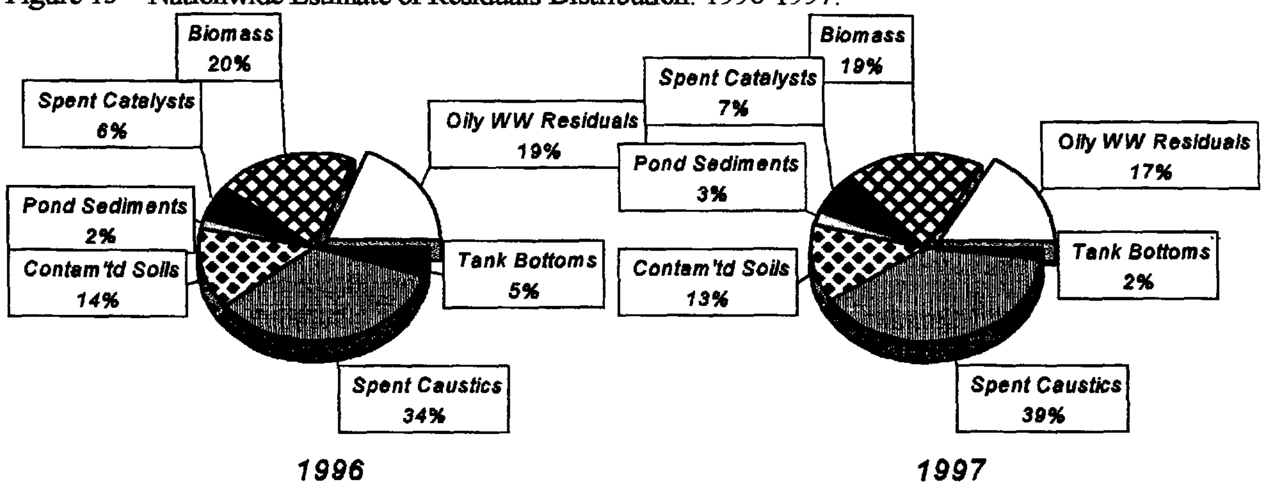


Figure 13 shows the relative contribution of the residual streams, with certain streams grouped together. The FCC catalyst, hydro. catalyst, and other spent catalyst streams are combined into a *spent catalysts* category; and a *spent caustics* category includes spent cresylic caustic, spent naphthenic caustic, and spent sulfidic caustic. The *oily wastewater residuals* (i.e., API separator sludge, DAF float, primary sludges, and slop oil emulsion solids) make up a third grouping. The contribution of each category in 1997 is estimated to be within five percentage points of its contribution to the 1996 data.

Figure 13—Nationwide Estimate of Residuals Distribution: 1996-1997.

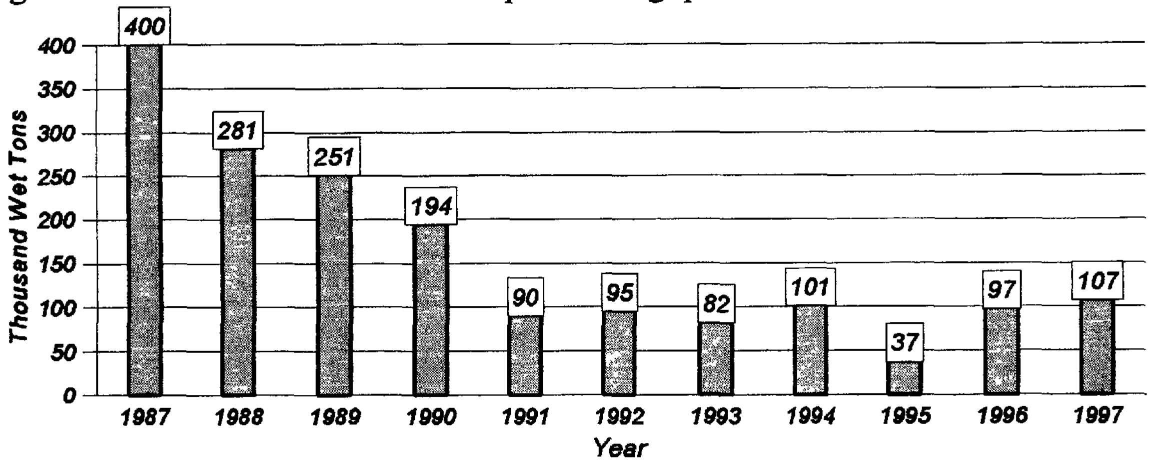


The remainder of this section presents detailed information for the individual streams, with the streams arranged in alphabetical order. The data for this section are summarized in the tables of Appendix C.

API SEPARATOR SLUDGE[1]

The U.S. petroleum refining industry managed an estimated 107 thousand wet tons of API Separator Sludge in 1997, which was a 10% increase from 1996. A summary of the quantity of API Separator Sludge managed per year is presented in Figure 14. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

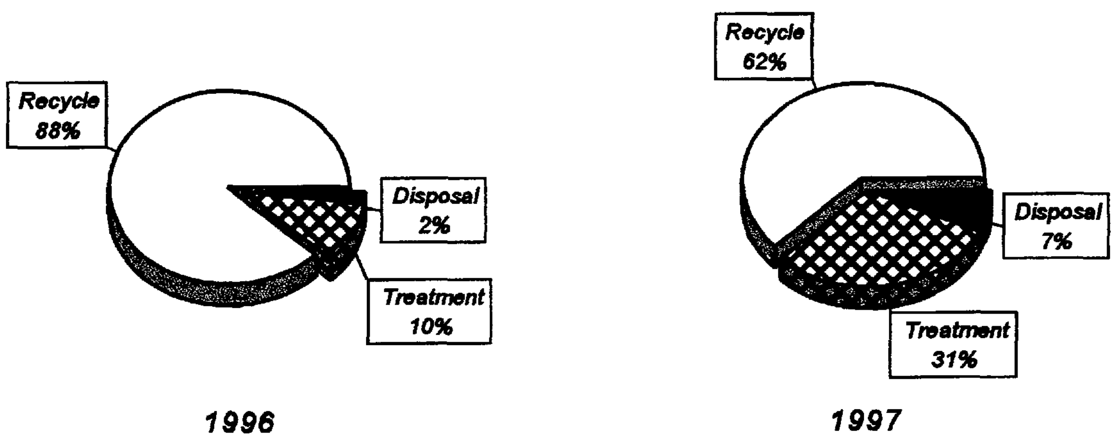
Figure 14—Nationwide Estimates of API Separator Sludge per Year: 1987-1997.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 88, which shows a decrease from 723 thousand wet tons in 1996 to 467 thousand wet tons in 1997, a decrease of 35%.

The portion of the API Separator Sludge stream that is managed by each management practice is shown in Figure 15 for 1996 and 1997. Recycling continues to be the dominant management practice for this stream.

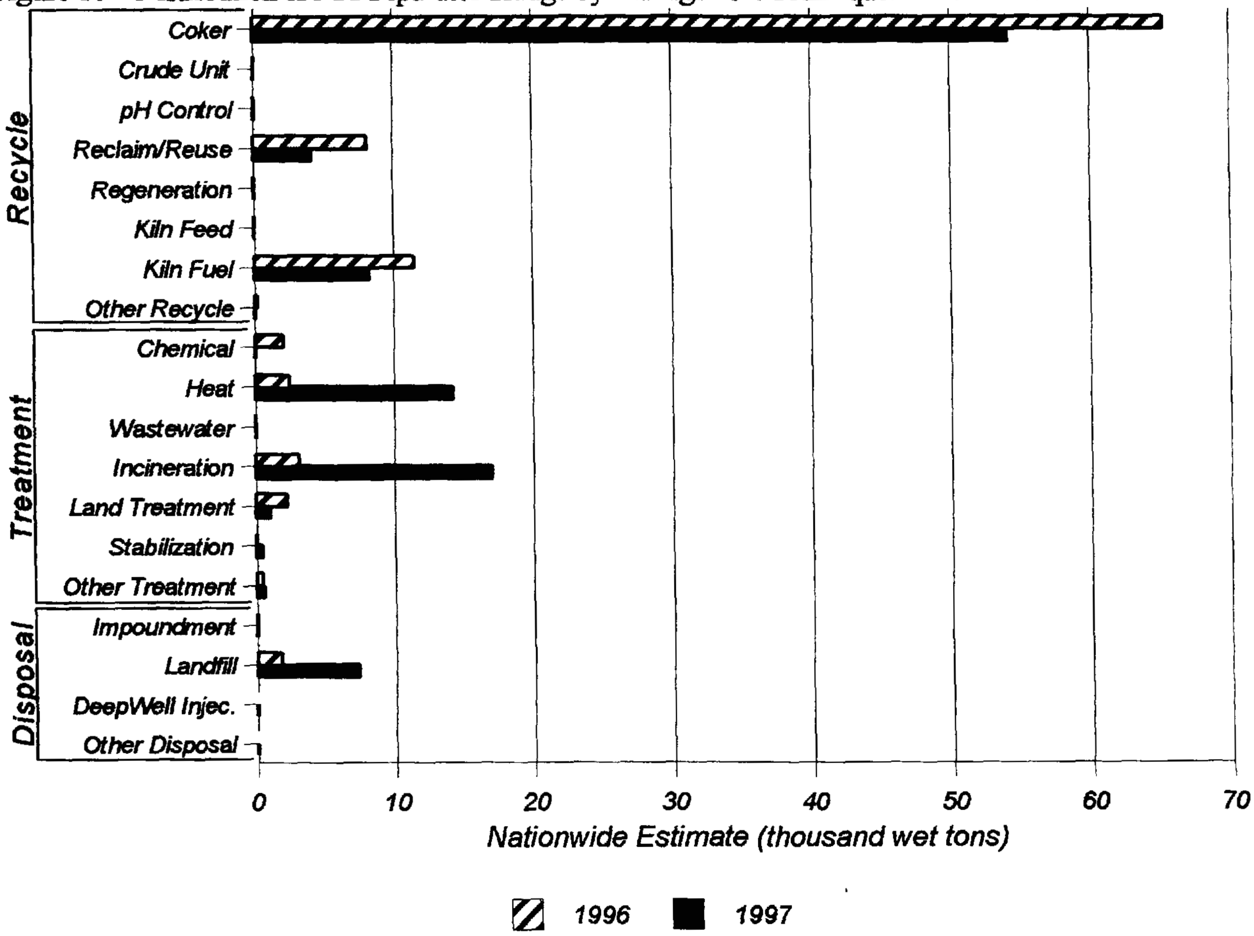
Figure 15—Nationwide Estimates of API Separator Sludge by Management Practice: 1996-1997.



[1]Recall that this report uses labels such as API Separator Sludge in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 16 shows the API Separator Sludge distribution by management technique for 1996 and 1997. This stream is most commonly managed by techniques that recycle the oil content, primarily by routing the stream to a *coker*. When oil is recovered from this stream by thermal desorption, it is reported as *reclamation*. End uses reported for reclaimed or reused material were *oil recovery* and *fuels blending*. The end-use categories are defined in Appendix A.

Figure 16—Distribution of API Separator Sludge by Management Technique: 1996-1997.



The 1997 survey prompted respondents who listed land treating or landfilling this stream to explain the circumstances. Some facilities indicated having exported the residual to Canada for landfilling, others explained that the material in question did not fall within the RCRA definition for this stream, and one facility cited a 'no migration land farm permit' as allowing land treatment of certain RCRA wastes.

Responses in the *other* categories are listed below.

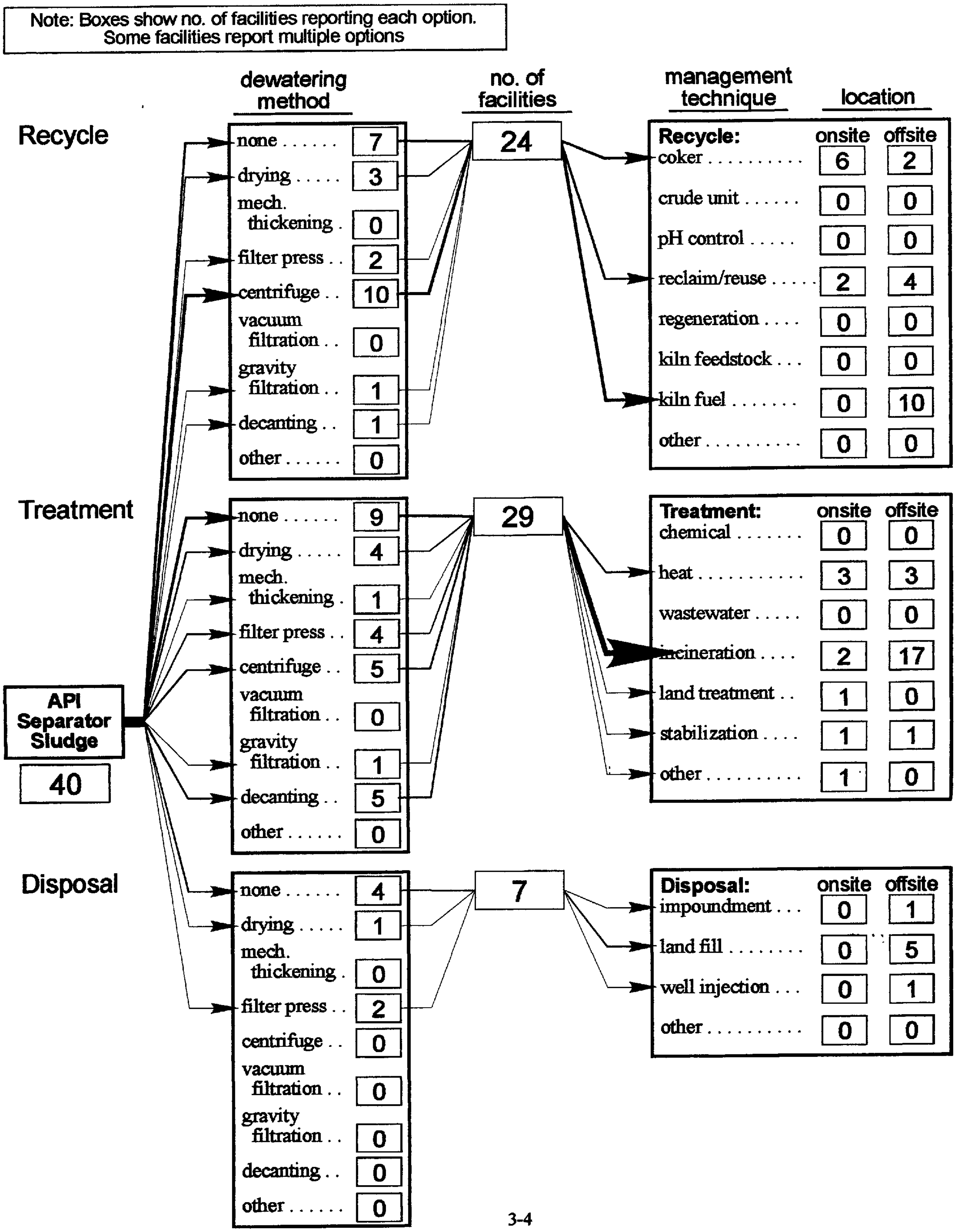
Other Recycle: none.

Other Treatment: one facility sends this stream to Permitted Storage.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 17 - API Separator Sludge Summary: 1997



The following three graphs summarize the cost data reported for API Separator Sludge.

Figure 18—Onsite Management Cost for API Separator Sludge: 1997

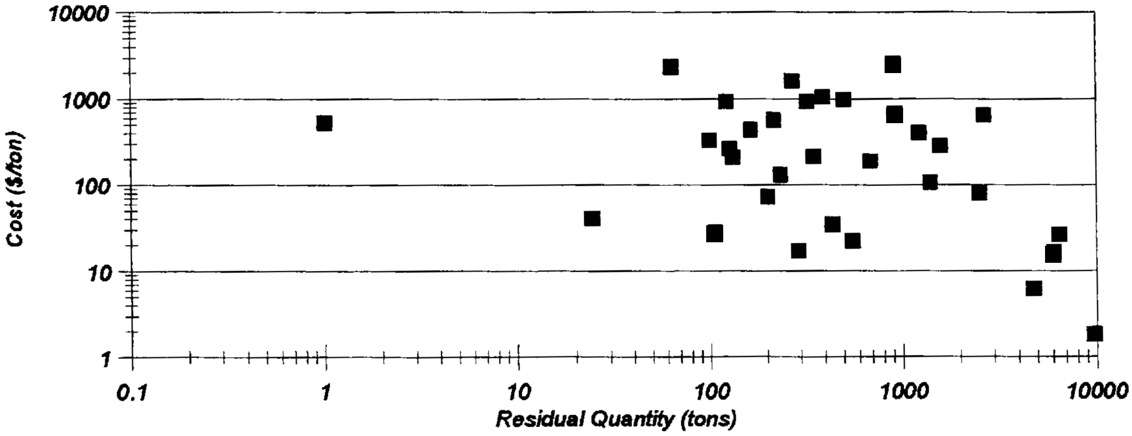


Figure 19—Offsite Management Cost for API Separator Sludge: 1997

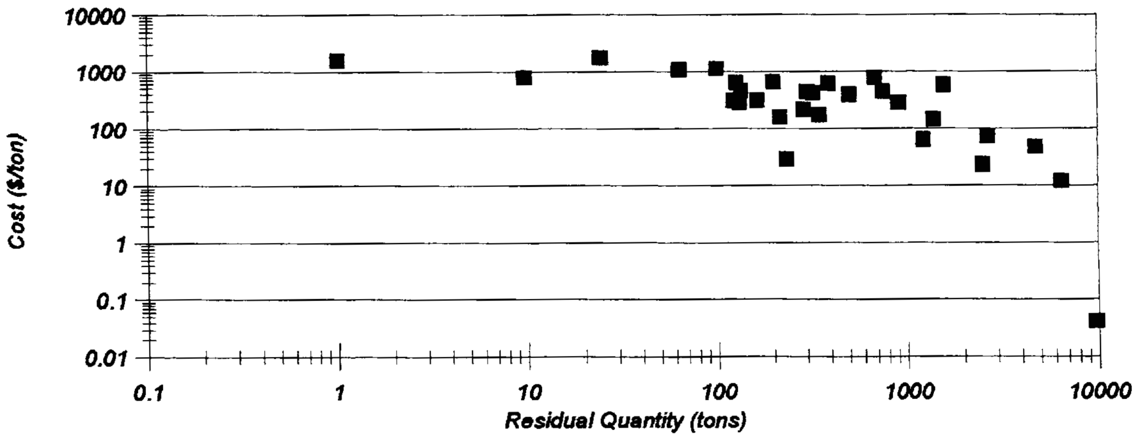
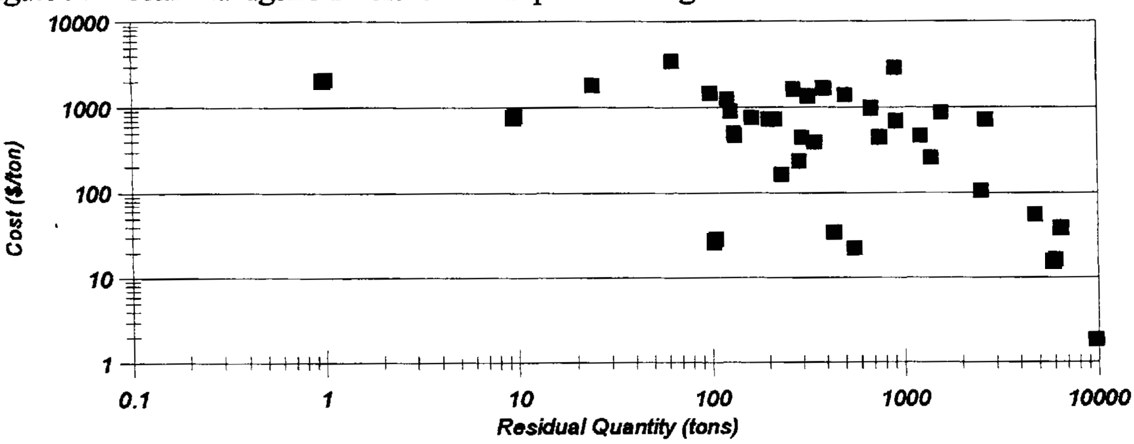


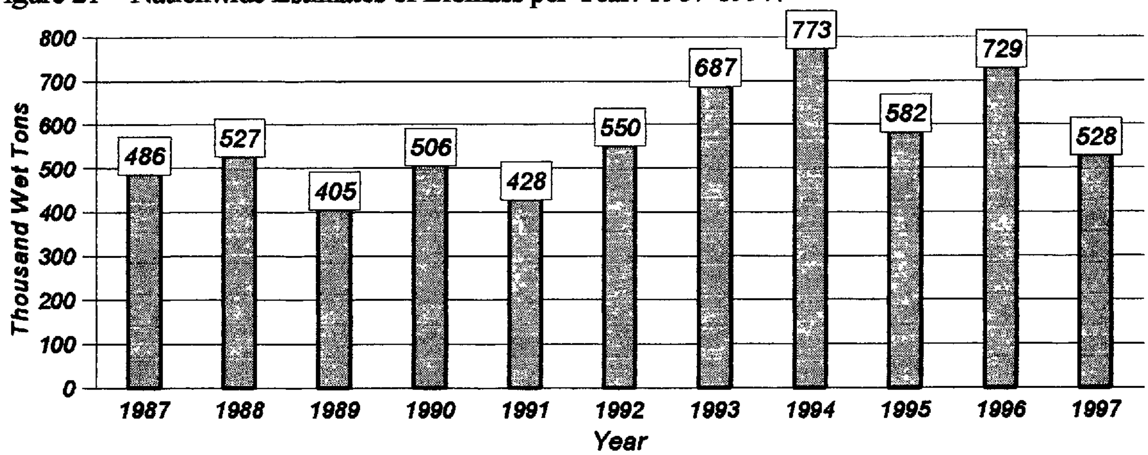
Figure 20—Total Management Cost for API Separator Sludge: 1997



BIOMASS[2]

The U.S. petroleum refining industry managed an estimated 528 thousand wet tons of Biomass in 1997, which was a 28% decrease from 1996. A summary of the quantity of Biomass managed per year is presented in Figure 21. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 21—Nationwide Estimates of Biomass per Year: 1987-1997.



The portion of the Biomass stream that is managed by each management practice is shown in Figure 22 for 1996 and 1997. Treatment continues to be the most common management practice for this stream.

Figure 22—Nationwide Estimates of Biomass by Management Practice: 1996-1997.

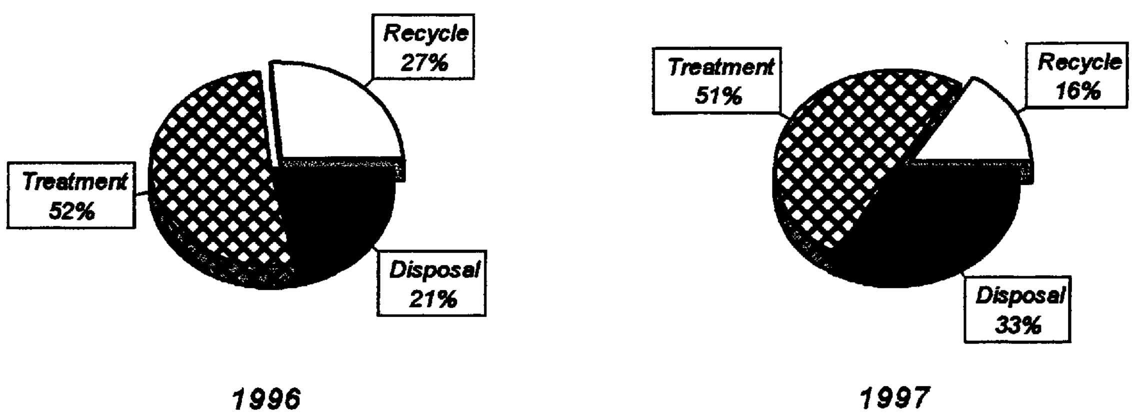
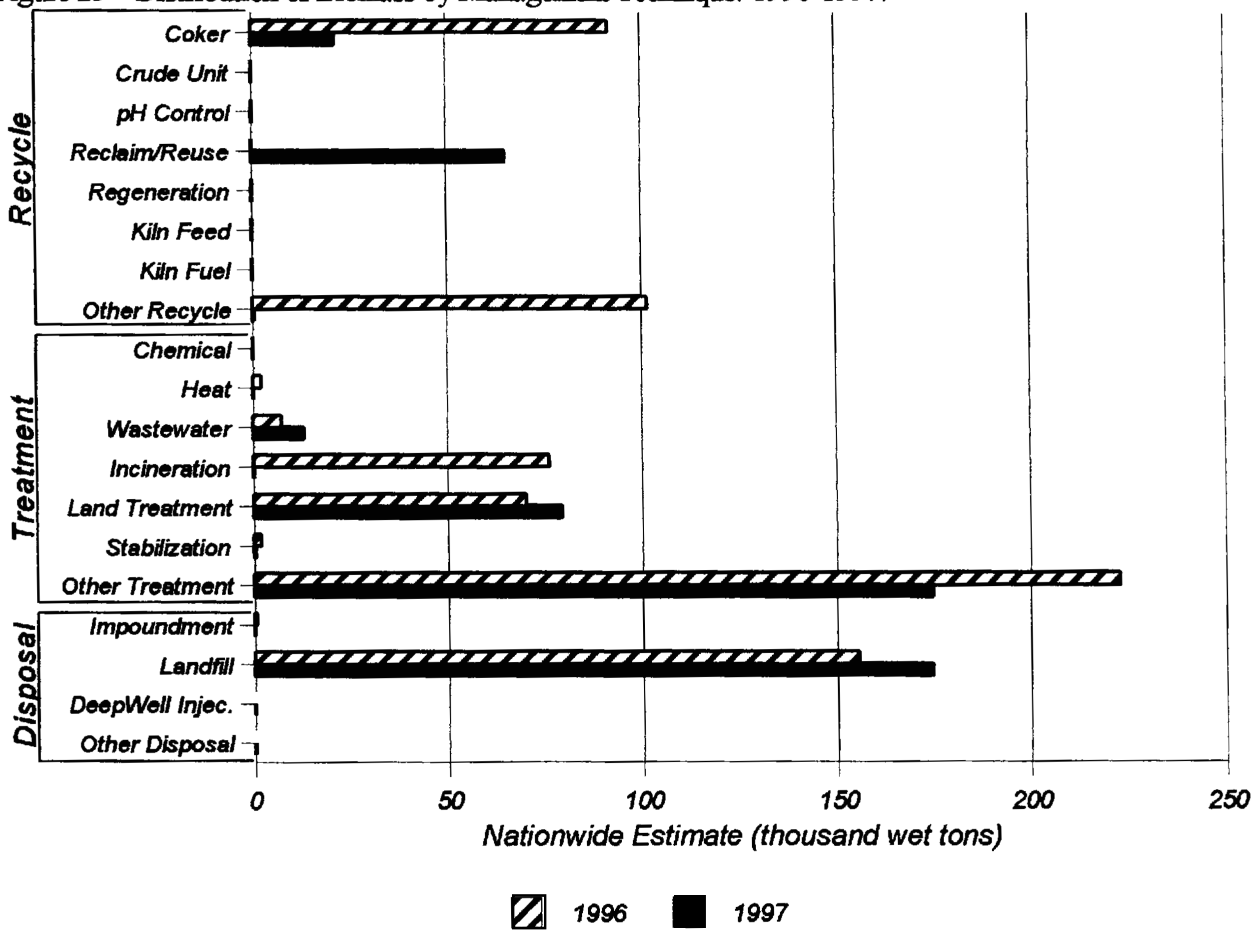


Figure 23 shows the Biomass distribution by management technique for 1996 and 1997. One facility reported *fuels blending* as the end use for reclaimed or reused material. The end-use categories are defined in Appendix A.

[2]Recall that this report uses labels such as Biomass in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 23—Distribution of Biomass by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: one facility biotreats this stream and blends it to make topsoil.

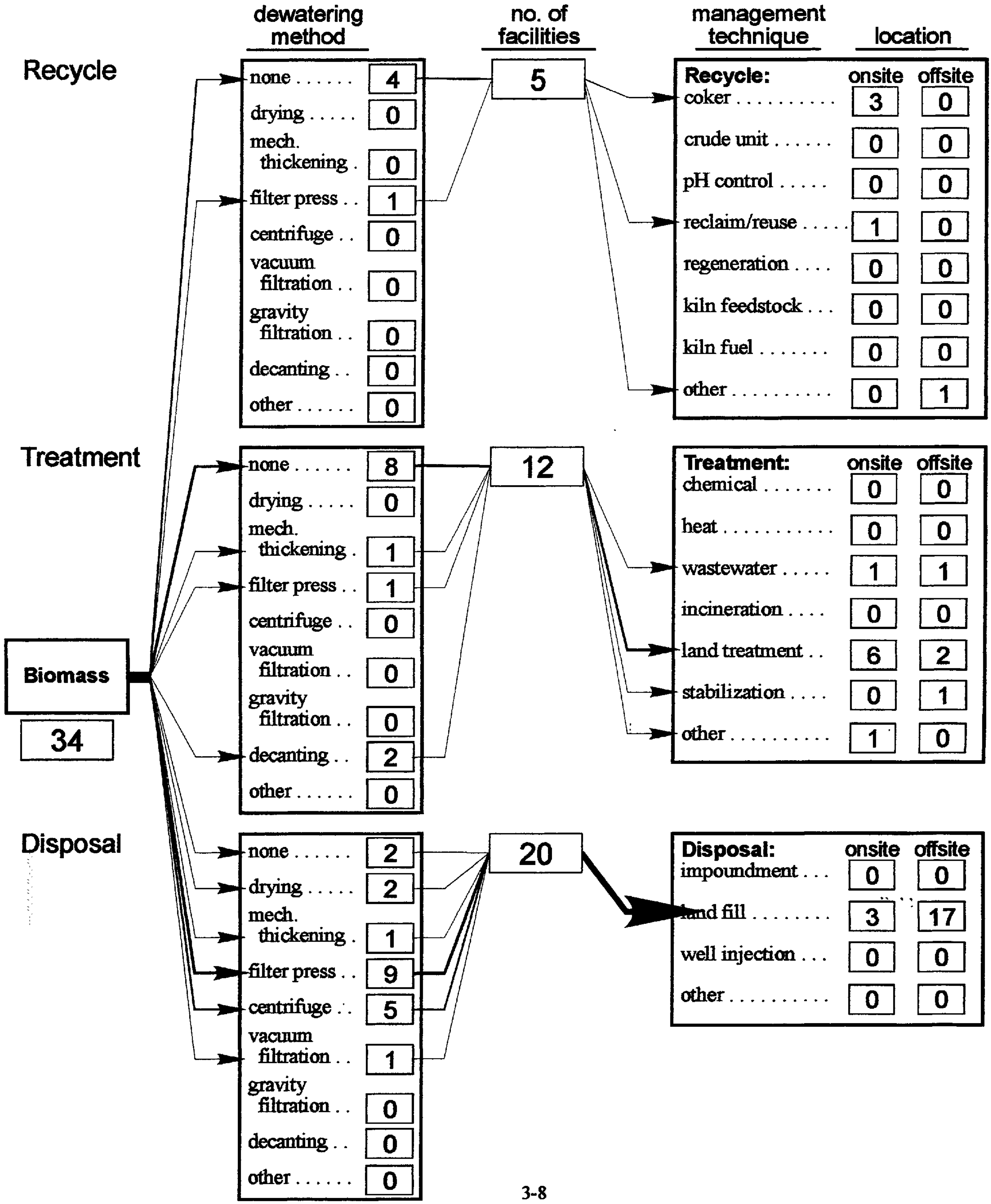
Other Treatment: one facility treats biomass in a sludge digester.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 24 - Biomass Summary: 1997

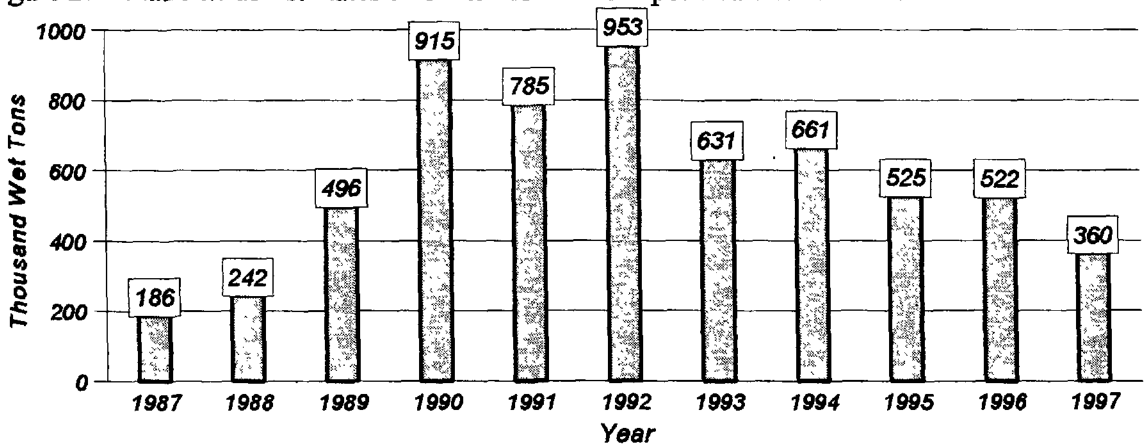
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



CONTAMINATED SOILS[3]

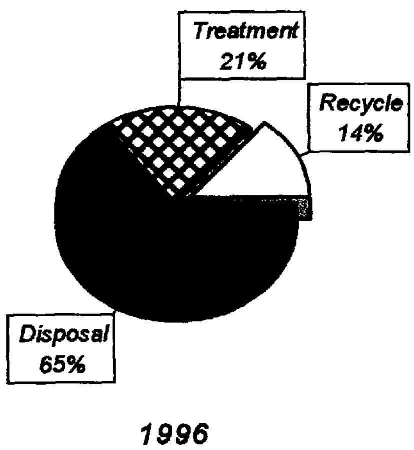
The U.S. petroleum refining industry managed an estimated 360 thousand wet tons of Contaminated Soils in 1997, which was a 31% reduction from 1996. A summary of the quantity of Contaminated Soils managed per year is presented in Figure 25.

Figure 25—Nationwide Estimates of Contaminated Soils per Year: 1987-1997.



The portion of the Contaminated Soils stream that is managed by each management practice is shown in Figure 26 for 1996 and 1997. While the portion of this stream that is recycled continues to increase, disposal is still the most common practice.

Figure 26—Nationwide Estimates of Contaminated Soils by Management Practice: 1996-1997.



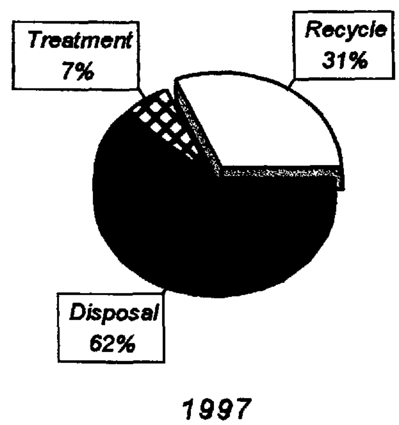
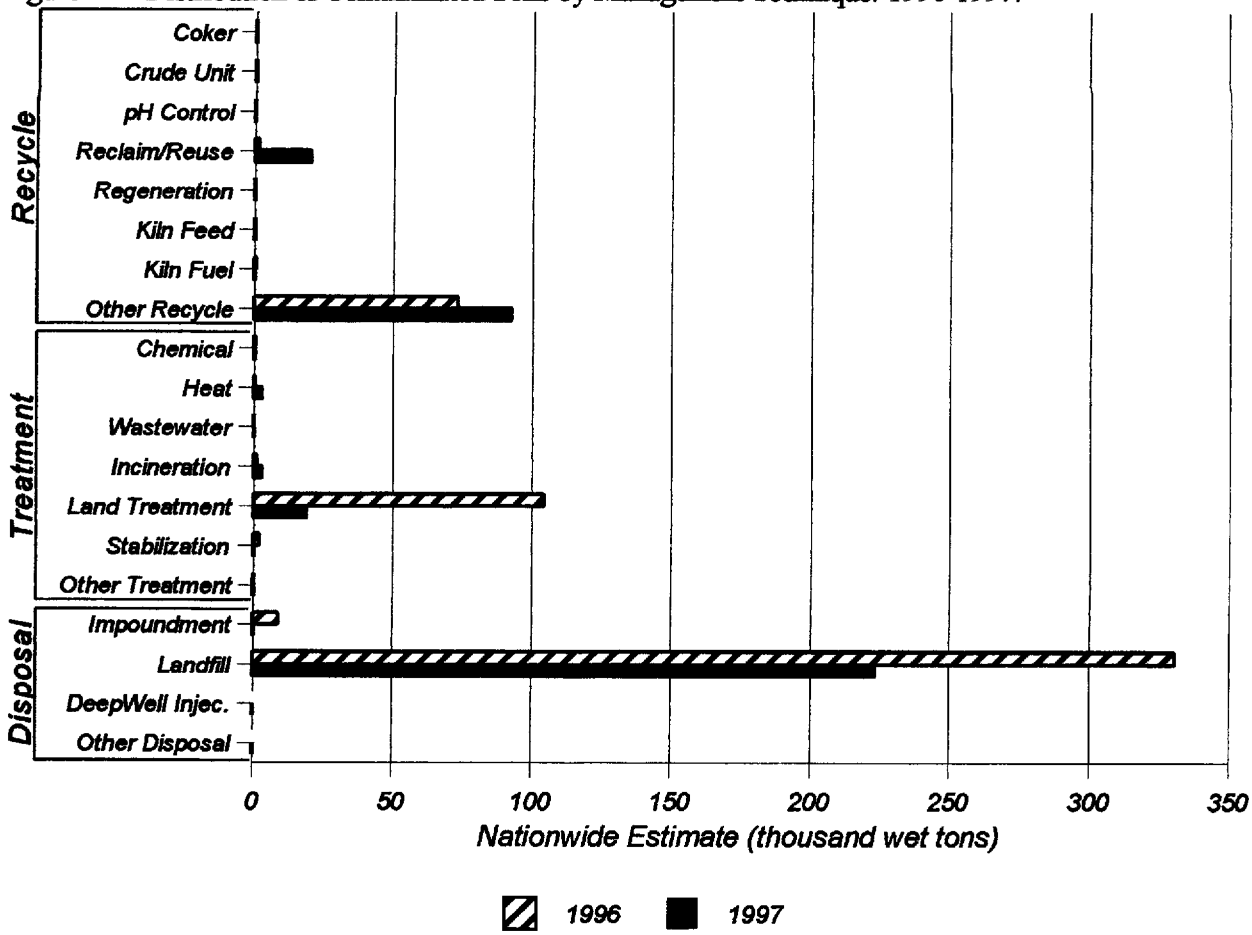


Figure 27 shows the Contaminated Soils distribution by management technique for 1996 and 1997. This stream is still primarily either *landfilled* or *land treated*, although some facilities find innovative ways to recycle contaminated soil. An end use reported for reclaimed or reused material was to ***recover asphalt and return it to the process***.

---

[3]Recall that this report uses labels such as Contaminated Soils in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 27—Distribution of Contaminated Soils by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: five facilities blend this stream into asphalt and/or roadbed material.

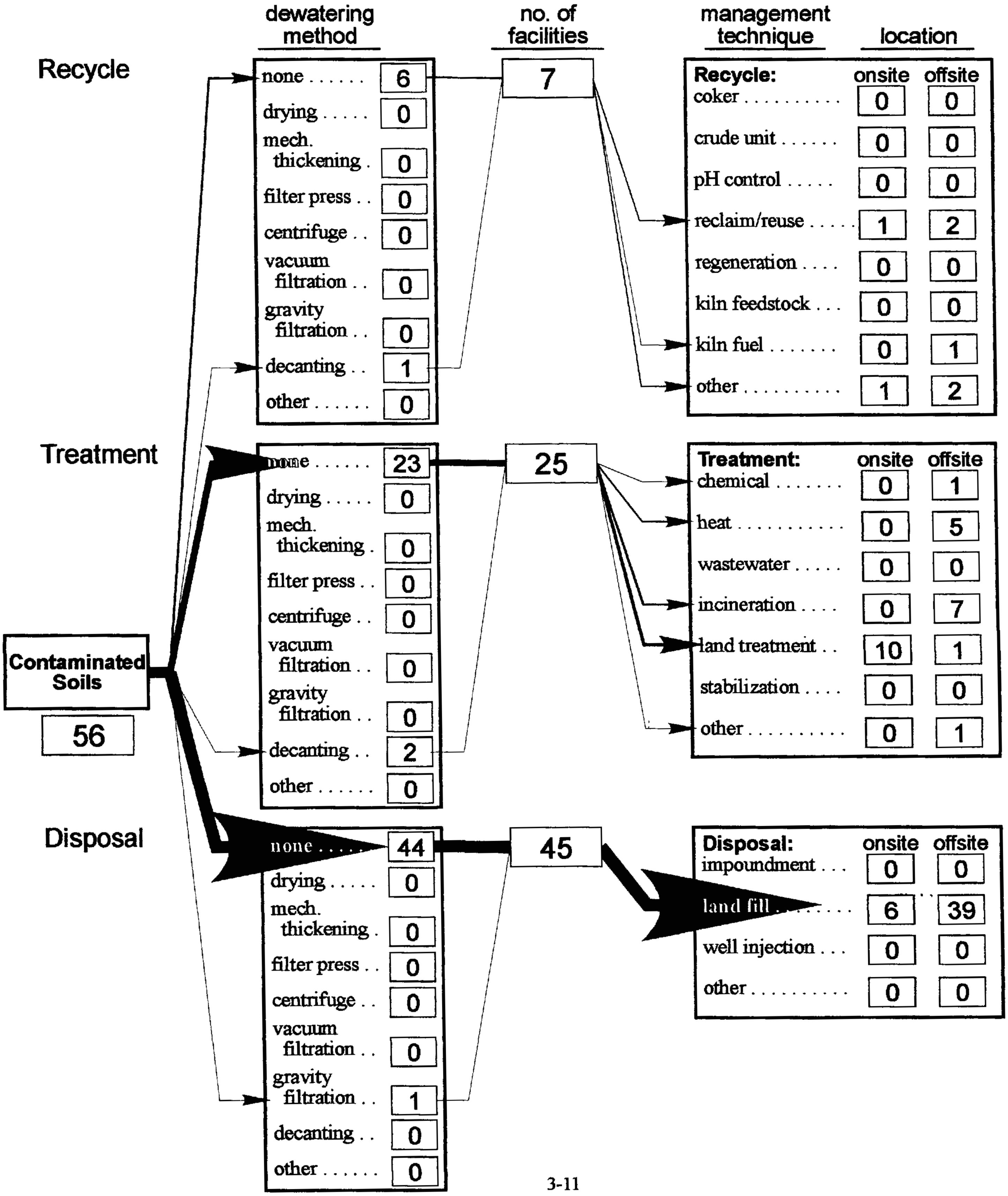
Other Treatment: one facility treats this stream by macroencapsulation.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 28 - Contaminated Soils Summary: 1997

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



The following three graphs summarize the cost data reported for Contaminated Soils.

Figure 29—Onsite Management Cost for Contaminated Soils: 1997

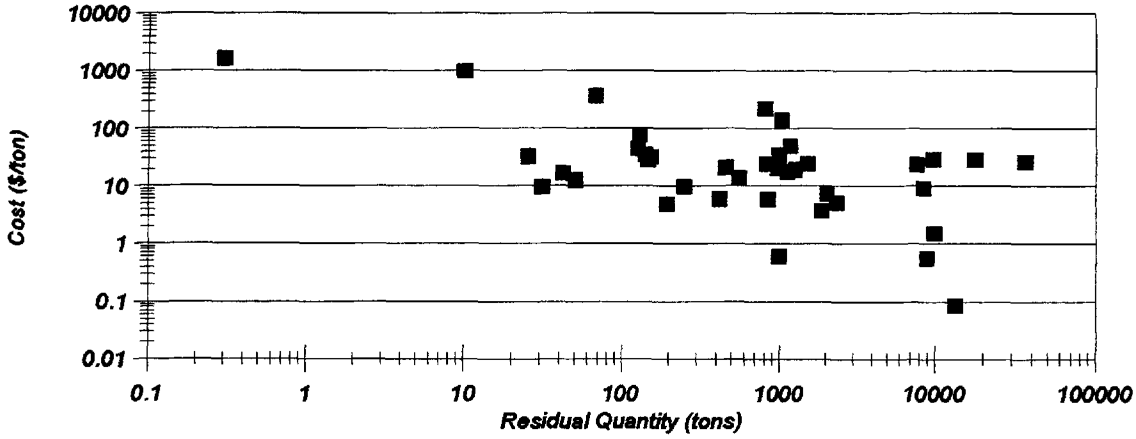


Figure 30—Offsite Management Cost for Contaminated Soils: 1997

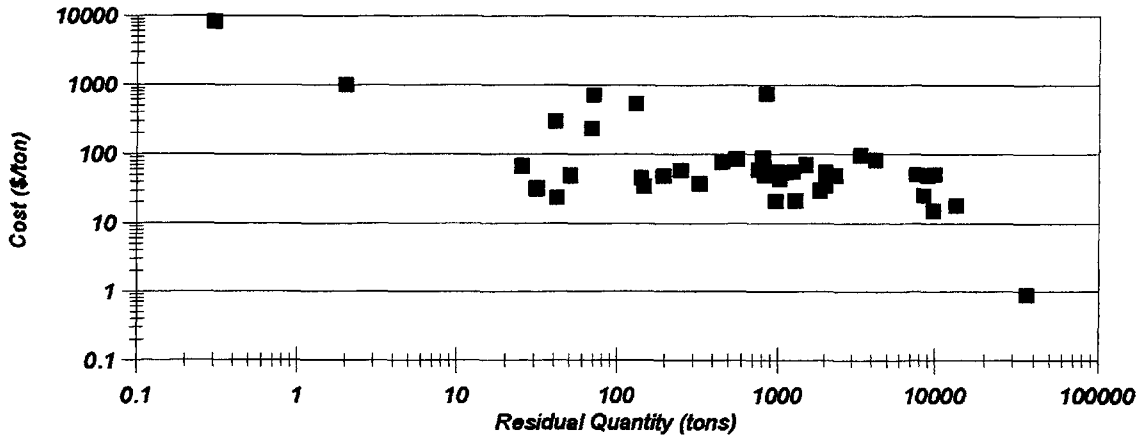
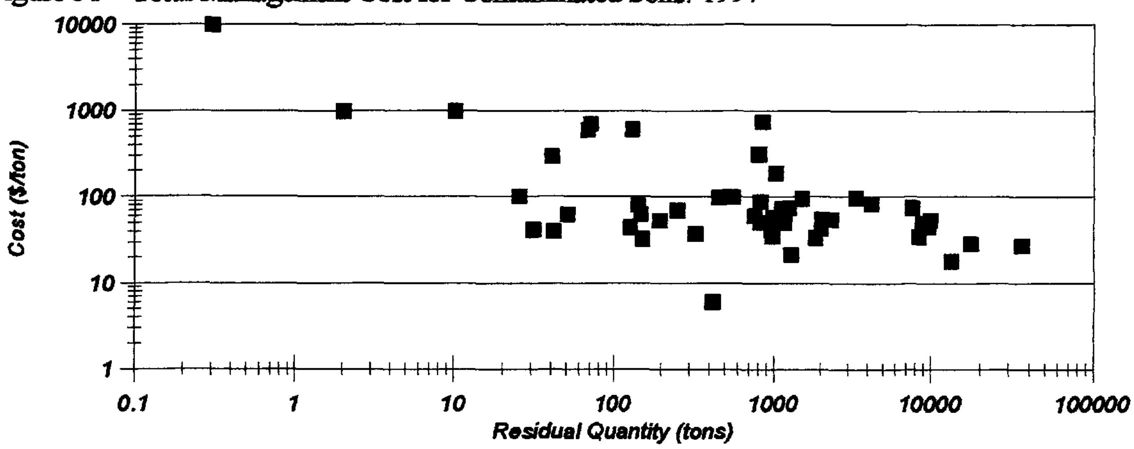


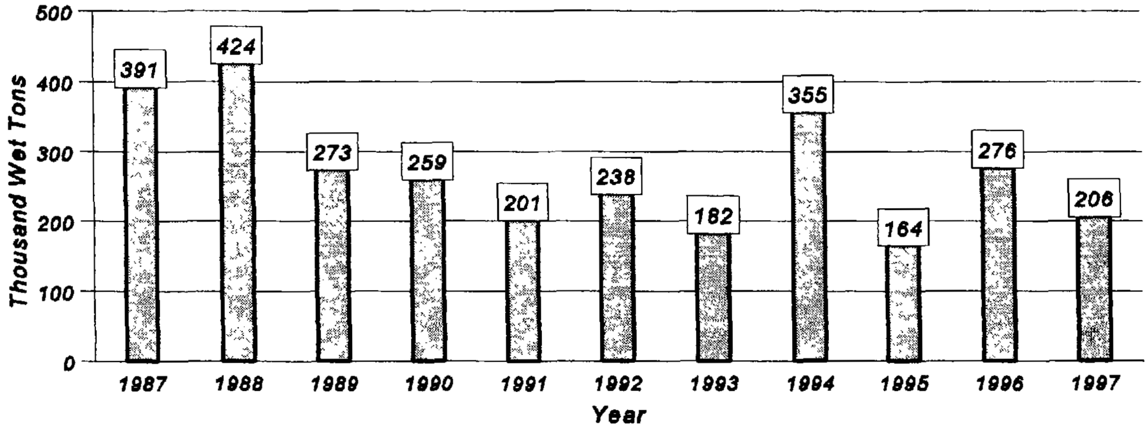
Figure 31—Total Management Cost for Contaminated Soils: 1997



DAF FLOAT[4]

The U.S. petroleum refining industry managed an estimated 206 thousand wet tons of Dissolved Air Flotation (DAF) Float in 1997, which was a 26% decrease from 1996. A summary of the quantity of DAF Float managed per year is presented in Figure 32. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered water rather than true residuals.

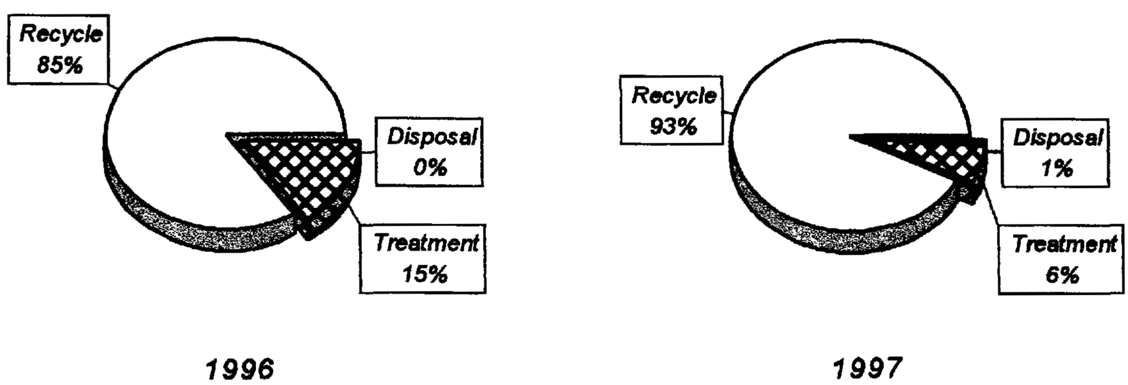
Figure 32—Nationwide Estimates of DAF Float per Year: 1987-1997.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 88, which shows a decrease from 723 thousand wet tons in 1996 to 467 thousand wet tons in 1997, a decrease of 35%.

The portion of the DAF Float stream that is managed by each management practice is shown in Figure 33 for 1996 and 1997. Recycling continues to be the dominant practice.

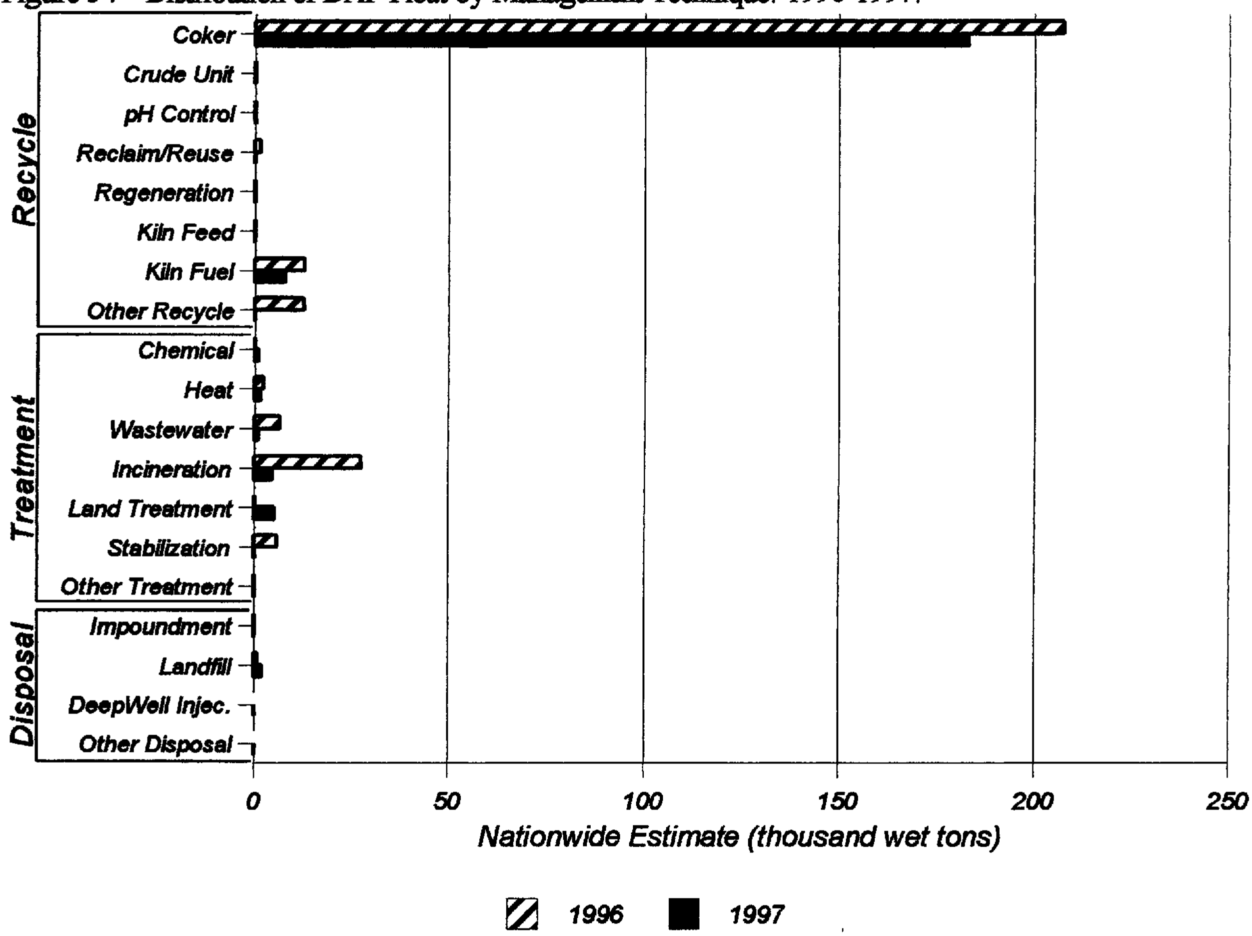
Figure 33—Nationwide Estimates of DAF Float by Management Practice: 1996-1997.



[4]Recall that this report uses labels such as DAF Float in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 34 shows the DAF Float distribution by management technique for 1996 and 1997. While this stream is grouped with the oily wastewater residuals, it often includes relatively large volumes of water. It is most commonly managed by being routed to a *coker*. An end use reported for reclaimed or reused material was *oil recovery*. The end-use categories are defined in Appendix A.

Figure 34—Distribution of DAF Float by Management Technique: 1996-1997.



The 1997 survey prompted respondents who listed land treating or landfilling this stream to explain the circumstances. Some facilities indicated having exported the residual to Canada for landfilling, others explained that the material in question did not fall within the RCRA definition for this stream, and one facility cited a 'no migration land farm permit' as allowing land treatment of certain RCRA wastes.

Responses in the *other* categories are listed below.

Other Recycle: none.

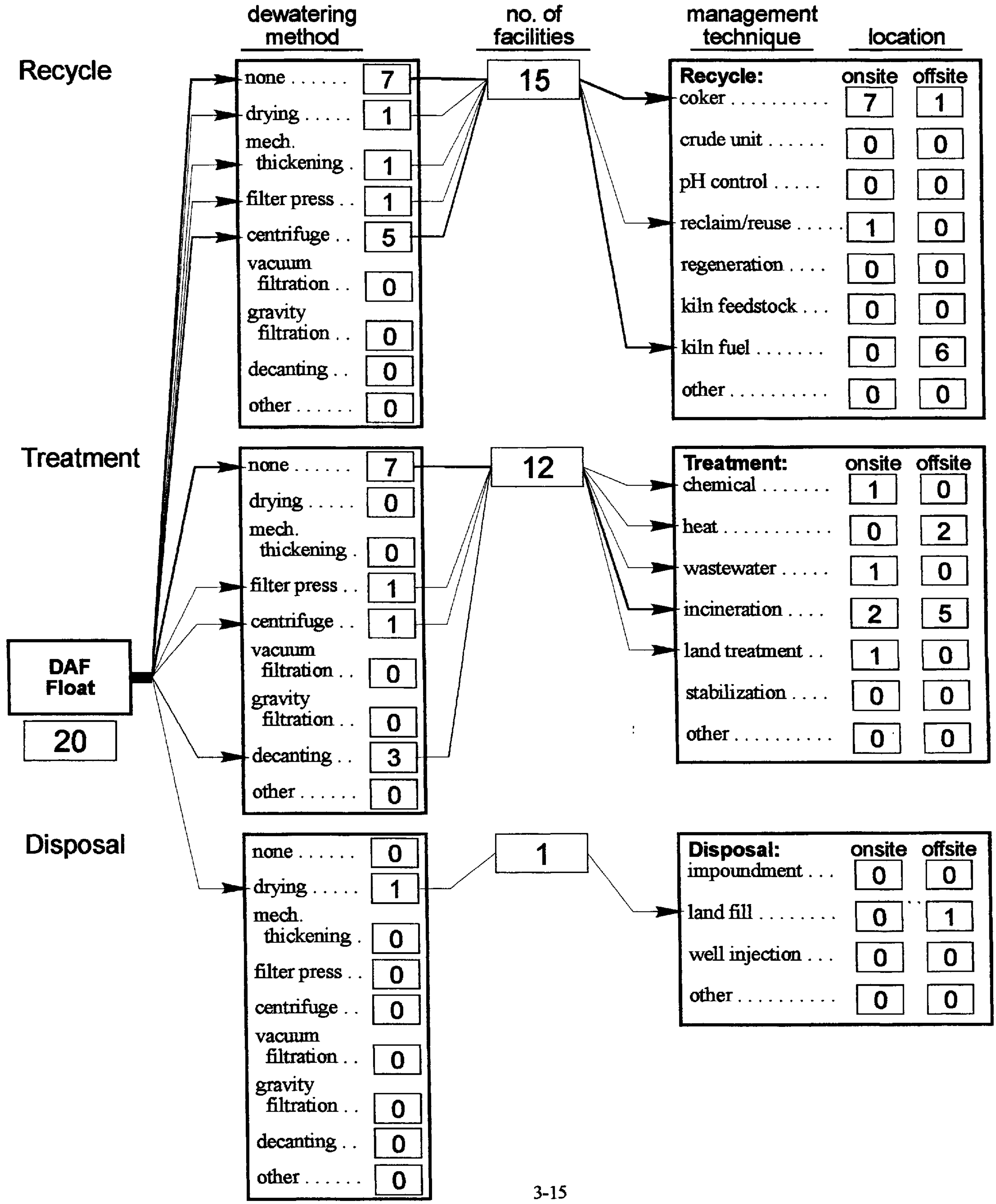
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 35 - DAF Float Summary: 1997

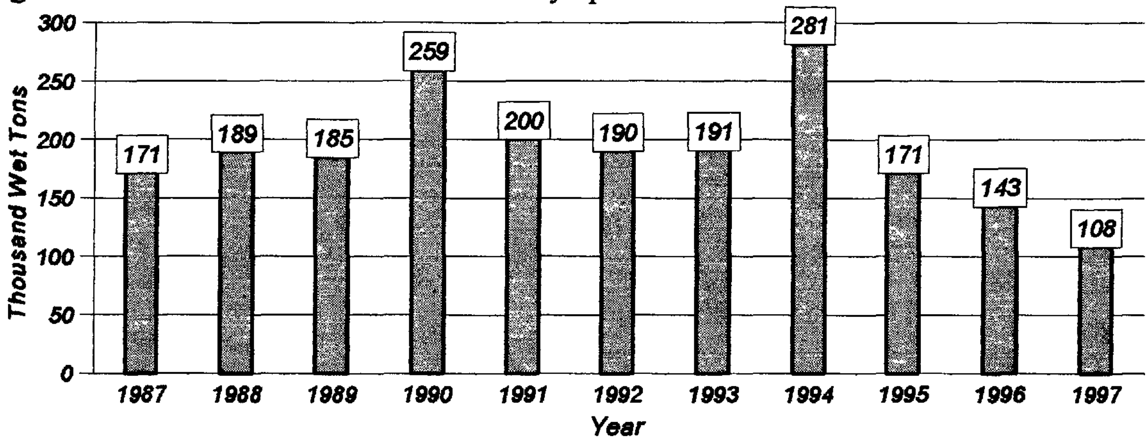
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



FCC CATALYST[5]

The U.S. petroleum refining industry managed an estimated 108 thousand wet tons of Fluidized-bed Catalytic Cracking (FCC) Catalyst in 1997, which was a 25% reduction from 1996. A summary of the quantity of FCC Catalyst managed per year is presented in Figure 36.

Figure 36—Nationwide Estimates of FCC Catalyst per Year: 1987-1997.



The portion of the FCC Catalyst stream that is managed by each management practice is shown in Figure 37 for 1996 and 1997. Disposal continues to be the most common practice.

Figure 37—Nationwide Estimates of FCC Catalyst by Management Practice: 1996-1997.

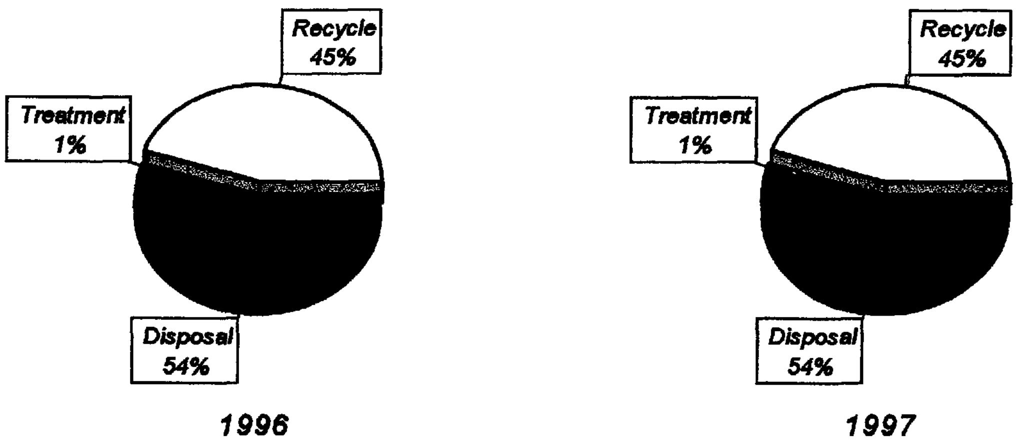
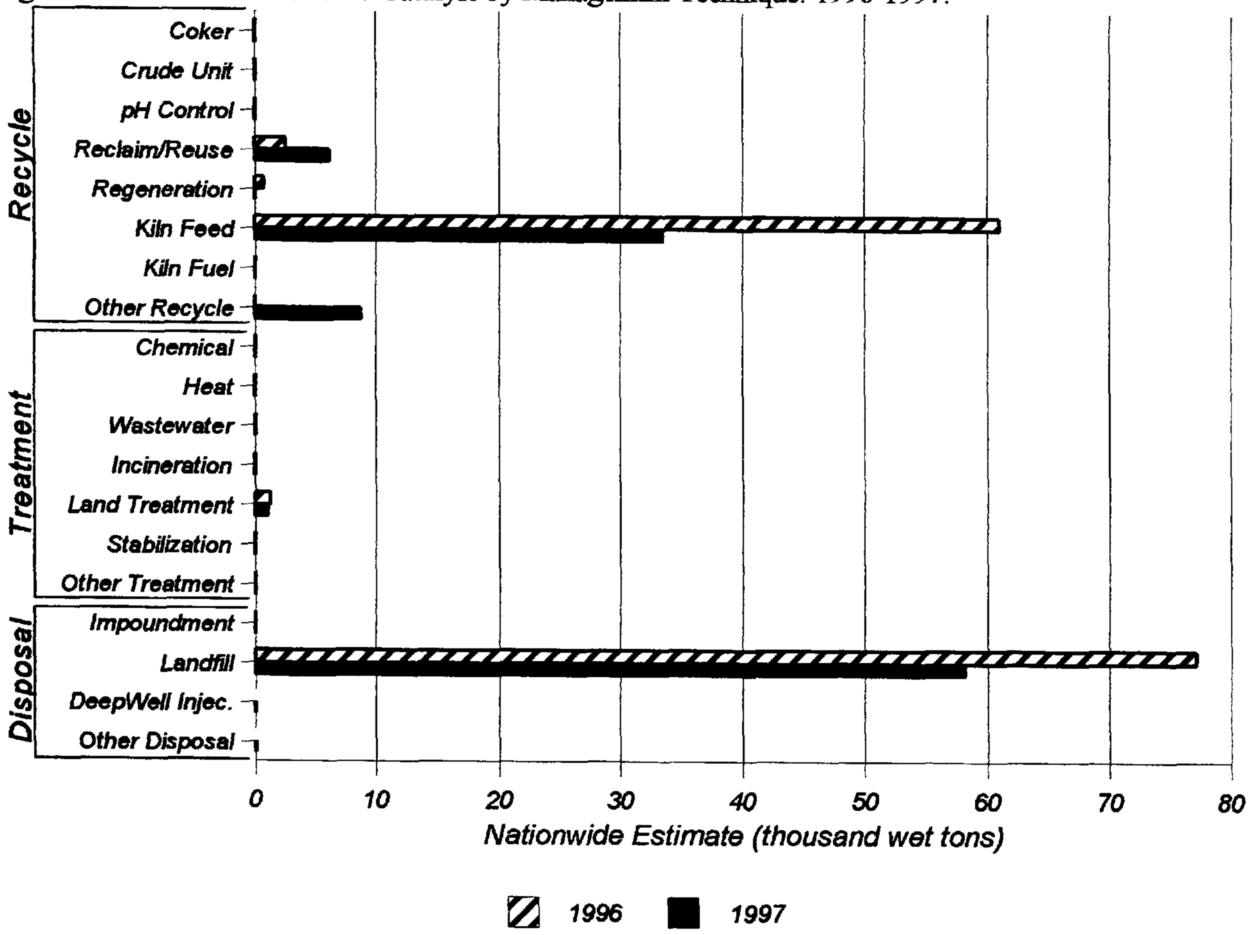


Figure 38 shows the FCC Catalyst distribution by management technique for 1996 and 1997. Spent catalyst is typically recycled as cement *kiln feedstock*, whereas fines from the flue gas are typically *landfilled*. One facility sends this stream for reuse in the *steel industry*. Several others report sale to a *catalyst broker* as the end use for reclaimed or reused material. The end-use categories are defined in Appendix A.

---

[5]Recall that this report uses labels such as FCC Catalyst in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 38—Distribution of FCC Catalyst by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: one facility reports blending this stream into roadbase materials.

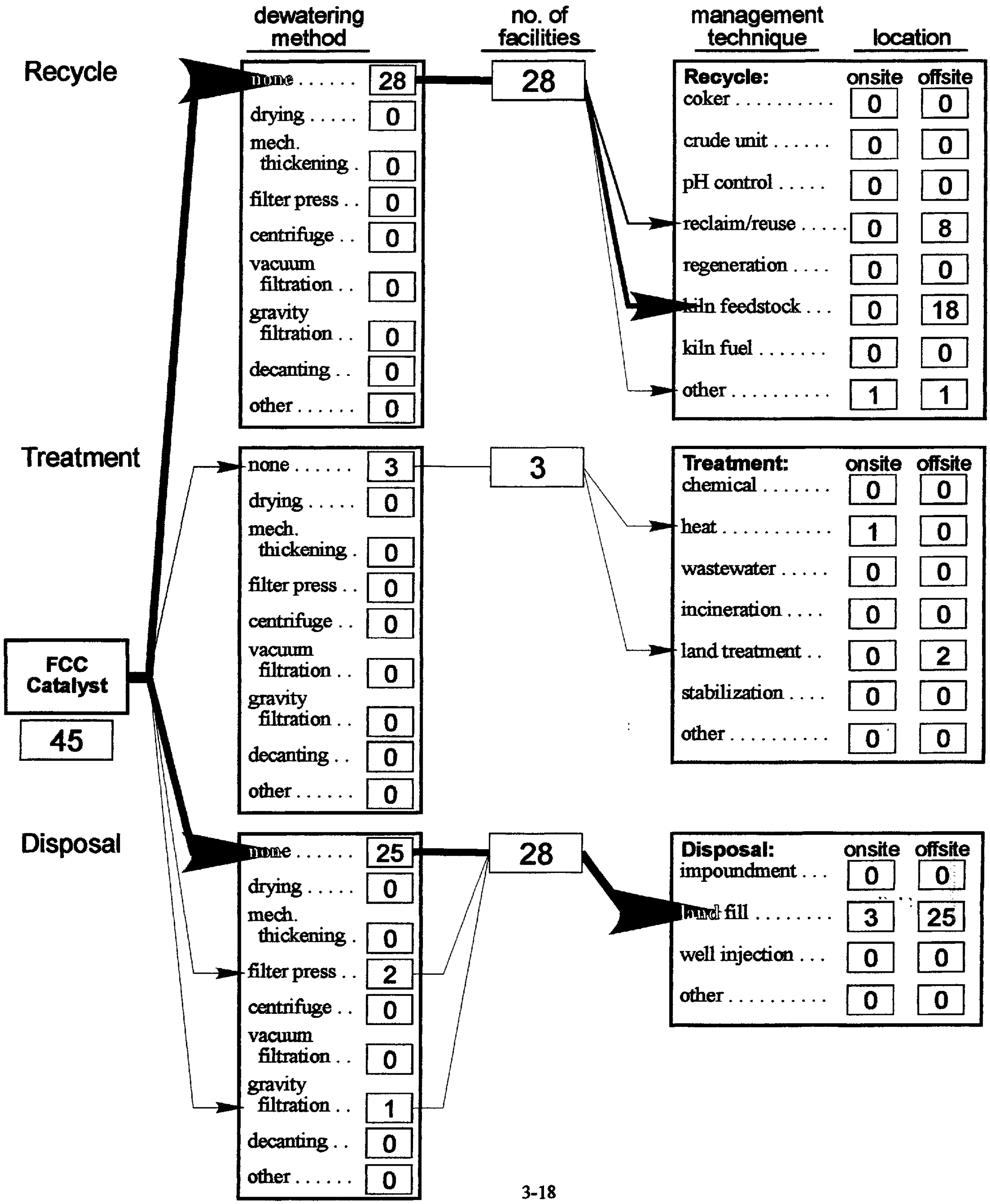
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 39 - FCC Catalyst Summary: 1997

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



The following three graphs summarize the cost data reported for FCC Catalyst.

Figure 40—Onsite Management Cost for FCC Catalyst: 1997

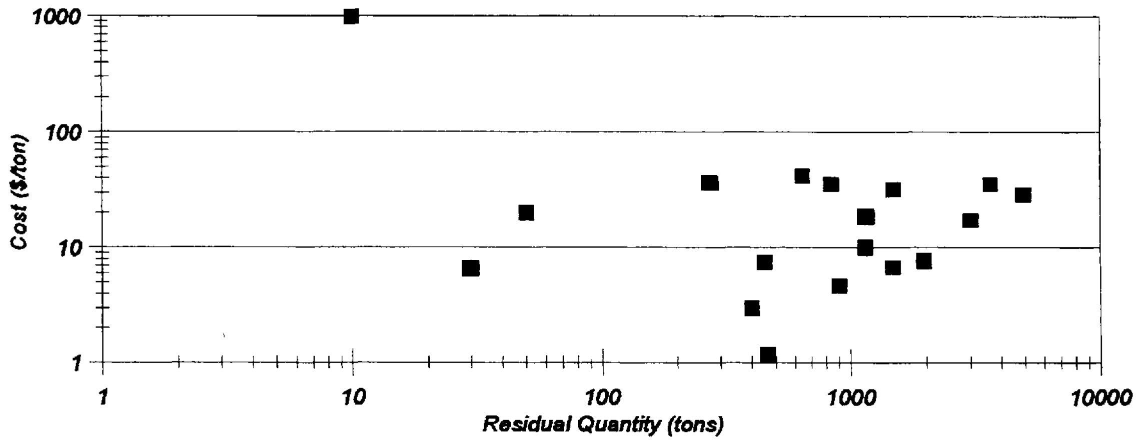


Figure 41—Offsite Management Cost for FCC Catalyst: 1997

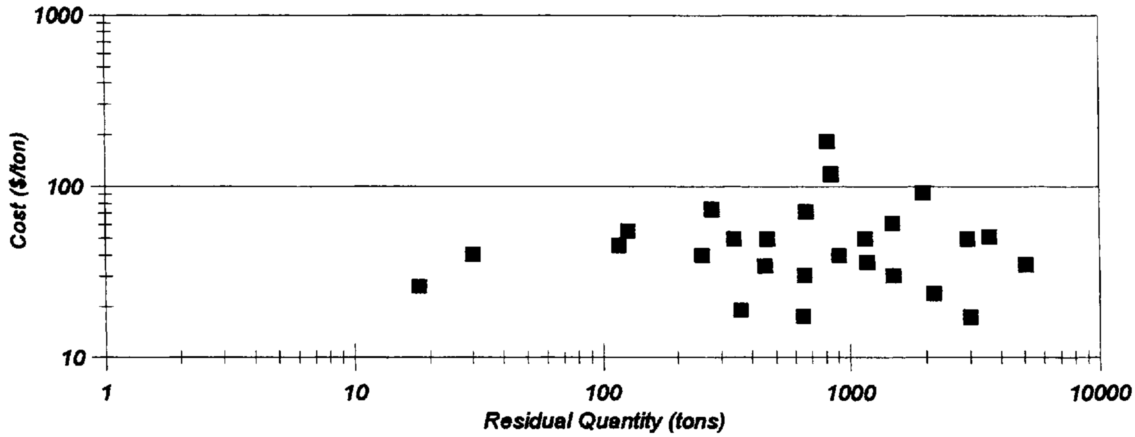
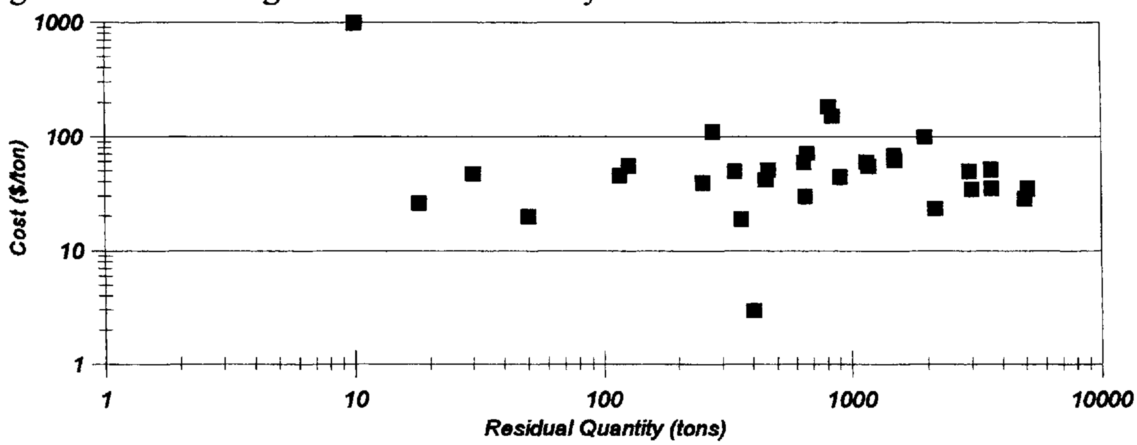


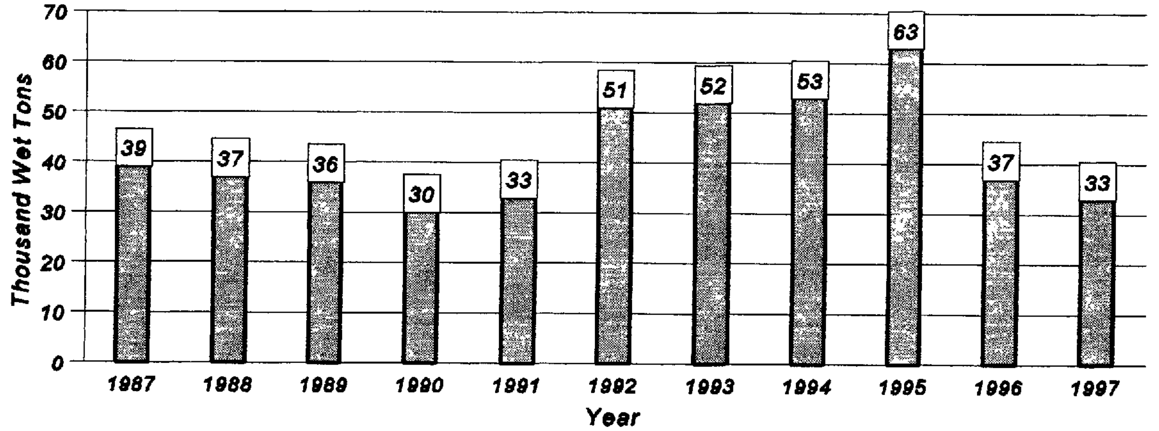
Figure 42—Total Management Cost for FCC Catalyst: 1997



HYDRO. CATALYST[6]

Hydro. Catalyst is a generic label applied in this report to catalysts used to remove sulfur, nitrogen, and metals. These catalysts are variously referred to in the industry by such terms as hydroprocessing, hydrotreating, hydrorefining, hydrofinishing, and other hydro-prefixed descriptors. The U.S. petroleum refining industry managed an estimated 33 thousand wet tons of Hydro. Catalyst in 1997, which was an 11% decrease from 1996. A summary of the quantity of Hydro. Catalyst managed per year is presented in Figure 43.

Figure 43—Nationwide Estimates of Hydro. Catalyst per Year: 1987-1997.



The portion of the Hydro. Catalyst stream that is managed by each management practice is shown in Figure 44 for 1996 and 1997. Recycling continues to be the most common practice.

Figure 44—Nationwide Estimates of Hydro. Catalyst by Management Practice: 1996-1997.

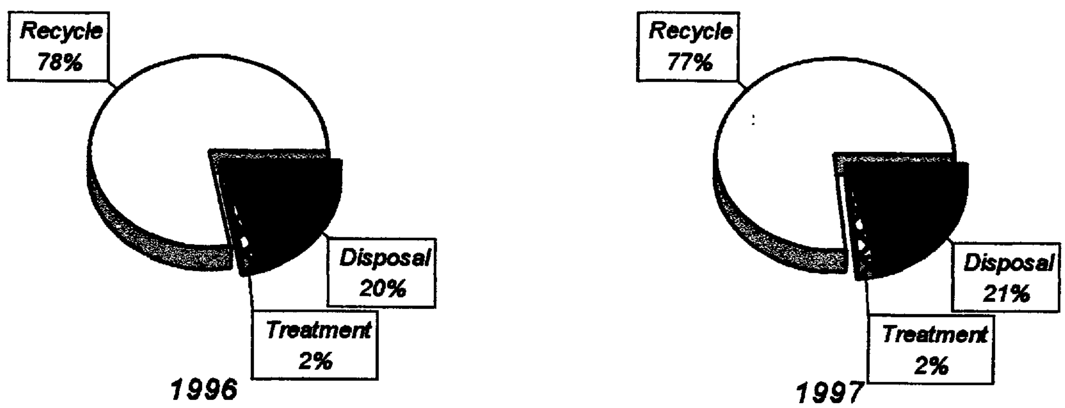
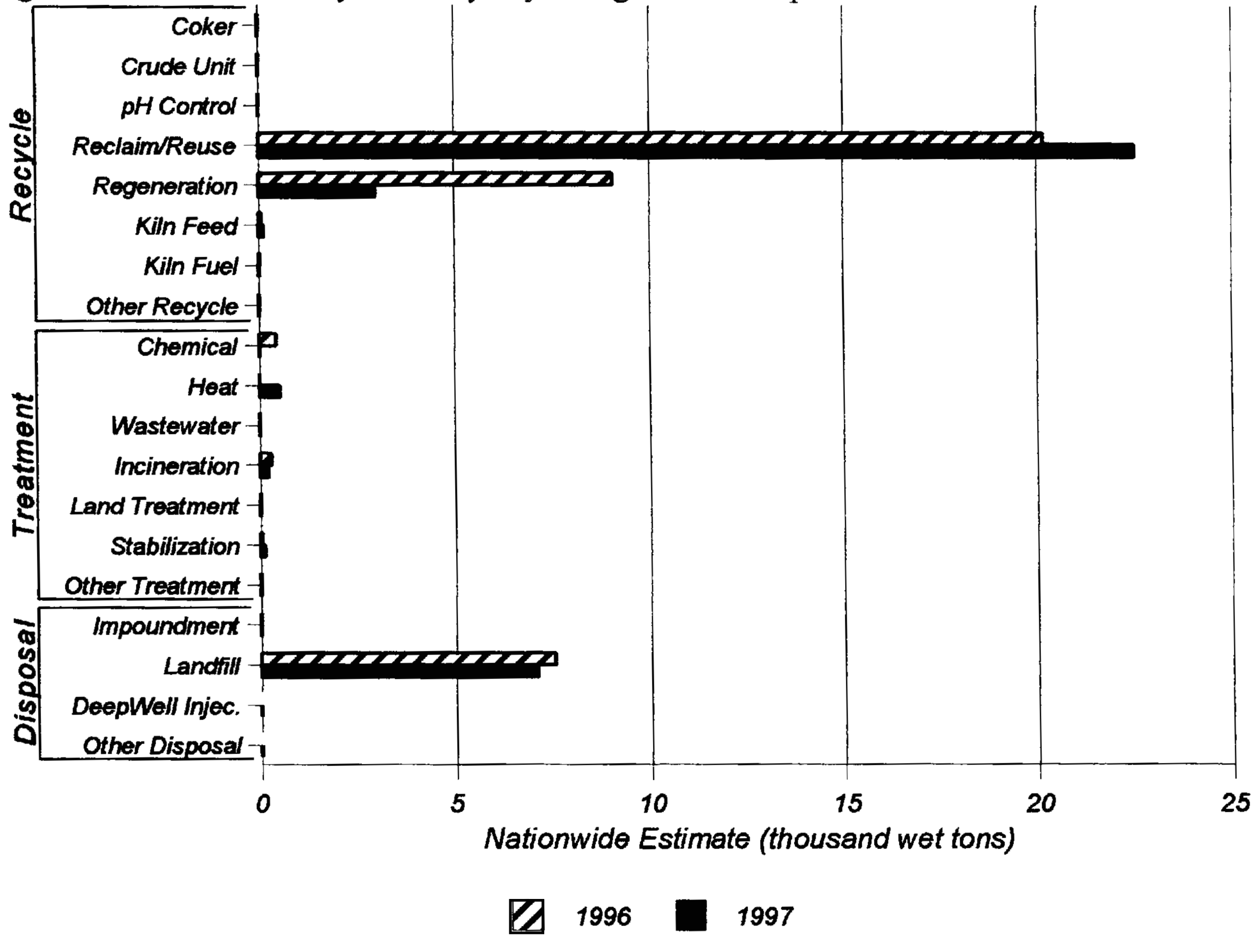


Figure 45 shows the Hydro. Catalyst distribution by management technique for 1996 and 1997. This stream is typically *reclaimed*, *regenerated*, or *landfilled*. The end use reported for reclaimed or reused material was always *metals recovery*. The end-use categories are defined in Appendix A.

[6] Recall that API uses labels such as Hydro. Catalyst in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 45—Distribution of Hydro. Catalyst by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: none.

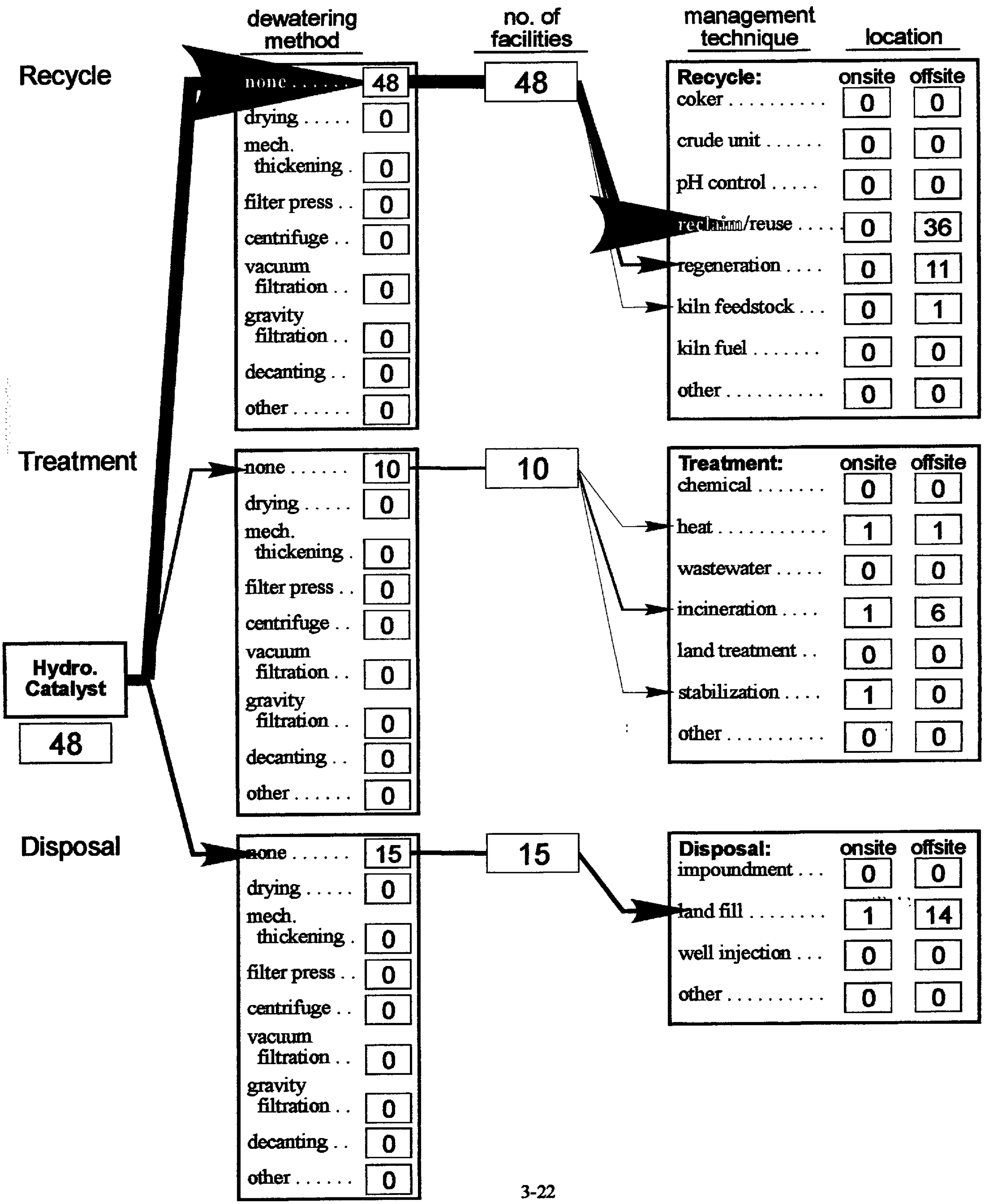
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 46 - Hydro. Catalyst Summary: 1997

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



The following three graphs summarize the cost data reported for Hydro. Catalyst.

Figure 47—Onsite Management Cost for Hydro. Catalyst: 1997

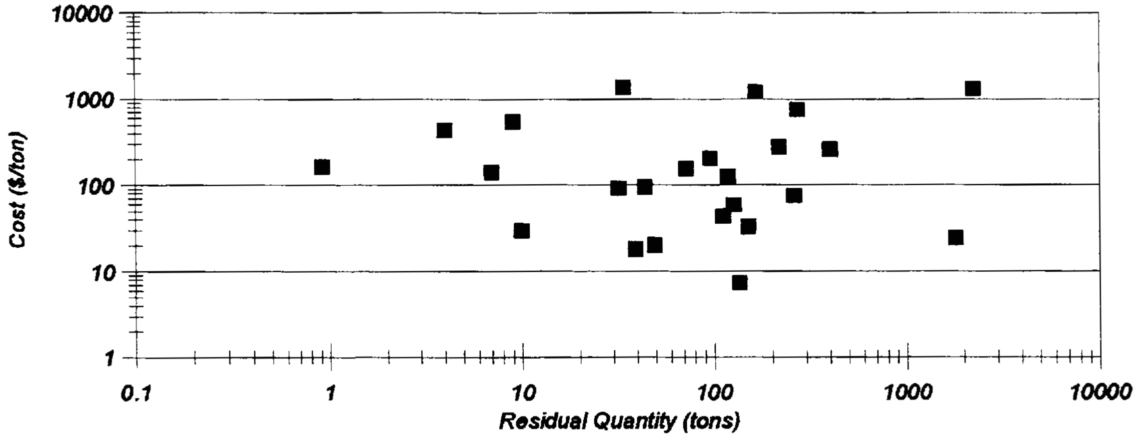


Figure 48—Offsite Management Cost for Hydro. Catalyst: 1997

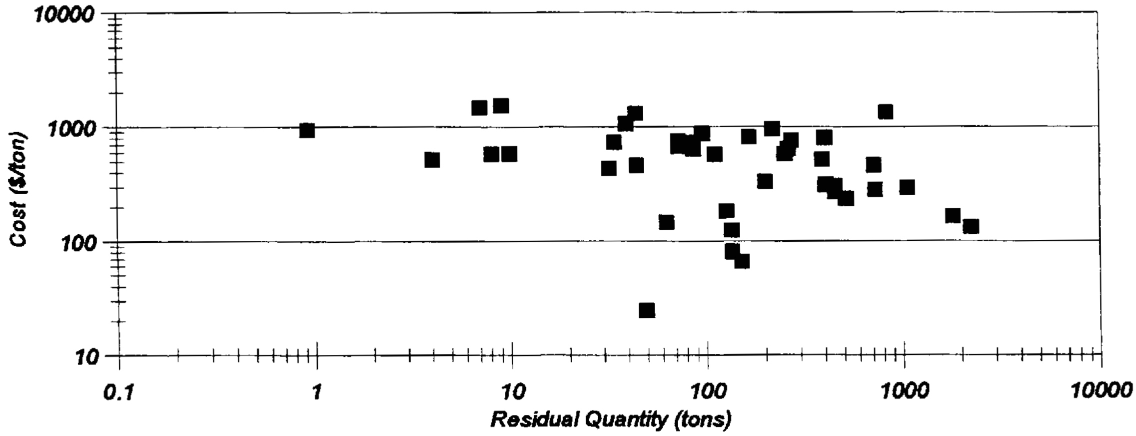
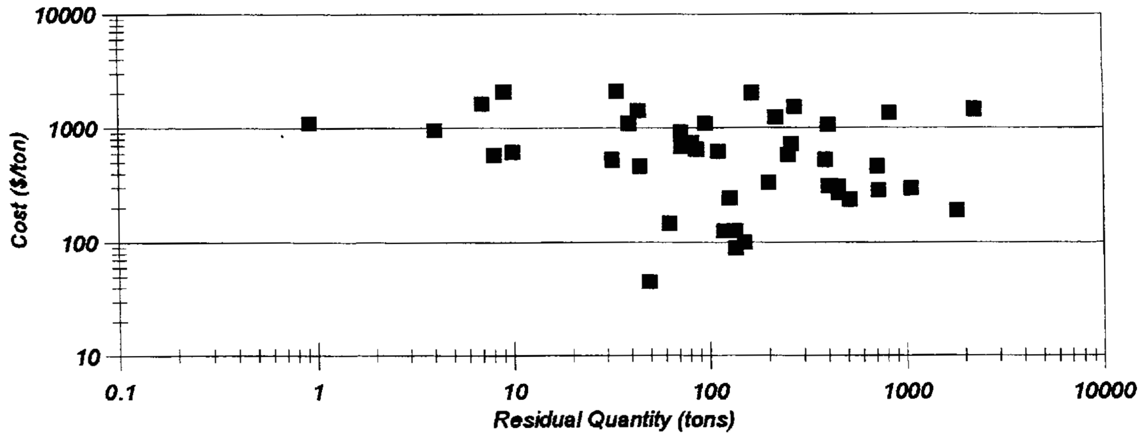


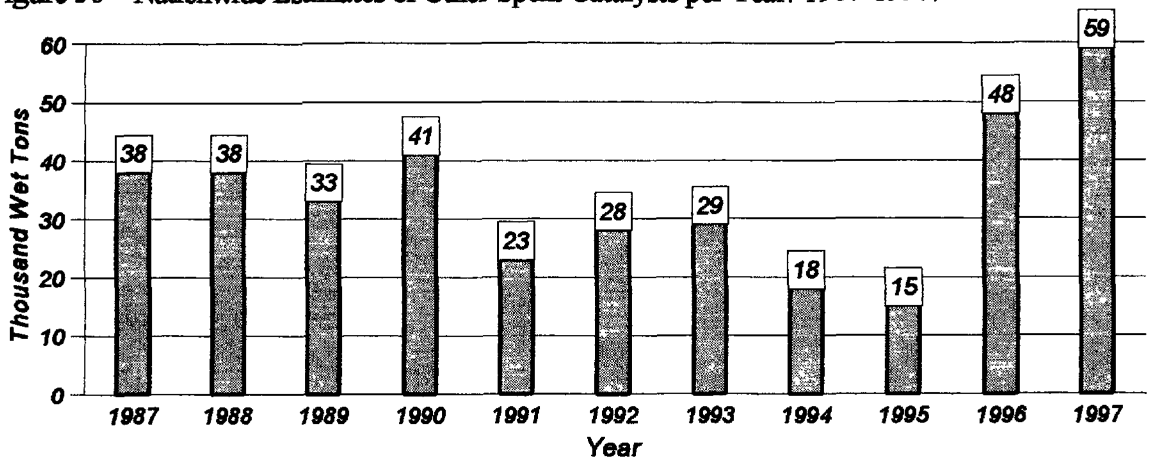
Figure 49—Total Management Cost for Hydro. Catalyst: 1997



OTHER SPENT CATALYSTS[7]

The U.S. petroleum refining industry managed an estimated 59 thousand wet tons of Other Spent Catalysts in 1997, which was a 25% increase from 1996. A summary of the quantity of Other Spent Catalysts managed per year is presented in Figure 50.

Figure 50—Nationwide Estimates of Other Spent Catalysts per Year: 1987-1997.



The portion of the Other Spent Catalysts stream that is managed by each management practice is shown in Figure 51 for 1996 and 1997. Recycling continues to be the dominant practice.

Figure 51—Nationwide Estimates of Other Spent Catalysts by Management Practice: 1996-1997.

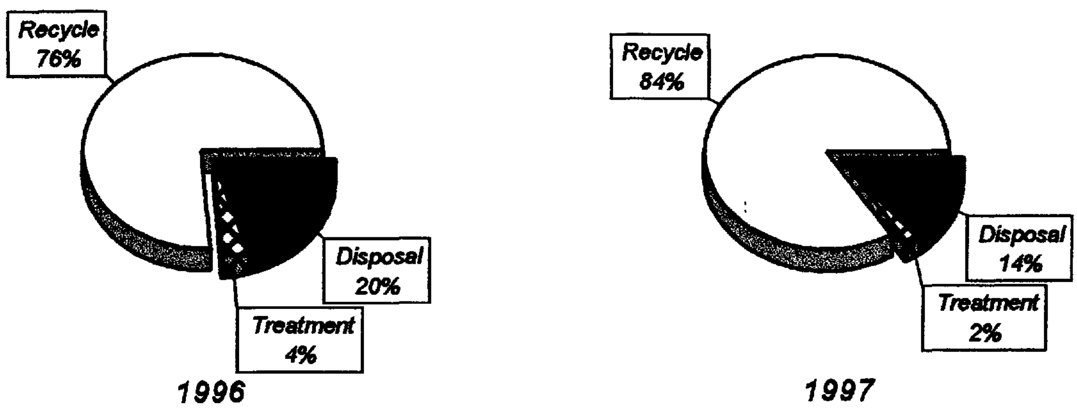
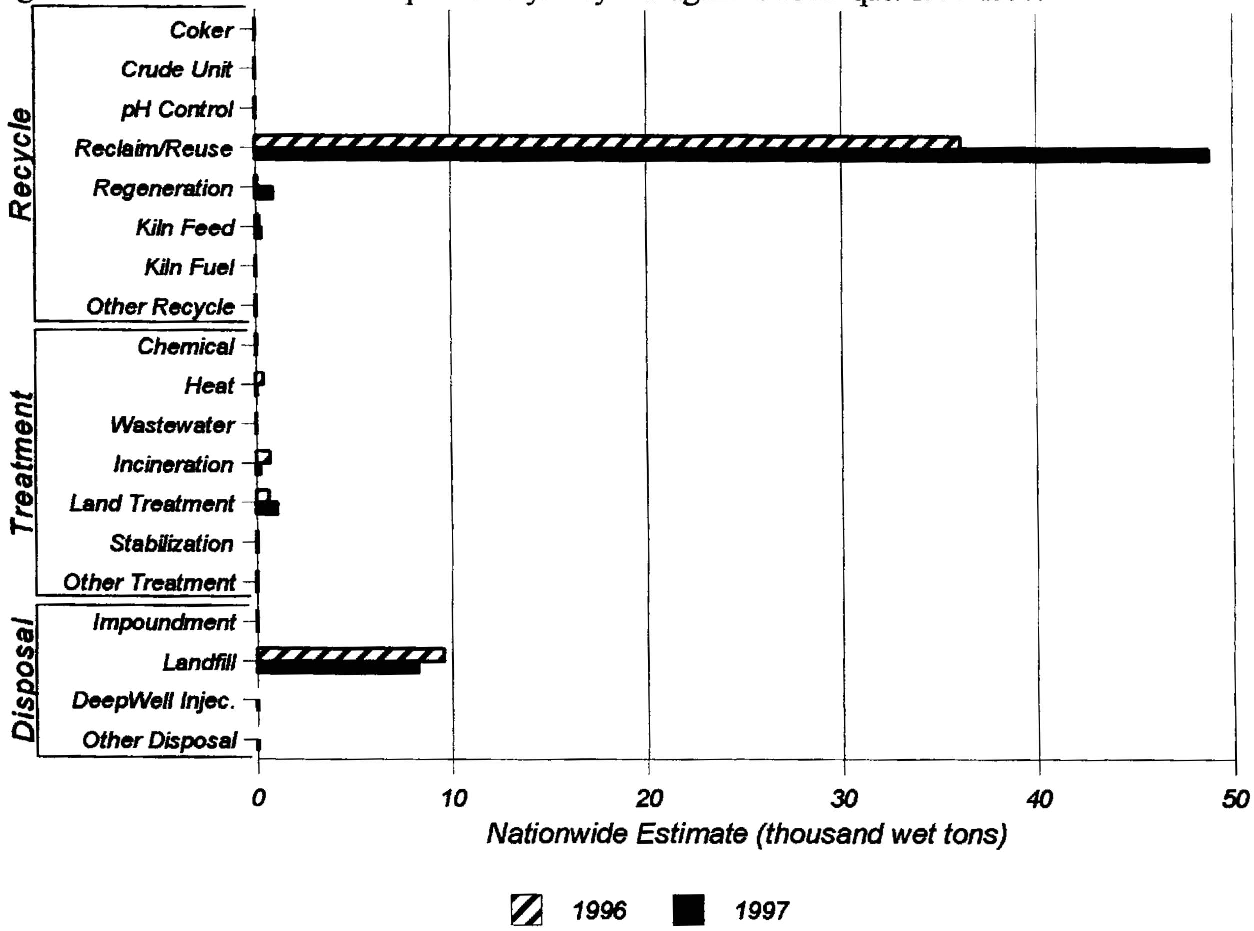


Figure 52 shows the Other Spent Catalysts distribution by management technique for 1996 and 1997. This stream is typically *reclaimed* or *landfilled*. The end uses reported for reclaimed or reused material was ***metals recovery*** in every case. The end-use categories are defined in Appendix A.

[7]Recall that this report uses labels such as Other Spent Catalysts in the broader context of a ***residual stream*** which includes materials that are not subject to RCRA regulation.

Figure 52—Distribution of Other Spent Catalysts by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: none.

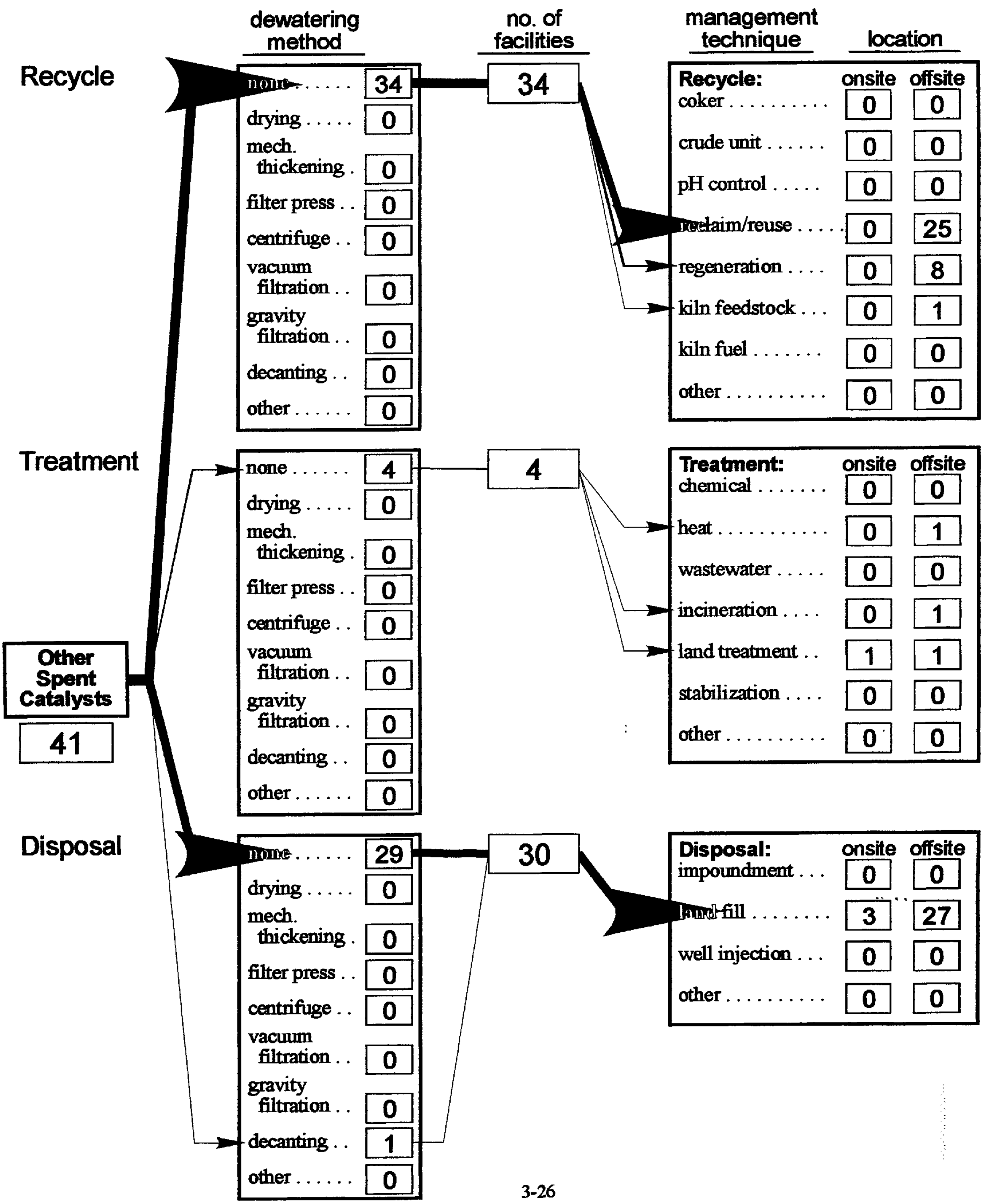
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 53 - Other Spent Catalysts Summary: 1997

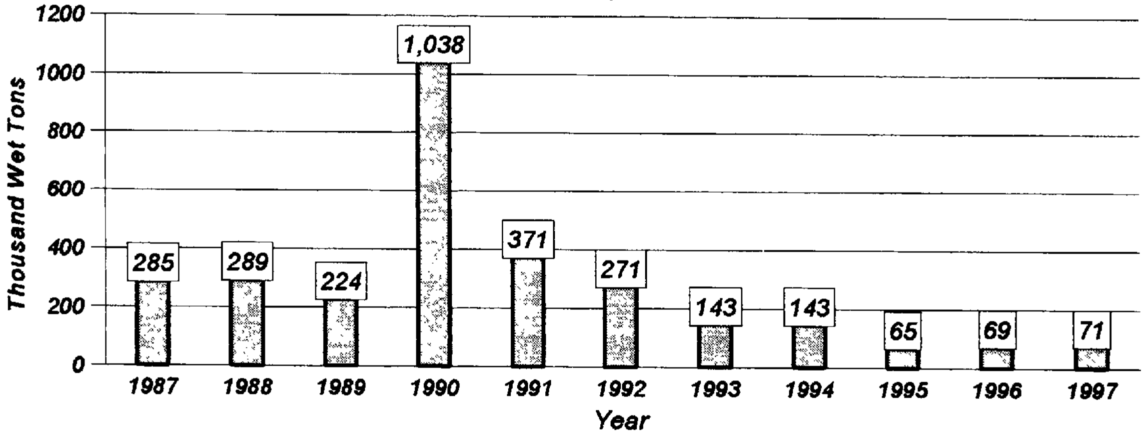
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



POND SEDIMENTS[8]

The U.S. petroleum refining industry managed an estimated 71 thousand wet tons of Pond Sediments in 1997, which was a 3% increase from 1996. A summary of the quantity of Pond Sediments managed per year is presented in Figure 54. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 54—Nationwide Estimates of Pond Sediments per Year: 1987-1997.



The portion of the Pond Sediments stream that is managed by each management practice is shown in Figure 55 for 1996 and 1997. Disposal continues to decline, with treatment having now become the most common practice.

Figure 55—Nationwide Estimates of Pond Sediments by Management Practice: 1996-1997.

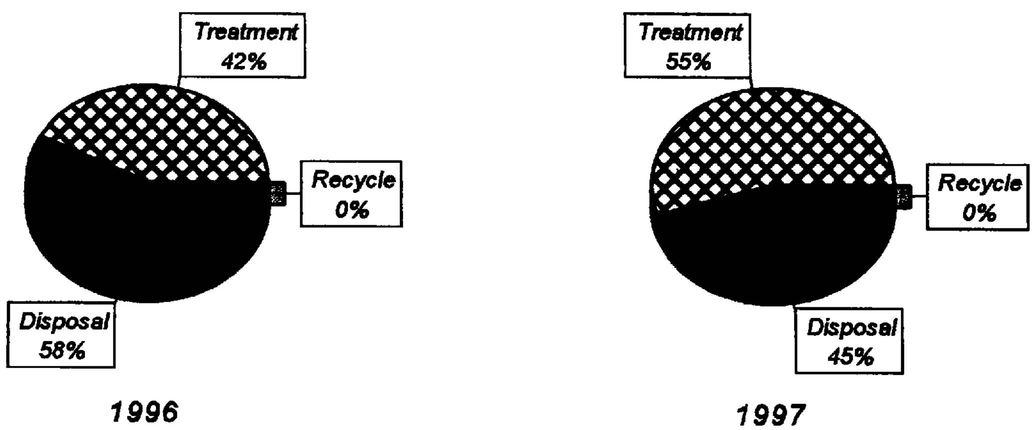


Figure 56 shows the Pond Sediments distribution by management technique for 1996 and 1997. This stream is typically managed in some land-applied manner, either by being *landfilled* or by first being *stabilized*.

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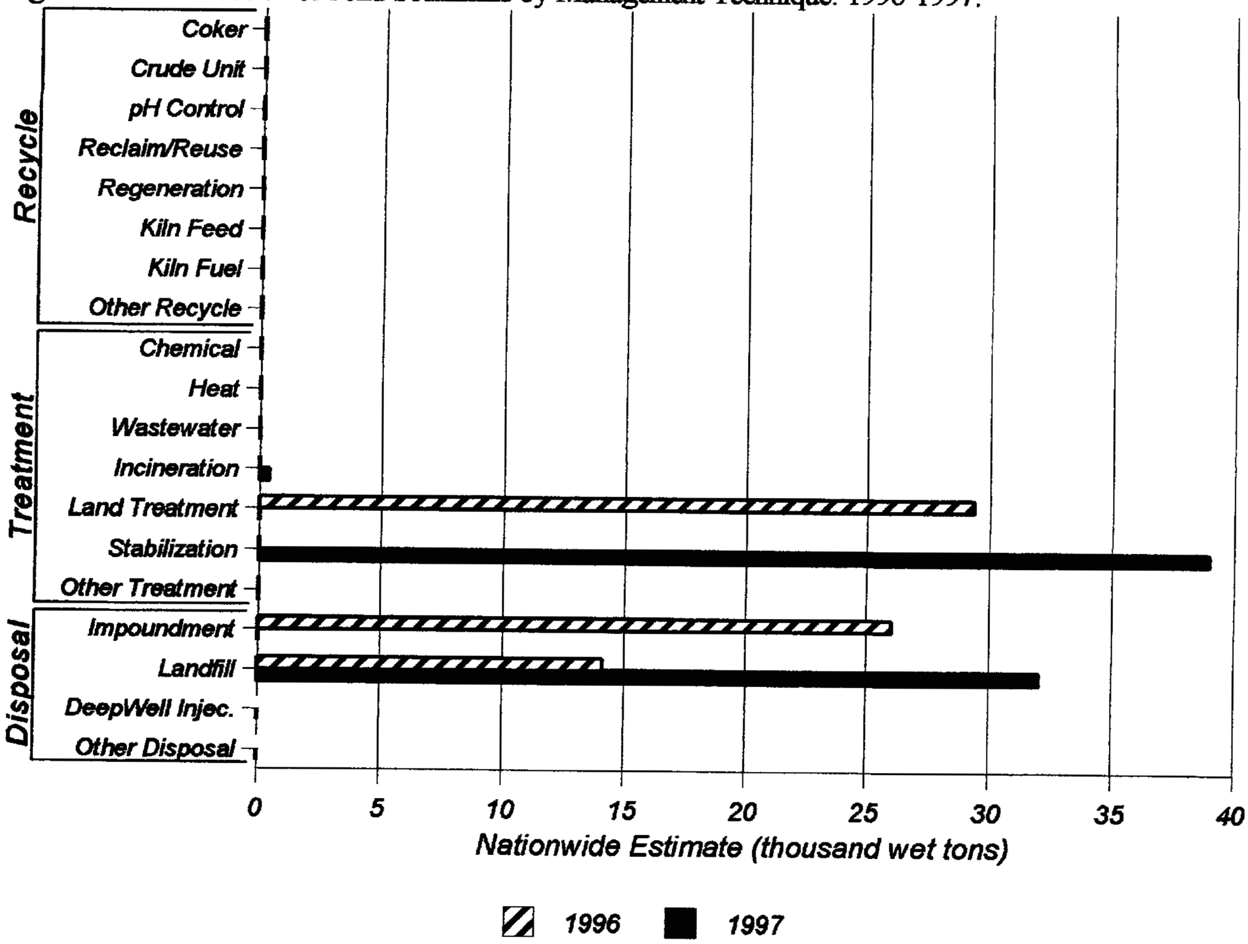
[8]Recall that this report uses labels such as Pond Sediments in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 56—Distribution of Pond Sediments by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: none.

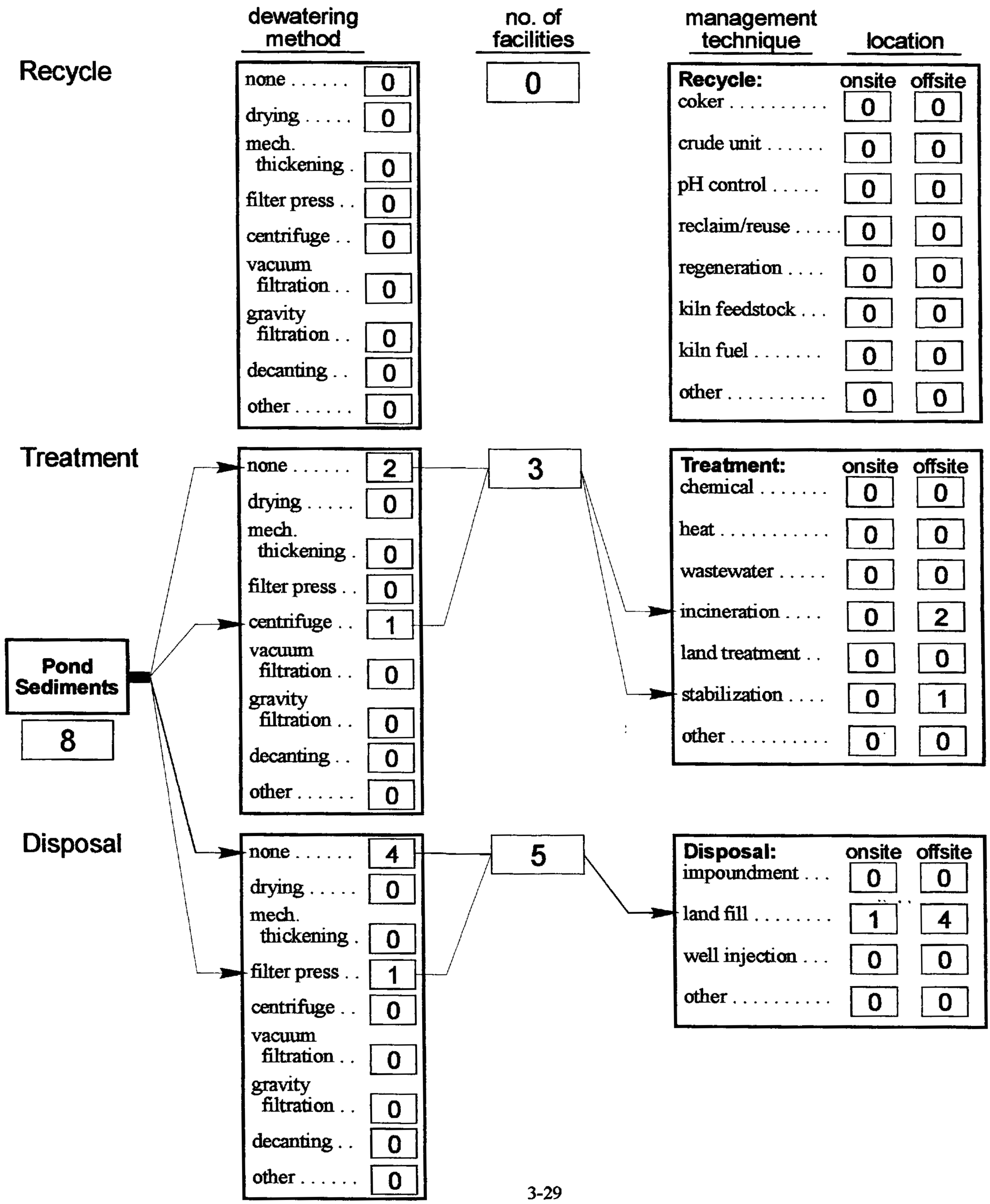
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 57 - Pond Sediments Summary: 1997

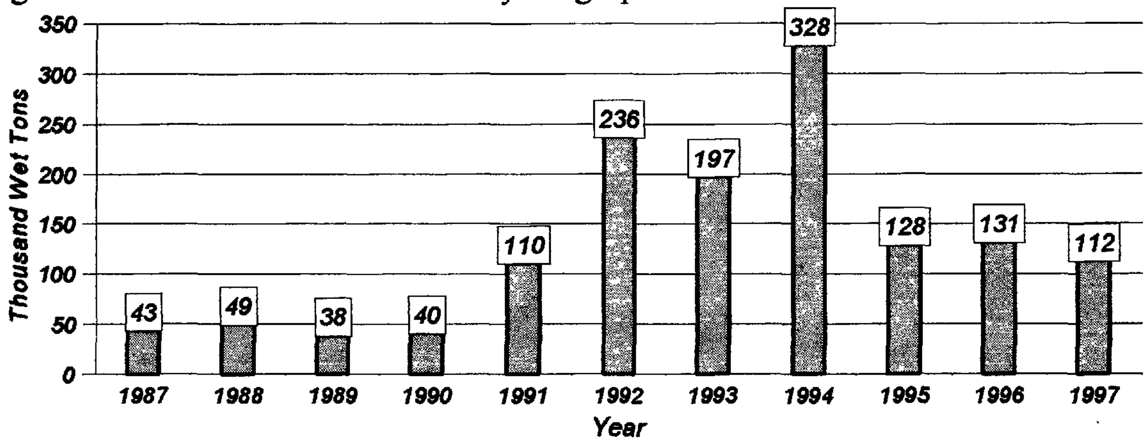
Note: Boxes show no. of facilities reporting each option. Some facilities report multiple options



PRIMARY SLUDGES[9]

The U.S. petroleum refining industry managed an estimated 112 thousand wet tons of Primary Sludges in 1997, which was a 14% decrease from 1996. A summary of the quantity of Primary Sludges managed per year is presented in Figure 58. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

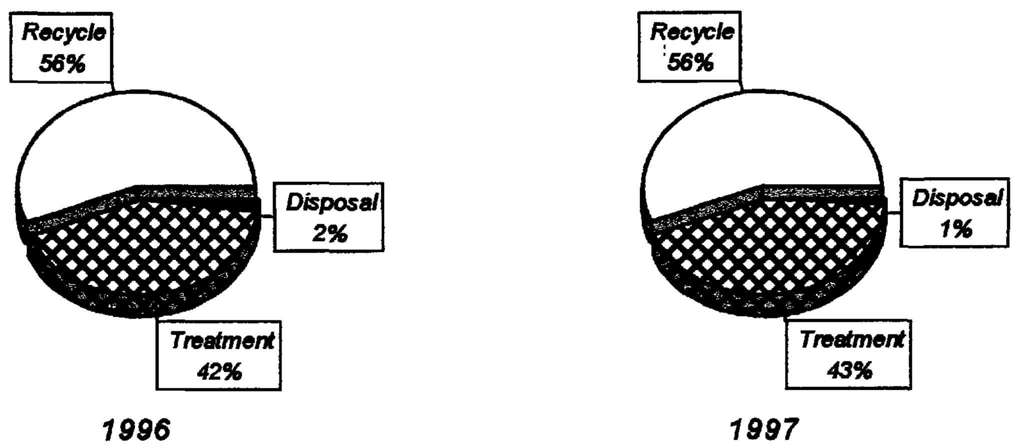
Figure 58—Nationwide Estimates of Primary Sludges per Year: 1987-1997.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 88, which shows a decrease from 723 thousand wet tons in 1996 to 467 thousand wet tons in 1997, a decrease of 35%.

The portion of the Primary Sludges stream that is managed by each management practice is shown in Figure 59 for 1996 and 1997. Recycling continues to be the most common practice.

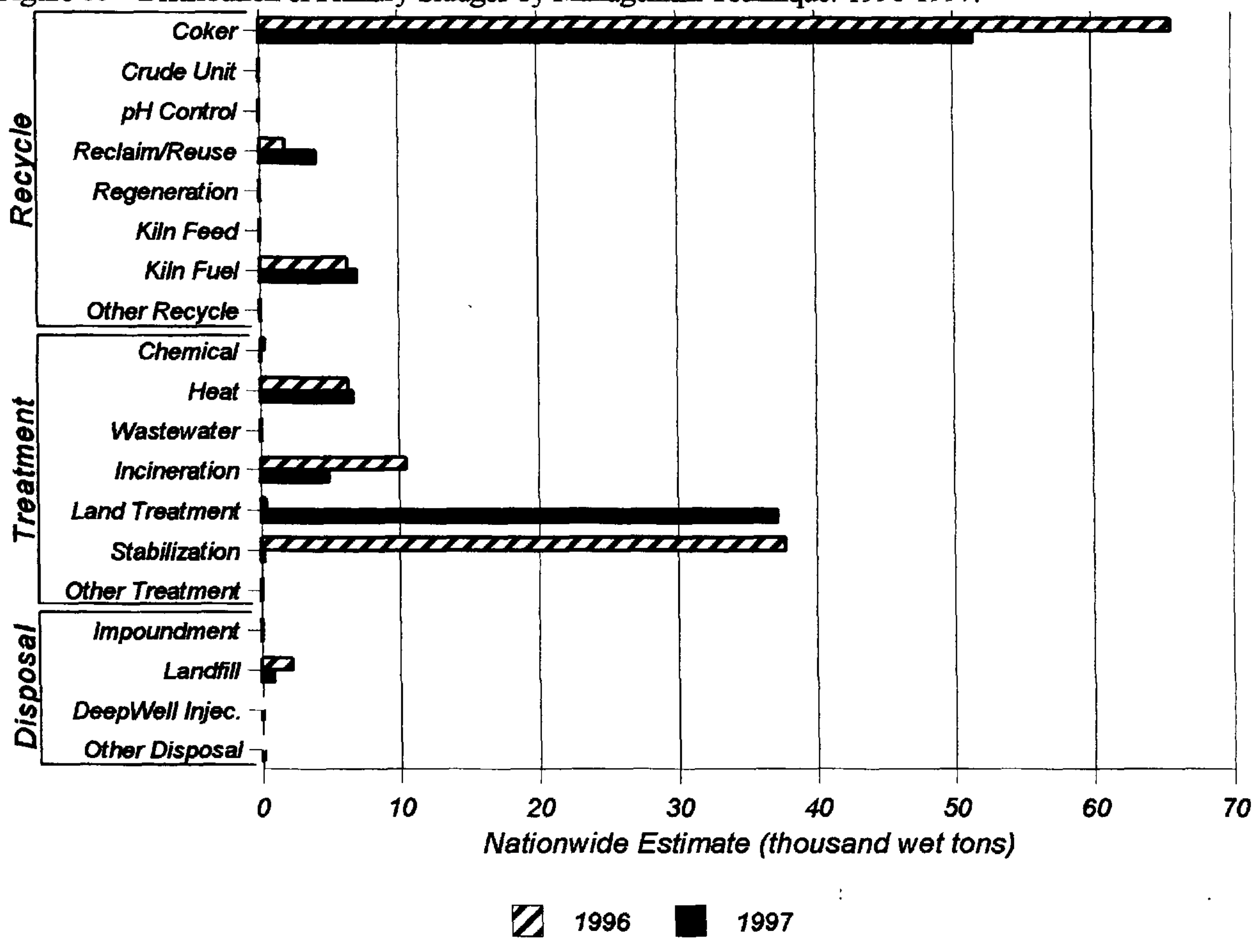
Figure 59—Nationwide Estimates of Primary Sludges by Management Practice: 1996-1997.



[9]Recall that this report uses labels such as Primary Sludges in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 60 shows the Primary Sludges distribution by management technique for 1996 and 1997. This stream is most commonly managed by techniques that recycle the oil content, primarily by routing the stream to a *coker*. This stream may also contain significant quantities of contaminated soil, and is sometimes *land treated*. End uses reported for reclaimed or reused material were *oil recovery* and *fuels blending*. The end-use categories are defined in Appendix A.

Figure 60—Distribution of Primary Sludges by Management Technique: 1996-1997.



The 1997 survey prompted respondents who listed land treating or landfilling this stream to explain the circumstances. Some facilities indicated having exported the residual to Canada for landfilling, others explained that the material in question did not fall within the RCRA definition for this stream, and one facility cited a 'no migration land farm permit' as allowing land treatment of certain RCRA wastes.

Responses in the *other* categories are listed below.

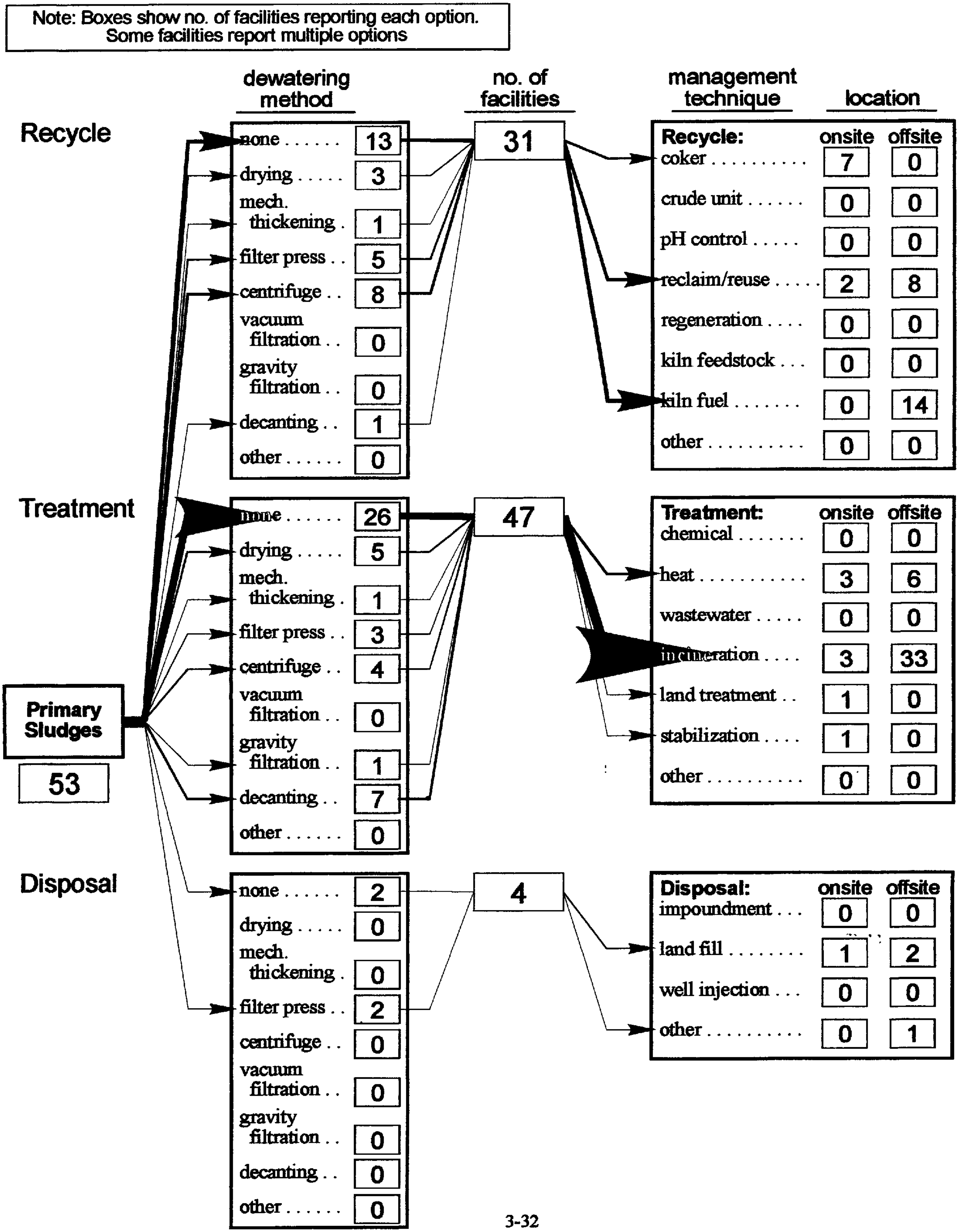
Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 61 - Primary Sludges Summary: 1997



The following three graphs summarize the cost data reported for Primary Sludges.

Figure 62—Onsite Management Cost for Primary Sludges: 1997

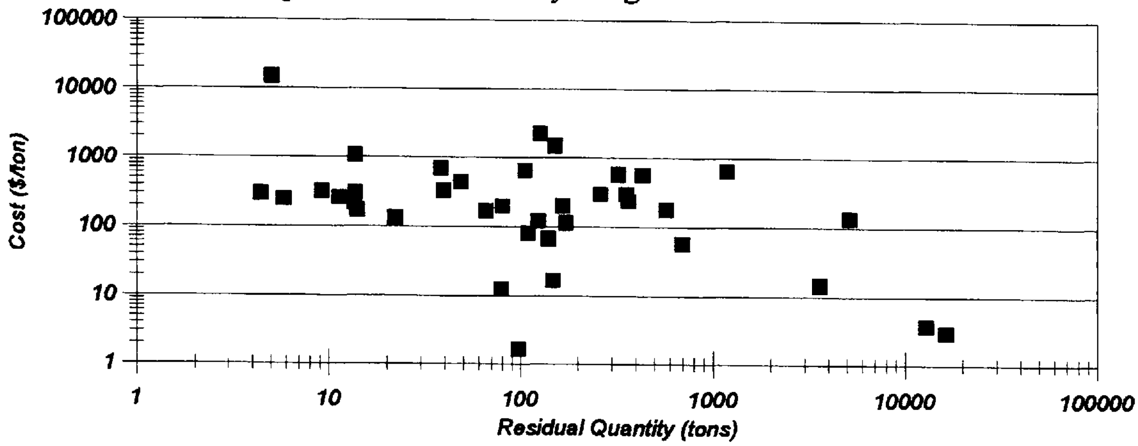


Figure 63—Offsite Management Cost for Primary Sludges: 1997

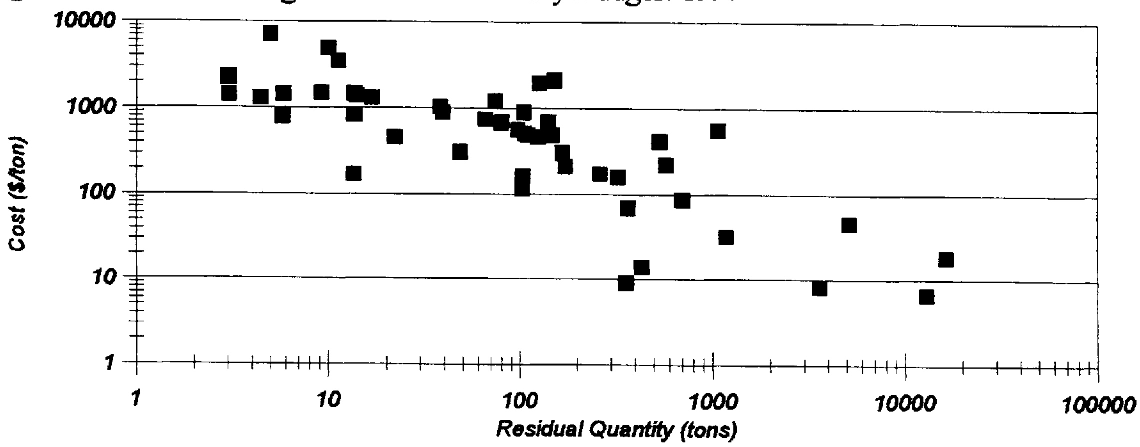
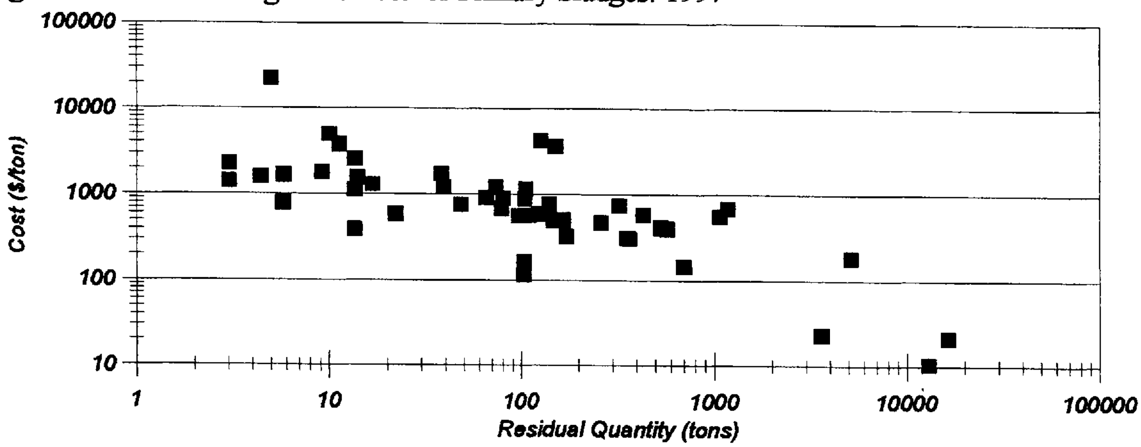


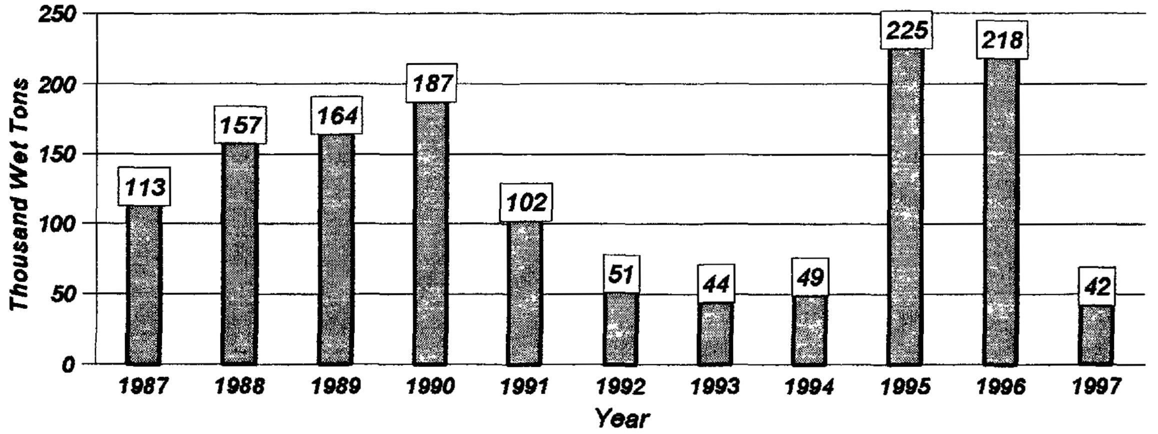
Figure 64—Total Management Cost for Primary Sludges: 1997



SLOP OIL EMULSION SOLIDS[10]

The U.S. petroleum refining industry managed an estimated 42 thousand wet tons of Slop Oil Emulsion Solids in 1997, which was an 81% reduction from 1996. A summary of the quantity of Slop Oil Emulsion Solids managed per year is presented in Figure 65. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered water rather than true residuals.

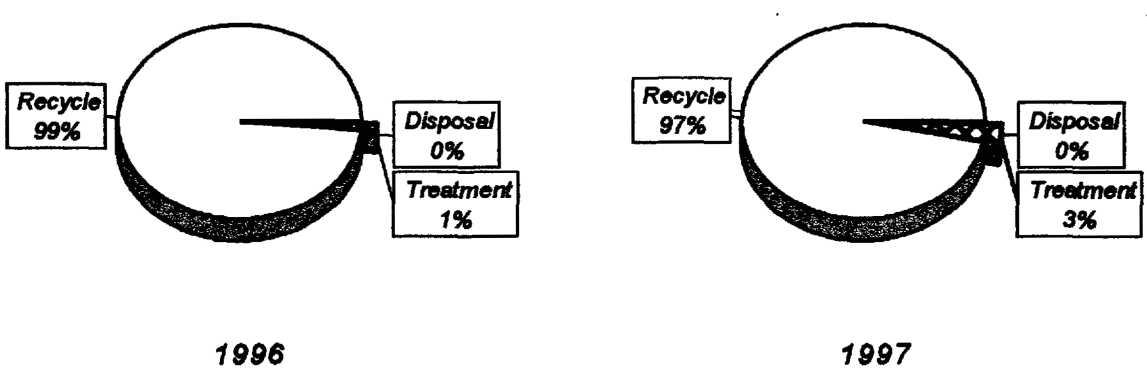
Figure 65—Nationwide Estimates of Slop Oil Emulsion Solids per Year: 1987-1997.



Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantities of these oily wastewater streams are summarized in Figure 88, which shows a decrease from 723 thousand wet tons in 1996 to 467 thousand wet tons in 1997, a decrease of 35%.

The portion of the Slop Oil Emulsion Solids stream that is managed by each management practice is shown in Figure 66 for 1996 and 1997. Recycling continues to be the dominant practice.

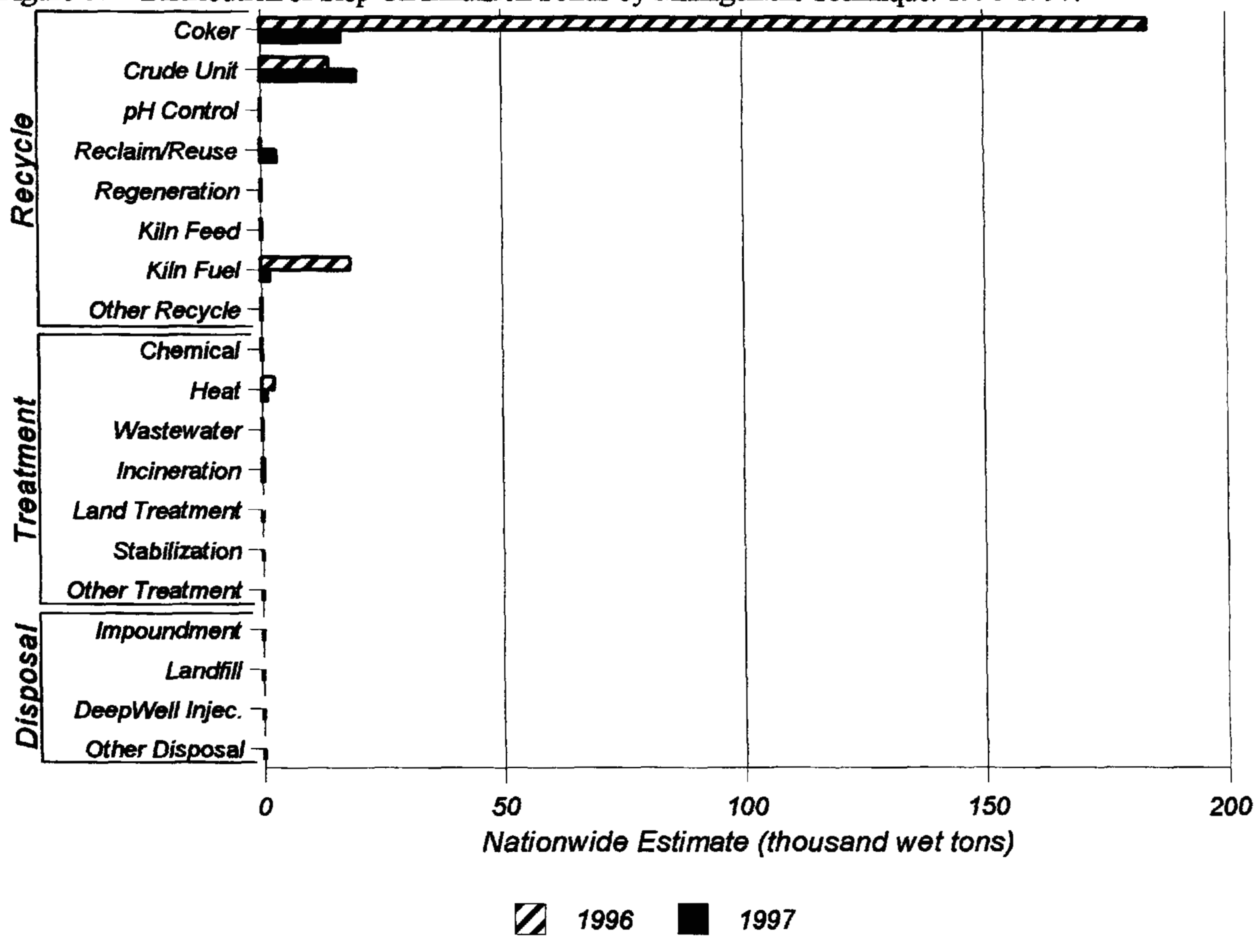
Figure 66—Nationwide Estimates of Slop Oil Emulsion Solids by Management Practice: 1996-1997.



[10] Recall that this report uses labels such as Slop Oil Emulsion Solids in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 67 shows the Slop Oil Emulsion Solids distribution by management technique for 1996 and 1997. This stream is most commonly managed by techniques that recycle the oil content, primarily by routing the stream to either a *coker* or to the *crude unit*. End uses reported for reclaimed or reused material were *oil recovery* and *fuels blending*. The end-use categories are defined in Appendix A.

Figure 67—Distribution of Slop Oil Emulsion Solids by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

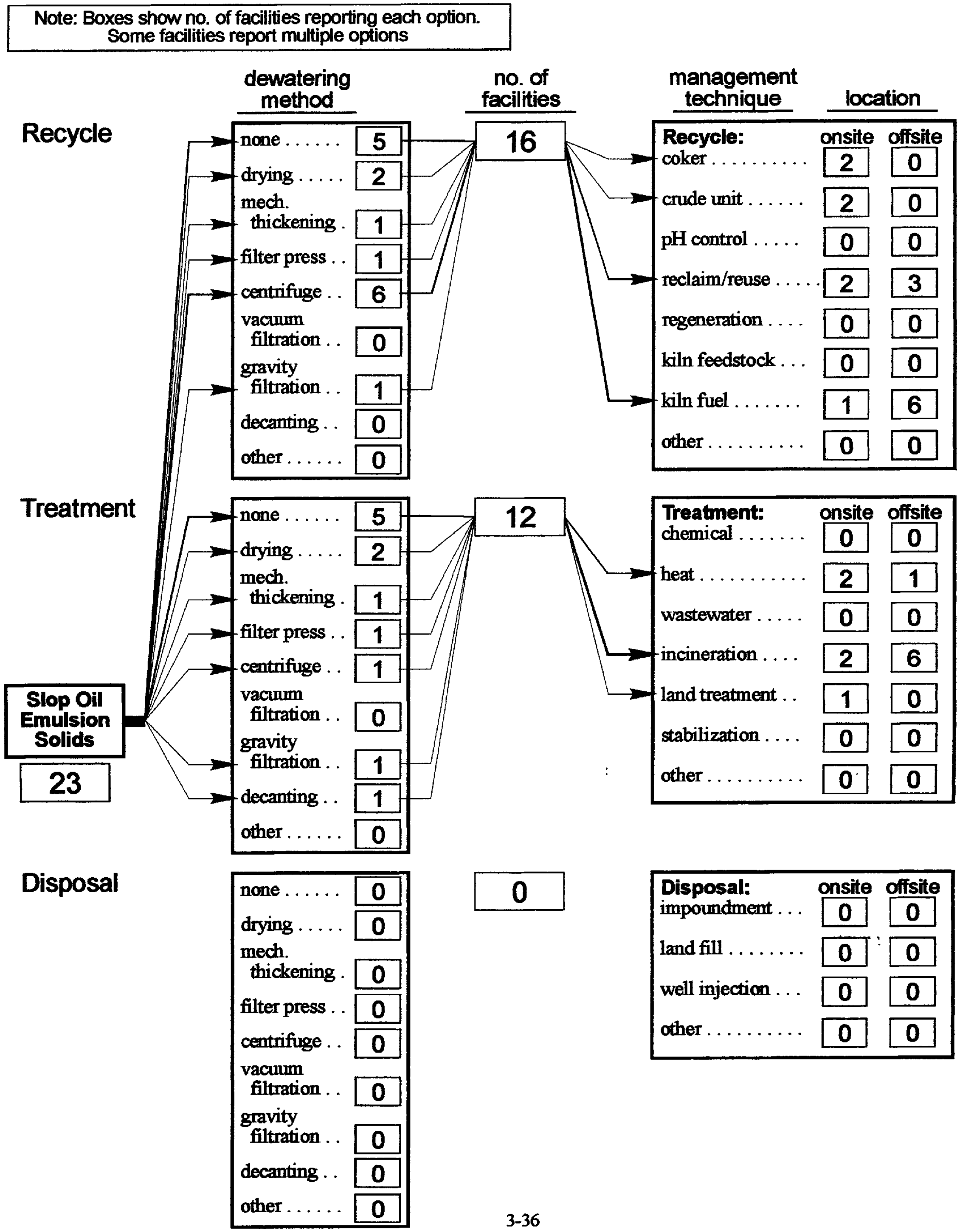
Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

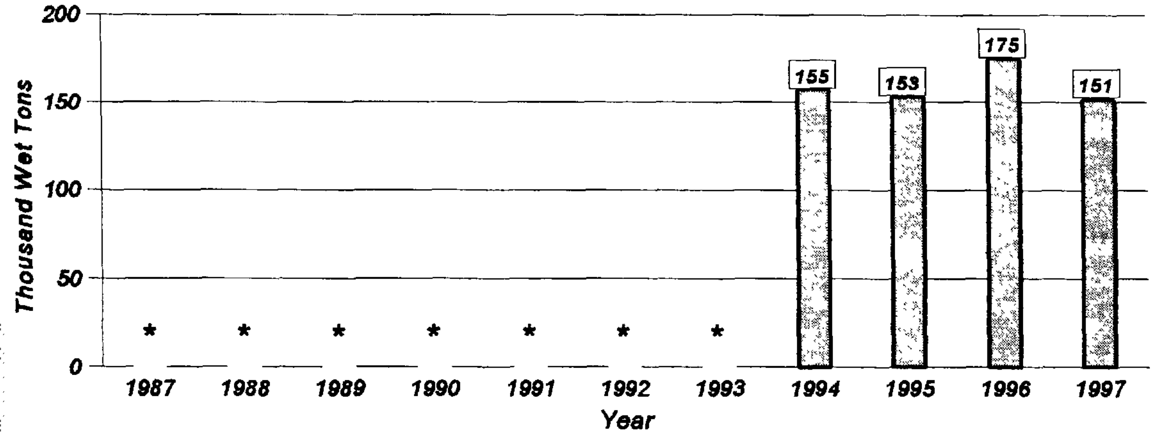
Figure 68 - Slop Oil Emulsion Solids Summary: 1997



SPENT CRESYLIC CAUSTIC[11]

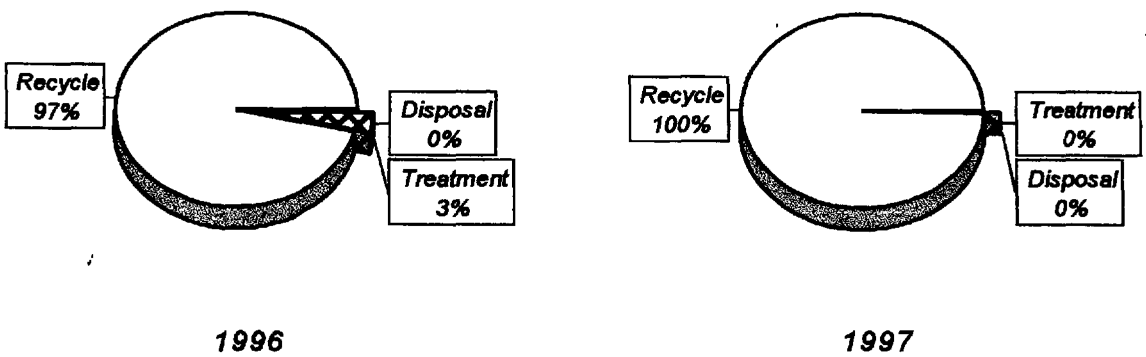
The U.S. petroleum refining industry managed an estimated 151 thousand wet tons of Spent Cresylic Caustic in 1997, which was a 13% decrease from 1996. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 69. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows a decrease from 1,271 thousand wet tons in 1996 to 1,056 thousand wet tons in 1997, a decrease of 17%.

Figure 69—Nationwide Estimates of Spent Cresylic Caustic per Year: 1994-1997.



The portion of the Spent Cresylic Caustic stream that is managed by each management practice is shown in Figure 70 for 1996 and 1997. Virtually all of this stream is recycled.

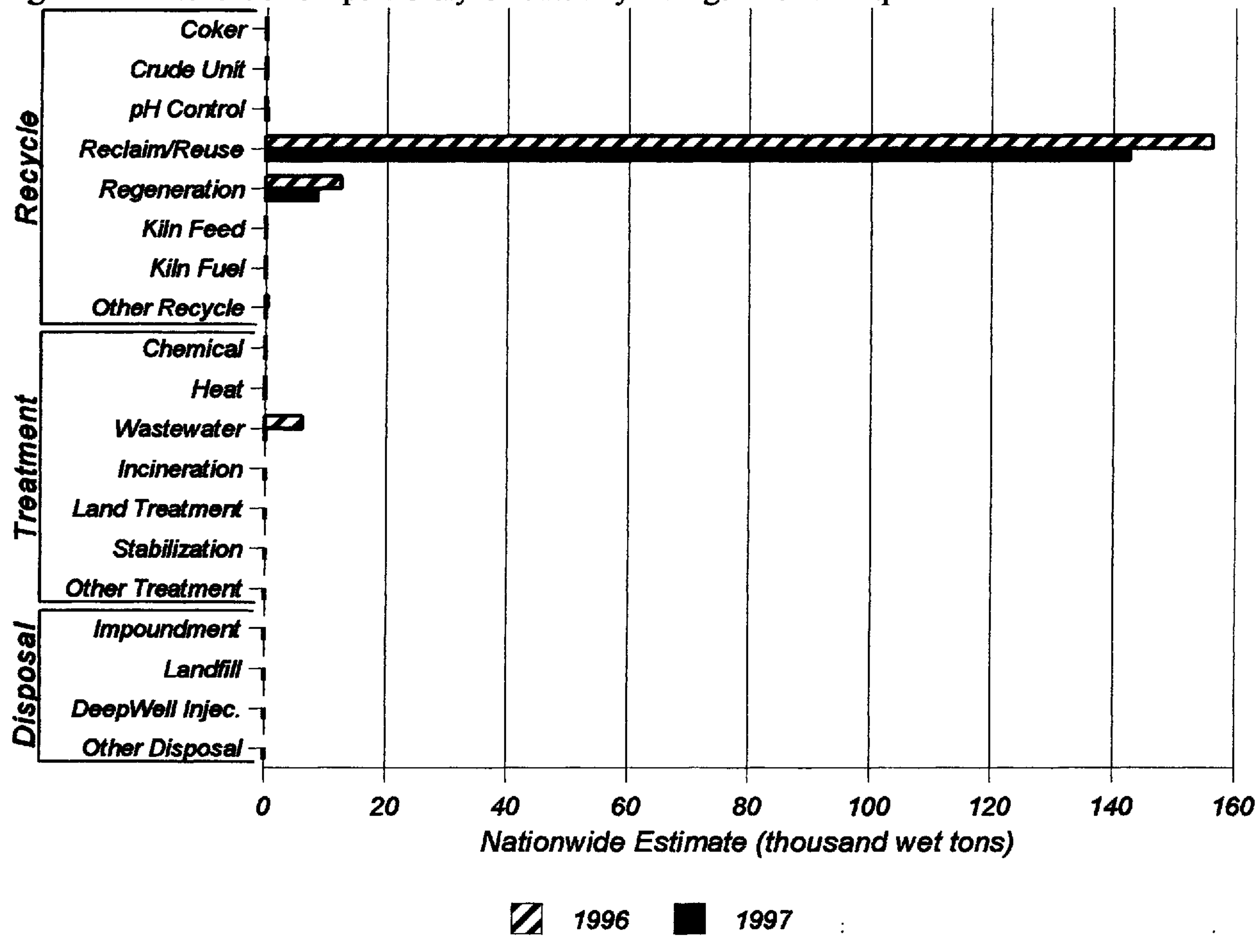
Figure 70—Nationwide Estimates of Spent Cresylic Caustic by Management Practice: 1996-1997.



[11]Recall that this report uses labels such as Spent Cresylic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 71 shows the Spent Cresylic Caustic distribution by management technique for 1996 and 1997. The most common management technique continues to be *reclamation*. End uses reported for reclaimed or reused material were sale to a *caustics processor/broker*, reuse in *chemical processing*, and in one case, reuse as a product used for *metals recovery*. The end-use categories are defined in Appendix A.

Figure 71—Distribution of Spent Cresylic Caustic by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: none.

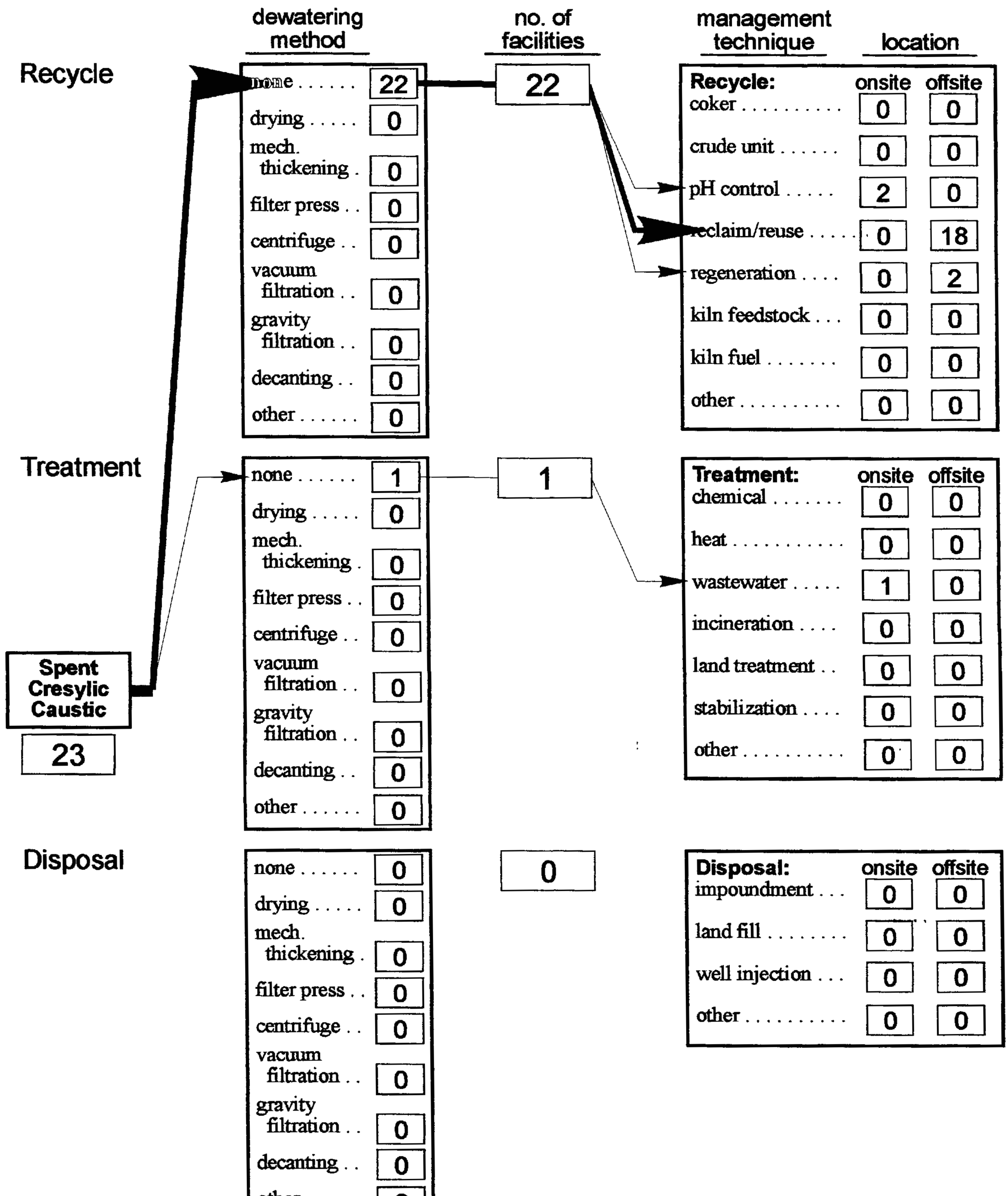
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 72 - Spent Cresylic Caustic Summary: 1997

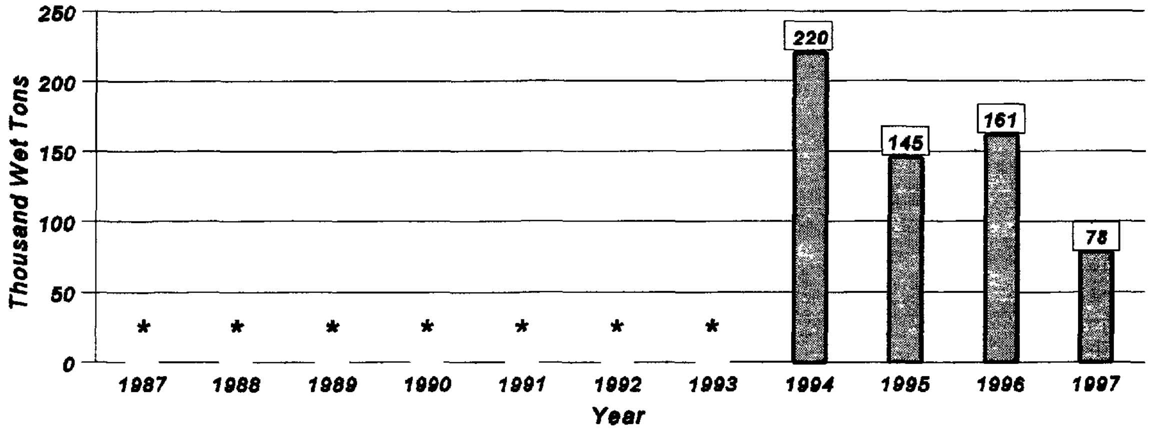
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



SPENT NAPHTHENIC CAUSTIC[12]

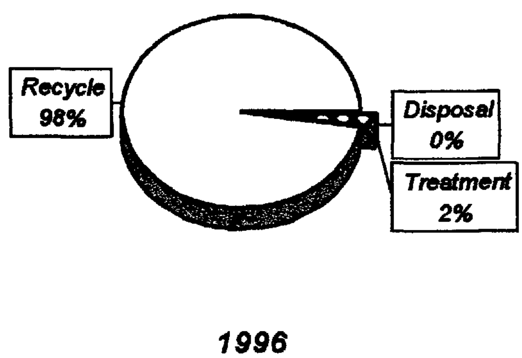
The U.S. petroleum refining industry managed an estimated 78 thousand wet tons of Spent Naphthenic Caustic in 1997, which was a 52% decrease from 1996. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 73. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows a decrease from 1,271 thousand wet tons in 1996 to 1,056 thousand wet tons in 1997, a decrease of 17%.

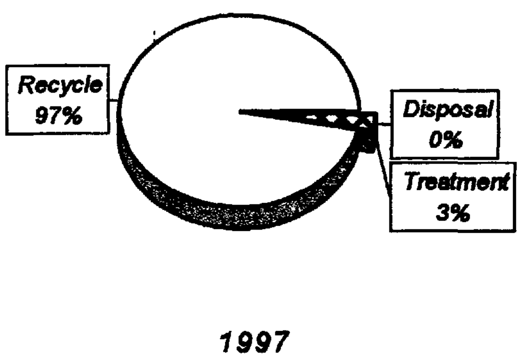
Figure 73—Nationwide Estimates of Spent Naphthenic Caustic per Year: 1994-1997.



The portion of the Spent Naphthenic Caustic stream that is managed by each management practice is shown in Figure 74 for 1996 and 1997. Recycling continues to be the dominant practice.

Figure 74—Nationwide Estimates of Spent Naphthenic Caustic by Management Practice: 1996-1997.

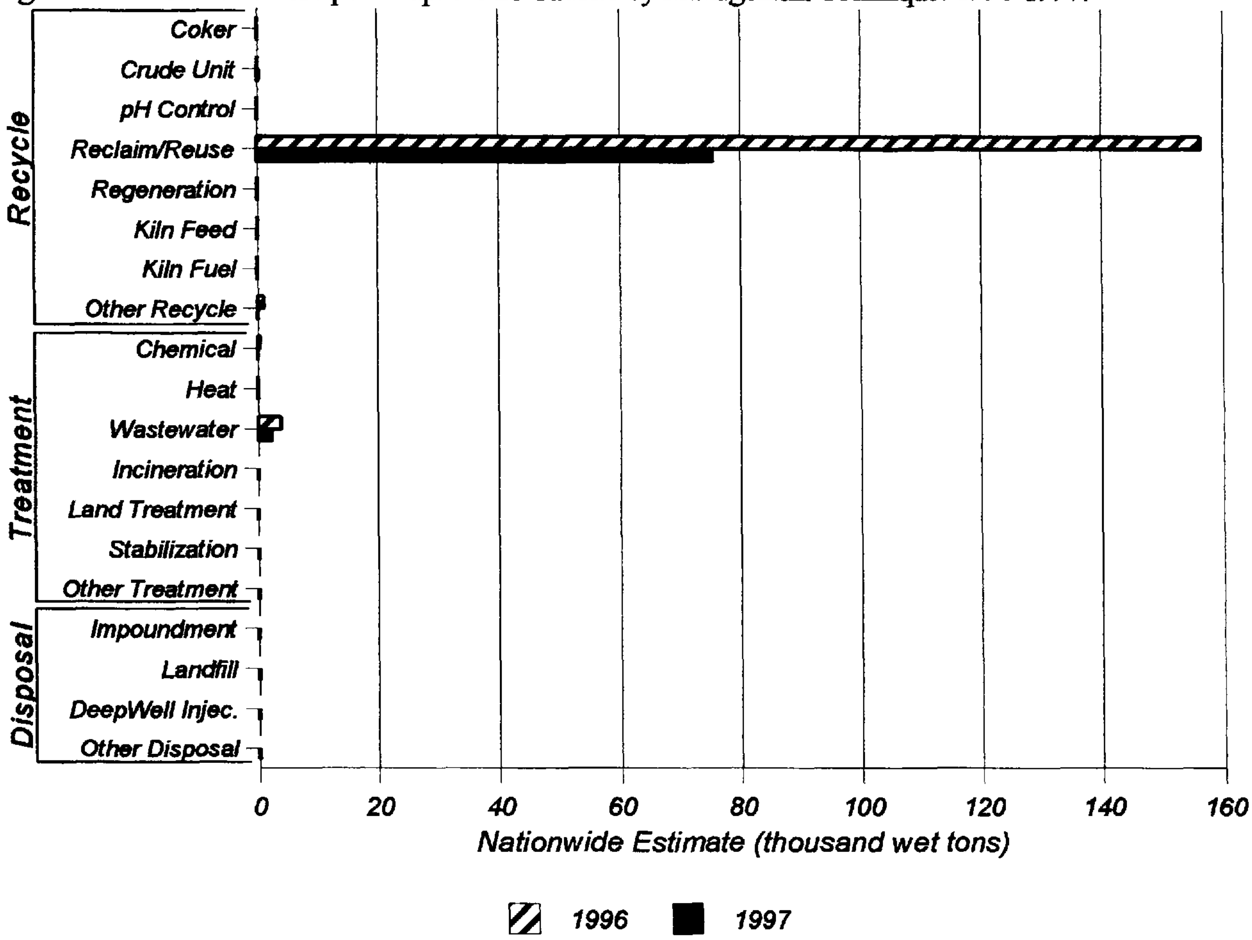




[12]Recall that this report uses labels such as Spent Naphthenic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 75 shows the Spent Naphthenic Caustic distribution by management technique for 1996 and 1997. The dominant management technique continues to be *reclamation*. The end use reported for reclaimed or reused material was sale to a *caustics processor/broker*, as defined in Appendix A.

Figure 75—Distribution of Spent Naphthenic Caustic by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

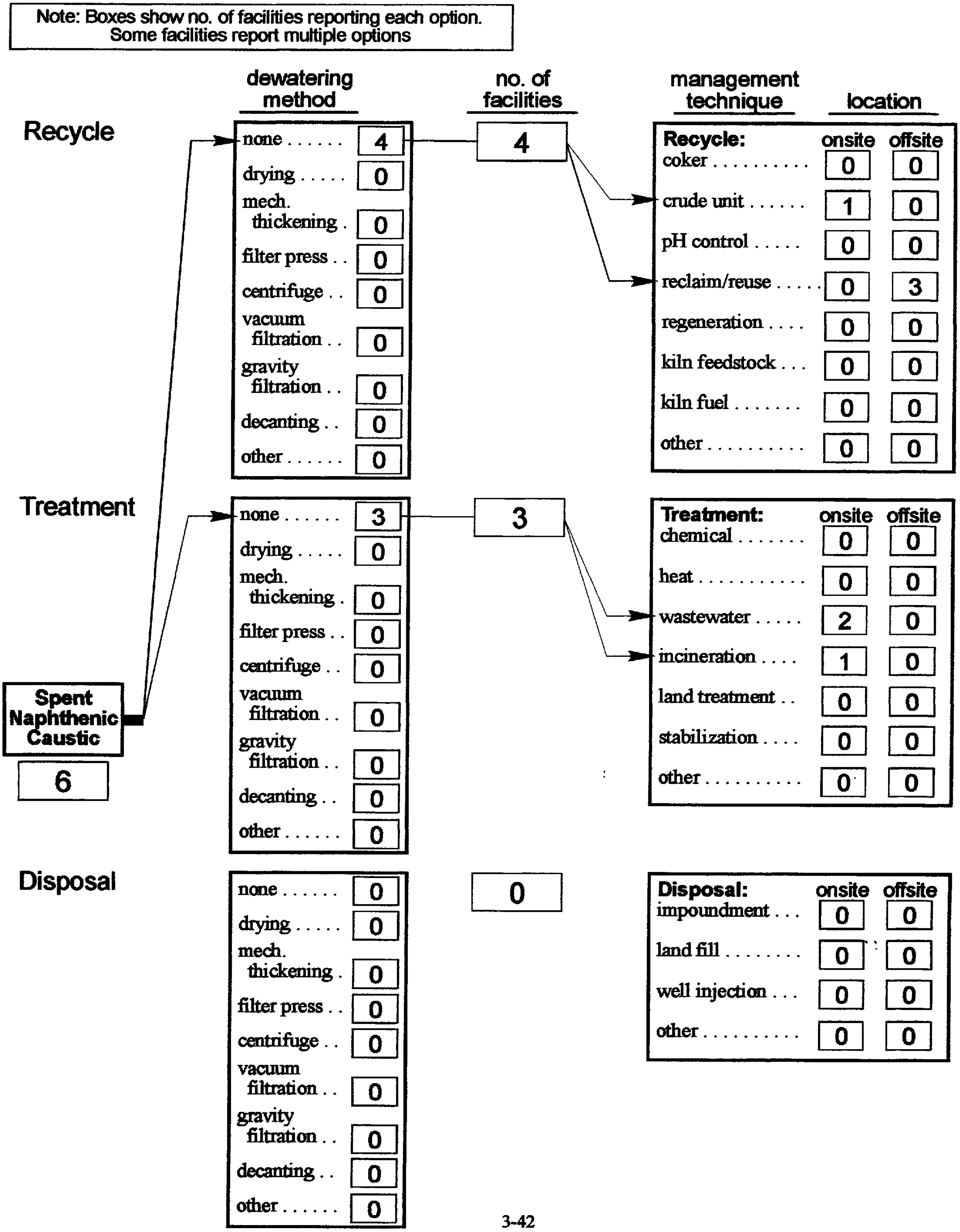
Other Recycle: none.

Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

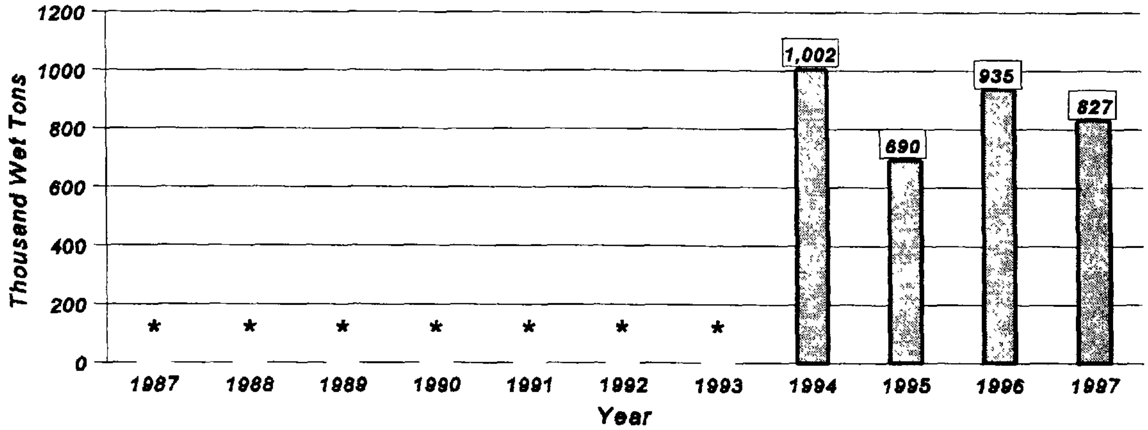
Figure 76 - Spent Naphthenic Caustic Summary: 1997



SPENT SULFIDIC CAUSTIC[13]

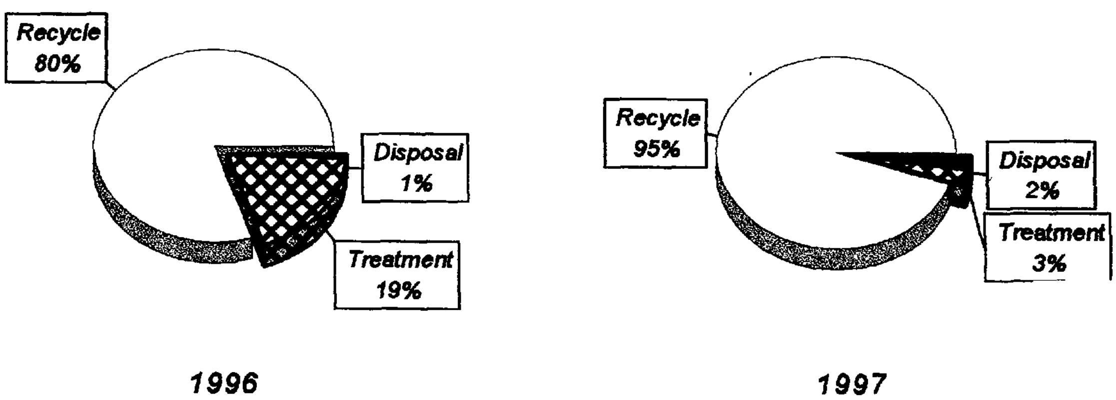
The U.S. petroleum refining industry managed an estimated 827 thousand wet tons of Spent Sulfidic Caustic in 1997, which was a 12% decrease from 1996. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 77. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows a decrease from 1,271 thousand wet tons in 1996 to 1,056 thousand wet tons in 1997, a decrease of 17%.

Figure 77—Nationwide Estimates of Spent Sulfidic Caustic per Year: 1994-1997.



The portion of the Spent Sulfidic Caustic stream that is managed by each management practice is shown in Figure 78 for 1996 and 1997. Recycling continues to be the most common practice.

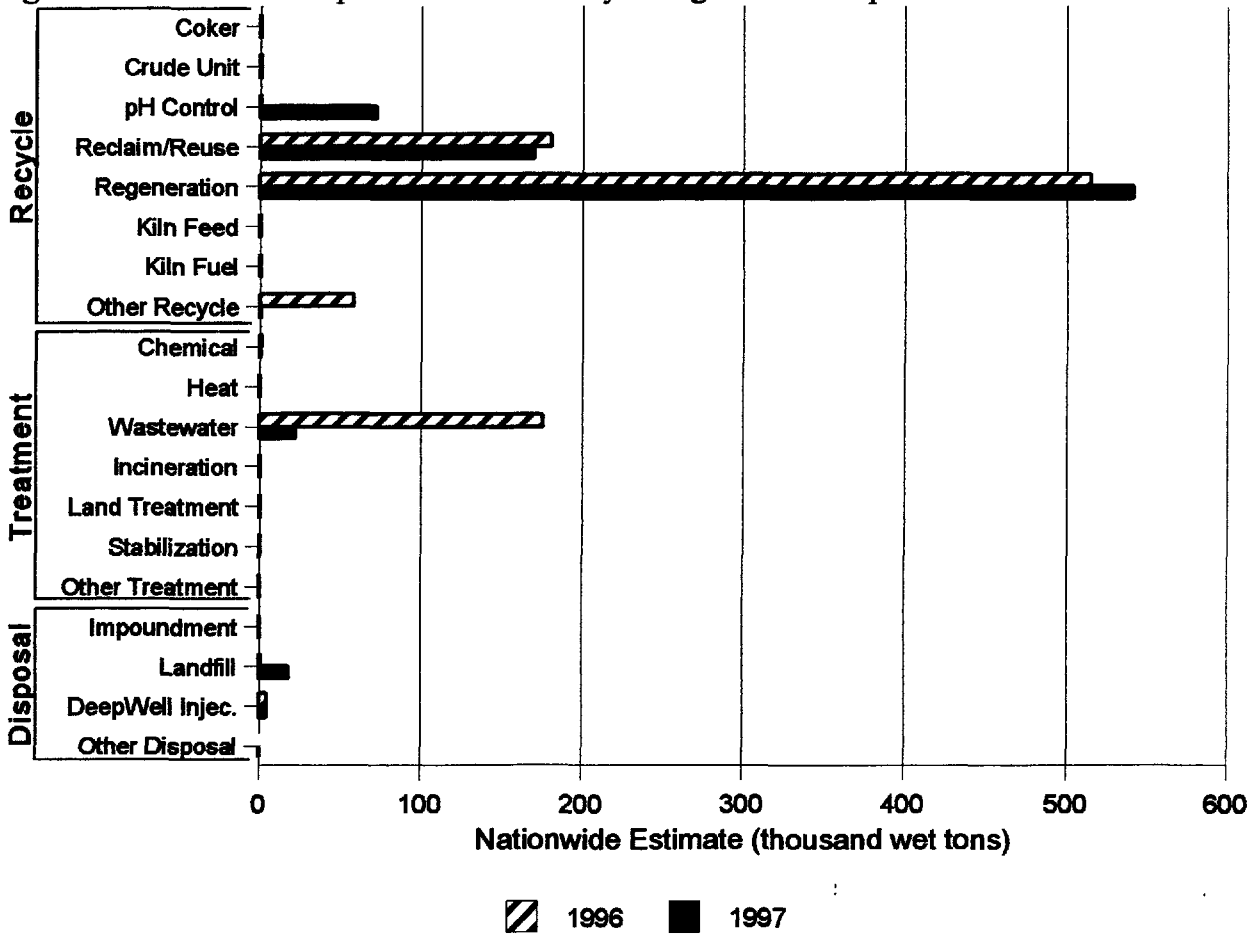
Figure 78—Nationwide Estimates of Spent Sulfidic Caustic by Management Practice: 1996-1997.



[13]Recall that this report uses labels such as Spent Sulfidic Caustic in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 79 shows the Spent Sulfidic Caustic distribution by management technique for 1996 and 1997. This stream is typically *regenerated*, recycled for *pH control*, *reclaimed*, or managed in the *wastewater* treatment facility. End uses reported for reclaimed or reused material were sale to a *caustics processor/broker*, reuse in *chemical processing*, and reuse in the *paper industry*. The end-use categories are defined in Appendix A.

Figure 79—Distribution of Spent Sulfidic Caustic by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

Other Recycle: one facility recycles this stream to a sour water stripper.

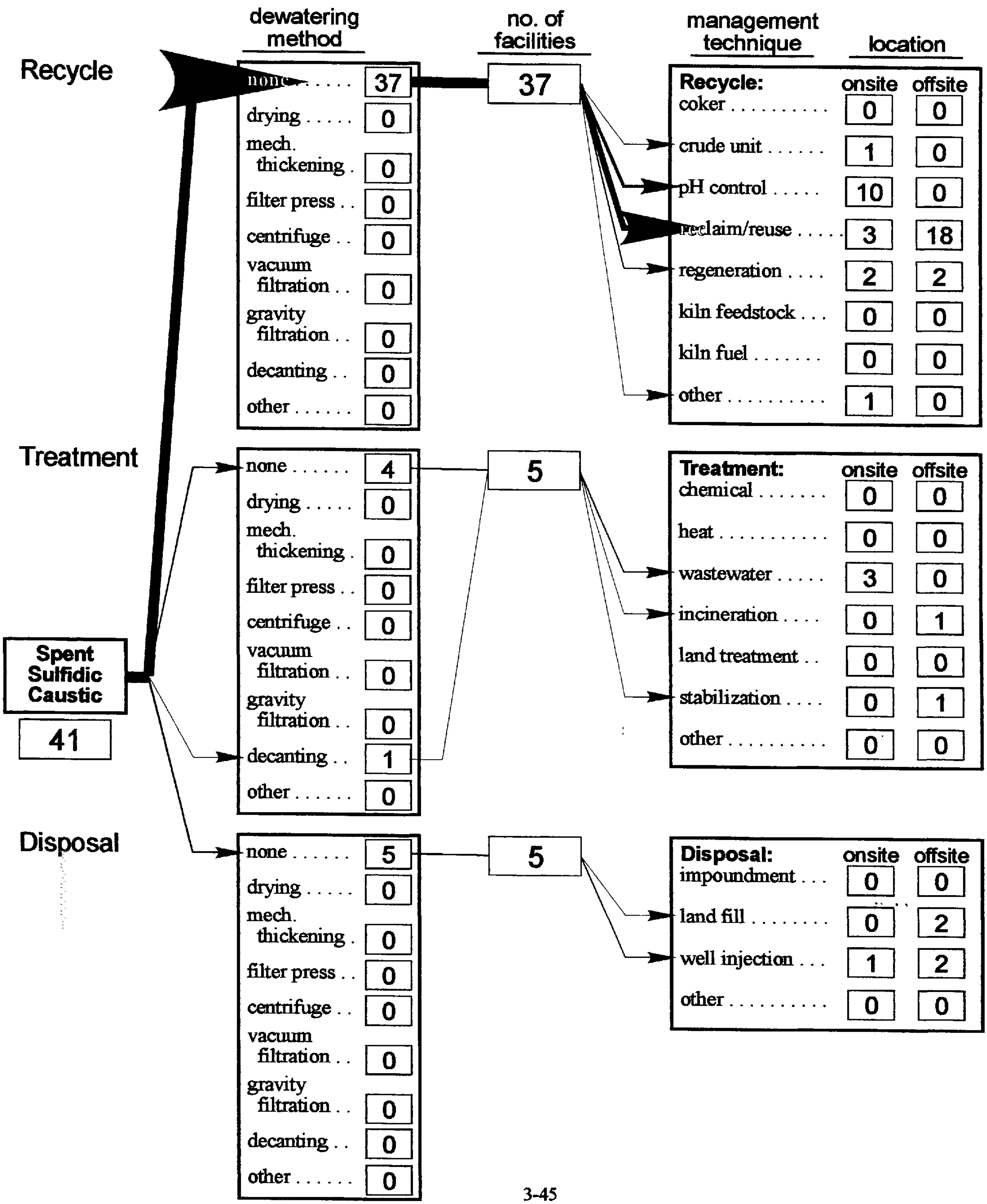
Other Treatment: none.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 80 - Spent Sulfidic Caustic Summary: 1997

Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



The following three graphs summarize the cost data reported for Spent Sulfidic Caustic.

Figure 81—Onsite Management Cost for Spent Sulfidic Caustic: 1997

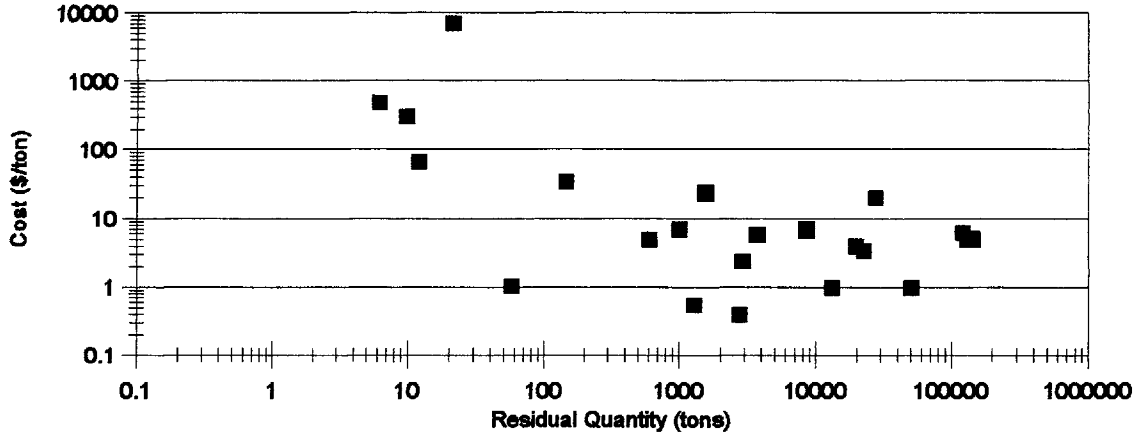


Figure 82—Offsite Management Cost for Spent Sulfidic Caustic: 1997

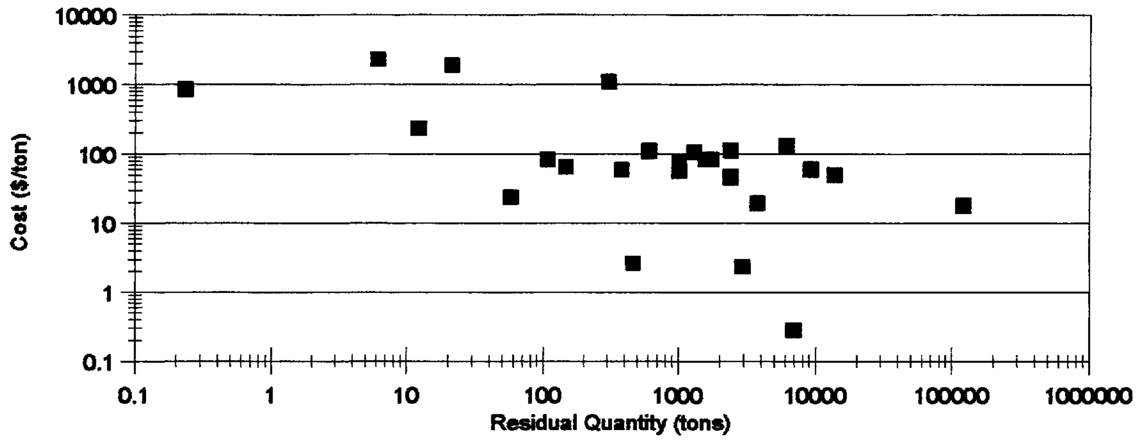
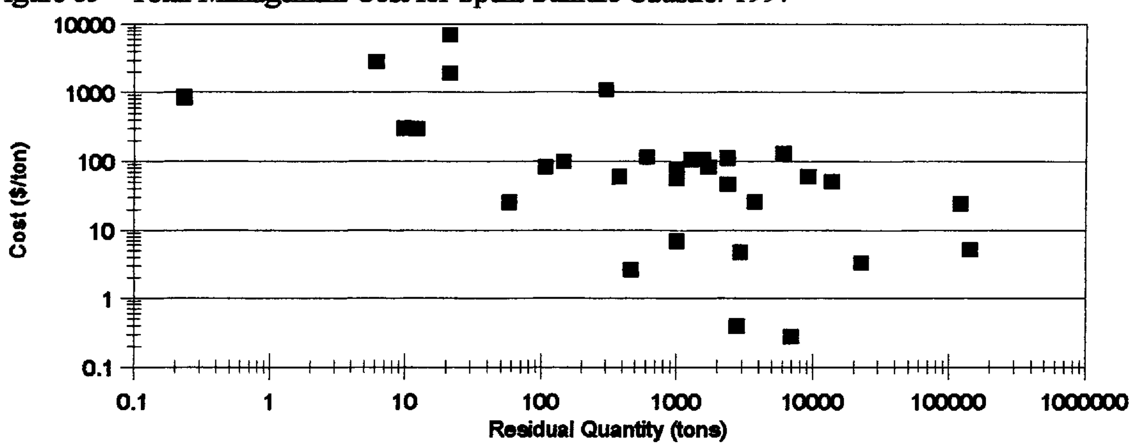


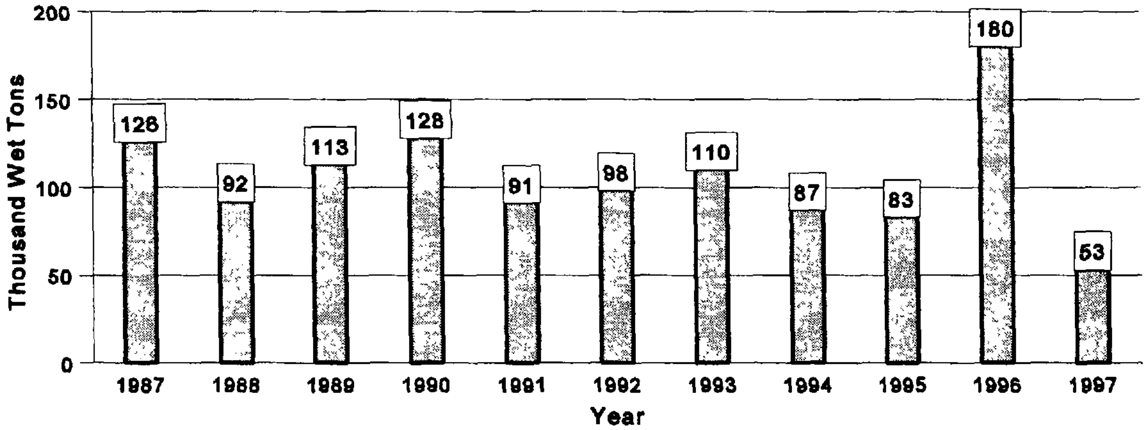
Figure 83—Total Management Cost for Spent Sulfidic Caustic: 1997



TANK BOTTOMS[14]

The U.S. petroleum refining industry managed an estimated 53 thousand wet tons of Tank Bottoms in 1997, which was a 71% decrease from 1996. A summary of the quantity of Tank Bottoms managed per year is presented in Figure 84. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 84—Nationwide Estimates of Tank Bottoms per Year: 1987-1997.



The portion of the Tank Bottoms stream that is managed by each management practice is shown in Figure 85 for 1996 and 1997. Whereas 1996 had shown an upward spike in quantity, most of which was recycled, the estimated quantity for 1997 has dropped considerably. The most common management practice is again disposal, as it was prior to 1996.

Figure 85—Nationwide Estimates of Tank Bottoms by Management Practice: 1996-1997.

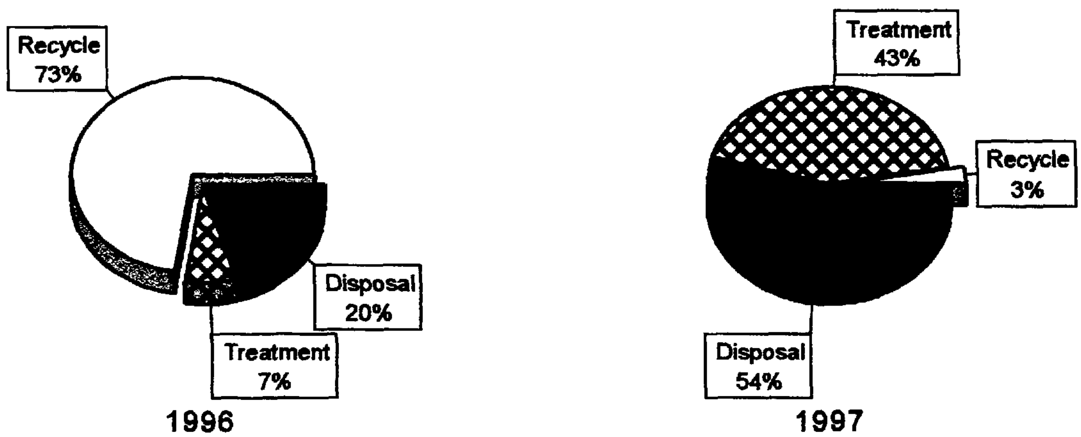
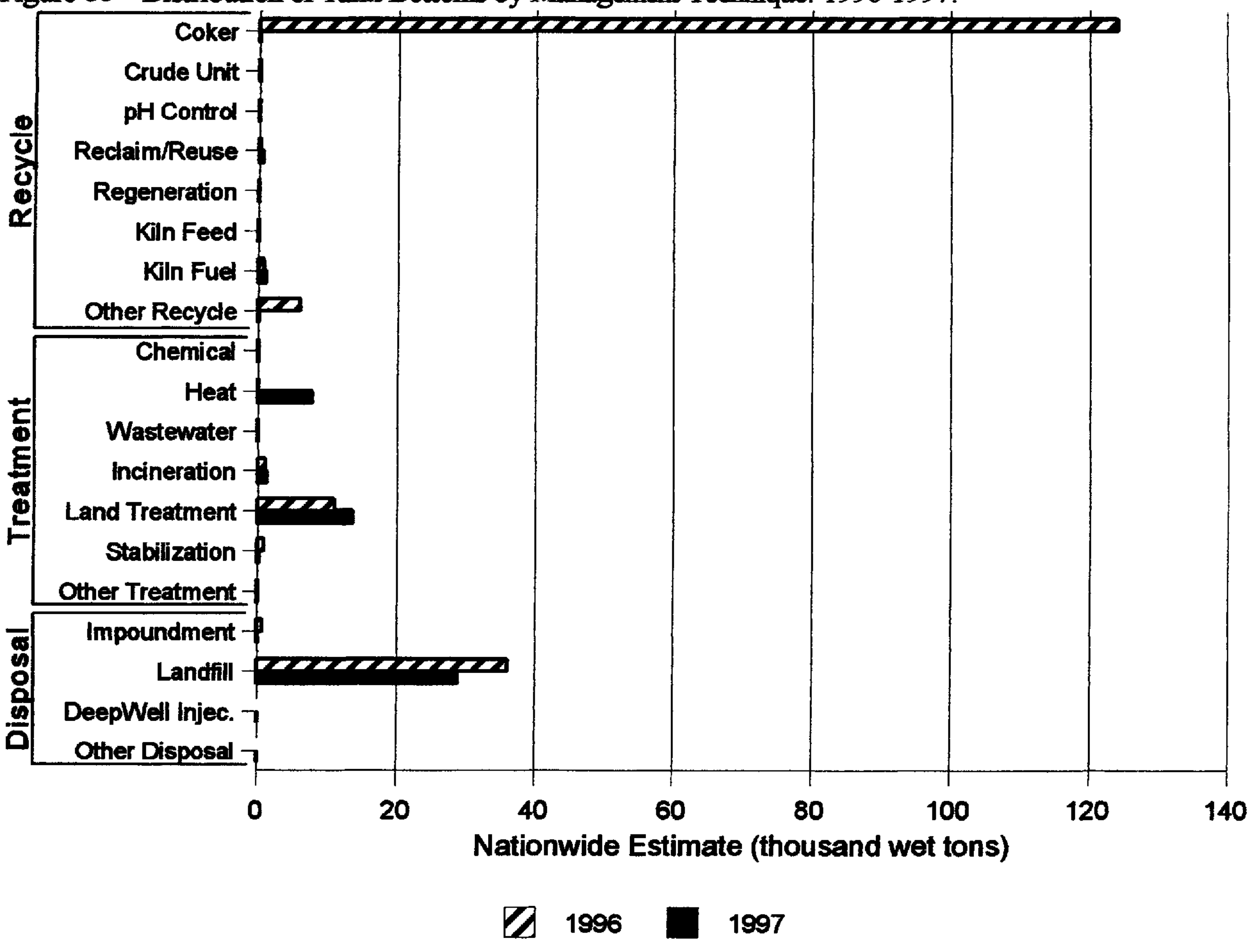


Figure 86 shows the Tank Bottoms distribution by management technique for 1996 and 1997. This stream may contain significant quantities of contaminated soil, and is often managed by *land treatment* or by disposal in a *landfill*. End uses reported for reclaimed or reused material were *oil recovery* and *fuels blending*. The end-use categories are defined in Appendix A.

[14]Recall that this report uses labels such as Tank Bottoms in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 86—Distribution of Tank Bottoms by Management Technique: 1996-1997.



Responses in the *other* categories are listed below.

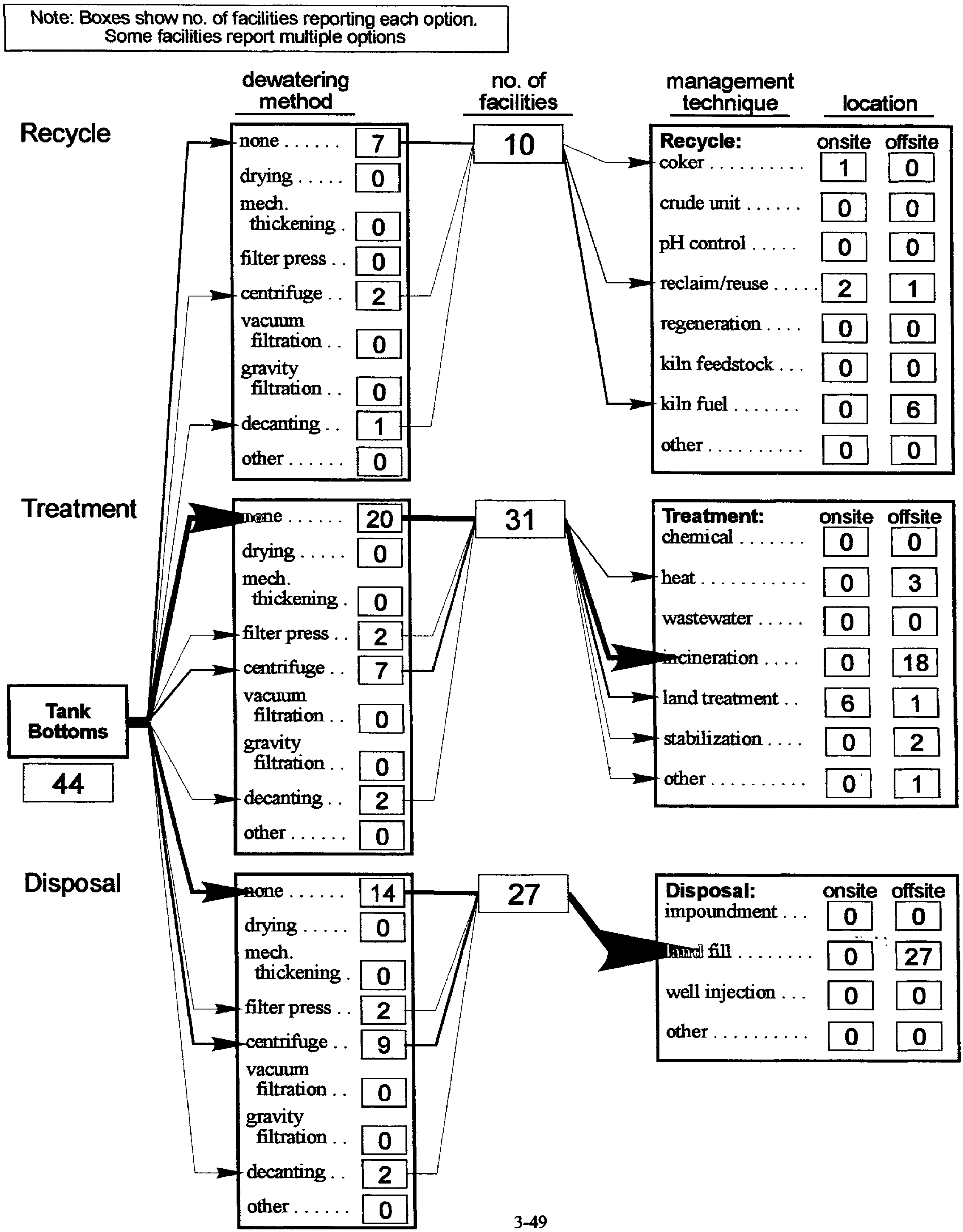
Other Recycle: none.

Other Treatment: one facility treats this stream by macroencapsulation.

Other Disposal: none.

The schematic on the next page illustrates the distribution of dewatering techniques and onsite versus offsite management for this stream by number of respondents.

Figure 87 - Tank Bottoms Summary: 1997

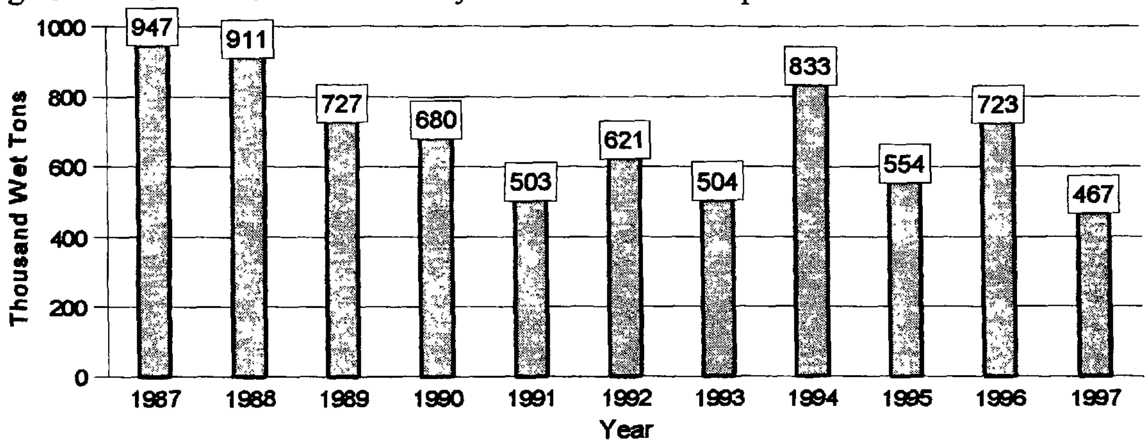


Section 4
COMBINED STREAMS

OILY WASTEWATER RESIDUALS[15]

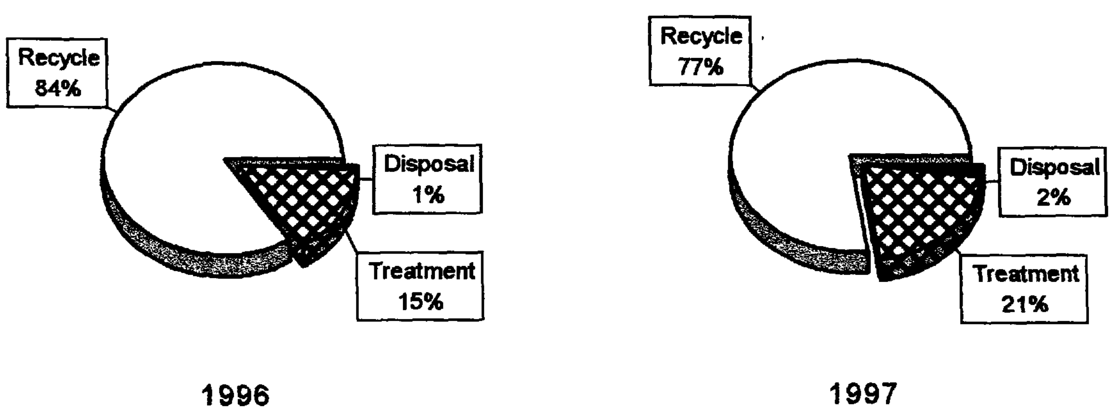
Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantity of these oily wastewater streams decreased from 723 thousand wet tons in 1996 to 467 thousand wet tons in 1997, a decrease of 35%. The combined quantities are summarized in Figure 88. The data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Figure 88—Nationwide Estimates of Oily Wastewater Residuals per Year: 1987-1997.



The portion of the Oily Wastewater Residuals managed by each management practice is shown in Figure 89 for 1996 and 1997. Recycling continues to be the dominant management practice.

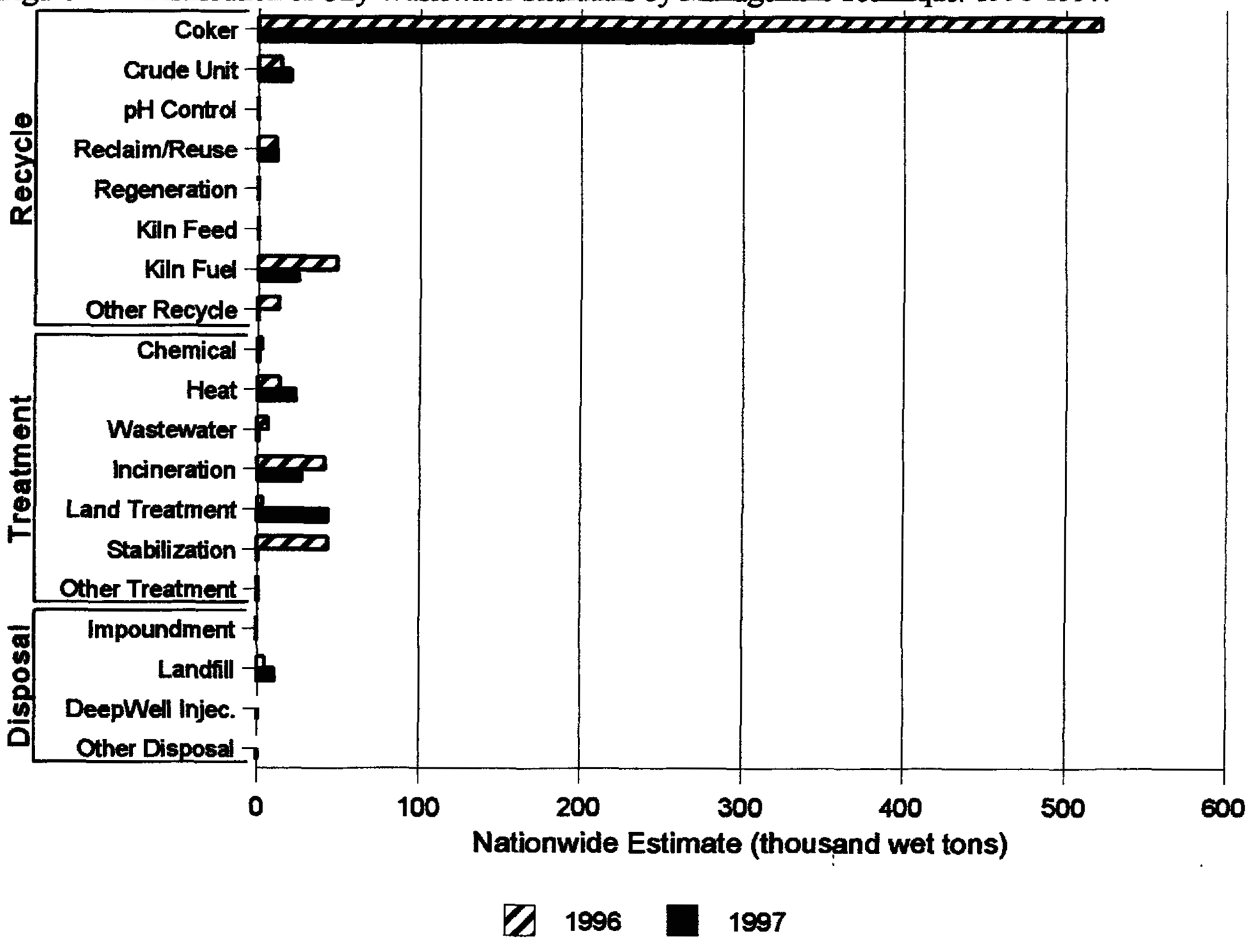
Figure 89—Nationwide Estimates of Oily Wastewater Residuals by Management Practice: 1996-1997.



[15]Recall that this report uses labels such as Oily Wastewater Residuals in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 90 shows the Oily Wastewater Residuals distribution by management technique for 1996 and 1997. These streams are managed primarily by techniques that recycle the oil content. This is most commonly accomplished by routing them to a *coker*. These streams are sometimes sent to a fuels blending unit for incorporation into *kiln fuel*. When oil is recovered from these streams by thermal desorption, it is reported as *reclamation*. End uses reported for reclaimed or reused material were *oil recovery* and *fuels blending*. The end-use categories are defined in Appendix A.

Figure 90—Distribution of Oily Wastewater Residuals by Management Technique: 1996-1997.

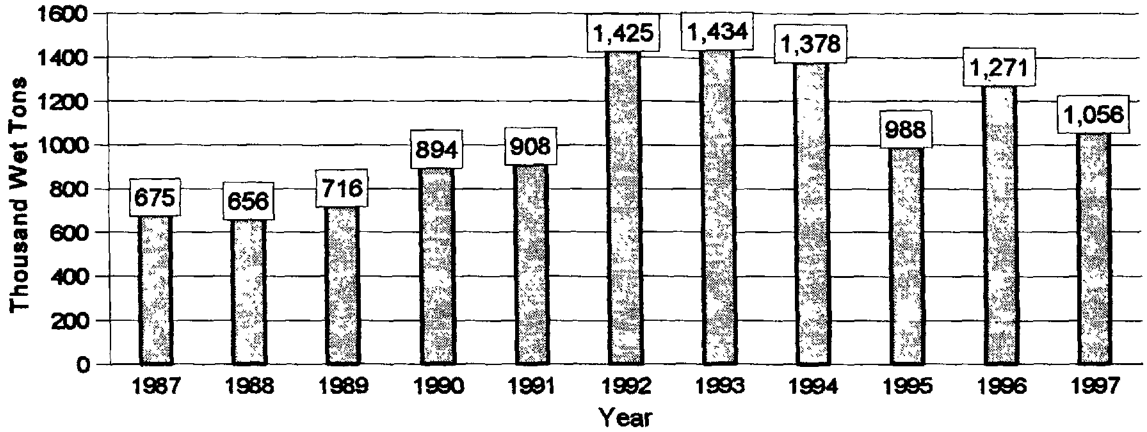


Responses in the *other* categories are listed in the sections for each of the streams that comprise oily wastewater residuals (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids).

SPENT CAUSTICS[16]

The U.S. petroleum refining industry managed an estimated 1,056 thousand wet tons of Spent Caustics (i.e., the Spent Cresylic Caustic, Spent Naphthenic Caustic, and Spent Sulfidic Caustic streams combined) in 1997, which was a 17% decrease from 1996. A summary of the quantity of Spent Caustics managed per year is presented in Figure 91.

Figure 91—Nationwide Estimates of Spent Caustics per Year: 1987-1997.



The portion of the Spent Caustics stream that is managed by each management practice is shown in Figure 92 for 1996 and 1997. Recycling continues to be the most common practice.

Figure 92—Nationwide Estimates of Spent Caustics by Management Practice: 1996-1997.

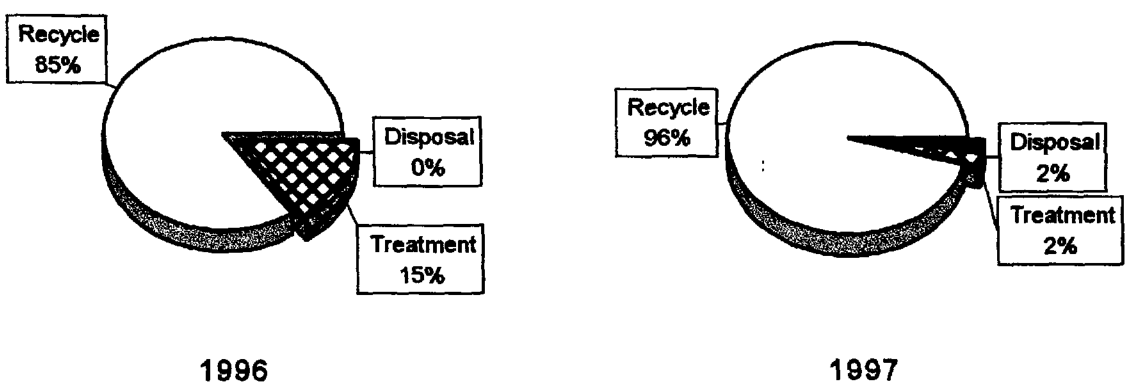
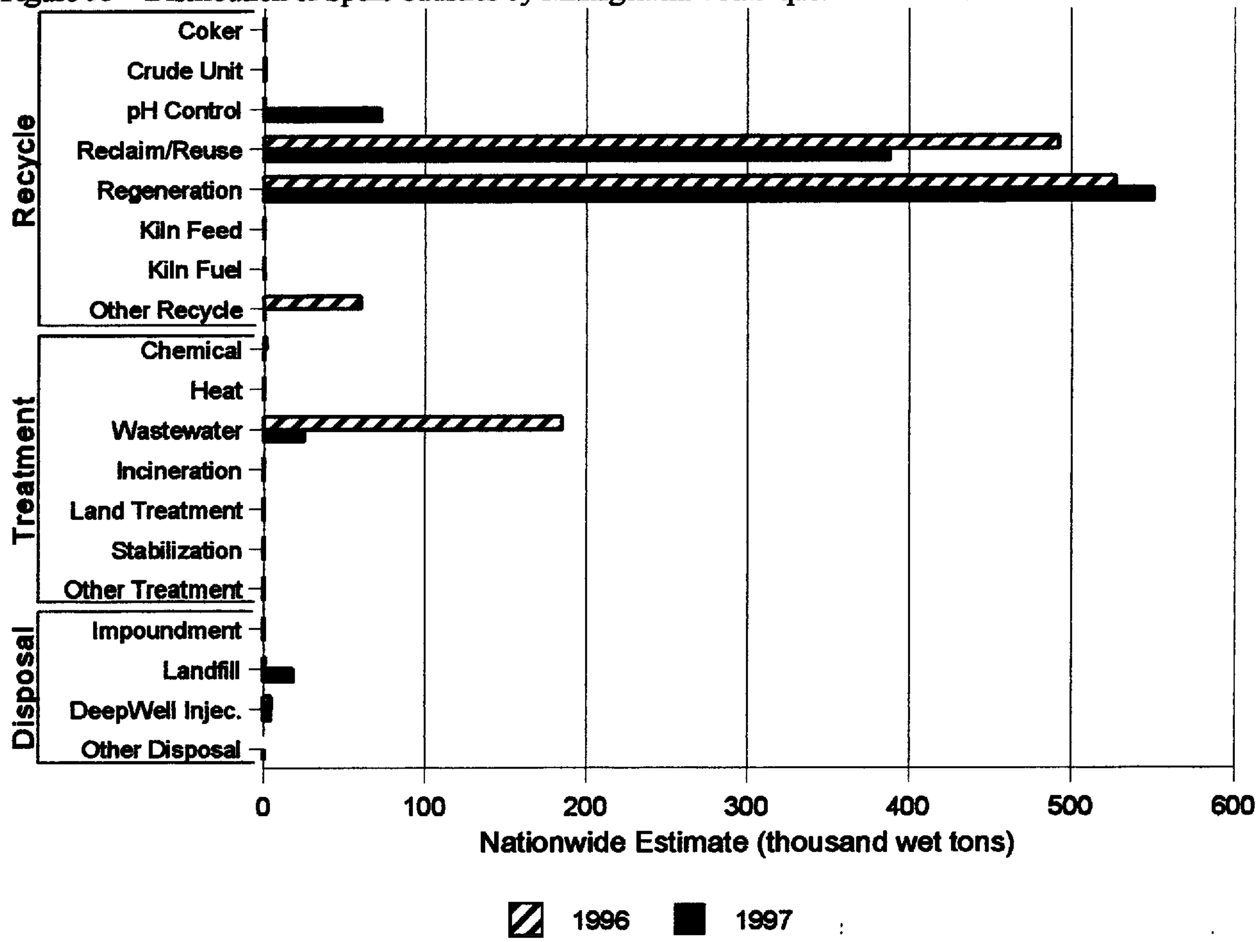


Figure 93 shows the Spent Caustics distribution by management technique for 1996 and 1997. While recycling by *regeneration* and *reclamation* are the dominant techniques used to manage Spent Caustics, there is significant variation depending upon the type of caustic. Referring back to Figures 71, 75, and 79, it is evident that it is much more common to *regenerate* spent sulfidic caustic, whereas spent cresylic or naphthenic caustics are more likely to be *reused* in another industry. Reuse of cresylic and naphthenic

[16]Recall that this report uses labels such as Spent Caustics in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

caustics is typically associated with either sale to a *caustics processor/broker* or reuse in *chemical processing*. Sulfidic caustic that is reused may additionally end up in the *paper industry*. The end-use categories are defined in Appendix A. Spent caustics may also be managed by *wastewater* treatment, or may be recycled for *pH control* in the wastewater plant.

Figure 93—Distribution of Spent Caustics by Management Technique: 1996-1997.



Responses in the *other* categories are listed in the sections for each of the streams that comprise Spent Caustics (i.e., Spent Cresylic Caustic, Spent Naphthenic Caustic, and Spent Sulfidic Caustic).

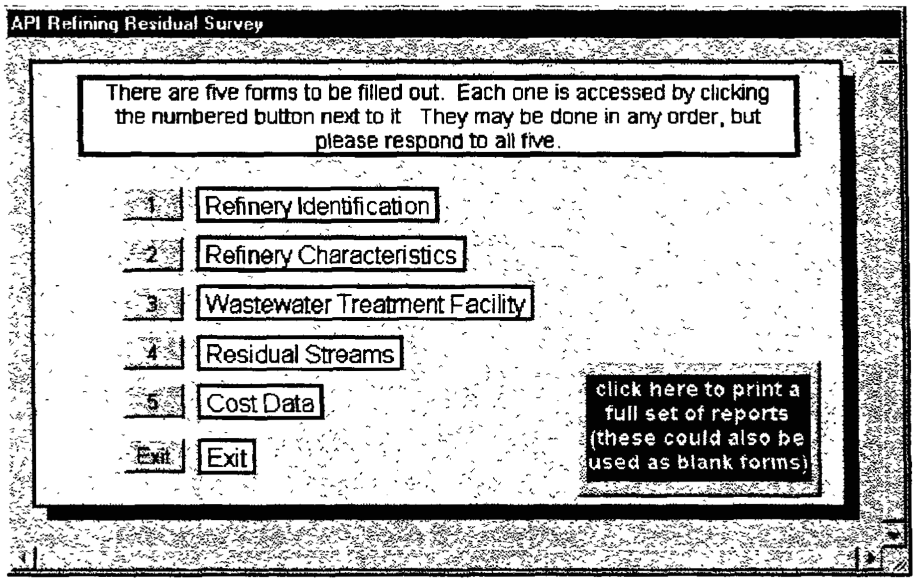
Appendix A
ELECTRONIC SURVEY FORM

The 1997 API Refining Residual Survey was distributed as a set of diskettes containing Paradox® Runtime™ and a custom Paradox® application. Paradox® Runtime™ is software that allows an end user to run custom Paradox® applications without requiring that they have Paradox® or any other application software. Both Paradox® and Paradox® Runtime™ are owned by Borland International, who allows companies registered to use both products to distribute unlimited copies of Paradox® Runtime™ on a royalty-free basis to end users in order to run custom Paradox® applications. In this instance, the registered application developer is The TGB Partnership, and the custom Paradox® application is the 1997 API Refining Residual Survey.

The custom application required the following computer system features and capabilities.

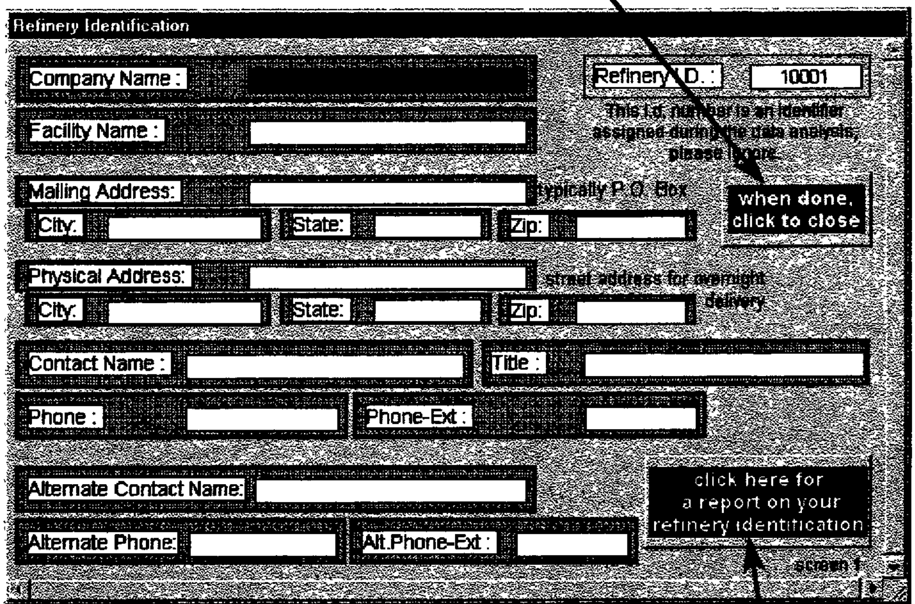
Processor	386 or higher.
Memory (RAM)	6 MB (8 MB recommended).
Hard disk	13 MB of free space.
Video monitor	VGA or higher.
Operating system	Microsoft Windows, version 3.1 or later.
Mouse	Required.

Upon loading the software, a Runtime icon group is created in the Program Manager (or, in Windows 95 parlance, a shortcut icon is added to the Start Menu). Double-clicking the Runtime icon (or single-clicking on the Runtime shortcut icon) results in the following menu being displayed on the screen.



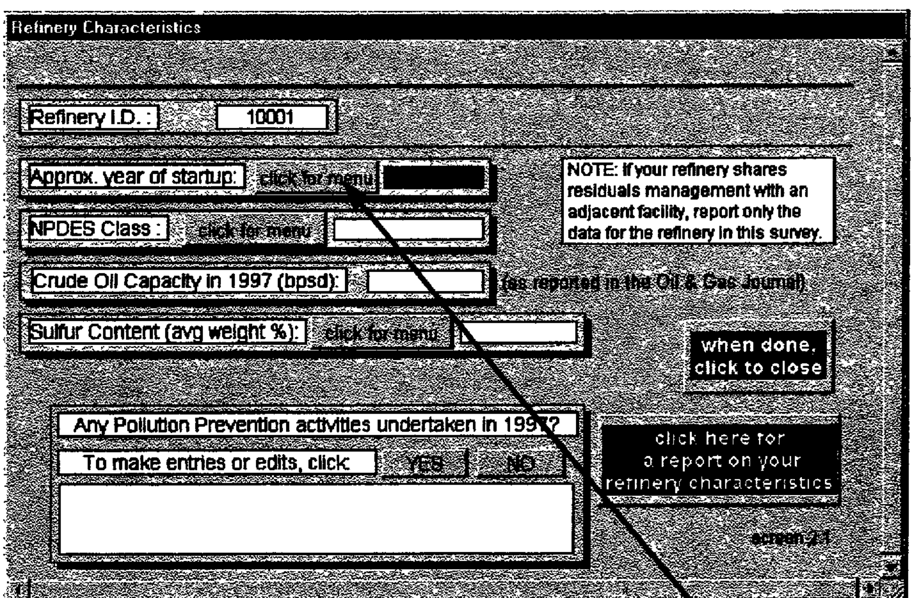
The on-screen instructions direct the user to click on a button to open a form. Completing the survey requires filling out each of the five forms. An additional button allows the user to print out a paper copy of the forms. The user begins the survey by clicking on Button 1–Refinery Identification, which brings up the screen shown on the next page.

At any time, the user may return to the main menu by clicking this button. All data will be automatically saved, and can be revised by returning to this form.



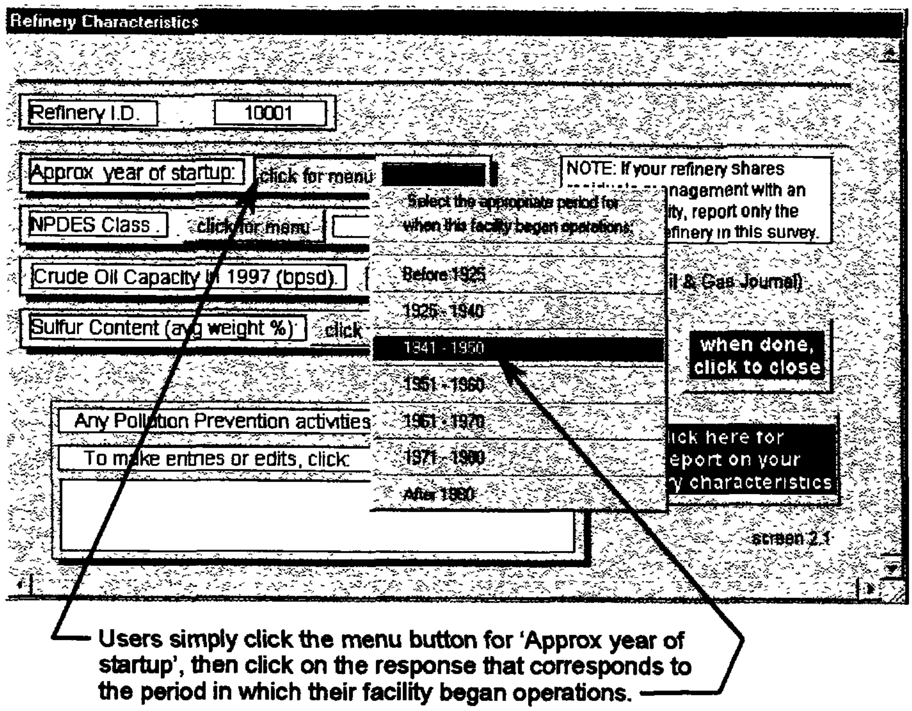
Clicking this button will print a report of the data on this page.

Returning to the main menu and clicking Button 2–Refinery Characteristics brings up the following screen.

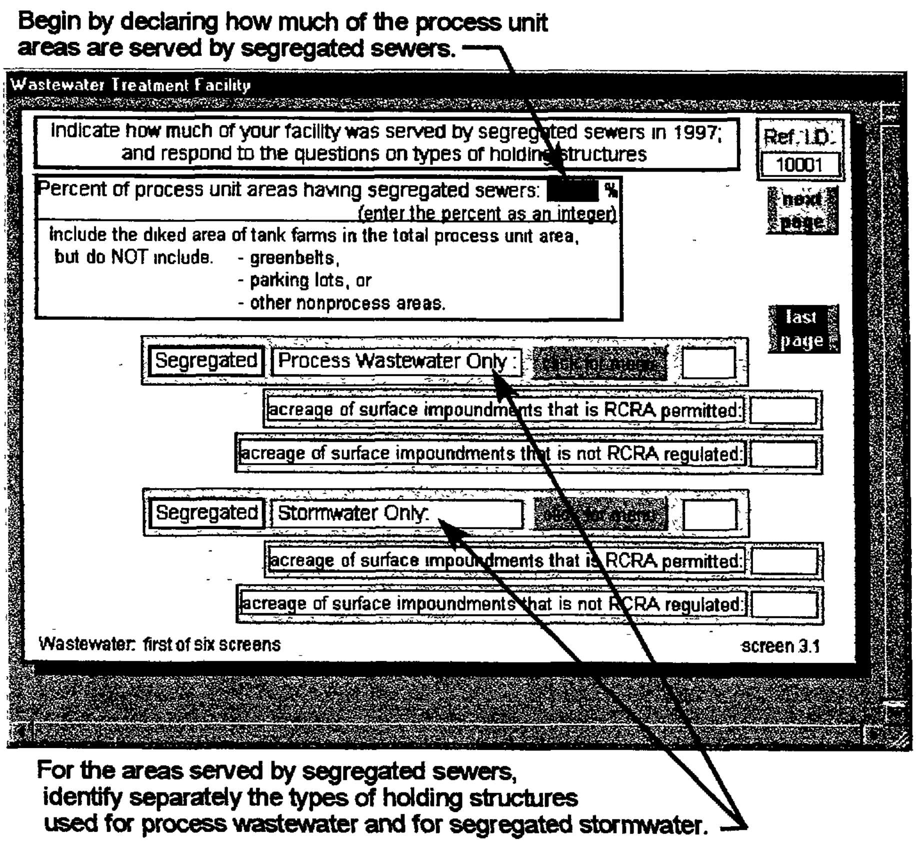


Many of the survey questions include a button that brings up a list for choosing a response.

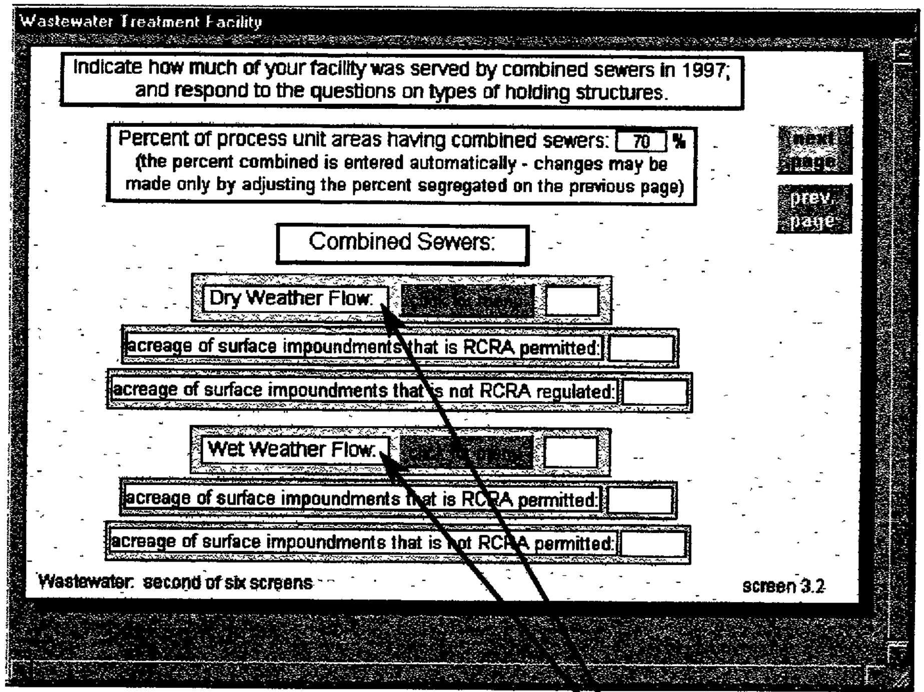
On-screen buttons allow the user to access a list from which to choose a response. This format is handy to the user in that it does not require any particular computer skills, nor does it require searching through an instruction manual for a list. Providing a list of appropriate response choices also promotes consistent entry of data. A sample list is shown on the next screen.



The third button on the main menu opens a multi-page form collecting data on the refinery's wastewater treatment facility.

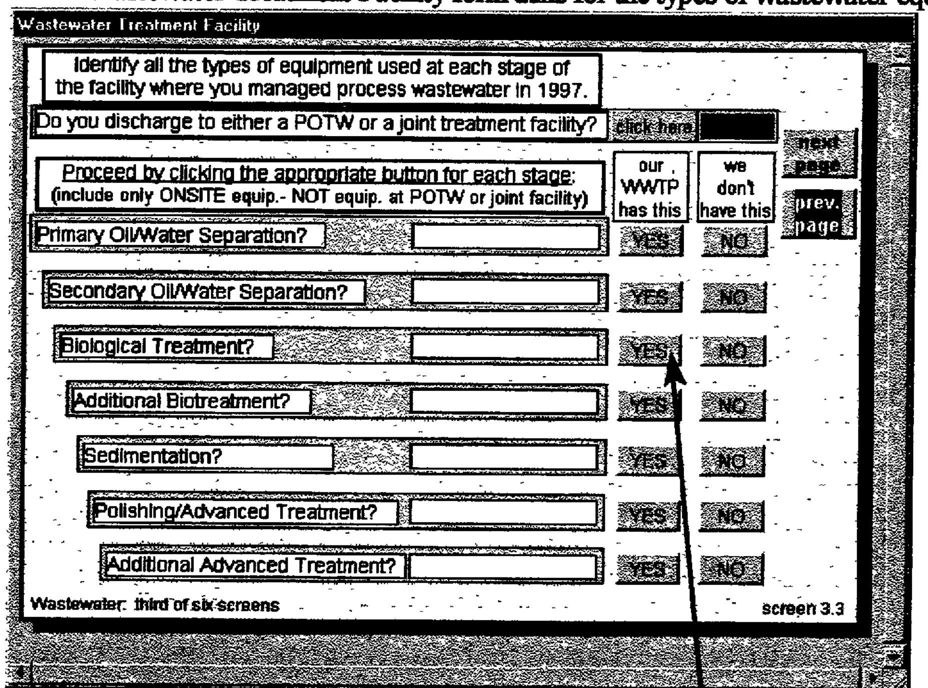


The first page of the Wastewater Treatment Facility form requests that the user indicate the extent to which the refinery is served by segregated sewers, and the types of holding structures used for containing segregated sewer flow. The menu buttons offer the choices of 'tanks only', 'tanks and impoundments', and 'surface impoundments only'. If the user indicates the use of surface impoundments, then the acreage is requested. The next page collects information on the holding structures containing combined sewer flow.



For the areas served by combined sewers, identify separately the types of holding structures used for dry weather flow and for wet weather flow.

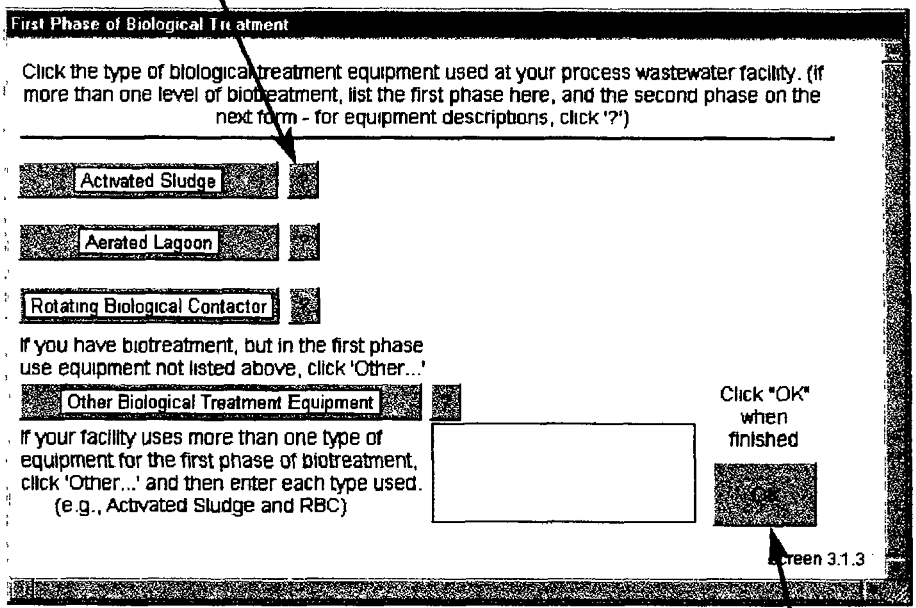
The third page of the Wastewater Treatment Facility form asks for the types of wastewater equipment used.



For each level of wastewater treatment, there is a button to open a form containing a list of equipment

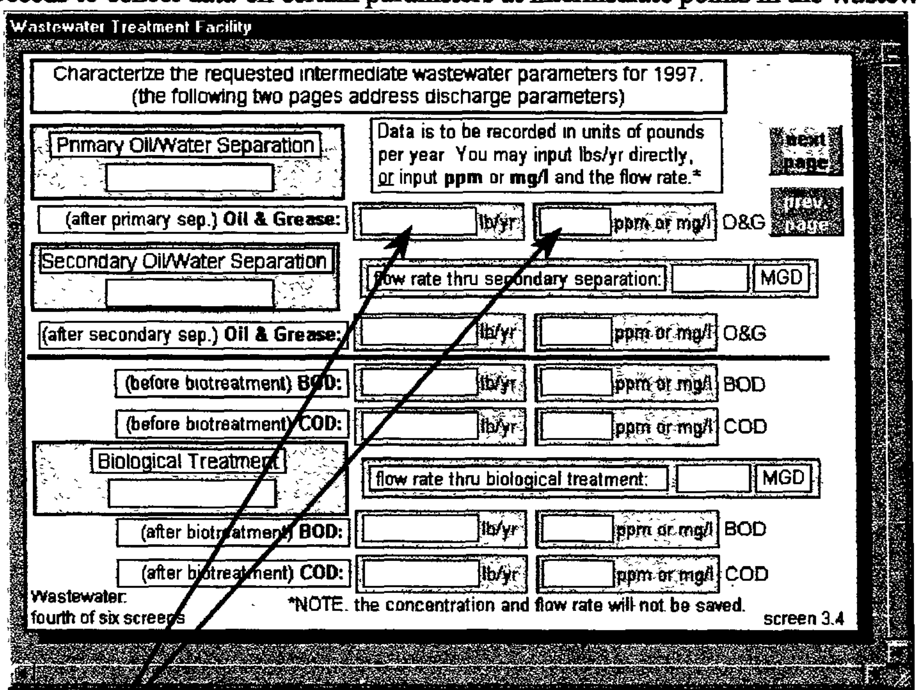
The form shows various levels of wastewater treatment, and includes a button for each. Clicking the button calls up another form containing a list of the types of equipment typical to that level of treatment. One such list is shown on the next screen.

As with the residual streams and treatment techniques, the <?> button pops up a description.



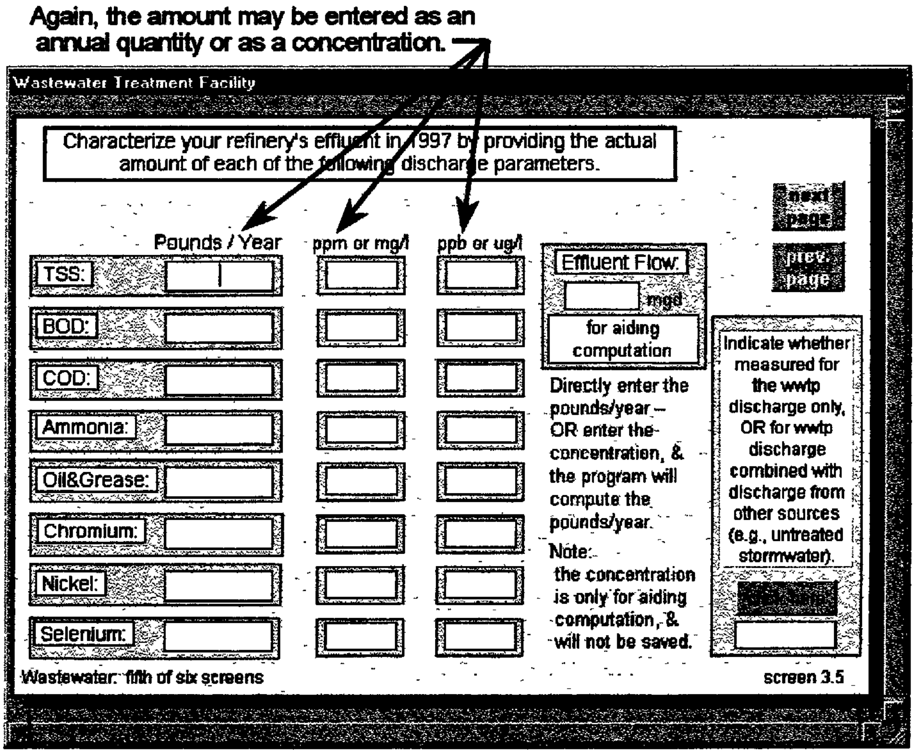
Whenever the user has gone to an attached form, a button is provided for returning to the sending form.

The survey proceeds to collect data on certain parameters at intermediate points in the wastewater system.

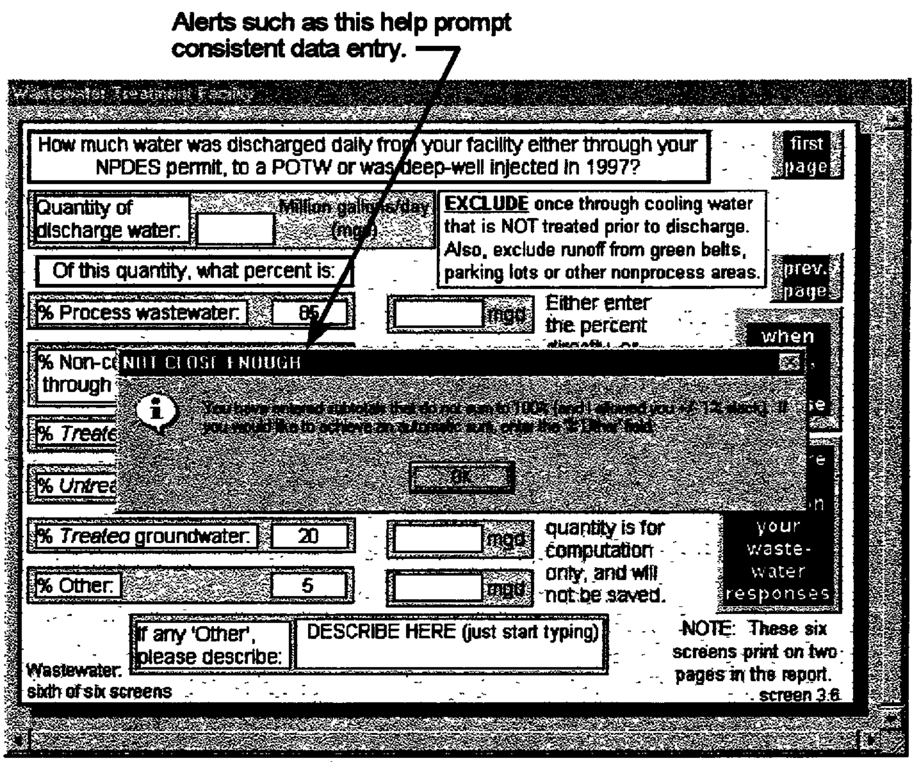


Where parameter values are requested as annual quantities, the form allows entry as a concentration (i.e., ppm or mg/l), which the form then automatically converts to pounds per year.

The next screen requests the levels of these and other parameters in the water discharged by the facility.



The final page of the Wastewater Treatment Facility form collects data on the quantity and sources of discharge water.



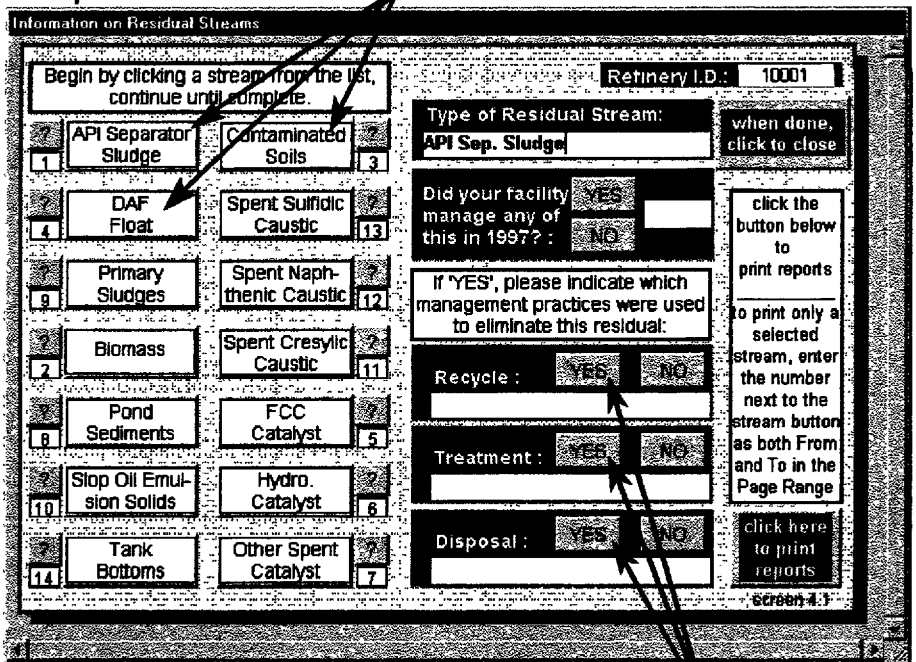
The first three forms of the survey have collected information on the facility. Button 4–Residual Streams–opens the form that gathers the actual residuals management information. This form has a button for each residual stream in the survey, with a <?> button next to each. Clicking on the <?> button produces a pop up message with a brief description of that residual.

The 14 residual streams in the 1997 survey and the definitions assigned to each are listed below.

API Separator Sludge—the sludge that settles out by gravity in the API separator. (aka K051)
Biomass—excess microorganisms (dead bugs) and other sludge removed from biological treatment units, (aka BIOX sludge). This does NOT include sediment from polishing ponds, which should be reported as Pond Sediments.
Contaminated Soils—includes dirt and dirt mixed with construction rubble that has been contaminated by spills or leaks. This does NOT include clean dirt excavated for construction.
DAF Float—the froth skimmed off the top of a DAF unit (the sludge on the bottom is Primary Sludge). For gas flotation units other than DAF (e.g., DNF, IAF), both the float and the sludge are primary sludges. DAF Float is RCRA listing K048.
FCC Catalyst—this includes withdrawal of equilibrium catalysts, solids drawn off from an electrostatic precipitator, and sludge from an FCC catalyst settling pond. If routed to TANKAGE for settling, however, the tank sludge should be reported as Tank Bottoms.
Hydro. Catalyst—catalysts that are used to remove sulfur, nitrogen, & metals. This residual is typically only generated when a reactor is reloaded during a turnaround. This does NOT include precious metal or raw water treating catalysts.
Other Spent Catalyst—only include other SOLID catalysts, such as precious metal or raw water treating catalysts. These are also typically generated only at turnarounds.
Pond Sediments—sludges (including underlying soils) removed from the bottom of ponds or pond sites, including polishing ponds downstream from bio units, raw water intake ponds, and stormwater holding ponds - but NOT catalyst settling ponds.
Primary Sludges—generally any wastewater residual that is not separately classified (i.e., everything removed from the wastewater stream other than from the API Separator, bio-treatment units, or the float from DAF units). This category includes BOTH F037 AND F038.
Slop Oil Emulsion Solids—solids (aka K049) derived from the breaking of slop oil emulsions. If the solids are not managed until after settling to the bottom of a vessel or container, they should NOT be reported as Slop Oil Emulsion Solids.
Spent Cresylic Caustic—this spent caustic is typically from treating gasoline.
Spent Naphthenic Caustic—this spent caustic is typically from treating jet fuel.
Spent Sulfidic Caustic—this is spent caustic that was used for the removal of hydrogen sulfide from light-end products.
Tank Bottoms—sludge cleaned from tanks storing oily contents, including crude oil, refined products (both leaded and unleaded), and bottoms receiver tanks (i.e., tanks collecting the heaviest product fraction from process units).

It should be understood that the residual stream labels used in this survey are NOT used in a regulatory sense. Whereas the Environmental Protection Agency (EPA) regulations implementing RCRA have given these terms special meaning, the usage here is in a broader, more generic sense. API's intent is to have survey participants report the management of all residual type materials (e.g., materials that are byproducts or residuals of petroleum refining operations). This includes residuals that are beneficially recycled or reclaimed, as well as materials that are discarded.

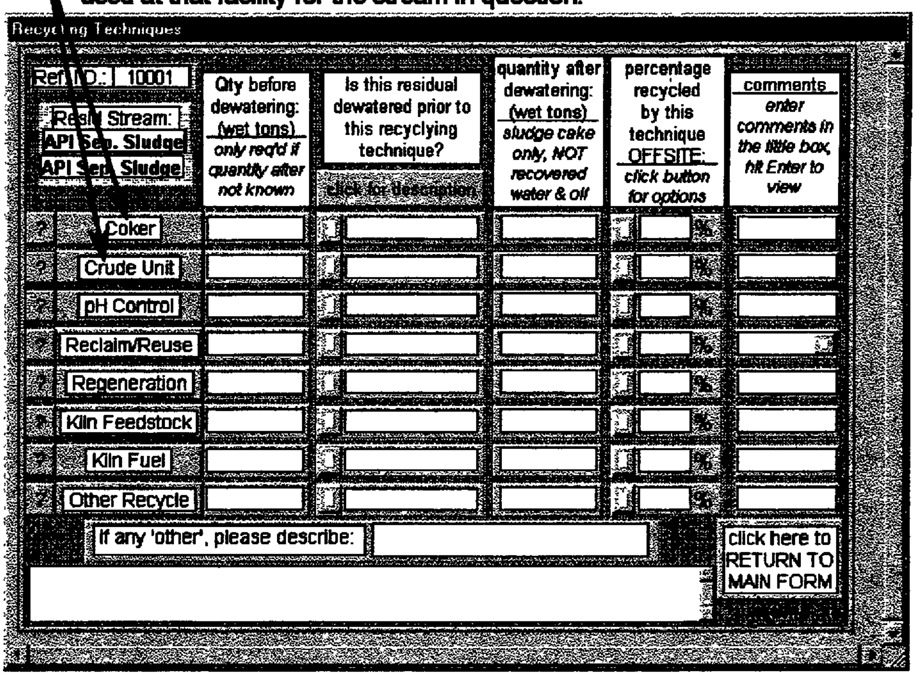
The user selects each stream in turn, and answers the questions for that stream.



Clicking <YES> for a management practice brings up a menu of that practice's management techniques.

The user clicks a button with a stream name, and then fills in the information for it. Clicking <YES> for any of the management practices calls a form listing management techniques, with the currently selected stream active. When a form for a selected management practice is first called for a particular stream, it has no data. After data have been entered and the form has been exited, the user can return to that form to revise the data by again selecting that stream and management practice. The called form will reappear, but will now show the data entered previously.

The user fills out the information for each technique used at that facility for the stream in question.



The management techniques from the 1996 and 1997 surveys are listed below, with the definitions assigned to them for the 1997 survey.

Recycle

Coker—this refers to routing the residual back to the coker, which is a thermal cracking unit (i.e., no catalysts).

Crude Unit—this refers to routing the residual back to a crude unit, which is an atmospheric or vacuum distillation unit.

~~Cat Cracker—this refers to routing the residual back to a cat cracker (fluidized-bed or other).~~ [*Discontinued as a treatment technique in the 1997 survey.*]

pH Control—this refers to routing a caustic residual to mix with an acidic stream in order to balance the pH or to render the acidic stream less corrosive.

Reclaim/Reuse—extracting usable material from the residual, or reusing the residual in some manner other than its original purpose. If restored to its original use, report it as Regeneration.

Regeneration—restoring residual material so that it may be returned to its original use (typically applied to catalysts); this also applies to the oxidation of spent caustics IF resulting in reusable caustic (even though it also involves reclamation of oil).

Kiln Feedstock—this applies if the residual is used as a raw material (rather than for fuel) at a cement kiln.

Kiln Fuel—this applies to residuals that are sent to cement kilns to be used as fuel.

Other Recycle—this applies to any Recycling Technique not listed above.

Treatment

Chemical—this involves the addition of chemicals for the purpose of treatment, such as flocculant to settle out solids from emulsions.

Heat—medium to high heat methods (e.g., hot oil, electric drier, rotary kiln, thermal desorption) should be reported as Heat Treatment. Use of low heat, such as steam, should be reported as Dewatering and NOT as Heat Treatment.

Wastewater Treatment—this applies to residuals that are routed to wastewater, typically through the sewer. Do NOT include material sent to the sludge digester, to sludge thickening, or liquids returned to the wastewater stream from dewatering operations.

Incineration—this applies to enclosed combustion, and typically requires auxiliary fuel.

Land Treatment—this includes any landspreading or landfarming operation. The residual may be broadcast onto the ground or injected just under the surface, and may involve subsequent activities to promote biodegradation, such as tilling, watering, or fertilizing.

Stabilization—this applies to solidification with agents such as lime or cement for purposes of reducing leachability.

Other Treatment—this applies to any Treatment Technique not listed above.

Disposal

Impoundment—this refers to permanently placing (not just storing) in a depression in the ground or in an area diked with an earthen material (e.g., a pit, pond, or lagoon). This does NOT apply to settling or bio ponds associated with Treatment Techniques.

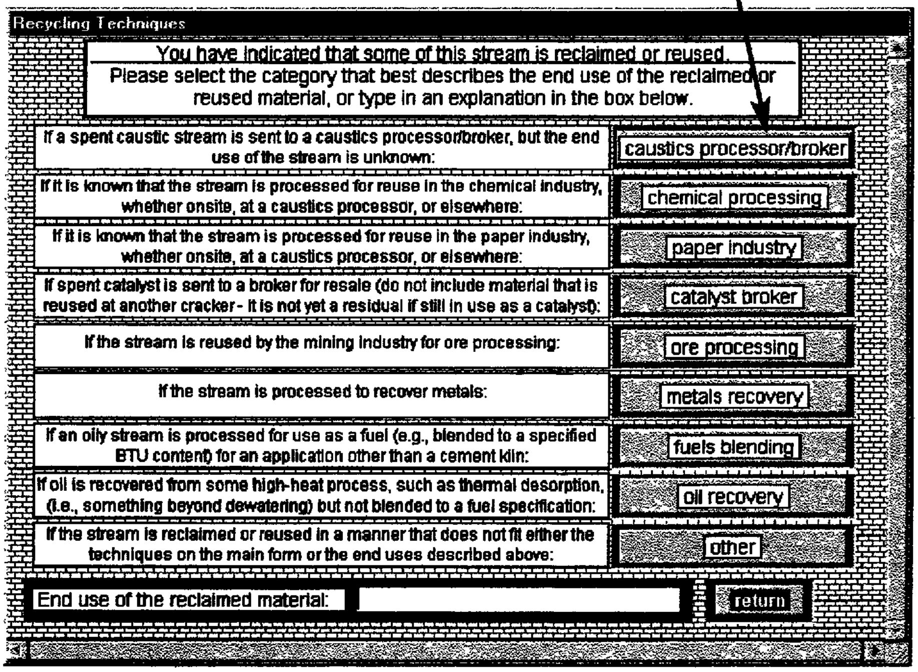
Landfill—this applies to material that is collected in or on the ground and covered. It typically involves only nonflowing residual material.

Well Injection—this applies to injection into a deep well which would typically extend into a nonporous rock formation. Surface injection is classified as Land Treatment.

Other Disposal—this applies to any Disposal Technique not listed above.

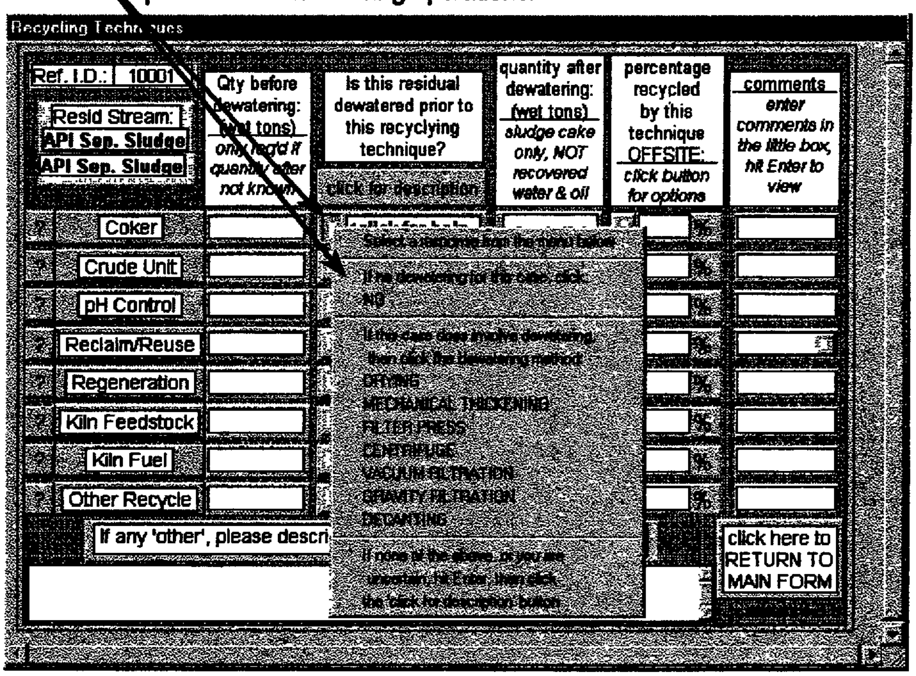
The 1997 survey added a form that is called automatically when entries are made to the Reclaim/Reuse management technique. This called form requests information on the end use of the reclaimed or reused material.

Select the appropriate end-use category from this list.

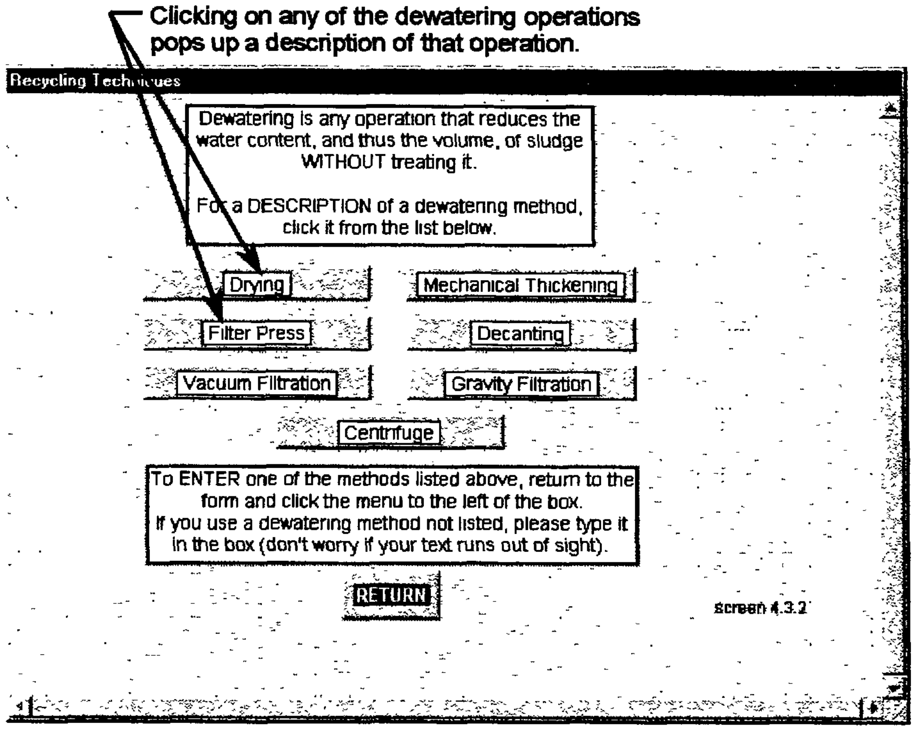


The form that is called by selecting a management practice also includes a question on the type of dewatering operations used, if any. This question is repeated for each management technique listed on the form. As with most other non-numerical queries, a pop up menu is provided to facilitate the response.

Clicking the dewatering <help> button pops up a menu of dewatering operations.



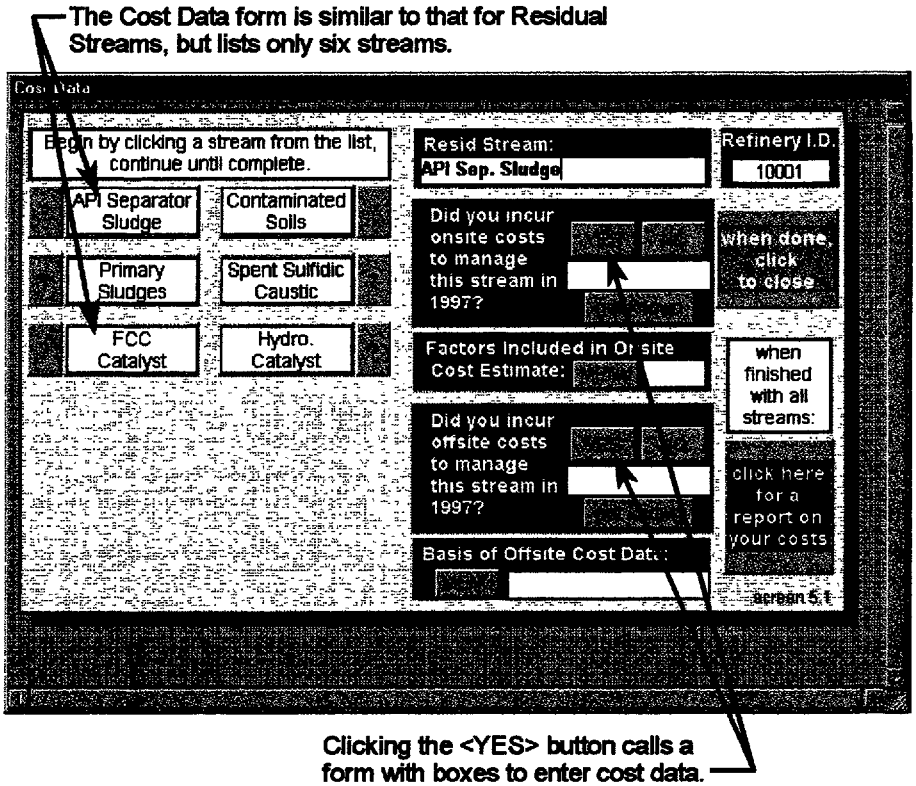
The <click for description> button under the dewatering question calls a form with the dewatering operations listed, as shown on the next screen.



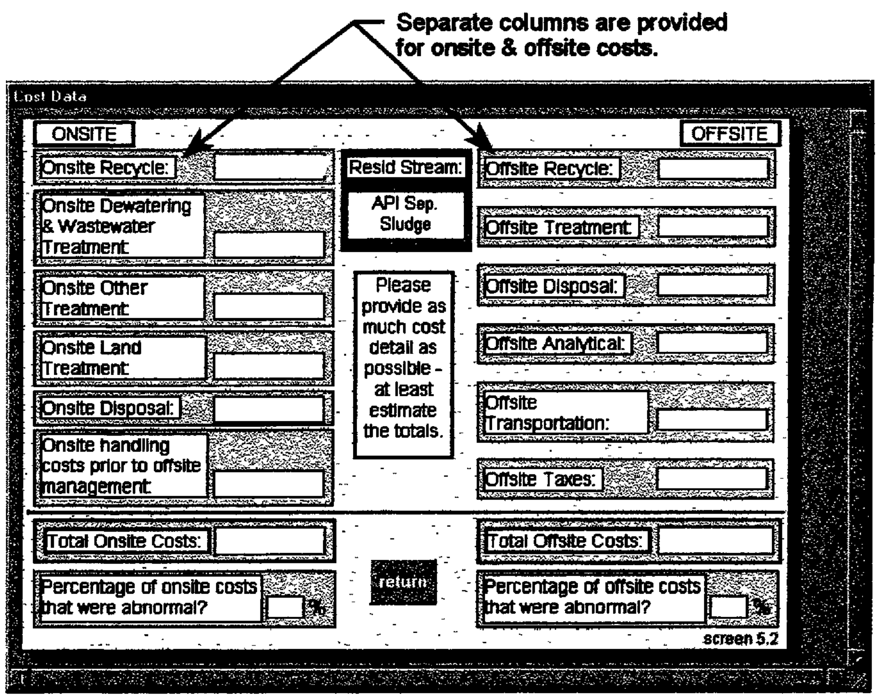
Clicking on the button with the name of a dewatering operation pops up a menu with a description of that operation. The descriptions of the dewatering operations are listed below.

Drying—Drying with low heat, such as steam, is classified as Dewatering. Medium to high heat (e.g., hot oil, electric drier, or rotary kiln) is classified as Heat Treatment, rather than as Dewatering.
Mechanical Thickening—This generally involves a round tank with rotating arms in the bottom that stir the sludge. Liquid is drawn off the top by flowing over a weir into a trough. The sludge isn't treated, it just has some of its liquid removed.
Filter Press—The sludge is pressed against a rigid, sieve-like filter to squeeze liquid out.
Decanting (Gravity Settling)—The sludge is placed in a tank, roll off box, or other container from which water is drawn off from the top.
Vacuum Filtration—This is similar to a filter press, but flow of liquid through the filter is assisted by maintaining a negative pressure beyond the filter.
Gravity Filtration—The sludge is placed in a container (such as a roll off box designed for this purpose) which allows water to drain out through a screen or filter in the bottom.
Centrifuge—This is kind of like putting sludge in your washing machine on the SPIN cycle.

The final form of the survey is activated by clicking Button 5–Cost Data. This form is similar in appearance to the Residual Streams form, but contains 6 streams rather than 14, as shown in the following screen.



Clicking <YES> for either the onsite or offsite cost question calls a form for entering the cost data, shown in the next screen.



The user may return to any form or page and edit the entries. After completing the survey, the respondent copies the files to a diskette and mails it to API.

Appendix B
DESCRIPTION OF STATISTICAL PROCEDURES

The 1997 API Refining Residual Survey used similar statistical analysis methods as used in previous years. No changes were made in the procedures for generating the regression model, extrapolating the respondent data to nationwide estimates, or in estimating nationwide quantities for the individual residual streams. This was done to maintain consistency in the reporting methods from year to year.

DATA COLLECTION

The 1995 survey was the first to require electronic submission of data. While this impacted the mechanics of compiling the data, it required no change in the procedures used to analyze the data. The electronic format was continued with the 1996 and 1997 surveys.

It was observed that a certain amount of the variability in earlier surveys was attributable to inconsistency in the assumptions made by respondents. Quantities had varied depending upon whether a facility reported the amount of residual before dewatering, or only the sludge cake remaining after dewatering. Furthermore, the assignment of categories by respondents had varied due to differing interpretations of the meaning of certain survey terms. To promote consistency, the 1995 survey included explicit instructions to report only the quantity of residual remaining after dewatering, exclusive of recovered oil or water. Another step taken to facilitate consistency was to add a pop up message box for each category in the survey, containing a definition of the label for that category. These guidance tools were enhanced in the 1996 and 1997 surveys.

Data continue to be collected on the same 15 residual streams as in the 1994 survey, but combining the two primary sludge categories from that survey resulted in 14 streams beginning with the 1995 survey. The 15 streams in the 1994 survey were only half the 30 streams included in earlier surveys, but those 15 streams represented approximately 80% of the total residual quantity from the previous surveys. The 1994 report concluded that the data pattern had changed very little with the fewer streams, and the regression model used previously was retained and has continued in use with subsequent surveys.

REGRESSION MODEL

In order to generate an estimate of the total quantity of residuals managed nationwide, a model must be developed for predicting the quantity of residuals managed at the facilities which did not respond, based on the data received from those refineries that did respond. The development of this model involves establishing the relationship of some known quantity to the unknown quantity of residuals. In each year of the API Refining Residual Survey, the known quantity of throughput capacity has been used to predict the unknown quantity of residuals managed. The model assumes a linear relationship between throughput capacity and the square root of the total quantity of residuals managed, as shown in the following equation.

$$\sqrt{R} = b_0 + b_1 C$$

Where:
R = estimate of total residuals managed by a facility (wet tons),
b_0 = the y-intercept of the regression line,
b_1 = the slope of the regression line, and
C = the throughput capacity of the facility (bsd).

The value of R is described as an estimate of the total quantity of residuals managed by a refinery, but in fact is now taken as the total of those streams included in the survey. Given this revised definition of R, which was first introduced in the 1994 survey, throughput capacity continues to be an acceptable predictor of the square root of residual quantity. The known value of throughput capacity was taken as that published by the Oil & Gas Journal in the table, *Worldwide Refineries-Capacities as of January 1, 1997.*

FITTING THE MODEL TO THE 1997 DATA

Data from five of the 70 respondents to the 1997 survey were either missing or inaccessible on the submitted diskettes. Data from the remaining 65 respondents were plotted on a scale of $R^{0.5}$ versus C and assessed for outliers. A linear regression was displayed on the scattergraph of the data, with parallel bounds drawn on either side of the regression. A visual appraisal identified one data point falling well above the upper bound. The data were then ranked by squared error, confirming that the facility visually identified from the scattergraph did indeed have a substantially larger squared error than the other facilities. This outlier was removed, and the final regression was then performed on the remaining 64 facilities.

The equation developed from the 1997 survey is:

$$\sqrt{R} = 22.8 + 7.17\times10^{-4}C$$

with an R^2 measure of correlation equal to 0.58.

INDUSTRY ESTIMATES

The industry estimates were determined in the same manner as in previous years. First, the throughput capacity was determined from the Oil & Gas Journal table for each facility that did not respond. This value was then input as C in the regression equation to calculate an estimated value of R for that facility. The square root of a quantity, however, is a biased estimator and thus requires a correction factor to yield an unbiased estimate. After the bias correction was made to each facility estimate, the nonrespondent quantities were summed and added to the sum of the respondent quantities. This yielded the total residual estimate for the U.S. petroleum refining industry. The reliability of this estimate can be stated as a percent error. Both the bias corrections for the individual estimates and the percent error for the nationwide estimate are explained below.

ESTIMATING NONRESPONDENT QUANTITIES

Biased Estimate

A biased estimate of the quantity of residuals managed by each nonrespondent facility is calculated from the regression equation:

$$\sqrt{R} = 22.8 + 7.17\times10^{-4}C$$

And then:

$$R = \left(\sqrt{R}\right)^2$$

In order to illustrate this determination, assume a throughput capacity of 72,000 bsd:

$$\begin{aligned}\sqrt{R} &= 22.8 + 7.17\times10^{-4}\,(72{,}000)\\ &= 74.424\\ R &= (74.424)^2\\ R &= 5{,}539\end{aligned}$$

Bias Correction

The bias correction factor is derived from the following relationship:[1]

$$V\left(\sqrt{R}\right) = E(R) - \left[E\left(\sqrt{R}\right)\right]^2$$

where V is the variance and E is the expected value. Rearranging the above equation to solve for $E(R)$ and using R^* to represent $E(R)$, the expected or unbiased value, the following equation is obtained:

$$E(R) = \left[E\left(\sqrt{R}\right)\right]^2 + V\left(\sqrt{R}\right)$$

$$R^* = R + V\left(\sqrt{R}\right)$$

The variance, $V\left(\sqrt{R}\right)$, in the above equation is calculated from the equation[2] below for an individual nonrespondent facility h. This equation represents the variance of a new observation, independent of the values from which the regression analysis is based.

$$V\left(\sqrt{R_h}\right) = MSE\left[1 + \frac{1}{n} + \frac{\left(C_h - \overline{C}\right)^2}{\sum_{i=1}^{n}\left(C_i - \overline{C}\right)^2}\right]$$

Where: C_h = the throughput capacity of nonrespondent facility h,
C_i = the throughput capacity of respondent facility i,
$\overline{C}$ = the average of the throughput capacities of the respondent facilities,

And the mean square error, MSE, is determined as follows:

$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-2} = \frac{210{,}629}{62} = 3397$$

Where: $y_i = \sqrt{R}$ as reported for respondent facility i, and
$\hat{y}_i = \sqrt{R}$ as predicted for the same facility, from the regression equation.

The average capacity of the respondent facilities is 111,472 bsd and the sum of the squares equals 570,500,000,000. The bias correction factor for the illustration of 72,000 bsd is then calculated as follows:

$$V\left(\sqrt{R_h}\right) = 3397\left[1 + \frac{1}{64} + \frac{(72{,}000 - 111{,}472)^2}{570{,}500{,}000{,}000}\right]$$

$$= 3{,}459$$

The unbiased residual estimate is then the sum of the biased estimate plus the bias correction factor:

$$R^* = R + V\left(\sqrt{R}\right)$$

$$R^* = 5{,}539 + 3{,}459$$

$$= 8{,}998 \text{ wet tons.}$$

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[1]Meyer, Paul L., 1970, *Introductory Probability and Statistical Applications*, 2nd ed., Addison-Wesley Publishing Company, Reading, Massachusetts, pp. 134-135.

[2]Neter, John and William Wasserman, 1974, *Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Design*, Richard D. Irwin, Inc., Homewood, IL, pp. 69-74.

Variance of the Unbiased Estimate

Each residual estimate for a nonrespondent has a variance associated with it. This variance is the variance of the unbiased estimate which is different from the variance of the square root of the biased value discussed previously (i.e., the bias correction factor). The variance of the unbiased estimate, based on the equation for R^*, is:

$$V(R^*) = V(R) + V\left[V\left(\sqrt{R}\right)\right]$$

The first term in the above equation, $V(R)$, is the variance of R and can be derived from the following relationship:[3]

$$V(R) \cong \left[\frac{\partial R}{\partial \sqrt{R}}\right]^2 V\left(\sqrt{R}\right) = \left[\frac{\partial \left(\sqrt{R}\right)^2}{\partial \sqrt{R}}\right]^2 V\left(\sqrt{R}\right)$$

$$= \left[2\sqrt{R}\right]^2 V\left(\sqrt{R}\right)$$

$$= 4R \times V\left(\sqrt{R}\right)$$

The second term is the variance of a variance. If σ^2 represents a variance, then the variance of σ^2 is:[4]

$$V\left(\sigma^2\right) = \frac{2\sigma^4}{n-1}$$

Rewriting the above equation in terms of R, the second term becomes:

$$V\left[V\left(\sqrt{R}\right)\right] = \frac{2\left[V\left(\sqrt{R}\right)\right]^2}{n-1}$$

Putting the first and second terms together, the variance of the unbiased estimate can now be stated in terms of the biased estimate and the bias correction factor (both of which were determined previously) as:

$$V(R^*) = 4R \times V\left(\sqrt{R}\right) + \frac{2\left[V\left(\sqrt{R}\right)\right]^2}{n-1}$$

For the illustration of a 72,000 bsd facility, the biased estimate was 5,539 and the bias correction factor was 3,459, and thus the unbiased estimate of the residual quantity is 8,998 wet tons. The variance of the unbiased estimate is

$$V(R^*) = 4(5{,}539)(3{,}459) + \frac{2(3{,}459)^2}{64-1}$$

$$= 77{,}017{,}435$$

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[3]*Op. cit., Introductory Probability and Statistical Applications*, pg. 139.

[4]Bury, Karl V., *Statistical Models in Applied Science*, Wiley-Interscience, New York, pp.249-250.

ESTIMATES FOR THE U.S. PETROLEUM INDUSTRY

Estimated Nationwide Total Residuals

The estimated total quantity of residuals for the U.S. petroleum refining industry is the sum of the residual quantities reported by the respondent facilities plus the unbiased estimates for the nonrespondent facilities. The total quantity reported by the respondent facilities was 1,179,360 wet tons, resulting in an estimate of 1,556,731 for the nonrespondent facilities. The total nationwide estimate of the quantity of these residual streams for the petroleum refining industry is therefore 2,736,091 wet tons.

Variance of the Total Result

The variance of the total estimated quantity is the sum of the variances associated with each individual facility. As in previous years, this calculation was simplified by assuming that the residual quantities of the respondents are known quantities which have no variance. Therefore, only the nonrespondents contribute to the variance of the total estimate. Since the total residual quantity for the industry, *T*, is a linear combination (sum) of the individual facility quantities, the total variance is calculated by the following equation:[5]

$$V(T) = V(R_1^*) + V(R_2^*) + \ldots + V(R_n^*) = \sum_{h=1}^{n} V(R_h^*)$$

Where:

$V(R_h^*)$ = the variance of the unbiased estimate for nonrespondent facility *h*, and *n* is the number of nonrespondent facilities.

The sum of the variances of the unbiased estimate for the nonrespondent facilities for the 1997 survey is 18,114,000,000.

Percent Error for the Estimate of Total Residuals

The percent error is based on the prediction interval for the estimate of total residuals, which is dependent upon the total variance and the confidence level chosen. For a 95% confidence level, the prediction interval is calculated by the following equations:[6]

$$T_U = T + 2\sqrt{V(T)}$$

$$T_L = T - 2\sqrt{V(T)}$$

where the coefficient 2 is the approximate value of the Student's *t* distribution for sample sizes larger than 30, and T_U and T_L are the upper and lower limits, respectively. Using the above equations, the prediction interval for the total industry is 2,466,915 to 3,005,268 wet tons.

The percent error, *E%*, is then expressed as:

$$E\% = \frac{2\sqrt{V(T)}}{T} \times 100\%$$

The percent error for the 1997 estimate is 9.8%.

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[5]Box, George E.P., William G. Hunter, and J. Stuart Hunter, 1978, *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, New York, pp. 87-88.

[6]*Op. cit.*, *Applied Linear Statistical Models*, pp. 71-74.

RESIDUAL STREAM ESTIMATES

The estimated total quantity of residuals for the U.S. petroleum refining industry was subdivided into individual residual streams and management techniques based on the proportion of each in the respondents' total. This method of proportioning the total to the individual categories assumes that the regression equation developed for the total is also valid for each residual stream and management technique. This assumption is not known to be valid, but the procedure is used for consistency with previous surveys.

The proportioning procedure begins with the calculation of the ratio of the quantity reported by respondents for a given category to the total quantity reported by respondents. This ratio is then multiplied by the total quantity estimated for nonrespondents. The sum of the quantity reported by respondents plus that determined by proportion for nonrespondents is then the estimated nationwide total for that category.

This procedure may be illustrated by considering the API Separator Sludge stream. This stream represents 46,063 tons of the 1,179,360 total tons reported by respondents, or 3.9%. Applying the 3.9% proportion to the estimated nonrespondent total of 1,556,731 yields 60,802 tons. Adding the respondent and nonrespondent quantities yields an estimated nationwide total quantity of API Separator Sludge of 106,865 wet tons.

Appendix C
DATA TABLES

Table C.1—Summary of Respondent Data in Wet Tons: 1997

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms	1997 Subtotals
Coker	23,332	9,124	0	78,882	0	0	0	0	22,179	7,110	0	0	0	7	140,635
Crude Unit	0	0	0	0	0	0	0	0	0	8,512	0	85	85	0	8,682
pH Control*	0	0	0	0	0	0	0	0	0	0	104	0	31,034	0	31,139
Reclamation/Reuse	1,792	28,100	8,559	50	2,631	9,690	21,024	0	1,746	1,381	61,489	32,528	73,058	217	242,245
Regeneration	0	0	0	0	0	1,283	383	0	0	0	3,660	0	233,458	0	238,784
Kiln Feedstock	0	0	0	0	14,439	49	123	0	0	0	0	0	0	0	14,611
Kiln Fuel	3,548	0	0	3,349	0	0	0	0	2,994	720	0	0	0	441	11,053
Recycle Other*	0	159	39,830	0	3,776	0	0	0	0	0	0	0	21	0	43,786
Recycle Subtotal	28,672	37,383	48,389	82,281	20,847	11,022	21,531	0	26,920	17,703	65,253	32,613	337,656	665	730,935
Chemical	0	0	143	368	0	0	0	0	0	0	0	0	0	0	511
Heat	6,081	0	1,222	640	18	220	17	0	2,861	363	0	0	0	3,320	14,742
Wastewater	0	5,453	0	338	0	0	0	0	0	0	30	910	9,446	0	16,177
Incineration	7,307	0	1,191	1,932	0	82	86	158	2,100	166	0	4	6	505	13,539
Land Treatment	435	34,204	8,037	..2,249	451	0	465	0	16,022	34	0	0	0	5,864	67,760
Stabilization	185	147	0	0	0	44	0	16,800	48	0	0	0	0	65	17,289
Treatment Other	227	75,250	0	0	0	0	0	0	0	0	0	0	0	10	75,488
Treatment Subtotal	14,235	115,054	10,594	5,528	469	345	568	16,958	21,031	563	30	914	9,452	9,764	205,506
Impoundment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Landfill	3,154	75,216	96,147	894	25,047	3,046	3,539	13,797	365	0	0	0	7,681	12,386	241,271
DeepWell Injection	2	0	0	0	0	0	0	0	0	0	0	0	1,623	0	1,625
Disposal Other	0	0	0	0	0	0	0	0	22	0	0	0	0	0	22
Disposal Subtotal	3,156	75,216	96,147	894	25,047	3,046	3,539	13,797	387	0	0	0	9,304	12,386	242,918
1997 Stream Totals	46,063	227,653	155,131	88,703	46,362	14,414	25,638	30,755	48,337	18,266	65,283	33,527	356,412	22,815	1,179,360

* pH Control was added as a separate category in the 1997 survey, in response to frequent indications in prior years' surveys of spent caustics being recycled for this purpose. This year's survey discontinued the separate category for Cat Cracker. Reporting this management technique in the 1997 survey would have required listing the quantity under Other Recycle, and including an explanation. No facilities did so.

Table C.2—Nationwide Estimates in Wet Tons: 1997

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms	1997 Subtotals	1996 Subtotals	Difference
Coker	54,130	21,168	0	183,005	0	0	0	0	51,455	16,495	0	0	0	16	326,270	737,536	(411,267)
Crude Unit	0	0	0	0	0	0	0	0	0	19,748	0	197	197	0	20,142	14,270	5,872
pH Control*	0	0	0	0	0	0	0	0	0	0	242	0	71,999	0	72,241		72,241
Reclamation/Reuse	4,157	65,191	19,857	116	6,104	22,481	48,776	0	4,051	3,157	142,653	75,464	169,492	503	562,005	564,281	(2,276)
Regeneration	0	0	0	0	0	2,976	890	0	0	0	8,490	0	541,618	0	553,974	537,160	16,813
Kiln Feedstock	0	0	0	0	33,498	114	285	0	0	0	0	0	0	0	33,897	61,160	(27,262)
Kiln Fuel	8,231	0	1	7,770	0	0	0	0	6,947	1,671	0	0	0	1,024	25,644	49,829	(24,185)
Recycle Other*	0	369	92,405	0	8,761	0	0	0	0	0	0	0	49	0	101,583	253,018	(151,435)
Recycle Subtotal	68,518	86,729	112,262	190,891	48,364	25,571	49,951	0	62,453	41,070	151,386	75,662	783,355	1,543	1,695,755	2,217,254	(521,498)
Chemical	0	0	333	854	0	0	0	0	0	0	0	0	0	0	1,187	3,920	(2,734)
Heat	14,107	0	2,835	1,486	42	510	40	0	6,638	841	0	0	0	7,702	34,201	15,766	18,435
Wastewater	0	12,651	0	784	0	0	0	0	0	0	70	2,111	21,915	0	37,530	198,338	(160,808)
Incineration	16,953	0	2,764	4,483	0	189	200	367	4,872	386	0	9	14	1,173	31,410	120,389	(88,979)
Land Treatment	1,008	79,353	18,645	5,218	1,046	0	1,079	0	37,170	79	0	0	0	13,604	157,202	219,039	(61,837)
Stabilization	430	341	0	0	0	102	0	38,976	111	0	0	0	1	150	40,111	47,987	(7,876)
Treatment Other	527	174,579	1	0	0	0	0	0	0	0	0	0	0	23	175,130	223,100	(47,970)
Treatment Subtotal	33,025	266,923	24,578	12,824	1,087	801	1,318	39,343	48,792	1,306	70	2,120	21,929	22,652	476,770	828,539	(351,769)
Impoundment	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	36,164	(36,164)
Landfill	7,317	174,499	223,060	2,074	58,109	7,067	8,209	32,009	846	0	0	0	17,819	28,734	559,745	635,074	(75,330)
DeepWell Injection	4	0	0	0	0	0	0	0	0	0	0	0	3,765	0	3,769	4,429	(660)
Disposal Other	0	0	0	0	0	0	0	0	51	0	0	0	0	0	51	34	18
Disposal Subtotal	7,322	174,499	223,060	2,074	58,109	7,067	8,209	32,009	897	0	0	0	21,584	28,734	563,565	675,701	(112,136)
1997 Stream Totals	108,865	528,151	359,900	205,790	107,560	33,439	59,479	71,351	112,142	42,377	151,455	77,782	826,869	52,930	2,736,091	3,721,494	(985,403)
1996 Stream Totals	96,977	728,751	521,684	276,370	142,559	37,484	47,694	69,482	130,946	218,415	174,869	161,248	934,711	180,304	3,721,494		
Difference	9,888	(200,600)	(161,784)	(70,580)	(34,999)	(4,045)	11,784	1,870	(18,804)	(176,038)	(23,413)	(83,466)	(107,842)	(127,374)	(985,403)		

* pH Control was added as a separate category in the 1997 survey, in response to frequent indications in prior years' surveys of spent caustics being recycled for this purpose. This year's survey discontinued the separate category for Cat Cracker. The small quantity reported in this category for FCC Catalyst in 1996 has been deleted.

Table C.3—Number of Respondents for Each Category: 1997

Management Technique	API Sep. Sludge	Biomass	Contaminated Soils	DAF Float	FCC Catalyst	Hydro. Catalyst	Other Spent Catalyst	Pond Sediments	Primary Sludges	Slop Oil Emulsion Solids	Spent Cresylic Caustic	Spent Naphthenic Caustic	Spent Sulfidic Caustic	Tank Bottoms
Coker	8	3	0	8	0	0	0	0	7	2	0	0	0	1
Crude Unit	0	0	0	0	0	0	0	0	0	2	0	1	1	0
pH Control	0	0	0	0	0	0	0	0	0	0	2	0	10	0
Reclamation/Reuse	6	1	3	1	8	36	25	0	10	5	18	3	21	3
Regeneration	0	0	0	0	0	11	8	0	0	0	2	0	4	0
Kiln Feedstock	0	0	0	0	18	1	1	0	0	0	0	0	0	0
Kiln Fuel	10	0	1	6	0	0	0	0	14	7	0	0	0	6
Recycle Other	0	1	3	0	2	0	0	0	0	0	0	0	1	0
Recycle Subtotal	24	5	7	15	28	48	34	0	31	16	22	4	37	10
Chemical	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Heat	6	0	5	2	1	2	1	0	9	3	0	0	0	3
Wastewater	0	2	0	1	0	0	0	0	0	0	1	2	3	0
Incineration	19	0	7	7	0	7	1	2	36	8	0	1	1	18
Land Treatment	1	8	11	1	2	0	2	0	1	1	0	0	0	7
Stabilization	2	1	0	0	0	1	0	1	1	0	0	0	1	2
Treatment Other	1	1	1	0	0	0	0	0	0	0	0	0	0	1
Treatment Subtotal	29	12	25	12	3	10	4	3	47	12	1	3	5	31
Impoundment	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Landfill	5	20	45	1	28	15	30	5	3	0	0	0	2	27
DeepWell Injection	1	0	0	0	0	0	0	0	0	0	0	0	3	0
Disposal Other	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Disposal Subtotal	7	20	45	1	28	15	30	5	4	0	0	0	5	27
1997 Stream Totals*	40	34	56	20	45	48	41	8	53	23	23	6	41	44

* The subtotals exceed the stream totals because some facilities report more than one management technique for a stream.

Appendix D
PARTICIPATION SUMMARY

1997 Survey Participants*

AGE Refining
American Refining Group
ARCO
BP
CITGO
Cenex
Chevron
Clark Refining & Marketing
Coastal Corp.
Conoco
Crown Central Petroleum
Equilon
Ergon
Exxon
Farmland Industries
FINA
Giant Refining
Hunt Refining
Huntway Refining
La Gloria Oil and Gas
Lea Refining
Lyondell-Citgo
MAPCO
Marathon Ashland
Mobil
Montana Refining
Motiva
Murphy Oil
National Coop. Refinery Assoc.
Navajo Refining
Pennzoil Quaker State
Phillips
Placid Refining
San Joaquin Refining
Sinclair
Somerset Refinery
Tosco
U.S. Oil & Refining
Ultramar Diamond Shamrock
United Refining
Valero
Wynnewood Refining
Young Refining

Companies Participating at Least Once in the 1995-1997 Period*

AGE Refining
American Refining Group
(was Kendall)
Amoco
ARCO
Ashland
BHP Petr. Americas
(now Tesoro Hawaii)
Big West Oil (Flying J)
BP
Cenex
Chevron
CITGO
Clark Refining & Marketing
Coastal Corp.
Conoco
Countrymark Cooperative
Crown Central Petroleum
Ergon
Exxon
Farmland Industries
FINA
Giant Refining
Golden Bear Oil Specialties
(was Witco)
Hunt Refining
Huntway Refining
La Gloria Oil and Gas
Lea Refining
Lion Oil
Lyondell-Citgo
MAPCO
(now Williams Refining)
Marathon
Mobil
Montana Refining
Murphy Oil
National Cooperative Refining Assoc.
Navajo Refining
Neste Trifinery
Paramount Petroleum
Pennzoil
Phillips
Placid Refining
Pride Refining
San Joaquin Refining
Shell
(certain facilities now Equilon or Motiva)
Sinclair
Somerset Refinery
Sound Refining
Star (now Motiva)
Sun
Tesoro
Texaco (now Equilon)
Tosco
Total
(now Ultramar Diamond Shamrock)
Ultramar Diamond Shamrock
U.S. Oil & Refining
United Refining
Valero
Wynnewood Refining
(Gary Williams Energy)
Young Refining

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*Listing indicates participation in the survey by one or more of a company's facilities.

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