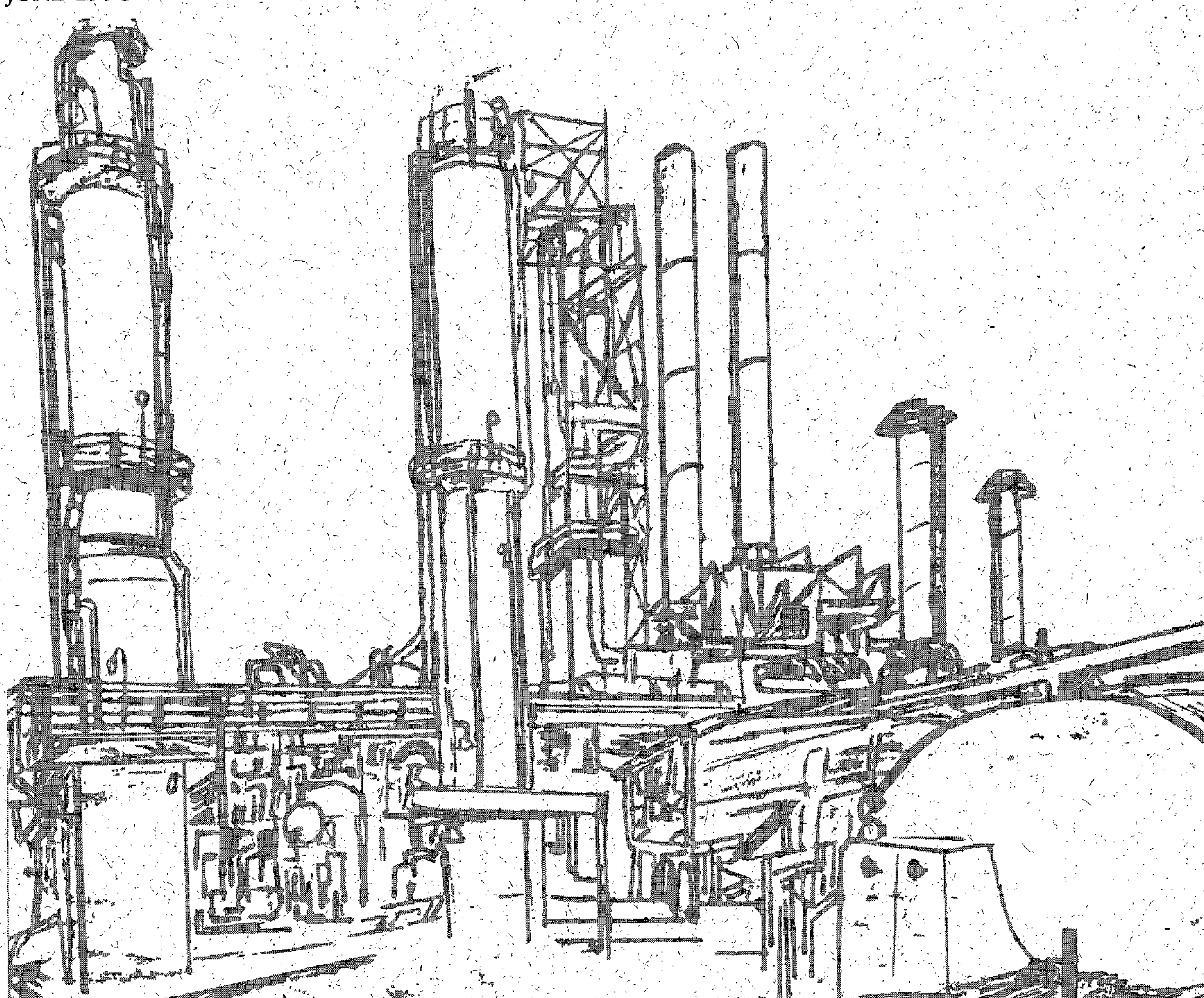
American Petroleum Institute

STEP Strategies for Today's Environmental Partnership

MANAGEMENT OF RESIDUAL MATERIALS: 1996

PETROLEUM REFINING PERFORMANCE

HEALTH AND ENVIRONMENTAL AFFAIRS DEPARTMENT
PUBLICATION NUMBER 345
JUNE 1998



American Petroleum Institute

American Petroleum Institute Environmental, Health, and Safety Mission and Guiding Principles

MISSION

The members of the American Petroleum Institute are dedicated to continuous efforts to improve the compatibility of our operations with the environment while economically developing energy resources and supplying high quality products and services to consumers. We recognize our responsibility to work with the public, the government, and others to develop and to use natural resources in an environmentally sound manner while protecting the health and safety of our employees and the public. To meet these responsibilities, API members pledge to manage our businesses according to the following principles using sound science to prioritize risks and to implement cost-effective management practices:

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- To recognize and to respond to community concerns about our raw materials, products and operations.
- To operate our plants and facilities, and to handle our raw materials and products in a manner that protects the environment, and the safety and health of our employees and the public.
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- To counsel customers, transporters and others in the safe use, transportation and disposal of our raw materials, products and waste materials.
- To economically develop and produce natural resources and to conserve those resources by using energy efficiently.
- To extend knowledge by conducting or supporting research on the safety, health and environmental effects of our raw materials, products, processes and waste materials.
- To commit to reduce overall emission and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Management of Residual Materials: 1996

Petroleum Refining Performance

Health and Environmental Affairs Department

API PUBLICATION NUMBER 345

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At each refinery participating in the survey, one or more individuals assumed the responsibility to complete the survey questionnaire. Their efforts deserve special recognition and thanks from the industry.

Carol Gosnell (API) is recognized for her contribution to the cover art for this publication.

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EXECUTIVE SUMMARY

The 1996 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).

1996 Refining Residual Survey–Response Level

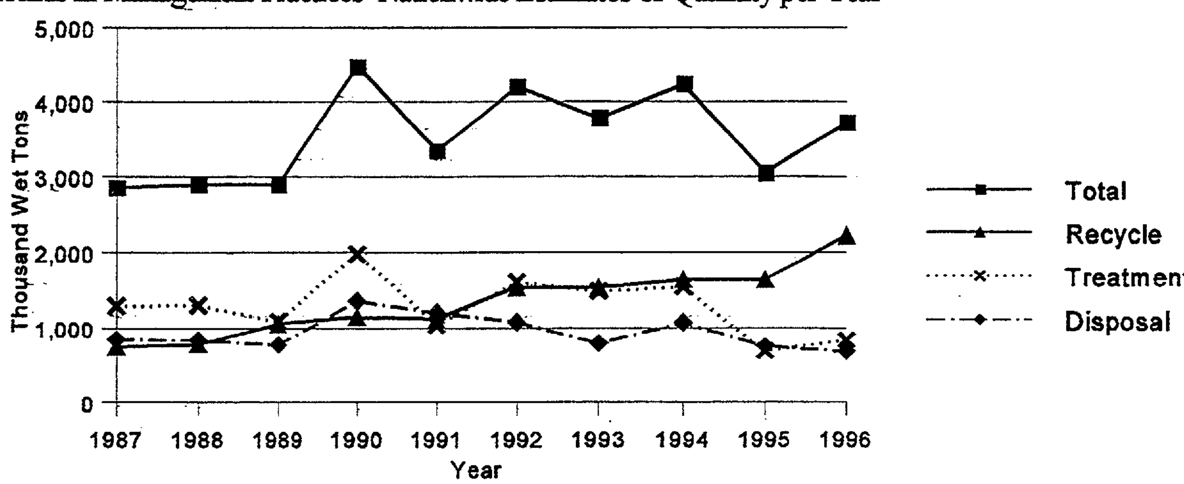
	Estimated U.S. Total	Survey Respondents	Percent
No. of Facilities	152	79	52 %
Refining Capacity	15,534,500 bsd	8,925,800 bsd	57 %
Residual Quantity	3,722,000 wet tons	1,887,000 wet tons	51 %

The 1996 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 through enhanced guidance on the survey form. 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 survey. In the following chart, the data for 1987 through 1994 have been adjusted by deleting the quantities considered to be recovered oil or water rather than true residuals.

Trends in Management Practices–Nationwide Estimates of Quantity per Year

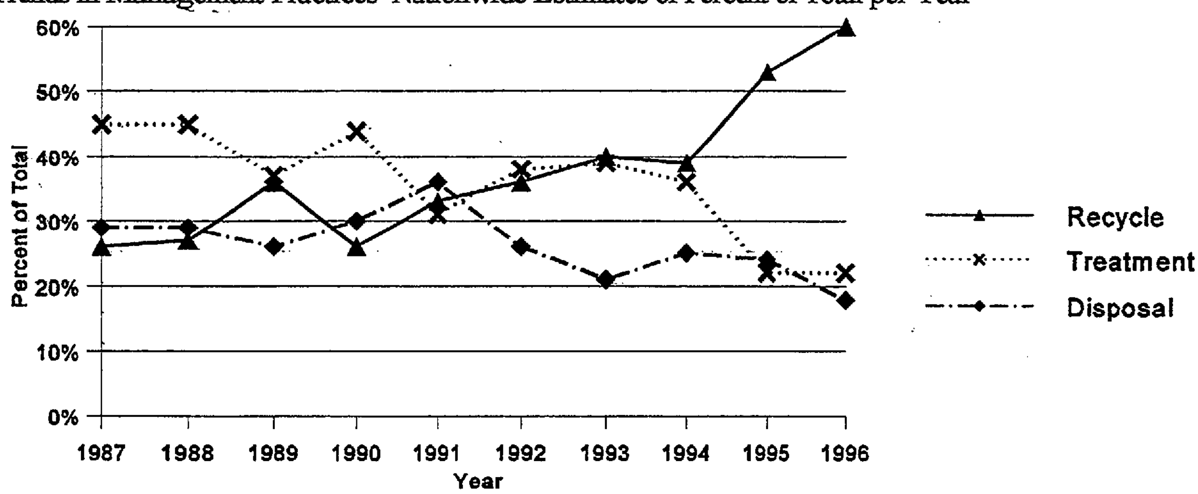


The specific adjustments made to the 1987 through 1994 data were to delete the amounts shown as managed by wastewater treatment from the streams that are reduced by dewatering, which are the *tank bottoms*, *API separator sludge*, *DAF float*, *primary sludges*, *slop oil emulsion solids*, *biomass*, 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 estimated total quantity of residuals managed at U.S. refineries increased from 3,049,000 wet tons in 1995 to 3,722,000 wet tons in 1996, an increase of 673,000 wet tons. The 1996 nationwide estimate, however, is still lower than the annual estimated quantities for 1992 through 1994. 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.

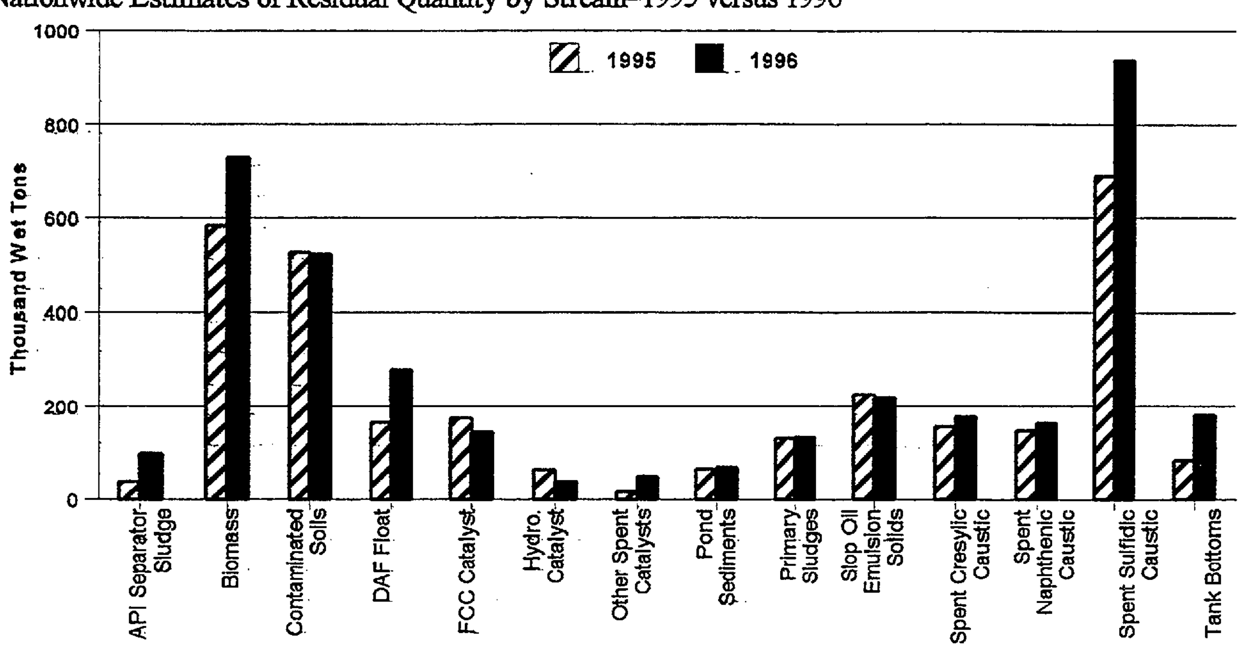
The portion of residual material reported as having been *recycled* continues the strong upward trend of recent years, with well over half of the total quantity managed now shown as *recycled*.

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



The next chart compares residual quantities by stream for 1995 and 1996.

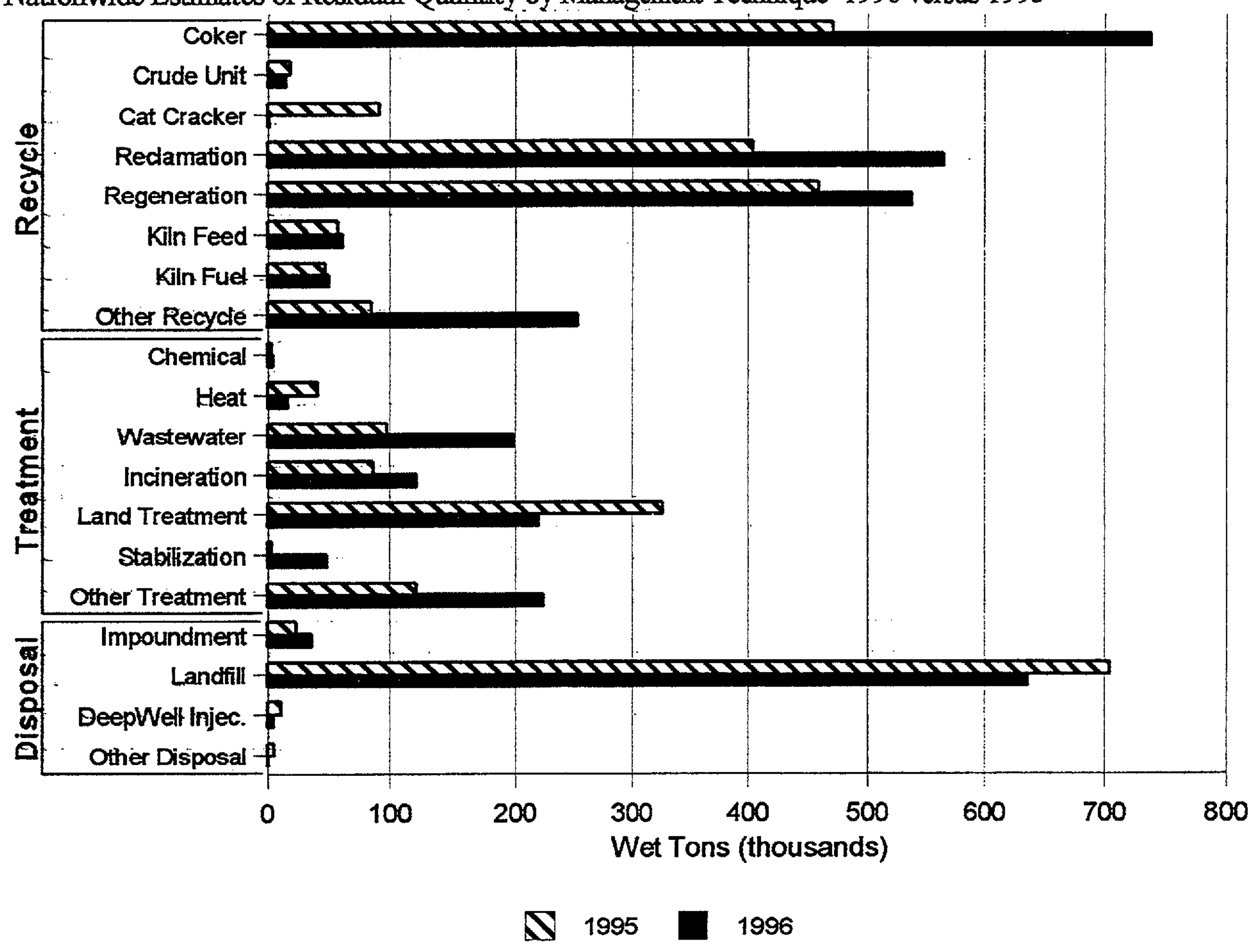
Nationwide Estimates of Residual Quantity by Stream–1995 versus 1996



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 increased from 554,000 wet tons in 1995 to 726,000 wet tons in 1996.

Another step taken in the 1995 survey to improve reporting consistency was to combine all manner of *land farming* and *land spreading* into a single *land treatment* category. This approach was continued in the 1996 survey. The 1996 survey additionally discontinued the *physical treatment* category. In the following chart, the quantity reported under *physical treatment* in 1995 has been combined with *other treatment* in order to make the data comparable to 1996.

Nationwide Estimates of Residual Quantity by Management Technique–1996 versus 1995



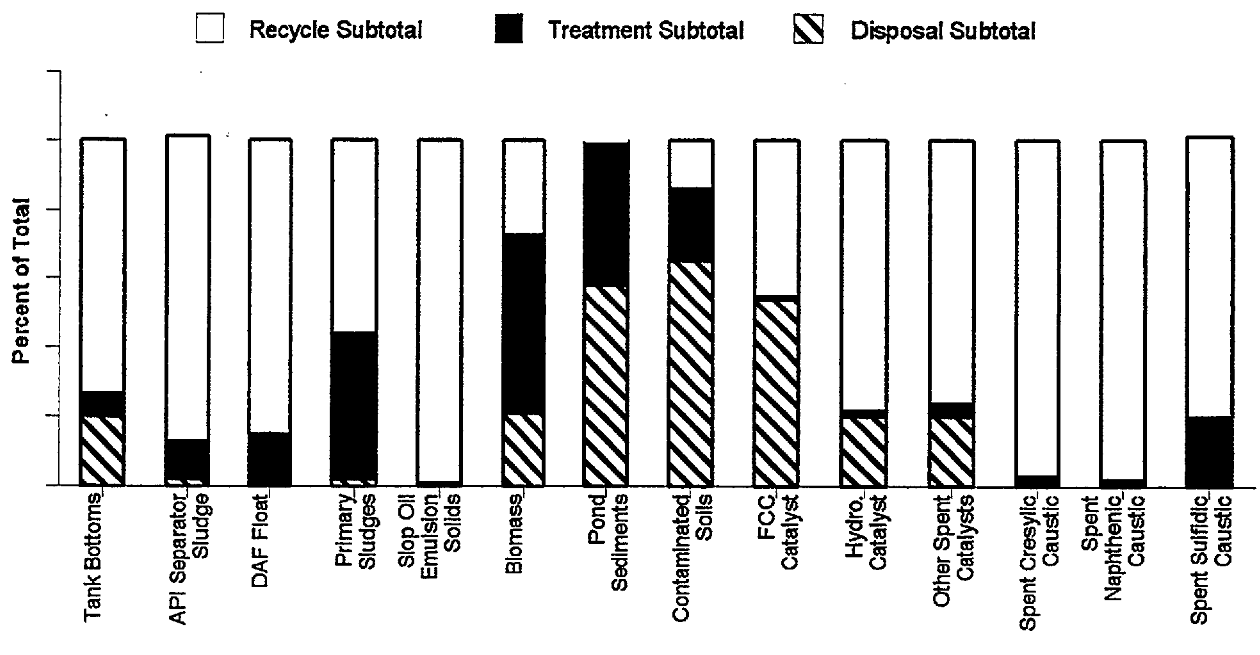
The most significant difference in the quantity per residual stream from 1995 to 1996 is the increase in the quantities of *biomass*, *DAF float*, and *spent sulfidic caustic*. These three streams, in fact, account for 75% of the total increase in estimated quantities from 1995 to 1996.

The *biomass*, *DAF float*, and *spent sulfidic caustic* streams often contain very small concentrations of the residual in a relatively large volume of water. Wide variation in the quantities reported for these streams may be due at least in part to differences in how reporting facilities account for the accompanying volume of water. In the 1996 survey, for example, three facilities reported managing *biomass* by *wastewater treatment*, and one facility reported this practice for *DAF float*. Follow up phone calls confirmed this to be the case, but the streams in questions were less than 5% solids. Other facilities use a continuous flow coker technology that requires large amounts of water. *Spent sulfidic caustic* is increasingly used for pH control in the wastewater plant, and again the quantity reported typically includes large volumes of water. Thus the increase in the *biomass*, *DAF float*, and *spent sulfidic caustic* streams shows up in the management techniques primarily under *coker*, *other recycle* (for pH control), and *wastewater treatment*.

The improved data integrity in the 1996 survey has virtually eliminated routing to the *cat cracker* as a management practice. It was found that most materials reported as being routed to the *cat cracker* were in reality routed to either the *coker* or the *crude unit*, with the exception of *FCC catalyst*. When *FCC catalyst* is routed to a *cat cracker*, however, it is for continued use as a catalyst. If it has been processed in some manner in order to restore its suitability for service, it should be reported as *regenerated*. If, on the other hand, it is cascaded for continued use as a catalyst without any processing to improve its performance, then it is still being used for its intended function, and would not yet be a residual. Thus it appears that U.S. refineries do not process residuals by routing them to the *cat cracker*.

The next chart displays the nationwide distribution by management practice for each stream, as estimated from the 1996 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.

Nationwide Estimates of Distribution by Management Practice–1996



The most evident trend of the last two years in the management of residual material by U.S. refineries is the movement toward *recycling* as the dominant management practice.

Section 1
METHODOLOGY

LISTING OF REFINERIES

The term 'petroleum refinery' is used differently in various contexts. For purposes of the 1996 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 1996 survey was distributed in electronic format (i.e., computer software on diskettes), in a similar manner to the 1995 survey. 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, 1997* published by the Oil & Gas Journal. Excluding those refineries that were found to either not actually process crude or to have been shut down resulted in a final count of 152 refineries. Of these, 79 responded to the survey.

RATIONALE FOR SURVEY CLARIFICATIONS

As was explained in last year's report, 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.

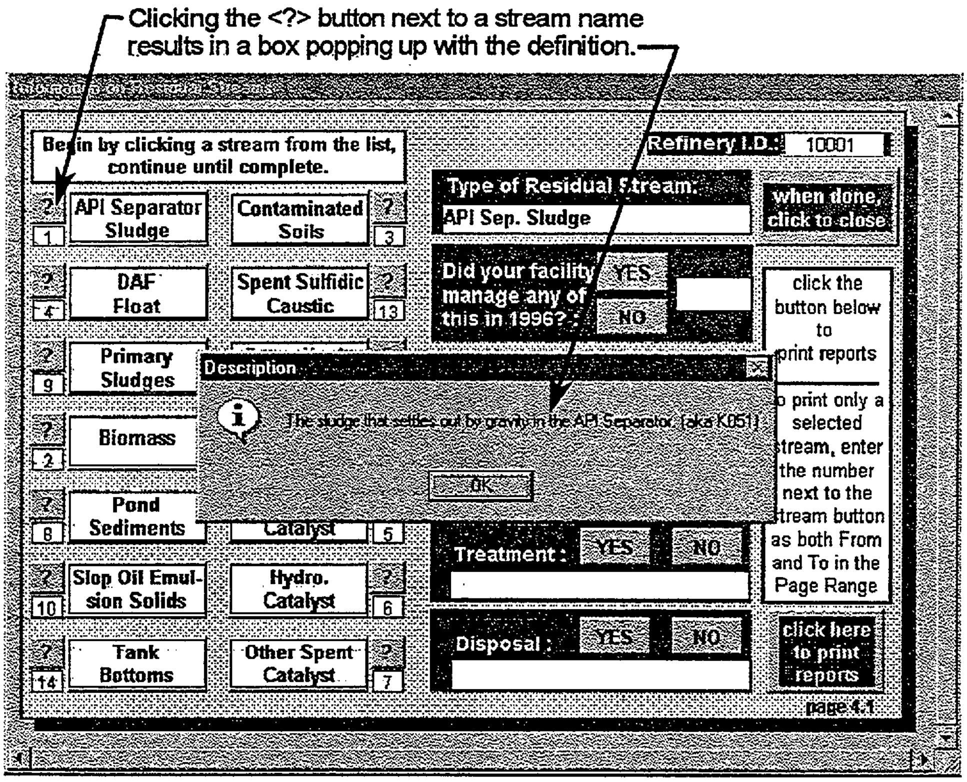
RESIDUAL STREAMS

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 survey 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 1996 survey continued to group management techniques into three categories of management practice–recycling, treatment, and disposal. The management techniques from the 1995 and 1996 surveys, with the definitions assigned to them for the 1996 survey, are listed in Appendix A. Note that the *physical treatment* 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 treatment*, to accommodate comparison with the 1996 data. *Each of these management techniques is allowed under certain regulatory scenarios*.

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 1996 survey is

$$\sqrt{R} = 28.0 + 8.88 \times 10^{-4} C$$

with an R^2 measure of correlation equal to 0.70 and a percent error of 7.7%. The statistical analysis is described in more detail in Appendix B.

Section 2
RESULTS

RESPONSE RATE

The 1996 survey response rate is illustrated by several parameters in the following charts.

Figure 2—Response Rate by Refinery Capacity.

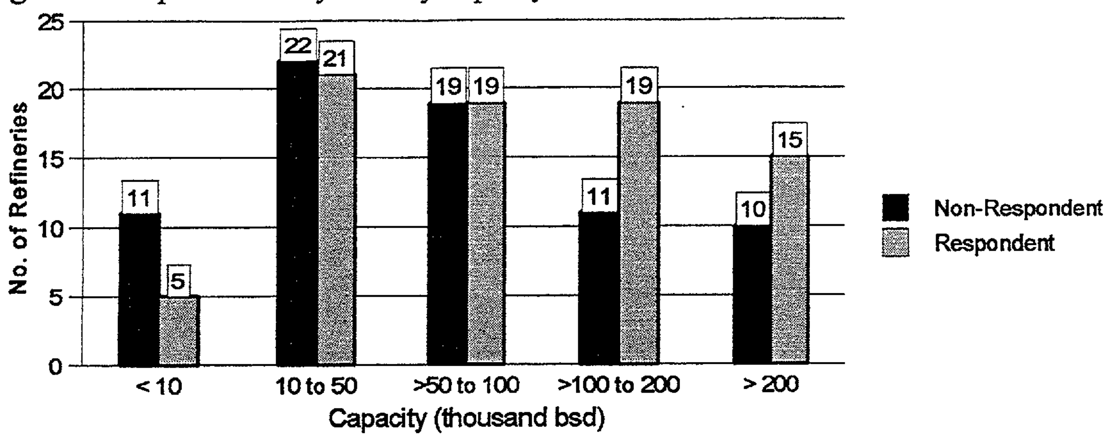


Figure 3—U.S. Department of Energy's Petroleum Administration for Defense (PAD) regions.

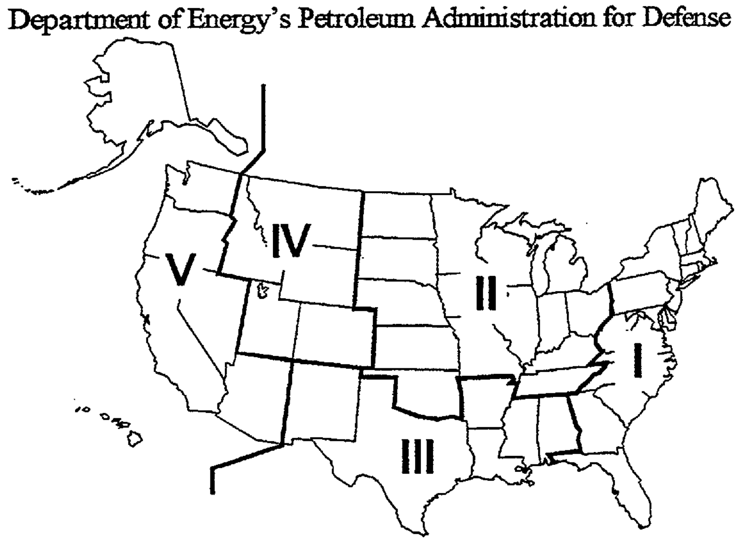


Figure 4—Response Rate by PAD Region.

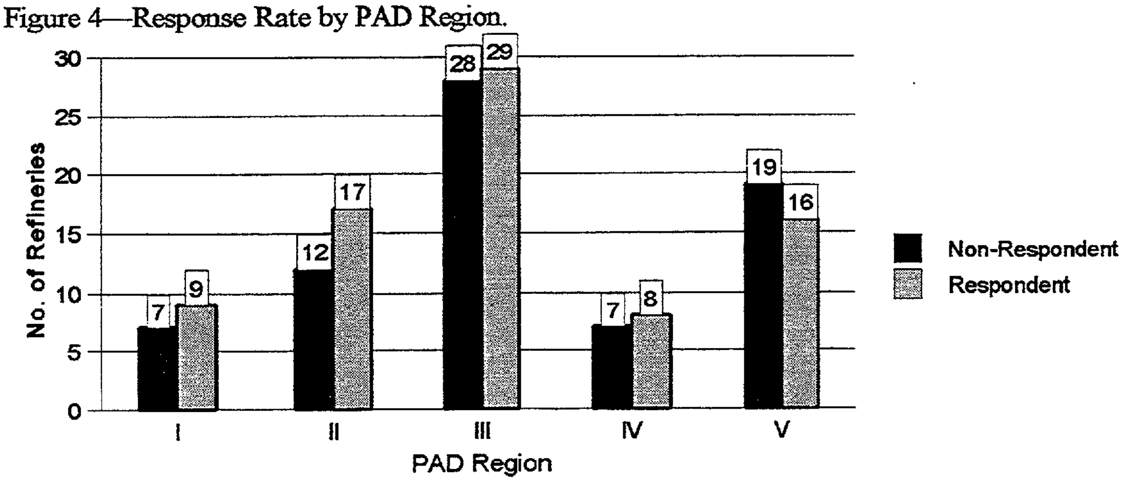


Figure 5—Response Distribution by Complexity of Facility.

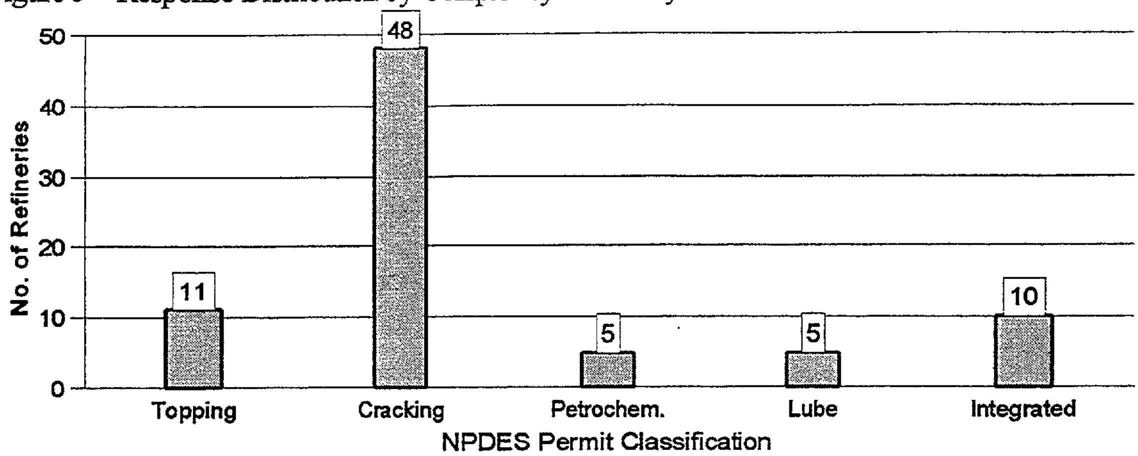


Figure 6—Response Distribution by Age of Facility.

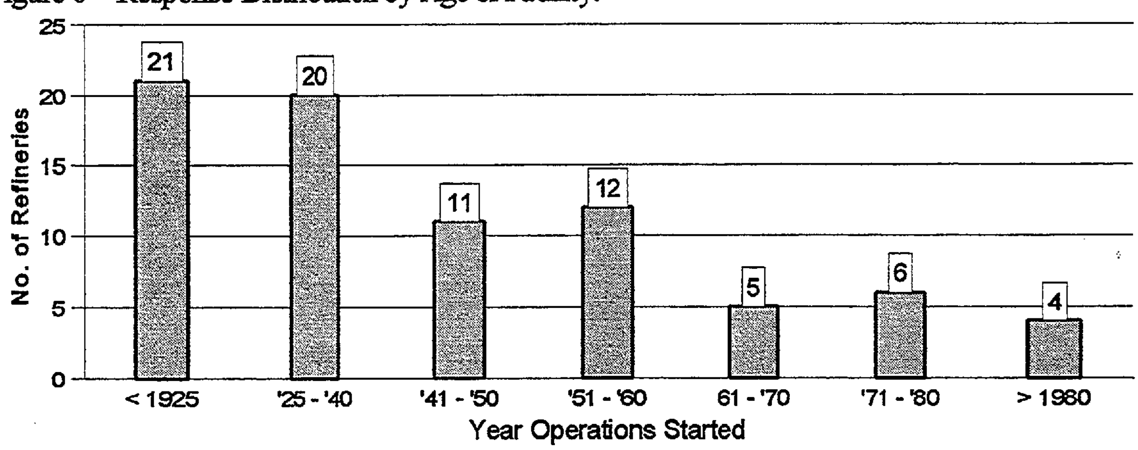
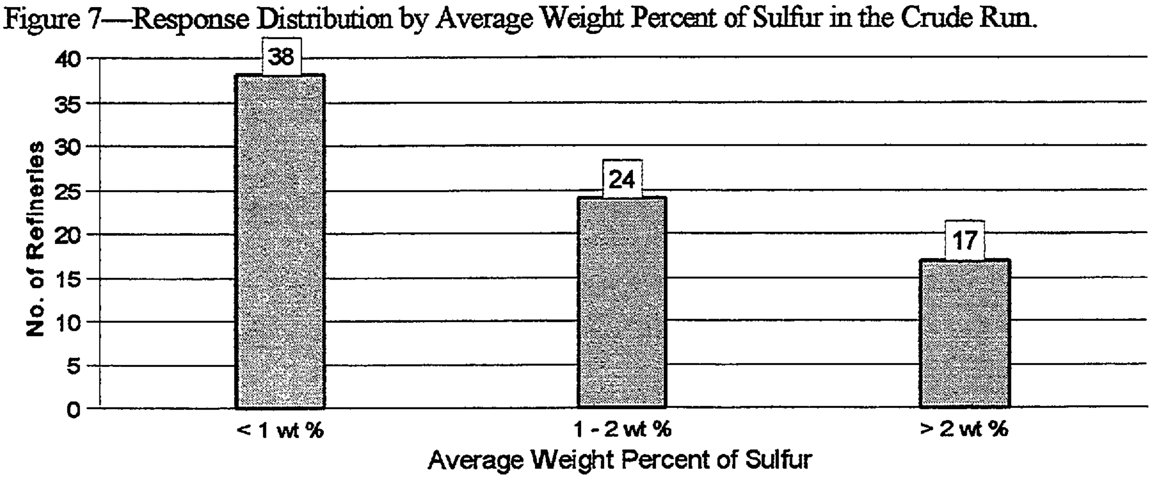


Figure 7—Response Distribution by Average Weight Percent of Sulfur in the Crude Run.



The number of responses from each NPDES Permit Classification for each residual stream are summarized in Table 1, and are 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:	11	48	5	5	10
Distribution by Residual Stream:					
API Separator Sludge	3	35	4	2	4
Biomass	3	29	4	3	8
Contaminated Soils	8	43	5	5	10
DAF Float	0	22	1	2	6
FCC Catalyst	0	30	5	3	9
Hydro. Catalyst	4	35	4	3	9
Other Spent Catalysts	2	31	3	3	7
Pond Sediments	0	3	1	2	2
Primary Sludges	8	42	5	4	10
Slop Oil Emulsion Solids	1	17	3	2	5
Spent Cresylic Caustic	0	19	2	3	7
Spent Naphthenic Caustic	1	2	1	0	3
Spent Sulfidic Caustic	3	31	4	3	9
Tank Bottoms	5	40	4	4	9

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	27%	73%	80%	40%	40%
Biomass	27%	60%	80%	60%	80%
Contaminated Soils	73%	90%	100%	100%	100%
DAF Float	0%	46%	20%	40%	60%
FCC Catalyst	0%	63%	100%	60%	90%
Hydro. Catalyst	36%	73%	80%	60%	90%
Other Spent Catalysts	18%	65%	60%	60%	70%
Pond Sediments	0%	6%	20%	40%	20%
Primary Sludges	73%	88%	100%	80%	100%
Slop Oil Emulsion Solids	9%	35%	60%	40%	50%
Spent Cresylic Caustic	0%	40%	40%	60%	70%
Spent Naphthenic Caustic	9%	4%	20%	0%	30%
Spent Sulfidic Caustic	27%	65%	80%	60%	90%
Tank Bottoms	45%	83%	80%	80%	90%

WASTEWATER MANAGEMENT

Every responding facility indicated that its wastewater is treated prior to discharge. All of the 79 responding facilities reported having primary oil-water separation equipment, with 57 indicating that they use an API Separator. The remaining 22 facilities listed various types of equipment for primary separation, with the most frequent mention being a corrugated plate interceptor. A new question in the 1996 survey asks whether the facility discharges to a publicly-owned treatment works (POTW), a joint treatment facility (i.e., a privately-owned wastewater treatment 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 eight facilities reported discharging after secondary separation, of which six discharge to a POTW and one to a joint treatment facility. Of the remaining 67 facilities, 64 have some form of biotreatment and the three without biotreatment have some form of advanced treatment. Thus 77 of the 79 facilities (97%) report having biotreatment and/or advanced treatment, or discharging to another facility for further treatment.

The most common equipment configuration (reported by 62% of respondents) includes primary separation, gas flotation, and biotreatment. The following list summarizes the responses.

Primary separation . . .	100% (typically an API Separator)
Secondary separation .	80% (typically some type of gas flotation)
Secondary biological treatment .	81% (typically includes activated sludge)
Advanced treatment . .	43% of all reporting facilities (filtration is most common), and 52% 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 asks whether the effluent parameters were measured at the discharge from the wastewater treatment plant, or for the combined discharge of wastewater and untreated stormwater.

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. Twenty one facilities reported having 100% segregated sewers, and another eighteen facilities reported having some segregated sewers and some combined sewers. The remaining half of the respondents indicated having 100% combined sewers. These responses are summarized below.

100% Segregated Sewers	21 facilities
Some Segregated/Some Combined .	18 facilities
100% Combined	40 facilities

In that some facilities have both segregated sewers and combined sewers, the total number of responses in Figure 9 exceeds 79.

Figure 8--Wastewater Treatment System Summary. (total number of responses = 79)

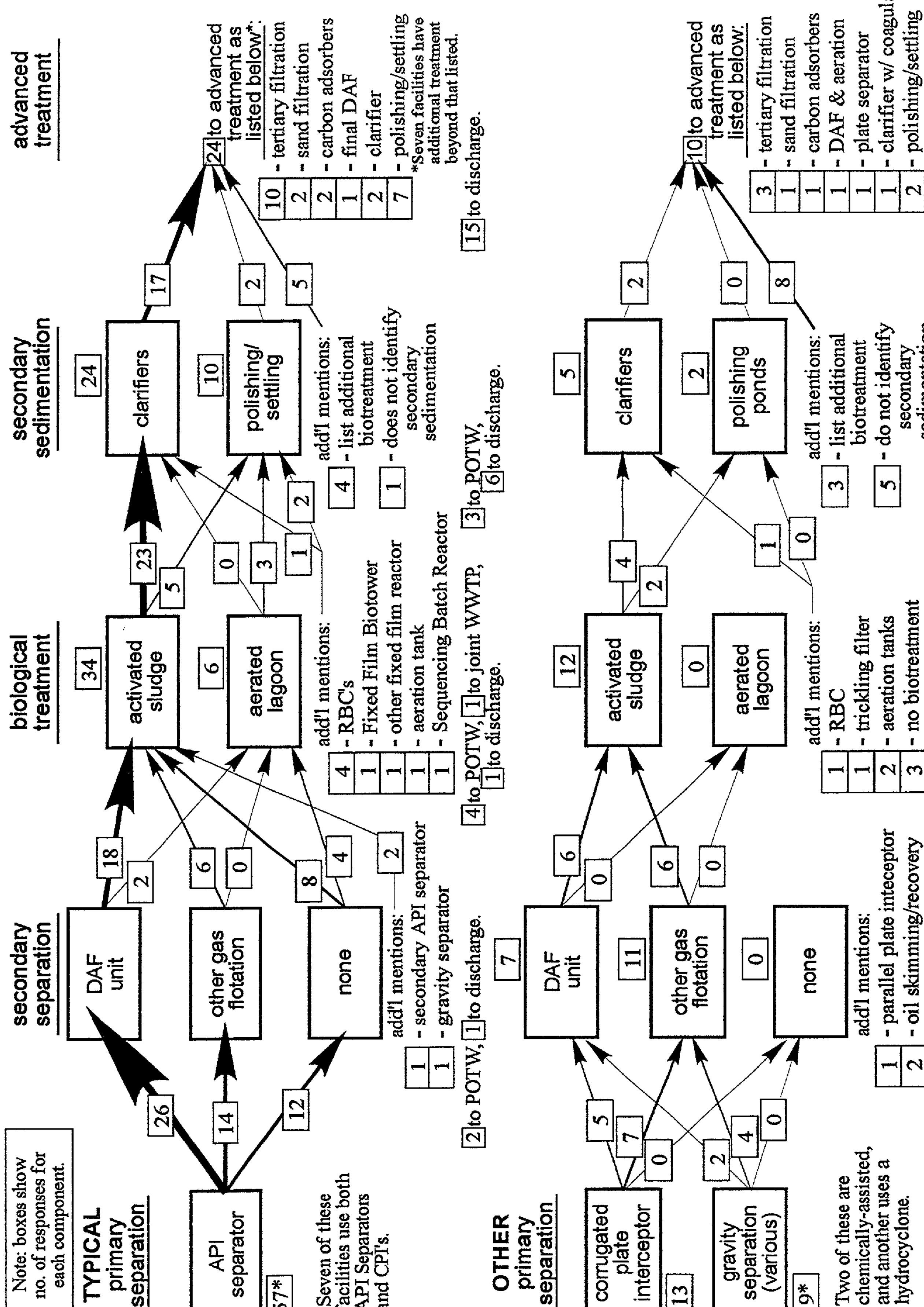
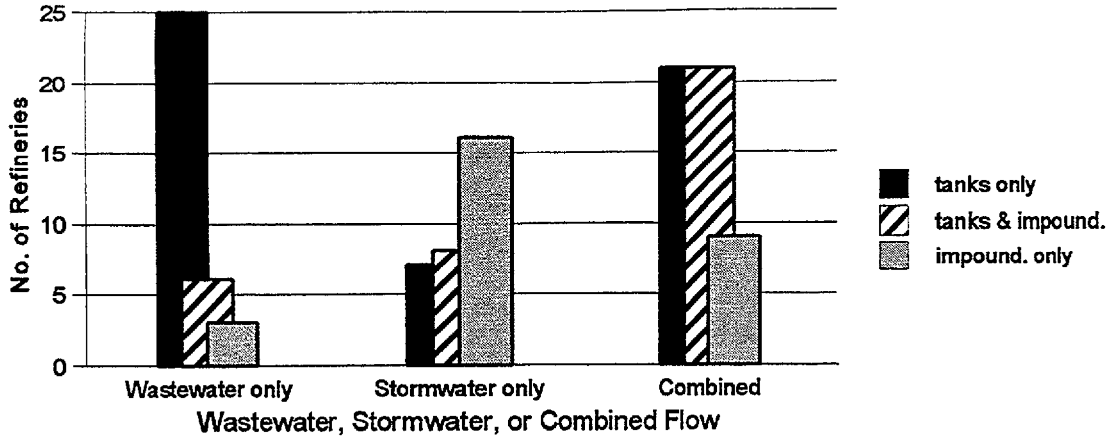


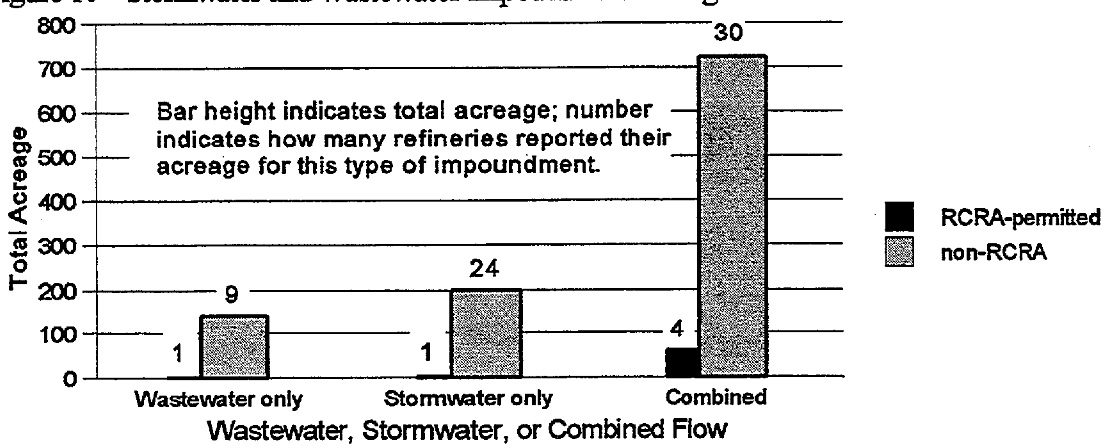
Figure 9—Stormwater and Wastewater Holding Structures.



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.

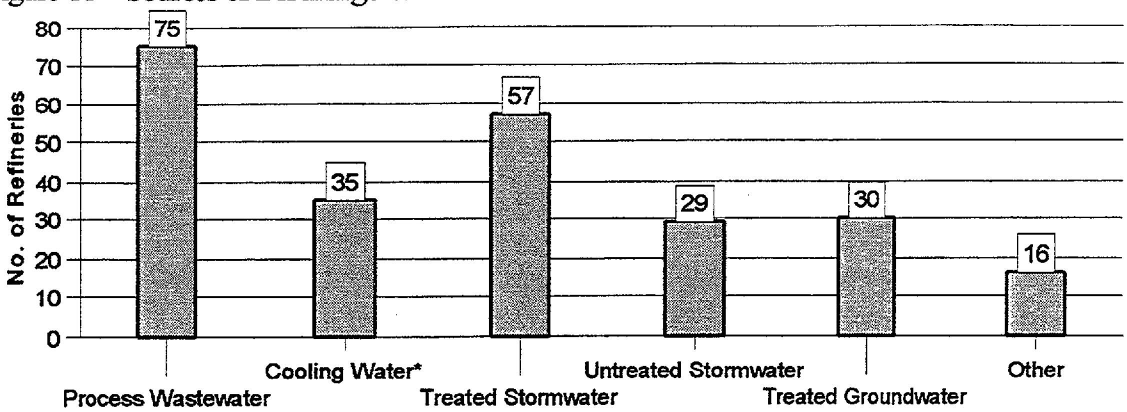
	average of all responses	average without largest & smallest
RCRA-permitted:	10.4 acres	4.3 acres
not RCRA regulated:	16.8 acres	11.6 acres

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 2.7 million gallons per day (MGD), and the median rate was 1.0 MGD. One facility indicated that it practices 100% evaporation, and thus is a zero discharge facility. All but three of the remaining respondents gave a breakdown of the sources of their discharge water, with each 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 1996 (MGD)	Median Flow 1995 (MGD)
Process Wastewater	75	13 – 100 %	73%	1.0	1.0
Noncontact Cooling Water*	35	1 – 70 %	21%	0.1	0.1
Treated Stormwater	57	0.5 – 60 %	7.5%	0.1	0.2
Untreated Stormwater	29	0.1 – 44 %	6.5%	0.08	0.1
Treated Groundwater	30	0.001 – 80 %	1.0%	0.04	0.05
Other	16	0.1 – 100 %	11%	0.1	0.03

* 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-1996	Median-1995
Total Suspended Solids (TSS)	76	73,000 lbs	66,000 lbs
Biochemical Oxygen Demand (BOD)	71	49,000 lbs	40,000 lbs
Chemical Oxygen Demand (COD)	69	380,000 lbs	310,000 lbs
Ammonia	73	9,700 lbs	9,400 lbs
Oil & Grease (O&G)	77	13,000 lbs	17,000 lbs
Chromium	50	26 lbs	29 lbs
Nickel	18	100 lbs	120 lbs
Selenium	25	120 lbs	42 lbs

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

	Median-1996	Median-1995
Total Suspended Solids (TSS)	140 lbs/MG	130 lbs/MG
Biochemical Oxygen Demand (BOD)	87 lbs/MG	77 lbs/MG
Chemical Oxygen Demand (COD)	750 lbs/MG	680 lbs/MG
Ammonia	26 lbs/MG	31 lbs/MG
Oil & Grease (O&G)	27 lbs/MG	26 lbs/MG
Chromium	0.04 lbs/MG	0.08 lbs/MG
Nickel	0.13 lbs/MG	0.20 lbs/MG
Selenium	0.12 lbs/MG	0.15 lbs/MG

In addition to the effluent parameters, the 1996 survey solicited measurements of certain wastewater parameters at intermediate points in the system. The survey requested the level of oil and grease levels 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 half 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.

Table 6—Water Quality Parameters at Intermediate Points (pounds per year).

	No. of Respondents reporting this parameter	Total Level* (pounds/year)	Average Level* (pounds/year)
Oil and Grease (O&G)			
After primary separation	37	45,200,000	1,290,000
After secondary separation	37	11,200,000	319,000
At effluent	37	1,990,000	57,000
Biochemical Oxygen Demand (BOD)			
Before biotreatment	40	57,900,000	1,480,000
After biotreatment	40	4,380,000	112,000
At effluent	40	4,120,000	106,000
Chemical Oxygen Demand (COD)			
Before biotreatment	43	168,000,000	3,990,000
After biotreatment	43	28,100,000	670,000
At effluent	43	26,100,000	622,000

*Two outliers were deleted from the O&G summary, and one each from the BOD and COD summaries.

POLLUTION PREVENTION

The simplified pollution prevention question introduced in the 1995 survey was retained in the 1996 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 1996. Most respondents listed only those projects brought on line in 1996, 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 1996 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. Regularly cleaned stormwater holding basins, catch basins, and drainage systems upstream of the oily sewer. Installed concrete curbing around process units to reduce solids entering the sewer.
Reduction of water to the oily water sewer.	Completed containment projects to better segregate stormwater from units. Installed closed loop pump cooling to minimize wastewater volume. Replaced seal fluid at dewaxing unit from water to neutral oil. Improved drainage and drain system to reduce the flow of water entering the plant from offsite.
Dewatering of oily sludges.	Installed new dewatering equipment. Replaced or improved existing dewatering equipment. Expanded the use of dewatering equipment.

Table 7—Pollution Prevention Activities (continued).

General Practice	Survey Response
Reduction/Containment of spills and leaks.	Improved housekeeping. Improved or expanded leak inspection programs. Installed an HDPE barrier wall twenty feet into the ground to intercept leaks, which are then collected and recovered. Installed covers on API Separators. Installed double bottoms in storage tanks. Upgraded rim seals on storage tank floating roofs. Replaced underground piping with either double-walled piping or aboveground piping. Replaced leaking lines or gaskets. Installed double seals on pumps.
Source reduction/process modification.	Initiated more stringent specifications for solids in the crude and used oil brought into the plant. Installed clarifier to remove solids from river water used for cooling. Process modifications to reduce benzene concentration in the wastewater. Improved sulfur processing, including installation of a NaHS unit. Improved oil/water separations in the process units. Reduced acids, caustics, and solids entering the sewer from process units. Converted loading racks from top loading to bottom loading. Modified combustion units to lower NOx emissions. Changed barometric pressure in crude to decrease wastewater flow. Eliminated the use of liquid chlorine as a biocide in cooling towers, by substituting a Br/Cl compound. Installed a centrifuge to remove oil from desalter effluent before it enters the sewer. Commissioned a Sats Gas plant to more efficiently process refinery gases. Installed piping and equipment to allow neutralization of Acid Soluble Oil with potassium hydroxide. Changed from high-concentration caustics to merox for gasoline treating. Installed a new sour water stripper and Claus plant, thereby eliminating a large SO_2 and odor source.
Waste segregation.	Kept nonlisted residuals from combining with listed wastes.

Table 7—Pollution Prevention Activities (continued).

General Practice	Survey Response
Recycling.	Found markets for materials formerly treated or disposed of. Installed a compressor to recover vacuum tail gas. Routed oily sludges to the coker. Designed & constructed a patented spent caustic stripper. Sent oily sludges to fuels blender. Blended contaminated soils into refinery roadbase. Installed vapor recovery for railcar loading of propylene. Recycled ethylene glycol. Mulched used lumber. Recycled employees' used motor oil. Segregated scrap metal and shipped to metals dealer. Used caustic stream for pH adjustment in the wastewater plant. Recycled spent catalysts, dessicants, and caustics. Recycled high mercury content wastes. Regenerated Stretford Solution and Sulfinol Solution by desalting. Recycled spent pleated paper filters for fuels blending. Blended bioremediated biomass and contaminated soils into topsoil. Recovered oil from a thermal desorption unit. Routed an oil-water separator drain to a crude tank for reprocessing. Recycled ceramic packing supports.
Education and training.	Raised awareness of the benefits of pollution prevention. Raised awareness of the facility's pollution prevention practices. Raised awareness of regulatory requirements. Initiated a Permanent Pollution Prevention Program.
Improved treatment.	Installed new and upgraded existing wastewater treatment facilities. Began to use bioremediation. Relocated a wastewater outfall to a larger-flowing stream.

Section 3
RESIDUAL STREAM PROFILES

The U.S. refining industry managed an estimated 3.72 million wet tons of material from the 14 residual streams included in the 1996 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.

Figure 12—Nationwide Estimate of Residual Quantity per Year: 1987-1996.

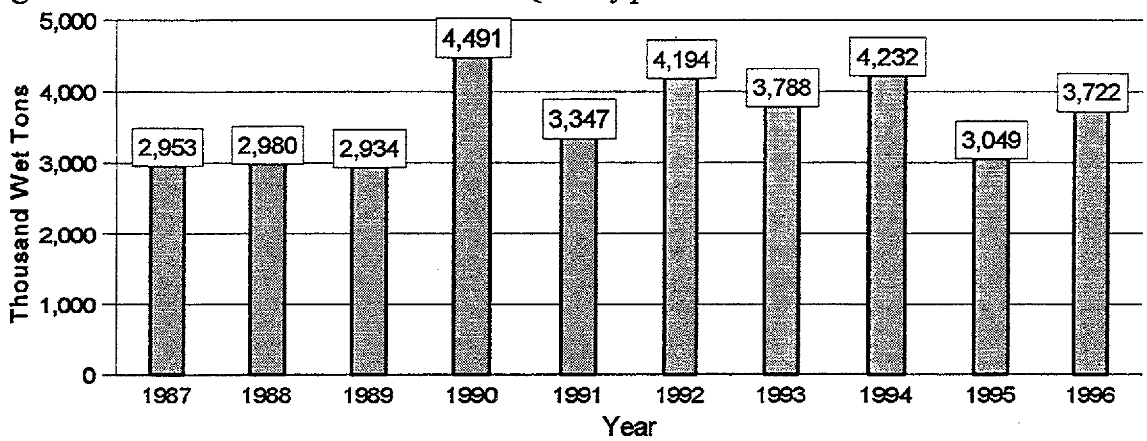
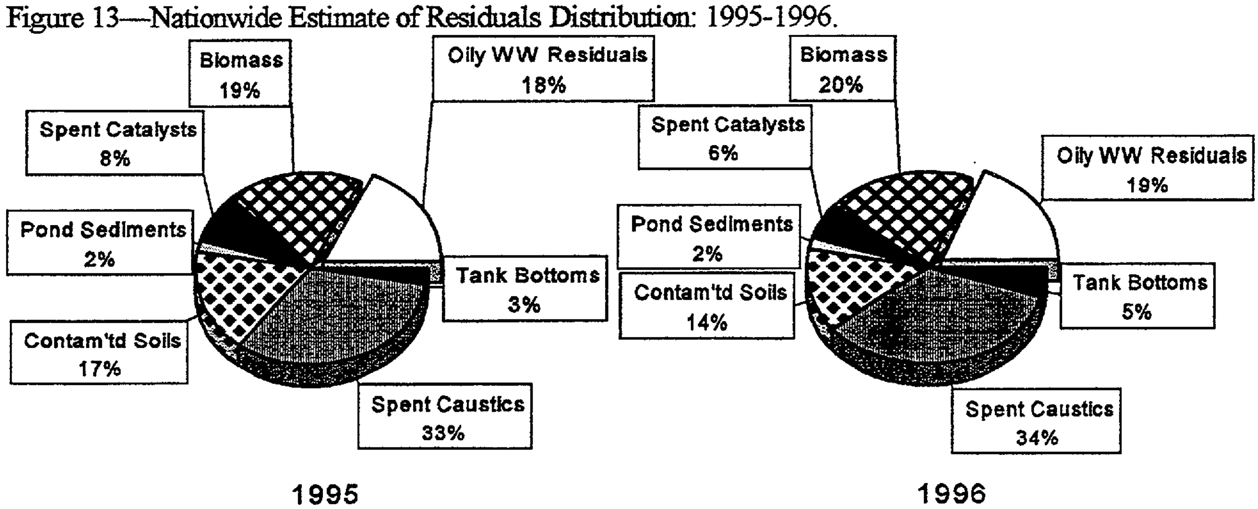


Figure 13 shows the relative contribution of the residual streams, with certain streams grouped together. The FCC catalyst, hydro. catalyst, and other spent catalyst streams are combined into a *spent catalysts* category; and a *spent caustics* category includes spent cresylic caustic, spent naphthenic 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 1996 is estimated to be within three percentage points of its contribution to the 1995 data.

Figure 13—Nationwide Estimate of Residuals Distribution: 1995-1996.

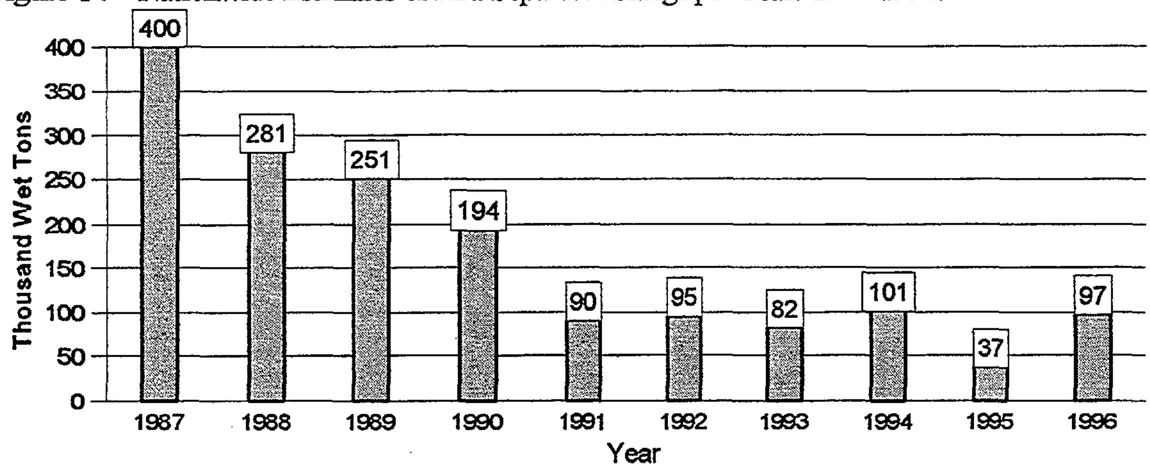


The remainder of this section presents detailed information for the individual streams, with the streams arranged in alphabetical order. The data for this section are summarized in the tables of Appendix C.

API SEPARATOR SLUDGE[1]

The U.S. petroleum refining industry managed an estimated 97 thousand wet tons of API Separator Sludge in 1996, which was a 162% increase from 1995. 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.

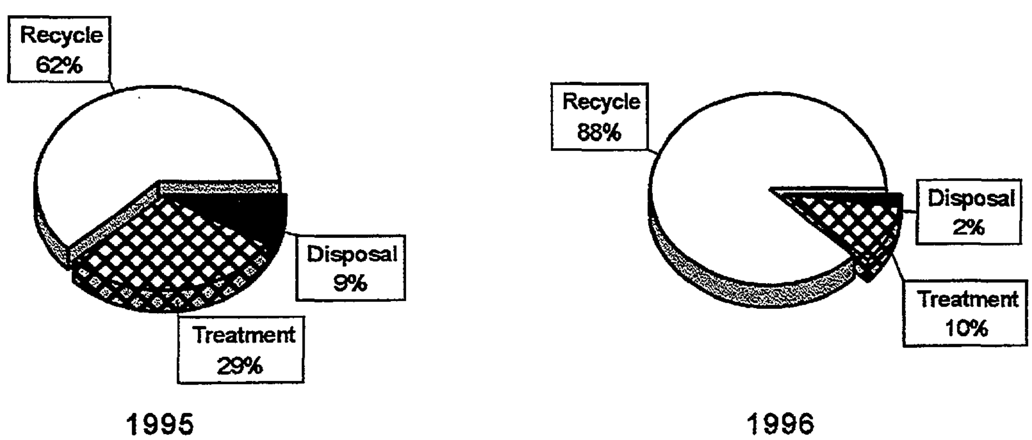
Figure 14—Nationwide Estimates of API Separator Sludge per Year: 1987-1996.



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 an increase from 554 thousand wet tons in 1995 to 723 thousand wet tons in 1996, an increase of 30%.

The portion of the API Separator Sludge stream that is managed by each management practice is shown in Figure 15 for 1995 and 1996. Recycling has become the dominant management practice, and disposal is disappearing as a management practice for this stream.

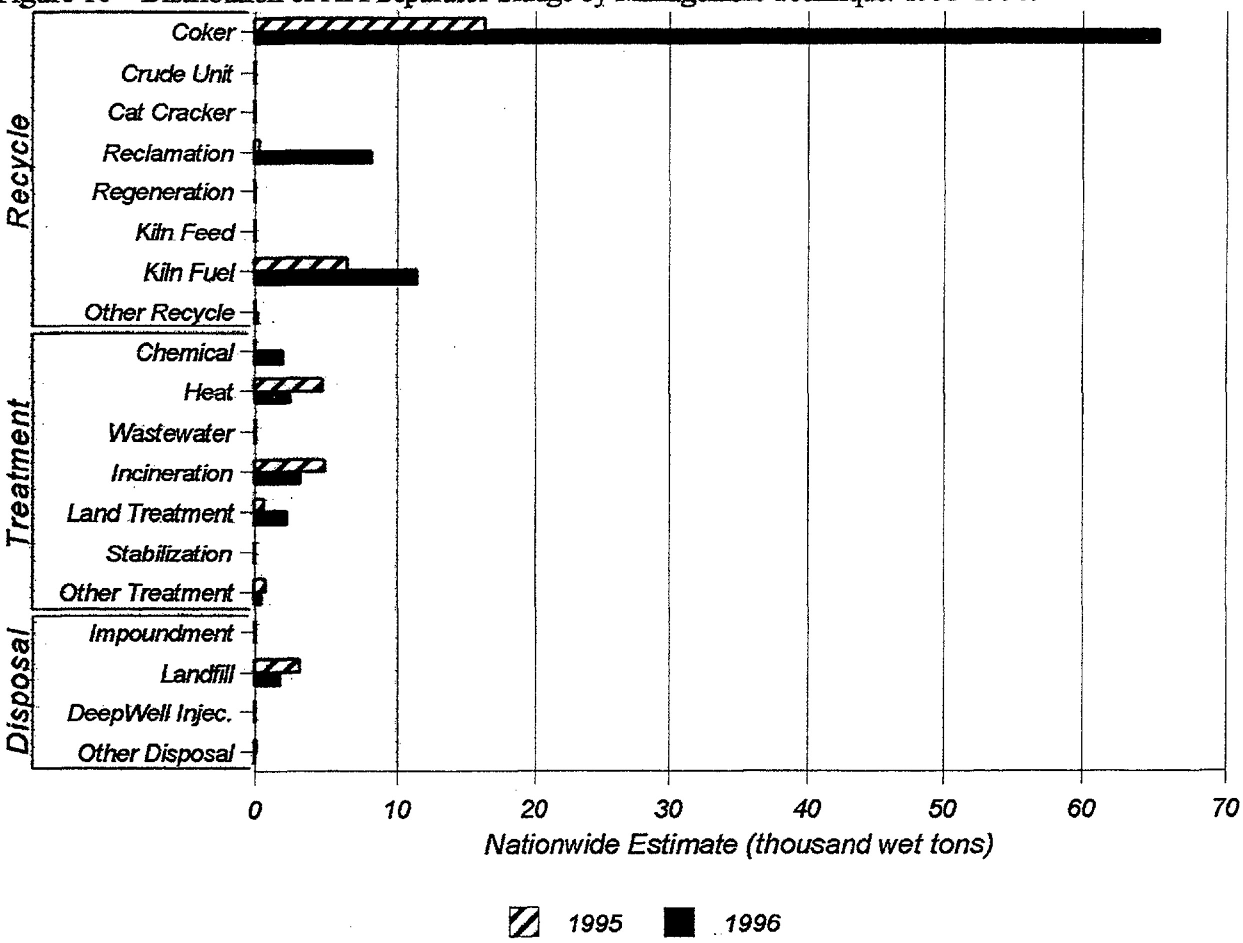
Figure 15—Nationwide Estimates of API Separator Sludge by Management Practice: 1995-1996.



[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 1995 and 1996. This stream is primarily managed by techniques that recycle the oil content. This is most commonly accomplished by routing the stream to a *coker*. Another frequently employed technique is to send this stream to a fuels blending unit for incorporation into *kiln fuel*. When oil is recovered from this stream by thermal desorption, it is reported as *reclamation*.

Figure 16—Distribution of API Separator Sludge by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: one facility reports recycling for aggregate manufacturing.

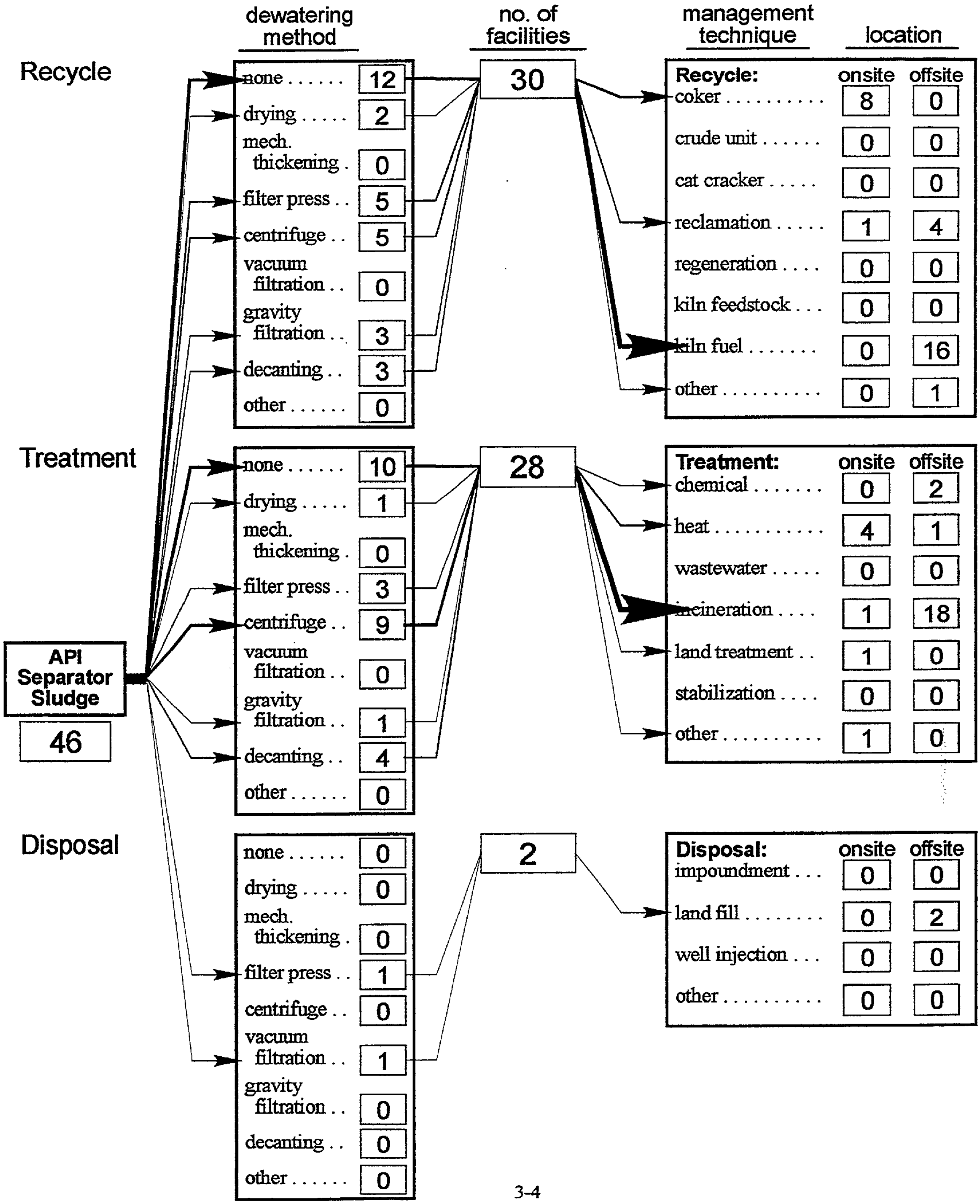
Other Treatment: one facility sends this stream to Permitted Storage.

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: 1996

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



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

Figure 18—Onsite Management Cost for API Separator Sludge: 1996

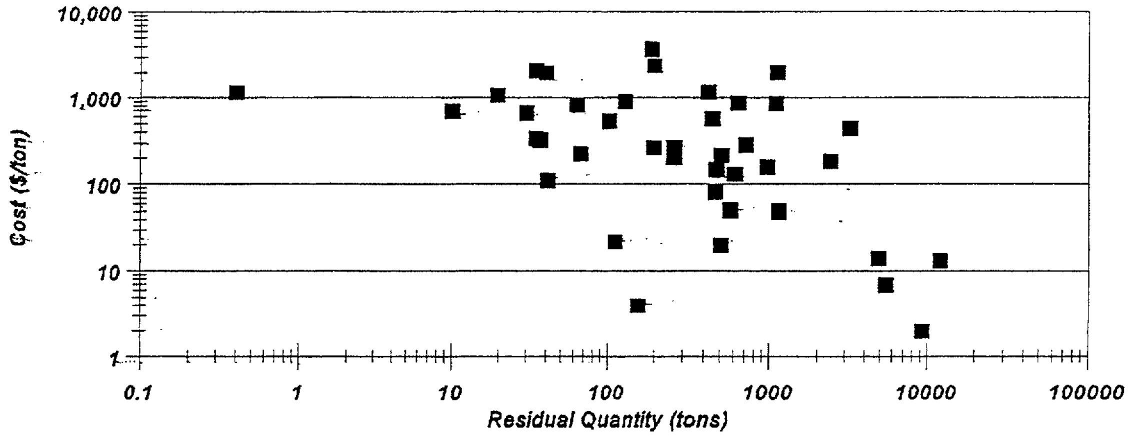


Figure 19—Offsite Management Cost for API Separator Sludge: 1996

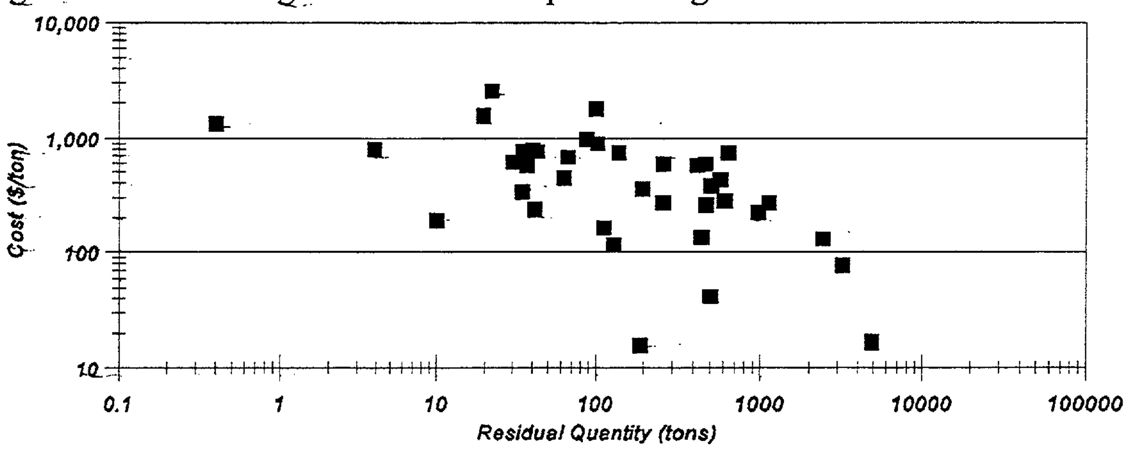
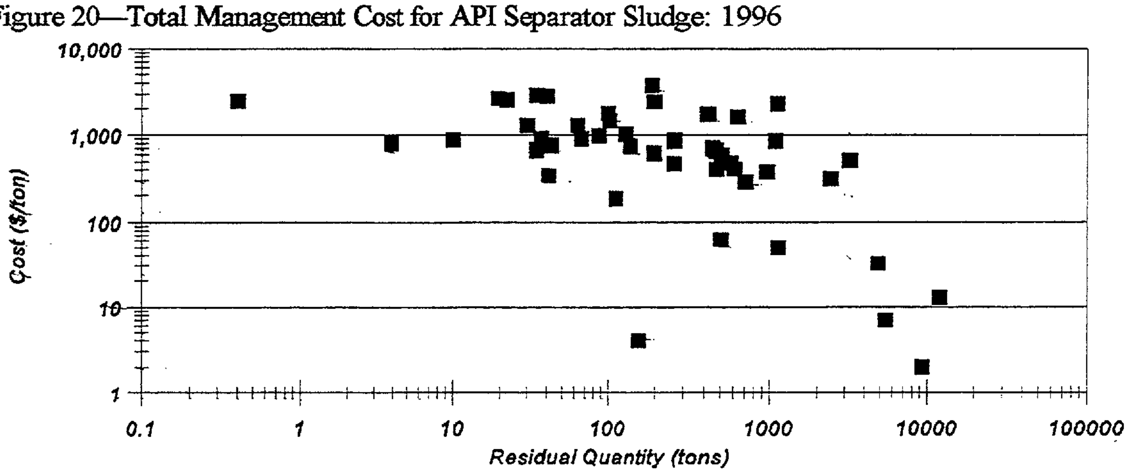


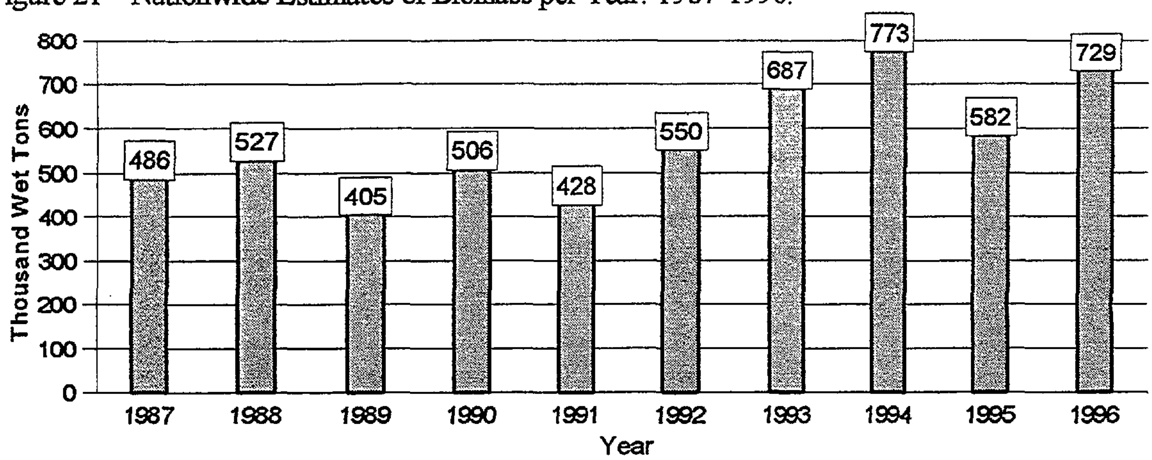
Figure 20—Total Management Cost for API Separator Sludge: 1996



BIOMASS[2]

The U.S. petroleum refining industry managed an estimated 729 thousand wet tons of Biomass in 1996, which was a 25% increase from 1995. 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: 1987-1996.



The portion of the Biomass stream that is managed by each management practice is shown in Figure 22 for 1995 and 1996. Treatment has become the dominant management practice, and disposal is declining as a management practice for this stream.

Figure 22—Nationwide Estimates of Biomass by Management Practice: 1995-1996.

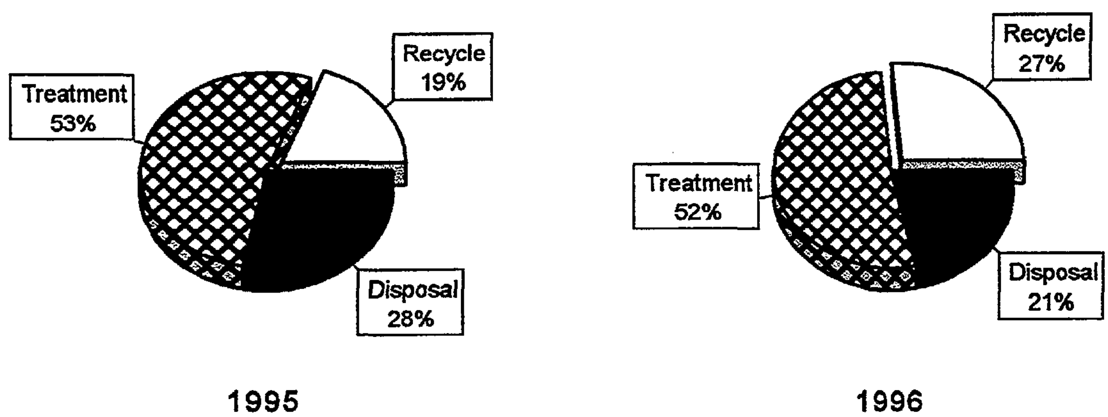
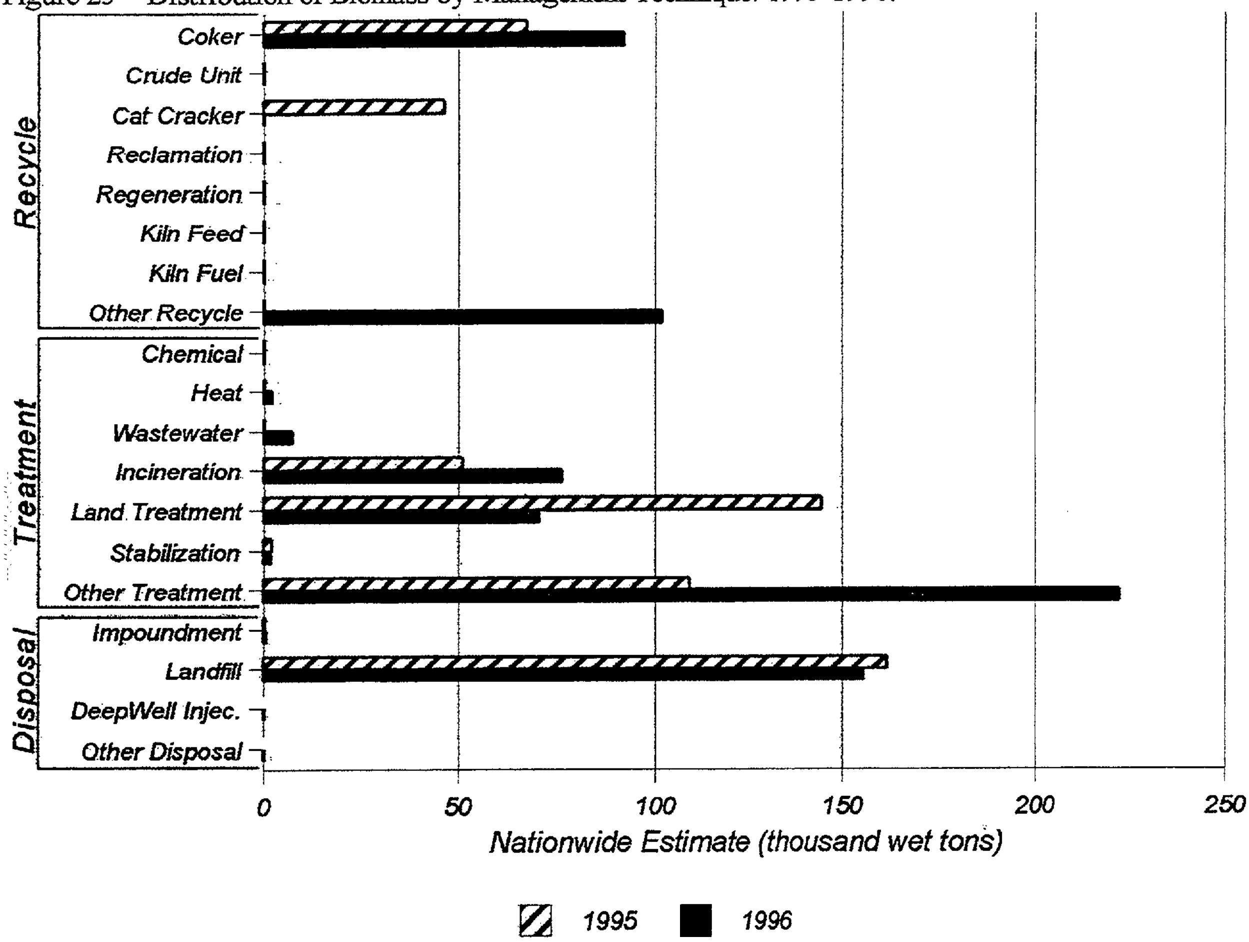


Figure 23 shows the Biomass distribution by management technique for 1995 and 1996. There appears to be a trend toward decreased *land treatment* and *landfill* applications of this stream.

[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: 1995-1996.



Responses in the *other* categories are listed below.

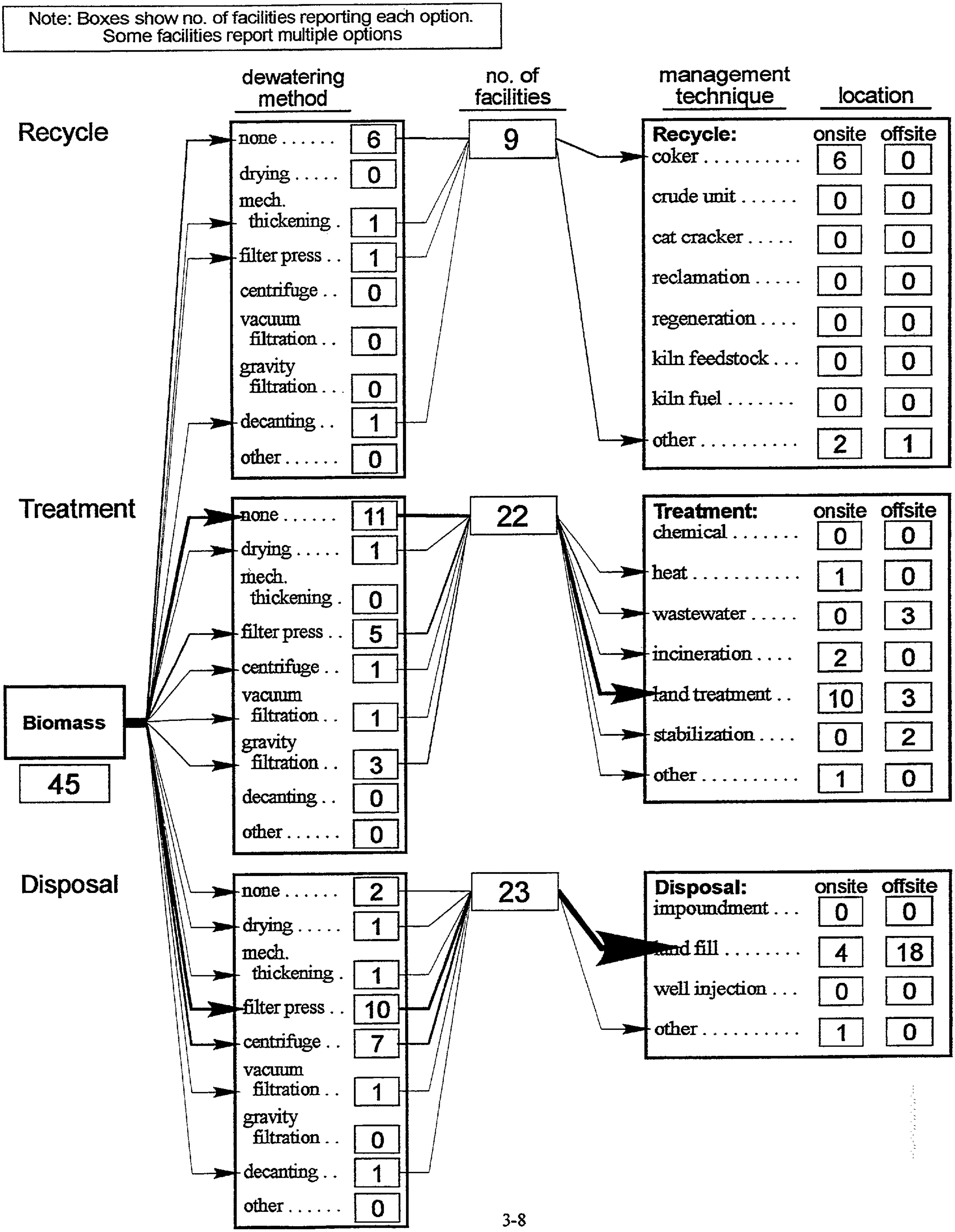
Other Recycle: one facility routes this stream to an RCC unit; another facility biotreats this stream and blends it to make topsoil.

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.

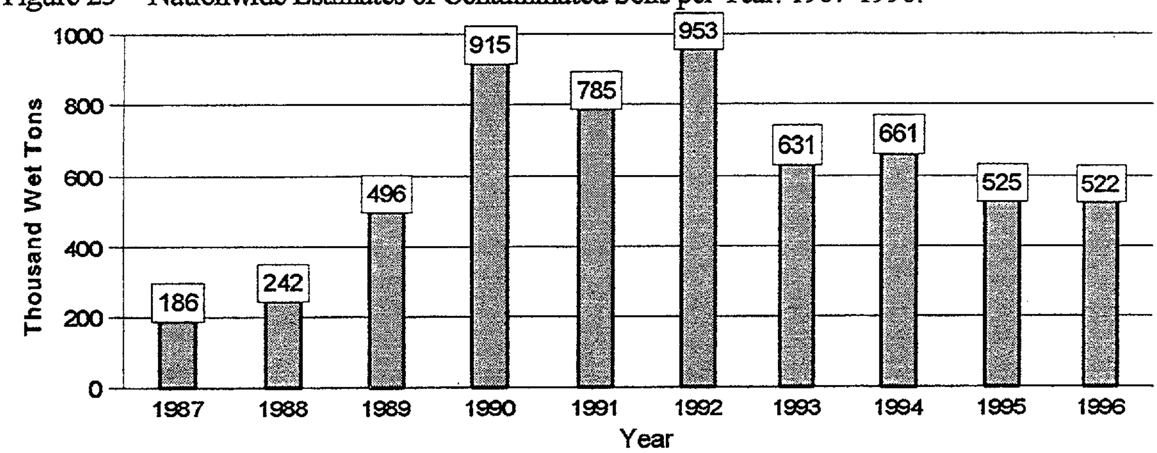
Figure 24 - Biomass: 1996



CONTAMINATED SOILS[3]

The U.S. petroleum refining industry managed an estimated 522 thousand wet tons of Contaminated Soils in 1996, which was a 1% reduction from 1995. 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: 1987-1996.



The portion of the Contaminated Soils stream that is managed by each management practice is shown in Figure 26 for 1995 and 1996. While the portion of this stream that was recycled increased significantly, disposal continues to be the most common practice.

Figure 26—Nationwide Estimates of Contaminated Soils by Management Practice: 1995-1996.

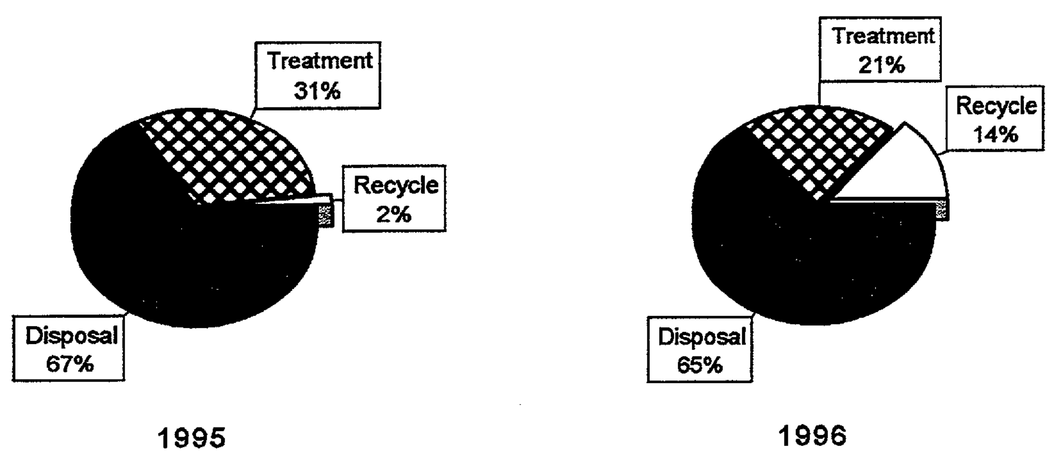
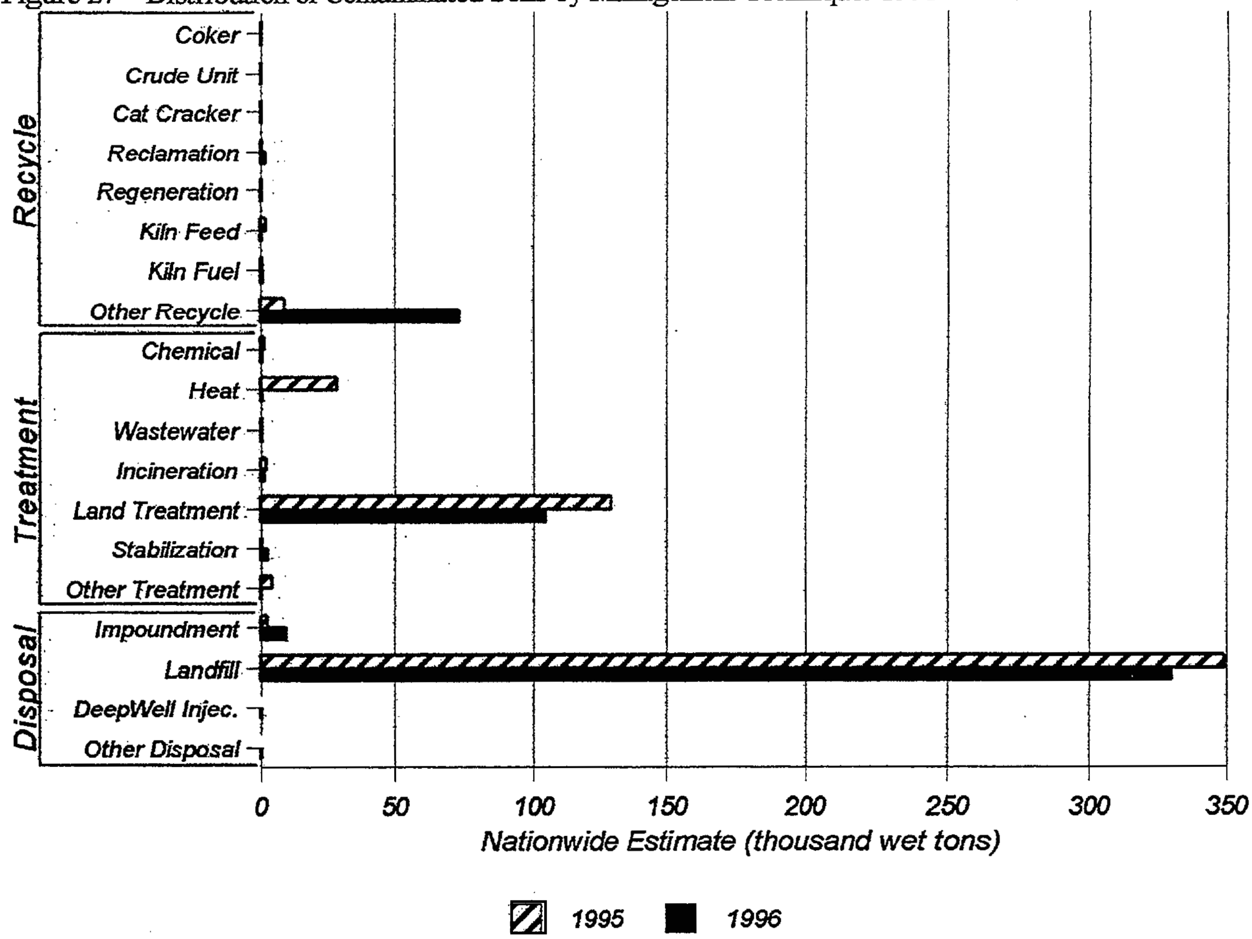


Figure 27 shows the Contaminated Soils distribution by management technique for 1995 and 1996. This stream is still primarily either *land treated* or *landfilled*, although some facilities find innovative ways to recycle contaminated soil.

[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: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: one facility reuses this stream as roadbed material without requiring any treatment of the contaminated soil; another incorporates this stream into asphalt; and another biotreats this stream and blends it to make topsoil.

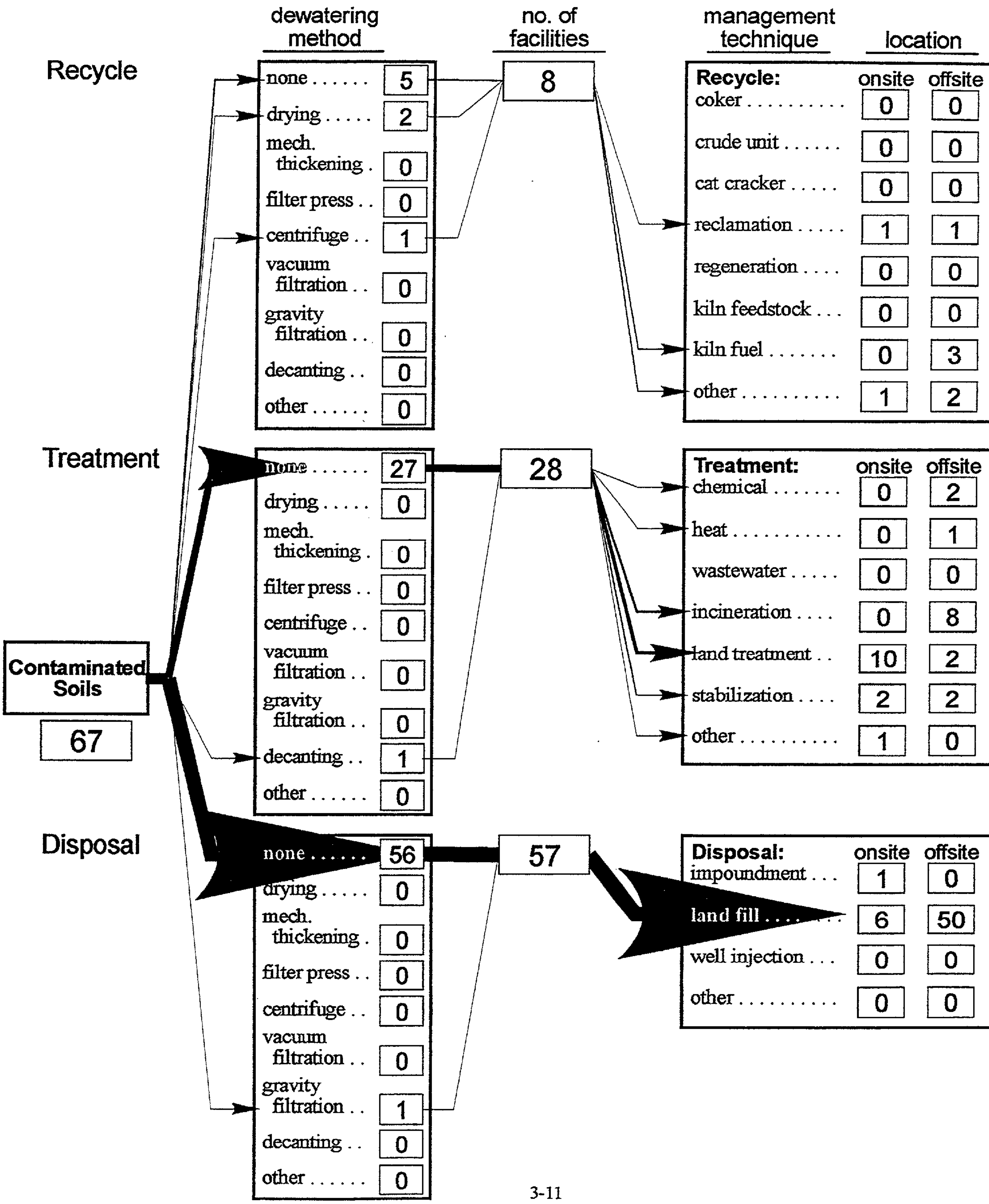
Other Treatment: one facility biotreats contaminated soil *in situ*.

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: 1996

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: 1996

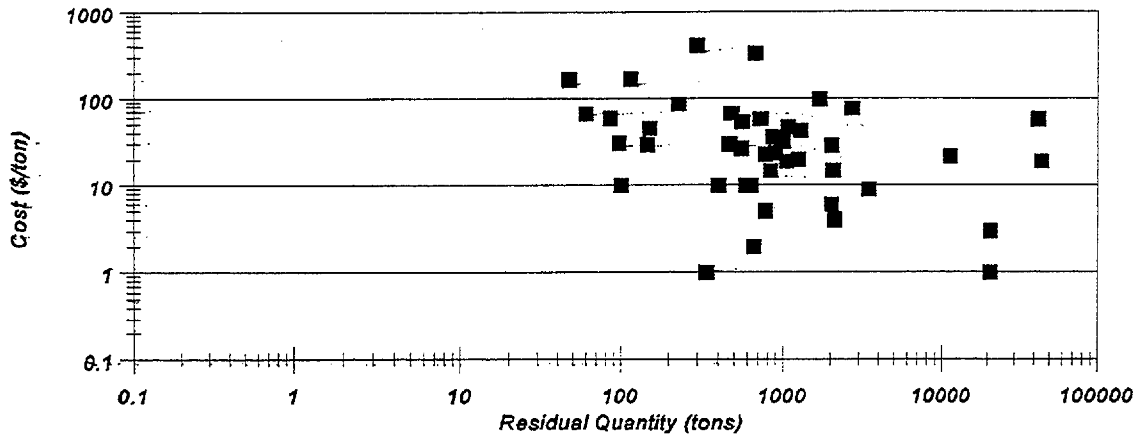


Figure 30—Offsite Management Cost for Contaminated Soils: 1996

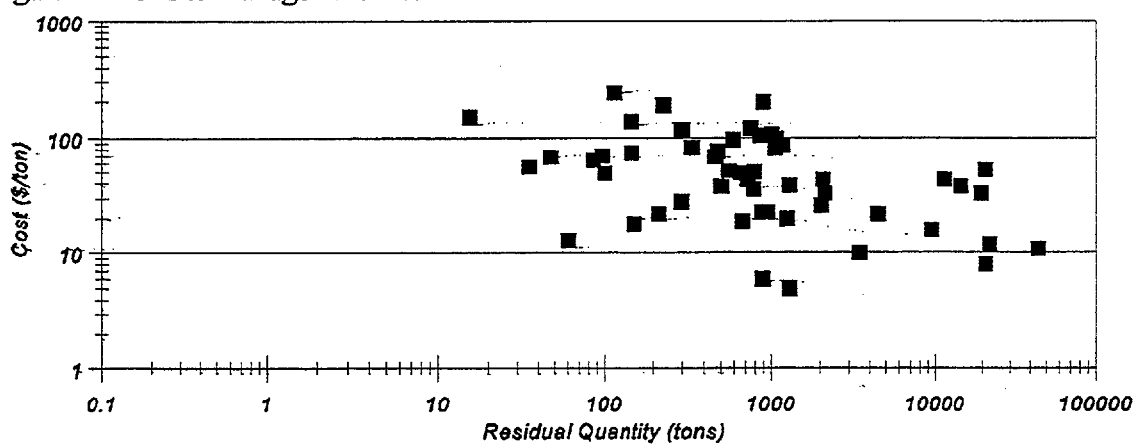
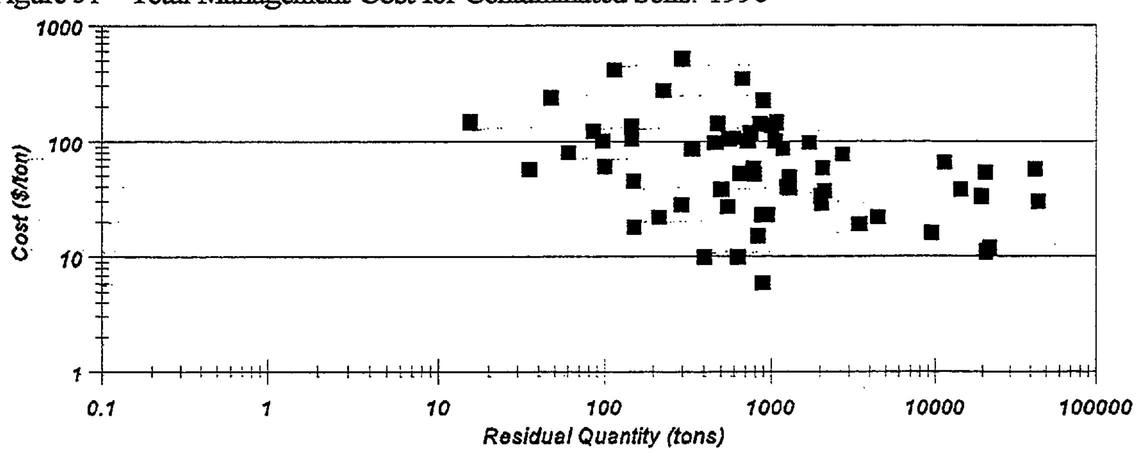


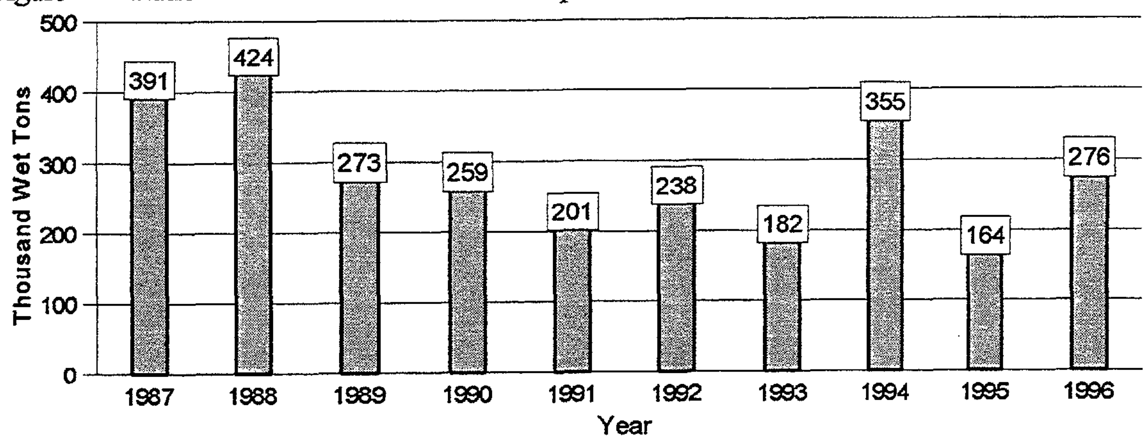
Figure 31—Total Management Cost for Contaminated Soils: 1996



DAF FLOAT[4]

The U.S. petroleum refining industry managed an estimated 276 thousand wet tons of Dissolved Air Flotation (DAF) Float in 1996, which was a 69% increase from 1995. 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.

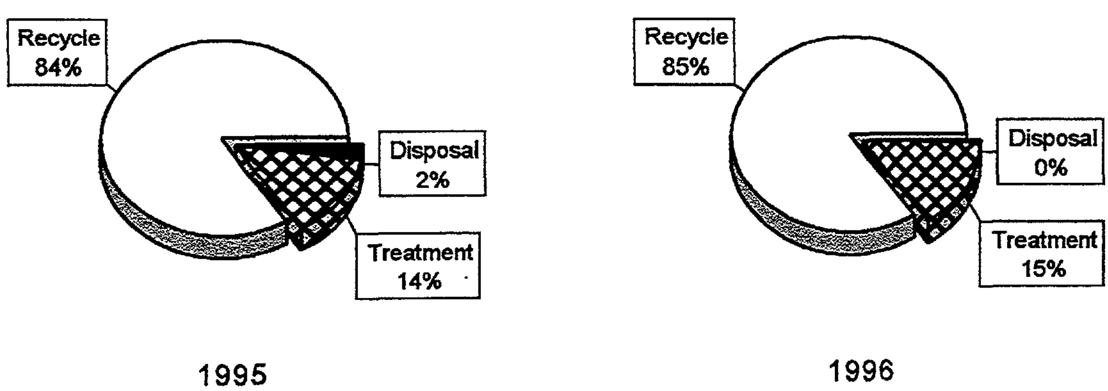
Figure 32—Nationwide Estimates of DAF Float per Year: 1987-1996.



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 an increase from 554 thousand wet tons in 1995 to 723 thousand wet tons in 1996, an increase of 30%.

The portion of the DAF Float stream that is managed by each management practice is shown in Figure 33 for 1995 and 1996. Recycling continues to be the dominant practice.

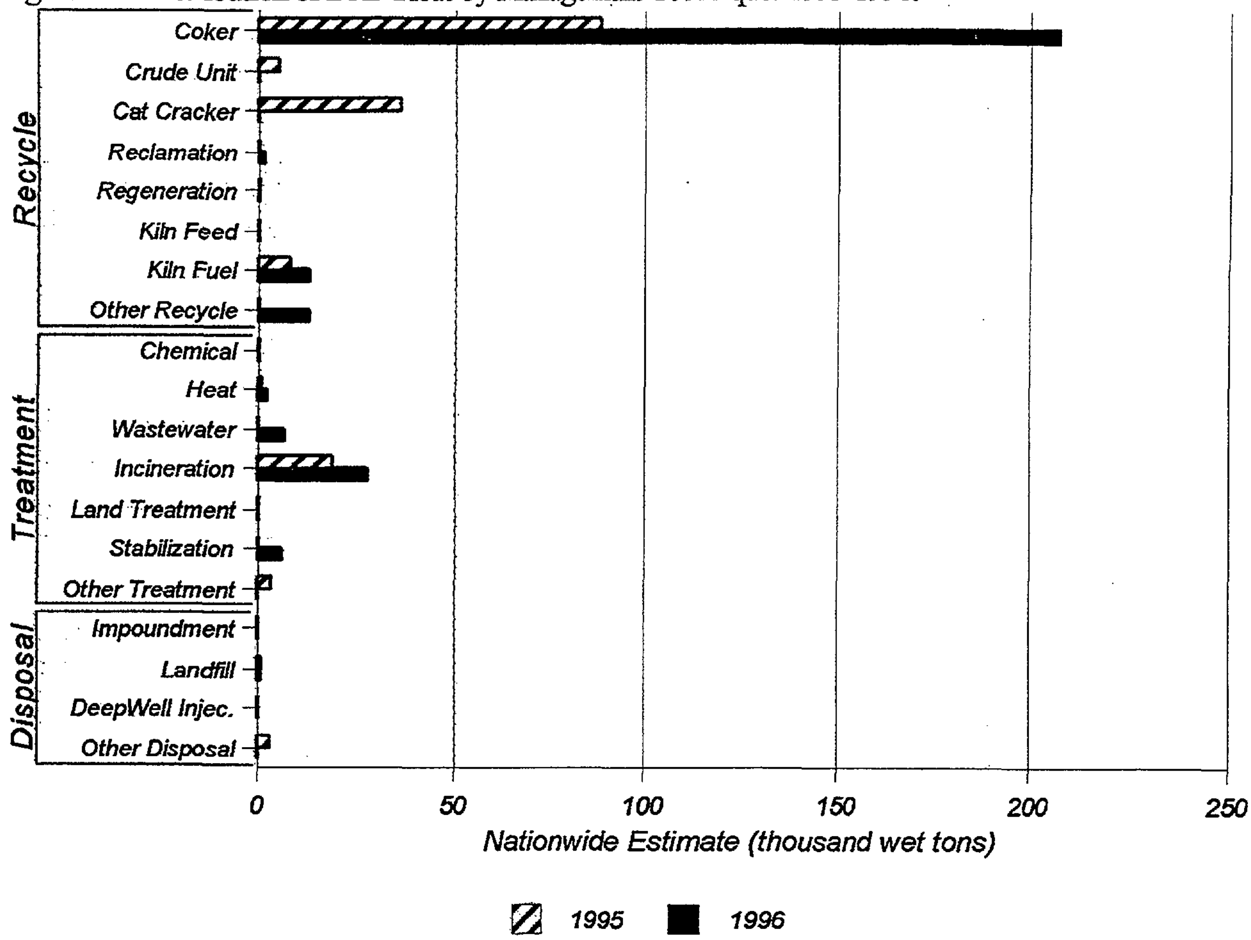
Figure 33—Nationwide Estimates of DAF Float by Management Practice: 1995-1996.



[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 1995 and 1996. 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*.

Figure 34—Distribution of DAF Float by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: one facility routes this stream to an RCC; another recycles it to desalters.

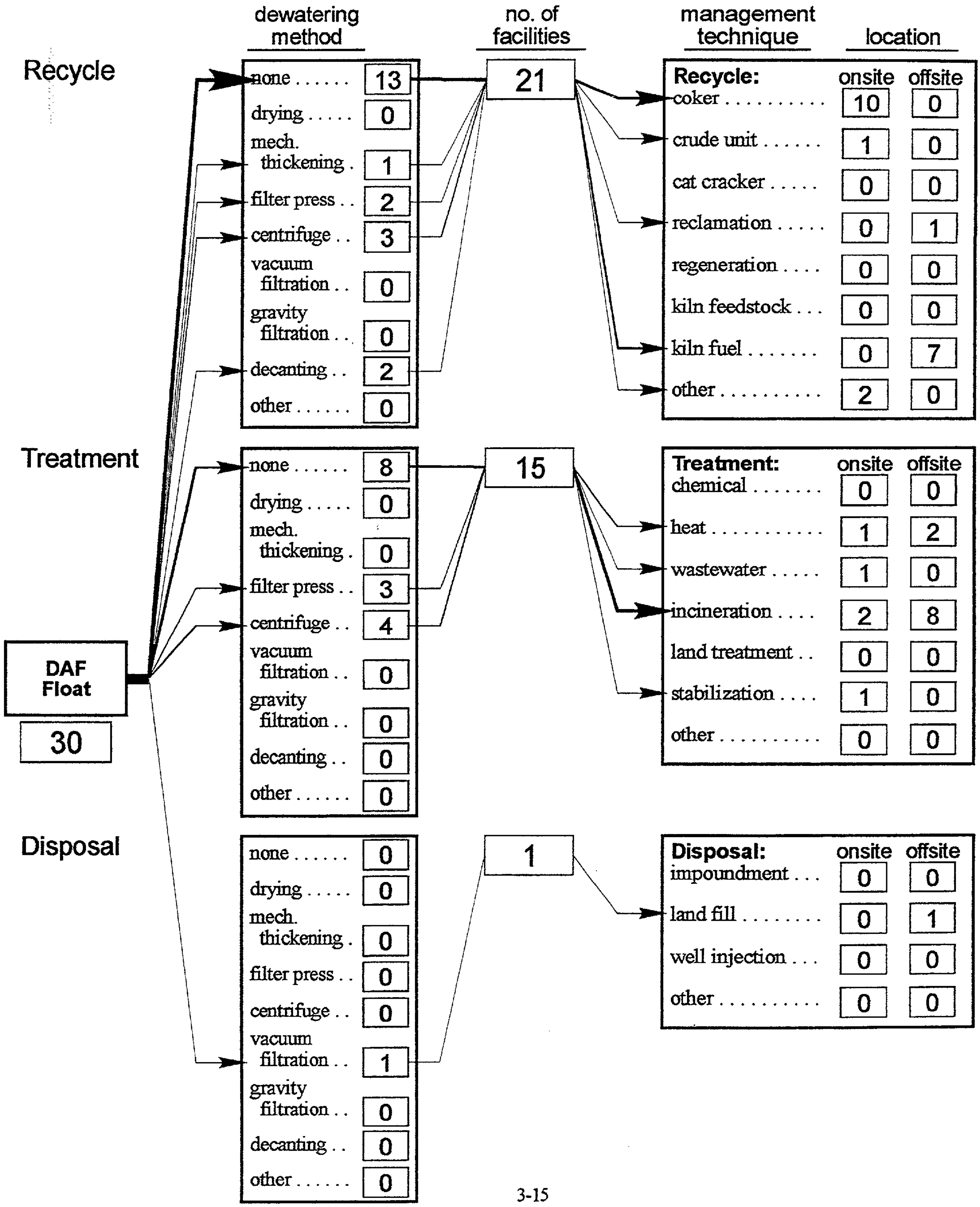
Other Treatment: none.

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: 1996

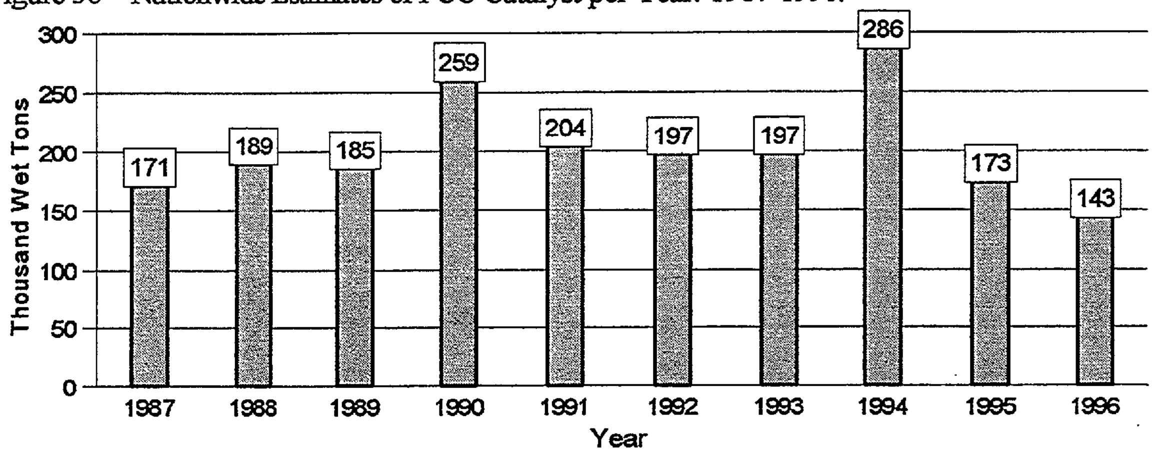
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



FCC CATALYST[5]

The U.S. petroleum refining industry managed an estimated 143 thousand wet tons of Fluidized-bed Catalytic Cracking (FCC) Catalyst in 1996, which was a 17% reduction from 1995. 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: 1987-1996.



The portion of the FCC Catalyst stream that is managed by each management practice is shown in Figure 37 for 1995 and 1996. Disposal continues to be the most common practice.

Figure 37—Nationwide Estimates of FCC Catalyst by Management Practice: 1995-1996.

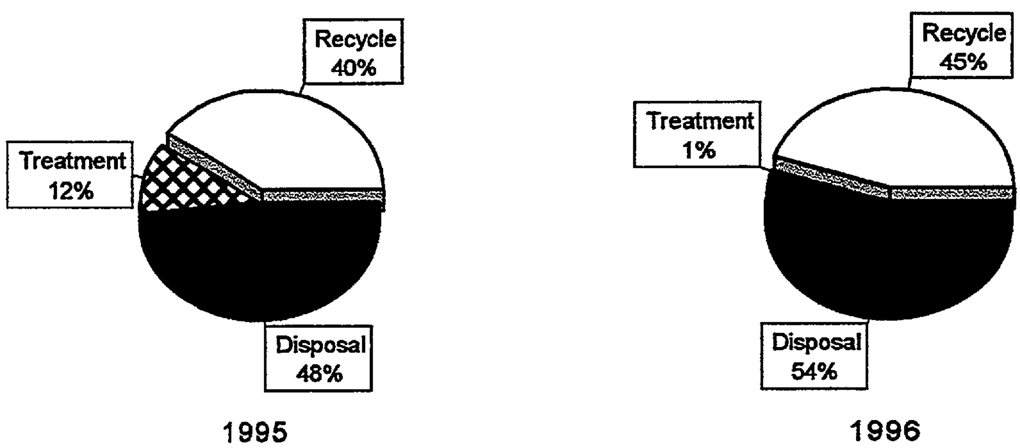
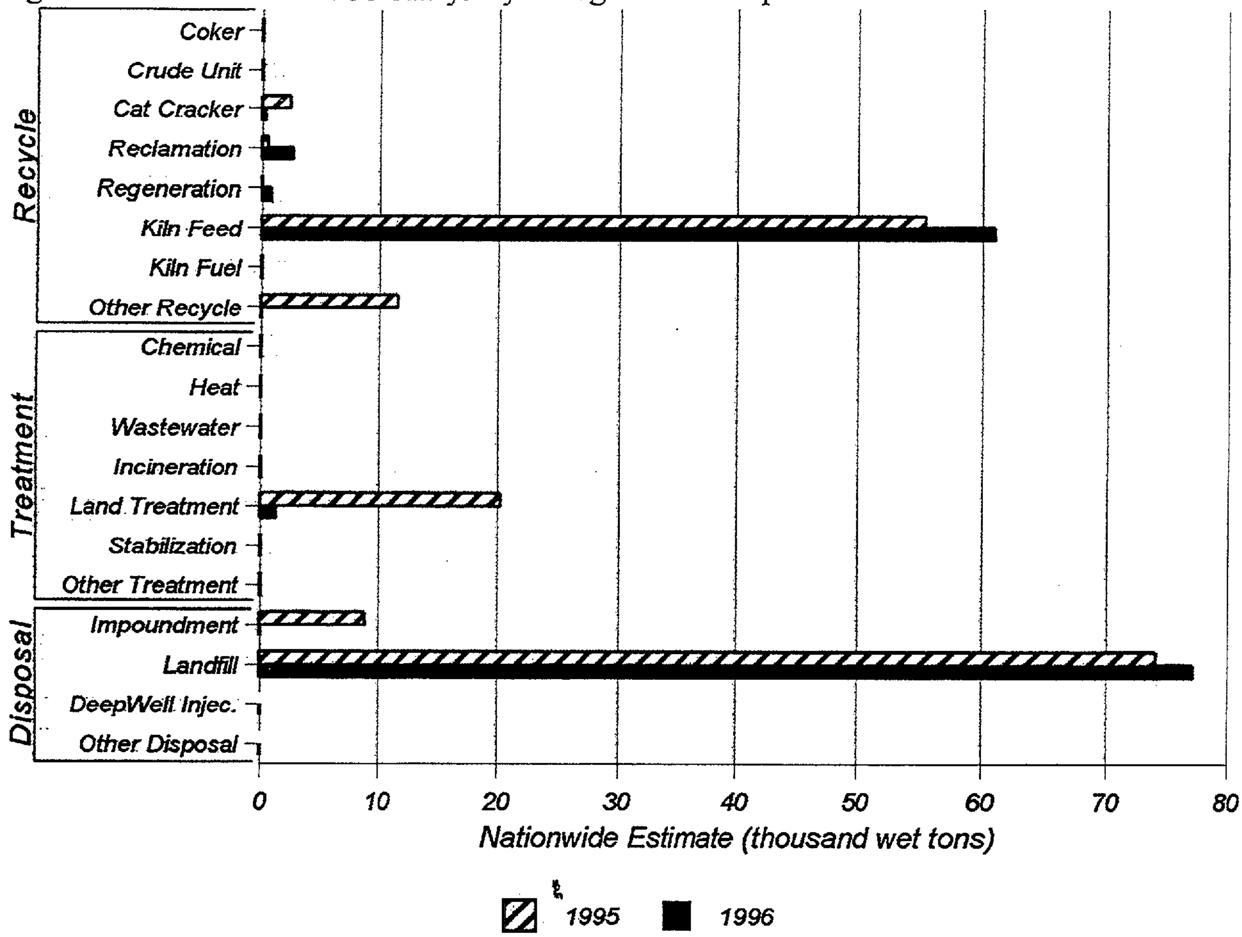


Figure 38 shows the FCC Catalyst distribution by management technique for 1995 and 1996. Spent catalyst is typically recycled as cement *kiln feedstock*, whereas fines from the flue gas are typically *landfilled*. One facility sends this stream for reuse in the steel industry.

[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: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

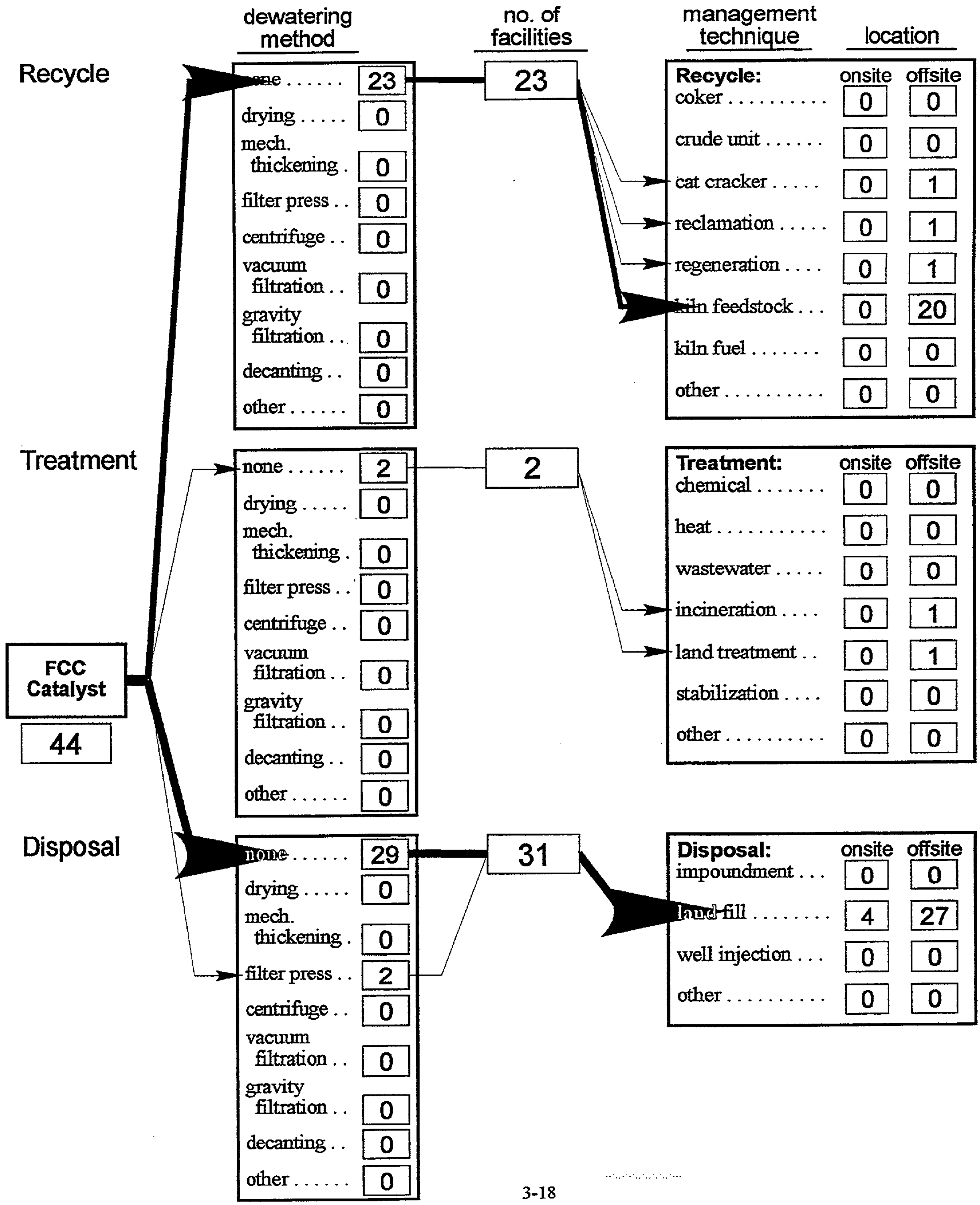
Other Treatment: none.

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 39 - FCC Catalyst Summary: 1996

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: 1996

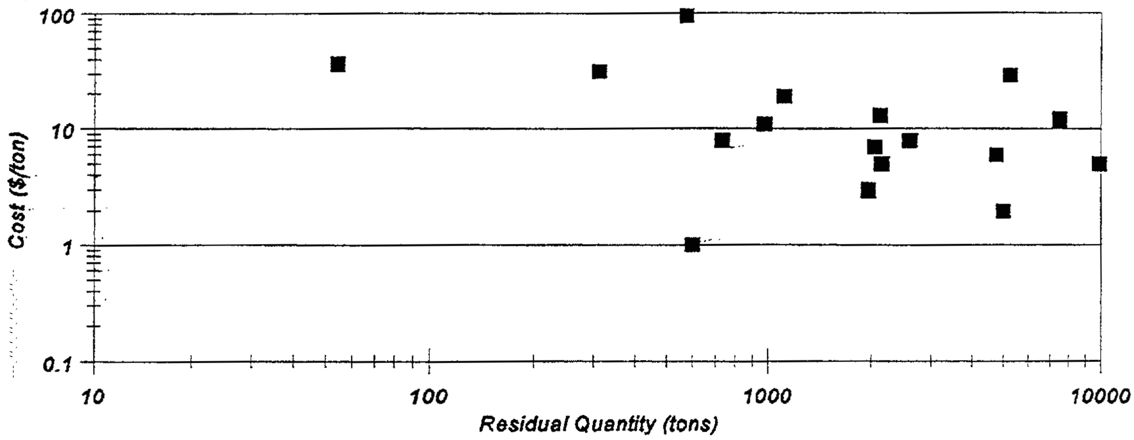


Figure 41—Offsite Management Cost for FCC Catalyst: 1996

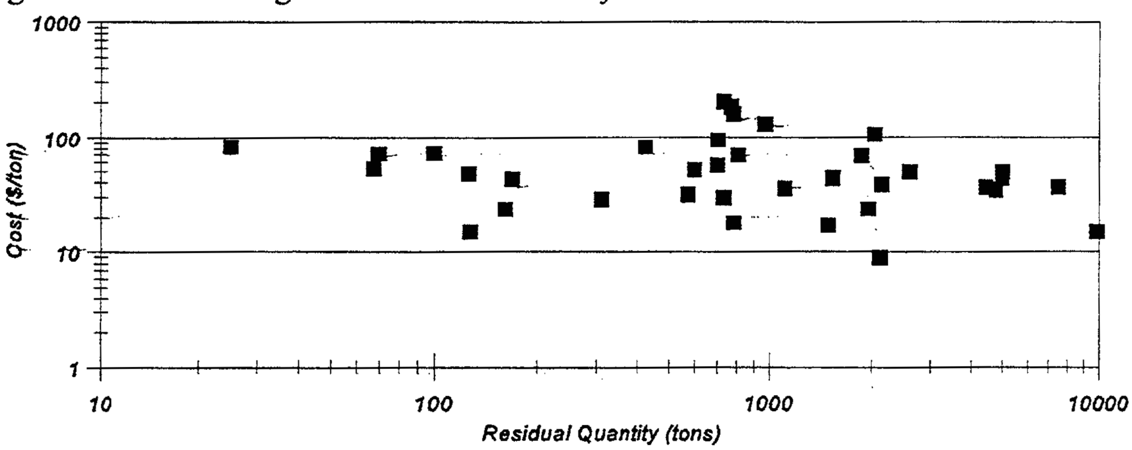
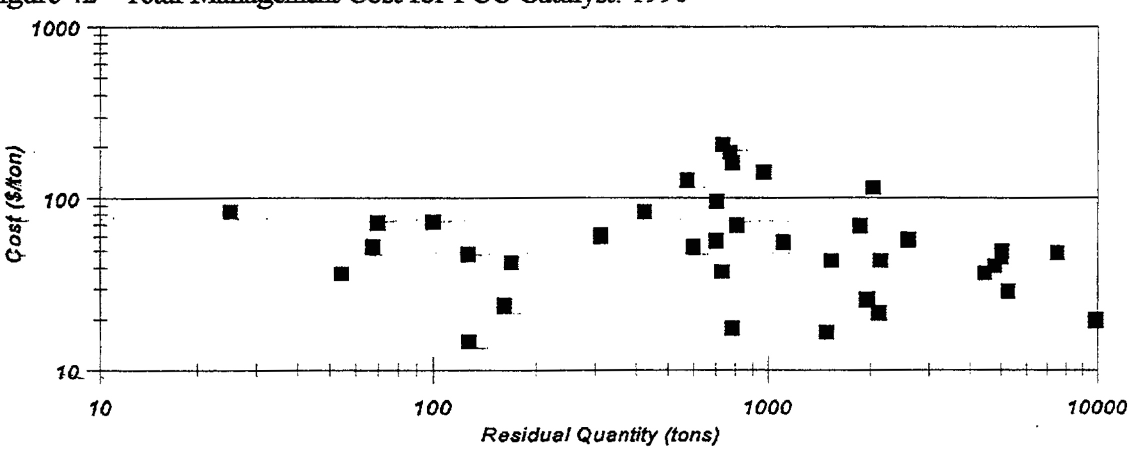


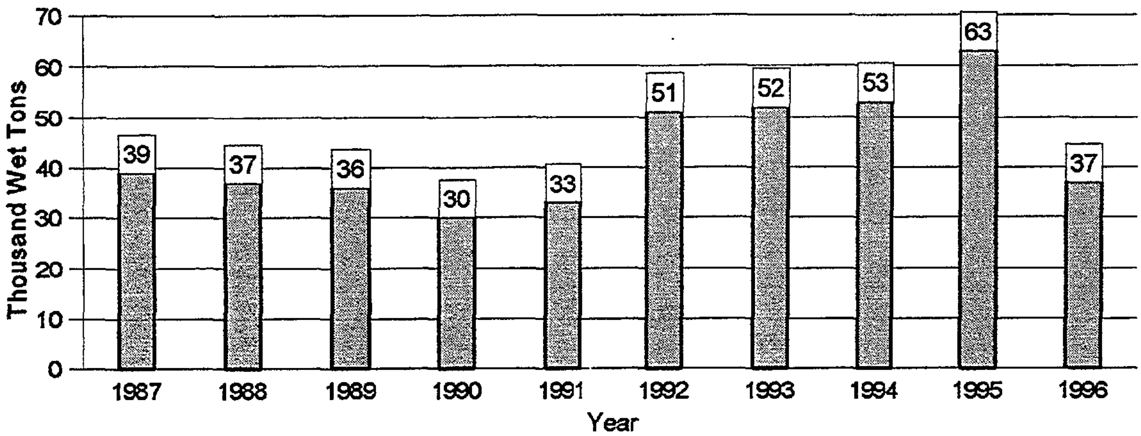
Figure 42—Total Management Cost for FCC Catalyst: 1996



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 37 thousand wet tons of Hydro. Catalyst in 1996, which was an 41% decrease from 1995. 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: 1987-1996.



The portion of the Hydro. Catalyst stream that is managed by each management practice is shown in Figure 44 for 1995 and 1996. Recycling continues to be the most common practice.

Figure 44—Nationwide Estimates of Hydro. Catalyst by Management Practice: 1995-1996.

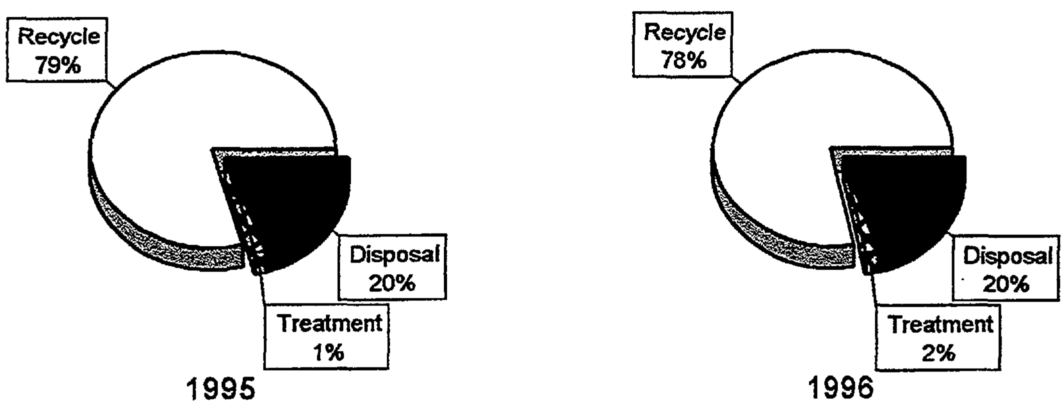
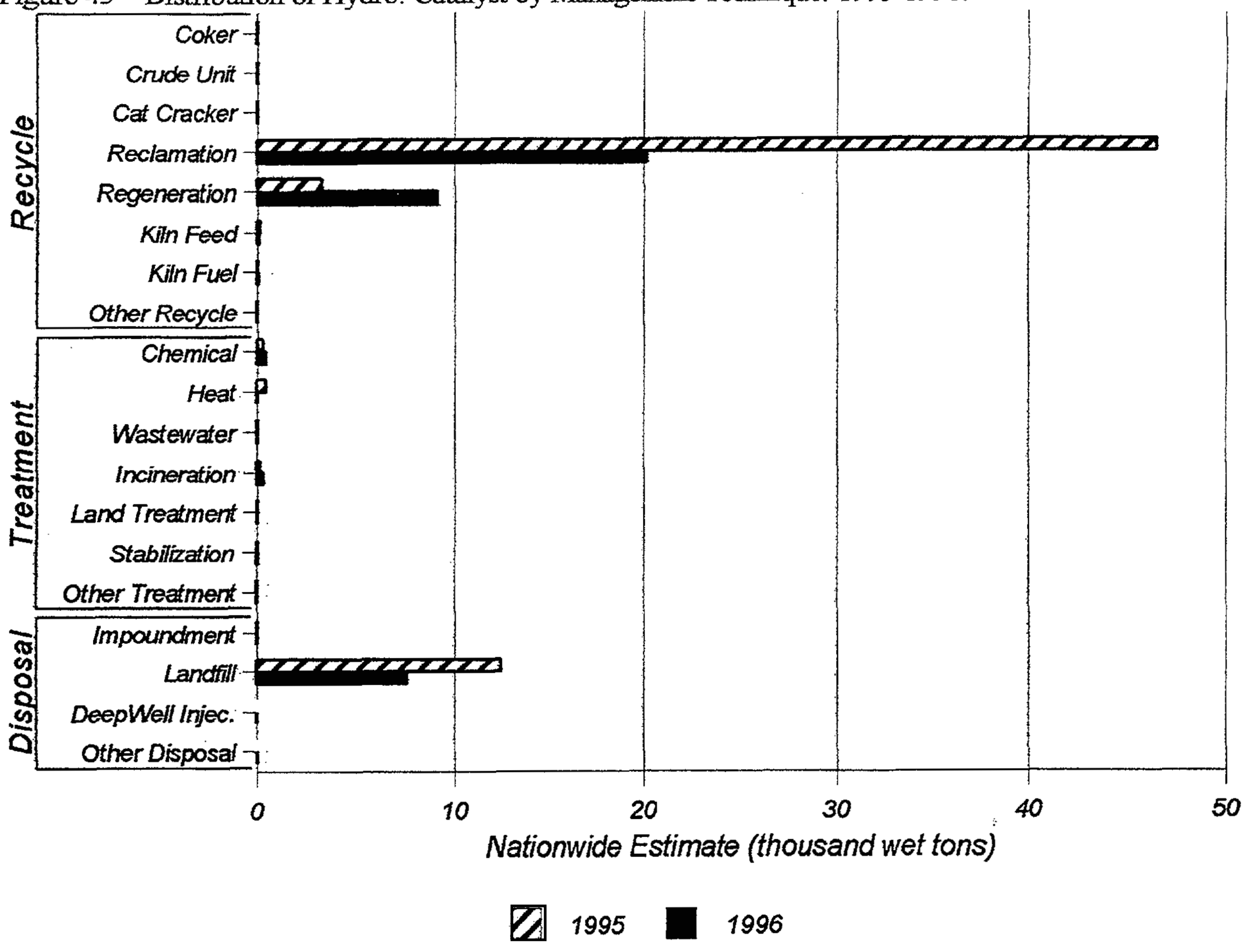


Figure 45 shows the Hydro. Catalyst distribution by management technique for 1995 and 1996. This stream is typically *reclaimed*, *regenerated*, or *landfilled*. The reclamation activity typically involves recovery of metals.

[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: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

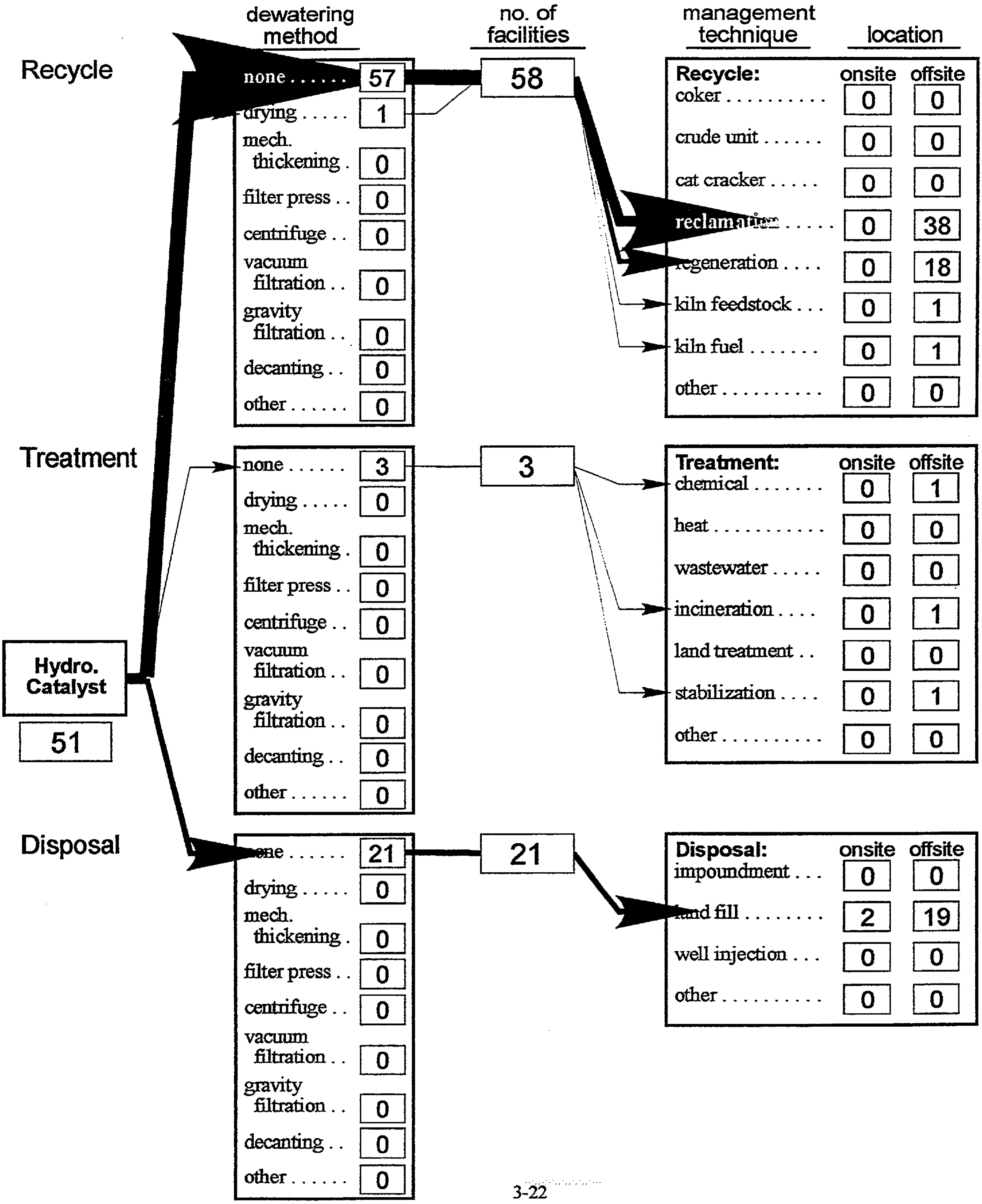
Other Treatment: none.

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: 1996

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: 1996

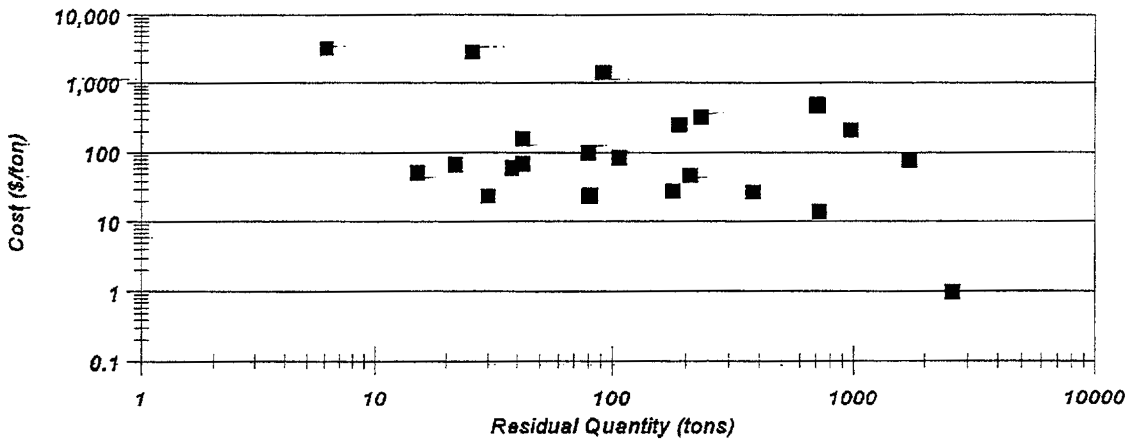


Figure 48—Offsite Management Cost for Hydro. Catalyst: 1996

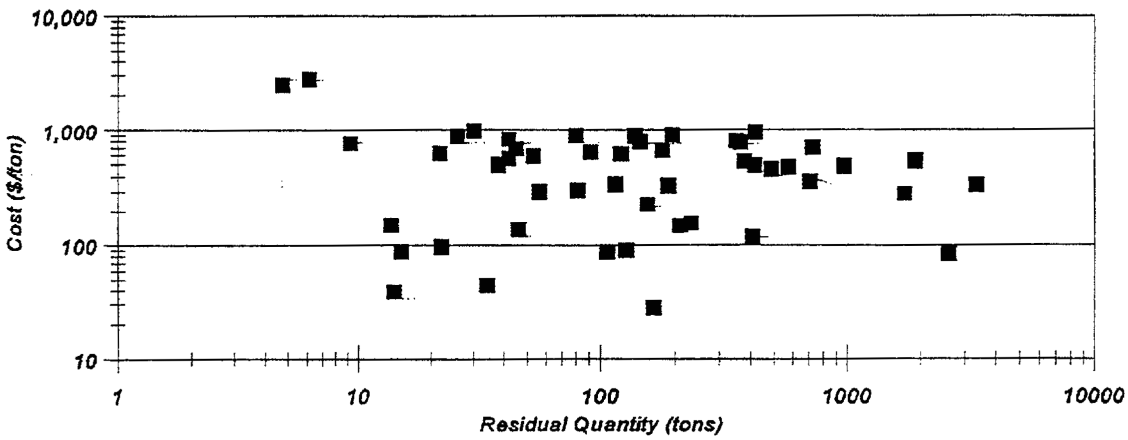
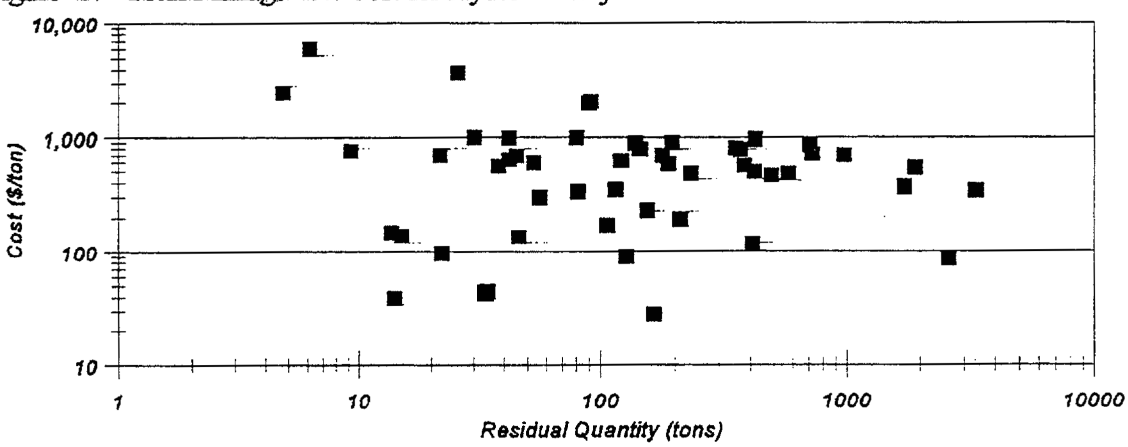


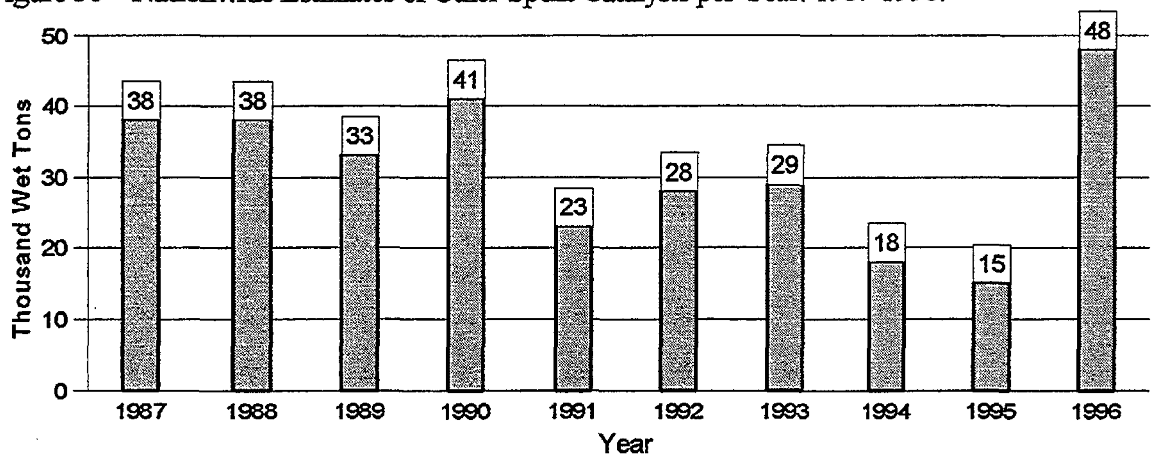
Figure 49—Total Management Cost for Hydro. Catalyst: 1996



OTHER SPENT CATALYSTS[7]

The U.S. petroleum refining industry managed an estimated 48 thousand wet tons of Other Spent Catalysts in 1996, which was a 209% increase from 1995. 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: 1987-1996.



The portion of the Other Spent Catalysts stream that is managed by each management practice is shown in Figure 51 for 1995 and 1996. Recycle has replaced disposal as the most common practice.

Figure 51—Nationwide Estimates of Other Spent Catalysts by Management Practice: 1995-1996.

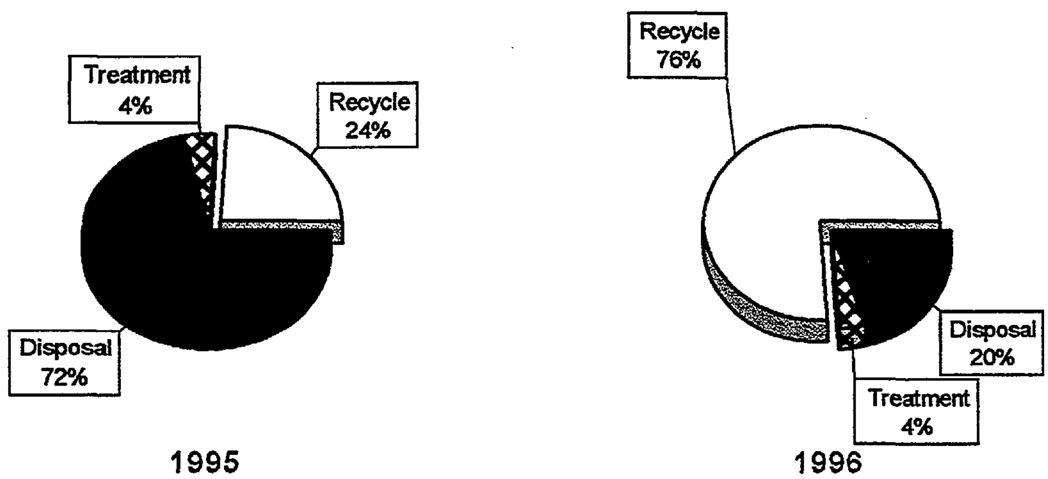
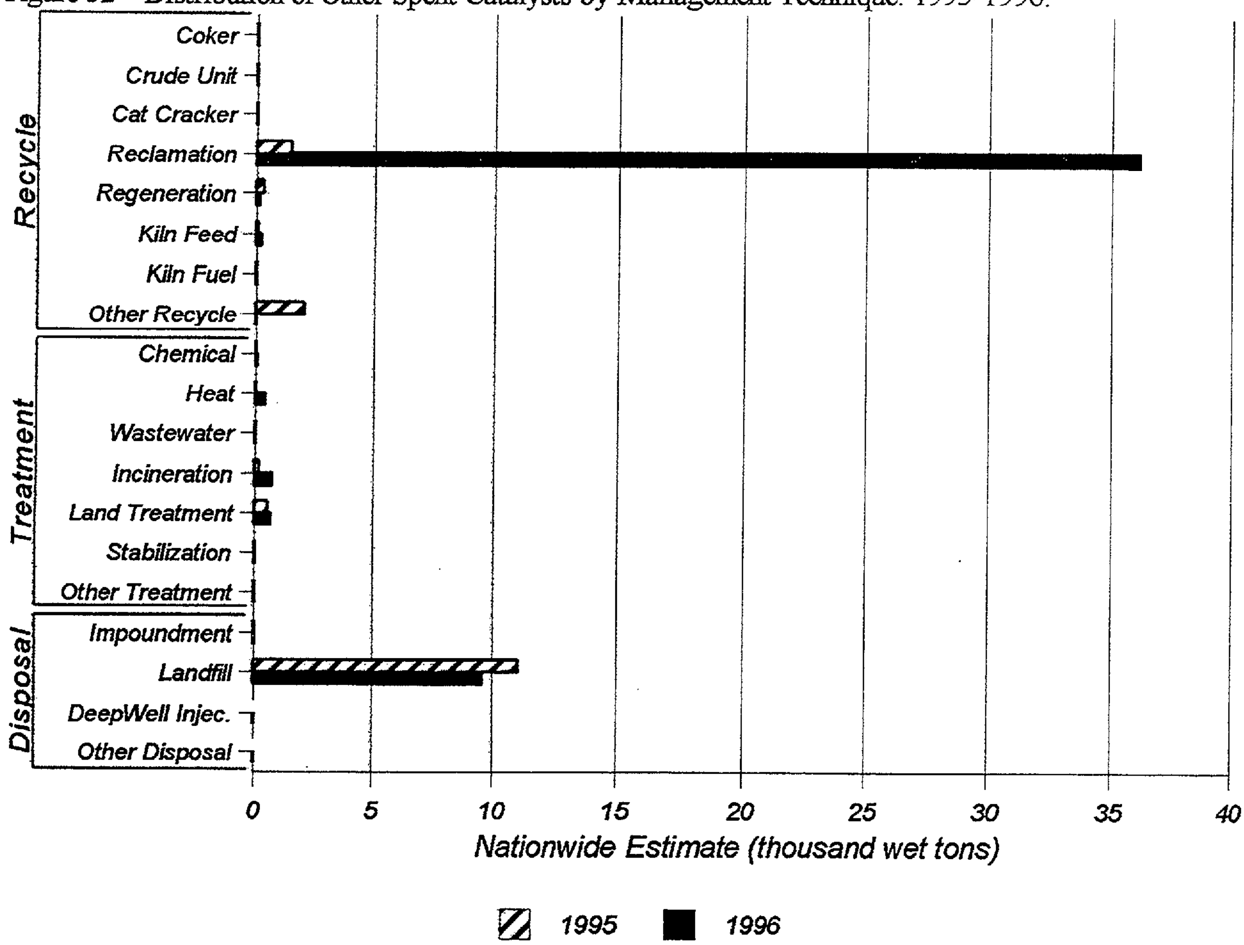


Figure 52 shows the Other Spent Catalysts distribution by management technique for 1995 and 1996. This stream is typically *reclaimed* or *landfilled*. Several reclamation activities are reported, including metals recovery, chemical industry reuse, and use in the fertilizer, aluminum, and mining industries.

[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: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

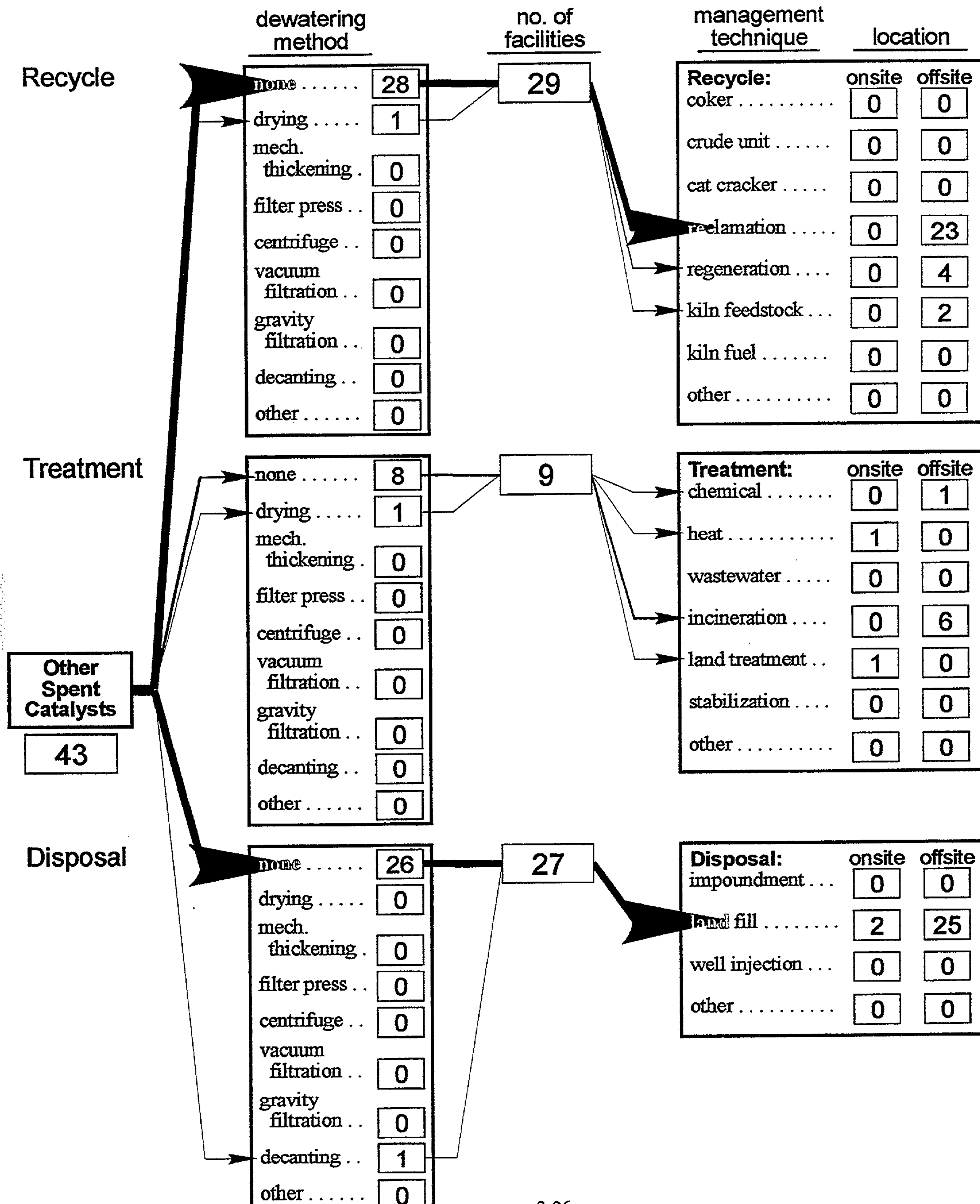
Other Treatment: none.

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: 1996

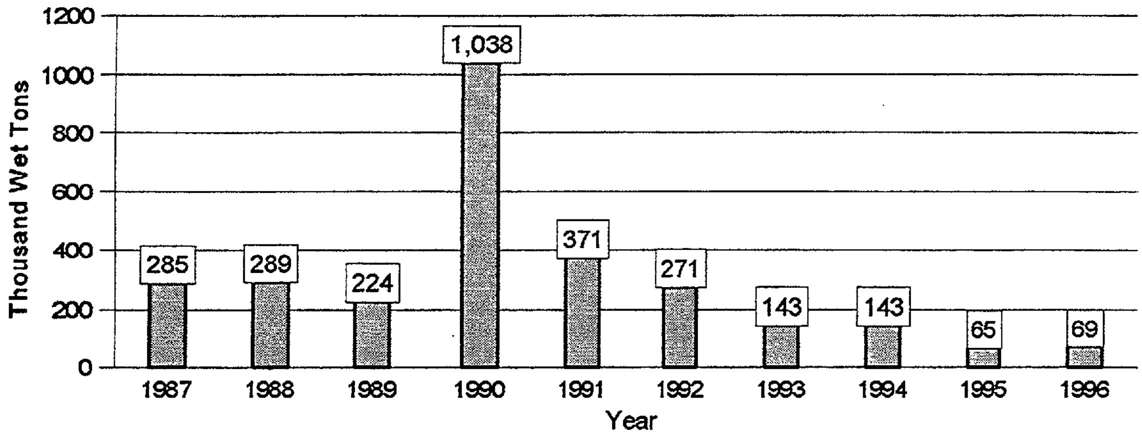
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



POND SEDIMENTS[8]

The U.S. petroleum refining industry managed an estimated 69 thousand wet tons of Pond Sediments in 1996, which was a 7% increase from 1995. 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: 1987-1996.



The portion of the Pond Sediments stream that is managed by each management practice is shown in Figure 55 for 1995 and 1996. While disposal shows a significant decline from the previous year, it continues to be the most common practice.

Figure 55—Nationwide Estimates of Pond Sediments by Management Practice: 1995-1996.

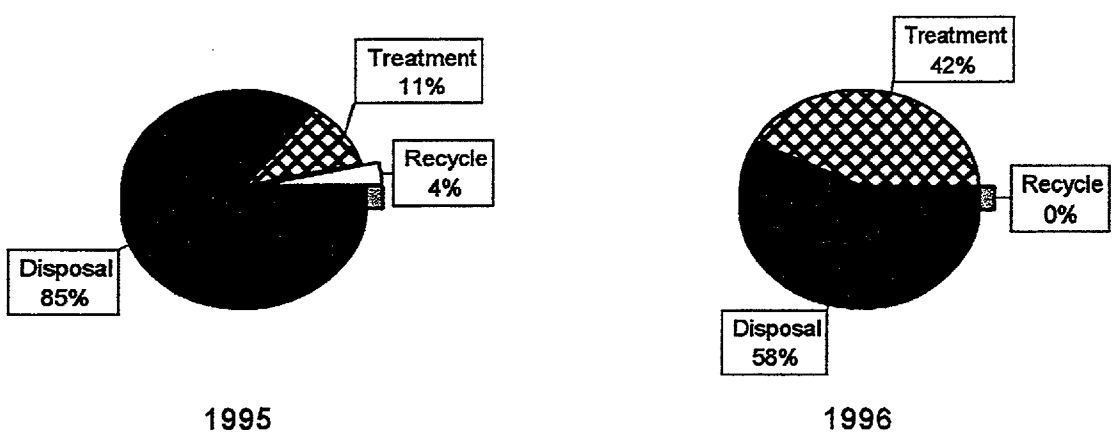
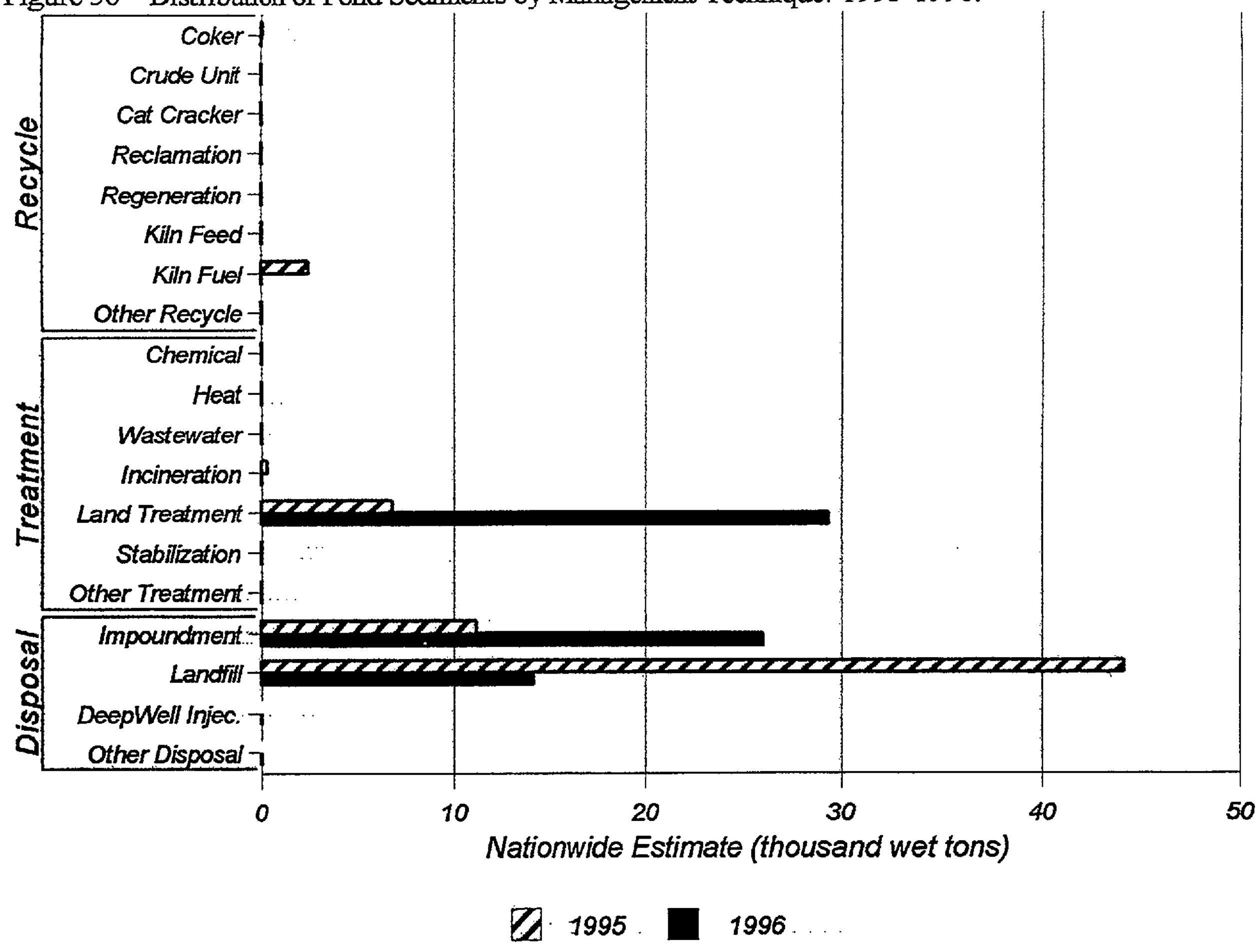


Figure 56 shows the Pond Sediments distribution by management technique for 1995 and 1996. This stream is typically managed in some land-applied manner, by being *land treated*, *impounded*, or *landfilled*.

[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: 1995-1996.



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: 1996

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

Pond Sediments: 8

Dewatering method

dewatering method	Recycle	Treatment	Disposal
none	0	2	3
drying	0	0	0
mech. thickening	0	0	0
filter press	0	0	2
centrifuge	0	0	0
vacuum filtration	0	0	0
gravity filtration	0	0	0
decanting	0	1	0
other	0	0	0

No. of facilities

	no. of facilities
Recycle	0
Treatment	3
Disposal	5

Management technique and location

Recycle:	onsite	offsite
coker	0	0
crude unit	0	0
cat cracker	0	0
reclamation	0	0
regeneration	0	0
kiln feedstock	0	0
kiln fuel	0	0
other	0	0

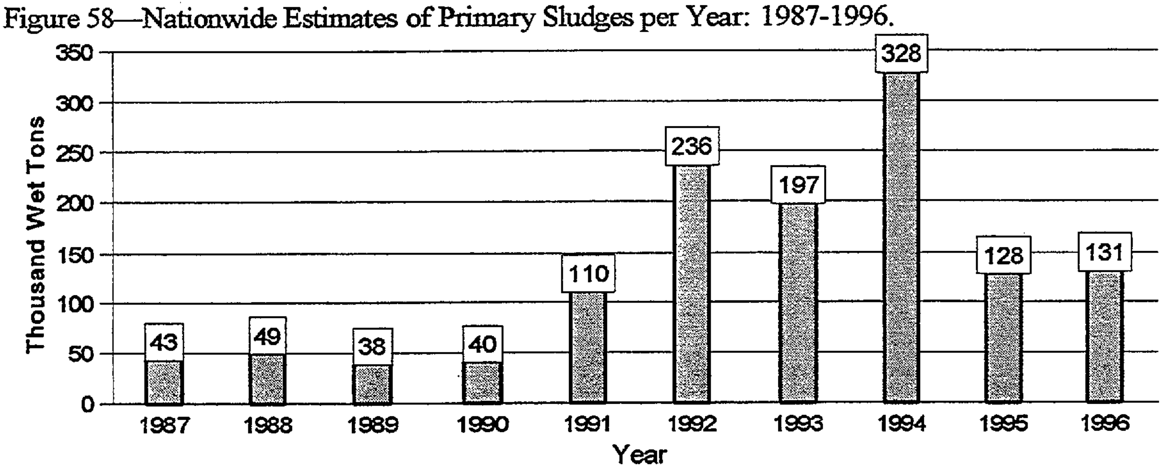
Treatment:	onsite	offsite
chemical	0	0
heat	0	0
wastewater	0	0
incineration	0	0
land treatment	3	0
stabilization	0	0
other	0	0

Disposal:	onsite	offsite
impoundment	1	0
land fill	0	4
well injection	0	0
other	0	0

PRIMARY SLUDGES[9]

The U.S. petroleum refining industry managed an estimated 131 thousand wet tons of Primary Sludges in 1996, which was a 2% increase from 1995. 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.

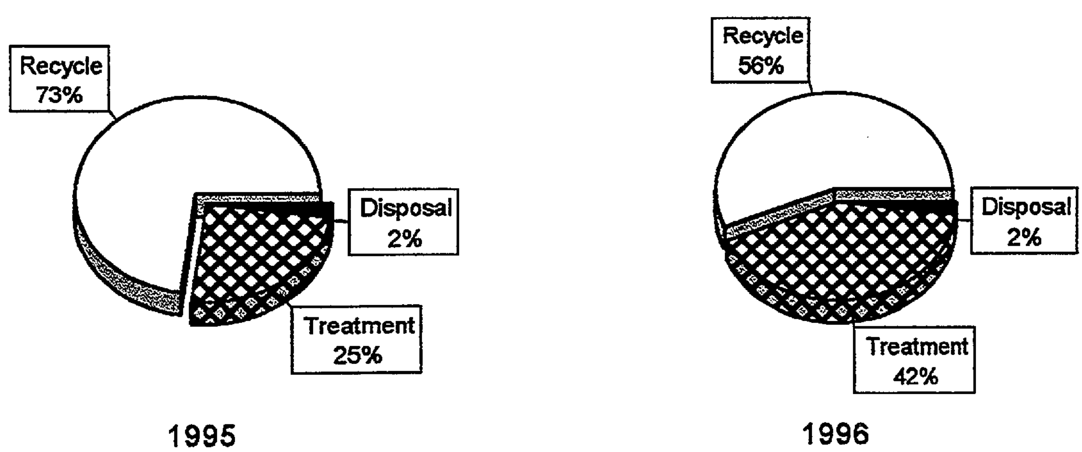
Figure 58—Nationwide Estimates of Primary Sludges per Year: 1987-1996.



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 an increase from 554 thousand wet tons in 1995 to 723 thousand wet tons in 1996, an increase of 30%.

The portion of the Primary Sludges stream that is managed by each management practice is shown in Figure 59 for 1995 and 1996. Recycling continues to be the most common practice.

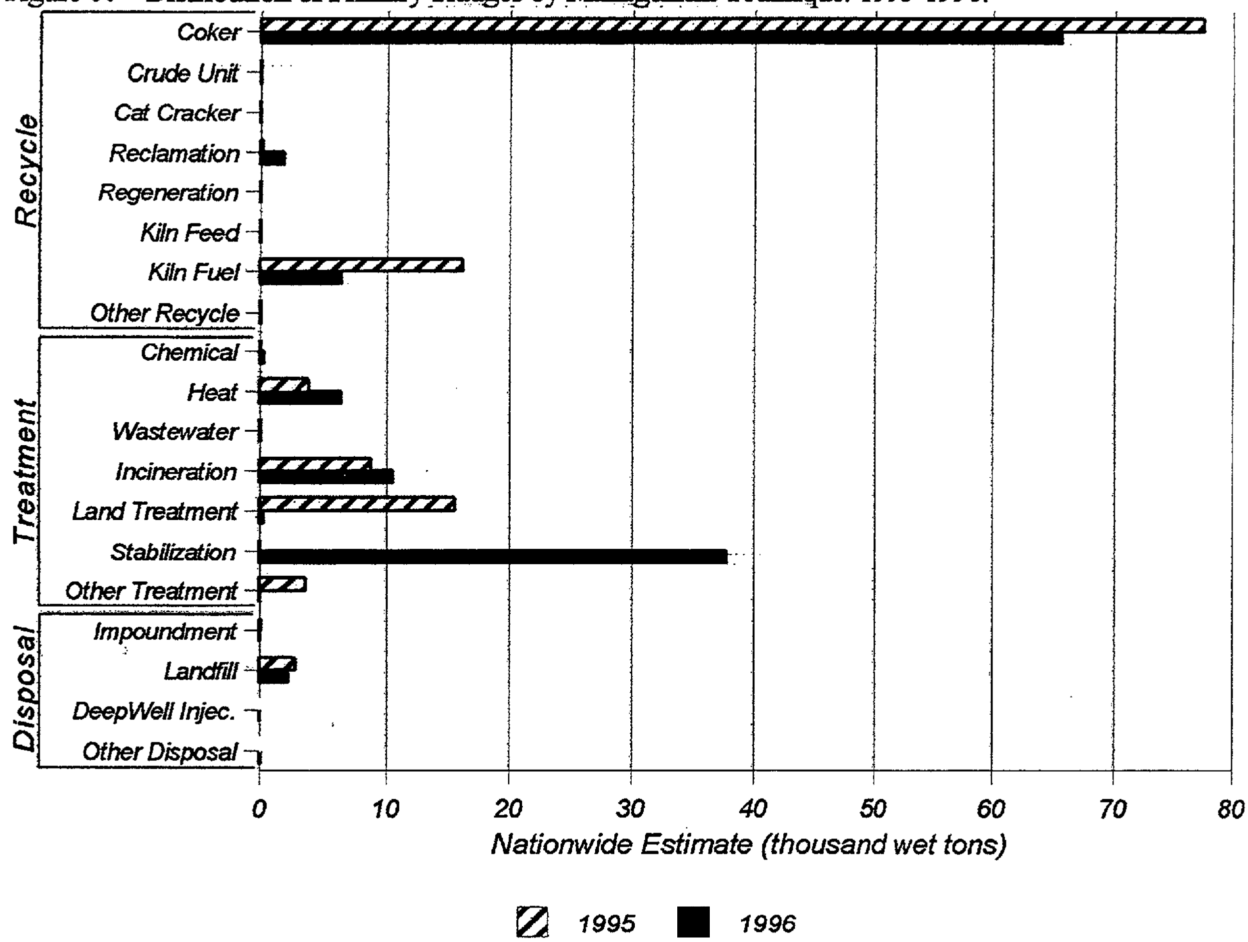
Figure 59—Nationwide Estimates of Primary Sludges by Management Practice: 1995-1996.



[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 1995 and 1996. This stream is primarily managed by techniques that recycle the oil content. This is most commonly accomplished by routing the stream to a *coker*. This stream may also contain significant quantities of contaminated soil, and is sometimes treated by *stabilization*.

Figure 60—Distribution of Primary Sludges by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

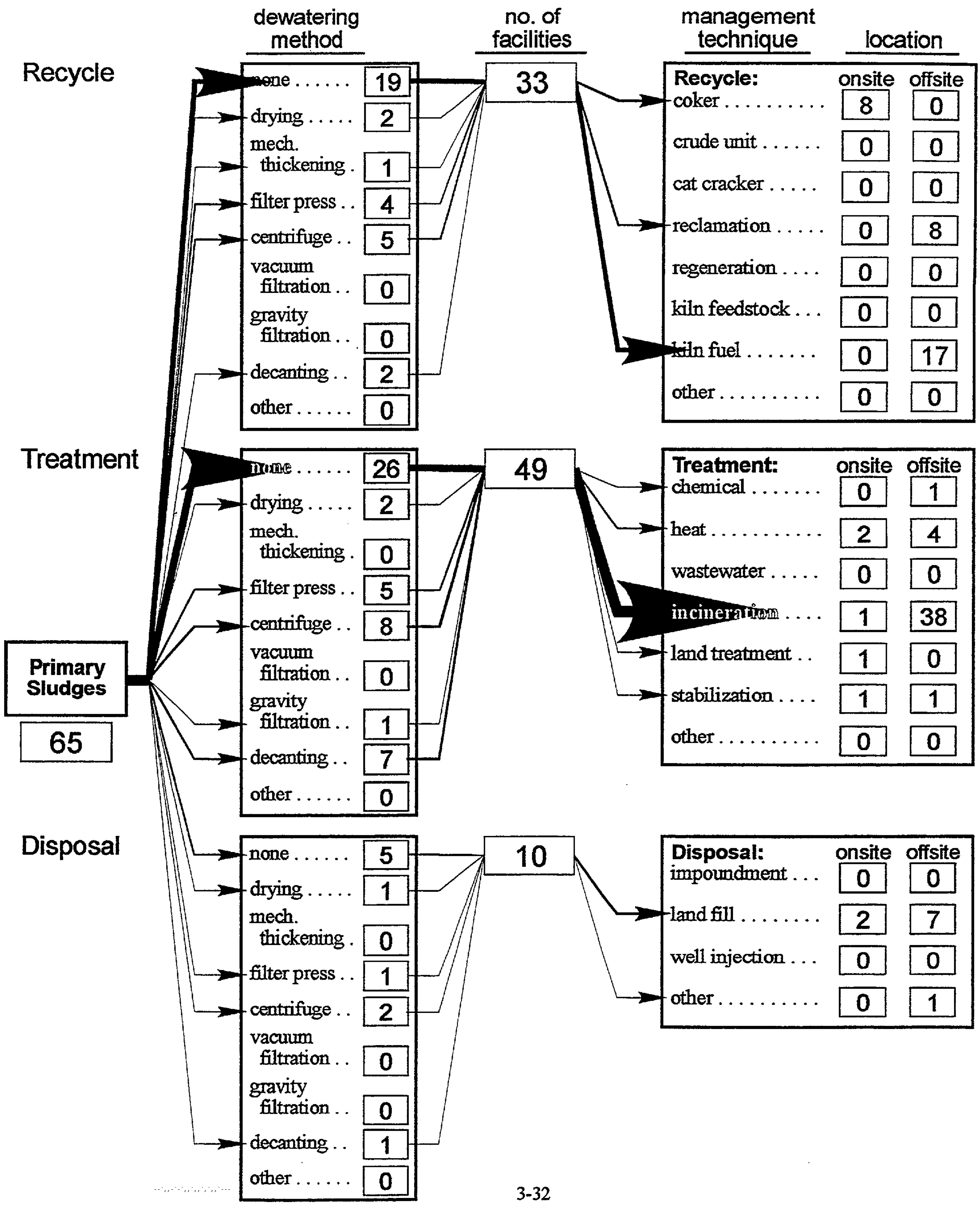
Other Treatment: none.

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: 1996

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



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

Figure 62—Onsite Management Cost for Primary Sludges: 1996

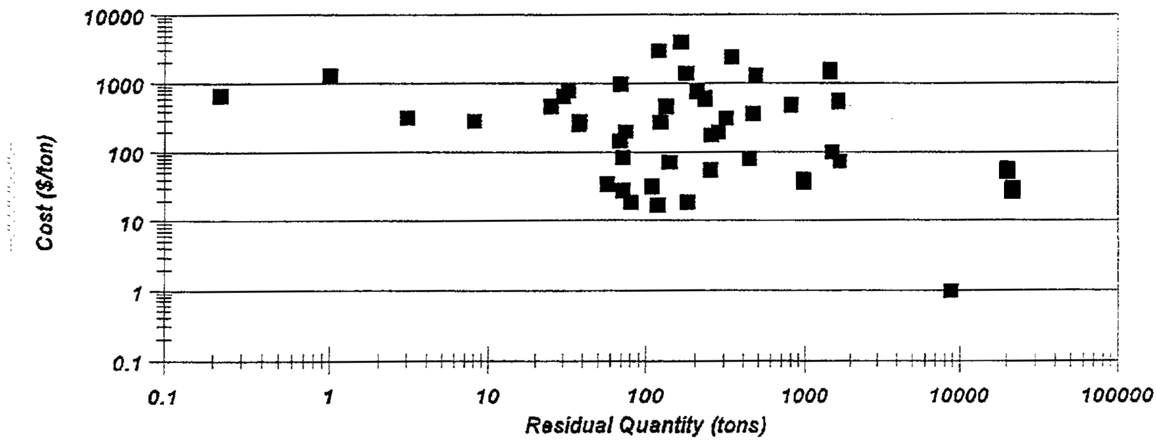


Figure 63—Offsite Management Cost for Primary Sludges: 1996

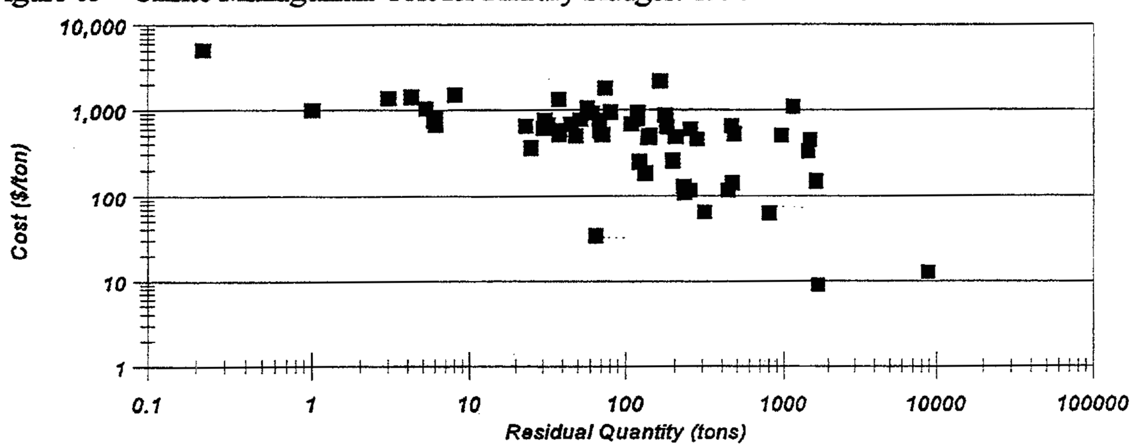
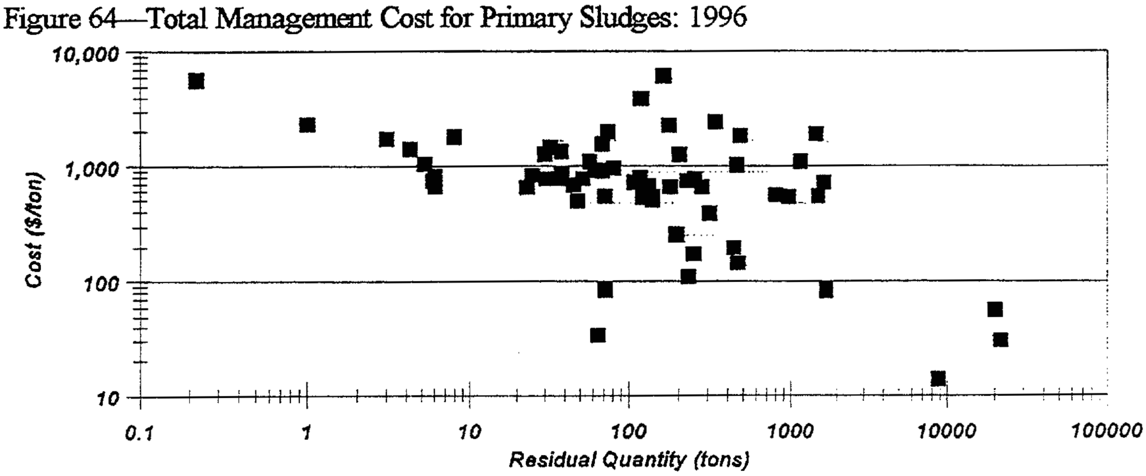


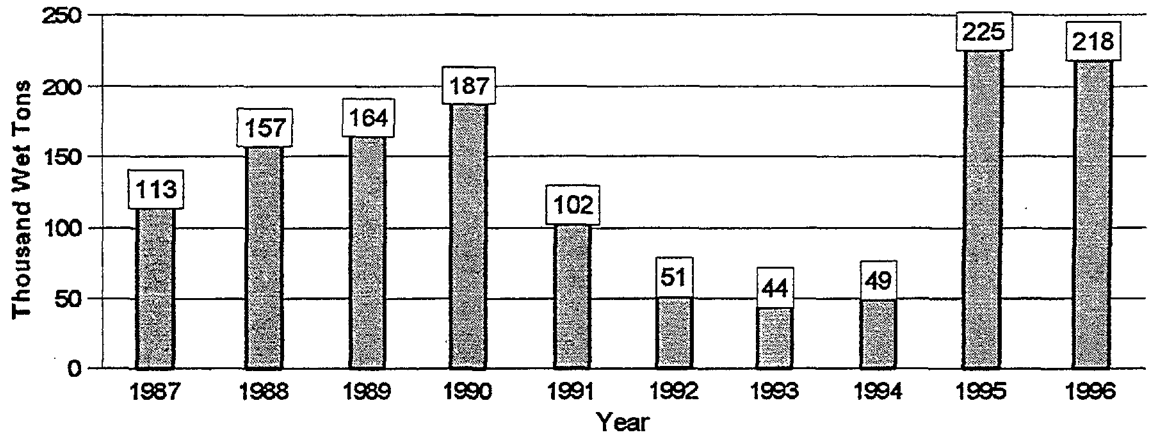
Figure 64—Total Management Cost for Primary Sludges: 1996



SLOP OIL EMULSION SOLIDS[10]

The U.S. petroleum refining industry managed an estimated 218 thousand wet tons of Slop Oil Emulsion Solids in 1996, which was a 3% reduction from 1995. 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.

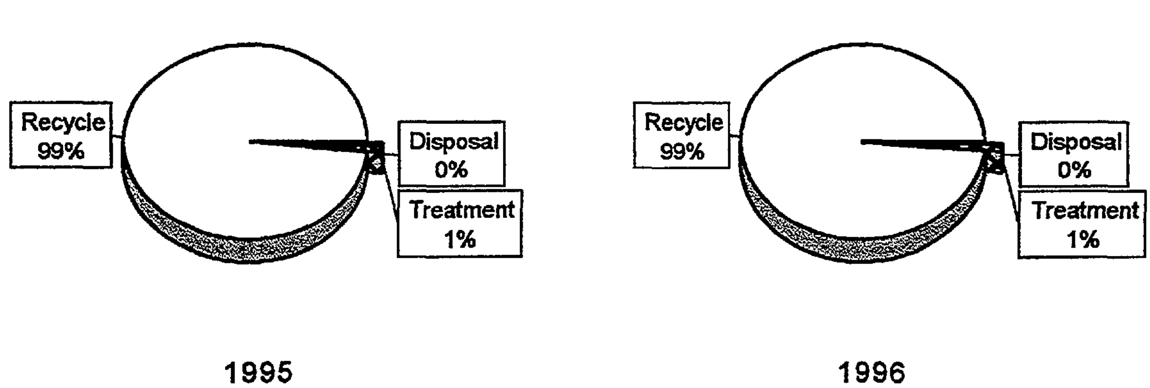
Figure 65—Nationwide Estimates of Slop Oil Emulsion Solids per Year: 1987-1996.



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 an increase from 554 thousand wet tons in 1995 to 723 thousand wet tons in 1996, an increase of 30%.

The portion of the Slop Oil Emulsion Solids stream that is managed by each management practice is shown in Figure 66 for 1995 and 1996. Recycling continues to be the dominant practice.

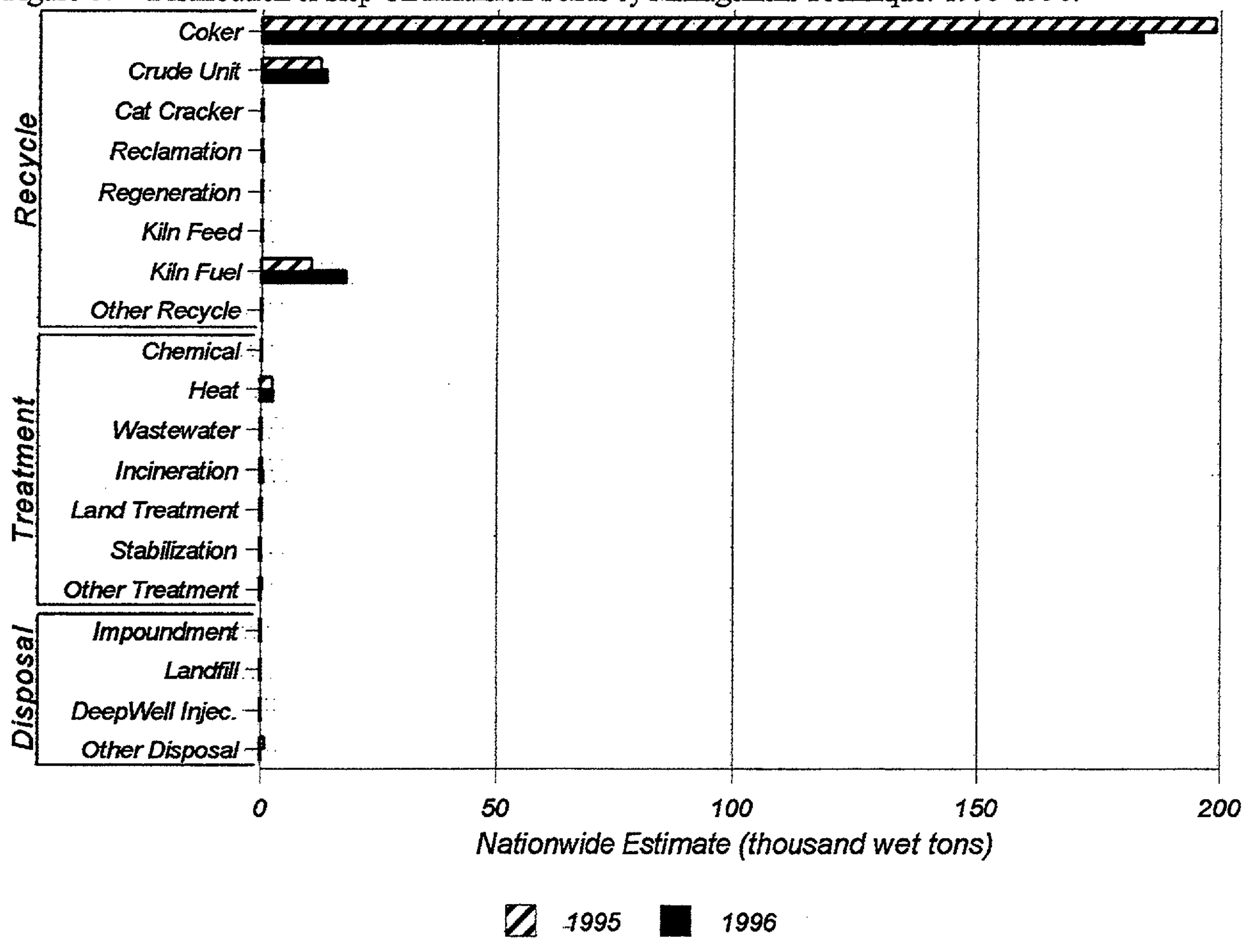
Figure 66—Nationwide Estimates of Slop Oil Emulsion Solids by Management Practice: 1995-1996.



[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 1995 and 1996. This stream is primarily managed by techniques that recycle the oil content. This is most commonly accomplished by routing the stream to a *coker*. This stream is also sometimes routed to a *crude unit*, or may be sent to a fuels blending unit for incorporation into *kiln fuel*.

Figure 67—Distribution of Slop Oil Emulsion Solids by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

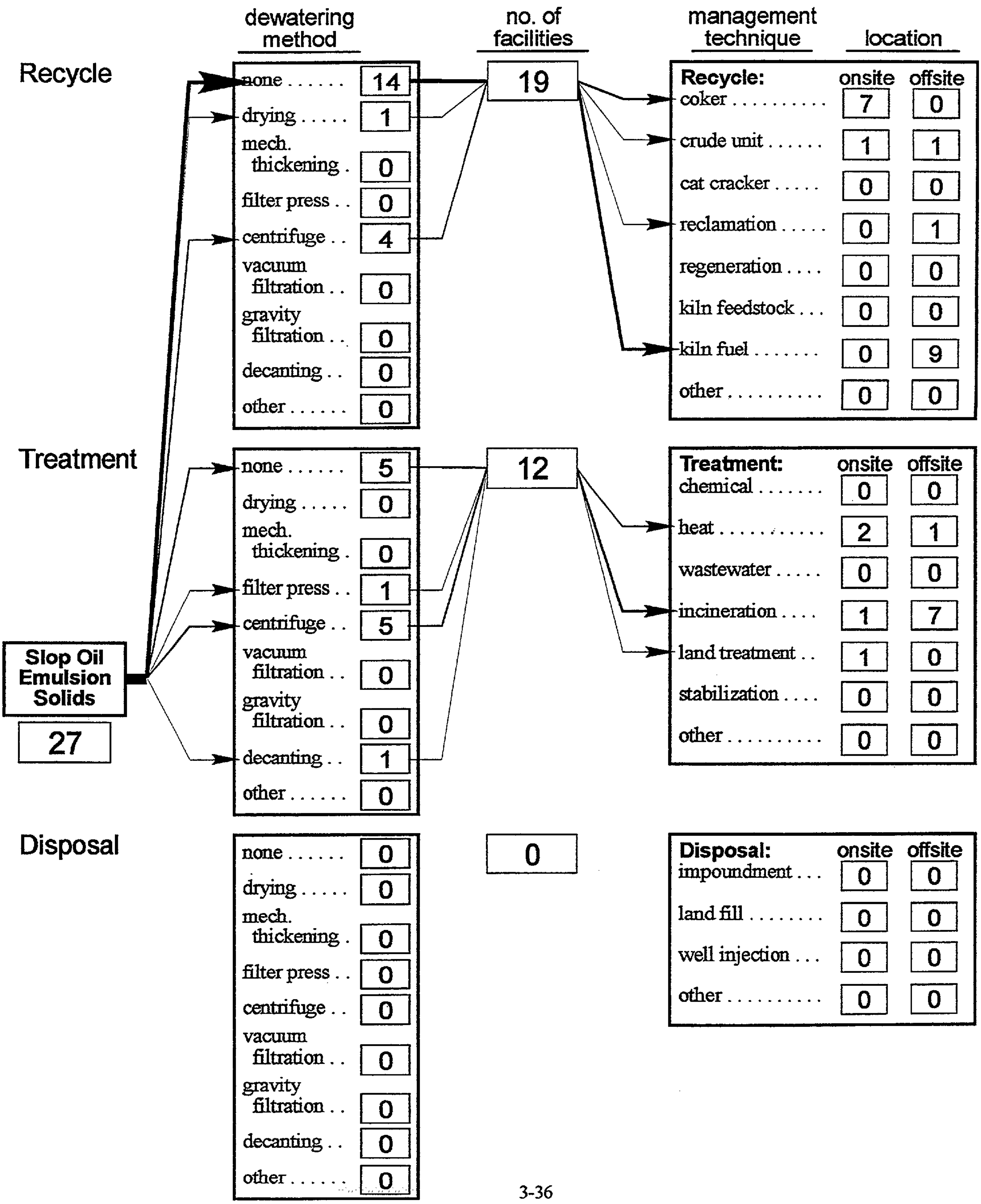
Other Treatment: one facility uses a proprietary biological process to treat oily sludges.

Other Disposal: one facility sends oily sludges to a Treatment, Storage, and Disposal Facility (T.S.D.F.) for disposal.

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: 1996

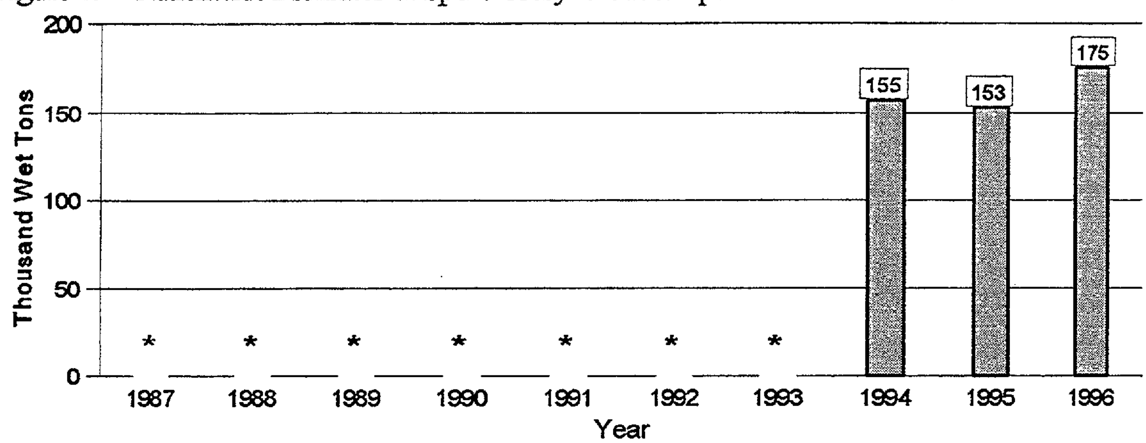
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



SPENT CRESYLIC CAUSTIC[11]

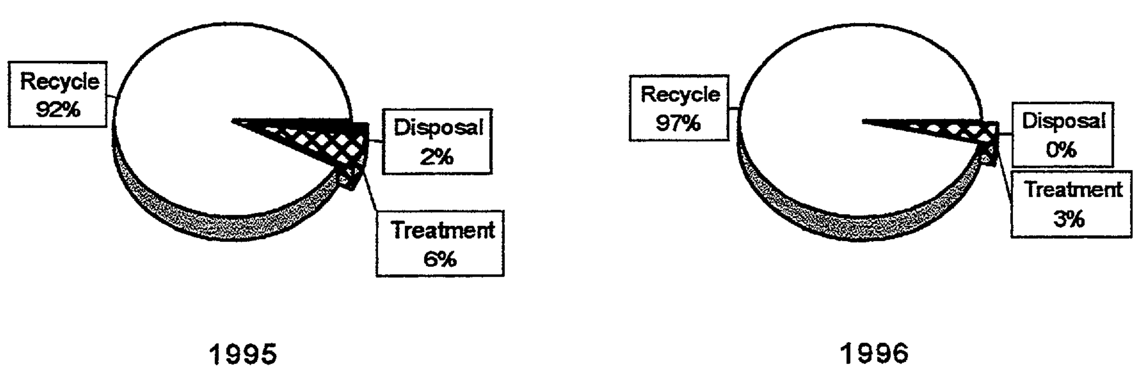
The U.S. petroleum refining industry managed an estimated 175 thousand wet tons of Spent Cresylic Caustic in 1996, which was a 14% increase from 1995. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 65. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows an increase from 988 thousand wet tons in 1995 to 1,271 thousand wet tons in 1996, an increase of 29%.

Figure 69—Nationwide Estimates of Spent Cresylic Caustic per Year: 1994-1996.



The portion of the Spent Cresylic Caustic stream that is managed by each management practice is shown in Figure 70 for 1995 and 1996. Recycling continues to be the dominant practice.

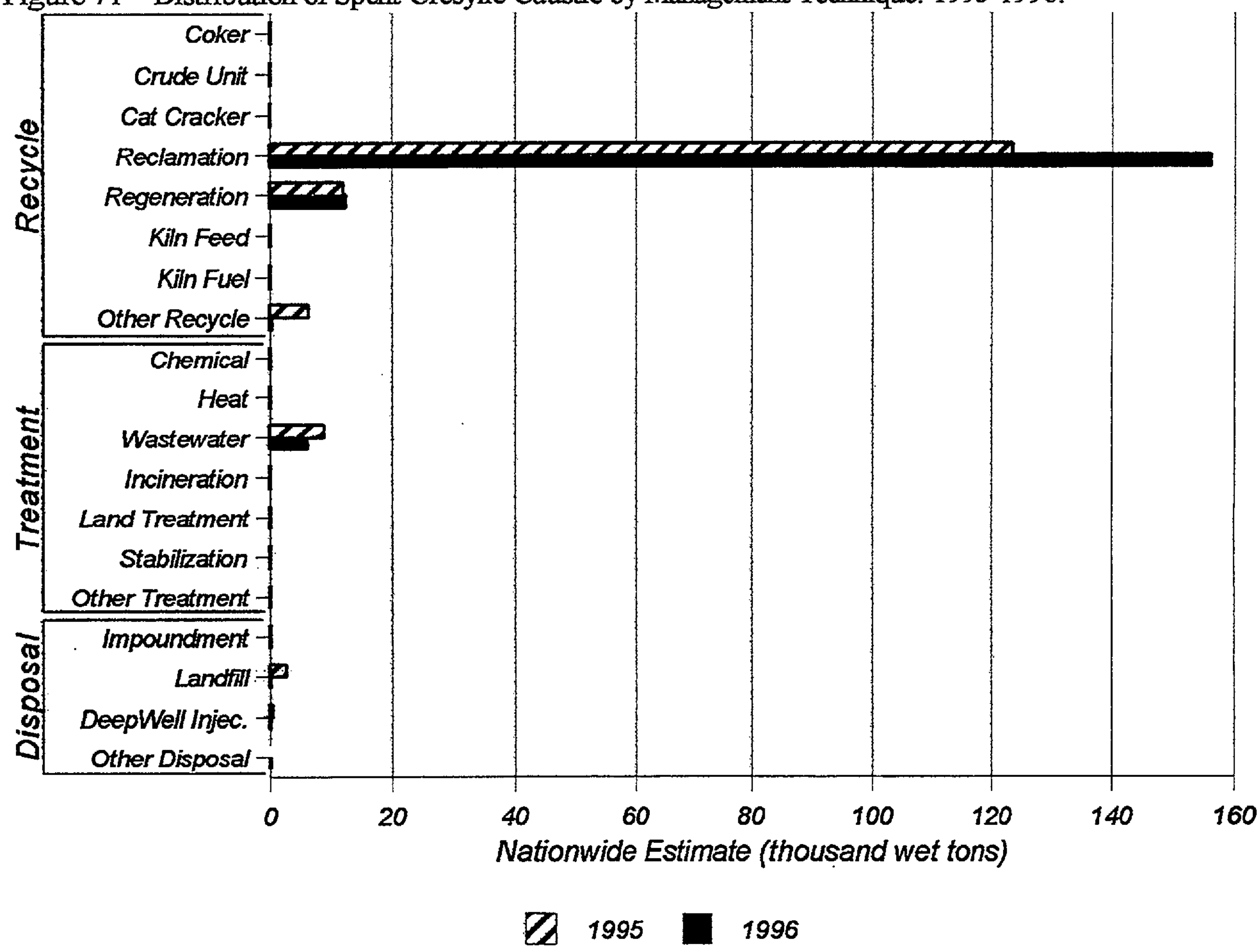
Figure 70—Nationwide Estimates of Spent Cresylic Caustic by Management Practice: 1995-1996.



[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 1995 and 1996. The most common management technique continues to be *reclamation*. Reclamation listings typically represent either reuse in the chemical industry or sale to a caustics processor/broker.

Figure 71—Distribution of Spent Cresylic Caustic by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: two facilities route this stream to a sour water stripper, and two others list reusing it for corrosion control (pH balance).

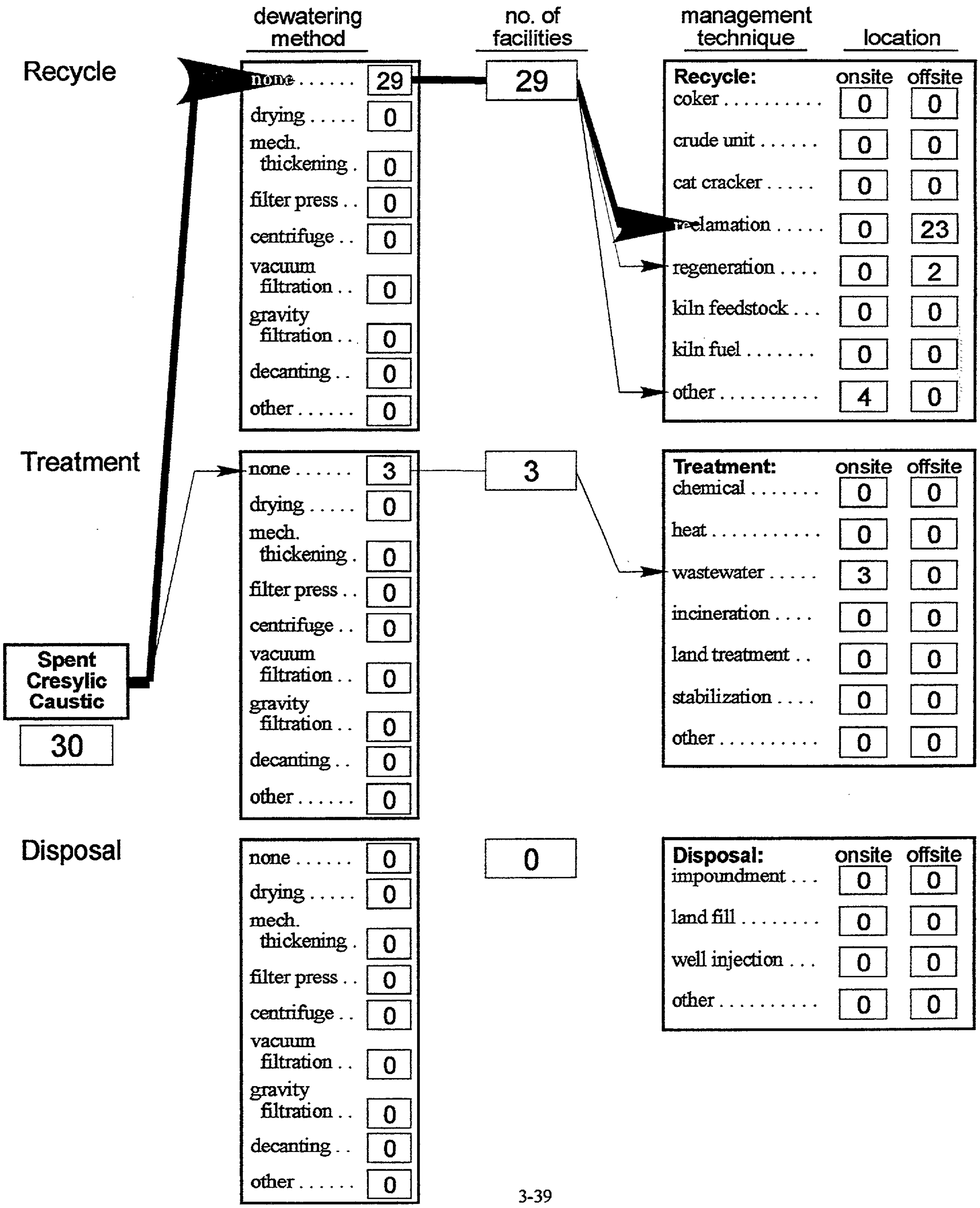
Other Treatment: none.

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: 1996

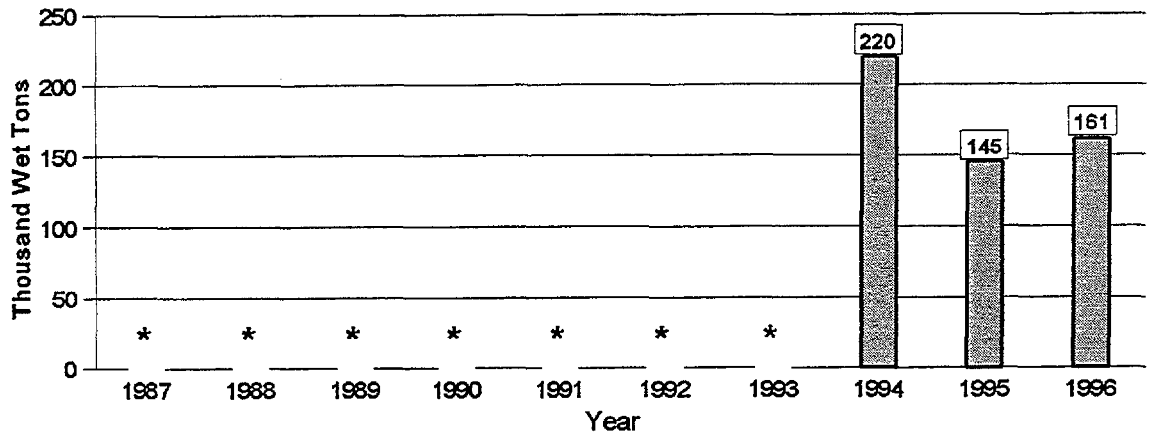
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



SPENT NAPHTHENIC CAUSTIC[12]

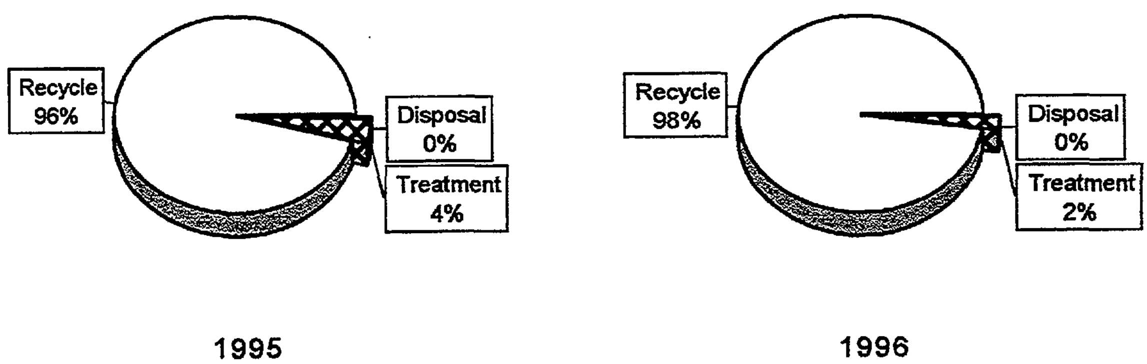
The U.S. petroleum refining industry managed an estimated 220 thousand wet tons of Spent Naphthenic Caustic in 1996, which was an 11% increase from 1995. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 73. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows an increase from 988 thousand wet tons in 1995 to 1,271 thousand wet tons in 1996, an increase of 29%.

Figure 73—Nationwide Estimates of Spent Naphthenic Caustic per Year: 1994-1996.



The portion of the Spent Naphthenic Caustic stream that is managed by each management practice is shown in Figure 74 for 1995 and 1996. Recycling continues to be the dominant practice.

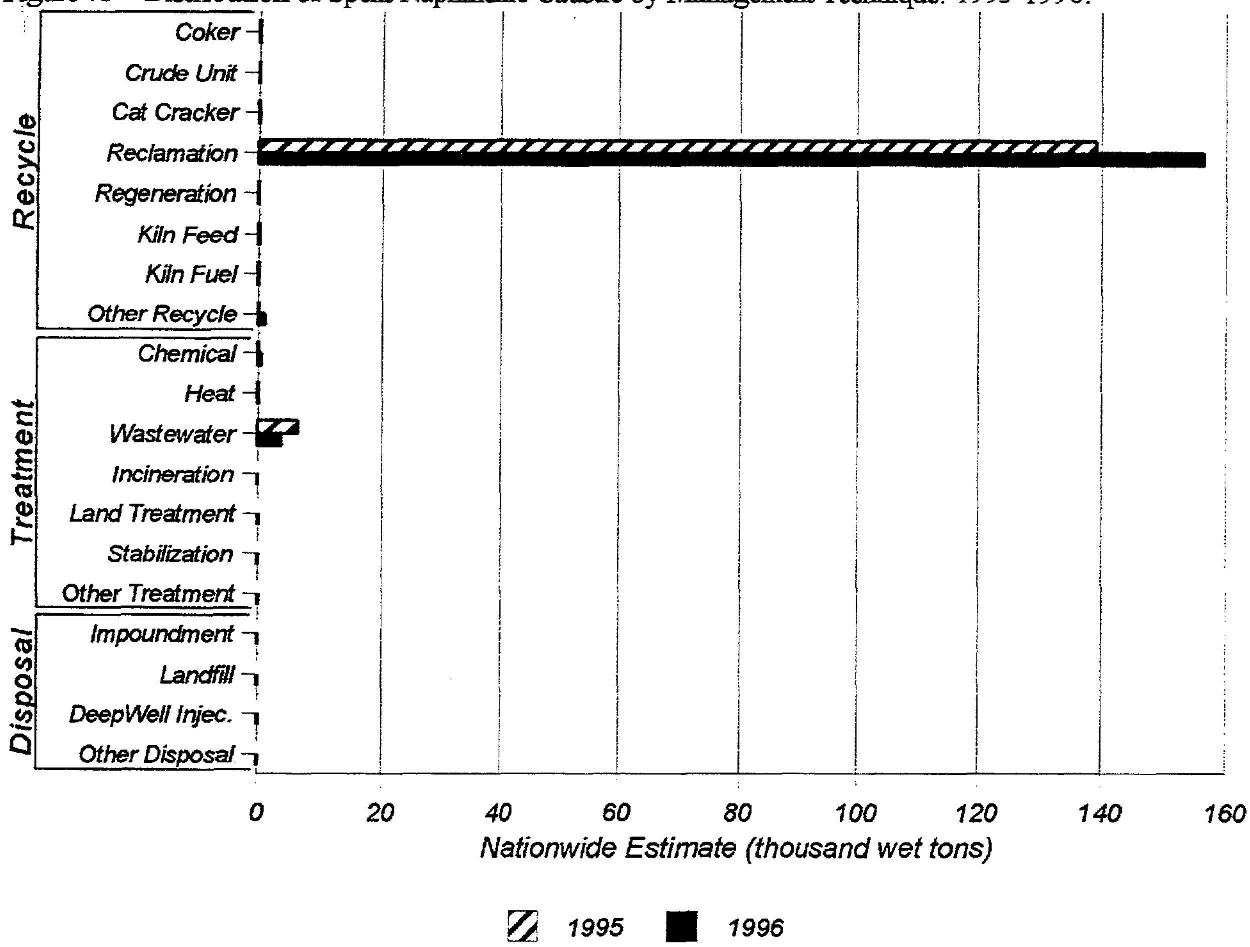
Figure 74—Nationwide Estimates of Spent Naphthenic Caustic by Management Practice: 1995-1996.



[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 1995 and 1996. The dominant management technique continues to be *reclamation*. Reclamation listings typically represent either reuse in the chemical industry or sale to a caustics processor/broker.

Figure 75—Distribution of Spent Naphthenic Caustic by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: none.

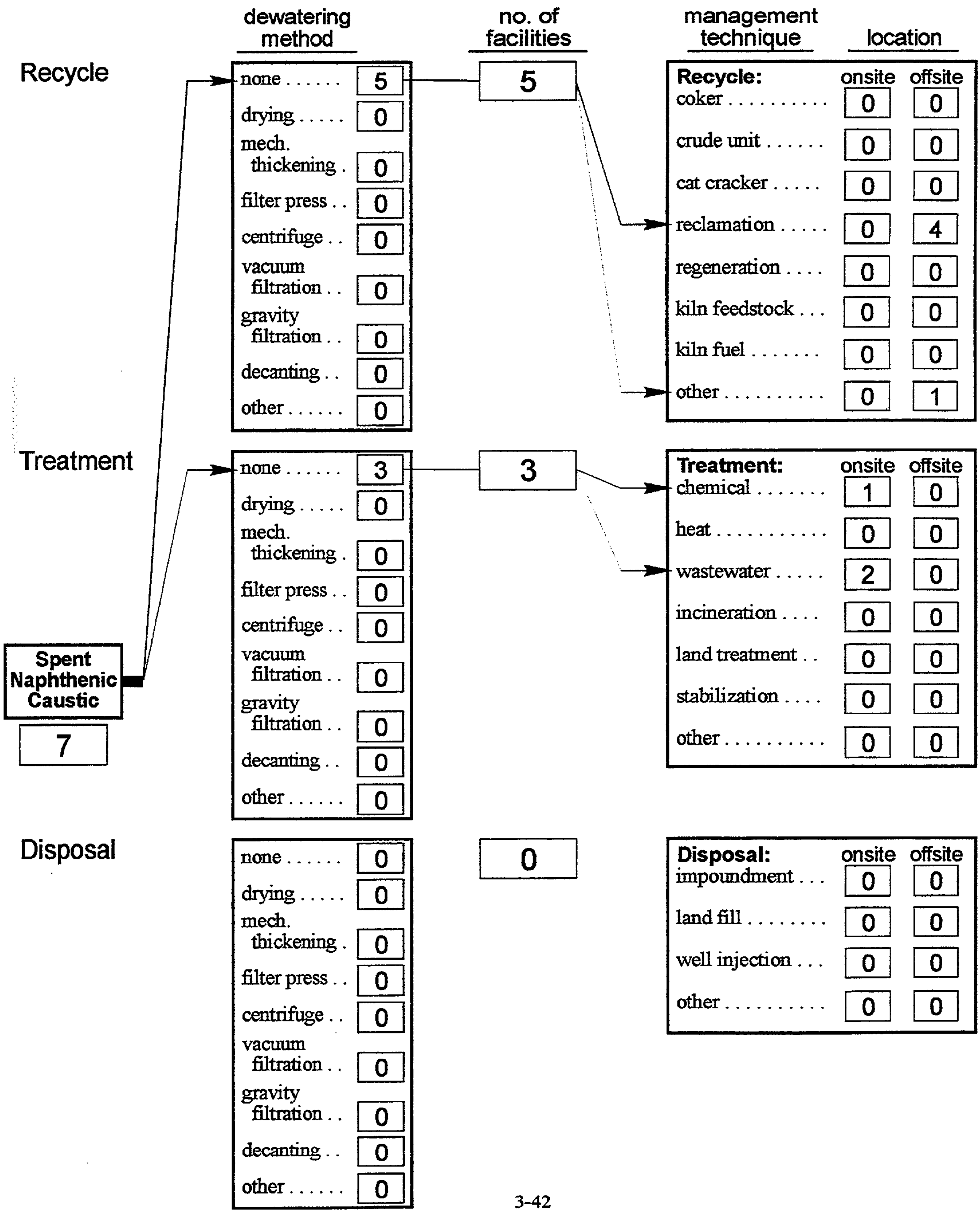
Other Treatment: none.

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: 1996

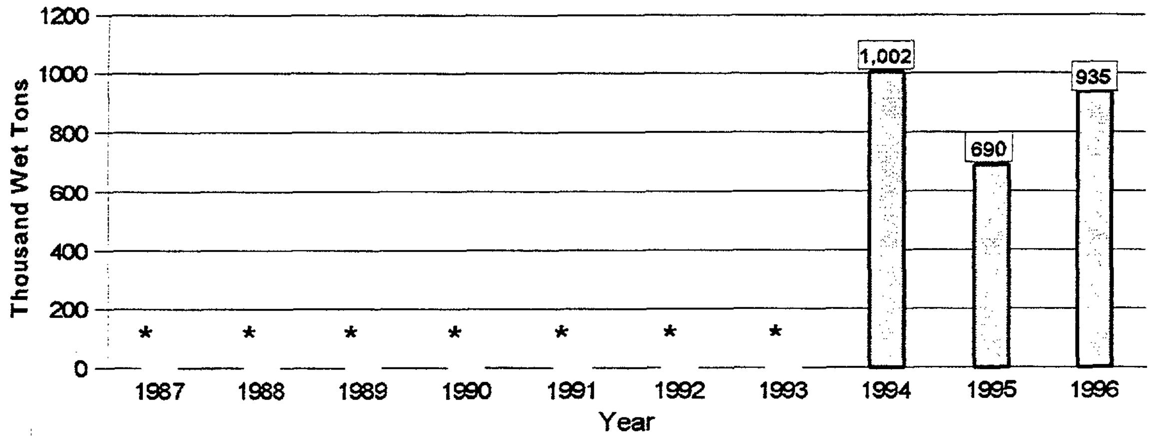
Note: Boxes show no. of facilities reporting each option.
Some facilities report multiple options



SPENT SULFIDIC CAUSTIC[13]

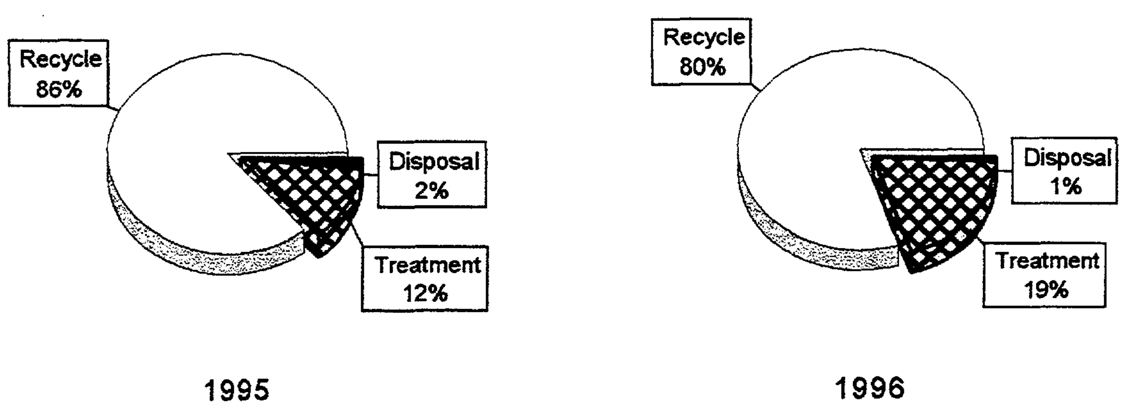
The U.S. petroleum refining industry managed an estimated 935 thousand wet tons of Spent Sulfidic Caustic in 1996, which was a 35% increase from 1995. This caustic was not identified as a separate residual stream prior to 1994, but a summary of the quantity managed per year from 1994 onward is presented in Figure 77. The combined quantities of all spent caustics managed per year since 1987 are summarized in Figure 91, which shows an increase from 988 thousand wet tons in 1995 to 1,271 thousand wet tons in 1996, an increase of 29%.

Figure 77—Nationwide Estimates of Spent Sulfidic Caustic per Year: 1994-1996.



The portion of the Spent Sulfidic Caustic stream that is managed by each management practice is shown in Figure 78 for 1995 and 1996. Recycling continues to be the most common practice.

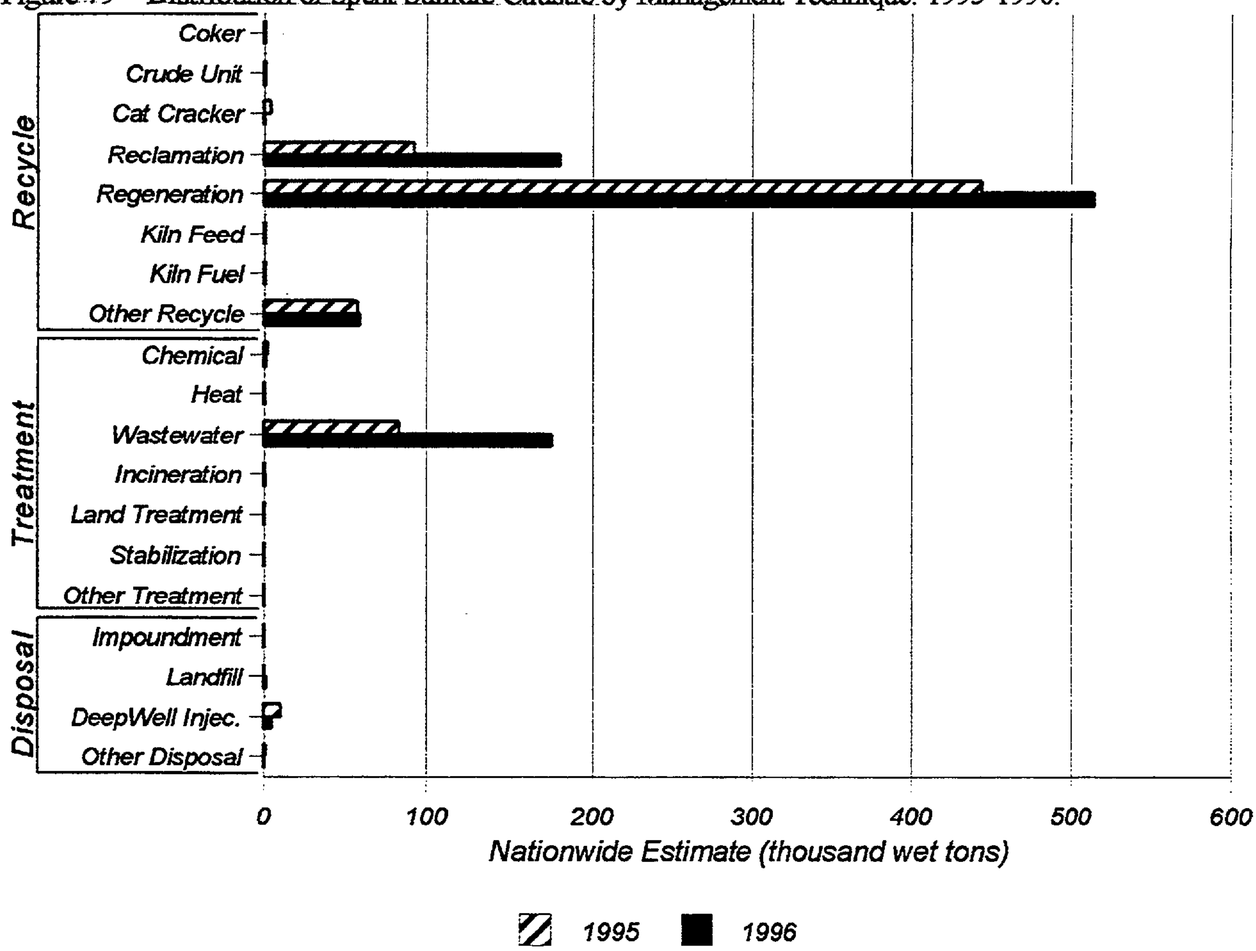
Figure 78—Nationwide Estimates of Spent Sulfidic Caustic by Management Practice: 1995-1996.



[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 1995 and 1996. This stream is typically *regenerated*, *recycled* for pH control, *reclaimed*, or managed in the *wastewater* treatment facility. Reclamation listings typically represent either reuse in the paper industry or sale to a caustics processor/broker, but in two cases involved recovery of elementary sulfur. The significant quantity estimated for *regeneration* is due primarily to the survey responses of one company with multiple facilities.

Figure 79—Distribution of Spent Sulfidic Caustic by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

Other Recycle: eight facilities reuse spent sulfidic caustic onsite for pH control, another routes this stream to a cracked gasoline treater for conversion to cresylic caustic, and another recycles this stream through an RCC unit.

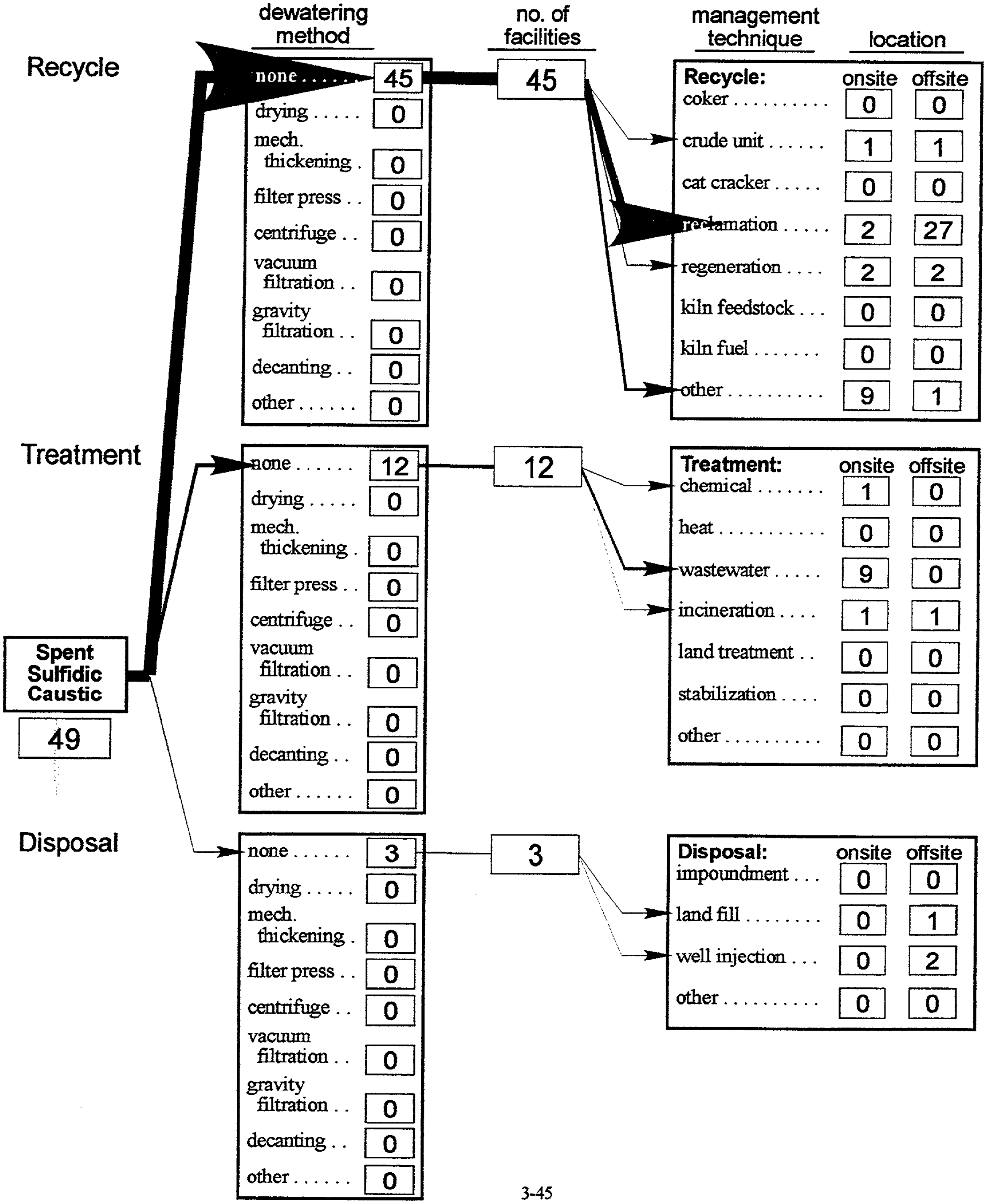
Other Treatment: none.

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: 1996

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: 1996

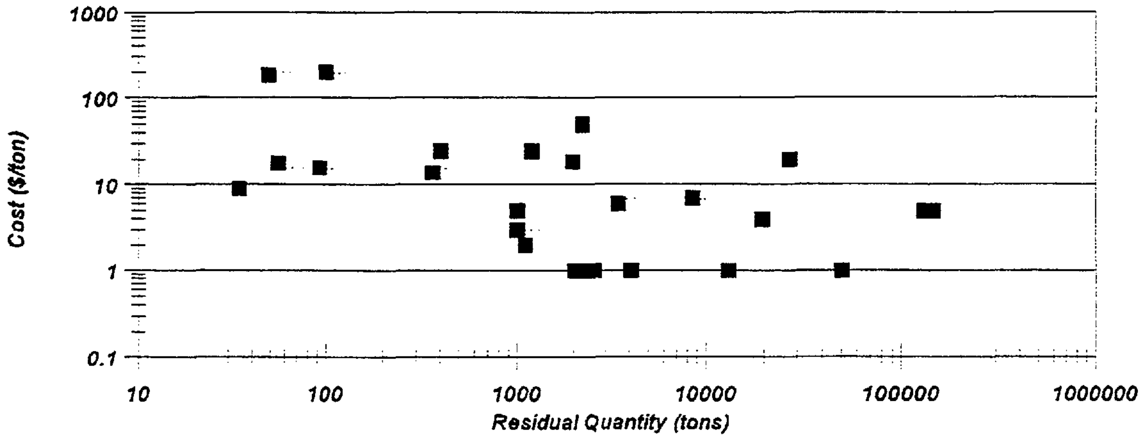


Figure 82—Offsite Management Cost for Spent Sulfidic Caustic: 1996

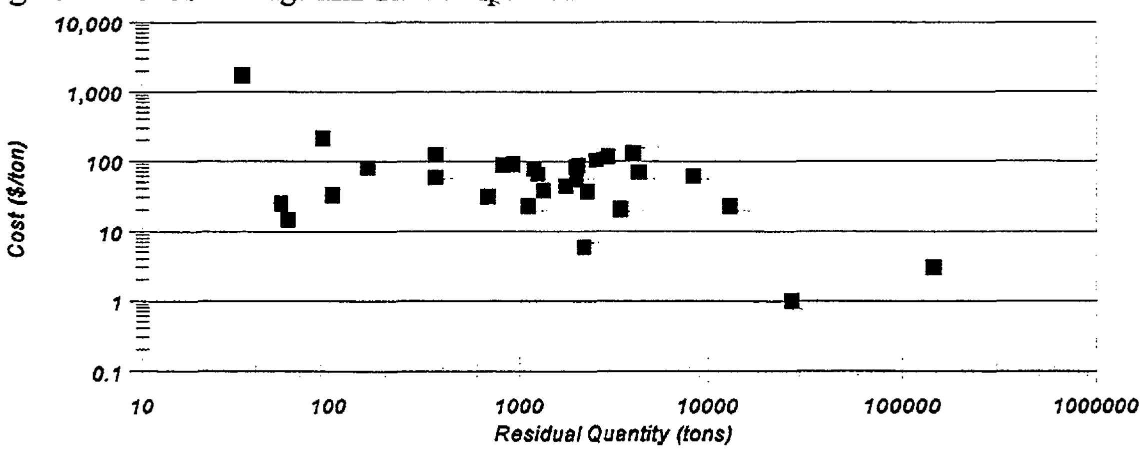
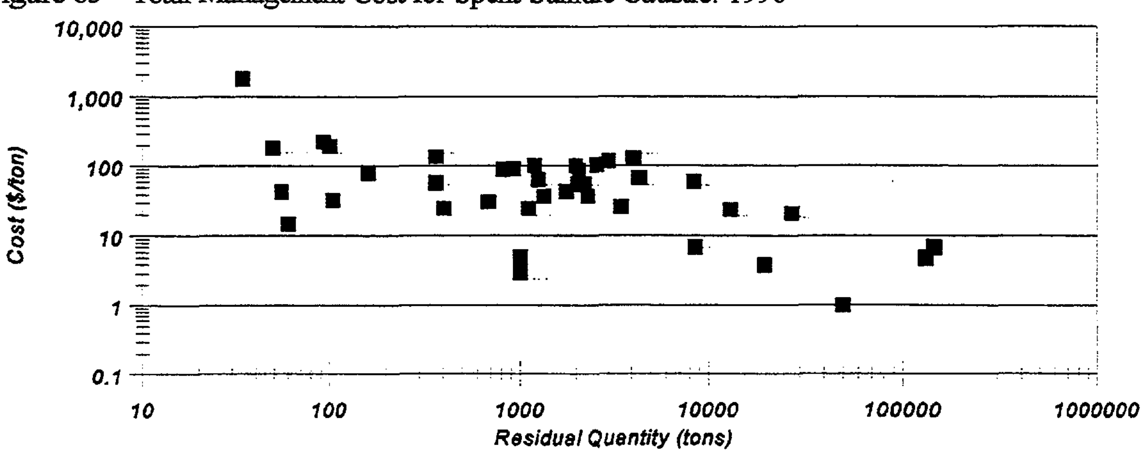


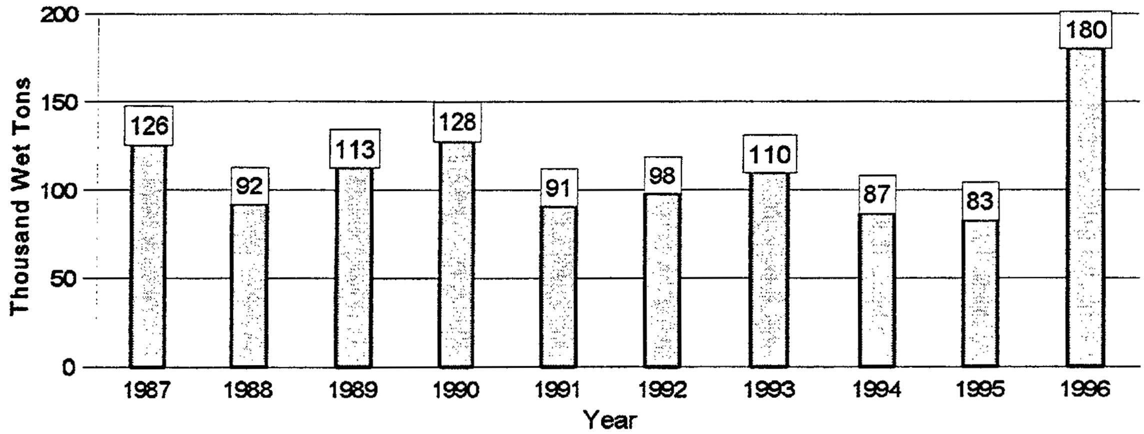
Figure 83—Total Management Cost for Spent Sulfidic Caustic: 1996



TANK BOTTOMS[14]

The U.S. petroleum refining industry managed an estimated 180 thousand wet tons of Tank Bottoms in 1996, which was a 116% increase from 1995. 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: 1987-1996.



The portion of the Tank Bottoms stream that is managed by each management practice is shown in Figure 85 for 1995 and 1996. While the total quantity managed is shown in Figure 84 to have increased significantly, Figure 85 shows that this increase was accompanied by a trend toward recycling.

Figure 85—Nationwide Estimates of Tank Bottoms by Management Practice: 1995-1996.

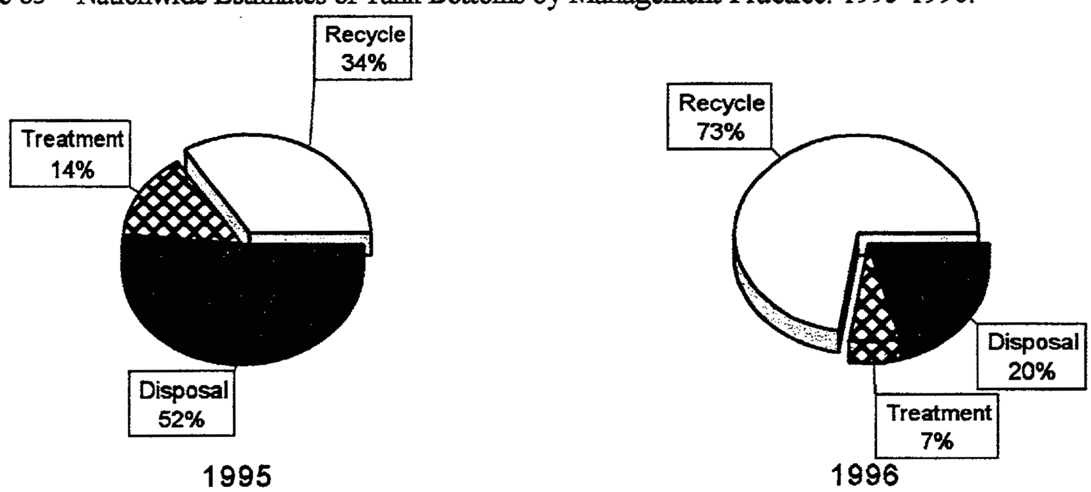


Figure 86 shows the Tank Bottoms distribution by management technique for 1995 and 1996. This stream is primarily managed by routing it to a *coker* in order to recycle the oil content. Other techniques used to manage this stream are to dispose of the material in a *landfill*, or to manage it by *land treatment*.

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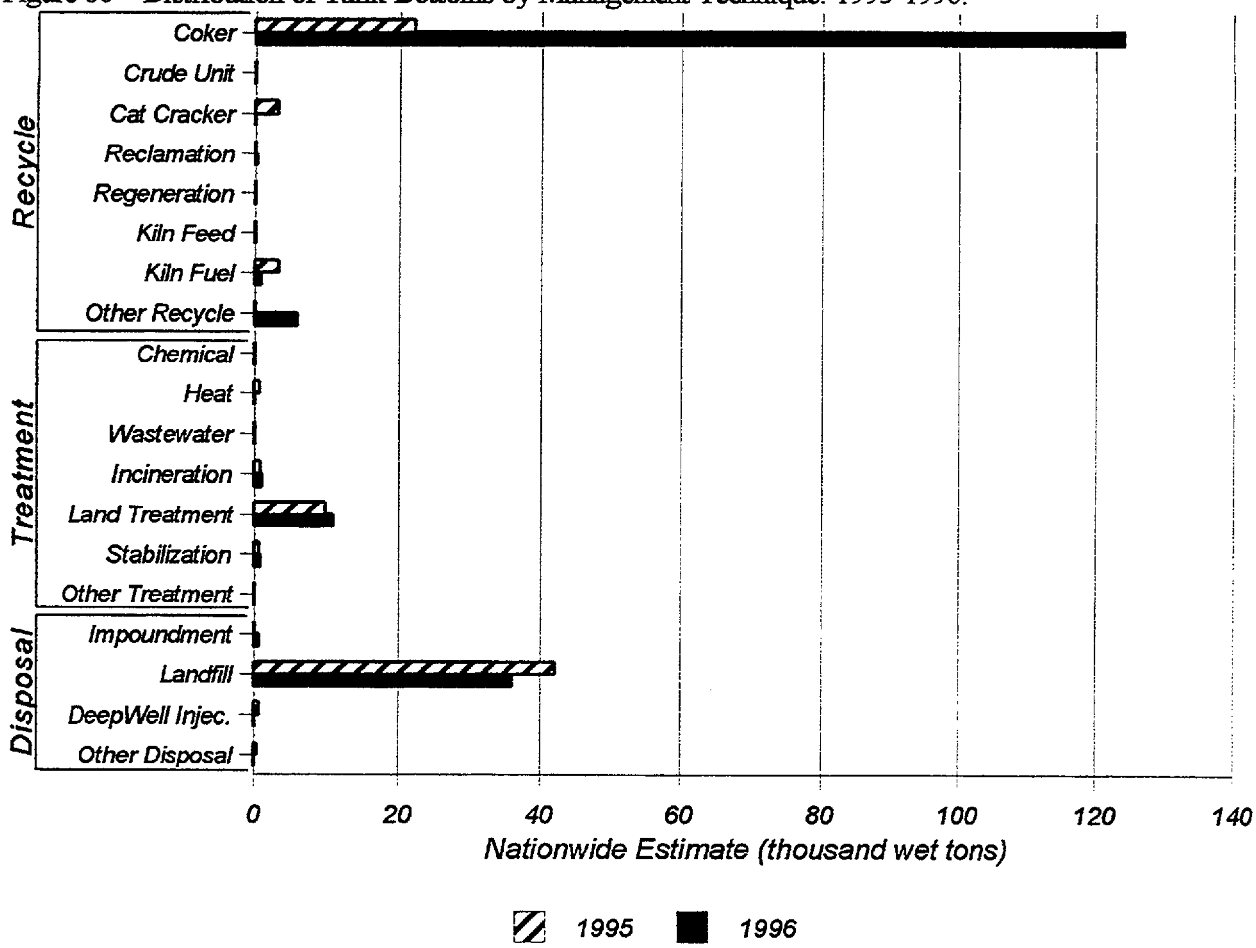
[14]Recall that this report uses labels such as Tank Bottoms in the broader context of a *residual stream* which includes materials that are not subject to RCRA regulation.

Figure 86—Distribution of Tank Bottoms by Management Technique: 1995-1996.



Responses in the *other* categories are listed below.

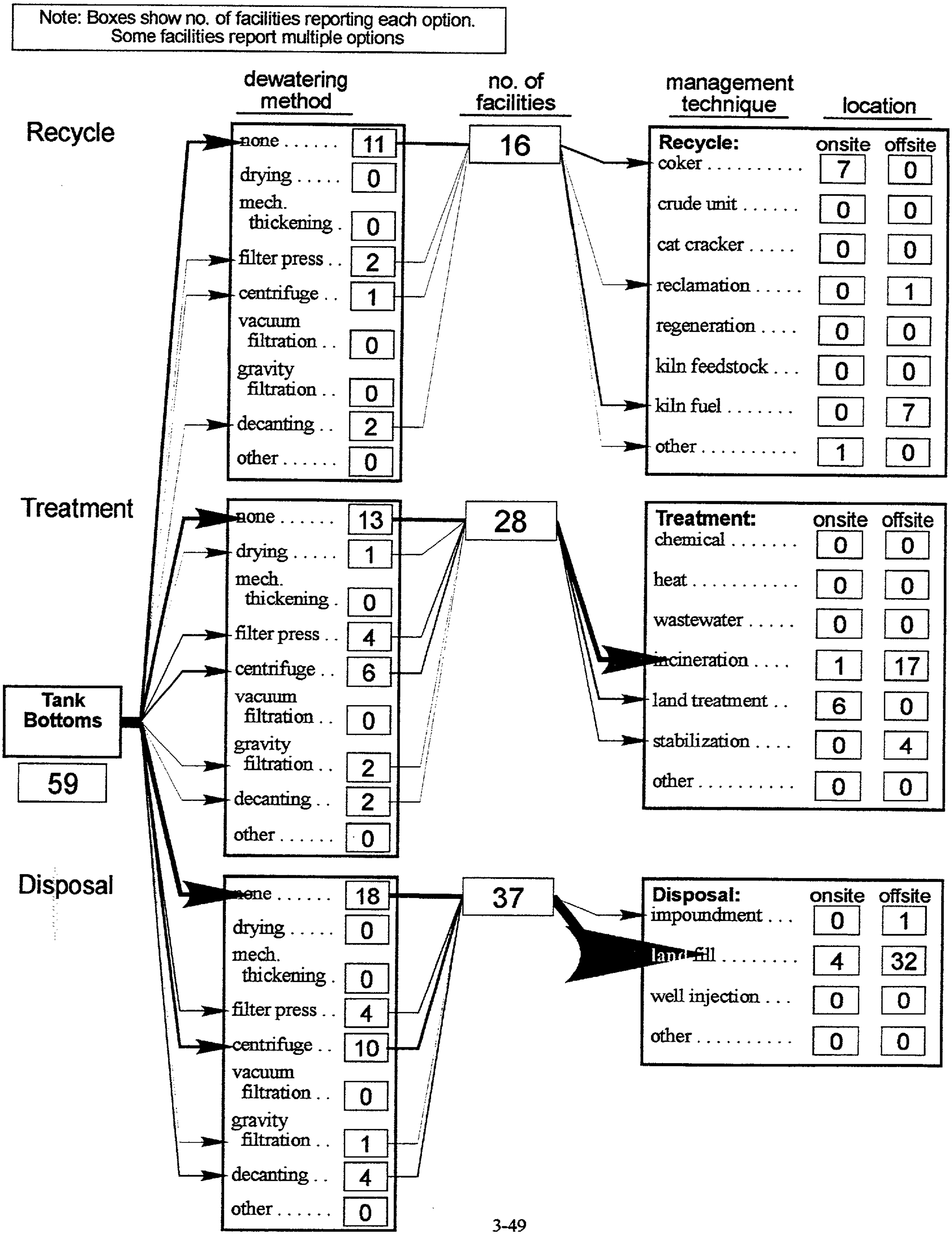
Other Recycle: one facility recycles tank bottoms to an RCC unit.

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 87 - Tank Bottoms Summary: 1996

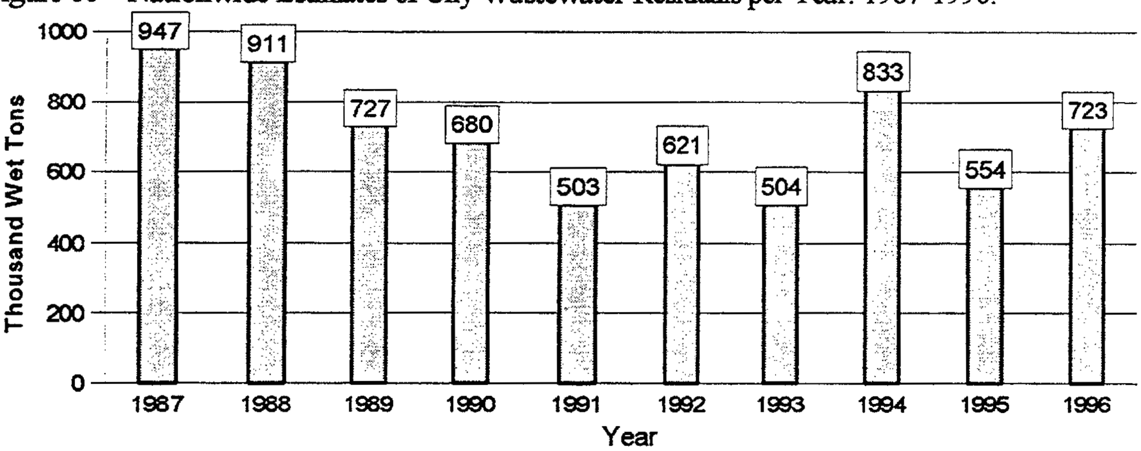


Section 4
COMBINED STREAMS

OILY WASTEWATER RESIDUALS[15]

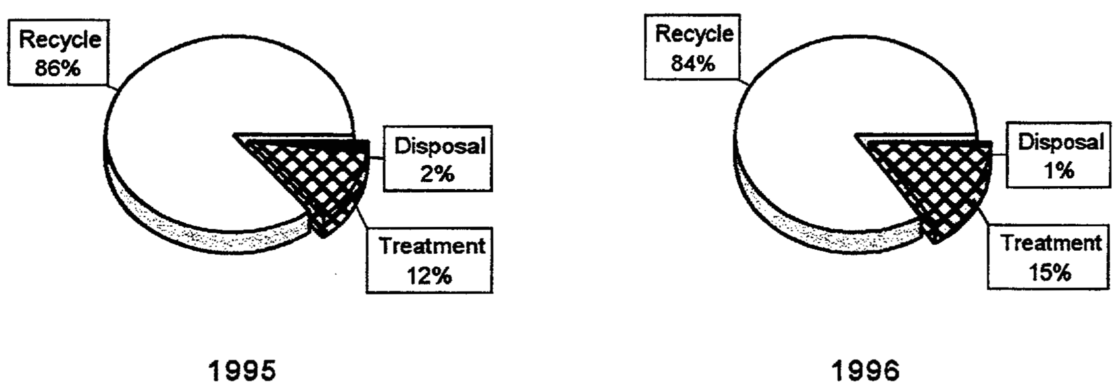
Several facilities combine some or all of the residuals associated with their wastewater treatment facility (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids). The combined quantity of these oily wastewater streams increased from 554 thousand wet tons in 1995 to 723 thousand wet tons in 1996, an increase of 30%. 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: 1987-1996.



The portion of the Oily Wastewater Residuals managed by each management practice is shown in Figure 89 for 1995 and 1996. Recycling continues to be the dominant management practice.

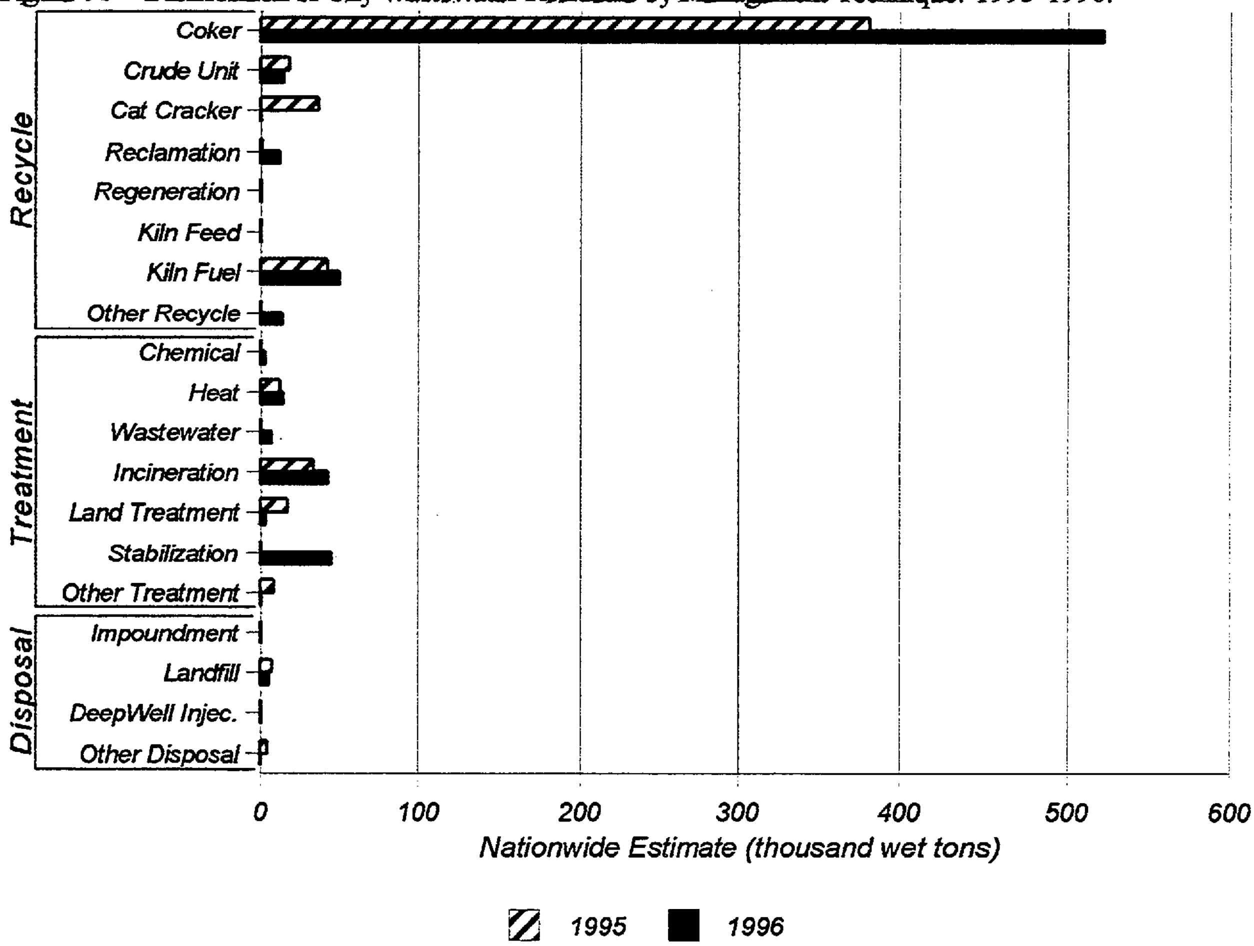
Figure 89—Nationwide Estimates of Oily Wastewater Residuals by Management Practice: 1995-1996.



[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 1995 and 1996. 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*.

Figure 90—Distribution of Oily Wastewater Residuals by Management Technique: 1995-1996.

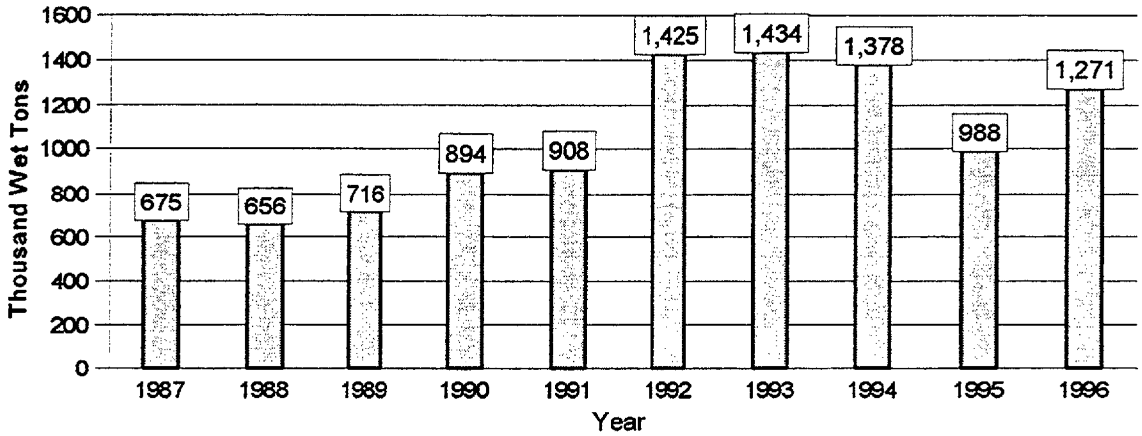


Responses in the *other* categories are listed in the sections for each of the streams that comprise oily wastewater residuals (i.e., API Separator Sludge, DAF Float, Primary Sludges, and Slop Oil Emulsion Solids).

SPENT CAUSTICS[16]

The U.S. petroleum refining industry managed an estimated 1,271 thousand wet tons of Spent Caustics (i.e., the Spent Cresylic Caustic, Spent Naphthenic Caustic, and Spent Sulfidic Caustic streams combined) in 1996, which was a 29% increase from 1995. 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: 1987-1996.



The portion of the Spent Caustics stream that is managed by each management practice is shown in Figure 92 for 1995 and 1996. Recycling continues to be the most common practice.

Figure 92—Nationwide Estimates of Spent Caustics by Management Practice: 1995-1996.

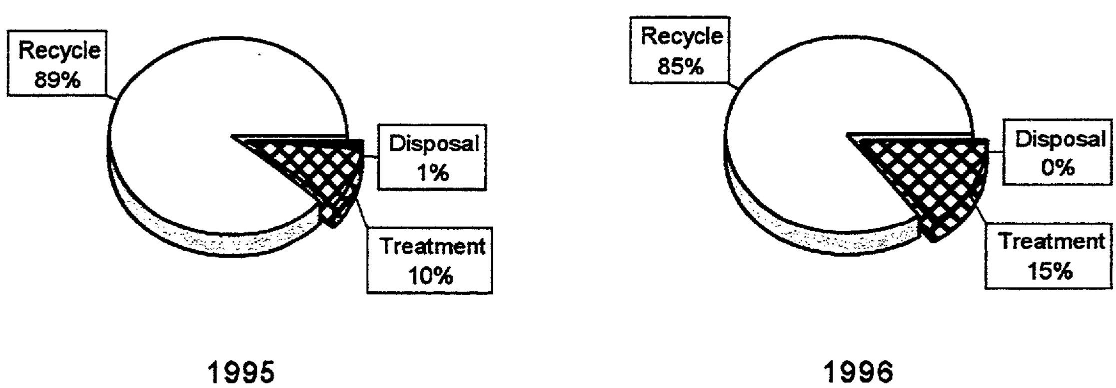
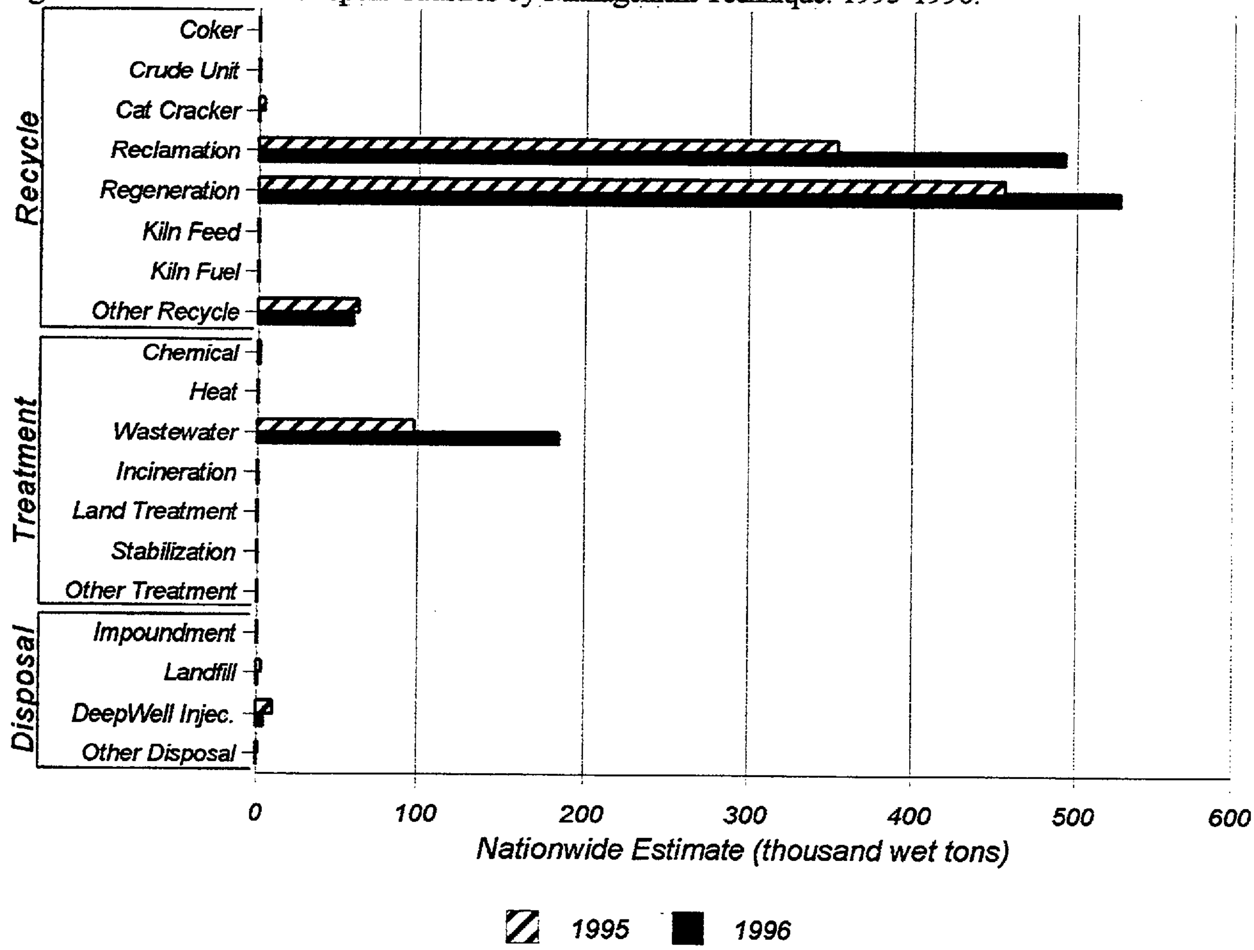


Figure 93 shows the Spent Caustics distribution by management technique for 1995 and 1996. While recycling by *regeneration* and *reclamation* are the dominant techniques used to manage Spent Caustics, there is significant variation depending upon the type of caustic. Referring back to Figures 71, 75, 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 (*reclaimed*). Reuse of cresylic and

[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.

naphthenic caustics is typically associated with chemical processing. Sulfidic caustic that is reused more commonly ends up in the paper industry. Spent caustics may be managed by *wastewater* treatment, or may be recycled for pH control in the wastewater plant. Spent caustics are the only type of residual reported as managed by *deep well injection* in 1996.

Figure 93—Distribution of Spent Caustics by Management Technique: 1995-1996.



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).

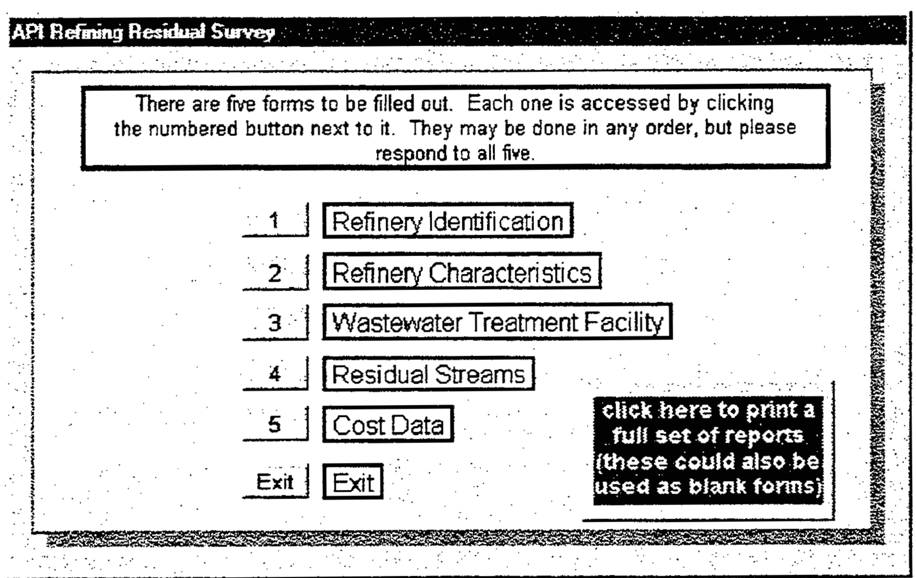
Appendix A
ELECTRONIC SURVEY FORM

The 1996 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 1996 API Refining Residual Survey.

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

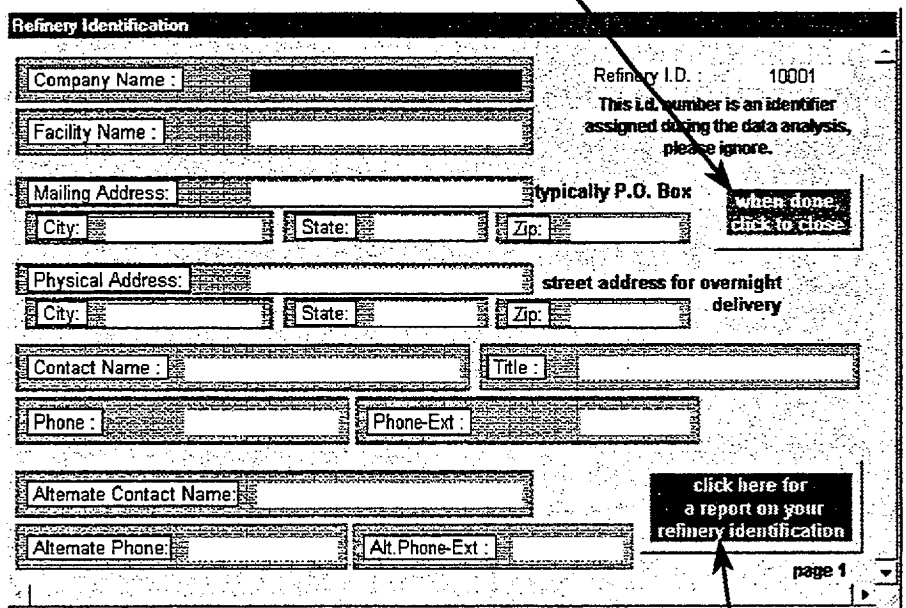
Processor	386 or higher.
Memory (RAM)	6 MB (8 MB recommended).
Hard disk	13 MB of free space.
Video monitor	VGA or higher.
Operating system	Microsoft Windows, version 3.1 or later.
Mouse	Required.

Upon loading the software, a Runtime icon group is created in the Program Manager. Double-clicking the Runtime icon results in the following menu being displayed on the screen.



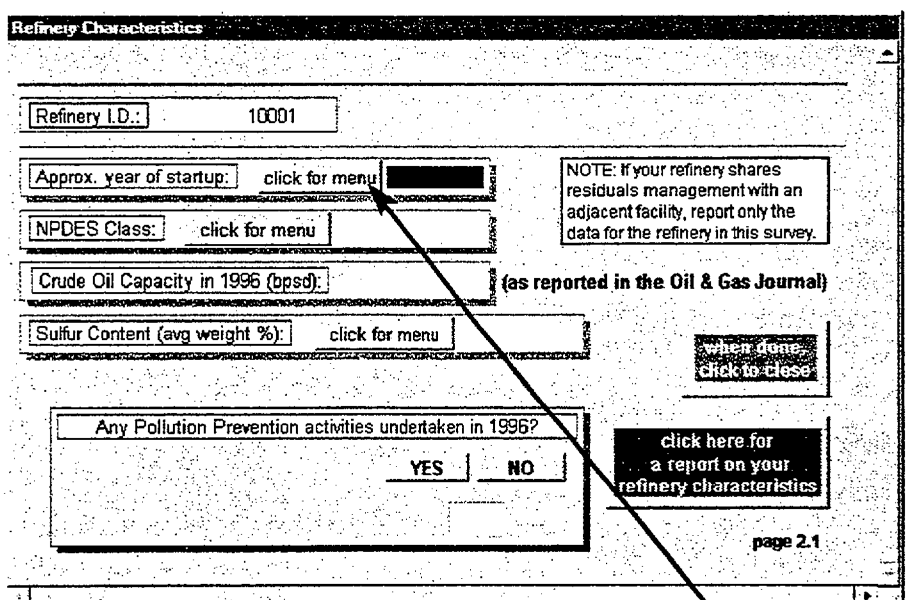
The written instructions direct the user to click on a button to open a form. Completing the survey requires filling out each of the five forms. A button was added for the 1996 survey, allowing the user to print out a paper copy of the forms. The user begins the survey by clicking on Button 1–Refinery 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.



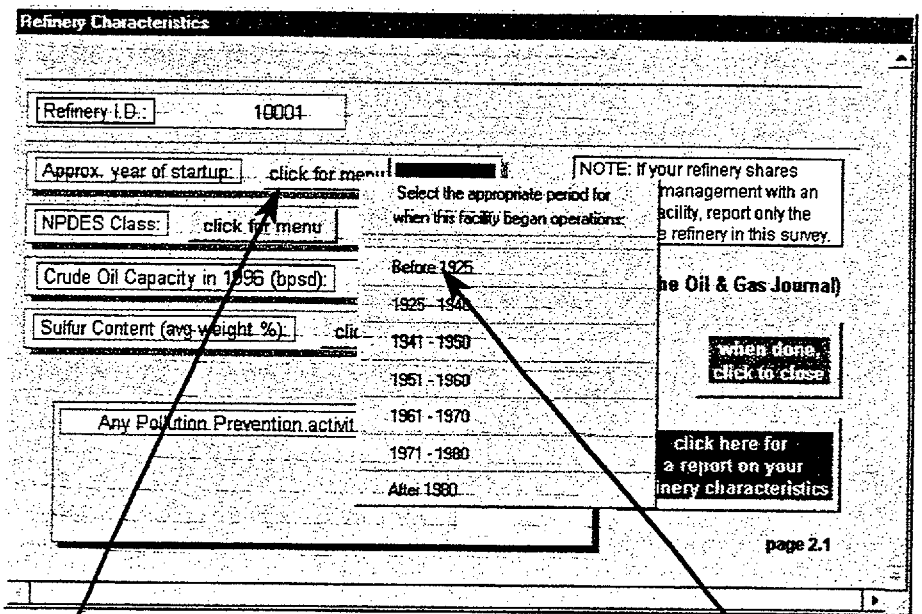
Clicking this button will print a report of the data on this page.

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



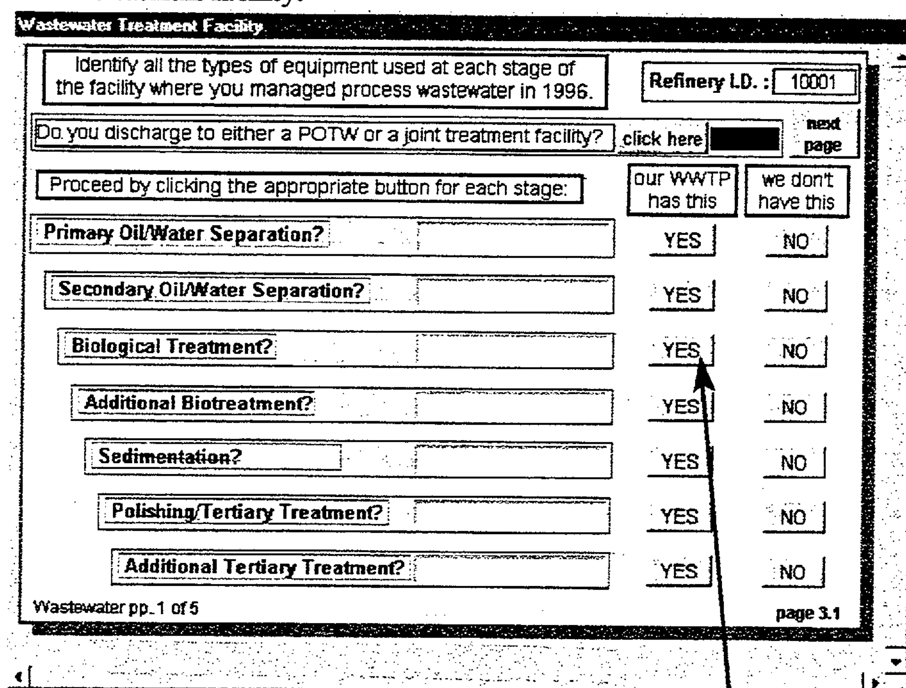
Many of the survey questions include a button that brings up a list for choosing a response.

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.



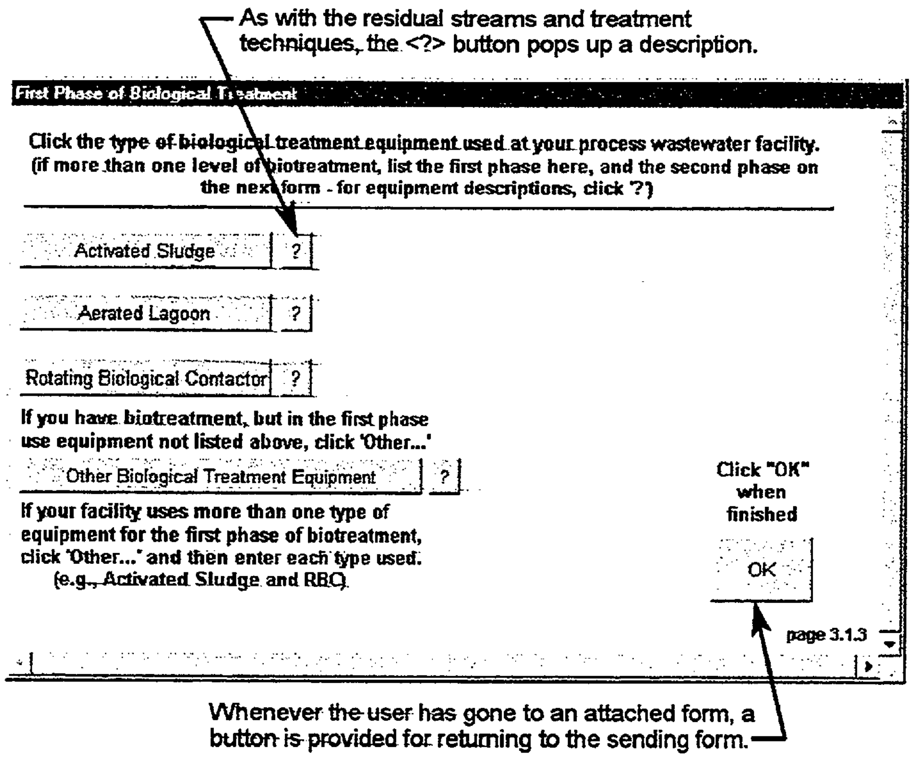
Users simply click the menu button for 'Approx year of startup', then click on the response that corresponds to the period in which their facility began operations.

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

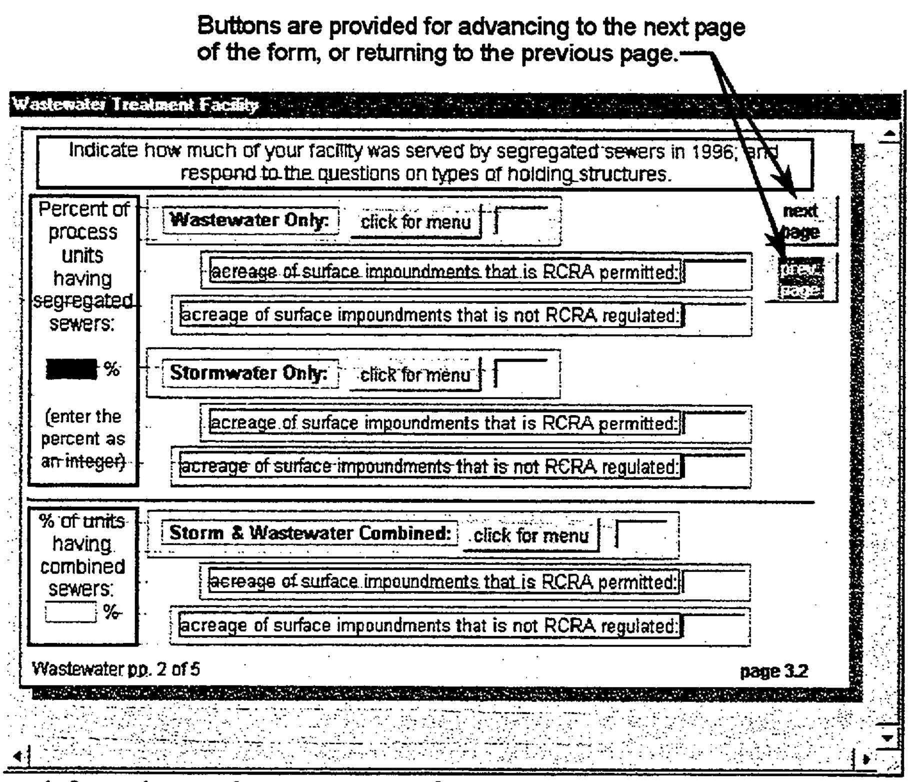


For each level of wastewater treatment, there is a button to open a form containing a list of equipment.

The first page of the Wastewater Treatment Facility form requests that the user indicate the types of equipment in use at the wastewater facility. The form shows various levels of wastewater treatment, and includes a button for each. Clicking the button calls up a form containing a list of the types of equipment typical to that level of treatment. One such list is shown on the next screen.

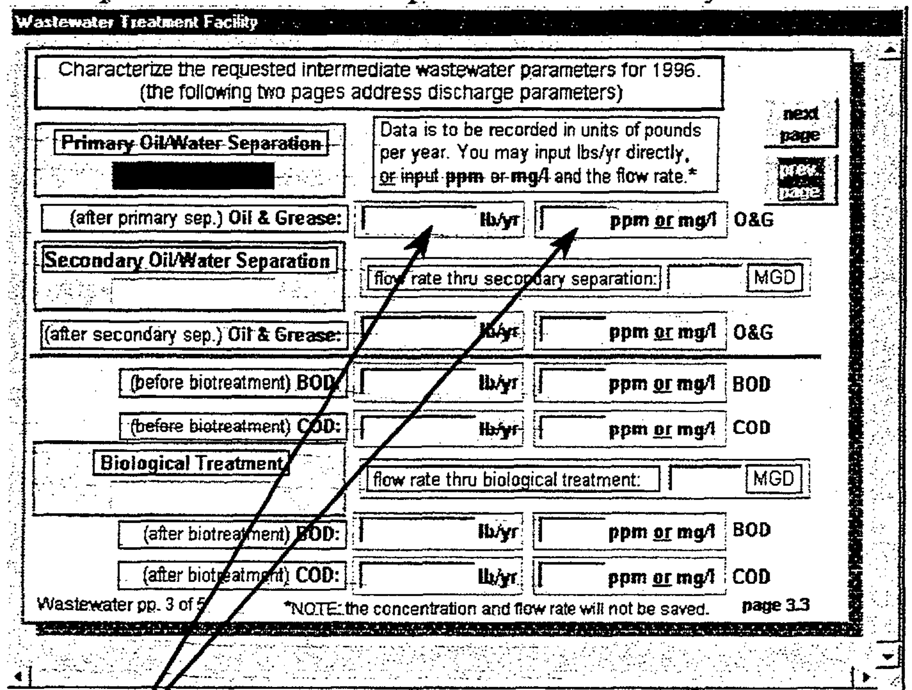


After responding to the equipment questions on the first page via its called lists, the user simply clicks the button labeled 'next page' to advance to the second page of the Wastewater Treatment Facility form.



This page collects information on the management of wastewater and stormwater. 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.

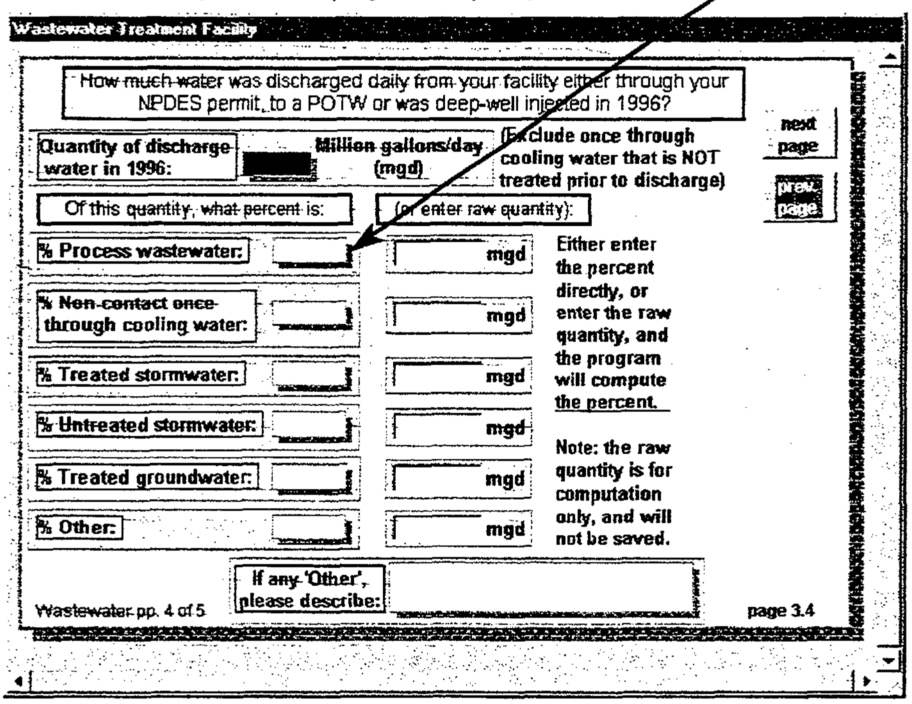
The third page of the Wastewater Treatment Facility form was revised for the 1996 survey to collect data on certain wastewater parameters at intermediate points in the wastewater system.



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.

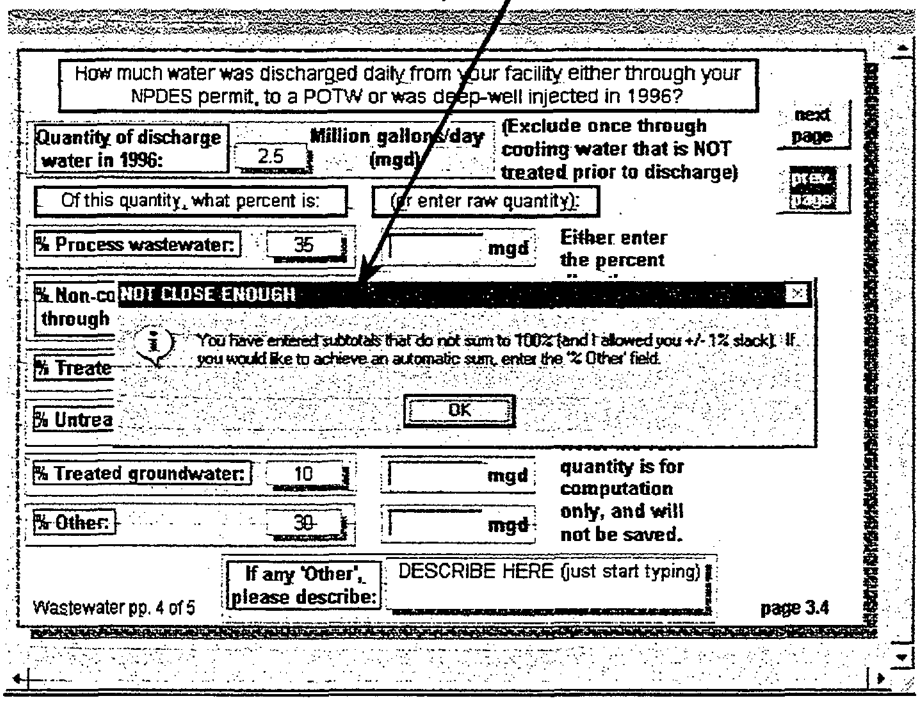
The survey proceeds to collect data on the quantity and sources of the water discharged from the facility.

If the user attempts to enter a decimal fraction rather than a percent, the program will prompt a correction.



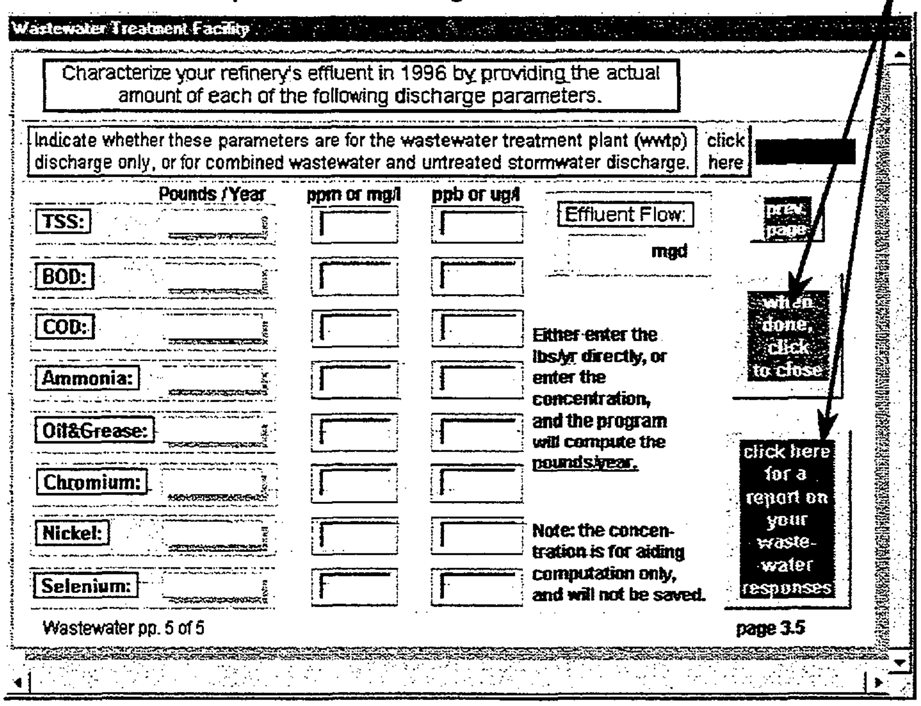
The next screen shows a typical message alerting the user of a data inconsistency.

Alerts such as this help prompt consistent data entry.



The final page of the Wastewater Treatment Facility form requests detail on the characteristics of the discharge water.

Being the last page of this form, the buttons for printing a report and for returning to the main menu are found here.



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 1996 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 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.

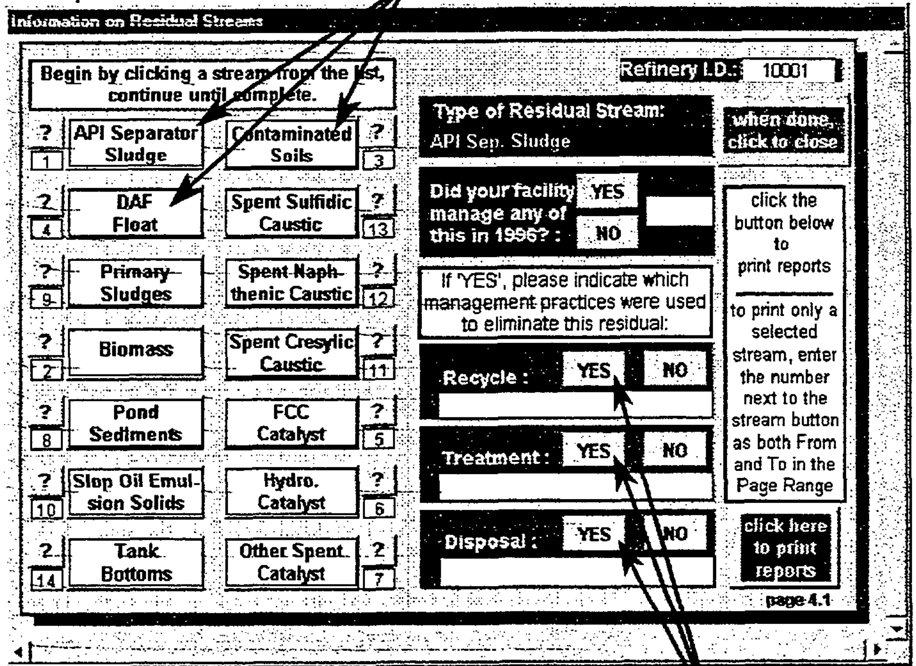
Spent Naphthenic Caustic—this spent caustic is typically from treating jet fuel.

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 storage tanks, including tanks storing crude oil, refined products (both leaded and unleaded), and bottoms receiver tanks (i.e., tanks collecting the heaviest product fraction from distillation 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.

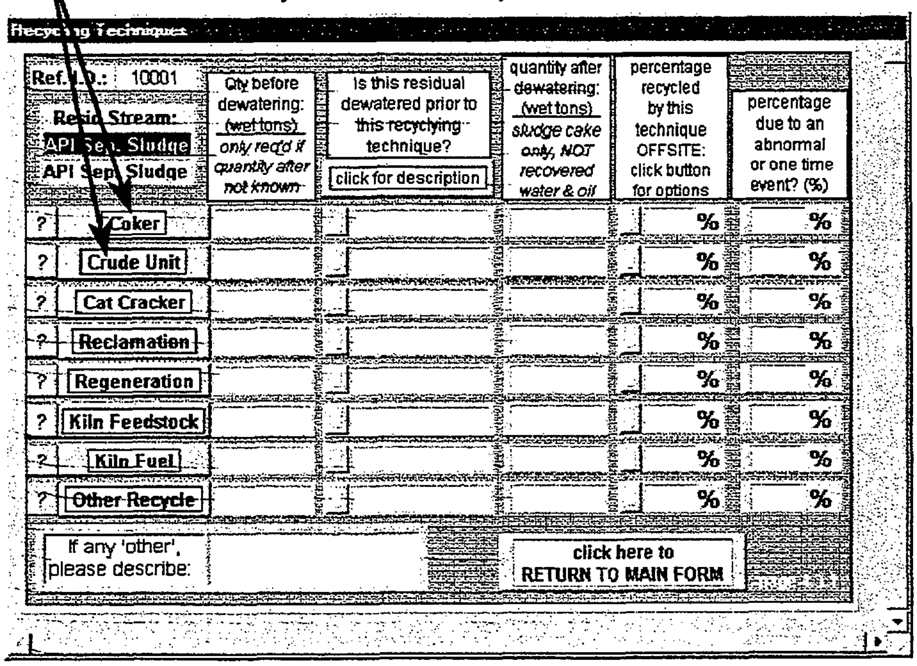
The user selects each stream in turn, and answers the questions for that stream.



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

Clicking a button with a stream name makes it the active stream in the form, and the user 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 data can be revised by selecting that stream and again clicking <YES> for that 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 1995 and 1996 surveys are listed below, with the definitions assigned to them for the 1996 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).

Reclamation—extracting oil or other usable material from the residual. If the residual is restored to its original use, however, then it is classified as Regeneration. Report thermal desorption here if it involves recovery; otherwise report it as Heat Treatment.

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).

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

Cement 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, is reported as Dewatering and NOT as Heat Treatment.

~~Physical—this is gravity separation; i.e., settling out into oil, water, and solid phases by standing in a tank for an extended period of time.~~ [*Discontinued as a treatment technique in the 1996 survey.*]

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 placing the residual 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, which are Treatment techniques.

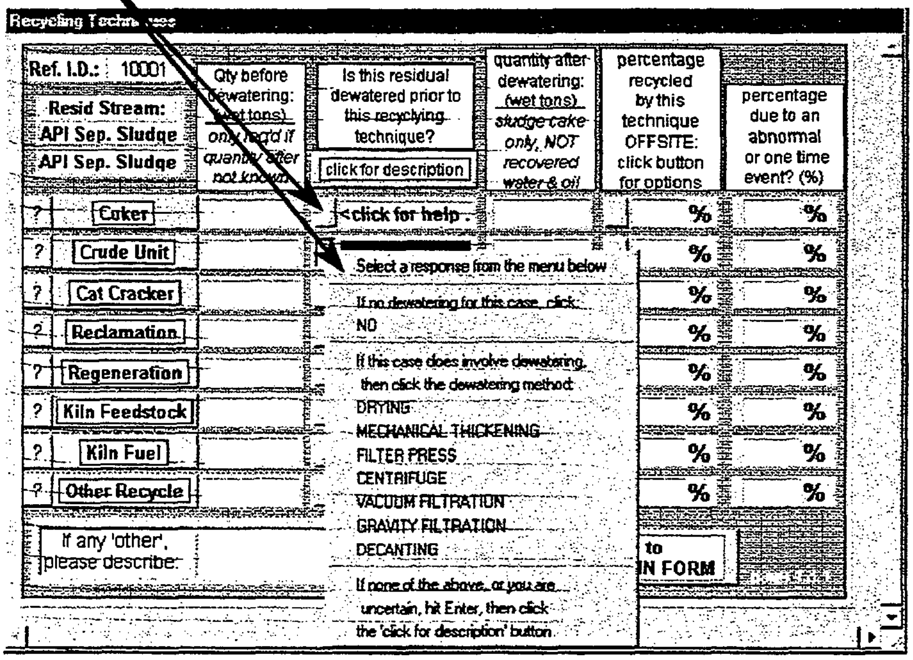
Landfill—this applies to material that is collected in or on the ground and covered. It typically involves only nonflowing residual material.

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.

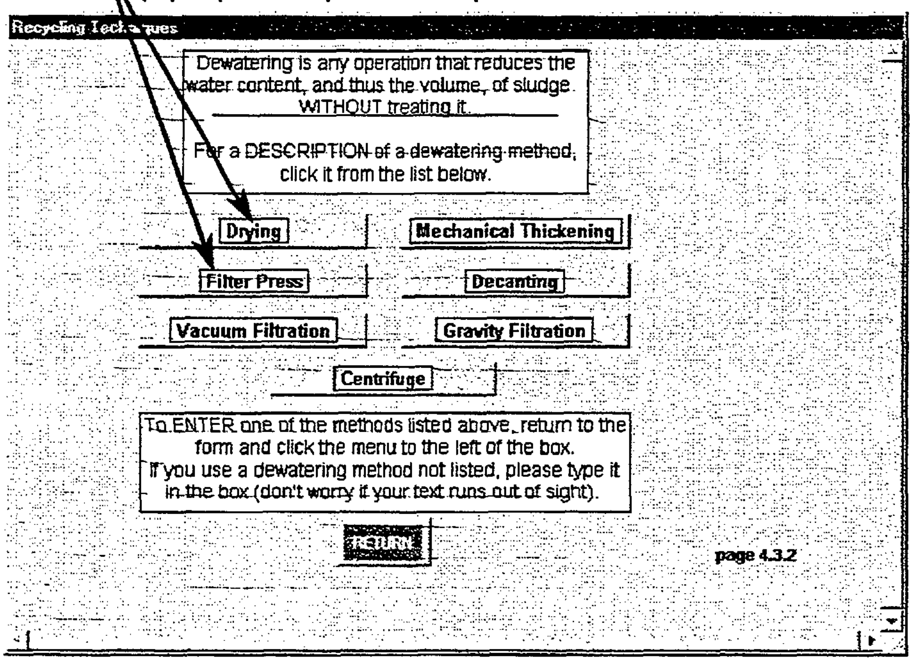
The form that is called by selecting a management practice includes a question on the type of dewatering operations used, if any. This question is repeated for each management technique listed on the form. As with most other non-numerical queries, a pop up menu is provided to facilitate the response.

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. Clicking on the button with the name of a dewatering operation pops up a menu with a description of that operation, as shown on the next screen.

Clicking on any of the dewatering operations pops up 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.

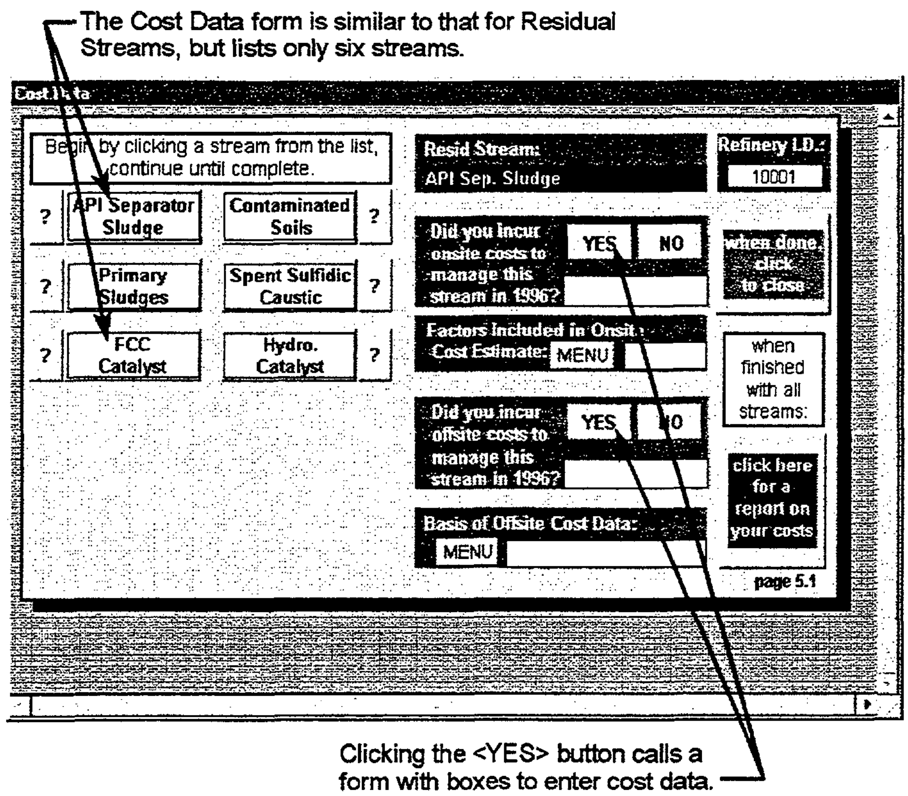
Decanting (Gravity Settling)—The sludge is placed in a tank, roll off box, or other container from which water is drawn off from the top.

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.

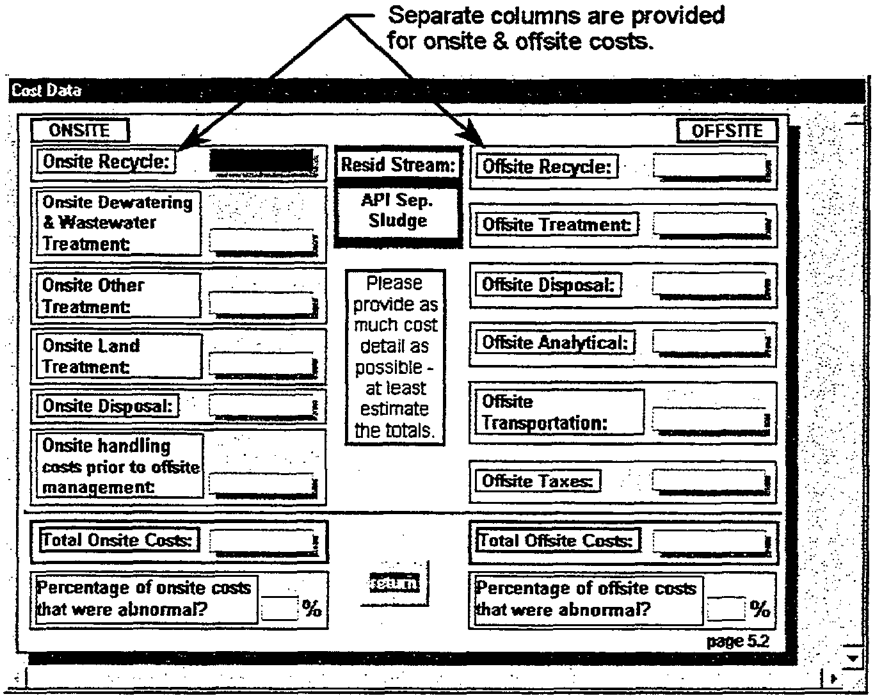
Gravity Filtration—The sludge is placed in a container (such as a roll off box designed for this purpose) which allows water to drain out through a screen or filter in the bottom.

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 directory to a diskette and mails it to API.

Appendix B
DESCRIPTION OF STATISTICAL PROCEDURES

The 1996 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 survey.

It was observed that a certain amount of the variance 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 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 survey.

Data were collected on the same 15 residual streams as in the 1994 survey, but combining the two primary sludge categories resulted in 14 streams in the 1995 and 1996 surveys. 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. In that the 1996 survey collected data on the same streams as in 1995, the same regression model was used again.

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 1996 DATA

Data from the 79 respondents to the 1996 survey 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 two data points falling above the upper bound, and two falling below the lower bound. The data were then ranked by squared error, confirming that the four facilities visually identified from the scattergraph did indeed have larger squared errors than the other facilities. These four outliers were removed, and the final regression was then performed on the remaining 75 facilities.

The equation developed from the 1996 survey is:

$$\sqrt{R} = 28.0 + 8.88\times10^{-4}C$$

with an R^2 measure of correlation equal to 0.70, which is the same level as for the 1995 survey.

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:

$$\sqrt{R} = 28.0 + 8.88\times10^{-4}C$$

And then:

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

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

$$\begin{aligned}\sqrt{R} &= 28.0 + 8.88\times10^{-4}\,(72{,}000)\\ &= 91.936\\ R &= (91.936)^2\\ R &= 8{,}452\end{aligned}$$

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:

$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-2} = \frac{224{,}183}{73} = 3071$$

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 107,358 bsd and the sum of the squares equals 663,700,000,000. The bias correction factor for the illustration of 72,000 bsd is then calculated as follows:

$$V\left(\sqrt{R_h}\right) = 3071\left[1 + \frac{1}{75} + \frac{(72{,}000 - 107{,}358)^2}{663{,}700{,}000{,}000}\right]$$
$$= 3{,}118$$

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

$$R^* = R + V\left(\sqrt{R}\right)$$
$$R^* = 8{,}452 + 3{,}118$$
$$= 11{,}570 \text{ wet tons.}$$

[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 8,452 and the bias correction factor was 3,118, and thus the unbiased estimate of the residual quantity is 11,570 wet tons. The variance of the unbiased estimate is

$$V(R^*) = 4(8{,}452)(3{,}118) + \frac{2(3{,}118)^2}{75-1}$$

$$= 105{,}676{,}100$$

This variance is between the value determined for the same illustration of 140,155,624 in the 1994 survey report and 87,145,716 in the 1995 survey report.

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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 1,708,451 wet tons, resulting in an estimate of 1,340,324 for the nonrespondent facilities. The total nationwide estimate of the quantity of these residual streams for the petroleum refining industry is therefore 3,048,776 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 1996 survey is 20,766,000,000.

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 3,433,533 to 4,009,949 wet tons.

The percent error, $E\%$, is then expressed as:

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

The percent error for the 1996 estimate is 7.7%.

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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 49,175 tons of the 1,887,198 total tons reported by respondents, or 2.6%. Applying the 2.6% proportion to the estimated nonrespondent total of 1,834,544 yields 47,802 tons. Adding the respondent and nonrespondent quantities yields an estimated nationwide total quantity of API Separator Sludge of 96,977 wet tons.

Appendix C
DATA TABLES

Table C.1—Summary of Respondent Data in Wet Tons: 1996

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	1996 Subtotals
Coker	33,089	46,506	0	105,118	0	0	0	0	33,306	93,082	0	0	0	62,885	373,985
Crude Unit	0	0	0	18	0	0	0	0	0	7,043	0	0	175	0	7,236
Cat Cracker	0	0	0	0	125	0	0	0	0	0	0	0	0	0	125
Reclamation	4,131	0	695	670	1,280	10,223	18,308	0	887	30	79,184	79,297	91,343	84	286,132
Regeneration	0	0	0	0	365	4,590	48	0	0	0	6,285	0	261,092	0	272,380
Kiln Feedstock	0	0	0	0	30,905	22	85	0	0	0	0	0	0	0	31,013
Kiln Fuel	5,792	0	223	6,448	0	4	0	0	3,192	9,210	0	0	0	397	25,267
Recycle Other	93	51,519	37,126	6,400	0	0	0	0	0	0	157	460	29,544	3,000	128,299
Recycle Subtotal	43,104	98,025	38,044	118,654	32,675	14,839	18,441	0	37,385	109,366	85,625	79,757	382,154	66,365	1,124,436
Chemical	1,003	0	122	0	0	208	26	0	123	0	0	177	329	0	1,988
Heat	1,225	1,004	97	1,099	0	0	194	0	3,189	1,187	0	0	0	0	7,995
Wastewater	0	3,590	0	3,250	0	0	0	0	0	0	3,046	1,830	88,856	0	100,572
Incineration	1,604	38,500	479	13,919	14	138	351	0	5,313	152	0	0	51	526	61,046
Land Treatment	1,137	35,551	52,821	0	633	0	328	14,878	136	47	0	0	0	5,537	111,069
Stabilization	0	839	1,012	2,908	0	13	0	0	19,137	0	0	0	0	424	24,333
Treatment Other*	227	112,876	25	0	0	0	0	0	0	0	0	0	0	0	113,128
Treatment Subtotal	5,196	192,360	54,556	21,176	647	359	898	14,878	27,898	1,387	3,046	2,007	89,236	6,487	420,131
Impoundment	0	298	4,500	0	0	0	0	13,200	0	0	0	0	0	340	18,338
Landfill	874	78,848	167,432	310	39,091	3,809	4,845	7,154	1,098	0	0	0	332	18,235	322,030
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	0	0	2,246	0	2,246
Disposal Other	0	0	0	0	0	0	0	0	17	0	0	0	0	0	17
Disposal Subtotal	874	79,146	171,932	310	39,091	3,809	4,845	20,354	1,116	0	0	0	2,578	18,575	342,631
1996 Stream Totals	49,175	369,531	264,532	140,140	72,413	19,007	24,185	35,232	66,399	110,752	88,671	81,764	473,968	91,427	1,887,198

* This year's survey discontinued the separate category for Physical Treatment. Any respondent that would have used that category previously would now have to report it under Other Treatment in the 1996 survey, and include an explanation.

Table C.2—Nationwide Estimates in Wet Tons: 1996

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	1996 Subtotals	1995 Subtotals	Difference
Coker	65,254	91,714	0	207,303	0	0	0	0	65,683	183,568	0	0	0	124,015	737,536	470,199	267,337
Crude Unit	0	0	0	35	0	0	0	0	0	13,890	0	0	345	0	14,270	17,818	(3,548)
Cat Cracker	0	0	0	0	247	0	0	0	0	0	0	0	0	0	247	91,111	(90,864)
Reclamation	8,147	0	1,371	1,321	2,524	20,160	36,104	0	1,750	59	156,159	156,382	180,138	166	564,281	403,809	160,472
Regeneration	0	0	0	0	720	9,052	96	0	0	0	12,394	0	514,899	0	537,160	458,404	78,756
Kiln Feedstock	0	0	0	0	60,948	43	168	0	0	0	0	0	0	0	61,160	57,343	3,817
Kiln Fuel	11,422	0	440	12,716	0	9	0	0	6,294	18,164	0	0	0	783	49,829	47,139	2,690
Recycle Other	183	101,601	73,216	12,622	0	0	0	0	0	0	309	907	58,264	5,916	253,018	84,673	168,345
Recycle Subtotal	85,005	193,315	75,027	233,998	64,439	29,264	36,368	0	73,728	215,680	168,862	157,290	753,646	130,879	2,217,500	1,630,496	587,004
Chemical	1,978	0	240	0	0	410	52	0	243	0	0	349	649	0	3,920	2,781	1,139
Heat	2,416	1,979	191	2,167	0	0	382	0	6,290	2,341	0	0	0	0	15,766	40,644	(24,878)
Wastewater	0	7,081	0	6,409	0	0	0	0	0	0	6,007	3,609	175,232	0	198,338	97,581	100,757
Incineration	3,163	75,926	945	27,450	28	272	691	0	10,477	301	0	0	100	1,036	120,389	86,169	34,220
Land Treatment	2,243	70,110	104,168	0	1,248	0	647	29,341	269	93	0	0	0	10,920	219,039	326,621	(107,582)
Stabilization	0	1,655	1,995	5,735	0	26	0	0	37,740	0	0	0	0	836	47,987	2,524	45,463
Treatment Other	448	222,603	49	0	0	0	0	0	0	0	0	0	0	0	223,100	120,381	102,719
Treatment Subtotal	10,248	379,353	107,589	41,762	1,276	708	1,772	29,341	55,018	2,735	6,007	3,958	175,981	12,793	828,539	676,701	151,838
Impoundment	0	588	8,874	0	0	0	0	26,032	0	0	0	0	0	671	36,164	22,576	13,588
Landfill	1,724	155,496	330,194	611	77,091	7,512	9,555	14,109	2,166	0	0	0	655	35,961	635,074	703,544	(68,470)
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	0	0	4,429	0	4,429	10,661	(6,232)
Disposal Other	0	0	0	0	0	0	0	0	34	0	0	0	0	0	34	4,797	(4,763)
Disposal Subtotal	1,724	156,084	339,068	611	77,091	7,512	9,555	40,141	2,200	0	0	0	5,084	36,631	675,701	741,578	(65,877)
1996 Stream Totals	96,977	728,751	521,684	276,370	142,806	37,484	47,694	69,482	130,946	218,415	174,869	161,248	934,711	180,304	3,721,741	3,048,775	672,966
1995 Stream Totals	37,039	581,642	524,817	163,587	172,853	63,066	15,421	65,002	128,169	225,433	153,172	145,257	689,918	83,402	3,048,778		
Difference	59,938	147,109	(3,133)	112,783	(30,047)	(25,582)	32,273	4,480	2,777	(7,018)	21,697	15,991	244,793	96,902	672,963		

* This year's survey discontinued the separate category for Physical Treatment. Quantities reported in this category in 1995 have been combined with Other Treatment.

Table C.3—Number of Respondents for Each Category: 1996

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	6	0	10	0	0	0	0	8	7	0	0	0	7
Crude Unit	0	0	0	1	0	0	0	0	0	2	0	0	2	0
Cat Cracker	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Reclamation	5	0	2	1	1	38	23	0	8	1	23	4	29	1
Regeneration	0	0	0	0	1	18	4	0	0	0	2	0	4	0
Kiln Feedstock	0	0	0	0	20	1	2	0	0	0	0	0	0	0
Kiln Fuel	16	0	3	7	0	1	0	0	17	9	0	0	0	7
Recycle Other	1	3	3	2	0	0	0	0	0	0	4	1	10	1
Recycle Subtotal	30	9	8	21	23	58	29	0	33	19	29	5	45	16
Chemical	2	0	2	0	0	1	1	0	1	0	0	1	1	0
Heat	5	1	1	3	0	0	1	0	6	3	0	0	0	0
Wastewater	0	3	0	1	0	0	0	0	0	0	3	2	9	0
Incineration	19	2	8	10	1	1	6	0	39	8	0	0	2	18
Land Treatment	1	13	12	0	1	0	1	3	1	1	0	0	0	6
Stabilization	0	2	4	1	0	1	0	0	2	0	0	0	0	4
Treatment Other	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Treatment Subtotal	28	22	28	15	2	3	9	3	49	12	3	3	12	28
Impoundment	0	1	1	0	0	0	0	1	0	0	0	0	0	1
Landfill	2	22	56	1	31	21	27	4	9	0	0	0	1	36
DeepWell Injection	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Disposal Other	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Disposal Subtotal	2	23	57	1	31	21	27	5	10	0	0	0	3	37
1996 Stream Totals	46	45	67	30	44	51	43	8	65	27	30	7	49	59

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

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